# PETROLOGY, CLAY MINERALOGY, PALEONTOLOGY, AND DEPOSITIONAL ENVIRONMENTS OF FOUR MISSOURIAN (UPPER PENNSYLVANIAN) SHALES OF MIDCONTINENT AND ILLINOIS BASINS

by

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PH.D. THESIS

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To my parents, without whose encouragement and support this would never have been completed.

"The face of places, and their forms decay;
And that is solid earth, that once was sea;
Seas, in their turn, retreating from the shore,
Make solid land, what ocean was before."

- Ovid, Metamorphoses, Fifteenth Book

"To study a sedimentary series requires the concurrence of all methods, since each of them throws light on one part of the past. Paleontology and field studies are complemented by sedimentology. Today, the study of silicates on the Earth's crust adds to that which can be obtained from the study of carbonates and detrital sediments."

- G. Millot, Geology of Clays

"Study the argillites and shales; they are the best witnesses of the original deposit, and, if there has been modification, they will have been the least affected."

- G. Millot, Geology of Clays

"Shale--is a sedimentary rock which forms during those moments of geologic time when the earth sighs of boredom."

- R. K. Crowder, Crowder's Unabashed Dictionary

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# INTRODUCTION

## Purpose of Study

This study involves aspects of the depositional environment of several Upper Pennsylvanian shales of the Midcontinent region and related units of the Illinois Basin. Upper Pennsylvanian strata in these regions are cyclic, consisting of regular sequences of thick grey coal-bearing shales, thin "middle" limestones, thin fissile black shales, and thick "upper" limestones. This study focuses on comparing two thick grey shales and two thin black shales: the grey Galesburg Shale and black Stark Shale of the Dennis cyclothem, and the grey Vilas and black Eudora of the Stanton cyclothem.

The first objective is to shed light on the riddle of Pennsylvanian cyclic deposition. Two major competing concepts exist, each with many variations. One concept is that the succession of depositional environments is a product of eustatic sea level change. A major point of contention within this school is the point in the rock record that corresponds to the maximum depth of water reached at a given locality. One theory holds that maximum submergence is represented by the fissile black shale member of the cyclothem (e.g., Heckel, 1977), while the other contends this point is somewhere above. (This is implicit in Illinois Basin studies, where the black shale is considered to be shallow, such as by Hickey and Younker, 1981, and

the overlying limestone shows shallowing-upward features, such as described by Tischler and Ruotsala, 1965.) It is necessary to answer this question, if the eustatic model is valid, in order to obtain some idea of the magnitude of sea level change and the symmetry (or lack thereof) of the mechanism involved.

The other major school holds that the succession of environments does not require sea level change, but can be explained by the lateral migration, abandonment, and consequent submergence of delta platforms (e.g., Ferm, 1970, Galloway and Brown, 1972, 1973). Progradation of the delta produces the increasingly terrestrial portion of the cycle, whereas subsidence and submergence of an area after the delta has shifted elsewhere produce the increasingly marine portion.

The thick grey shales of these cycles have received relatively little attention. This study is an attempt to rectify that lack, and to develop evidence that will aid in providing an answer to the puzzle of the overall cyclic pattern. It is possible that the shales will provide evidence that cannot be found or easily analyzed in other lithologies.

A second objective of this study is to shed light on the origins of the several subeconomic occurrences of resources. While none of the shales proper contains currently useful deposits, they do include low-enrichment deposits of a number of resources: the black shales are low-grade oil shales, with substantial enrichment of phosphate, uranium, vanadium, and zinc, as well as several other heavy metals. In some cases, these resources also occur and may even be enriched in adjacent rocks, either by continuation of the environment producing

them or by local diagenetic concentration. The grey shales also locally contain trace amounts of barite, sulfur, and gypsum, although these are probably secondary in origin. The Galesburg Shale has widespread coals and coaly horizons, although none of them is likely ever to be of economic value. But several coal-producing environments are present, and comparative studies may prove useful. Finally, of course, the shales may be used as a source of clay products, although problems with stratigraphic distribution and impurities greatly restrict their use, and they are currently not known to be exploited for this purpose.

A third purpose of this project is simply to test the validity of a multidisciplinary study of shale units. Previous study of shales by the author has indicated that many valuable lines of evidence about the original depositional system have been overlooked or misinterpreted by traditional single-approach studies. A multiple approach permits formulation of multiple working hypotheses to explain the observed phenomena, and provides an internal testing mechanism to eliminate untenable hypotheses.

## Philosophy of Study

This study has no pretensions of determining "ultimate truth," but is directed toward development of a reasonable working theory based on the empirical data assembled; this theory should conform to all available data and be useable as a predictive model.

The approach is to assemble as much empirical data as is reasonably practical, then to formulate hypotheses based on that data.

It should be understood that any hypothesis presented will be only that, and should not be considered an unalterable truth.

A virtue of a multidirectional approach to this study is that of reinforcing evidence. Many of the first level of conclusions based on the data are arguable presumptions, albeit ones that have a certain probability of being correct. When the evidence accumulated from several different sources concur, it has the effect of reinforcing the original conclusion, and increasing the probability of the correctness of the interpretation. On the other hand, if further evidence contradicts the original assumption, then the hypothesis is discarded and a new explanation sought. Thus, the process is self-testing to a certain degree. The final conclusions reached reflect mutually supporting hypotheses derived from empirical evidence; while they may not be absolute truth, they would represent some degree of approximation. Therefore, the conclusions are considered to be correct to the level that they have been tested and have not yet found to be wrong.

## Format of Discussion

To aid understanding, the evidence and discussion for this study will be presented in chapters of stratigraphy, constituents, petrology, and paleontology. Each chapter will include pertinent previous work, in order to avoid presenting it all at once. Each will also have a limited discussion of the results, although a final summary of the entire study will be presented separately. The intent is to construct a set of coherent subentities, and then to unify all into a single set of conclusions drawn from the multiple studies.

## Terms

The use of several terms in this study should be explained. Blatt and others (1980) observed that the term "shale" could refer to either fissile mudrock or the class of fine-grained sedimentary rocks that contain substantial amounts of clay minerals. Since "shale" is the term generally applied to rock units that locally vary from fissile to massive, it is used here in its broader sense, particularly stratigraphically. "Shale" will be used in its narrower sense only when comparing textural and sedimentological characteristics.

Reinson (1979) noted that the terms "transgression" and "regression" had two sets of closely related definitions. Transgression can be defined as the landward migration of shoreline, or it can refer to the vertical replacement of a shallow-water facies by a deeper-water one. (Regression, of course, means the opposite.) Since studies of Pennsylvanian cyclothems are based on vertical replacement of one facies by another in a single section, the latter set of definitions is used here.

## Structural Setting

Shales and mudstones are clastic rocks, derived from the weathering of pre-existing rocks. The sedimentology and mineralogy of the shales and mudstones reflect the weathering, transportational, and depositional environments involved in the reworking of older rocks. The positions and relief of uplifts and downwarps are major controls of weathering intensity, transportational patterns, and depositional

systems. Because of these relationships, it is necessary to include the role of tectonic elements when evaluating the development of shales and mudrocks.

The Pennsylvanian Period was one of marked tectonic activity in North America, both along the continental margins and in the cratonic interior. Many pronounced uplifts and basins that formed or reached maximum development during the Pennsylvanian, had profound influence on the depositional patterns of the period.

Much of this activity was a product of collisonal plate tectonics along the Ouachita-Marathon foldbelt (Kluth and Coney, 1981), which produced cratonic activity as well as marginal orogenies. A zippering effect of this suture began with Early Pennsylvanian activity in the Ouachitas and moved to the Marathon region by the end of the Pennsylvanian. Complementary activity in the Ancestral Rockies and other cratonic features also moved southward (referring to modern orientation) as the principal suturing activity did.

The Missourian Age, however, was rather uncharacteristic of the Pennsylvanian. Tectonic activity lapsed to a temporary minimum, and, coupled with rather marked marine transgressions, produced depositional patterns in some ways reminiscent of the Lower Paleozoic (Kosanke, et al., 1960; Rascoe, 1962; Mallory, 1972). Many of the structural features active earlier in the Pennsylvanian became dormant, and were eroded or filled. However, tectonic activity was widely reinitiated at the close of the age, beginning the much greater tempo of the Virgilian Age (e.g., UnKauf, 1970). The Midcontinent was largely a broad platform, periodically inundated by the sea. Several

basins and uplifts of low relief marked the region, but in some cases were so weakly developed as to leave their existence debatable. Other features, prominent during the preceding Desmoinesian Age, were no longer significant.

A good example of this trend is the Forest City Basin (1 on Fig. 1), located where Kansas, Missouri, Nebraska, and Iowa nearly adjoin. This basin formed in the Early Pennsylvanian, when uplift of the Nemaha ridge divided the North Kansas Basin (Lee, 1943) into the Forest City Basin on the east, and the Salina Basin on the west. The Forest City Basin was an active depocenter during the Desmoinesian Epoch, but may have been inactive during most of the Missourian. Lee (1943) noted only slight thickening of the Bronson Group in the basin, and stated that the Forest City Basin was no longer a distinct entity during the Missourian Epoch. Chamberlain and Lemish (1980) stated that 450 feet of relief developed in the basin during the Missourian. P. H. Heckel (pers. comm., 1981) found no evidence of basinal thickening in cores from the basin. Field observations during the course of this study support Lee and Heckel: the Galesburg Shale shows no evidence of significant relief-related features, and those in the Vilas are weak and equivocal.

The Nemaha Uplift (2 on Fig. 1), west of the Forest City Basin and stretching south into Oklahoma, was also significant during Desmoinesian time, but was rapidly disappearing in the Missourian. Merriam (1963) noted that the initial uplift was post-Mississippian and pre-Desmoinesian and that the uplift subsided and was buried from south to north. By the beginning of the Missourian, the southernmost

1. Forest City Basin
2. Nemaha Uplift
3. Ozark Dome
4. Bourbon Arch
5. Northeast Oklahoma Shelf
6. Anadarko-Arkoma Basin
7. Ouachita Mountains
8. Arbuckle Mountains
9. Wichita Mountains
10. Amarillo Mountains
11. Midland Basin
12. Delaware Basin
13. Central Basin Platform
14. Val Verde Basin
15. Marfa Basin
16. Eastern Shelf (Midland B)
17. Palo Duro Basin
18. Matador Arch
19. Dalhart Basin
20. Sierra Grande-Apishapa Uplift
21. Ardmore Basin
22. Frontrange
23. Denver Basin
24. Las Animas Arch
25. Central Kansas Uplift
26. Cambridge and Chadron Arches
27. Hugoton Embayment
28. Sedgwick Basin
29. Salina Basin
30. Williston Basin
31. Central Nebraska Basin
32. Sioux Uplift
33. Wisconsin Dome
34. Lincoln Fold
35. Fairfield Basin
36. LaSalle Anticlinal Belt
37. Savanna-Sabula Structure
38. DuQuoin Monocline
39. Western (Sparta) Shelf
40. Eastern Shelf (Illinois B)
41. Cincinnati Arch
42. Appalachian Basin

Figure 1. Missourian Structural Elements.
Positive elements and flexures in solid lines; basins dashed.

Based on Crouch (1971), Heckel (1980), Kluth and Coney (1981), Moore (1979), McCaslin (1981), Peterson (1966), Potter (1963), Walton (1960), Watney (1980), and Wermund and Jenkins (1969).

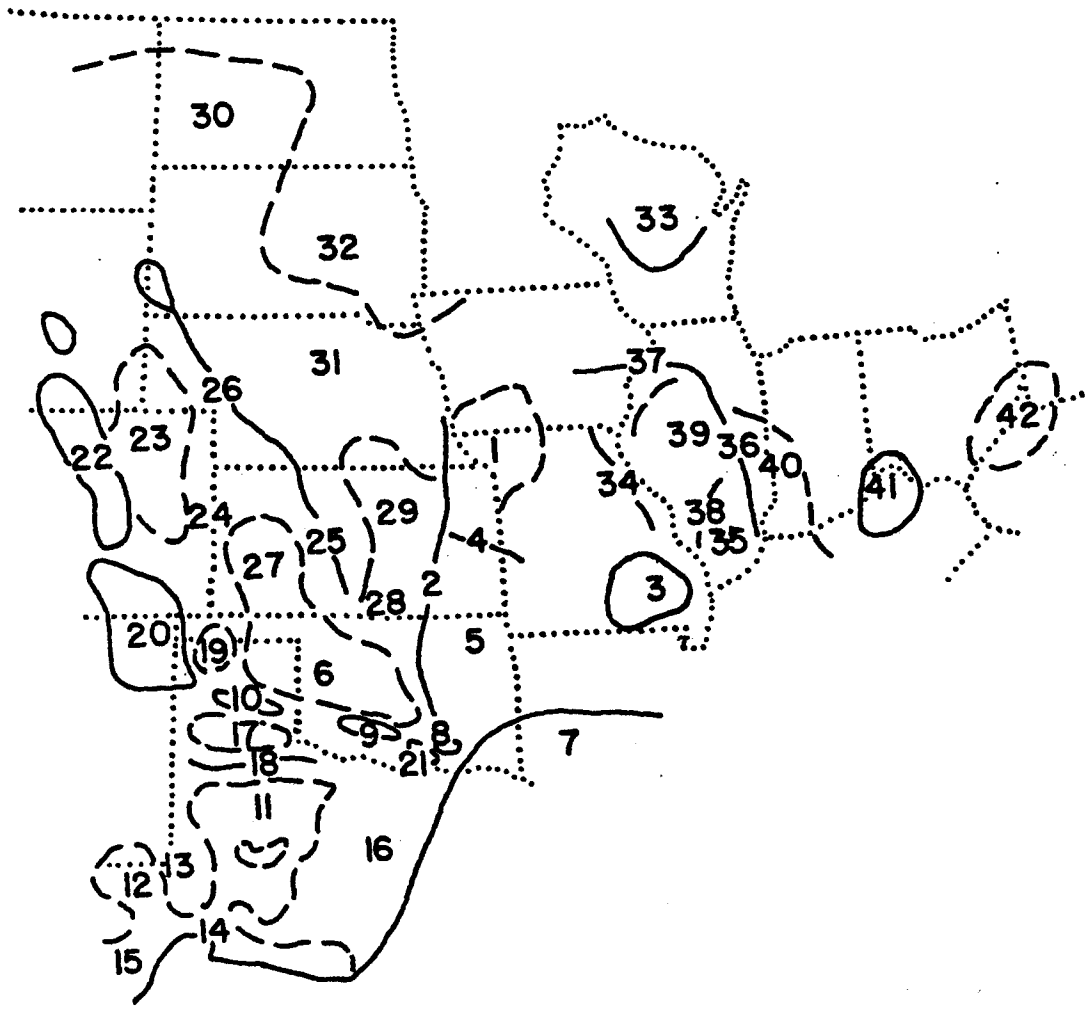
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Figure 1.

extension, dividing the Arkoma and Anadarko basins, was gone (Crouch, 1971); the southern portion was rapidly being covered, and by the start of the Virgilian Age even the highest parts in northeastern Kansas were covered by sediment (Jewett, 1951). Lee (1943) noted that even the Bronson Group, in the Lower Missourian, thins only slightly over most of the Nemaha Uplift.

Southeast of the Forest City Basin the Ozark Dome (3 on Fig. 1) was centered in southeastern Missouri (Keller, et al., 1953). This was a weak structure in the Missourian, and has a debatable history. Huffman (1959) stated that it underwent gentle uplift during the Desmoinesian, acquiring its present elongate shape and was subjected to normal faulting; King (1951) stated that it was crossed by several northwest-trending folds. Eardley (1962), on the other hand, felt that it was last uplifted in the Late Mississippian; in either case, Pennsylvanian seas almost or entirely covered the dome at their maximum extent (Wanless, 1957, noted that Desmoinesian limestones filled sinkholes on the top of the dome). Note that if the Ozark Dome was centered farther to the east, as indicated by the facies pattern found by Keller and others (1954), Missourian depositional patterns are far less anomalous than if the dome coincided with its present outline. Facies patterns indicate southwestern Missouri was a shallow platform, rather than part of the dome.

An even more debatable feature extended between the Nemaha Uplift and the Ozark Dome, forming the southern margin of the Forest City Basin. This was the Bourbon Arch (4 on Fig. 1), which trends vaguely northwestward through Bourbon, Allen, and Coffey counties in Kansas

(Lee, 1943). Lee noted that the arch was only slightly active during the Missourian. Jewett (1951) concluded that during the Missourian it was only an area of meeting and overlap of sediments from northern and southern sources. Huffman (1959) felt that the rocks over it thinned by convergence; Eardley (1962) felt that it was a shallow platform. Merriam (1963) called it a post-Mississippian, pre-Desmoinesian structure, and stated it was not important after the Desmoinesian. However, the more recent work on individual cyclothems in the area indicate that it may have had a much more significant history: Schenk (1967), Price (1981), Ravn (1981), and Mitchell (1981) found facies evidence for shallower water in both limestones and core shales. These cyclothems range from upper Desmoinesian (Marmaton Group) to middle Missourian (Kansas City Group) in age. However, Mitchell (1981), observed that the Missourian feature may not have been tectonic, but simply depositional patterns accentuating a relict high. It is possible that this weak feature endured into the Virgilian, as McMillan (1956) suggested that it was a depositional control in the Nodaway underclay.

Ravn (1981) noted several smaller, parallel features that may have influenced deposition during the early Missourian Epoch, including Gentile's (1976) Bates County Anticline. He also noted circumstantial evidence for a structure parallel to the Neosho River valley in southeastern Kansas. It is possible these structures may have influenced local depositional patterns during the deposition of the Galesburg and Vilas shales.

South of the Bourbon Arch was a poorly defined platform, the Northeast Oklahoma Shelf (5 on Fig. 1). Crouch (1971) stated that it was south of the Cherokee Basin (which was immediately south of the Bourbon Arch in the Desmoinesian). Huffman (1959) stated that it was continuous with the filled Cherokee Basin in the Missourian; Moore (1979) labelled the area the Cherokee Platform, and stated that it was slightly tilted to the south. Huffman (1959) called the shelf unstable; Moore (1979) stated that it was stable.

The southern margin of the shelf was the Anadarko-Arkoma Basin (6 on Fig. 1) trend, stretching from central Arkansas across Oklahoma and into the panhandle of Texas. By the early Missourian, the Arkoma (or McAlester) Basin was continuous with the Anadarko Basin, due to filling from the east and burial of the Nemaha Uplift (Rascoe, 1962; Crouch, 1971; Moore, 1979). The Anadarko Basin was asymmetric, with its deepest portion near the southern margin; during the Missourian it continued filling, principally from the east (Moore, 1979). In this interval, Krumme (1981) described the McAlester Basin as still extending eastward across Oklahoma, dividing the northern platform from a southern shelf. The axis of this feature is figured as extending toward, rather than south of, the Ozark Uplift. Bennison (1981) described this as the Arkoma seaway, following Dott's (1981) distinction: a basin is a sediment-filled trough, while a seaway is simply an area of deeper water. Thus, Bennison (1981) recognized the feature as being an area of different, presumably deeper water, facies, and not necessarily an area where subsidence and basin-filling are the primary controls. Thus, his use of the term "seaway" simply

describes an area of different facies, without implying that the control of the deeper water was due to greater structural subisdence; although it may have been, it could also have been due to greater distance from a clastic source.

South of the Anadarko-Arkoma trend was a series of uplifts: from east to west, the Ouachita Mountains (7 on Fig. 1), the Arbuckle Mountains (8 on Fig. 1), the Criner Hills, the Wichita Mountains (9 on Fig. 1), and the Amarillo Mountains (10 on Fig. 1). During the Missourian, most of the tectonic activity along this trend was subsiding, except in the western portion, where the Amarillo-Wichita system was undergoing uplift (Kluth and Coney, 1981). However, at the close of the Missourian, the Arbuckles were uplifted, and the Wichita-Amarillo-Criner Hills systems were refolded and faulted (Huffman, 1959; UnKauf, 1970).

In the south, the most important area for the Midcontinent was in the Panhandle region of Texas. This is the region where marine waters from the open ocean entered the Midcontinent sea, coming from the deep starved basins to the south. The geometry of the entrances would have had a major influence on the circulation and salinity of the epeiric sea. Here, the Palo Duro (or Plainview) Basin (17 on Fig. 1) was just south of the Amarillo-Wichita system. Like the Midland Basin to the south and the Anadarko Basin to the north, the Palo Duro Basin was usually starved of sediments during the Missourian.

The Palo Duro Basin apparently had a northward extension, the Dalhart Basin (19 on Fig. 1) (Roth, 1955; Totten, 1956). This was

divided from the Anadarko Basin and the Hugoton Embayment by a north-south ridge, the Cimarron Arch (Roth, 1955; Rascoe, 1962). However, it is difficult to determine how connected the Dalhart and Palo Duro Basins were during the Missourian. An eastward projection of the Sierra Grande Uplift (20 on Fig. 1), called the Bravo Dome (or Oldham Nose) reached toward the western end of the Amarillo Mountains. Late Pennsylvanian uplift of the system stripped the rock to the Precambrian basement in a continuous swath, obliterating any trace of a possible connection (Totten, 1956). In any case, such a connection must have been fairly narrow, as Totten (1956), Nicholson (1960), and Dutton (1980) all show gaps of about 15 miles; possibly they deduced this on the basis of facies patterns. Clastic influx must have been marked, also; Nicholson (1960) mentioned considerable clastics in the region during the Missourian, and Roth (1955) noted increasing amounts of arkose as more Precambrian rock was uplifted and exposed. Still, Nicholson (1960) noted that in the Missourian the centers of the Palo Duro, Dalhart, and Anadarko Basins remained deep; Evans (1966) felt that any sill in the system was between the Dalhart Basin and the Hugoton Embayment.

Another possible seaway into the Midcontinent was through the Ardmore Basin (21 on Fig. 1), part of the Anadarko Basin that extended southeast past the east end of the Wichita Mountains. UnKauf (1970) noted that the basin was filled with marine deposits until it was closed by the Arbuckle orogeny at the end of the Missourian. However, it was probably only a shallow connection, as it opened onto the

Eastern Shelf of Texas, and many of the petrographic features of the rocks in it also suggest shallow water.

The most important feature west of the Midcontinent region was the Frontrange uplift of the Ancestral Rockies (22 on Fig. 1). To the south, the Sierra Grande Uplift (20 on Fig. 1) was also active. Both uplifts were amagmatic, but shed arkosic sediments eastward. Most of the sediments accumulated as fan-deltas on the western margins of the Denver Basin (23 on Fig. 1) (as the Fountain Formation) and Hugoton Embayment (27 on Fig. 1). Both downwarps were not well-developed in the Missourian, but did prevent significant eastward progradation of clastic wedges.

The central portion of the Midcontinent region was marked by the Central Kansas Uplift (25 on Fig. 1) and the Cambridge and Chadron Arches (26 on Fig. 1), a long series of uplifts extending northwestward toward eastern Montana (Eardley, 1962). The uplifts were broad and low, but raised sufficiently for Pennsylvanian deposition to take place on exposed Precambrian rock (Merriam, 1963), although King (1951) noted that most of the subcrop in Kansas is Lower Ordovician. Rascoe (1962) stated that Missourian rocks thin over the Central Kansas Uplift. Similarly, McCauley (1956) noted that the Ancestral Black Hills, the northern extension of the Chadron Arch, were buried by the end of the Desmoinesian. The Central Kansas Uplift separated the Hugoton Embayment to the west from the Sedgwick Basin (28 on Fig. 1) to the southeast and the Salina Basin (29 on Fig. 1) to the northeast. The Cambridge and Chardon Arches essentially crossed the craton, although the weakly developed Williston Basin (30 on Fig. 1) is to the

northeast and the Central Nebraska Basin (31 on Fig. 1) is to the east (Walton, 1960). Cyclic marine deposition extended into the Williston Basin during the Missourian, with the seas entering the area via Montana (around the north end of the Chadron Arch) and a sag across the arch south of the Black Hills region (McCauley, 1956). However, by the Permian most of the Missourian strata had been bevelled off from North Dakota, so it is difficult to assess the previous extent of Missourian seas.

Along the edge of the exposed Precambrian craton, several features were weakly developed in the Pennsylvanian. The Transcontinental Arch had its western end destroyed by the Frontrange uplift (Eardley, 1962), while the eastern portion was almost completely overlapped by the Late Pennsylvanian, although subcrop data indicates that it was uplifted in the Desmoinesian. This truncated end is known in the Pennsylvanian as the Sioux Uplift (32 on Fig. 1) (Wilson, 1978). The Wisconsin Dome (33 on Fig. 1) was separated from the Sioux Uplift by a broad embayment which extended northeast to the vicinity of Upper Michigan (Eardley, 1962). The Wisconsin Arch extended south to northern Illinois, where it connected to the LaSalle anticlinal belt, the Savanna-Sabula structure, and the Kankakee Arch (King, 1951).

The Lincoln Fold (34 on Fig. 1) is a prominent northwest-trending fold extending from the northeastern margin of the Ozark Dome into southeastern Iowa (King, 1951). The fold is an asymmetrical anticline, with its steep side to the southwest, where some faulting also took place (McQueen, et al., 1941); the main fold also has many parallel flanking structures. The fold separates the Forest City

Basin and the Illinois Basin; it began as a regional warp in the Lower Ordovician, but was an active structure from the Upper Silurian or Lower Devonian (Koenig, 1961). Its influence on Missourian deposition is debatable: it was most active at the end of the Mississippian (McQueen, et al., 1941), but influenced deposition after that. Searight and Searight (1961) stated that it restricted deposition in the Lower Desmoinesian (Cabaniss), but was not important after that. McQueen and others (1941), however, stated that some arching took place in the early part of the Missourian, and Schenk (1967) and Price (1981) noted it had a pronounced effect on Altamont and Pawnee deposition near the end of the Desmoinesian. There is no persuasive evidence that it was an active barrier during the Missourian, but it probably functioned as a drainage divide during low sea level stands.

(Nomenclature problems abound with the Lincoln Fold. It was first identified as a structure in 1872, and named by Krey in 1924. However, in 1935 Howell described a structure he called the Mississippi River Arch which ran south through Illinois. This structure has been confused with the Lincoln Fold, and several spurious features have been attributed to it. B. J. Bunker, pers. comm., 1981, stated that these features came from incorrect stratigraphic correlations and a misunderstanding of regional tectonics; the fold system that divides the Forest City Basin from the Illinois Basin is correctly the Lincoln Fold.)

The Illinois Basin was active periodically during the Paleozoic; it was relatively active during the earlier Pennsylvanian, but was essentially filled by the Missourian. However, during the

Pennsylvanian, the basin became differentiated into several distinct parts, each of which had some significance to later deposition.

The Fairfield Basin (35 on Fig. 1) in southern Illinois became the deeper portion of the basin (Willman, et al., 1975). On the east, the LaSalle anticlinal belt (36 on Fig. 1), with its steep face toward the Fairfield Basin (King, 1951), was still active in the Pennsylvanian. At its northern end, it ran into northwest-trending Sandwich Fault (Bristol and Buschbach, 1971), which in turn ran into the east-west Savanna-Sabula structure (37 on Fig. 1); together these defined the northern boundary and eastern hinge line of the basin. The western hinge line of the basin was the DuQuoin Monocline (38 on Fig. 1), with its steep face to the east. To the west of the hinge line is the Sparta, or Western, shelf (39 on Fig. 1).

The Illinois Basin in the Pennsylvanian was more properly an embayment. Atherton (1971) stated that it opened toward the Black Warrior and Arkoma basins. The Illinois Basin was closed during the Mesozoic, with the uplift of the Pascola Arch (Willman, et al., 1975); this also produced the Rough Creek reverse fault zone and the Shawneetown structure, a mile-wide uplift separating the Fairfield Basin from the even deeper Moorman Syncline to the south (Swann, 1968; Bristol and Buschbach, 1971).

Minor elements modify the entire structural setting. Some apparently reflect major structural trends; for example, many of the minor folds in Iowa seem to reflect the northwest trend found in the Lincoln Fold, the LaSalle Anticline, and the obscure folds crossing the Ozark Dome (Lee, 1943; King, 1951). In the Forest City Basin, a

slightly younger set of folds trends northeast, along with the end of the Nemaha Uplift and the Thurman-Redfield structure (Lee, 1943). Walton (1960) notes that in western Kansas and eastern Colorado structures have a dominantly northeasterly trend, with northwesterly-trending structures producing isopachous reentrants. These two trends generally seem to be reflected in the principal joint directions in Upper Pennsylvanian strata, and may express the general compressional strain in the Midcontinent in the Pennsylvanian.

Other small structures commonly warp the Upper Pennsylvanian. Jewett (1951) noted several small domes around Coffeyville, Liberty, and Cherryvale in southeastern Kansas. Other domes, such as the Silver City and Rose domes of eastern Kansas, are apparently related to the later intrusion of kimberlites, but may have had some Missourian expression (Heckel, 1975). Finally, in the Illinois Basin, some local structures may be due to differential compaction over Silurian reefs (Willman, et al., 1975).

Structural elements in the Midcontinent had been quite active in the Desmoinesian, but were quiescent in the Missourian. Many were buried or eroded during the Missourian, and had far less influence than they had earlier. The relief in the Midcontinent was very low, but the various structural features, even with relict topography or very low levels of activity, played a large role in determining the direction of transport and distribution of sediments derived from the peripheral highlands.

# CHAPTER I

# STRATIGRAPHY

## Stratigraphic Terminology

Cyclic deposition in the Carboniferous strata of North America was first recognized by Udden (1912), although it had been known in Europe for at least a century prior to that. In 1932, Wanless and Weller introduced the term "cyclothem" to describe the succession of lithologies cyclically repeated in the Illinois Basin. Soon thereafter, higher orders of cyclicity were recognized; Moore (1936) called them "megacyclothems." He noted each cyclothem was a transgressive-regressive couplet which included an offshore limestone and a nearshore or subaerial shale unit. He labelled the limestones in a megacyclothem the lower, middle, upper, super, and fifth in upward succession. (Since these terms do not have genetic connotations, they will be used to describe the limestones.)

Variations of the megacyclothem concept are related to the problems of this study. In 1958, Weller equated Moore's Kansas megacyclothems to the simple cyclothems of Illinois. Bless (1968) noted that there were "mega-rhythms" in Spanish cyclothems that are closely comparable to those of North America. Stout (1981) recognized slightly different megacyclothems in Nebraska, which he attributed to a glacial-eustatic cycle.

Heckel (1977) suggested a simplification of the nomenclature and interpretation. He recognized that many of Moore's lower, super, and fifth limestones were simply fortuitous development of nearshore carbonate facies within the outside shales. Only the middle and upper limestones were significant in the overall development of the cyclothem. For this reason, Heckel recommended downgrading most of Moore's megacyclothems to simple cyclothems, resulting from a single transgressive-regressive event.

## Cyclothems

It is now appropriate to consider the general stratigraphic patterns found in Pennsylvanian cyclothems, then show how they relate to the studied units. To do this, the variations in cyclothems over vast areas must be considered, for, by finding the extreme limits of variability and continuity, insight may be gained on the less marked variation locally.

Perhaps one of the seemingly most innocuous problems of cyclothem nomenclature, but one of the more difficult, is what constitutes the base of the cyclothem. There is little doubt that Pennsylvanian cyclothems represent alternating deepening and shallowing of the sea, so the most useful stratigraphic horizons should be those of greatest depth and of maximum withdrawal. When and if these are found, a series of time lines can be constructed after the fashion of Israelsky (1949). Then facies distributions can be plotted for these times and depositional environments determined. Unfortunately, there

are major problems in determining both maximum transgression and regression.

One possible place for maximum withdrawal of the sea is at the base of the sandstone typically found in the cyclothems. In Illinois and elsewhere, this is often a prominent unconformity, with the sandstone above exhibiting sedimentologic characteristic of fluvial channel sands, having a dendritic pattern of distribution, and containing terrestrial plant fossils. Weller (1930) recognized this unconformity as the base of the cyclothem, stating the strata below it were marine, while those above were terrestrial. Presumably, the unconformity would represent maximum subaerial erosion, and thus maximum withdrawal of the sea.

However, not all the sandstones in the cyclothems are unconformable, and not all of them are subaerial channel sands. Stout (1931) felt that many of the sands in the Appalachian Basin were products of marine erosion and transport; thus, the coal and the underclay in the cyclothem were the subaerial phase, and the base of the coal represented maximum regression. Unfortunately, the evidence isn't consistent enough to choose one pattern over another. Krumbein and Sloss (1963) noted the occurrence of sand-filled channels up to 300 feet deep and several miles wide; Bless (1969) often found limestone pebble conglomerates at the base of the sandstone. But Kosanke and others (1960) noted many of the sandstones had a sheetlike geometry, gradational bases, and marine fossils. Some of the basal sands have a distributary-like pattern (Palomino-C., 1963). Thus, it is an oversimplification to assume all the sandstones in the cyclothems are

similar. They must be placed in the cyclothem with regard to their depositional environment. Bennison (1981) demonstrated this in Oklahoma cyclothems where he recognized not only a subaerial regressive sandstone unit, but also a transgressive sandstone between the paleosol and the marine units above (Fig. 4).

Another problem with interpreting cyclothems is that of lateral extent. This can tell a great deal about the depositional environments, as lateral continuity, variability, and gradations express the stability and relationships of the environments. Pennsylvanian cyclothems frequently have great lateral continuity, extending over much of interior North America. Wanless (1950) worked out many of the lateral facies relationships, interpreting the sequence as a result of an invasion and retreat of the sea. As a consequence, the rocks show the results of deepening of the sea in a given location, and the shallowing as the seas receded. Along the margins of the epeiric seas, particularly those along active orogenic belts, the pattern was strongly modified by deltaic progradation. Heckel (1980) elaborated on this model, extending it to the basins of Texas and Oklahoma and including the dominantly marine sequences of Kansas.

Thus, the marginal regions (e.g., Appalachian Basin, the Illinois Basin and eastern Oklahoma) are dominated by terrigenous clastics. Those limestones present are thin and shaly. Coals and channel sandstones are common. Basinward, the limestones become thicker and purer, clastic wedges thinner, coals less common, and sandstones more frequently marine. Along the shelf margins and on a few highs protected from clastic influx, thick buildups of phylloid algal

calcilutite occur, only occasionally interrupted by thin shales extending through them. The basins are generally filled with dark shales, occasional thin dark limestones, and deep sea fan deposits (Fig. 2 and 3).

As a result of this study, a significant variation to this pattern has been clarified. Over large parts of the Midcontinent region, terrigenous influx was insufficient to end carbonate production. In these regions, carbonate production continued into tidal flat facies and ceased only when subaerially exposed. At that point, soils and some coals developed, which were submerged with the next rise of the sea. Thus, although not close to the edge of the shelf, dominantly carbonate sequences could develop (Fig. 2).

## Units of Cyclothems

Cyclothems have been recognized in a great number of places. Many of the units involved reflect local conditions, such as variation in topography, climate, or terrigenous influx. Other lithologies are persistent, and show up in a wide variety of cyclothems. Here, the intent is to describe the variations of cyclothem units; when the relationships of the various units are understood, conclusions about the depositional environments can be made. When the general patterns are known, they can then be applied to specific units, such as those studied here.

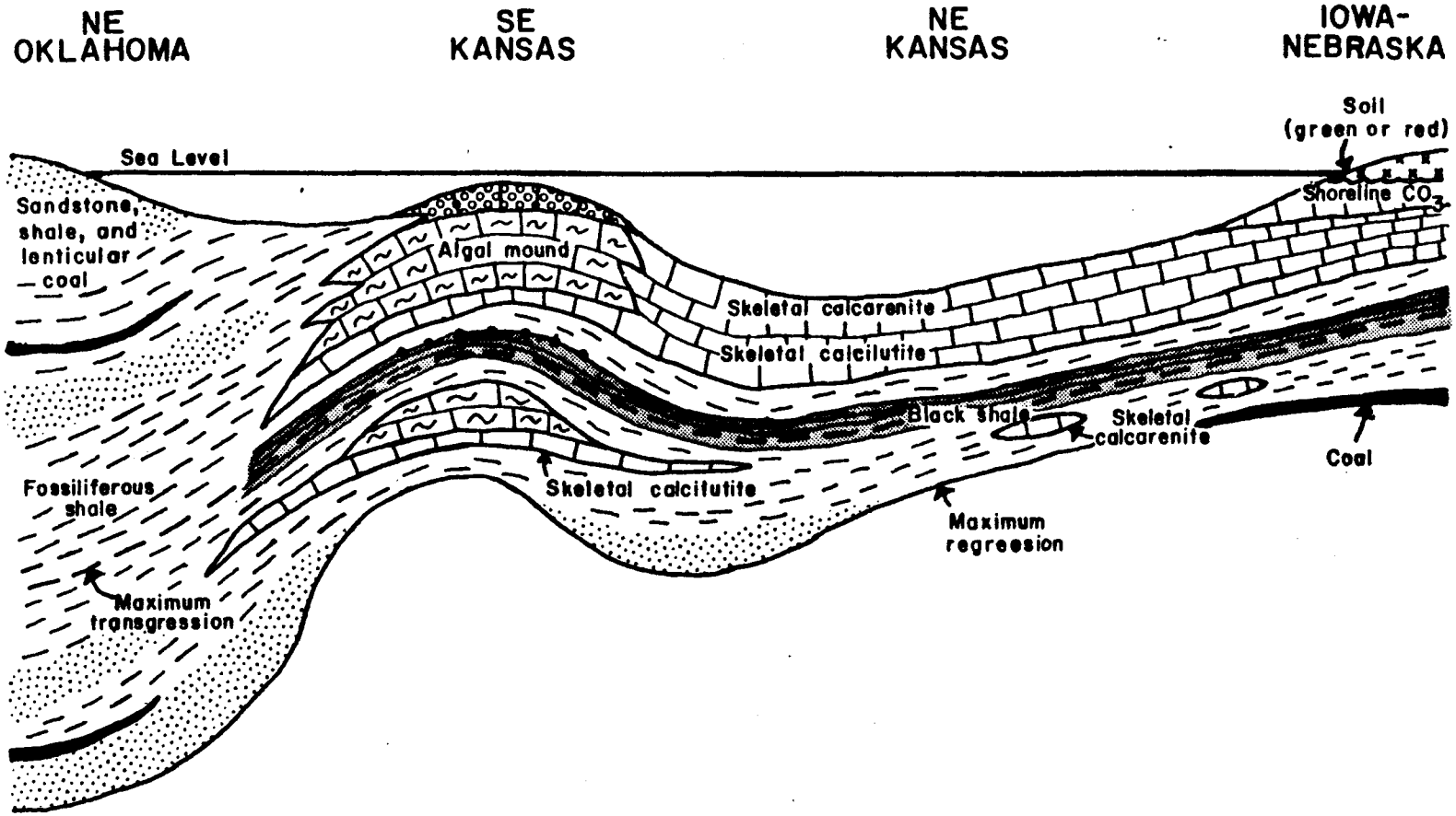



Figure 2. Conceptual diagram of facies relationships, Midcontinent cylothem (after Heckel, 1980).

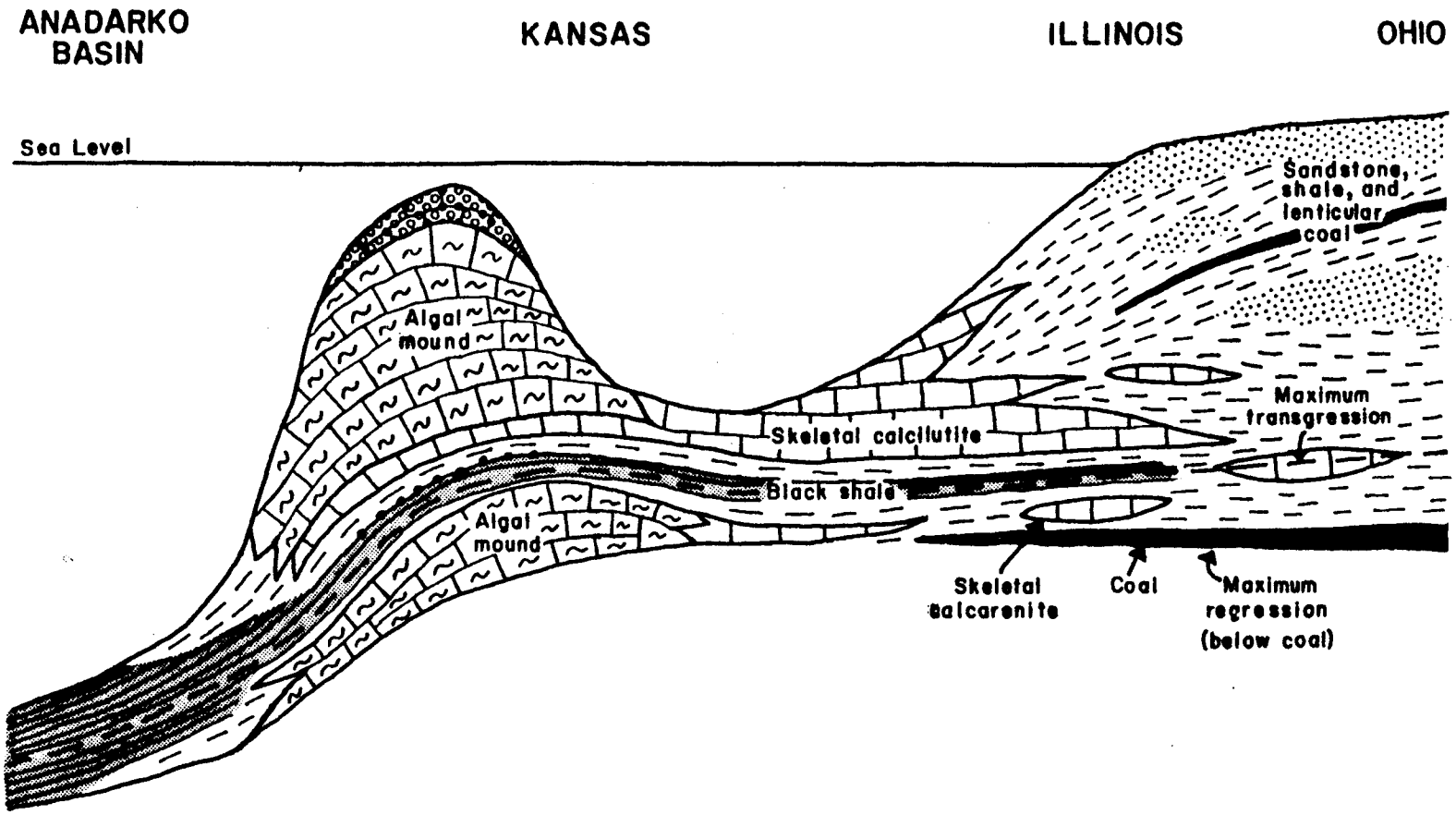
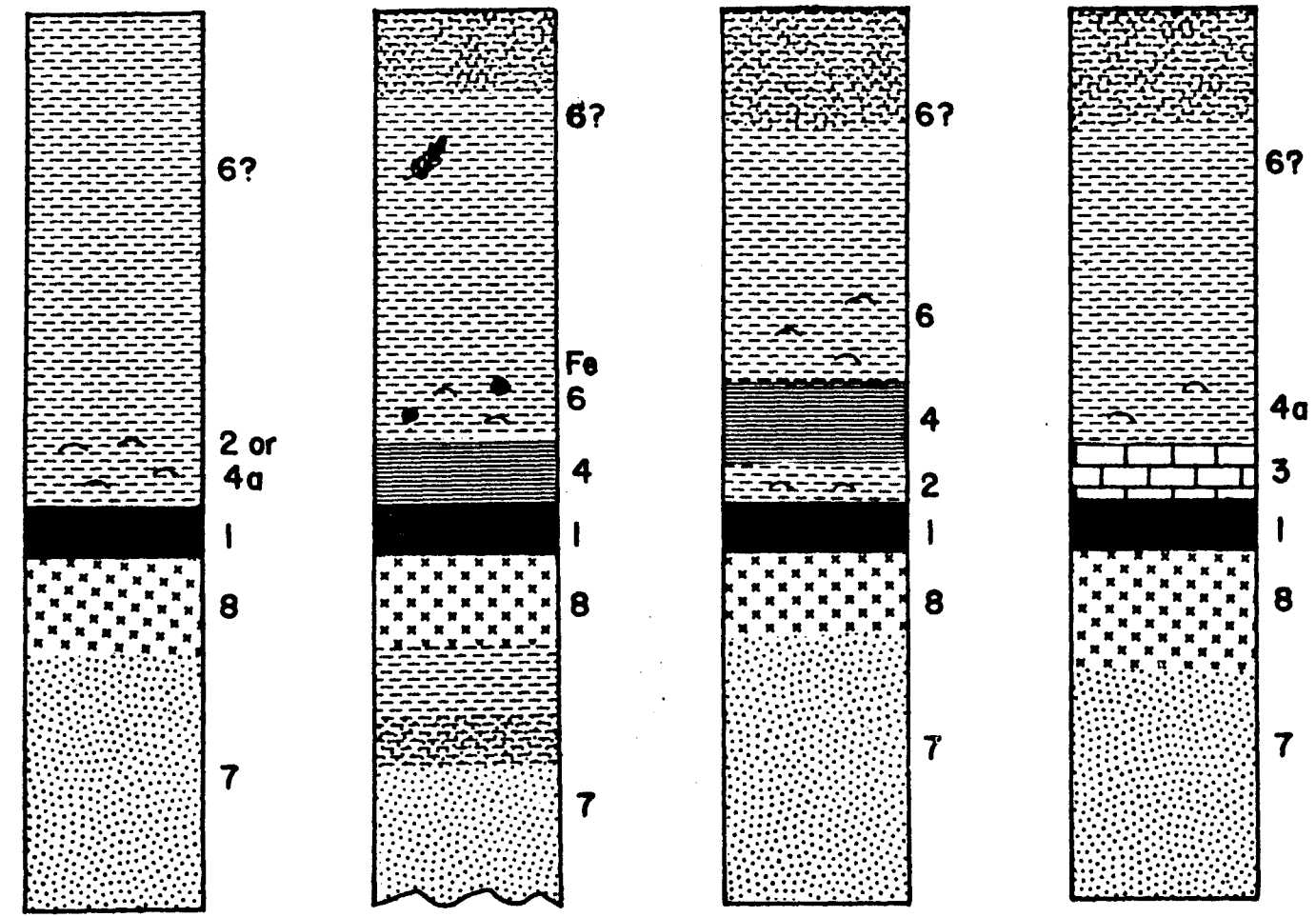



Figure 3. Conceptual diagram of facies relationships, Midcontinent cyclothem. Note that the pattern varies from that of Heckel (1977) in that carbonate deposition in the mound facies is uninterrupted by outside shale deposition.

Figure 4. Pennsylvanian cyclothems.

Key to lithologies

1 - coal
2 - transitional grey shale, brackish to marine
3 - carbonate below black shale
  a - shallow water facies, such as oölite or calcarenite
4 - black shale
  a - fossiliferous grey shale transition
5 - carbonate above black shale
  a - calcilutite, either phylloid algal or skeletal
  b - skeletal calcarenite
  c - oölite or laminated unfossiliferous fenestrate calcilutite
6 - grey shale with scattered marine fossils
  ? - sandy or silty grey shale, often with plant fragments
7 - sandstone, sometimes with associated sandy red or grey shales, sometimes conglomeratic at base
8 - seat earth, usually underclay, sometimes with associated "freshwater limestone" (caliche?)
9 - anhydrite
10 - other evaporites (e.g., halite, sylvite)
11 - transgressive sandstone, with fossils
Fe - siderite nodules
$PO_4$ - phosphate nodules


6?
2 or
4a
1
8
7
BRITISH
CYCLOTHEM
(Edwards and
(Stubblefield, 1947)
6?
Fe
6
4
1
8
7
ALLEGHENY
CYCLOTHEM
(Degens,et al, 1957)
6?
6
4
2
1
8
7
BRITISH
WESTPHALIAN
(Calver, 1968)
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YOREDALE
CYCLOTHEM
(Dunham, 1950)

Figure 4.

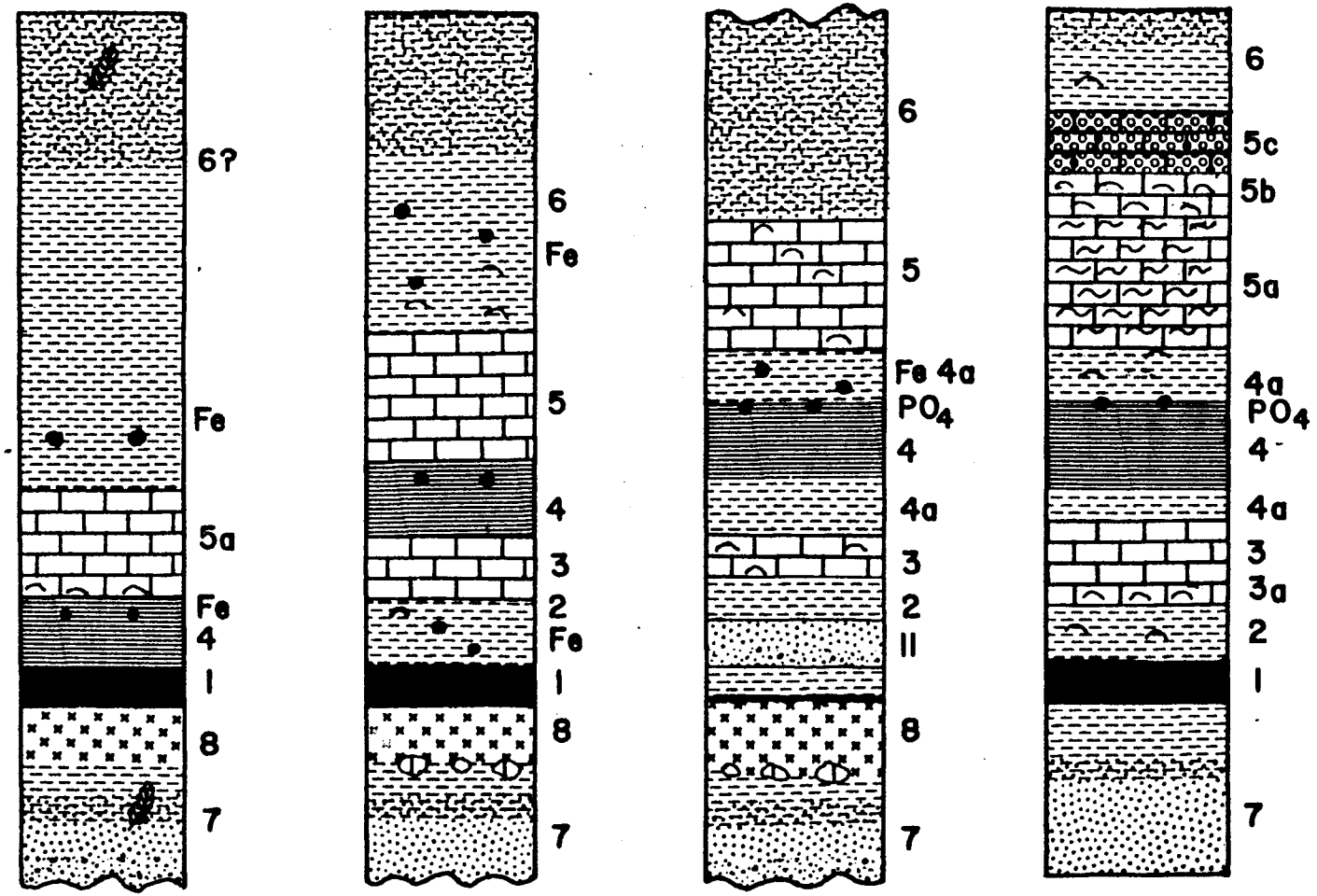



Figure 4 (cont'd.)

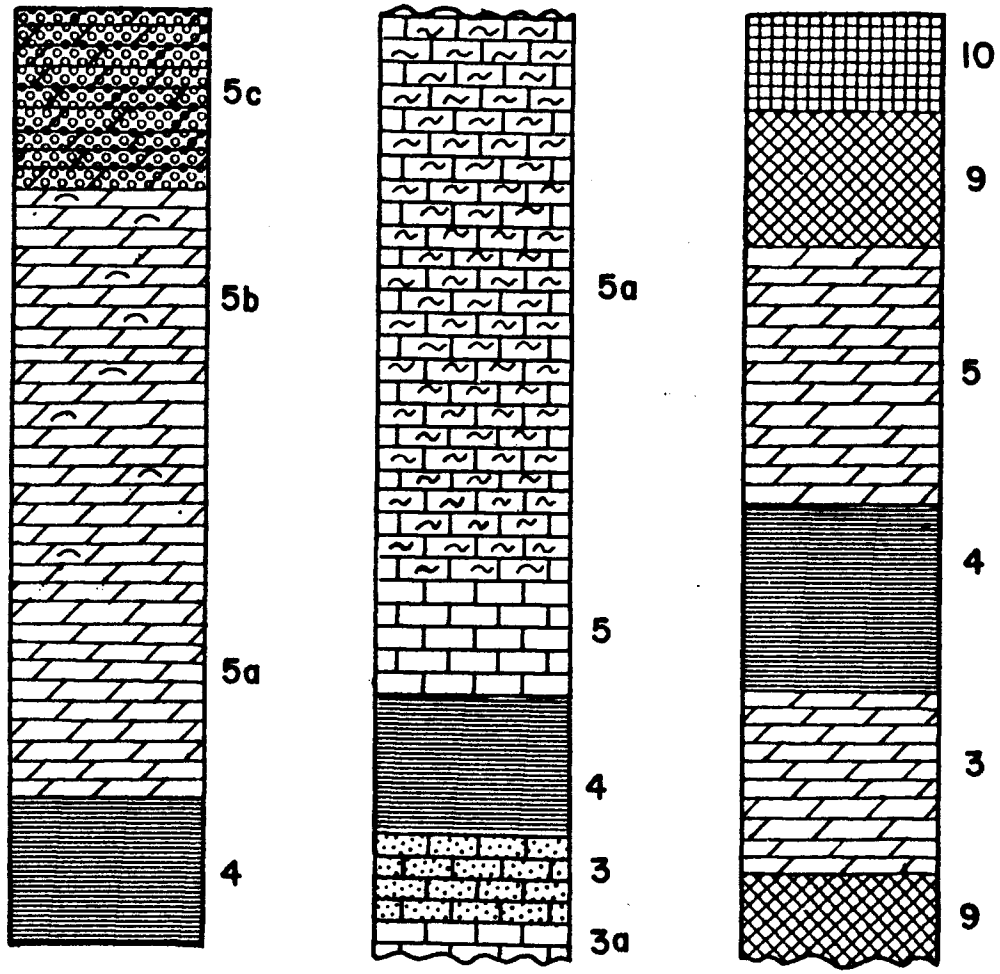



Figure 4 (cont'd.)

## Coal

The unit of cyclothem that attracts the most attention is the coal, as it is the unit of most economic interest. Coals are found in cyclothems across most of Europe and eastern North America to roughly the eastern margin of the Midcontinent area (the Western Interior Coal Basin). Usually, the coal is a black, banded, autochthonous coal, of variable purity, thickness, and areal distribution.

## Transitional Grey Shale

A grey to dark grey fossiliferous shale often occurs just above the coal. It may contain a good deal of coaly material and a wide range of fossils. Apparently it represents a range of environments from brackish to open marine, but to what degree it represents one or another influence is unclear, particularly when other units in the cyclothem are missing. In a cyclothem with strongly developed marine characteristics, it is a transitional unit, and thus difficult to classify.

## Middle Limestone

In more marine cyclothems, a limestone is developed below an overlying black shale. Moore's (1950, 1964) description is usually applicable: thin, massive, and bluish-grey. Toomey (1964) states these limestones are dominantly skeletal calcilutite. If shallow water facies (such as stromatolites, oölite, or abraded calcarenite) are developed, they occur at the base (Hite and Cater, 1972; Heckel, 1977; Watney, 1980). In some cases in the western United States, this

lower carbonate may also be dolomitized or sandy (Hite and Cater, 1972). Farther east, where coal is present in the section below, particularly where the limestone is thin and lenticular, it is frequently rich in coaly debris (Johnson, 1971), dark grey to black, and generally composed of lenses of coquina.

## Black Shale

One of the most unusual and frequently recurring lithologies of the cyclothem is the black shale. The black shale frequently occupies a central position in the cyclothem, often symmetrically sandwiched between two limestones. For this reason, Heckel and Baesemann (1975) labelled it and the associated grey shale transitions as the "core" shale. Although all black shales in cyclothems may not be of a single origin, certain recurring features suggest most of them have a common genesis. Characteristically, the black shales are laterally persistent, rich enough in organic material to produce a significant quantity of hydrocarbons when subjected to destructive distillation, and high in trace metals, including uranium. Frequently, they also contain nonskeletal apatite, either as laminations of sand-sized particles or as discrete nodules. They also generally lack carbonate and siliciclastic grains larger than fine silt. Their fauna consists chiefly of phosphatic forms: inarticulate brachiopods, fish, conularids, and conodonts. The conodonts form an abundant and characteristic assemblage: dominated by idiognathodid forms, but characterized by the genera Gondolella and Idioprioniodus. When calcareous invertebrates are present, they are usually forms that can be interpreted

as opportunistic; that is, they are quite abundant in thin horizons of low diversity. (Examples are the pectinid Dunbarella and the brachiopod Crurithyris.)

These black shales show a range of development. The most developed form is very fissile, breaking into thin, papery sheets on weathered outcrops. Transitional to this is black blocky mudstone, often with scattered burrows filled with pyrite or lighter grey mud. This transitional shale often displays distinct alternating layers of lighter and darker shale, each up to several millimeters thick. Nonskeletal apatite is generally most abundant in this upper black blocky phase, rather than in the blacker fissile horizon below. Near the contacts with the limestones the shale is often grey, calcareous, and quite fossiliferous. These facies are all gradational, although the fissile black shale is much more resistant, and forms prominent ledges on outcrop. Usually the upper transition is much thicker than the lower one. In some cases, the adjacent limestones are replaced by prodeltaic grey shales. In such cases, it is impossible to distinguish the core shale facies from the adjacent facies, and distinct contacts cannot be found.

(When a shorthand notation is required, the transitional grey shales are distinguished by referring to the lower as A and the upper as C; the black shale is the B facies.)

The black shales are apparently basinal facies, as they grade laterally into shelf limestones. In the Middle and Upper Pennsylvanian basins of Texas, the limestones bounding the deltaic formats (Forgotson, 1957) grade into black shales in the basins (Fisher,

et al., 1969; Galloway and Brown, 1972). These apparently represent major transgressions, with sediment being trapped near shore (Heckel, 1977, 1980); during deposition of the formats, clastics spill across the shelf and into the basin, depositing shales and silts and diluting organic deposition. This is also known from the Anadarko Basin, where Michlik (1981) traced Middle Pennsylvanian limestones basinward into dark shales, and where Seale (1981) traced the Hogshooter (Dennis) into a radioactive black shale. The black shale is the first facies lost toward shore. Along basin margins and over topographic highs, the black shale disappears and is replaced by a grey, fossiliferous, conodont-rich facies, as though the shale is composed of only the grey transitional units (Heckel, 1977; Mitchell, 1981).

Black shales of this type are widely reported. Those of the Paradox Basin are faunally similar (Peterson, 1966; Stone, 1968), while the Minnelusa of the Williston Basin (McCauley, 1956) and the Black Hills (Work, 1931; Jennings, 1958) includes physically and faunally related shales. Radioactive black shales are used for markers in western Nebraska (Wilson, 1978), adjacent Wyoming (Agatston, 1954), and western Kansas (Gordon, 1938; Parkhurst, 1959; Walton, 1960). Black shales with characteristic features are known from the Eastern Shelf of Texas (Stauffer and Plummer, 1932; Toomey, 1964) and southern Oklahoma (Bennison, 1981). Those of the Illinois Basin are also similar (Ostrom, et al., 1955; Lamar, et al., 1956; Wanless, 1957; Heckel, et al., 1980). The black shales of the Appalachian Basin are less clearly related, but rare occurrences of characteristic conodonts are reported (Merrill, 1974; von Bitter and

Merrill, 1978). Even European black shales may be related, as they also have faunal (Edwards and Stubblefield, 1947; Clarke, 1960; Calver, 1968, 1968a) and physical (Ponsford, 1955; Knowles, 1964) similarities.

## Upper Limestone

When terrigenous clastics do not obliterate it, there is generally a thick limestone developed over the black shale. This is what Moore (1936) termed the "upper limestone"; and Heckel (1977) interpreted it as being the regressive limestone. Generally, the base is a calcilutite with whole, unabraded and unmicritized shells (Heckel, 1977); in some cases, the basal transition is a very argillaceous dark, sometimes dolomitic skeletal calcilutite.

In some areas where terrigenous clastic input is very low especially along shelf edges and topographic highs, the upper limestome is frequently dominated by a phylloid algal calcilutite, which produced large mound-like buildups. They form rims to the Paradox Basin, to the basins of New Mexico and Texas, and to the Anadarko Basin in Oklahoma (Wermund, 1969; Hite and Cater, 1972; Wilson, 1975; Michlik, 1981). They have also been studied extensively in southeastern Kansas (Harbaugh, 1964; Heckel and Cocke, 1969) where they form prominent topographic escarpments. Algal mounds are also known locally farther to the east; for example, on the LaSalle Anticline (Tischler and Ruotsala, 1965) and in southcentral Ohio (Carothers, 1979).

The upper limestone may develop various shallow water facies when not obliterated by prograding terrigenous clastics. These include abraded, cross-bedded skeletal calcarenite, oölite, and laminated, unfossiliferous calcilutite with fenestral texture (Heckel, 1977, 1980). This sequence has been noted elsewhere: Wilson (1978) recognized an upward gradation in his cyclothems of western Nebraska from skeletal calcilutite to skeletal calcarenite to oölitic skeletal calcarenite to supratidal dolomite. Ostrom (1956) noted that a few well-developed limestones in Illinois were capped by oölitic skeletal calarenites.

On the basis of different lithologies and fortuitous shale partings, Moore (1936) distinguished the upper shallow water facies as a "super" limestone. Heckel (1977, 1980) recognized these facies as simply a later phase of the regressive limestone.

## Nearshore Shales

In the areas where terrigenous clastic influx was important, carbonate production was often overwhelmed by prograding deltaic complexes. Typically, this produced thick, sparsely fossiliferous, laminated grey shales, sometimes with local sandstone or limestone lenses. (If the latter were extensive enough, Moore (1936) classified them as "fifth" or "lower" limestones, depending on their relative position in the cyclothem. Heckel (1977, 1980) considered them to be simply fortuitous, formed where clastic influx simply slowed enough to permit formation of a carbonate unit.) The shales are usually quite micaceous, with abundant muscovite and lesser amounts of biotite and

detrital chlorite; they are frequently quite rich in coaly debris and sometimes contain abundant spherical to discoidal ironstone (siderite) concretions. These shales also contain a distinctive fauna with prominent gastropods and pelecypods; the limestones and related thin shales have faunas dominated by brachiopods, bryozoans, and crinoids.

These shales often make up the bulk of what Heckel and Baesemann (1975) referred to as the "outside" shale. In some cases, they represent the only lithology present; in many cases, others are present in a subordinate role.

These shales may become increasingly silty and sandy away from the marine core of the cyclothem, and become essentially unfossiliferous or rich in land plant debris (e.g., Illinois, Willman and Payne, 1942; Appalachian Basin, Degens, et al., 1957; Asturias, Bless, 1968; British Carboniferous, Edwards and Stubblefield, 1947; Dunham, 1950; Calver, 1968a). Whether these shales should be recognized as a distinct phase or simply more vigorous clastic influx is unclear.

## Sandstones

The sandstones of the cyclothems fall into two broad groups: (1) channeloid sandstones that overlie prominent unconformities, and (2) sheetlike sands that generally do not overlie unconformities. The former type is characterized by a sharp base, sometimes with a limestone pebble conglomerate (e.g., Bless, 1968; Dubois, 1979). These sandstones are frequently cross-bedded and may occupy channels

up to 300 feet deep and several miles across (e.g., Krumbein and Sloss, 1963).

Other sandstones have gradational basal and upper contacts. These are frequently sheet sands, and are difficult to distinguish from adjacent units (Kosanke, et al., 1960). Often, these contain marine fossils (Wilson, 1942; Kosanke, et al., 1960) and are occasionally ripple-marked (Hopkins and Simon, 1975). Generally, they are better sorted and lighter in color than the channel sands (Donahue and Rollins, 1974) and calcite-cemented rather than filled with argillaceous matrix. However, Kosanke and others (1960) observed that in some cases one type of sand may grade laterally into another. They cited previous workers who stated such relationships were produced by either tidal/marine action, or the filling of a subaerial channel with marine sand.

Bennison (1981) has subdivided the sheet sands, recognizing (1) regressive sands occurring above the sideritic grey shales, which may include most of those described above, and (2) transgressive sands occurring above the coal or underclay and which are frequently pebbly and/or coaly. Although the transgressive and regressive sands are generally similar, the transgressive sands occur in a different stratigraphic position, one apparently unknown in the Illinois and Appalachian basins. However, when there are no subaerial deposits present in the cyclothem, it may not be possible to distinguish the two kinds.

## Red Mudstones

Although not common in Pennsylvanian cyclothems of the Midcontinent and Illinois Basin, occasionally red mudstones are found in the upper part of the outside shales. They are usually unfossiliferous and massive, with a blocky fracture and occasional small slickensided surfaces, although Kotrous (1978) mentioned a laminated red shale. The contacts of the red mudstones are usually irregular and gradational. Redbeds are apparently related to seat earths, with which they intergrade laterally (Waagé, 1950). Donahue and Rollins (1974), Watney (1980), and Dott (1981) agree that these redbeds are paleosols, some with caliche horizons.

## Seat Earths

Seat earths are widespread in many cyclothems. In most North American cyclothems, the seat earths are underclays, but ganisters are common in some stratigraphic intervals.

Underclays are grey to green massive mudstones of variable thickness below coal seams. They usually have a blocky fracture, and often have small slickensided surfaces, particularly near the base. Rooted zones are commonly developed at the top, but not always present. Underclays are frequently pyritic and coaly, but rarely calcareous.

Although a controversial conclusion, underclays are here recognized as soil profiles (the principal evidence for this is discussed in the section on clay mineralogy). This interpretation is

supported by the stratigraphy. Underclays are the most persistent unit in many cyclothems (Eberl, 1980), something that would be expected in a unit that had developed over wide areas during maximum retreat of the seas. An underclay would be expected to develop wherever argillaceous rocks were exposed for sufficient time. They would not be expected in flood plain or alluvial fan environments, where repeated burial of the sediments would not permit deep weathering.

The "underclay" or "freshwater" limestone is a curious lithologic unit sometimes associated with the underclay, especially in Illinois. Typically, it is a nodular, argillaceous carbonate found at the contact between the underclay and the underlying grey shale. In some areas, it is a laminated carbonate, with Spirorbis, algae, and ostracodes (Donahue and Rollins, 1974; Hopkins and Simon, 1975). However, in most areas it lacks structure that would support this. In this study, the underclay limestone is apparently a caliche horizon. Not only does it occupy the contact between weathered and unweathered clay, but is also at the base of the leached zone. Petrographic evidence supports this interpretation, as the limestone shows features such as root tubes, roots, and concentric growth. The lack of spores (Peppers, 1964) is difficult to explain, unless the caliche formed underground. Dott's (1981) observations of caliche nodules at the bases of Upper Pennsylvanian paleosols in Oklahoma support this. Further, caliche is widespread during the Pennsylvanian (e.g., Knight, 1929; Donahue and Rollins, 1974; Heckel, 1977, 1978; Dubois, 1979; Watney, 1980; Loope and Schmitt, 1980; Dott, 1981) (Fig. 5). Thus,

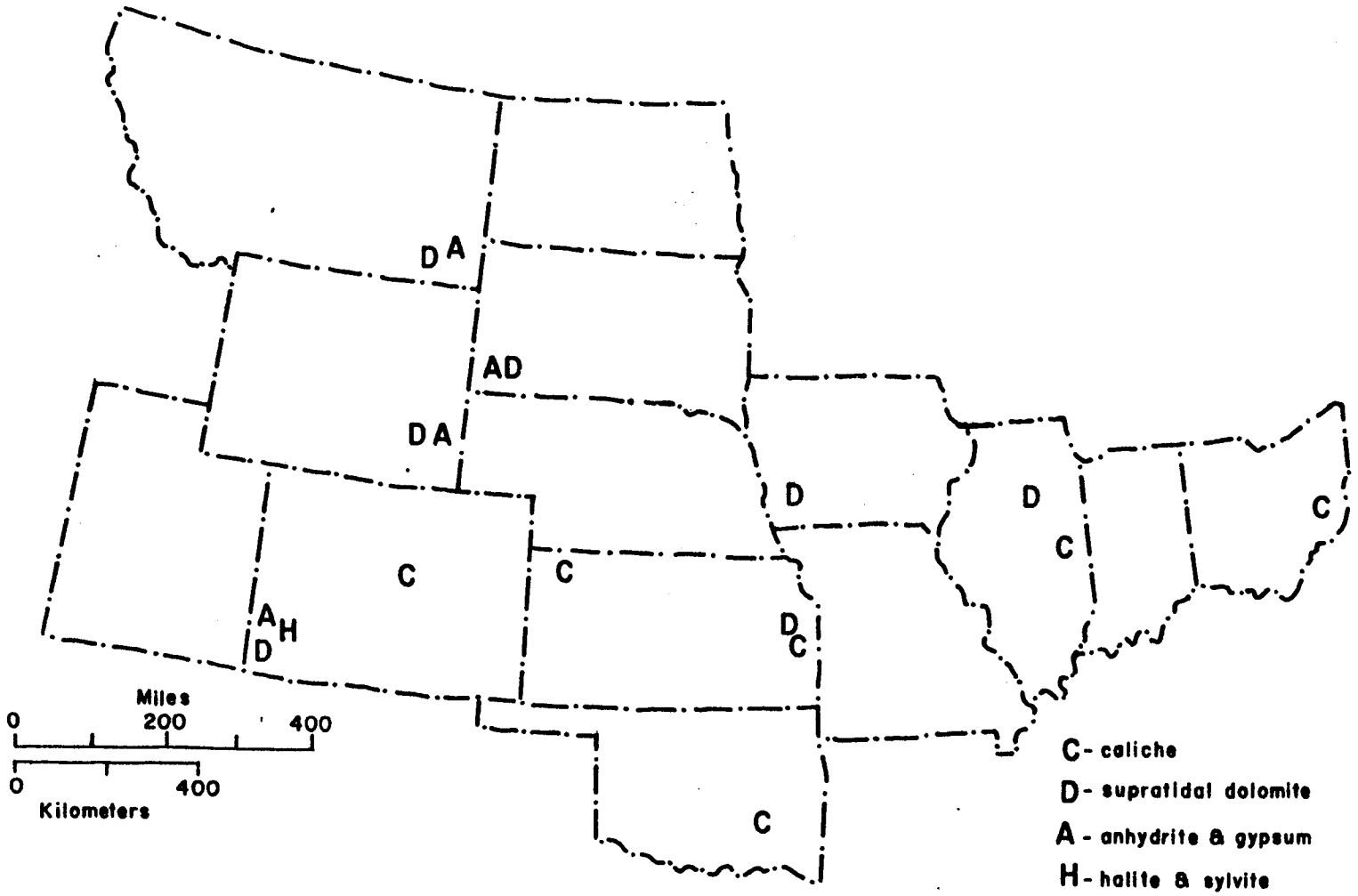



Figure 5. Distribution of Desmoinesian and Missourian sedimentological features indicating an arid or seasonally dry climate.

the horizon should probably not be considered a separate stratigraphic unit, but should be included with the underclay.

## Other Lithologies

While there are other ways to produce dolomite, that which formed in restricted shallow waters and sabkha environments is often found in Upper Pennsylvanian carbonates. The upper limestones, which are frequently capped by massive or laminated calcilutite (which often has a fenestral fabric and restricted fauna) become increasingly dolomitized upward. Tischler and Ruotsala (1965) noted that the upper beds of the LaSalle are dolomitic. This trend increases to the west, so that the Upper Pennsylvanian carbonates are frequently heavily dolomitized in western Nebraska where Wilson (1978) identified sabkha deposition. This is also true in the Williston Basin, especially around topographic highs such as the Ancestral Black Hills (McCauley, 1956). The carbonates in and around the Paradox Basin are often dolomitic both above and below the black shale (Hite and Cater, 1972).

In areas of minimal clastic influx and arid climates, the outside shale may be joined or replaced by evaporite deposition. In the Missourian, anhydrite and gypsum were being deposited in large quantities just to the west of the study area. Wilson (1978) noted it in western Nebraska, Mallory (1972) reported it in a basin in central South Dakota, and it was common in the Upper Pennsylvanian strata of the Williston Basin (McCauley, 1956). The evaporite facies were migrating eastward; halite deposition took place in the Paradox Basin

of Colorado in the Desmoinesian (Hite and Cater, 1972), but had migrated into the Midcontinent by the Lower Permian (Wilson, 1978). Thus, the Midcontinent in the Missourian was adjacent to encroaching evaporite deposition, indicating that the climate was becoming increasingly arid.

## Aspects of Cyclothem Deposition

### Asymmetry of Deposition

The details of transgression and regression are controlled by local and transient factors. The sediment laid down at any time is not entirely independent of the preceding sediment; variation in the sediment will determine the organisms living on it and in it, which will in turn affect sediment laid down. Thus, the transgressive portion of the cyclothem, often laid down on underlying shale or coal, may have a different suite of lithologies than the regressive portion, which is often laid down on an underlying carbonate or black shale. Variation in the rate of relative sea level rise or fall would also be a factor. P. H. Heckel (pers. comm., 1982) stated that even if the rates of sea level rise and fall were equal, less sediment would be deposited during transgression than regression. The rates were probably not equal, nor even necessarily uniform; this would have a profound effect on the local development of lithologies. Variations in sedimentary influx could also produce asymmetry, but would not be as systematic as that due to sea level change.

This sheds light on a major controversy: what is the relationship between the black shale and the underlying lithologies?

Frequently in the Illinois Basin, the black shale lies directly above the coal in the cyclothem, or with only minor intervening beds. This has produced the idea that black shale deposition must be linked to early flooding of the coal swam (e.g., Wanless, 1957; Zangerl and Richardson, 1963; Wilson, 1975). However, Wanless (1957) noted that in some cases there were marine beds between the black shale and the coal, and occasionally the black shale would be found without any associated coal. Farther west, in Kansas, the black shale often occurs sandwiched between two limestone layers of considerable thickness. There, it has been documented (Heckel, 1977; Watney, 1980) that shallow water facies (e.g., stromatolites, oölites, supratidal carbonates) occur only in the base of the middle limestone and the top of the upper limestone, away from the black shale. Facies such as whole-shell skeletal calcilutite without algae are found adjacent to the black shale, suggesting deposition below effective wave base and possibly below the photic limit. The problem of the black shale in the cyclothem comes down to three possible resolutions: (1) the black shales in Illinois and Kansas were produced in different environments; (2) before black shale deposition, there was an extremely rapid regression with no preserved evidence above the underlying limestone, followed by a transgression that produced the black shale, or (3) the invasion of the sea left little record in Illinois between the coal and the black shale. Of these, (1) is not supported, since both Illinois and Kansas black shales have the same faunas, and the same faunas and lithologies are found above the black shales, and (2) is speculative, as there is no supportive evidence. (3) is considered the most probable

explanation, especially since asymmetrical Pennsylvanian cycles are known elsewhere.

Asymmetric cyclothems have been documented in many places. Heckel (1977) suggested the comparative thinness of the transgressive limestone indicates a more rapid transgression than regression. Heckel also noted that during a transgression sediment would be trapped in rivers and estuaries, so that little would be expected to reach the basin. With little dilution of the autochthonous sediments, a condensed sequence would result. The core shales also support asymmetry. The blackest, most fissile portion (presumably the result of the most extreme conditions) is normally close to the bottom, and the upper grey transition is usually much thicker than the lower grey transition. Donahue and Rollins (1974[a]), on the basis of fauna, found some of the Appalachian Basin cyclothems had much more rapid transgressions than regressions. Calver (1968) found much the same thing in British cyclothems, but was able to demonstrate a symmetry of faunal facies about the core black shale. Notably, if Calver's lower succession was even more compressed into an inch or so, it would closely resemble that found in Illinois.

Rao (1981) noted in the Lower Permian periglacial marine deposits in Tasmania that the transition between limestone (which was presumably deposited during a glacial stage) and the overlying shale (deposited during an interglacial stage) is very sharp, indicating rapid deglaciation; the reverse shale-limestone transition is gradual, indicating slow ice buildup. If the same type of glaciation produced the sea level change that made the cyclothems in the

Pennsylvanian, then the resulting cyclothems would be expected to have thin, condensed, transgressive phases, while the regressive phase would be relatively thick and well-developed.

The type of transgression suggested for the Pennsylvanian cyclothems seems to be fairly common in the geologic record. Newell (1966), in discussing paraconformities (which would include the Illinois-type coal-black shale sequence as interpreted), noted they are usually not obvious, and that recognized soil profiles or related features are not often found with paraconformities.

McGugan (1965) discussed widespread, thin black shales above unconformities, noting they often had little or no sign of transgressive deposits, and suggested very slow sediment influx as a factor in their deposition. He also noted such shales are often radioactive and phosphatic. As an example, he mentioned a Permian black shale with dimensions similar to those found in the Pennsylvanian cyclothems in the Midcontinent. Curiously, its fauna consisted of fish debris, inarticulate brachiopods, and conularids, as is found in the Pennsylvanian black shales.

Goodwin and Anderson (1980) have introduced a concept that may have relevance to Pennsylvanian cyclothems. They recognized what they refer to as punctuated aggradational cycles (PACs), which are shallowing-upwards sedimentary packages with little evidence of any transgression. They suggest these PACs are caused by episodic changes in sea level relative to the land. Although they may have intended their PACs for smaller features (such as individual beds), rather than a whole cyclothem, the principle may still apply.

## Lateral Facies Changes in Cyclothems

While discussing Pennsylvanian cyclothems, it is necessary to make some observations on their horizontal and vertical facies change. As previously pointed out, the cyclothems as a whole have tremendous continuity. But do the individual lithosomes?

Several patterns are expected. One is that the less variable a unit, the more stable its environment would be. In keeping with Walther's Law, another expectation is that one would laterally replace facies with adjacent facies--thus, going from the basin center, one would expect to find the most basinal facies replaced by the adjacent facies. Both principles would be valid only if undisturbed by outside influences and if sedimentation were continuous.

The Upper Pennsylvanian basinal deposits of Texas and Oklahoma (Anadarko, Palo Duro, Dalhart, and so on) are principally dark grey to black bituminous shales, with thin dark limestones (Roth, 1955; Totten, 1956; Rascoe, 1962; Dutton, 1980). These shales are known to grade laterally into shallower-water limestones. Thus, if sea level were to rise, these deep facies would encroach onto the platform, and the related adjacent facies would migrate into what were previously shallower depths. Given the stability of the deep water environments, it would be expected that these shales would have little lateral variation.

This is indeed the case. Due to low relief, the black shale-depositing water covered huge areas; Moore (1950) noted that some of

the shales cover over 100,000 square miles. Heckel (1977) observed that the black shales change facies very slowly and are perhaps the most consistent units in the cyclothem. This great persistence and constancy of physical properties make the black shales almost ideal for correlation purposes, for which they are extensively used.

Thus, in a shoreward direction, the black shale should be lost, and the lower and upper grey shales would join to occupy the entire core shale position, producing a fossiliferous dark grey shale. Indeed, this is what happens over topographic highs and basin margins (Heckel, 1977; Watney, 1980; Mitchell, 1981). Grey shale occupies the entire core shale position in some of the incompletely developed cycles. The apparent inconsistency that in some cases in regions of active deposition, the black shale is found sandwiched between prodeltaic grey shales is readily explained if the black shale is the most offshore facies of the cyclothem. It would be the least likely to be obliterated by incoming terrigenous clastics. But a combination of decreasing depth during regression and active progradation of clastics can quickly obliterate any carbonate production as the water shallows; thus, the upper limestone is often replaced by a thick grey shale (Heckel, 1977). This variation is common in northeastern Oklahoma, and may also explain some of the cyclothems in the Appalachian Basin and Europe.

Heckel (1977) noted that the carbonates adjacent to the core shales also have little variability. Similar dark limestones interfinger with basinal shales in Texas and Oklahoma (Galloway and Brown,

1972; Michlik, 1981), suggesting that the stability of their environment is similar to that of the core shale.

However, away from the core shale, the carbonates have increasing variability. Many facies, such as oölites, stromatolites, cross-bedded skeletal calcarenites, and laminated unfossiliferous calcilutite interlayer and interfinger. Depositional relief becomes increasingly significant, as some facies will be found only in areas with certain characteristics. For example, many of the regressive limestones have facies in their upper portions peculiar to the northern shelf area (Payton, 1966; Heckel, 1978). But the most signficiant facies dependent on local relief is the phylloid algal mound facies. The mounds apparently developed on local topographic relief (Harbaugh, 1964; Tischler and Ruotsala, 1965; Heckel and Cocke, 1969); frequently they edged the shelf (Michlik, 1981) or the margin of drowning deltas (Harbaugh, 1964; Kenny, 1968). Frequently, the mounds from the previous cycle would provide enough topographic relief to localize mound growth again, producing a stacked series of mounds (Heckel and Cocke, 1969). On a more local scale, even ripples of winnowed calcarenite or quartz arenite sometimes provided favorable loci for mound growth (Frost, 1968). The mounds themselves further influenced local facies, as oölites and calcarenites frequently cap them (Heckel and Cocke, 1969) and facies due to restricted circulation occur behind them.

The outside shales are generally highly variable. Locally, they include fossiliferous marine shales or local limestones (Heckel, 1977), as well as various redbeds, sandstones, local conglomerates,

and coals, in addition to the more usual prodeltaic and alluvial muds that form the bulk of the outside shale. Local, discontinuous overbank black shales are mentioned by Donahue and Rollins (1974a). However, in the case of many coals and their associated underclays, great lateral continuity is again the rule (Wanless, 1957). This is probably due to widespread subaerial exposure between some marine incursions: Wanless (1957) in Illinois, Stout (1931) in Ohio, and even Brew (1979) in Arizona noted frequent, minor (in that no great denudation takes place) unconformities between cycles. Major unconformities, however, are lacking. As a result, soil profiles would be expected to be widespread, as the subaerial surface would be continuous. With encroachment of the sea, paralic swamps would cover the surface, and the soil would be modified by sea water. This would produce an apparently continuous facies; however, local examination may yield evidence of variation in both the coal and underclay.

The outside shales also show expected facies relationships. For example, Walton (1960) noted in western Kansas the Captain Creek (a middle limestone) laterally became successively a shale, then a sandy shale. Momper (1966a) noted a related phenomenon in the Denver Basin, where he recognized a westward increase in the effects of the hiatuses between cyclothems--an effective replacement of shallow water depositional facies with nondepositional/erosional facies.

## Stratigraphy of Examined Units

As the shales under study are units in cyclothems, relevant features of the adjacent limestones must be considered, as well as those of any other lithologies developed within the shales.

The shales examined in this study are in two pairs: (1) the lower pair consists of the Galesburg Shale, which lies above the Swope Formation and below the Dennis Formation; and the Stark Shale, the core shale of the Dennis cyclothem. (Some mention will also be made of the Shoal Creek cyclothem, the probable equivalent of the Dennis cyclothem in Illinois.) (2) The other pair of shales includes the Vilas Shale, which lies above the Plattsburg Formation and below the Stanton Formation, and the Eudora Shale, the core shale of the Stanton Formation (Fig. 6). These units are described more thoroughly in the following discussion.

### Bronson Group Lithologies

The lower pair of shales studied are units in the Bronson Group (named by Adams in Adams, et al., 1904), which includes three cyclothems (in ascending order): Hertha, Swope, and Dennis. Although Moore (1948) downgraded the Bronson Group to subgroup status and placed it in the Kansas City Group, Ravn (1981) recommended it again be raised to group status, in view of its widespread prominence (due to the three prominent limestones) as a readily recognizable unit along the outcrop belt. In this study, the Bronson will be recognized as a group.

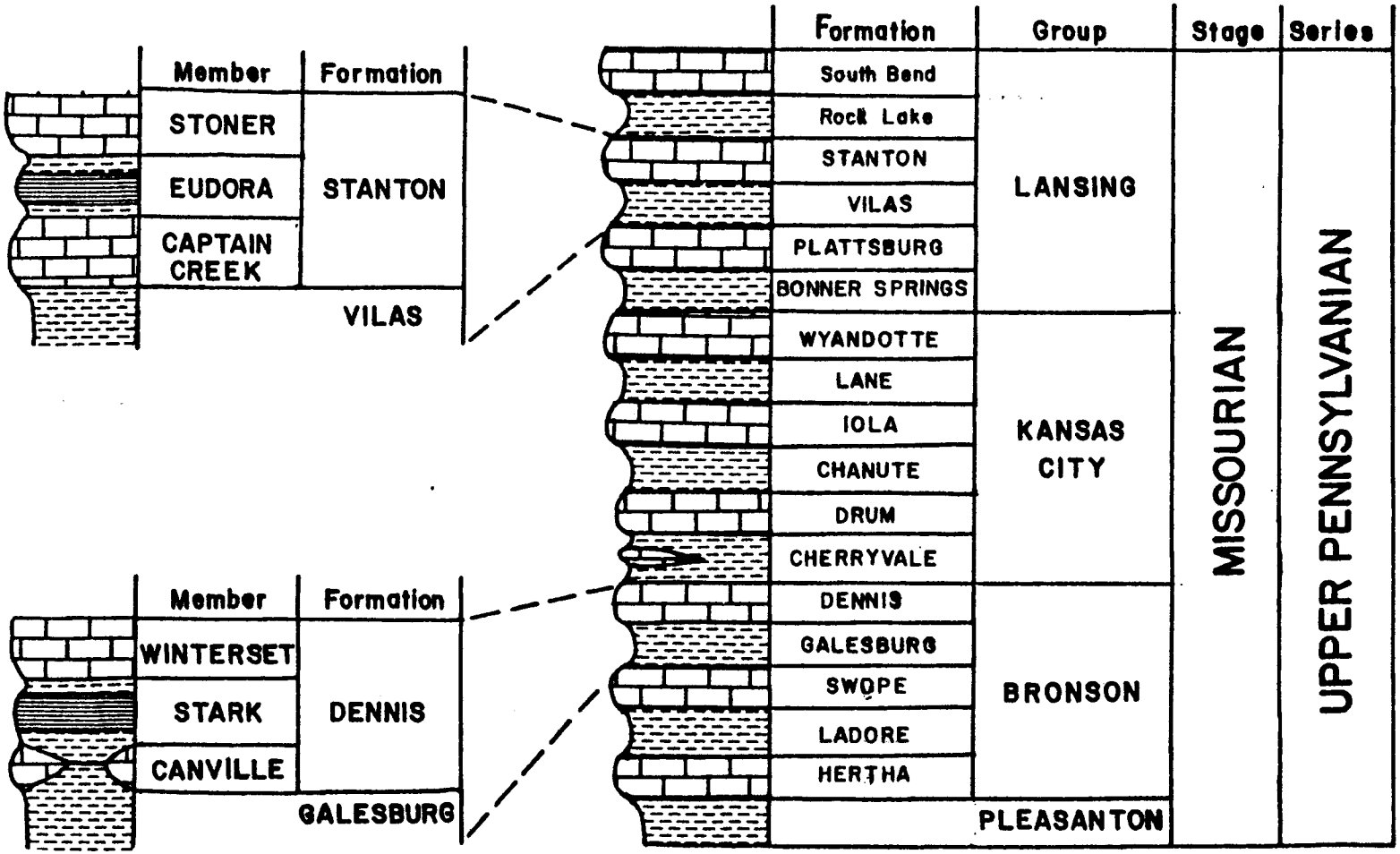



Figure 6. Stratigraphic positions of studied units.

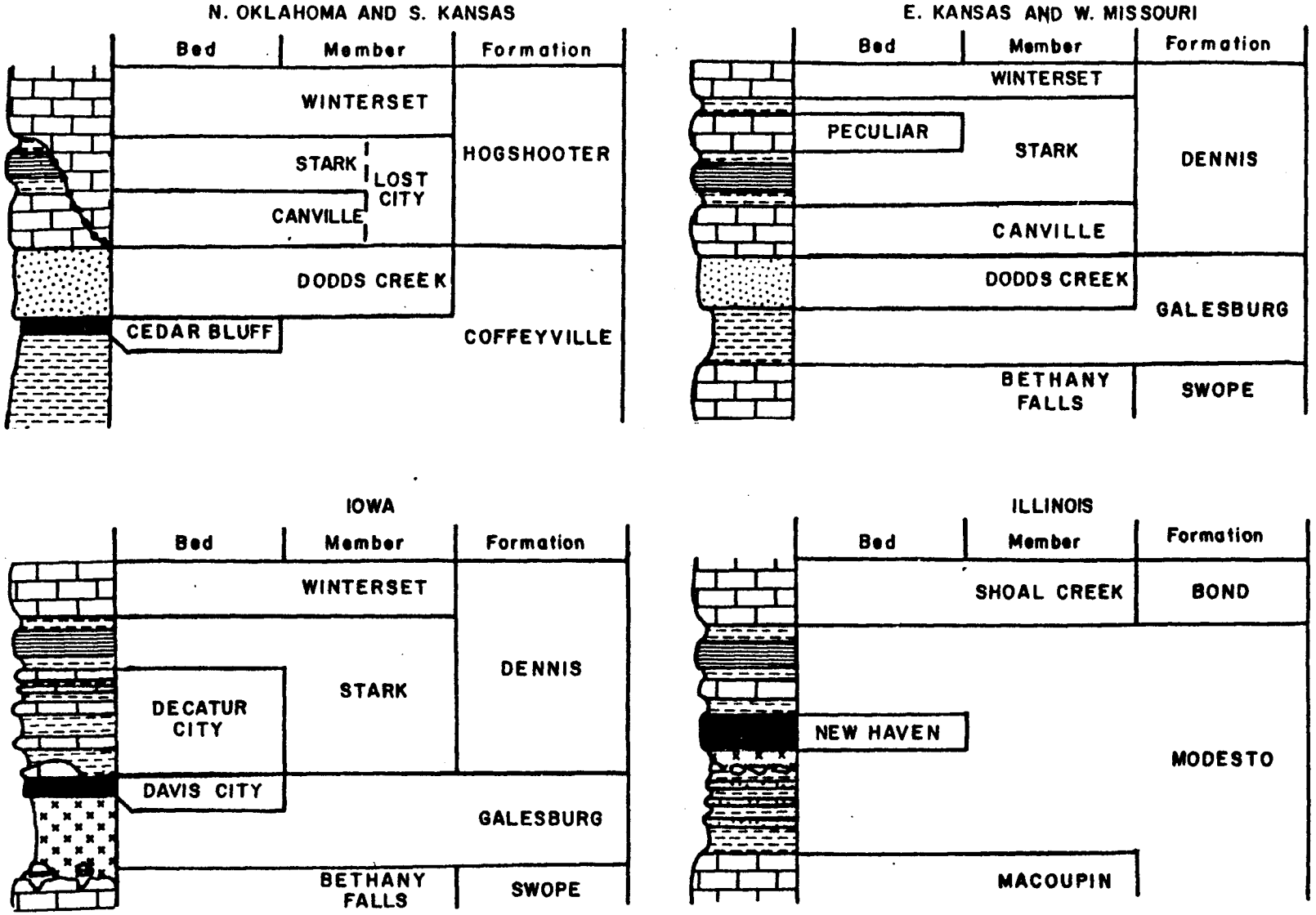



Figure 7. Composite stratigraphic relationships of the Galesburg and Stark shales.

Bethany Falls Limestone and Swope Cyclothem

The Swope cyclothem is important to this study as its prominent upper limestone member, the Bethany Falls Limestone, forms the substrate for the Galesburg Fromation. It is a typical Kansas cyclothem of Heckel (1977). Its middle limestone member, the Middle Creek, is one of Moore's (1964) examples of typical middle limestone lithology. Johnson (1971) described it as a carbonaceous "osagia" molluscan calcilutite, dark blue grey in color, with prominent vertical joints, burrows, and abundant pyrite. Payton (1966) recognized that the typical lithology overlaid shallow water Osagia and Ottonosia ("Cryptozoon") facies. Wenberg (1941) noted that the Middle Creek was extremely persistent and consistent, and so was a good unit for distinguishing the Swope cyclothem from the Dennis, as the middle limestone of the Dennis (the Canville) is rarely developed north of Kansas City.

The core shale of the Swope is the Hushpuckney. It is a well-developed fissile black shale, and locally contains apatite nodules. Named by Broadhead (1866) for its exposure at the falls of Big Creek near Bethany, Missouri, the Bethany Falls is a thick limestone, prominently exposed and frequently quarried along its outcrop from southeastern Kansas to Iowa and Nebraska. Along much of its outcrop, particularly toward the south, the top of the Bethany Falls is a thick, often cross-bedded, oölite. Usually, the upper contact of the oölite is quite sharp, with very few fragments of similar lithology

incorporated into the basal Galesburg (Gentile, 1976). Locally, stromatolites (Dimitracopoulos, 1979) and caliche (Heckel, 1977, 1978) are developed on the upper surface of the oölite.

Elsewhere, the upper facies of the Bethany Falls is a mottled, poorly fossiliferous light grey calcilutite, sometimes displaying a fenestral or laminated texture. Where this lithology is present, there is a thick "rubbly" transition to the overlying Galesburg. This consists of irregular clasts of calcilutite, similar to that of the upper Bethany Falls, in a matrix of greenish-grey clay (Lamerson, 1956; Gentile, 1976). This rubbly zone ranges from one to five feet thick. Notably, the clasts become smaller higher in the zone. Lamerson (1956) attributed these clasts to algae, but cited no evidence. Howe and Koenig (1961) believed they were related to the Bethany Falls, although they described them as "concretions."

The lateral terminations of the Bethany Falls are not definitely known. Mossler (1970) noted that only one limestone is present in the Swope cyclothem south of southern Bourbon County. Jungmann (1964) had identified this as the Bethany Falls, and commented on the fact that both underlying and overlying adjacent shale beds are rich in crinoid debris. Mossler (1970) described this southern limestone as a phylloid algal calcilutite and conceded that it could possibly be the Middle Creek Limestone rather than the Bethany Falls. P. H. Heckel (pers. comm., 1981) has concluded that only the Middle Creek is present southward from Erie, Kansas. Bennison (1981), working in southern Oklahoma, recently correlated the Denay Limestone with the Middle Creek; he recognized that middle (transgressive) limestones are

laterally more persistent than upper (regressive) ones. The Swope cyclothem shales out into the Arkoma seaway, and also becomes shaly in a deltaic region of northern Nebraska (Horne, 1965).

The relationship of the Bethany Falls and Swope to the other units of the Bronson Group is pivotal to understanding the history of Missourian deposition. A major question has been raised by the change in the fusulinids. The Bethany Falls is characterized by primitive, Demoinesian-type fusulinids, especially Eowaeringella ultimata (Heckel and Meacham, 1981), whereas the Winterset, a cycle above, is characterized by the first known triticitids in the Midcontinent outcrop (Thompson, et al., 1956). This is a sizeable evolutionary jump, and suggests a long interval of time between the Swope and Dennis inundations. However, Lamerson (1956), in searching for physical evidence of a significant break, found none.

## Galesburg Formation

The Galesburg Formation is the "outside" shale formation that separates the Swope and Dennis cyclothems, and is principally a mud rock. It was named by Adams (in Adams, et al., 1903) for exposures near Galesburg, Neosho County, Kansas.

The Galesburg naturally falls into very different but laterally equivalent provinces in the Midcontinent, which will be discussed separately.

### Southern Galesburg/Coffeyville Coarse Detrital Facies

South of roughly the position of the Bourbon Arch, the Galesburg is a southward-thickening clastic wedge; it is composed of poorly

fissile grey shale, muddy micaceous sandstone, and a few thin coals (Fig. 8). South of the disappearance of the Swope cyclothem in southernmost Kansas (O'Connor, 1962), the Galesburg shale cannot be separated from the underlying Ladore Shale. The resulting thick shale unit is known in southeastern Kansas and Oklahoma as the Coffeyville Formation, named by Schrader and Haworth (1905) for exposures around Coffeyville, Montgomery County, Kansas.

The Coffeyville in northeastern Oklahoma is generally recognized as a deltaic system. Bloesch (1930) noted that it is 200 to 300 feet thick in the northern tier of counties, and thickens toward the south. Visher and Rennison (1978) more precisely defined a southern Coffeyville delta, which thins to the northwest; beyond that, a northeast-southwest trend of clean sand about 30 feet thick was interpreted as a wave-reworked barrier bar complex. The delta proper was characterized by several lithologies. (1) Laminated carbonaceous shales were finely interlayered fissile black shale and silt laminae. They contained leaf imprints, siderite concretions, and local coals. Locally, they were mudcracked, slickensided, and massive due to root action. These shales were interpreted as crevasse splays. (2) Greenish-grey to dark grey finely bedded shales had bedding planes covered with tracks, trails, carbonaceous flakes, and mica. These were considered to be prodeltaic muds by Visher and Rennison (1978). (3) Fine-grained, parallel-bedded sandstone was found laterally between the splay deposits and the interdistributary bay deposits. These occurred near distributary channel sands.

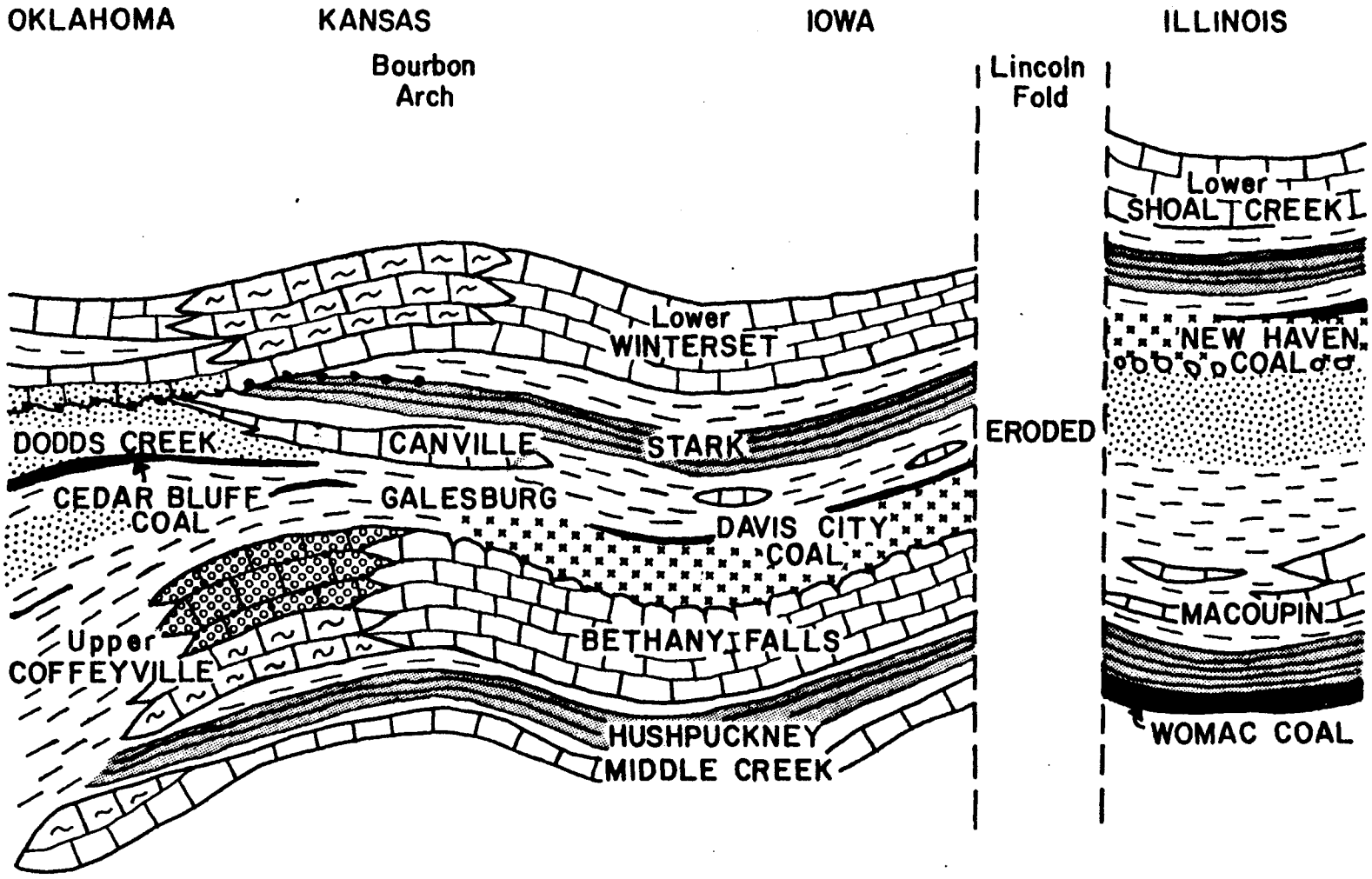



Figure 8. Stratigraphic relationships in the Swope and Dennis cyclothems. (Compare to Fig. 2 and 3.)

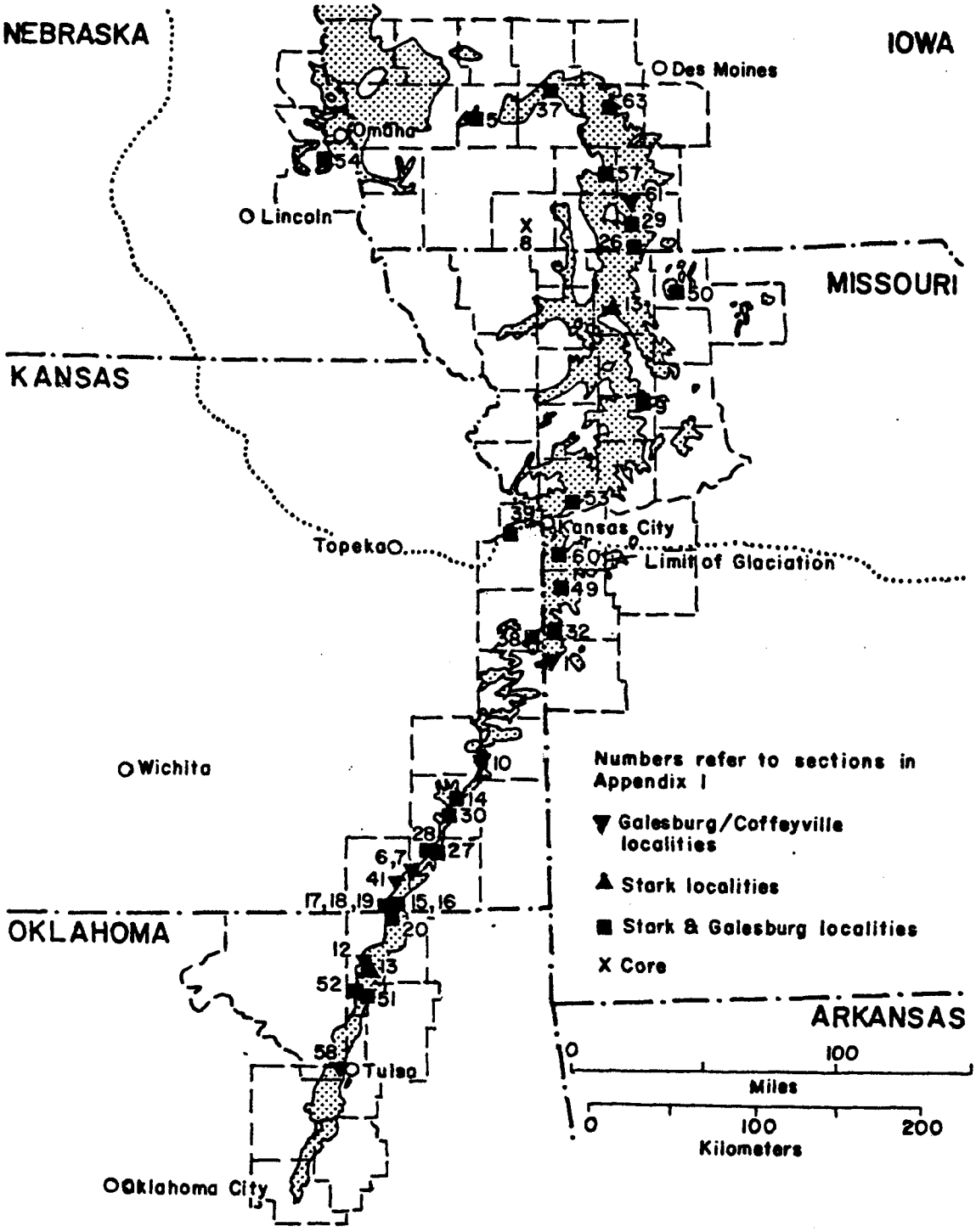



Figure 9. Galesburg and Stark outcrops. Pattern is Coffeyville and Hogshooter in Oklahoma, Dennis and Galesburg in Kansas, and Kansas City Group in Missouri, Iowa, and Nebraska.

Figure 10. Isopach map of Galesburg Shale (may represent Ladore Shale in Nebraska and Iowa).
(Isopachs from Horne, 1965; outcrops from this study for comparison)

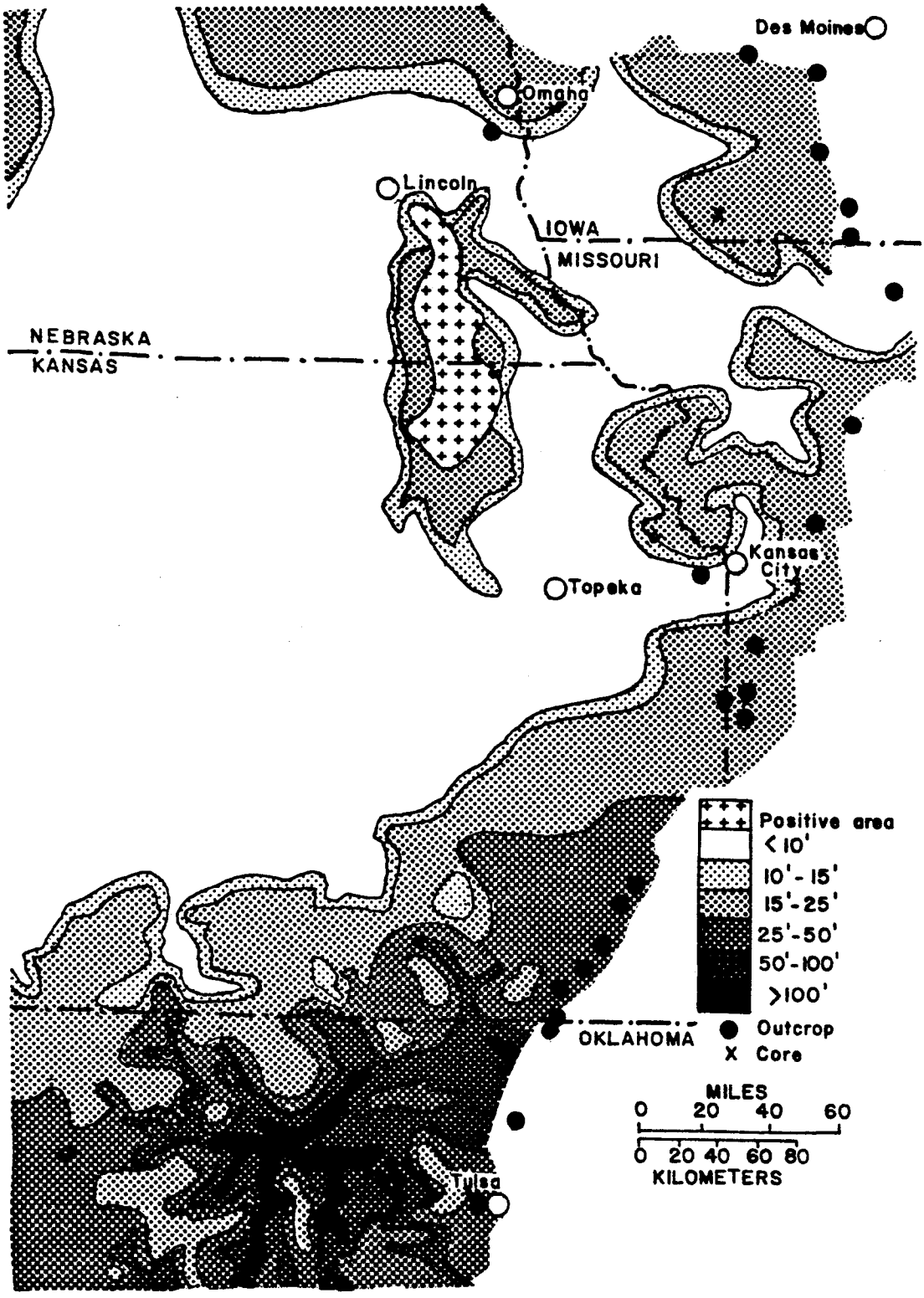

Des Moines
Omaha
Lincoln
IOWA
MISSOURI
NEBRASKA
KANSAS
Kansas City
Topeka
Positive area
< 10'
10'- 15'
15'-25'
25'-50'
50'-100'
>100'
Outcrop
X Core
OKLAHOMA
Tulsa
MILES
0 20 40 60
0 20 40 60 80
KILOMETERS

Figure 10.

Horne (1965), in mapping subsurface lithologies in the Coffeyville, recognized two deltas in this southern region, with one from the south and another, sandier one from the east. Horne also mentioned that the Nemaha Uplift produced small channel sands, local arkoses, and some marine redbeds in northeastern Kansas and adjacent Nebraska.

Bennison (1981) identified the Coffeyville south of the Arkoma seaway in southern Oklahoma, and noted that its thickness is about 350 feet, not greatly different from that in the Tulsa area.

Dodds Creek Sandstone and Cedar Bluff Coal.--The Dodds Creek Sandstone member of the Galesburg Formation was named by Jewett (1932) for outcrops along Dodds Creek in Labette County, Kansas. In the same paper, Jewett named the Cedar Bluff Coal, for exposures on Cedar Bluff, just north of Coffeyville, Montgomery County, Kansas.

In both cases, usage has departed from the original definitions. The Dodds Creek was originally defined as the sandstone overlying the Cedar Bluff Coal. However, since that time the term "Dodds Creek" has generally come to signify any sandstone within the Galesburg/ Coffeyville interval. For example, Zeller (1968) diagrammatically shows the Dodds Creek at the base of the Galesburg. The problem originates from the fact that there are often multiple coals and sandstones within the Galesburg/Coffeyville. In many places, one coal/ sandstone pair is dominant, and is named and correlated by inference on that basis, but the validity of this is dubious. At Cedar Bluff,

Moore (1937) mentioned four coals and three sandstones, although the Cedar Bluff Coal was by far the thickest of the four. Branson (1964) noted a thin coal below the Winterset in Oklahoma, with the Cedar Bluff Coal 11 to 40 feet below that, but it was not distinguished as a recognizable cyclothem.

The Cedar Bluff Coal is usually about six inches thick (Moore, 1937). Bloesch (1930) reported it to be a foot thick at a locality in northern Oklahoma, but where observed for this study (Locality Bt1), it was seen to be mostly shaly partings and bone coal, with the seam proper only four inches thick. The Cedar Bluff Coal is a black, banded coal, and generally lacks a prominent rooted zone. However, inspection of impression material at Coffeyville below the coal showed roots to be present.

The Dodds Creek lithology is widespread in the Galesburg/ Coffeyville, extending northward to the Bourbon Arch, although Gentile (1976) reports sandy Galesburg as far north as southern Bates County, Missouri. Stobbe (1971) stated that it could be traced westward to Cowley and Sumner counties, Kansas, and southward, possibly to Okfuskee County, Oklahoma. In the subsurface of Oklahoma (Jordan, 1957), the True Layton, McKinney, and Cleveland sands are considered equivalent to the Dodds Creek, and the Marchand sands discussed by Seale (1981) would also be roughly correlative; in subsurface Kansas, the Redd sand is equivalent (Jewett, 1954).

The Dodds Creek Sandstone is generally a thick-bedded, fine to very fine grained quartzose sandstone, with only slight rounding

of the grains (Verhulst, 1970). It thickens southward in Labette County, and becomes coarser southward (Stobbe, 1971).

The Dodds Creek Sandstone has several peculiar relationships. For example, as defined, it occurs above the Cedar Bluff and any other coal seams. This is in direct contrast to all the "ideal" cyclothems drawn, where the sandstone unit is always below the coal. The Dodds Creek generally lies above several feet of shale found above the Cedar Bluff Coal (Moore, 1937; Stobbe, 1971), but southwest of Coffeyville, about ten feet of Dodds Creek lies directly on a six-inch seam of Cedar Bluff Coal, with a sharp but conformable contact (Fig. 11). This sandstone in turn has dark brown apatite pebbles in its upper surface, and is overlain by the sandy calcarenite of the basal Winterset. The coal-sandstone ascending sequence is found at Canville Creek (Locality Ca1), and it is in southern Bates County (Gentile, 1976). Bennison (1981) provided an explanation for this by noting that the Dodds Creek is a transgressive sand, something rarely found in the North American Upper Pennsylvanian outside of Oklahoma. These sands are strand lines pushed back as the sea encroached on the coastal plain, producing a sheet sand over the top of the deltaic deposits below.

The Dodds Creek/Galesburg contact with the underlying Swope is also odd. Stobbe (1971) noted a limonitic crust on the top of the Swope from Erie, Kansas, southward, and attributed it to a soil horizon formed where the mottled or oölitic horizon at the top of the Bethany Falls was removed. At Liberty, in Montgomery County, he described a nodular argillaceous limestone below the Cedar Bluff Coal,

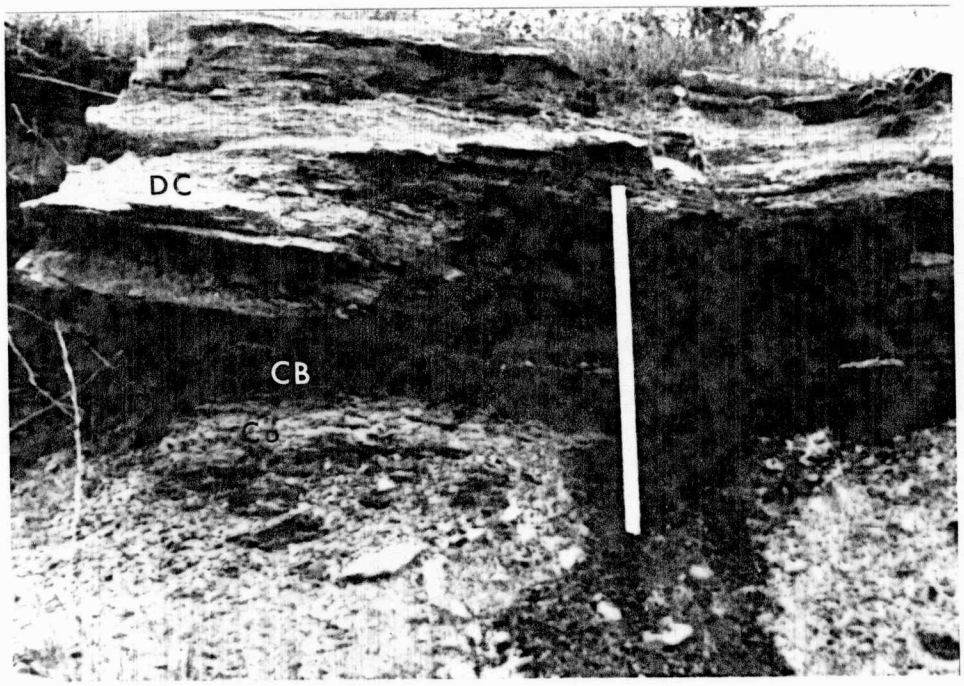



Figure 11. Locality Cf3, near Coffeyville, Kansas. Note the abrupt contacts between the base of the Dodds Creek Sandstone (DC), the Cedar Bluff coal (CB), and the lower Coffeyville Formation (Co) below. A well-preserved compression flora is found in the top of the Coffeyville shale here. Scale is 3 feet (91.5 cm). May, 1980.

and correlated it with the Bethany Falls. Stobbe thought the Dodds Creek beveled the Bethany Falls, but at the same time observed the lack of channels or any other sign of erosion cut into the Swope. Mossler (1970) observed lenses of intraclastic biosparites, with coarse fossil fragments in the lower Dodds Creek in Neosho County, which he suggested were reworked from the top of the Bethany Falls. Significantly, these lower sands may not be the environmental equivalent of the Dodds Creek (as originally defined), but rather environmentally different sandstones lower in the Galesburg/Coffeyville clastic sequence.

Northern Galesburg Mudstone Facies

North of the Bourbon Arch, the Galesburg is not, strictly speaking, a shale, but rather a mudstone, or, more precisely, an underclay. It is greenish-grey, blocky, and variably calcareous. Johnson (1971) described it as having slickensides and rootlets. Frequently it has pyrite framboids and occasional calcite or pyrite structures that suggest mineralization of roots. In some areas, it has small calcite nodules up to 5 millimeters across, which sometimes contain coarsely crystalline kaolinite septarian fillings. The mudstone grades downward into the underyling Bethany Falls Limestone through the previously described "rubbly zone." The Galesburg in the north is quite thin compared to the overlying and underlying limestones. (This is probably why Keyes (1898) advocated ignoring it altogether as insignificant, and called the three limestone formations the Bethany Limestone, although he admitted the previous definitions of the Bethany Falls and the Winterset were very specific.)

For this study, the Galesburg in the northern region is redefined simply as the blocky mudstone facies. Quite distinct from it, and usually readily identifiable on outcrop is an overlying, fossiliferous, somewhat fissile grey shale. Because this is a product of a far different environment and is gradational upward into the fissile black Stark shale, this fossiliferous shale is reassigned to the Stark.

The blocky Galesburg is fairly uniform, varying principally from three to eight feet thick (Lamerson, 1956). Locally in Kansas City, it is missing completely, with fossiliferous grey Stark resting on the rubbly zone of the Bethany Falls. In general, the Galesburg does not show any consistent direction of thickening or any evidence of sediment transport. However, a possible exception was described by Kinerney (1961) in a locality southeast of Kansas City, where 40 feet of grey shale are found below the black fissile Stark. Below this is a limestone pebble conglomerate, with clasts up to 7 inches by 12 inches. The clasts are of fine-grained, grey, laminated limestone, found together with marine fossils and wood. Below this conglomerate is fissile black shale (possibly the Hushpuckney), underlain by two layers of thin, massive limestone (possibly the Middle Creek); the significance of this local channel is not known.

The persistence and consistency of the Galesburg blocky mudstone facies in the Forest City Basin may be useful stratigraphically. It is in marked contrast to the Ladore Shale, the outside shale below the Swope cyclothem. The Ladore is a sandy marine shale, 5 to 15 feet thick in Missouri (Searight and Howe, 1961). It thickens toward the north, and becomes sandier to the east (Lamerson, 1956).

Heckel and Meacham (1981) contended that traditional correlations in the lower Missourian strata of eastern Nebraska and western Iowa were off by a cycle, based on the evidence given by fusulinids. This conclusion is supported by the shale lithologies: the "Fontana" (as traditionally assigned) is a blocky, noncalcareous, nonfossiliferous grey-green mudstone overlying a rubbly calcilutite, similar to the Galesburg elsewhere in the Forest City Basin. The "Galesburg" is a thin fossiliferous shale overlying a fossiliferous limestone and more closely resembles the Ladore. (Note that this miscorrelation may affect the data given in the isopach map in Fig. 10.)

Davis City Coal.--The Davis City Coal is a thin, black, banded coal found at the top of the Galesburg mudstone in Iowa and Missouri. Although not over two inches thick, it forms a useful stratigraphic marker, as it divides the blocky mudstone underclay from the overlying grey fossiliferous shale. Even where coal is locally absent, the base of the overlying grey shale is always coaly. The coal is herein named for an exposure southwest of Davis City, Decatur County, Iowa (locality DC1; Fig. 12).

Although very thin, the coal is widespread and has attracted some note. Bain (1898) noted it in its type area, as did Wenberg (1941), L. M. Cline (unpub. Iowa Geol. Surv. open file report), and Johnson (1971). Howe and Koenig (1961) and Searight and Howe (1961) reported it in northern and western Missouri. The coal is associated with the underlying underclay, and indicates a period of subaerial exposure

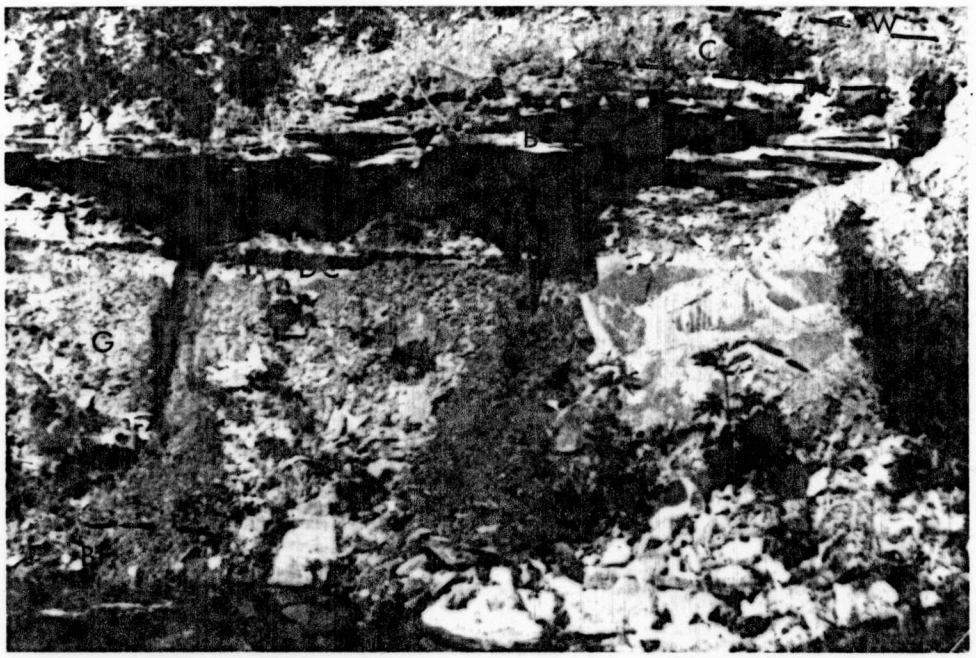



Figure 12. Locality DC1, Davis City, Iowa. Complete cyclothem, with the Bethany Falls rubbly zone approximately at water level (BF); the overlying Galesburg underclay (G), the Davis City Coal (DC), and Stark showing three divisions of lower grey transition (A), black fissile (B), and upper grey transition (C). The Winterset Limestone (W) is at the top. The scale bar in the center is 3 feet (91.5 cm) long. June, 1979.

(but one not due to deltaic progradation) between two marine intervals.

Dennis Formation

The Dennis Formation was named by Adams (in Adams et al., 1903) for exposures near Dennis, Labette County, Kansas (Fig. 13). In Kansas, it consists of three members (ascending): the Canville Limestone, the Stark Shale, and the Winterset Limestone. Locally, these members are also recognized in northern Oklahoma, but where the Stark is missing, the limestone below the Winterset is called the Lost City. Also in Oklahoma, the Dennis Formation is called the Hogshooter, named by Gould and others (1910) for exposures along Hogshooter Creek in eastern Washington County, Oklahoma. The Dennis cyclothem is the uppermost of the three cyclothems forming the Bronson Group, and it underlies the Cherryvale Formation of the Kansas City Group.

Canville and Lost City Limestones

The Canville Limestone is the middle or transgressive limestone member of the Dennis cyclothem. It was named by Jewett (1932) for exposures along Canville Creek in Neosho County, Kansas. It generally fits the description of a middle limestone, being a thin, dark, burrowed skeletal calcilutite, without bedding and with vertical joints (O'Connor, 1962; Gentile, 1976). Locally, the Canville has abundant fine quartz sand (Hanson, 1957). It also contains small local phylloid algal mounds in southeastern Kansas (Frost, 1968) where it reaches its maximum thickness of about 7 feet. A typical mound is about 3 feet high and 80 feet wide. Frost describes them as being

Figure 13. Two views of Locality Del, near Dennis, Kansas, showing the Dennis cyclothem. Coal is exposed at the base, overlain by a variably calcareous lower grey Stark (A) unit, locally becoming limestone of Canville (Ca) lithology. Above is the fissile black (B) unit of the Stark with a carbonate concretion (sc). The black B unit is overlain by the upper grey transitional (C) unit with most of the apatite nodules concentrated at the contact between the B and the C unit. The Winterset Limestone (W) is at the top. The scale bars are 3 feet (91.5 cm) long. August, 1978.

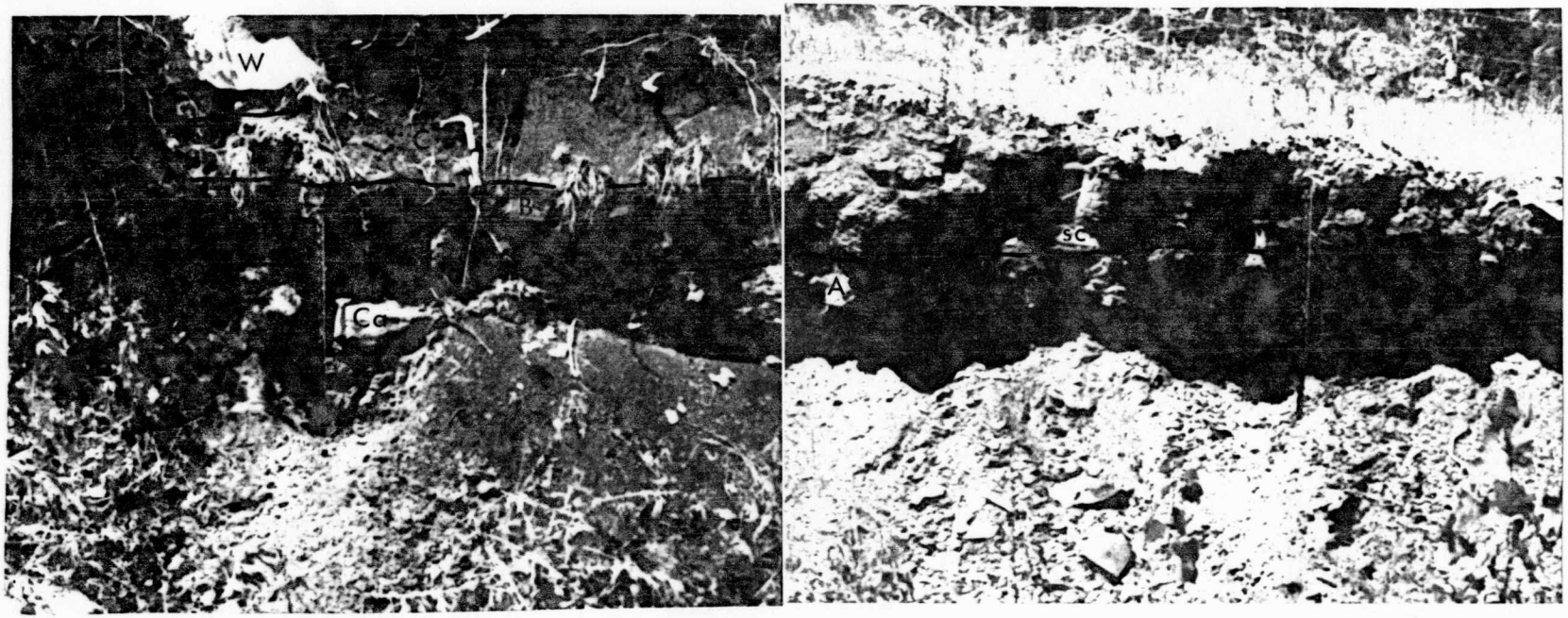



Figure 13.

analogous to small, Florida Bay-type mound structures. The mound is an algal-bryozoan calcilutite overlying a brachiopod skeletal calcilutite; laterally the Canville becomes a dark skeletal calcilutite with a diverse unabraded and unsorted assemblage of myalinid pelecypods, brachiopods, bryozoans, crinoids, Osagia, gastropods, and calcareous foraminifers.

The Canville disappears north of Linn County, Kansas (Lamerson, 1956). This corresponds roughly with the transition from the Missourian phylloid algal mound facies belt to the open marine facies belt (Heckel, 1977); it also corresponds generally to the northern margin of the Bourbon Arch and the change in the underlying Galesburg Formation from the clastic wedge to the mudstone facies. To the north, local limestone lenses occur at the Canville interval that have been given that name. In some cases, the lithology is similar to that in the south (Lamerson, 1956; Johnson, 1971; Price, 1977), but in others it is calcarenitic and quite coaly, and consists of a shell hash of myalinids, ostracodes, fish fragments, and brachiopods. Locally, in Decatur County, Iowa, several of these beds alternate with fossiliferous coaly shale to form a set of beds up to four feet thick. These are referred to as the Decatur City beds, after the exposure in the quarry west of Decatur City, Iowa (Locality DeCl). Because of the variable lithology (and variable depositional environments) of the northern Canville equivalent and its discontinuous stratigraphic expression, it is here proposed to abandon the use of the term Canville north of its limit in Linn County in order to avoid misleading environmental interpretations.

Southward in Oklahoma, Oakes (1940) directly equated the Canville to that of Kansas. There, the Canville and Stark are locally present, which Oakes attributed to deposition only in minor structural basins. He noted that they were closely related to the Winterset, and were not erosionally truncated. Cronoble and Mankin (1965) placed the Canville, the Lost City, and the Stark in the Coffeyville Formation, since they concluded those units formed in low energy environments while the basal Winterset formed in a high energy environment.

The Lost City Limestone was named by Gould (in Gould et al., 1911) for exposures near Lost City, Tulsa County, Oklahoma. The Lost City is also a transgressive limestone (Frost, 1975). At Tulsa it is a lenticular body up to 40 feet thick (Visher and Rennison, 1978), where it is a phylloid algal calcilutite mound (Heckel and Cocke, 1969), locally recrystallized and dolomitized, with rare solitary rugose corals and pelecypods at the top (Hanson, 1957) (Fig. 16). Bennison (1981) noted the Lost City disappears abruptly south of the mound facies, becoming lost in the detrital facies of the Arkoma seaway. Cronoble (1962) believed the Lost City to be either erosional remnants or deposited in local lows, as was the Canville, whereas Visher and Rennison (1978) believed it to be deposited in interdistributary bays, and equivalent to the upper Coffeyville. In any event, it is equivalent to the Canville, as apatite pebbles are found in the base of the Winterset over each unit; this unique horizon is used as a marker bed (Oakes, 1940; Cronoble and Mankin, 1965). Cronoble (1962) also noted the similar lithologies (outside of the mount facies) and probable similar origins of the Lost City and the Canville.

Stark Shale

The Stark Shale is the core shale of the Dennis cyclothem. The Stark was named by Jewett (1932) for exposures near Stark, Neosho County, Kansas. Like many such core shales, it can be divided into three units.

The basal unit is a thin grey transition shale, usually fossiliferous and finely flaky on outcrop. In the area north of the Bourbon Arch, where it overlies the Galesburg blocky mudstone or the Davis City Coal, it is often coaly and may have coaly stringers (Johnson, 1971). Locally, the fauna may be abundant enough to produce thin lenses and beds of argillaceous, coaly, skeletal calcarenite. These beds are particularly prominent in Decatur County, Iowa, where they alternate with grey, coaly shale to produce the aforementioned Decatur City beds. These are herein included with the Stark, rather than identified as Canville, due to (1) their similarity with the alternating shale from which they differ only by being somewhat more fossiliferous and calcareous; (2) a lithology that is markedly different from typical Canville; (3) their variable stratigraphic position; and (4) the frequent multiplicity of horizons. The fauna of the lower grey transition typically includes myalinid pelecypods, fish fragments, and inarticulate and a few articulate brachiopods. Johnson (1971) noted Crurithyris is usually abundant just below the black shale.

The fissile black shale is the most prominent unit in the Stark, as it is fairly resistant and generally a ledge former. Typically, it is two or three feet thick, but in isolated exposures in southeastern Kansas and adjacent Oklahoma it reaches thicknesses of 14 feet (Fig. 14). Bennison (1981) recognized an equivalent unit, the Cudjo black shale bed, in southern Oklahoma, below a thin limestone that he identified as the Hogshooter and above a transgressive limestone. It is uncertain how continuous the black shale facies is across the Arkoma seaway, but Bennison indicated at least local occurrences. In southeastern Kansas and northeastern Oklahoma the upper and lower transitional grey units are quite thin or absent and not obvious, so the fissile black shale composes the bulk of the shale. The Stark in the area does exhibit one of the characteristics of the black shale lithology: typically, due to weathering, the contacts with the transitional units look rather sharp, but they are generally gradational. They are also asymmetric, as the hardest, blackest Stark is near the base, grading rather abruptly from the lower grey unit. The rest of the Stark basically grades more slowly upwards to the base of the Winterset, becoming less fissile and less black. The contact between the black and upper grey shales is generally placed at the weathering slope break.

The black Stark conforms very well to the general characteristics of such shales: its fauna is essentially fish fragments, inarticulate brachiopods, and conodonts. It is phosphatic, noncalcareous, rich in

Figure 14. Two views of Locality CB1, at Cedar Bluff, near Coffeyville, Kansas. Top of fossiliferous Coffeyville Formation (Co) with coal lentils, overlain by argillaceous Canville Limestone (Can), and the lower Stark grey transition (A), with the thick black fissile unit (B) above. Note concretion (sc) in Stark. Apatite nodules occur at the top of the black unit. The Winterset (W) at the top is composed of alternating shale and limestone ledges. Scale bars are 3 feet (91.5 cm) long. June, 1979.

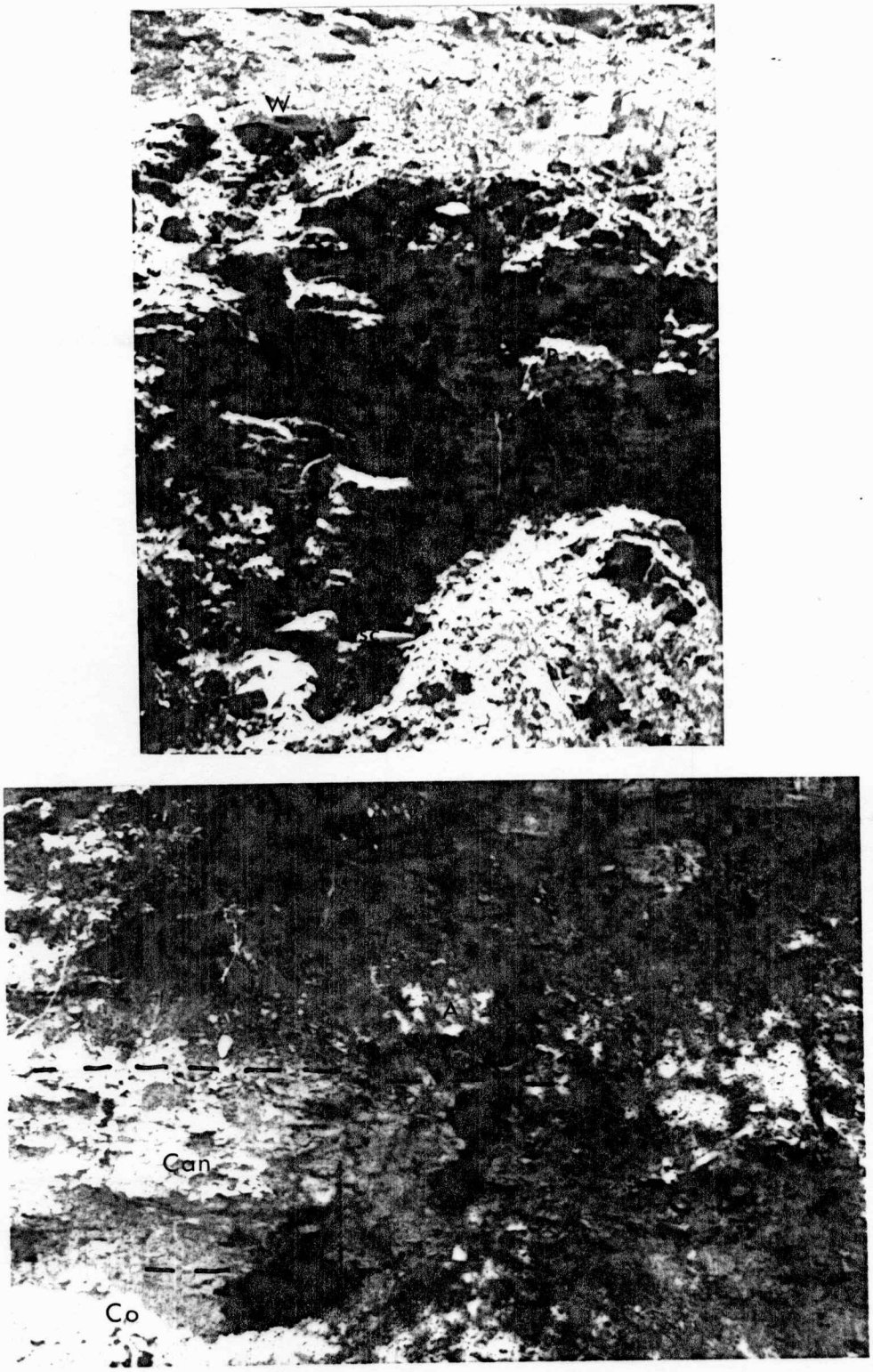



Figure 14.

trace metals (Coveney, 1979), and will yield some hydrocarbons when subjected to destructive distillation (Bloesch, 1930).

In some localities in northeastern Oklahoma and southeastern Kansas, the Stark contains black calcitic lenses (Hanson, 1957) up to 20 feet long and a foot thick (Cronoble and Mankin, 1965). They considered them to be epigenetic, as the laminae through them are parallel to and continuous with those in the black shale (see examples, Fig. 13 and 14).

The upper unit is a grey to greenish grey fossiliferous transition shale between the black shale and the overlying Winterset Limestone. The fauna becomes increasingly diverse and abundant upwards, but in the lower part Crurithyris and pectinoids may be prominent (Johnson, 1971). The portion just above the black shale unit frequently has many lighter grey burrows 3 or 4 millimeters in diameter; these frequently have pyrite cores. These burrows extend downward to the top of the black fissile horizon (Price, 1977).

Associated with the black to grey transition are occasional spherical grey or brown apatite nodules up to 4 centimeters in diameter. These are most common in northeastern Oklahoma, and become more scattered northward. The nodules become increasingly lens-like to the north, and are last seen in northcentral Missouri.

Locally, the upper grey unit also has carbonate horizons in Cass County, Missouri,and also in Jackson and Ray counties (Lamerson, 1956). These horizons are irregular in thickness, but usually persistent. They are usually very argillaceous and poor in megafossils, generally appearing to be little more than cemented shale. Usually, only one

horizon is present, but locally there may be more. The horizons fade in and out laterally due to the variable carbonate content, and they may disappear completely. They are included with the Stark as they are little more than cemented shale, and are in marked contrast to the much purer, bedded, fossiliferous Winterset above them. These cemented shale layers are herein referred to as the Peculiar beds, after a locality at Peculiar, Missouri, where the lateral change due to variable resistance is well-expressed (Fig. 15).

The Stark is remarkable in its areal distribution. Many of the Missourian core shales locally lose their black facies, usually over topographic highs or around basin margins (Heckel, 1977). Some similar Desmoinesian core shales may disappear into the thick basinal sequences of the Anadarko Basin (Price, 1981). The Stark, however, remains uniformly black to its limits. Although Horne (1965) mapped some local red and green shales around the Nemaha Uplift and showed a few grey areas in Iowa, this could reflect miscorrelation or incomplete drillers' logs, as all cores from Nebraska and Iowa contain black Stark (P. H. Heckel, pers. comm., 1982). Southward into Oklahoma, however, its distribution is irregular, even though its greatest thickness is in this area. This is attributed to local erosion of previously present Stark, for which evidence will be presented in the next section.

### Winterset Limestone

The Winterset Limestone is the upper, or regressive limestone of the Dennis cyclothem, named by Tilton (in Tilton and Bain, 1897) for

Figure 15. Locality Pq1, Peculiar, Missouri. Complete cyclothem, with the Bethany Falls (BF) at the base, showing the rubbly zone at the top, overlain by the Galesburg (G) and lower grey unit (A) of the Stark, indistinguishable because of slumping. Above are the resistant black shale (B) and the upper grey unit (C), with the Peculiar bed (P) near the top of the upper grey unit. Note the discontinuous appearance of the Peculiar bed, due to weathering of the very argillaceous limestone. Skeletal calcilutite of the Winterset Limestone (W) forms the top of the exposure. The scale bar is 3 feet (91.5 cm) long. May, 1980.

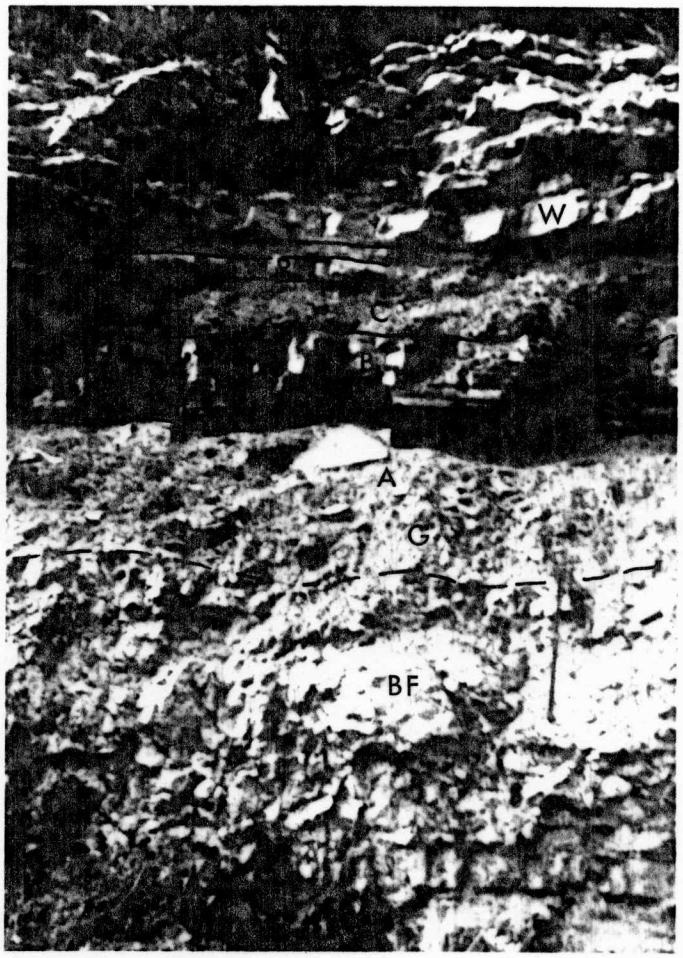



Figure 15.

exposures in the vicinity of Winterset, Madison County, Iowa. It may be one of the most widespread Missourian limestones, as it can be traced through much of the Midcontinent, from Nebraska and Iowa to Oklahoma, where it grades into a radioactive black shale in the Anadarko Basin (Seale, 1981). Probable equivalents are also found in the Illinois and Appalachian Basins. Like the Bethany Falls, which is in the depositionally equivalent position in the next lower cyclothem, the Winterset achieves considerable thickness, and is widely quarried. However, the Winterset differs from the Bethany Falls in two important respects. One is that it is generally very shaly, with many partings (Searight and Howe, 1961); in Kansas City, a prominent medial parting is up to 2 feet thick (Lane, 1939; Parizek, 1965). Gentile (1976) noted lower Winterset partings of grey to black shale 4 to 6 inches thick in western Missouri. The Winterset is also remarkably cherty in the upper part (Searight and Howe, 1961; Parizek, 1965; Johnson, 1971; Gentile, 1976; Dubois, 1979) with white, grey, blue or red chert locally present. Lane (1939) stated that it is the chertiest unit in the Midcontinent Pennsylvanian.

In this study, the basal Winterset is of immediate interest. North of the phylloid algal mound facies in southeastern Kansas, the basal Winterset is a grey, argillaceous, pyritic skeletal calcilutite (Payton, 1966; Johnson, 1971; Frost, 1975; Price, 1977). The contact with the upper Stark is gradational, but accentuated by weathering. Locally, the fine-grained matrix of the horizon may be partially dolomitized (Price, 1977). Johnson (1971) noted that its biota is the

most diverse of any in the cyclothem, but that it lacks algae. Thus, he concluded that it represented relatively deep water.

Above this basal horizon, the Winterset is usually a brachiopod-echinoderm-dominated skeletal calcilutite (Payton, 1966). Locally, phylloid algae and green algae may appear, along with micrite envelopes (Price, 1977). The upper Winterset is locally oölitic or a poorly fossiliferous calcilutite, like the Bethany Falls (Payton, 1966). Laminated dolomitic calcilutite (Johnson, 1971) and Osagia skeletal calcarenite (Price, 1977) are also present.

The Winterset previously has been subdivided at the prominent shaly parting in the middle. Curiously, this parting is equivalent to a laminated dolomitic calcilutite in parts of eastern Kansas (Frost, 1968), and is overlain by phylloid algal mound rock. The shaly parting in the middle also locally contains plant fragments (Lane, 1939). It is possible this pattern indicates shallowing conditions, with minor deepening above. Whatever the cause, it may have important connections to the depositional environments of the shale partings of the Winterset.

In southeastern Kansas, the Winterset, like many of the regressive limestones and a few of the transgressive limestones, develops into a phylloid algal mound complex (Fig. 16). In this case, the Winterset thickens from the 25 to 40 feet common in Missouri (Searight and Howe, 1961) to 60 feet where the mound facies outcrops in Kansas (Heckel and Cocke, 1969) and to over 100 feet in subsurface Kansas (Frost, 1968).

South of the principal mound tract, the Winterset displays more variable thickness and lithology. It is principally an argillaceous

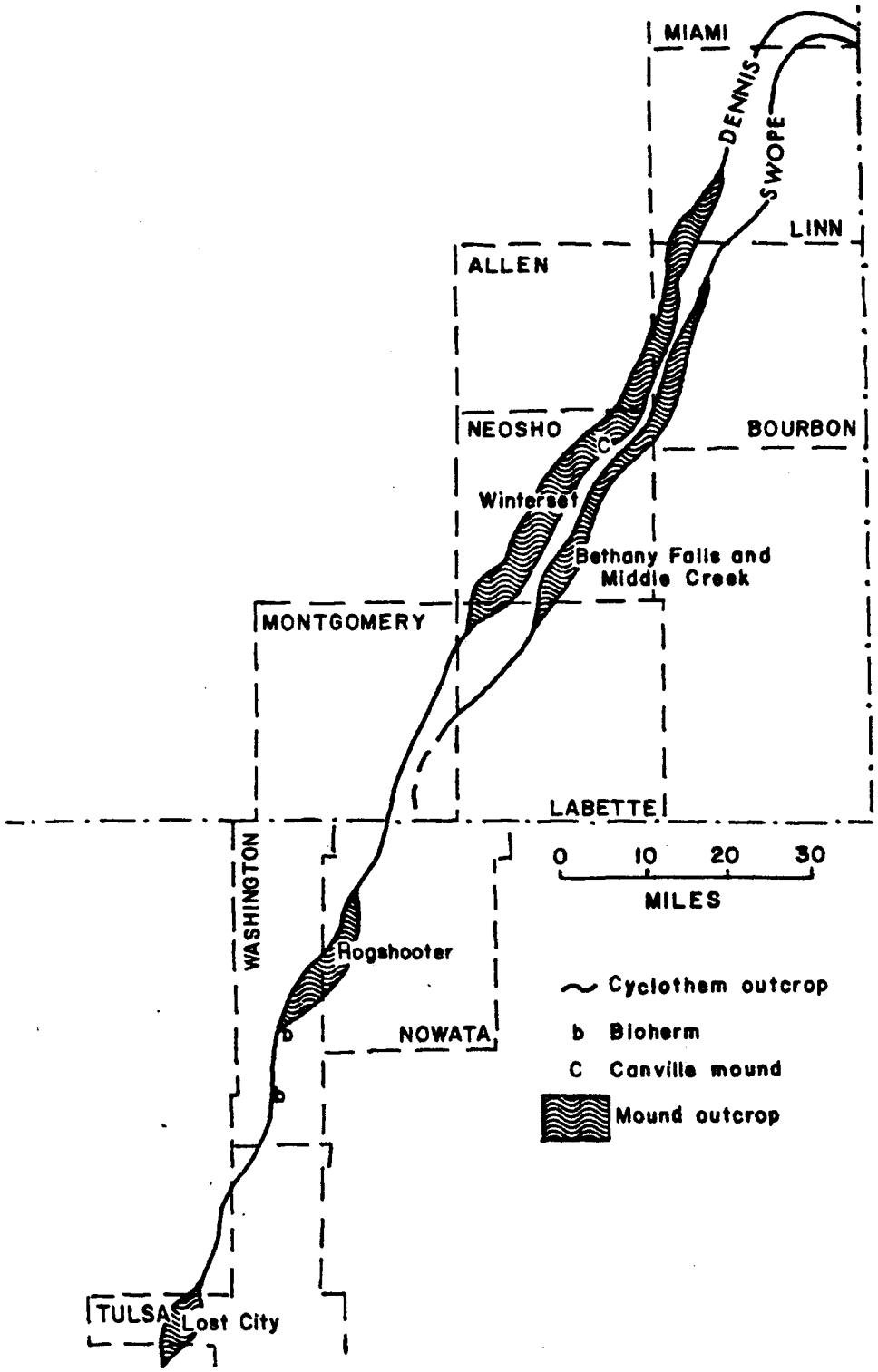



Figure 16. Dennis and Swope mound facies (From Heckel and Cocke, 1969).

skeletal calcilutite to calcarenite, with crinoid columnals as the most conspicuous bioclast. Fossiliferous shale interbeds are abundant (Frost, 1968). Locally, however, other lithologies develop. Visher and Rennison (1978) state that over the principal distributary of the Coffeyville delta, the Winterset is an oösparite or calcareous orthoquartzite. And in Nowata and Washington counties, the Winterset locally forms another phylloid algal mound about 25 feet thick (Heckel and Cocke, 1969), compared to its 10-foot average in Nowata County (Branson, 1964). Bennison (1981) correlated it across the Arkoma seaway, and noted that the limestone disappears across that axis, but reappears as a thin limestone above the Cudjo black shale on the south side.

The basal Winterset in extreme southeastern Kansas and northeastern Oklahoma has an interesting relationship with beds below it. The basal foot of the Winterset often has abundant brown phosphate nodules in it, and is persistent enough to be used as a stratigraphic marker (Oakes, 1940). Although like the rest of the Winterset, it is mostly a crinoidal skeletal calcilutite, it also contains quartz sand and some glaucony (Hanson, 1957; Cronoble and Mankin, 1965; Frost, 1968) and locally it is cross-bedded (Frost, 1968) (Fig. 17). In the few areas where there is the normal Dennis succession of Canville, Stark, and Winterset, there are no apatite pebbles in the base of the Winterset, but rather they appear in their typical position in the upper Stark. This evidence suggests that currents swept portions of the bottom during Winterset deposition and is supported by the high concentration of typically core-shale conodonts in the basal beds.

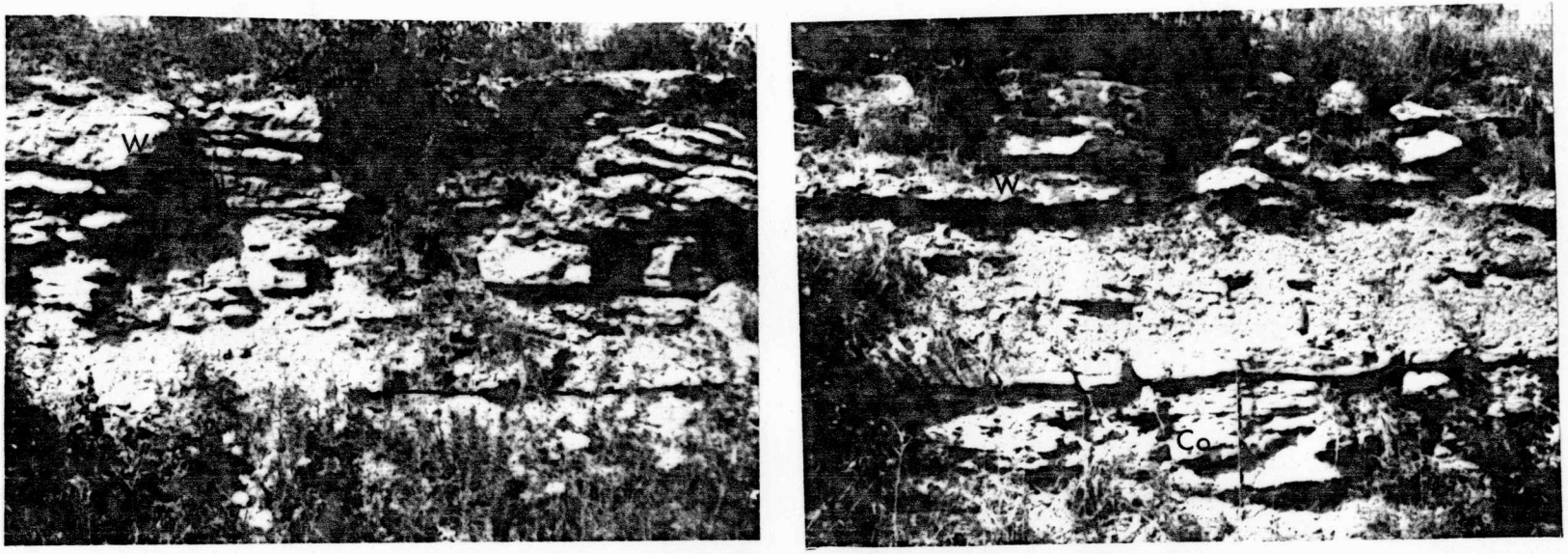



Figure 17. Locality Cf1, near Coffeyville, Kansas. Upper Coffeyville Formation (C), overlain by the Winterset Limestone (W). Note the prominent large-scale irregular cross-bedding dipping toward the right (east) in the Winterset. The scale bars are 3 feet (91.5 cm) long. August, 1979.

Thus, it seems likely that the general absence of the Stark and Canville in this area could be due to submarine erosion, with the conodonts and apatite pebbles concentrated in the base of the Winterset where a low net depositional rate would also permit glaucony to form.

This southern end of Winterset deposition also produced other local lithologies. In Washington County, there are a pair of small structures described as reefs (Cronoble, 1962; Cronoble and Mankin, 1965) (Fig. 16). The larger one, at Ramona, is at least 14 feet high (Branson, 1964) and over 100 feet wide (Cronoble and Mankin, 1965) (Fig. 18). Cronoble (1962) stated that the reef cores are micritic and "mostly algal," but with a range of bioclasts. The flanks consist of stratified skeletal debris, and include colonial tabulate corals, horn corals, conularids, fenestrate bryozoans, and crinoids close to the core, with the last two groups and brachiopods becoming important farther away. The reef structures lack both the morphology and lithology of the typical phylloid algal mound.

## Illinois Equivalents of Swope-Dennis Interval

Ideally, comparison of cyclothems between the Midcontinent and the Illinois Basin should yield some understanding of lateral variation of particular units, and thus some idea of the relative stability of certain phases and the environments that produced them. Certain aspects of the Illinois cyclothems are similar to those of the Midcontinent, and show very well general variations in pattern (Heckel, 1977).

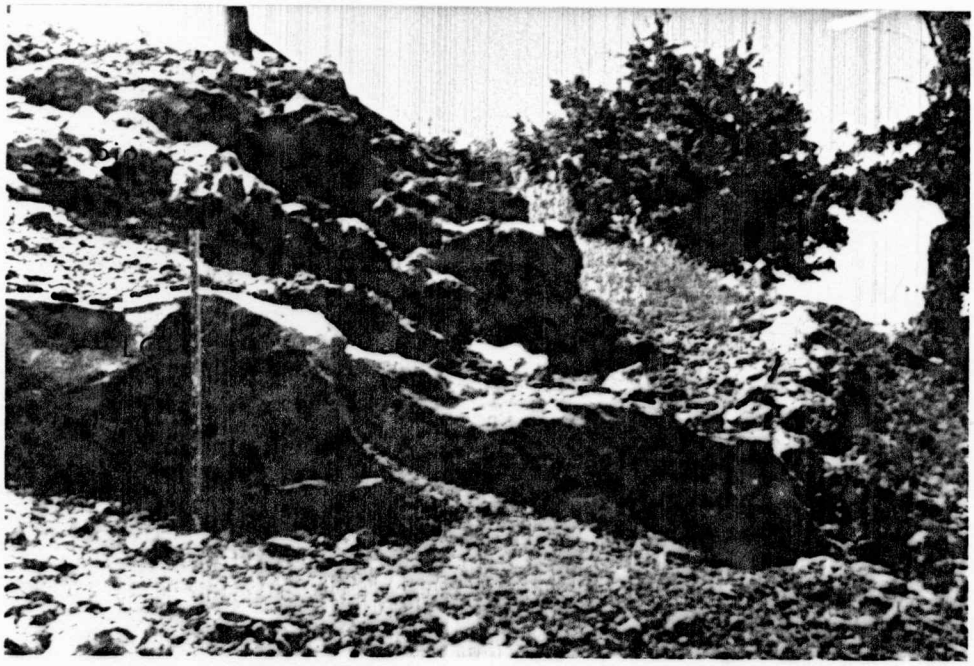


Figure 18. Locality Ra2, Ramona, Oklahoma. Bioherm in the Winterset Limestone (bio) with the Lost City Limestone Member (LC) below. Scale is 3 feet (91.5 cm). June 1979.

However, a major difficulty arises in determining precise stratigraphic correlations.

Shoal Creek and Macoupin Cyclothems

The correlation of the Shoal Creek Limestone of southern Illinois with the Winterset Limestone of the Midcontinent is generally accepted (Moore, 1962; Palomino-C., 1963; Hopkins and Simon, 1975). More recently, however, Merrill (1980) argued that this correlation is unreasonable, as the idiognathodid conodonts of the two are different. He suggested that the conodonts more closely resemble those of the Iola cyclothem in the Midcontinent, and he also observed that the conodonts in the Shoal Creek resemble those found in the Hall and LaSalle limestones of northern Illinois. If the Shoal Creek is in fact equivalent to the Winterset, then the unnamed black shale below it is probably equivalent to the Stark, and the unnamed sandy greenish-grey shale below that is equivalent to the Galesburg Shale. The next limestone down, the Macoupin, would be equivalent to the Bethany Falls Member of the Swope cyclothem. This correlation is supported by the appearance of Gondolella denuda, a characteristic conodont of the Hushpuckney Shale Member of the Swope cyclothem, in the black shale below the Macoupin (J. W. Swade, pers. comm., 1981); however, faunal characteristics of Appalachian Basin cyclothems raise some questions about this correlation (see Appendix C).

The Shoal Creek Limestone Member, the basal member of the Bond Formation (Fig. 7; Fig. 19), was named for exposures along Shoal Creek in Clinton County, Illinois, by Engelmann (1868). The Shoal Creek is a

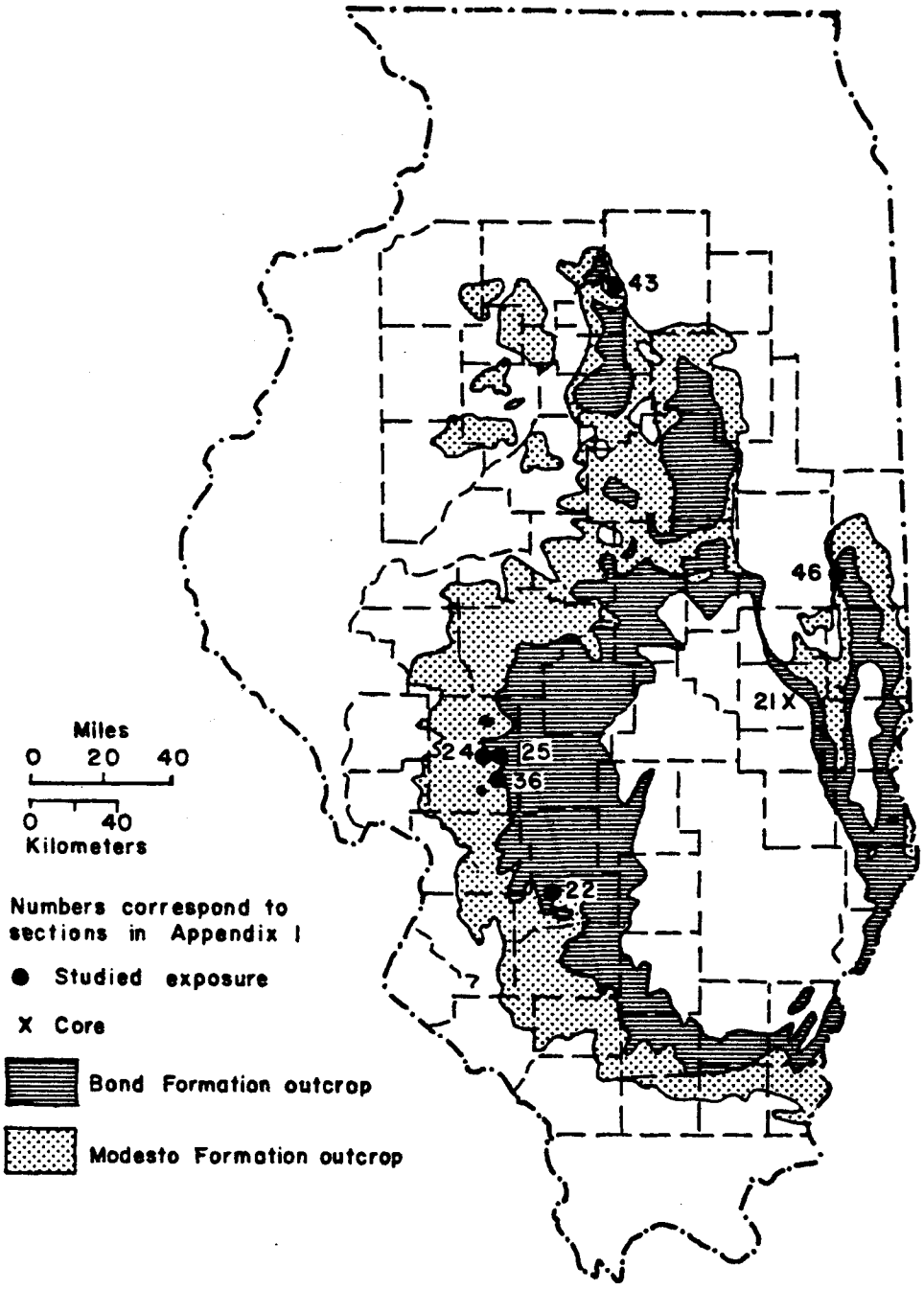



Figure 19. Studied Pennsylvanian localities--Illinois.

fossiliferous limestone, usually between 6 and 8 feet thick, but ranging up to 20 feet. It is one of the thickest and most persistent limestones in the Pennsylvanian section of Illinois, and has been widely quarried. It is also used as a marker in geophysical logging of deep wells in the Illinois Basin.

The beds below the Shoal Creek belong to the Modesto Formation, and are largely unnamed. Palomino-C. (1963) noted that the locally phosphatic, fissile black shale below the Shoal Creek is very continuous, although locally grey facies are present. Below that, a poorly-developed coal (the New Haven Coal) and underclay are sometimes present (Palomino-C., 1963).

The bulk of the interval between the Shoal Creek and the Macoupin is sandy shale believed by Palomino-C. (1963) to be related to southward-draining delta distributaries. Some of the sand may be marine, as Weller (1957) reported it was fossiliferous in southeastern Illinois. These sandstone bodies are not prominent enough to be named.

The Macoupin Limestone is a thin but persistent limestone, named by Wanless (1931a) for exposures along Macoupin Creek, Macoupin County, Illinois. Usually, it is a dark grey, argillaceous, crinoidal limestone, generally 2 feet, but occasionally up to 5 feet thick. It overlies a persistent fissile black shale, which in turn overlies the Womac Coal.

The Shoal Creek has been correlated with the LaSalle Limestone (Hopkins and Simon, 1975) and thus samples from the type LaSalle were included in this study, but this may be incorrect. R. J. Jacobson (written comm., 1980) stated that the LaSalle Limestone is now

believed equivalent to the Millersville or Livingston limestones which lie above the Shoal Creek. Fraser (1970) explained the miscorrelation as due to structural complications and the lithologic similarity of succeeding cyclothems.

The Fithian cyclothem was also included in this study, both because it is an important reference section that includes the type illite and because it was once thought to be equivalent to the Macoupin (Wilson, 1942; Kerr and Kulp, 1951). However, it has since been equated with the Flannigan cyclothem (Peppers, 1964).

## Lansing Group Lithologies

The upper pair of shales under study are units of the Lansing Group, which was named by Hinds (1912) for exposures near Lansing, Leavenworth County, Kansas. This group comprises three formations (in ascending order): the Plattsburg Formation, the Vilas Shale, and the Stanton Formation. It also includes three cyclothems: the Plattsburg is the lowest, and is separated by the Vilas from the two above in the Stanton Formation. The lower three members of the Stanton constitute a complete typical cyclothem (the Stanton cyclothem). The South Bend Limestone Member is the transgressive limestone of an upper cyclothem (the South Bend cyclothem) which is incomplete along the outcrop everywhere but Nebraska (Heckel, et al., 1979) (Fig. 20 and 21).

### Plattsburg Cyclothem and Spring Hill Limestone

The Plattsburg cyclothem comprises in ascending order (1) the Merriam Limestone, the middle limestone which is discontinuous in

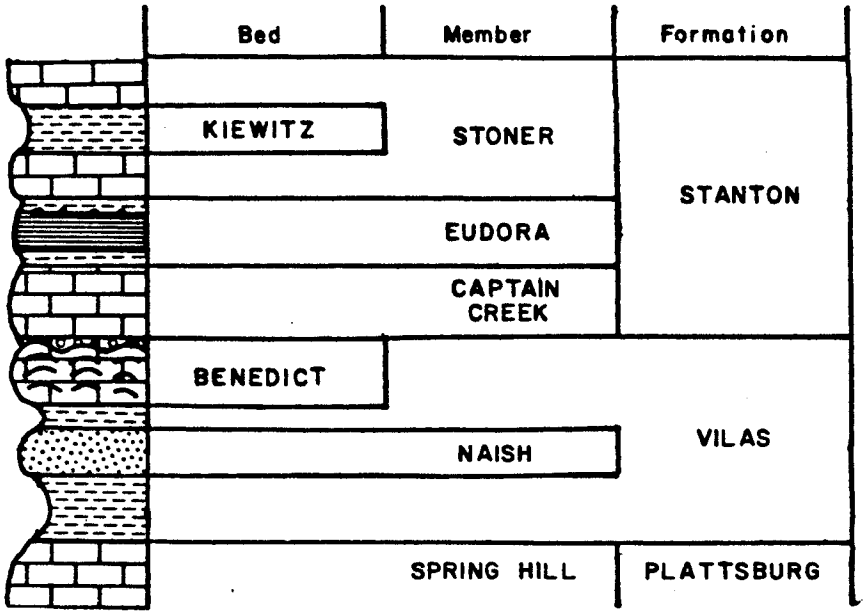



Figure 20. Composite stratigraphic relationships of the Vilas and Eudora shales.

southern Kansas; (2) the Hickory Creek Shale, which, although the core shale, lacks a black facies in the outcrop belt; and (3) the Spring Hill Limestone, named by Moore (1932) for an exposure in southern Johnson County, Kansas. The Spring Hill is shaly, very fossiliferous, and locally includes phylloid algal mounds of relatively great thickness (Heckel and Cocke, 1969). The southern algal mound interfingers southward with the Vilas Shale (Harbaugh, 1959; Davis, 1959) (Fig. 22). The upper beds are calcarenite, locally with oölite and pisolite present (Davis, 1959; Heckel and Cocke, 1969; Nelson, 1978).

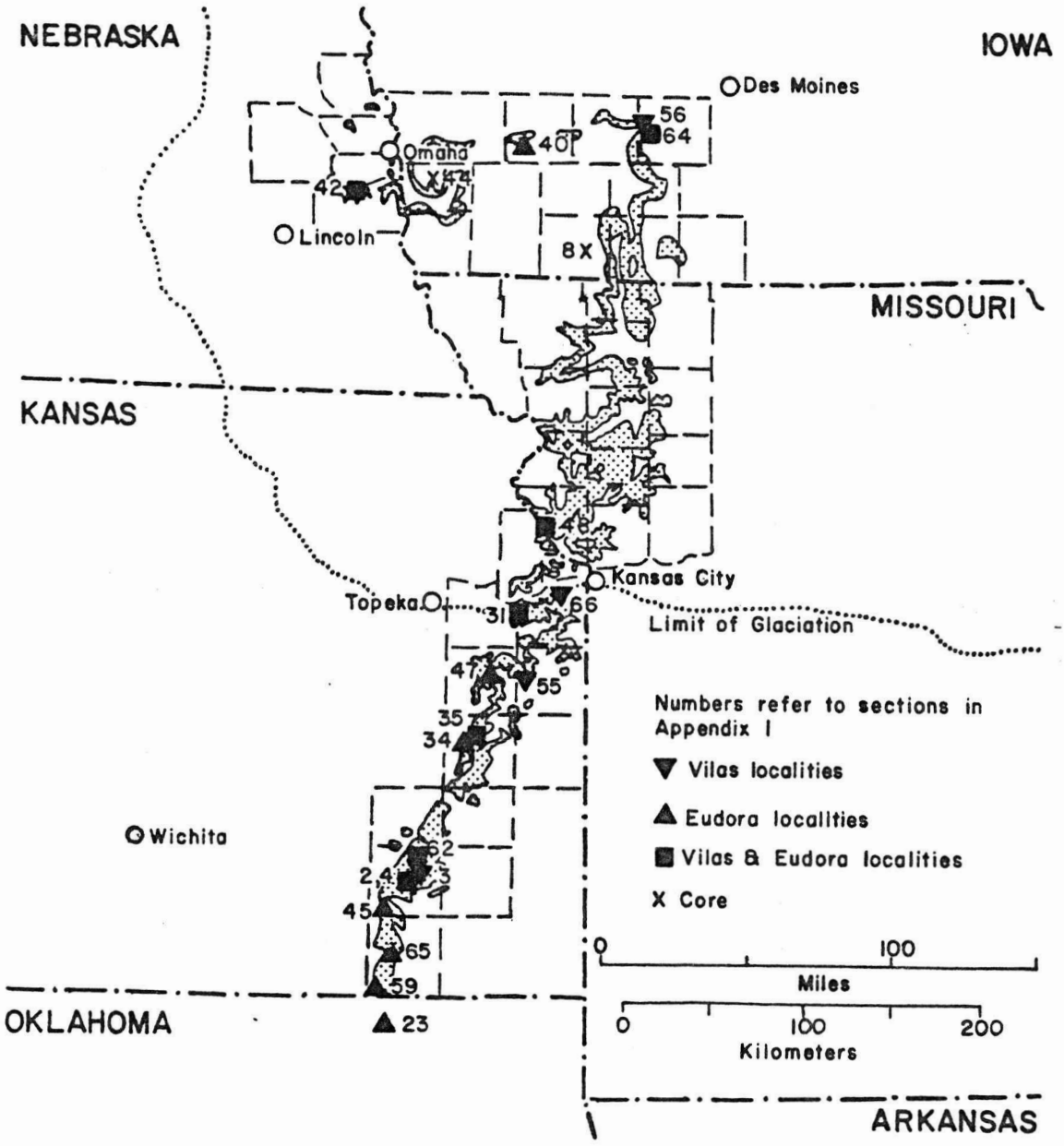



Figure 21. Vilas and Eudora outcrops. Pattern is Lansing Group.

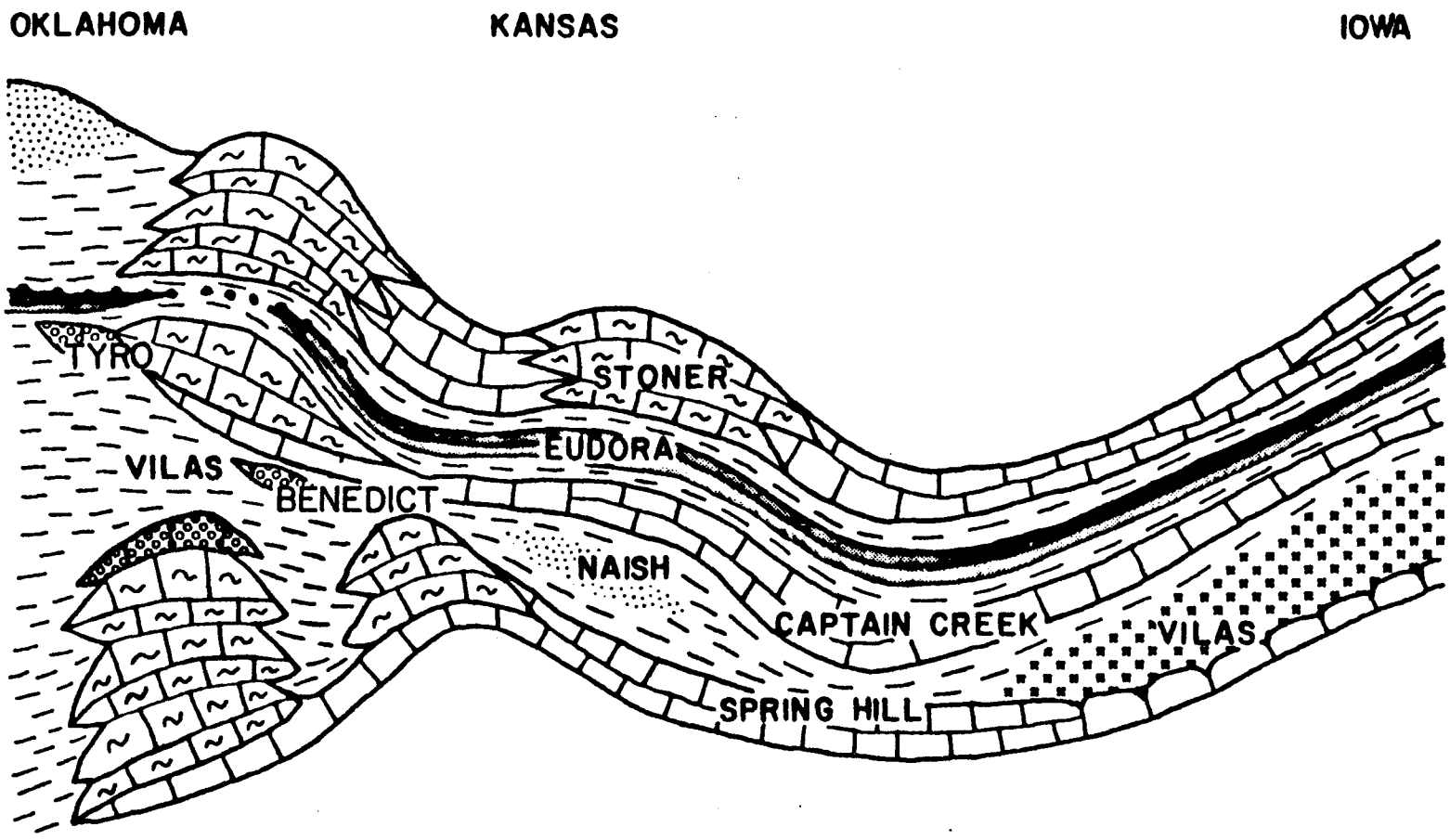



Figure 22. Stratigraphic relationships of the upper part of the Plattsburg cyclothem, Vilas Shale, and the lower Stanton cyclothem. (Compare to Fig. 2 and 3).

Vilas Shale

The Vilas Shale is an outside shale formation, named by Haworth (1899) for exposures near Vilas, Wilson County, Kansas. Its diverse lithologies range from grey shale to red mudstone and fossiliferous sandstone. Generally, it is a silty to sandy micaceous poorly fissile grey shale, with small sparse fossils, including conodonts, ostracodes, and small gastropods and pelecypods. At a locality near Buffalo, Kansas (WCL1), the Vilas contains a thin horizon crowded with oncolitic nodules and the gastropod Hypselentoma.

The Vilas varies tremendously in thickness (Fig. 23). North of the Bourbon Arch, it is usually 10 to 20 feet thick, although it attains 35 feet in the Bedford core from Taylor County, Iowa, in the Forest City Basin. In eastern to southern Kansas, the Vilas thins locally to absence over the two Spring Hill algal mound complexes. Between the two mounds, the Vilas thickens to about 100 feet near the type locality (Wagner, 1962). South of the southern mound complex, the Vilas again thickens to about 100 feet. South of the Plattsburg disappearance, the Vilas becomes the upper portion of the Lane-Vilas Shale (O'Connor, 1962), which becomes the lower part of the Wann Formation of Oklahoma (Heckel, 1975).

The Vilas is a product of increased detrital influx, probably related to a retreat of the sea at the close of the Plattsburg inundation. However, whether or not there was subaerial exposure at any time during Vilas deposition is an open question. Coal in the Vilas

Figure 23. Isopach map of Vilas Shale (Isopachs from Kenny, 1968; outcrops from this study shown for comparison)

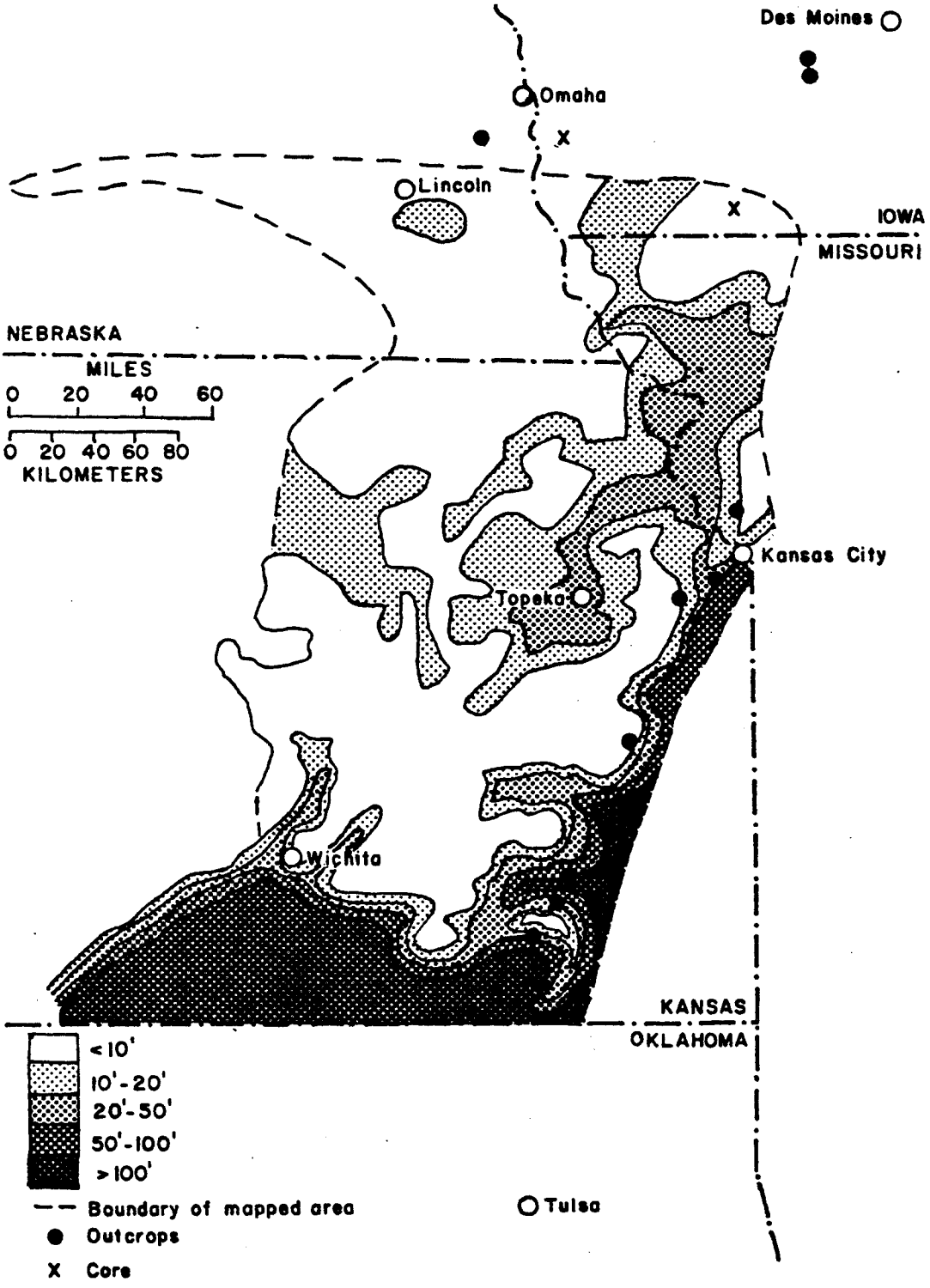

Des Moines
Omaha
Lincoln
IOWA
MISSOURI
NEBRASKA
MILES
0 20 40 60
0 20 40 60 80
KILOMETERS
Kansas City
Topeka
Wichita
KANSAS
OKLAHOMA
< 10'
10'-20'
20'-50'
50'-100'
> 100'
Boundary of mapped area
Outcrops
Core
Tulsa

Figure 23.

was reported only by Ver Wiebe and Vickery (1932) in Kansas and by Kenny (1968) in northwestern Missouri, but none was encountered in this study. To the north, around the margins of the Forest City Basin, the lower Vilas is a red mudstone facies, which is a practical stratigraphic marker. Where the Plattsburg is thin, this zone of oxidation apparently penetrated it, and the upper part of the underlying Bonner Springs Shale is also red (Wenberg, 1941; Heckel, 1980). The blocky, slickensided texture of the red Vilas often continues up into the overlying green mudstone, which in turn grades upward into a grey fossiliferous shale. This continuation of texture, along with the irregular nature of the red-green contact, suggest that the upper portion of the mudstone was reduced by marine organic matter during the early phase of transgression.

However, in the Bedford core nearer the center of the Forest City Basin, deposition may have been continuous. There, the Vilas is sandier and thicker, with fossils throughout the section, and both upper and basal contacts are gradational. In the Kansas City area, too, deposition may have been continuous as fossils occur through the Vilas, although the sharp contacts with both the Spring Hill and Captain Creek are possible disconformities.

Newell (1933) described the Vilas as having a red zone with associated limestone nodules in east central Kansas. Although it is tempting to interpret it as a soil zone developed on the topographically high Spring Hill algal mound, the two apparently do not coincide. The Vilas remains grey where it thins over the Spring Hill mound.

In northern Wilson County, Kansas, the Vilas thickens between algal mounds. Deposition was apparently continuous from the Spring Hill, as the skeletal calcarenite layers of the upper Spring Hill are replaced by increasing interbeds of fossiliferous grey shale, eventually replacing it entirely (Kinell, 1964; Heckel, et al., 1979). The overlying Vilas contains a marine fauna, as well as abundant siderite concretions.

The combination of variable thickness of the Vilas with a sharp upper contact suggests the possibility of erosional truncation. Chelikowsky and Burgat (1947) noted that the thick Vilas sections were sandy, whereas the thin ones were not and thus they attributed the changes in thickness to differential compaction. Wagner (1962) noted that the relatively continuous Benedict bed of stromatolites near the top maintained its general position with respect to the overlying Captain Creek; he concluded the Vilas was thus not greatly eroded (although he recognized several feet of local microrelief) and that the variations in the Vilas thickness came principally from the filling of lows in the underlying Spring Hill. Kenny (1968) felt that the top of the Vilas was a disconformity, and cited Harbaugh's (1965) observation of scour features filled with carbonate debris. In a study of the carbonate facies of the overlying Captain Creek Limestone, Heckel (1978) interpreted much of the Vilas to be probably a delta platform, with its margin facing northwest across central Wilson County. There, a rim of wave-washed oölite underlies the edge of the Captain Creek phylloid algal mound, resting on the edge of the thicker Vilas. In contrast, in the topographically much lower basin, the Captain Creek

shows no evidence of shallow water deposition above the thinner Vilas, which was thus inferred to be all prodeltaic. On the platform, channels developed in the Vilas were filled with Stanton carbonates. Heckel (1978) believed that these channels were cut into the Vilas as river channels or distributaries, as it is unlikely that they were cut by marine currents during transgression. Curiously, the basal deposits lack reworked clasts of Vilas. They also lack positive evidence of fluvial deposition, as would be expected if the Vilas were a deltaic aggradation platform.

A tentative line of evidence about erosion comes from the siderite concretions. MacDonald and Byers (1981) determined that in some cases, concretion zones could be correlated, as the specific depositional conditions in one horizon would produce a consistent, often unique, set of features in the concretions. Among their criteria was simple consideration of size, shape, and spacing. Where a gradational sequence is exposed in the Vilas above the Spring Hill, the concretions are flattened. However, where the top of the sequence is present, sequential and apparently undisturbed, the concretions are almost spherical. Near Altoona where the overlying Stanton units show a channel facies (Locality A11) (Heckel, 1966, 1977, 1978), only flattened concretions are present, which suggests erosion or at least non-deposition of the upper round-concretion-bearing portion of the Vilas.

The thinned Vilas over the southern Spring Hill algal mound sharply overlies the skeletal calcarenite capping the mount (Heckel, 1978). There, Vilas deposition was slow enough that phylloid algae

periodically became established, producing a series of algal calcilutite lenses in the Vilas. Toward Oklahoma, the Vilas again thickens, and interfingers with the upper Spring Hill, which Davis (1959) interpreted as detrital filling against the Spring Hill mound which was eventually overwhelmed by it. O'Connor (1962) noted siderite concretions in the lower and middle Vilas in this region.

Naish Sandstone

In the Kansas City area, the Vilas contains fine-grained quartz arenite, which is persistent from the Missouri River valley to the Marais des Cygnes valley (Newell, 1933). Usually, it is a foot or two thick, with ripple marks, but Newell (1935) reported locally it is thicker, and cross-bedded. It is generally well-cemented, but locally may be an aquifer. This study reveals it to be very clean, massive to thickly bedded, with a sharp lower contact, grading upward into a series of distinct sand and shale layers (Fig. 24). It is also quite fossiliferous, with large pelecypods prominent in one horizon.

The unit apparently has never been formally named. Although Newell (1933) stated that he named it in Kansas Geological Survey Bulletin 21 (published in 1935), only sections describing it appear there, with no name given. Moore mentioned the Naish by name, and listed and described it in a section at Camp Naish (Stop 33 of Kans. Geol. Soc., 1932), but did not formally describe it, stating only:

> In most places there is no evidence of a "lower" limestone in the Stanton cycle, but along the Kansas River such a bed has been recognized in a very sandy limestone or calcareous sandstone which is called Naish. (Moore, 1932, p.93)

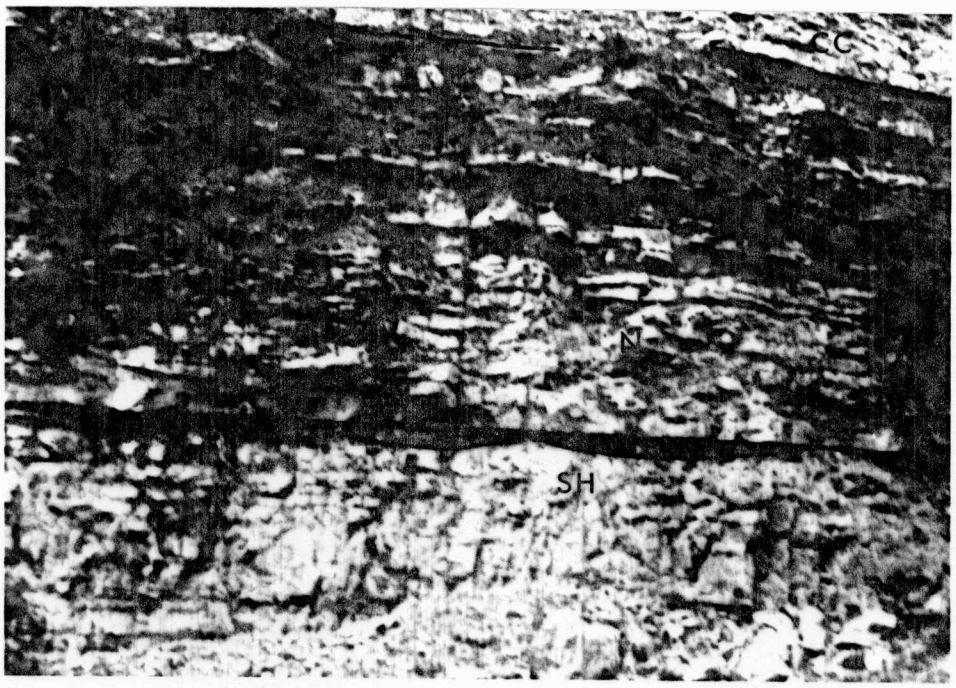



Figure 24. Locality Sn1, near Stanton, Kansas. Quarry wall showing the prominent development of the Naish Sandstone (N) in the Vilas Shale. Note the thin shale between the base of the Naish and the underlying Spring Hill Member (SH) of the Plattsburg Formation. The Captain Creek Member (CC) of the Stanton Formation is at the top. The scale bar at the center is 3 feet (91.5 cm) long. May, 1980.

Although the sandstone is well described, possibly laterally continuous, and has an implicit type section, the use of the name and most mention of it ended with the early 1930s publications.

A massive fine-grained sandy layer also occurs near the top of the Vilas in the Bedford, Iowa, core. It apparently has a sharp lower contact (although the actual contact is lost, the fissile clay shale below is markedly different). It grades up into shaly Captain Creek Limestone. This sandstone is also quite fossiliferous, with large gastropods and echinoderms. Unlike the Naish, however, it is very argillaceous, and it has been dolomitized. Although still marine, it probably represents a different environment than the "type" Naish.

Benedict limestone bed

The Benedict bed was named by Heckel (1975) for exposure in northern Wilson County, Kansas, near the town of Benedict. It is a normally thin (1 to 4 feet) limestone layer separated by up to three feet of fossiliferous shale from the base of the Captain Creek Limestone. It consists of two distinct facies; the lower is a stromatolitic horizon, which Newell (1933) described as usually being isolated heads a foot or two in diameter, but sometimes joined. Heckel (1978) refers to a locality where the stromatolites grew on shale cores of some relief. Above the stromatolites is often a variable thickness of oölite (Newell, 1933; Wagner, 1962; Heckel, 1978). It is usually thin and argillaceous, but Heckel (1978) noted it could reach 20 feet in thickness, and be locally continuous with the base of the Captain Creek. Characteristically, it contains poorly preserved

molluscs and Punctospirifer (Newell, 1933). Notably, the Benedict bed is absent along the axis of the Wilson County Channel (Heckel, 1966), but is present a few miles away.

Newell (1933) and Wagner (1962) both placed the Benedict bed in the Vilas, as it is a lentil within the upper part of the shale. Heckel (1978) preferred to include it in the Captain Creek, arguing that it represents the initial phase of the Stanton transgression. The former usage is followed here.

Stanton Formation

The Stanton Formation was named by Swallow and Hawn (1865) for prominent exposures near Stanton, Miami County, Kansas, and properly established in the sequence by Newell (1933).

The Stanton Formation has five members (ascending): the Captain Creek Limestone, the Eudora Shale, the Stoner Limestone, the Rock Lake Shale, and the South Bend Limestone. The lower three members represent a typical transgressive limestone-core shale-regressive limestone portion of a cyclothem; the Rock Lake, on the other hand, is an outside shale, and the South Bend is part of the next transgression, much of which may have been overwhelmed by terrigenous clastic influx from the south (Heckel, 1978). Only the lower three units are involved in this study.

The Stanton is quite prominent in eastern Kansas, but southward rapidly disappears into the thick, shaly Wann Formation of Oklahoma. Northward, in Iowa, the Stanton has often been misidentified, because it is thin, often shaly, and usually covered by Pleistocene overburden.

However, recent conodont work reported by von Bitter and Heckel (1978) has found that the Eudora shale of the Stanton previously has been confused with the Heebner, the core shale of the Virgilian Oread cyclothem.

Captain Creek Limestone

The Captain Creek Limestone was named by Newell (1935) for exposures along Captain Creek in extreme eastern Douglas County, Kansas. Although remarkably thick (4 to 5 feet of calcilutite) and persistent along the entire outcrop, it thins to less than a foot in Iowa and Nebraska. It thickens steadily to the southward to southeastern Kansas, where it reaches 45 feet in thickness and produces the lowest of the three stacked phylloid algal mounds of the Stanton (Heckel and Cocke, 1969). The Captain Creek calcilutite facies is even found in the Wilson County Channel, which led Heckel (1978) to conclude that initial carbonate deposition of the Stanton transgression simply filled pre-existing lows in the Vilas, and was not subject to winnowing currents.

In extreme southeastern Kansas, the basal bed of the Captain Creek becomes oölitic. On the Oklahoma border the Tyro Oölite lies just below the Eudora Shale which enables correlation of the Tyro Oölite with the Captain Creek.

Eudora Shale

The Eudora Shale was named by Condra (1930) for exposures east of Eudora, Douglas County, Kansas. In eastern Kansas and northward, it displays a fissile black phosphatic facies with upper and lower grey

adjacent transitional shales. In Iowa and Nebraska, the black facies becomes quite thin, but has abundant light grey apatite sand in laminae. In Kansas and Missouri, phosphate nodules are common (Searight and Howe, 1961). Kenny (1968) reported that the Eudora black shale contains a fauna of inarticulate brachiopods, pectinoids, conodonts, Conularia, low-spired gastropods, and land plants.

In southeastern Kansas, over the thicker Captain Creek phylloid algal mound, the Eudora becomes grey, fossiliferous, and thin to locally missing. Kenny (1968) also observed that the black Eudora facies apparently occurs only east of the Nemaha Uplift; to the west it is a grey shale. An interesting relationship is shown in the Wilson County Channel, where Heckel (1978) described black Eudora in the base of the channel, but only grey Eudora farther up on the sides of the channel. He considered this to relate to the positions of these horizons with respect to the oxygen minimum level; however, he did not consider postdepositional loss, such as erosion along the upper sides of the channel or slumping of the black facies from the channel side.

South of the mound region, the thin phosphatic black facies of the Eudora reappears as far as Copan Dam in Washington County (P. H. Heckel, pers. comm., 1981). This black facies is overlain by a thick grey shale which represents the equivalent of the upper grey unit farther north, probably all of the Stoner, and much of the Rock Lake Shale as well (Heckel, 1975). This grey shale is very fossiliferous (Oakes, 1940; O'Connor, 1962; Senich, 1978), both in diversity and abundance and dominated by molluscs, unlike the fauna farther north (Newell, 1935; Heckel, 1975). In some localities, the grey shale also contains

siderite nodules (first noted by Newell, 1935); these apparently formed quite early, as the shells that they surround or fill are relatively uncrushed by compaction.

This grey shale sequence ranges up to 60 feet thick (O'Connor, 1962) and contains sandy layers to the south. Although equivalent to higher units as well, it is all assigned to the Eudora. Oakes (1940) traced the thick Eudora southward to the mounds around Bartlesville.

The section at Tyro, Montgomery County, Kansas (Locality Ty1), deserves special mention. Both southwestward and northward, the Eudora shows a relatively normal sequence of black shale overlain by thick fossiliferous grey shales with some sandstone. However, at Tyro, only dark grey shale is present, but it is marked by a horizon of apatite nodules and abundant conodonts (Malinky, 1980). Above a thin upper grey shale unit is a lens of calcareous conglomeratic sandstone with shale pebbles (Heckel, 1978). Over this is a sequence of shale with calcareous sandstone ripples and rare marine fossils, in turn overlain by another sandstone with shale pebbles and marked load casts (Moussavi-Harami, 1980).

Stoner Limestone

The Stoner Limestone was named by Condra (1930) for exposures at Stoner Farm, near South Bend, Cass County, Nebraska. It is a typical regressive limestone over much of its extent, mostly skeletal calcilutite with two phylloid algal mound developments, one in Anderson County, Kansas, where it reaches thicknesses of about 25 feet, and one in the southern mound area, where it is about 40 feet thick (Heckel

Figure 25. Locality Lo1, near Louisville, Nebraska. Complete cyclothem, with the Spring Hill Member (SH) of the Plattsburg Formation at the base, showing the rubbly upper contact. It is overlain by the Vilas Shale (V) containing the stray limestone lenses in the upper part, in turn overlain by the 8 inch (20 cm) thick Captain Creek Limestone (CC) and thin Eudora Shale (E), with the fissile black unit near the base. The Eudora is overlain by the Stoner Limestone (S) with the Kiewitz Shale bed (K). September, 1979.

and Cocke, 1969). In some areas, the top is similar to the upper Bethany Falls: a mottled, rubbly calcilutite with birdseye (Searight and Howe, 1961; Siebels, 1979). Siebels also noted the basal layer is dolomitized, similar to the basal Winterset described by Price (1977).

The Wilson County Channel (Heckel, 1966) attained at least 80 feet of depositional relief during Stoner deposition (Heckel, 1978). It is a half to a mile wide and at least 22 miles long, trending ENE-WSW across Wilson County. The channel facies in the Stoner is mainly spar-cemented skeletal calcarenite above a basal calcilutite, and is quite different from the adjacent phylloid algal mound. The trough of the channel remained a topographic low after Stoner deposition and was later filled by quartz arenites of the Rock Lake Shale and basal South Bend (Heckel, 1978). Several other similar channels are also known, forming part of the network of channels that provided water interchange for the Stanton phylloid algal mound tract.

Kiewitz Shale.--The Kiewitz Shale is a very fossiliferous, grey-green shale, named by Condra (1930) for its exposure at Kiewitz Quarry in southern Sarpy County, Nebraska. It is separated from the Eudora by a foot or two of limestone, known as the Dyson Hollow bed, which is generally recognized as the base of the Stoner. The Kiewitz is up to three feet thick, and occurs throughout southeastern Nebraska and adjacent Iowa (Fig. 25).

# CHAPTER II

# CONSTITUENTS

## Clay Mineralogy

### Introduction

In dominantly shaly rocks, one of the most important sources of information about their history comes from the clay mineralogy. In this study, the clay mineralogy of 109 grey shale samples, 59 black shale samples (those containing enough organic material to require bleaching to release the clay; see Appendix A), 32 underclay samples, and clay samples from 114 limestone and 9 sandstones were examined.

Clay minerals can reflect all phases of the rock's history: parent material, weathering history, transportation, depositional environment, and diagenesis. Keller (1970) noted that most mudstones and shales are principally detrital, and are made of preexisting clays (some of which may have undergone alteration of interlayer components), although he also cited unpublished reports of minor authigenic illite on laminae of Pennsylvania shales in Missouri. In this study, diagenetic effects can be discounted in most cases, or are readily recognized. This is done by employing a larger size fraction (up to 63 microns) of the clay; Heroux and others (1979) noted that this larger fraction does not alter readily, and is used to determine patterns in

the original sedimentary environment. Using the larger fraction is also important in getting less biased information on the total clay mineralogy: Gibbs (1977) noted a wide range in mean grain size among the various clay minerals from the Amazon River (chlorite the largest at about 10 microns), and Baker (1973) noted that only samples including the larger fractions (up to 63 microns) accurately represented the clays carried by the Columbia River and transported in the adjacent ocean. Post-burial diagenesis can generally be discounted, as recurring variations show up vertically in both outcrop and subsurface clay sequences, indicating that no post-depositional homogenization has taken place, at least in the particle size range discussed. The wide range of mineral phases present would not be a stable equilibrium assemblage, and would not coexist if sufficient heat had been present to initiate reactions.

The clay mineralogy of a shale or mudstone reflects the weathering, transportation, and/or diagenetic history of the rock. Those clay suites found in the Midcontinent and adjacent regions are broadly similar, and generally reflect prevailing weathering and depositional conditions. The clay suites found by other workers in Pennsylvanian sediments of central North America are similar to those found in this study (Table 1). Among the general trends, important ones are (1) the increase in kaolinite in sediments derived from uplifted areas and (2) the greater abundance of kaolinite in Demoinesian and older Pennsylvanian sediments compared to Missourian sediments.

Table 1

Pennsylvanian clay mineralogy, Midcontinent and adjacent regions

| Unit | Area | Age | Lithology | Clays* | Author |
|---|---|---|---|---|---|
| Molas, Glen Eyrie, Belden | Cent Colo. | L,M Penn | Redbeds, carbonates, grey shale | I,K,S,m I-S | 1 |
| Lower Pottsville | N Ala. | L Penn | Shale | I,K,C,m I-S | 2 |
| Minturn, Fountain | Cent Colo. | M,U Penn | Redbeds, grey shales, carbonates | I,C,mI-S, mC-V | 1 |
| Naco? | Ariz. | M,U Penn | Shale | I,C | 3 |
| Fountain | S Colo. | M Penn | Shale | I,K,mI-S | 2 |
| Minturn | S Colo. | M Penn | Carbonate | I,C,mI-S | 2 |
| Holdenville | Kans. | M Penn | Shale | I,C,K,V mI-S | 4 |
| Exello | Kans., Okla. | M Penn | Black shale | I,K,C | 5 |
| Cherokee | S Iowa | M Penn | Shales | I,K,C,m I-S | 6 |

Table 1 (cont'd.)

| Unit | Area | Age | Lithology | Clays* | Author |
|---|---|---|---|---|---|
| Cherokee Marmaton | Mo., Iowa | M Penn | Shales | I,K,V | 25 |
| Cherokee, Marmaton | S Iowa Penn | M | Shale | I,K,V | 7 |
| Kalo | N Iowa | M Penn | Shale, carbonate | I,K,mI-S | 2 |
| Cherokee | E Iowa | M Penn | Siltstone | I,K,C,m I-S | 2 |
| Colchester Herrin | Ill. | M Penn | Underclay | I,K,C,mI-S | 8 |
| Herrin | Ill. | M Penn | Underclay | I,C,V, mI-S(reg) | 9 |
| Oquirrh | Utah | U Penn | Carbonate, sandstone | I,C,K,m C-S(reg) | 10 |
| Honaker Trail | Utah | U Penn | Shale, carbonate | I,mC-S(reg) | 2 |
| Madera | N.M. | U Penn | Shale, carbonate | I,C,K,S, mI-S,mC-S | 11 |
| Cisco | Texas | U Penn | Shales | I,K,C,V mI-S | 12 |
| Vilas | E Kans. | U Penn | Shale | I,K,C | 13 |

Table 1 (cont'd.)

| Unit | Area | Age | Lithology | Clays* | Author |
|---|---|---|---|---|---|
| Kansas City | E Kans. | U Penn | Sandstone | I,K,V, mI-S | 14 |
| Heebner | Kans., Okla. | U Penn | Black shale | I,K,mI-S | 15 |
| Nodaway | Kans. | U Penn | Underclay | I,K,C,mI-S | 16 |
| Leavenworth | Kans. - Iowa | U Penn | Carbonate | K,K,C,mI-S | 17 |
| Kansas City Lansing | W Kans. | U Penn | Shales | I,C,mI-S | 18 |
| Kansas City | Kans., Mo. | U Penn | Shales | I,K,C | 19 |
| Missourian-Wolfcampian | Kans. | U Penn, L Perm | Shales | I,K,C,m | 20 |
| Bethany Falls | Kans. | U Penn | Carbonate | I,C,mI-S (K,V**) | 21 |
| Galesburg | W Kans. | U Penn | Shale | I,C,mI-S | 2 |
| Rakes Creek | Neb. | U Penn | Redbed | I,K,S,V, sepiolite? | 22 |

Table 1 (cont'd.)

| Unit | Area | Age | Lithology | Clays* | Author |
|---|---|---|---|---|---|
| Bonner Springs | Neb. | U Penn | Shale | I,K,C,S | 23 |
| Bethany Falls Galesburg, Winterset | Iowa, Mo. | U Penn | Carbonate shale | I,C,S,m I-S | 24 |
| Minnelusa | W So.Dak. | U Penn | Shales | I,K,mI-S | 2 |
| Pontiac | Ill. | U Penn | Carbonate | I,K,C,mI-S, mC-V | 26 |
| LaSalle | Ill. | U Penn | Carbonate | I,K | 27 |
| Brush Creek | Ohio | U Penn | Carbonate | I,K,C | 30 |
| Cambridge Ames | Ohio | U Penn | Carbonate | I,K,S | 28 |
| Cambridge | Ohio | U Penn | Carbonate | I,K,S | 29 |

m=mixed layer; I=illite; K=kaolinite; S=smectite; C=chlorite; v=vermiculite

*Clays are not listed in order of abundance

**K is authigenic; V from modern weathering

Table 1 (cont'd.)

1-Raup, 1966

2-Schutter, unpub. data

3-Wanless and Patterson, 1952

4-Dalton et al., 1958

5-Cassidy, 1968

6-McCormick, 1973

7-Brown et al., 1977

8-Parham, 1964

9-Stepusin, 1978

10-Tooker, 1962

11-Mukhopadhyay and Brookins, 1976

12-Shover, 1964

13-Kinell, 1964

14-Verhulst, 1970

15-Crouch, 1971

16-McMillan, 1956

17-Toomey, 1964

18-Twell, 1958

19-Coveney, 1979

20-Cubitt, 1979

21-Mossler, 1970

22-Kotrous, 1978

23-Whitcomb, 1965

24-Payton, 1966

25-Bailey et al., 1962

26-Fraser, 1970

27-Grim, Lamar and Bradley, 1937

28-Bradley, 1964

29-Kozusko, 1968

30-Ottum, 1969

In some cases studied, weathering history is the primary variable in the clay patterns. This is particularly true in the case of the underclays, which generally overlie a uniform lithology, show no evidence of transportation, and are overlain by an autochthonous coal or smut. Presumably, for at least a short time, these underclays functioned as a soil for the plants of the coal swamp.

Most of the clay patterns found in the rocks studied reflect aspects of transportation and deposition. It is generally agreed that clays entering marine waters probably do not undergo profound structural changes, although a great deal of exchangeable ion interchange may occur (Whitehouse and McCarter, 1958; Weaver, 1959; Grim, 1968; Berner, 1971). Thus, the clay patterns found largely represent the clays eroded from the source areas, and indicate variables of source and weathering.

Important manifestations of detrital clay stability extend to special environments. Neither carbonate nor carbonaceous material significantly alter the detrital clay minerals present. Weaver (1960) and Millot (1970), among other workers, recognized that the clays present in carbonate rocks reflect those brought into the basin, and their variation can be interpreted in the same manner as that in shale. Black, organic-rich shales do not have a unique clay suite, although they are often characterized by certain clays. Weaver (1958, 1960) noted that widespread marine black shales are usually dominated by

illite or illite-smectite mixed layer clays, whereas continental black shales are kaolinitic. Strahl (1958) went so far as to state that the marineness of a black shale can be determined by its illite: kaolinite ratio. But other clays can also be dominant. Ferrell (1965) reported that the Cretaceous Thermopolis Shale of Wyoming was dominated largely by smectite (apparently of volcanic origin). A sample of the Graneros Shale of Colorado, run for comparative purposes in this study, was similarly dominated by expandable clays. Nearly every major clay mineral has been reported from black shales (Table 2).

The detailed technical procedure of the clay mineralogy is discussed in Appendix A, but it is necessary to refer to pertinent aspects of it here:

(1) When evaluating numerical values of clays, note that the values reflect the particular method of semiquantitative analysis chosen; in many cases, use of a different method would change the order of clay abundance within a sample.

(2) The illite crystallinity indix (IXI) or value is derived from Weaver's (1960) use of numbers to describe the sharpness of the illite 001 peak, and thus the degree of crystallinity of the illite. Generally, the index reflects the amount of potassium in the illite, with lower numbers reflecting weathered illite that has lost potassium.

(3) The methodologies selected for processing carbonates and black shales apparently did not affect the clay minerals present; in both cases, the clays present are those expected by continuation of prevailing patterns.

Table 2

Clay mineralogy of black shales

| Unit | Area | Age | Clays* | Ref |
|---|---|---|---|---|
| Lower Thermopolis | Cent. Wyo. | Cretaceous | mostly S | 1 |
| Hamilton Group | N.Y. | Middle Devonian | I,C,S | 2 |
| Excello | Okla., Kans. | Middle Pennsylvanian | I,K,C | 3 |
| Heebner | Okla., Kans. | Upper Pennsylvanian | I,mI-S, K | 4 |
| Graneros | S. Colo. | Cretaceous | I,K,C,S, mI-S | 5 |
| Chattanooga | NE Okla. | Mississippian | I,C | 5 |
| Ophir | Utah | Cambrian | I | 5 |
| Mecca Quarry | W Ind. | Middle Pennsylvanian | I,K,C, mI-S | 5 |
| Paradox | Colorado | Middle Pennsylvanian | I,C,mI-S | 5 |

S = smectite; I = illite; K = kaolinite; C - chlorite;

mI-S = mixed layer illite-smectite

*Clays are not listed in order of abundance

1-Ferrel, 1965

2-Grossman et al., 1979

3-Cassidy, 1968

4-Crouch, 1971

5-Schutter, unpublished data

(4) A major source of difficulty in comparing the clays of this study to those of others lies in nomenclature. Surprisingly, for illite and several related clays, this is not as consistent as it might be, and explains a good deal of apparent variation in described clay suites. This problem will be described in more detail in the illite section below.

Perhaps the simplest way to present the interpretation of the clays present is to first describe the general conditions under which they would be expected to be found, then describe how these conditions relate to the patterns found in the studied rocks. For this reason, the discussion will first focus on the factors governing clay formation.

## Conditions of Clay Formation

Grim (1968) noted that several factors were important in determining the clays produced during weathering. These include the nature of the parent material, especially in regard to the content of alkali and alkaline earths; the climate; the topography; the vegetation, especially in regard to the organic acids it produces; and time. The leaching and removal of cations is central to the problem; note that no alteration of clays takes place until all the carbonate is removed (Grim, 1968).

### Kaolinite

Weaver (1959) noted that kaolinite is not a common mineral in shales. This is probably largely due to the fact that kaolinite is

most stable under low metal-ion concentrations, although it apparently does not alter readily in seawater.

Keller (1970) summarized the conditions for kaolinite formation as follows: (1) removal of $Ca^{+2}$, $Mg^{+2}$, $Fe^{+2}$, $Na^{+}$, and $K^{+}$ ions. This requires rainfall at least periodically greater than evaporation, permeable rocks, and percolating water. $Fe^{+2}$ may be removed either by oxidation or formation of sulfide. Granitic rocks usually weather directly to kaolinite, whereas gabbros weather first to smectites, then to kaolinite (apparently $Na^{+}$ and $K^{+}$ aluminosilicates lose metal ions more quickly than $Mg^{+2}$ and $Fe^{+2}$ silicates). (2) Addition of $H^{+}$. This is done by making the water acidic, which is why the process usually requires nonmarine waters. (3) Achieving a high Al:Si ratio through loss of silica.

Thus, kaolinite is most readily formed in warm, wet, well-drained areas, particularly if there is a substantial plant cover to provide organic acids. Zkhus (1978) recognized it as a humid, continental clay. Griffin and others (1968) noted that it is a low-latitude clay; in the marine environment it is most abundant off tropical coasts that are not dominated by rivers draining active highlands (which tend to be illitic).

Kaolinite in marine shales is a theoretical puzzle: it is unstable in a metal-rich, basic environment, and should not be present. But it is, although it doesn't form there. Thus, as Grim (1968) observed, kaolinitic shales reflect a kaolinitic source. But once in the ocean, apparently thermodynamic pressures are insufficient to alter it. Weaver (1959) and Berner (1971) noted that the basic structural change

from a 1:1 clay to a 2:1 clay does not take place; Whitehouse and McCarter (1958) demonstrated this experimentally. Keller (1970) suggested that kaolinite persists in the marine environment if it is accompanied by 2:1 clays (e.g., illite and smectite) which will prevent dissolution of the kaolinite by more readily releasing silica; he suggested that rapid flocculation and deposition may also be a factor. In any case, the result is a general decrease of kaolinite away from land, which Parham (1966) stated can be used as an indicator of distance offshore.

Illite

Illite is the most abundant clay mineral in shales (Weaver, 1959) and in carbonates (Weaver, 1967). This is not surprising, as the potassium ion fits very tightly into the interlayer exchangeable sites, making illite a very stable configuration. Illite closely resembles muscovite, from which it varies principally in having less aluminum in the tetrahedral sites, giving it a weaker layer charge and consequently permitting it to hold less potassium.

Illite has very few factors critical to its formation. The most important is the relative activities of $K^+$ and $H^+$ (Keller, 1970). In some cases, the relative activities of $K^+$ versus $Mg^{+2}$, $Na^+$, and/or $Fe^{+2}$ may also be important, as chlorite or smectite may become stable phases (Swindale and Fan, 1967; Grim, 1968; Keller, 1970; Weaver and Pollard, 1975; Buol et al., 1980). Silica and aluminum should also be high (Buol et al., 1980). Thus, illite is generally stable in an alkaline, metal-rich environment, such as the ocean or a less-than-completely-leached soil.

Here, a problem arises in clay nomenclature. During the weathering of clays, the $K^+$ ion is generally leached from the illite and is replaced by $H_3O^+$, followed by larger ions (White, 1962; Keller, 1964; Rich, 1964). Eventually, the result is 14Å clay minerals (Rich, 1964), most of which are expandable. This weathered illite is usually referred to as "stripped", "open", or "degraded" illite. Thus, because of expandable layers, weathered illite has a low-angle "tail" on the X-ray pattern (Keller, 1964), giving it a "shaggy" appearance (Shover, 1964). Rich (1964) and Stepusin (1978) noted that the problem is further compounded when the newly-expanded layers are propped open by $Al^{+3}$ and other hydrated ions; typically, weathered illite will not completely collapse to 10Å when heated (which is one cause for its underestimation in sediments).

The problem comes in naming what is essentially a weathered illite. Generally, the partially weathered material is referred to as a mixed layer clay, because it is a mixture of illite and expandable stripped illite. But what is a completely expandable 14Å clay? Normally, it is referred to as smectite. However, smectite normally contains less aluminum and more silicon in the tetrahedral layer than illite, giving it a lower layer charge. It is also usually dominated by metal ions (with the exception of $K^+$) such as $Fe^{+2}$, $Mg^{+2}$, $Ca^{+2}$, or $Na^+$. It is not known whether these chemical changes take place in a typical weathering profile, but because leaching is the dominant factor, it seems more likely that the expandable clay in weathered illite is simply stripped of $K^+$, with $H_3O^+$ taking its place.

The problem is further complicated by the frequent use of the term "vermiculite" for stripped illite. Strictly speaking, vermiculite is a 2:1 clay with a layer charge higher than that of smectite, and with the interlayer dominated by $H_3O^+$; a diagnostic feature is that it does not expand when it is exposed to an ethylene-glycol-saturated atmosphere. However, Stepusin (1978) cited a personal communication from J. Hower that vermiculite derived from the weathering of illite will expand to 17Å when exposed to ethylene glycol. Stepusin also labelled this expandable clay as vermiculite, because she considered it unlikely that the aluminum-silicon substitution had taken place. So, what is the clay?

The sense of this study is that most of the material involved is, or was, illite. For the purposes of description in this study, the clay with mixed illite and expandable layers will be categorized as a "mixed layer" clay (invariably random; no regular mixed layer clays were observed). If the clay is completely expandable, with a peak normally at 14Å and at 17Å when saturated with ethylene glycol, it will be referred to as smectite; this does not imply that it is montmorillonite. The term "vermiculite" will be discarded as redundant.

The illite crystallinity index (IXI) should again be mentioned here. Essentially, as employed in this study, it is a measure of the degree of weathering of the illite. It compares the unweathered illite peak to a lower angle value, which would include a certain percentage of expanded layers. The fewer weathered layers, the larger

the ratio. A ratio of about 1.4 or less reflects substantial weathering.

At this point, some discussion of the relationships of illite, weathered illite, and kaolinite should be made. These clays make up the majority of the clay found in the Pennsylvanian cyclothems, and their relationships indicate the nature of the processes that worked on them. This should be particularly true if in situ weathering profiles exist, and they might be expected in that part of the cyclothem that supposedly involves subaerial processes.

The subaerial portion of a cyclothem is most readily located if an autochthonous coal is present: Any seat earth below it should have acted as a soil for some length of time, and should show some pattern of weathering. The pattern would depend on the length of time and the conditions under which the soil evolved.

Theoretically, several patterns and relationships could evolve. In intensely leached, well-drained areas, kaolinite or even iron and aluminum oxides and hydroxides would be expected (Keller, 1964; Loughnan, 1969, Buol et al., 1980). Kaolinite might also be expected to form in poorly drained areas if the groundwater was acidic enough to permit the $H^+$ activity to exceed that of whatever metal ions were present (Eckhardt and von Gaertner, 1962). A modern example of this process is described by Staub and Cohen (1978) in the seat earth of a Carolina swamp.

However, in poorly drained areas where ion activity (particularly $K^+$) remained high and the groundwater was not excessively acid, weathered illite might be expected. Millot (1970) stated that such

mixed layer clays are characteristic of pedogenic processes, and are well-known from modern examples (e.g., Droste, 1956; White, 1962). It is worth noting that in the modern examples, illite crystallinity increases with proximity to the parent material, reflecting less weathering. Swindale and Uehara (1966) noted that in swampy areas where plant recycling of $K^+$ maintains high levels of the ion, even formation of illite from kaolinite may be expected.

With these patterns in mind, soil profiles should be readily recognized. Indeed, there are many examples. Dalton and others (1958) recognized one at the Desmoinesian-Missourian unconformity in Kansas, in part based on the weathering of the illite. Ostrom and Potter (1961) recognized a profile at the Mississippian-Pennsylvanian unconformity in southern Illinois, based on the same feature.

But much controversy surrounds the underclays, which should be the obvious examples. Wanless and others (1969) stated that underclays cannot be soils because they lack significant alteration. Parham (1964) stated that underclays were formed by deposition in brackish water. This was based on his recognition that in the Illinois Basin many underclays become more kaolinitic toward the margins of the basin, which he attributed to an offshore decrease in kaolinite brought in by rivers (Fig. 26).

However, many workers note that most features of underclays can be explained by soil processes. Hughes (1970), using Parham's (1964) data, observed that the occurrence of kaolinite along the margin of the Illinois Basin could be explained by better soil drainage; the center of the basin remained illitic due to lack of leaching; and the local

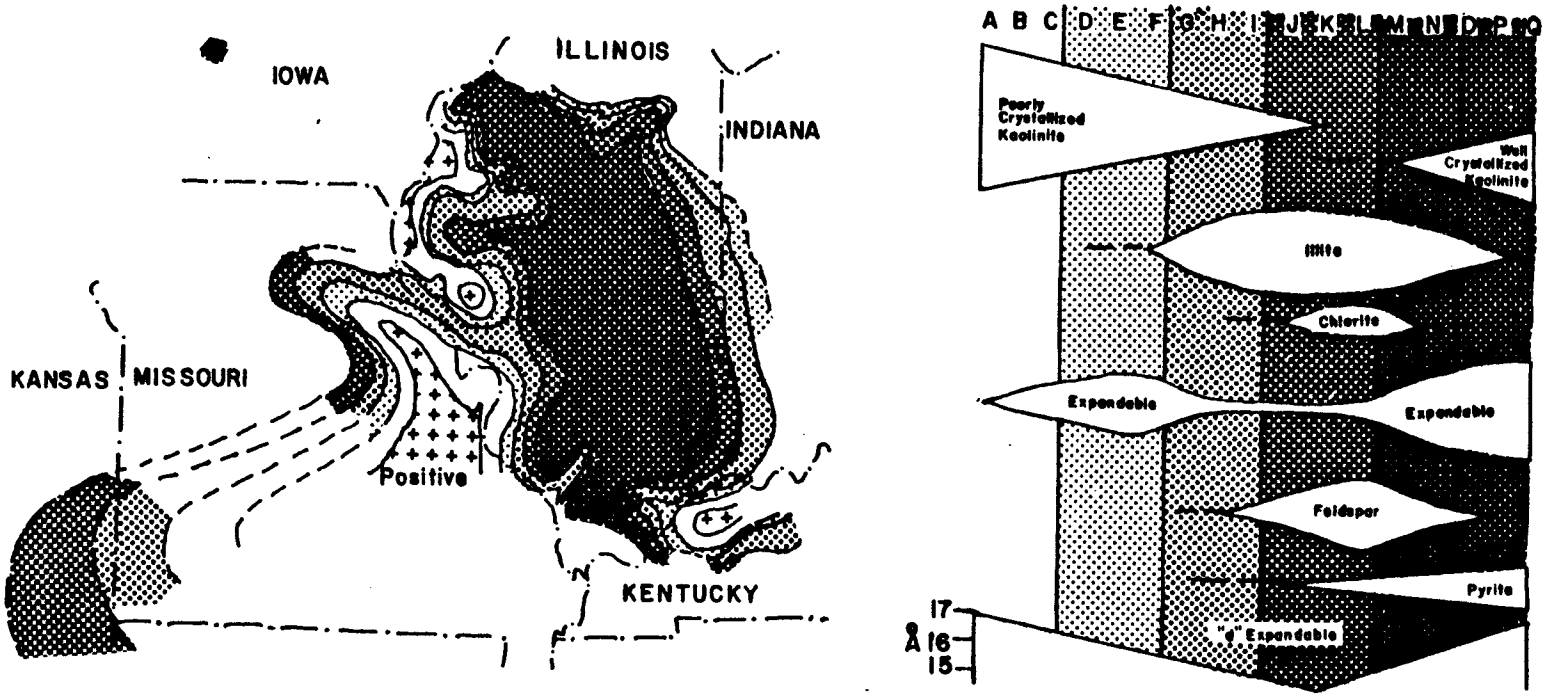



Figure 26. Clay mineral facies of the Colchester (No. 2) underclay.

Map from Parham, 1964; diagram from Hughes, 1970.

well-crystallized kaolinite in the basin center could be explained by plants reducing metal activity in an acid environment. Stepusin (1978) noted a profile of upward-decreasing illite crystallinity in the underclay of the Herrin coal in Illinois, and attributed it to weathering, but stopped short of calling it a soil due to the presence of a regular mixed-layer clay, which she felt would not permit it to be a soil. Roeschmann (1971) referred to the underclays of the Ruhr as soils, and stated they formed with slow but continuous input from floods. (However, he cited Teichmüller (1962) as attributing the upward-increasing degradation of illite to the upward movement of pore fluids during compaction.) Huddle and Patterson (1961) summarized the work done on underclays and concluded that they were soils. They cited Weller's (1930, 1956) explanation of why many underclays were kaolinitic, which would not be expected in a poorly-drained environment. Weller stated that the soil formed long before submergence, a conclusion supported by Schultz (1958). This is also consistent with Roeschmann's (1971) observation that many fossil soils are polygenetic.

There is a further modification to this idea. Rather than a simple soil profile, McMillan (1956) suggested that the Nodaway underclay in Kansas was a "gley", that is, a swamp soil with minimal leaching, but with a loss of structure and a reduction of any iron present. However, because most underclays do exhibit an upward-leached or weathering profile, this interpretation does not appear to apply generally.

It would be appropriate here to mention the relationship of the weathering profiles to sedimentary parent material. In cyclothemic

deposits, it would be expected that a soil would develop on the exposed surface of the previous cyclothem--usually shale or limestone. Grim (1968) noted that no weathering of clays would take place until all the carbonate was removed; Buol and others (1980) noted that both limestones and shales produce dense, impermeable soils, with the clays present largely reflecting the original clay component. Carroll and Starkey (1959) noted that thickness of limestone soils depends on the amount of clay in the parent; clayey limestones produce thick profiles, often eventually with significant evolution. But drainage is the key. As Carroll and Starkey noted, when the water moves, especially when charged with $CO_2$ and organic acids, even silica is removed; eventually only alumina and ferric oxide remain. When there's no circulation, the process is retarded. Limestone and shale soils are generally rich in metal ions and have a high pH, conditions not favorable to the formation of kaolinite. Millot (1970) noted that these rocks tend to have very weak clay evolution; if the soil does eventually become completely leached, smectite may form, and even kaolinite may form in exceptionally well-drained areas. However, a weathered illite profile would be expected on a limestone or a shale; in the Midcontinent, such profiles are present when not masked by sedimentation (Fig. 27).

However, not all underclays will necessarily exhibit a weathering profile. Some coals, particularly alluvial ones, exist for too short a time to develop a profile. Sequences containing such coals show virtually no variation between the seat earth and other alluvial sediments.

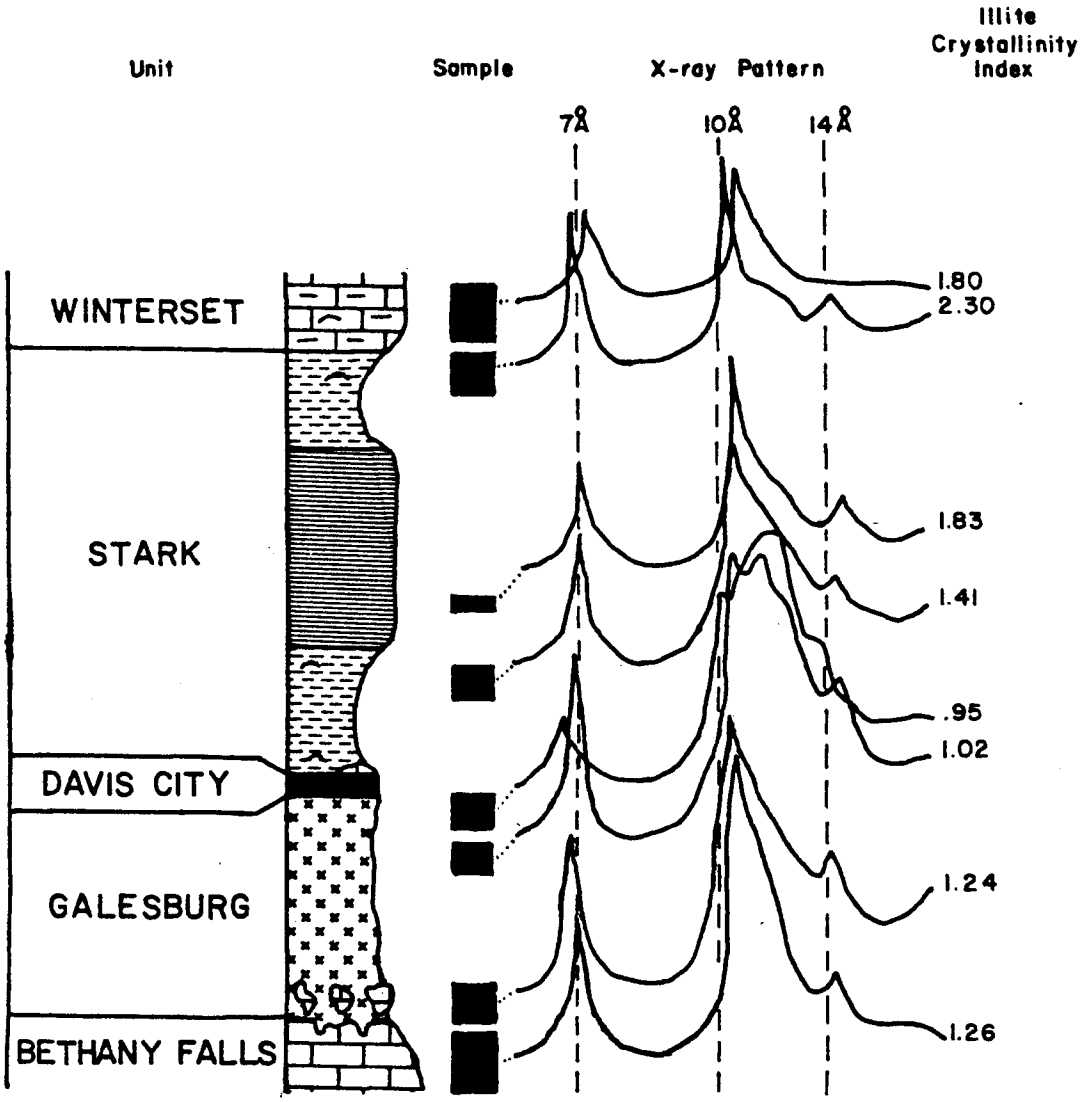



Figure 27. Clay profile--Davis City, Iowa DC1

Note that the width of the illite peak at 10Å increases and the illite crystallinity index decreases upward from the top of the Bethany Falls to the Davis City Coal. The pattern reverses above the coal, then reverses again at the base of the Winterset.

An interesting observation of unknown significance is that Upper Pennsylvanian sediments of the Midcontinent are markedly more illitic than Middle Pennsylvanian sediments, which usually have very high kaolinite percentages. In the Middle Pennsylvanian rocks of Iowa, McCormick (1973) and Brown and others (1977) consistently reported significant kaolinite values. Grim (1968) noted that Lower and Middle Pennsylvanian underclays in the Illinois Basin are much more kaolinitic than the Upper Pennsylvanian ones. Several comparative samples from the Middle Pennsylvanian of Iowa run during this study support the observation of anomalously kaolinitic sediments with minimal illite present.

The cause of this pattern is problematic. Huddle and Patterson (1961) attributed it to longer periods of weathering in the Early and Middle Pennsylvanian. It could also be a result of greater tectonism; with greater uplift producing better drainage, more kaolinite might be produced. This would correspond to the much thicker Lower and Middle Pennsylvanian strata (compared to the Upper Pennsylvanian) both in the Illinois Basin and the Midcontinent. It could reflect the changing climate of the Pennsylvanian; as the climate dried out at the close of the period, rainfall may have become increasingly sporadic and ineffective for leaching. The cause of the loss of kaolinite in the Upper Pennsylvanian sediments may be any or all of these mechanisms; in any event, it reflects a major change in the depositional environment.

In addition to weathering profiles, illitic sediments might be expected to produce the reciprocal of the pattern, that is, a

regradational sequence when exposed to seawater. Stripped illite has an ability to regain its $K^+$ ion very readily in seawater (Grim, 1968; Keller, 1970). That this is the situation in the Pennsylvanian is borne out by illite polytype: Brown and others (1977) noted that the illite in Iowa sediments was always the high-temperature 2M polytype (indicating a relatively high temperature of formation, but not precluding a polycyclic history), which is interpreted as being detrital. Weaver and Pollard (1975) noted that the authigenic 1Md polytype is rare in Paleozoic sediments, indicating that there was little neoformation of illite. Thus, as detrital illite enters the marine environment and acquires $K^+$, it should become better crystallized. Raup (1966) endorsed this idea, and noted that in the center of the basin where deposition was slower, the illite had time to react more completely and become better crystallized. This can be seen in the upper portion of Figure 27, where the marine clays become increasingly better crystallized farther above the coal (and presumably farther from shore). Empirically, illite that has reabsorbed its potassium seems to have an illite crystallinity index of about 1.7 to 2.0; this agrees well with Weaver's (1960) observation that unmetamorphosed Atoka sediments have a ratio of about 1.8.

Smectite

As mentioned above, any clay that has a 14Å basal spacing, which swells to a 17Å spacing when exposed to ethylene glycol, is called smectite in this study. This is not to suggest that it is what is commonly labelled montmorillonite; at this point, it cannot be ruled out that it is montmorillonite, although that seems rather unlikely.

Keller (1970) listed the conditions for formation of smectite: (1) retention of metal ions, such as $Mg^{+2}$, $Ca^{+2}$, $Fe^{+2}$, $Na^{+}$; (2) relatively low $K^{+}$; (3) retention of silica; (4) ineffective leaching in low permeability soils with stagnant alkaline water; and (5) a semi-arid climate. Buol and others (1980) noted that smectites typically form from parents rich in $Mg^{+2}$ and $Fe^{+2}$. Usually this means basic igneous rocks (Keller, 1970); presumably the weathering of argillaceous dolomite may also be suitable, if this can be done while keeping the $K^{+}$ activity low.

Grim (1968) noted that smectite usually reflects slightly unusual conditions, such as volcanism. He suggested that an area lacking volcanism and subject to lateritic weathering would be expected to produce little smectite. Griffin and others (1968) noted that although smectite is the only abundant authigenic clay in the oceans today, it forms mainly in areas of marked volcanic activity and the material sometimes labelled "smectite" elsewhere may be weathered illite and chlorite.

The question of whether smectite should persist, particularly in a marine environment, is much debated. Whitehouse and McCarter (1958) stated that smectite in seawater should convert to illite and chlorite; Powers (1957) and Grim (1968) agreed, although Powers felt that only chlorite was the end point. Weaver and Pollard (1975) favored transformation of smectite to illite, noting that "marine" illites had more $Mg^{+2}$ than "terrestrial" ones, and attributed that to a montmorillonite precursor. Keller (1970) stated that stripped illite-type smectite reverts upon entering the ocean, but that "true

montmorillonite", if not badly weathered, acquires little $K^{+}$. Eberl and Hower (1976) noted that a true smectite, with a small layer charge, would require substitution of $Al^{+3}$ for $Si^{+4}$ in the tetrahedral layer, something that would happen so slowly at ocean-bottom conditions as to be insignificant. Stripped illite, however, with a higher layer charge and no necessity for major substitution, would readily reconstitute in seawater.

Vermiculite

As has been noted above, the presence of vermiculite in the studied sediments is problematic, being chiefly a matter of definition. Stepusin (1978) stated that the conversion of illite to vermiculite is simply a matter of changing the interlayer ions; Buol and others (1980) stated that vermiculite forms under conditions of intermediate pH, with a mica (e.g., illite) parent; $K^{+}$ and $Mg^{+2}$ must be completely removed, $Al^{+3}$ activity is low, and $Si^{+4}$ activity is high. Essentially, the resulting product is 2:1 clay with the interlayer dominated by $H_3O^{+}$, that is, a swelling clay usually derived from illite.

Such vermiculite is unstable in seawater, rapidly reverting to illite (Weaver and Pollard, 1975). Rich (1964) noted that the high pH of seawater is unfavorable to vermiculite, and that the $H_3O^{+}$ is rapidly neutralized by water and proton transfer; the result is rapid conversion to illite. In short, whether weathered illite is called smectite, vermiculite, or simply "stripped" illite, it behaves the same, and rapidly reconverts to illite when entering the ocean.

Chlorite

Chlorite is a very common accessory clay; Weaver and Pollard (1975) estimated that it occurs in 75 to 90 percent of all sedimentary rocks, with the bulk of it detrital in origin. Fe- and Mg-rich chlorites weather more quickly than illite in an oxidizing environment (Liebling and Scherp, 1980), although Millot (1970) noted that chlorite remains stable in poorly drained soils of modest chemical activity. Stepusin (1978) found an upward decrease in chlorite in the underclay of the Herrin coal in Illinois, which she attributed to leaching. Since chlorite usually is rapidly depleted from the soil, it is usually abundant only in rapidly transported and deposited (Keller, 1970) or high latitude (Griffin et al., 1968) sediments. It also is relatively coarse-grained and poorly sorted (e.g., Gibbs, 1977) compared to other clays.

During weathering, chlorite loses its brucite layer through leaching, producing a "vermiculite" similar to that of stripped illite (Droste, 1956; Loughnan, 1969; Millot, 1970; Weaver and Pollard, 1975). This is often stabilized by $Al^{+3}$ and $Fe^{+3}$ precipitating between the layers, and is transported to the ocean, where it reverts to normal chlorite (Weaver and Pollard, 1975).

However, the behavior of chlorite in the weathering system is not that simple. In addition to Fe- and Mg-chlorites, an Al-chlorite can form (often known as a "soil chlorite") by what Jackson (1963) referred to as the "antigibbsite effect". In this process, excess aluminum in

the system precipitates between the sheets of stripped illite or chlorite, producing a gibbsite layer between 2:1 clay sheets. Buol and others (1980) suggested that this is most readily achieved in an environment with moderate to high pH, with high activities of both $Al^{+3}$ and $Si^{+4}$. Behaviorally, this structure is similar to the other chlorites, but is dioctahedral rather than trioctahedral. Weaver and Pollard (1975) suggested that such "soil chlorites" are usually poorly crystallized, with fuzzy X-ray peaks.

Cate and Sukhai (1964) reported a further variation on chlorite in the soil; in an environment with alternating wet and dry phases, the following reaction can take place:

$$2\ \text{Al-clay} + Fe(OH)_2 \rightleftharpoons 3\ \text{Fe-clay} + 2\ Al(OH)_3$$

dry wet

Wetting helps reduce $Fe^{+3}$ in the system to $Fe^{+2}$, which replaces the $Al^{+3}$ in the exchangeable sites. This can produce Fe-chlorites, or the $Fe^{+2}$ may be replaced by bases, producing other clays and freeing the $Fe^{+2}$ to produce sulfide. Repetition of this process may ultimately destroy the clay (Buol et al., 1980). Probably due in part to this process, soil chlorites tend to be ferruginous (Loughnan, 1969; Weaver and Pollard, 1975). Buol and others (1980) noted that this process is important, especially in coastal lowlands and it may also be important in other wet, reduced soils that dry out periodically.

Chlorite behavior is very similar to that of illite in the marine environment in that when a degraded clay reaches the ocean, it will regain lost ions (Grim, 1968; Keller, 1970). Such a stripped clay may form either chlorite or illite, with chlorite favored if the Mg/K

ratio is greater than 5:1 (Powers, 1957). Whitehouse and McCarter (1958) noted that the ratio, rather than the total concentrations, is the critical factor. They also suggested that agitation favors illite, although Parham (1966) noted that chlorite tends to occur closer to shore than illite. This reconstitution of chlorite accounts for Shover's (1964) observation that his marine chlorites were better crystallized than his terrestrial chlorites. Chlorite may also form from smectites, although its situation is analogous to that of illite, with it forming only from stripped 2:1 clays rather than from smectites with metallic interlayer cations (Powers, 1957; Whitehouse and McCarter, 1958; Grim, 1968).

Chlorite can also form directly from seawater and non-clay detrital material. Swindale and Fan (1967) reported gibbsite altering to chlorite (other clays could form in a similar fashion, depending on concentration of $Mg^{+2}$, $K^{+}$, $H^{+}$, and silicic acid).

The formation of chlorite could be a major control in the early diagenesis of marine sediments. Drever (1971) suggested that Fe-chlorite could be a source of iron for anaerobic processes, yielding pyrite and Mg-chlorite, with a concomitant lowering of pH and possible carbonate dissolution. Grossman and others (1979) took the opposite position: that pyrite formation and loss of $Fe^{+2}$ governed whether the chlorite would be Fe-rich or Mg-rich; this would also produce a direct correlation with increasing Mg-chlorite and pyrite.

$Mg^{+2}$ loss within the sediment by formation of Mg-chlorite may govern several other reactions. Phosphate crystallization is poisoned by $Mg^{+2}$, so a sink (such as chlorite) is required. Chlorite

may compete with dolomite for $Mg^{+2}$ (Wedepohl, 1971). Tischler and Ruotsala (1965) suggested that chlorite may inhibit dolomitization, as regrading stripped clays would take up $Mg^{+2}$ from dolomitizing solutions.

Glaucony

"Glauconite" has long been used to describe green, iron-rich clays that form authigenically in marine sediments. The name has a specific mineralogical meaning, applying to an illite-like structure. However, not all marine green clays have the defined structure and composition. Odin and Matter (1981) introduced the term "glaucony" for all such clays, and advocated its use when the specific composition is unknown. In most petrographic studies, including this one, the verification of a glauconite structure is not possible, so the more general term is applied here. This probably does not significantly alter the interpretation, as any clay of the glaucony group would require slow deposition and a marginal level of oxidation to permit both ferric and ferrous iron to enter its structure.

Glaucony is a marine authigenic clay. The principal requirement for its formation is low to negative net sedimentation (Grim, 1968; Berner, 1971; Odin and Letolle, 1980), which permits the chemical reactions to proceed before being completely isolated from seawater. Berner (1971) cited current-swept bank tops as an example of a typical locus of glaucony formation.

Glaucony forms most readily in the presence of organic material, such as fecal pellets (Grim, 1968; Berner, 1971). This is due to the

need to maintain a slightly reducing microenvironment, to permit iron of both valence states to enter the structure. Berner (1971) noted that glaucony is not stable in the presence of pyrite, and that a generally aerobic environment prevails. High iron levels are also helpful (Grim, 1968); Odin and Letolle (1980) suggested that glaucony is more common in low latitude seas due to the high levels of iron introduced by tropical rivers. Detrital mica, especially biotite, is also helpful (Grim, 1968); however, glaucony displays an inverse relationship with kaolinite (Odin and Letolle, 1980).

Odin and Letolle (1980) believed that temperature is also important; from modern in situ measurements of glaucony-producing environments, they found a temperature range of 7 to 15°C. They also noted that glaucony tends to occur more frequently in hot-temperate and tropical climates where some leached clays and metal ions are produced by nearby land masses, but at considerable depths, usually in the 100 to 150 meter range; 30 meters is roughly the minimum, as above that the water is too warm and aereated.

Glaucony usually occurs in calcareous sediments, but is rare in pure clay rocks, quartzarenites, or chemically precipitated limestones (Grim, 1968). Grim also noted that glaucony is rare in rocks with algae, corals, or bryozoans. Odin and Letolle (1980) noted that glaucony is often found with phosphorite, but stated that the two minerals alternate in deposition, rather than form simultaneously. Both are favored by low clastic influx and favorable substrate, and tend to occur in at the same depth range in low latitudes.

## Clay Distribution

The tables and figures describing the clay suites often present only the chlorite percentage and standard deviation; when kaolinite is not present, the illite percentage is simply the reciprocal of the chlorite, and the standard deviation the same. "Illite" on the tables includes mixed-layer illite-smectite and smectite, since they are probably derived from the illite.

### Galesburg Shale

The Galesburg Shale is divisible into two regional clay facies, which correspond to the two gross lithofacies present. The blocky mudstone lithofacies north of the Bourbon Arch, and essentially coinciding with the Forest City Basin, is characterized by poorly crystalline illite, whereas south of the arch the detrital clastic facies is significantly kaolinitic with better crystallized illite.

The blocky mudstone facies of the Galesburg in the Forest City Basin lies immediately below the Davis City Coal or a coaly equivalent horizon, which is in turn overlain by the basal marine deposits of the Stark Shale. The Galesburg displays well the features expected in a weathered soil profile; the mudstone directly below the coal is most weathered and has the poorest illite crystallinity, while farther down the mudstone is somewhat less weathered. It appears likely the Galesburg formed largely by weathering of the Bethany Falls Limestone beneath it; texturally, the contact suggests weathering, with the limestone broken upward into small irregular cobbles surrounded by clay,

which become increasingly smaller upwards. The clay mineralogy supports this derivation, as the clay from the Bethany Falls is quite similar, but generally better crystallized. Also, there is no evidence of any detrital influx during Galesburg formation, either in gross sedimentology or in the clay mineralogy. Kaolinite is almost entirely lacking, and it is found only in the southernmost areas, where it may be simply authigenic kaolinite forming in the cracks of septarian microconcretions and other voids.

It is difficult to state whether the chlorite in the soil diminishes upward, or whether significant Al-chlorite replaces the other chlorites. On the average, chlorite content does decrease, supporting Stepusin's (1978) observation of its decrease upward in an underclay due to weathering. But statistically this may not be significant, as the standard deviation is quite large.

An interesting variation in the general pattern occurs at Princeton, Missouri, where the Bethany Falls is an oölite that contains authigenic kaolinite. The overlying Galesburg is exceptionally weathered, producing a free-swelling 14Å clay (smectite) at the top. This exceptional leaching of the clay may be related to its position on what may have been a local topographic high (i.e., an oölite shoal).

The Galesburg/Coffeyville complex in southeastern Kansas and northeastern Oklahoma represents the distal end of a prograding deltaic complex that apparently built northwestward, consisting at least in part of clastics derived from the Ouachita foldbelt. The clay suite is relatively rich in kaolinite and unweathered illite, indicating that

the sediments were derived from well-drained uplands, and/or an area where erosion proceeded more quickly than weathering. This is supported by the abundant detrital muscovite flakes in the shale, with lesser amounts of biotite and detrital chlorite. The clay mineralogy of this shale suite is in marked contrast to that of the Forest City Basin north of the Bourbon Arch (Fig. 28), which is a result of weathering; the southern Galesburg and the Coffeyville were produced by terrigenous clastic influx. It is particularly significant that the coals in this southern area show little or no development of a soil profile, indicating that they were products of short-lived phenomena, and had little opportunity to modify the clays beneath them. But the freshness of the clays gives no indication of how much of the Galesburg/Coffeyville was subaerially deposited, and how much was deposited in a shallow marine environment. Any subaerially exposed parts of this sequence were buried rapidly by more detrital influx, and had no opportunity to develop a weathered profile.

Vilas Shale

The southern Vilas is very similar to the southern Galesburg/Coffeyville, and is also derived from southeastern sources. Like the older shale, it is rich in kaolinite, unweathered illite, and detrital micas, and was probably derived under similar conditions. However, the Vilas was apparently deposited completely in a shallow marine environment, as it generally lacks coal and has marine fossils throughout.

Both southern clastic wedges show an interesting feature. Just below the contacts of these outside shales and the overlying middle

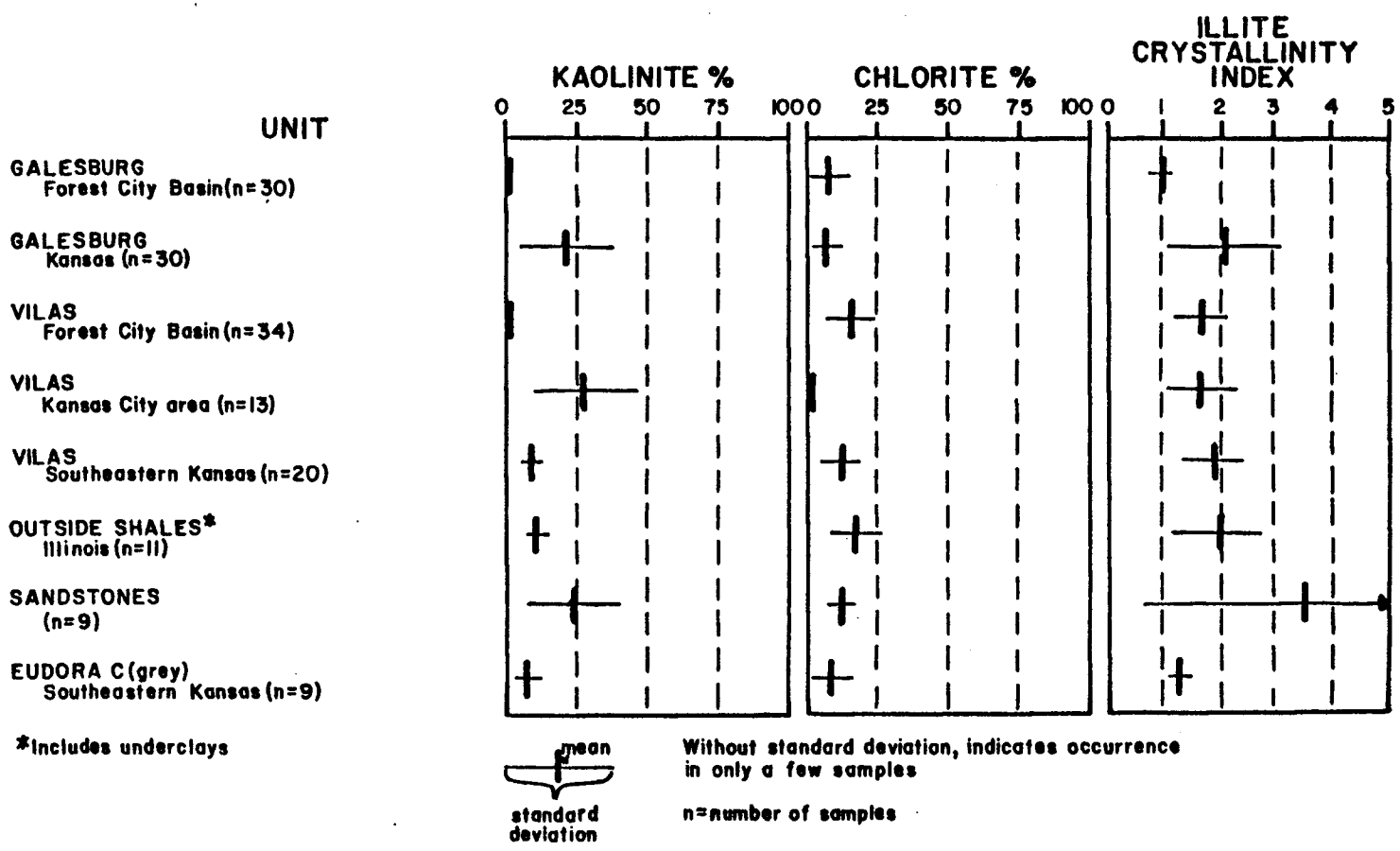



Figure 28. Average clay mineralogy of outside shales.

limestones, the illite becomes much less crystalline and kaolinite content often drops. Unfortunately this contact is not exposed often enough to determine if this is significant, but if it is, two possible explanations are suggested. One is that during early transgression, the principal distant source was cut off, possibly through ponding and sediment trapping on the major river systems. Local sources, derived from low-lying coastal swamps (with slow, partially submergent soil formation) would yield poorly crystalline illite and little kaolinite, which would be dispersed by coastal currents. Alternately, the phenomenon could be post-depositional, with the clay modified by groundwater moving along the shale-limestone contact. At present, definitive evidence is unavailable.

The northern Vilas in most of the Forest City Basin is not only markedly different from the southern Vilas, but is also different from the northern Galesburg. Like the Galesburg, this northern Vilas is nearly free of kaolinite, but contains relatively well crystallized illite. Apparently there was little clastic influx from adjacent kaolinitic land masses, and the illite present was not significantly weathered. Much of the Vilas in this region appears to be deposited in a marine environment, as it is frequently fossiliferous. However, redbeds are present locally around the margins of the basin.

An anomalous section of Vilas in the Bedford, Iowa, core is a relatively thick, sandy, micaceous, kaolinitic horizon. Presumably, this is a clastic influx, representing part of a local deltaic or coastal transport system. Unfortunately, no evidence could be gathered regarding its source area.

The northern Vilas is, as noted above, the only unit studied that has a red mudstone facies. Curiously, the process of producing a red zone apparently did not produce significantly different clays, as the illite crystallinity and chlorite percent of the red mudstones and overlying green and grey mudstones are virtually identical (Table 3). The illite is less well-crystallized than usual in the Vilas in the area, but not significantly so. In some red and adjacent grey samples, a free-swelling 14Å smectite is present, but kaolinite is absent.

This undistinctive clay suite is apparently a frequent feature of redbeds. Shover (1964) noted that Upper Pennsylvanian redbeds in Texas did not have a distinctive clay mineralogy, and were widely variable in composition. Raup (1966) noted a similar pattern in the Minturn (Pennsylvanian) of Colorado, where illite was fairly uniform in arkose, red and grey shales, and limestones. On the other hand, Thompson (1970) noted that chlorite in Ordovician redbeds was less common and more iron-poor than in the drab adjacent rocks. This latter pattern is not verified in the Pennsylvanian redbeds. Notably, most of these red mudstones contain little kaolinite.

It is unclear if the red color is a product of soil formation or diagenesis. Kotrous (1978) concluded that an Upper Pennsylvanian redbed in Nebraska is a residuum, but he also noted that the Vilas there was reported to be a red, laminated shale that was undisturbed by rooting. Buol and others (1980) noted that clayey, iron-rich limestones (a good description of the underlying Spring Hill) often weather to red soils. Loughnan (1969) noted that red soils have little

Table 3

Comparative clay mineralogy of redbeds and related rocks

| | C% | K% | IXI |
|---|---|---|---|
| Vilas - red | m=17.5 | - | m=1.48 |
| n=6 | s= 8.7 | | s= .22 |
| Vilas - Grey[1] | m=16.7 | - | m=1.46 |
| n=6 | s= 3.6 | | s= .16 |
| Galesburg, NW Kansas - red | m=33.2 | - | m=1.45 |
| n=6[2] | s= 4.3 | | s= .12 |
| Minnelusa - red | - | 25.4 | 2.36 |
| n=1 | | | |
| Fountain - red | - | 85.6 | 1.23 |
| n=1 | | | |
| Minturn - grey | 48.7 | - | 1.57 |
| n=2 | | | |

C%=chlorite %; K%=kaolinite %; IXI=illite crystallinity index; n=number of samples; m=mean; s=standard deviation

[1]Adjacent to underlying red mudstone

[2]Without anomalously chloritic sample

organic material present, and usually contain mostly illite, smectite, and chlorite. Thompson (1970), however, felt that the red color in his sediments was secondary in origin, and Buol and others (1980) noted that iron hydroxide (limonite) can dehydrate and produce a red sediment diagenetically.

The Vilas in the Kansas City area is represented by a third clay suite. Here the Vilas is markedly kaolinitic, but lacks chlorite, which is a major component of the southern clay suite. The illite crystallinity is not significantly different from either the southern or northern Vilas.

This may be related to a local deltaic system. The Vilas is anomalously thick in the Kansas City area, thinning both to the south and the north. It is also anomalously sandy, although it is apparently marine throughout as indicated by marine fossils. A potential source would be the markedly kaolinitic residuum that formed on the Ozark Uplift during the Early Pennsylvanian (Keller et al., 1954); if a local stream followed the structural trends present, it may have been funnelled from the Ozark region to the Kansas City region (Fig. 29).

Outside Shales of the Illinois Basin

The outside shales of the Illinois Basin have instructive relationships to those of the Midcontinent. Like the terrigenous clastic clays of the southern Galesburg/Coffeyville and the southern Vilas, the Illinois shales have significant amounts of both chlorite and

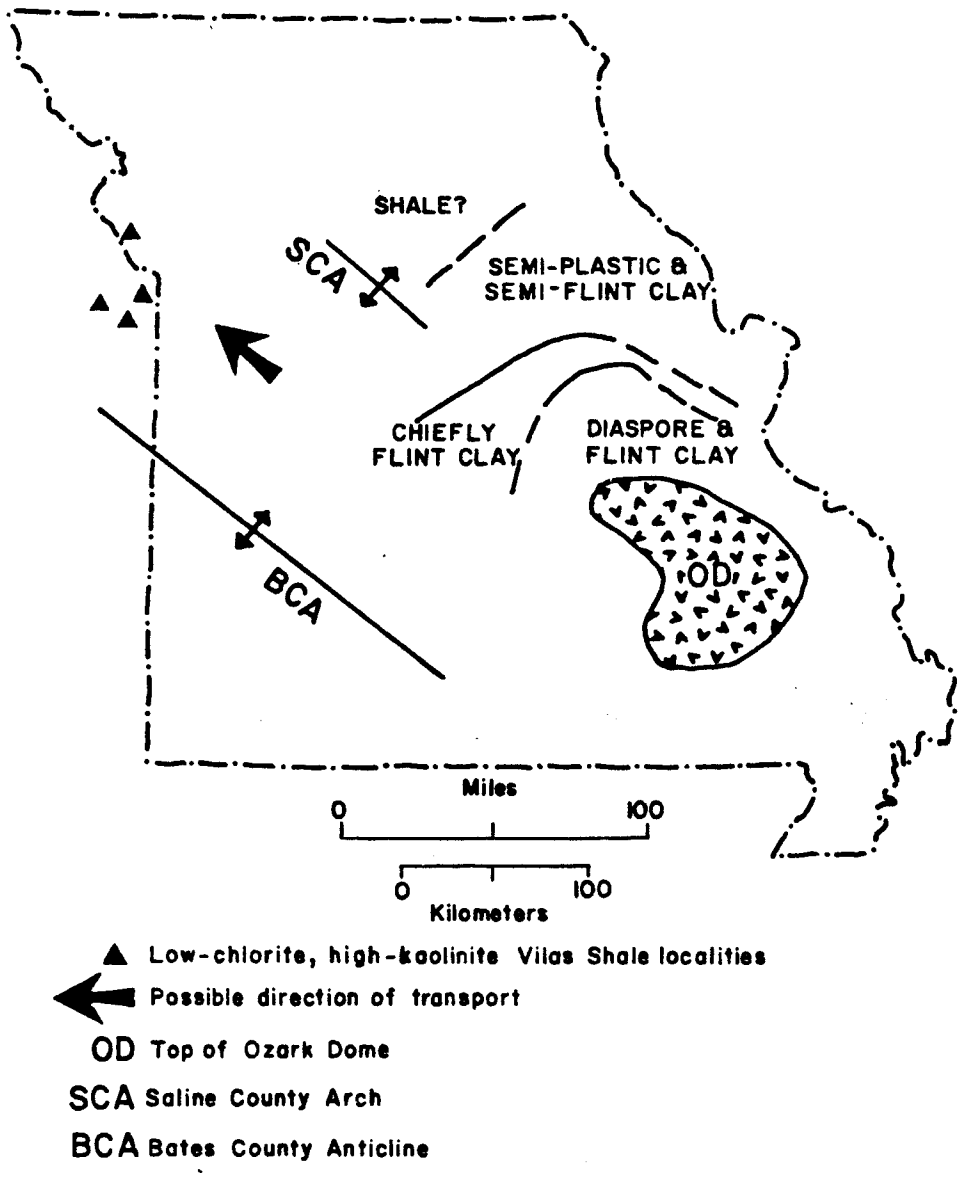



Fig. 29. Low-chlorite, high kaolinite Vilas and its relationship to structural and depositional trends.

Clay distribution of Pennsylvanian source sediments from Keller, Westcott, and Bledsoe, 1954; structure adapted from Searight and Searight, 1961.

kaolinite, and tend to have unweathered illite; again, this basically represents the erosion of uplands of some relief (Fig. 28). But because the Illinois shales are consistently different from the northern Vilas and northern Galesburg shales in the Forest City Basin, there is no indication of significant influx of clay from the Illinois Basin during deposition of either of these shales. By the same token, the chlorite-free Vilas in the Kansas City area was not derived from Illinois Basin-type clays.

However, it is possible that the clastics of northeastern Oklahoma and southeastern Kansas are related to those in Illinois. Mineralogically, they are alike. It is also apparent from the evidence above that the river systems developed in Illinois did not drain into the Forest City Basin. If they followed the regional pattern documented by Potter (1963), they drained southward east of the Ozark Dome until blocked by the Ouachitas. Unless they drained across the Ouachitas, they would have been deflected westward into the eastern end of the Anadarko Basin. In eastern Oklahoma, they would have mixed with Ouachita-derived clastics, and sediments from both sources would have contributed to the deltaic complex that periodically spread sediments into southeastern Kansas.

In passing, the Illinois underclays examined in this study should be mentioned. Both Eberl (1980) and this study found the Fithian underclay (Fig. 30) to follow the pattern of upward-decreasing illite crystallinity: such a profile was also noted in the probable

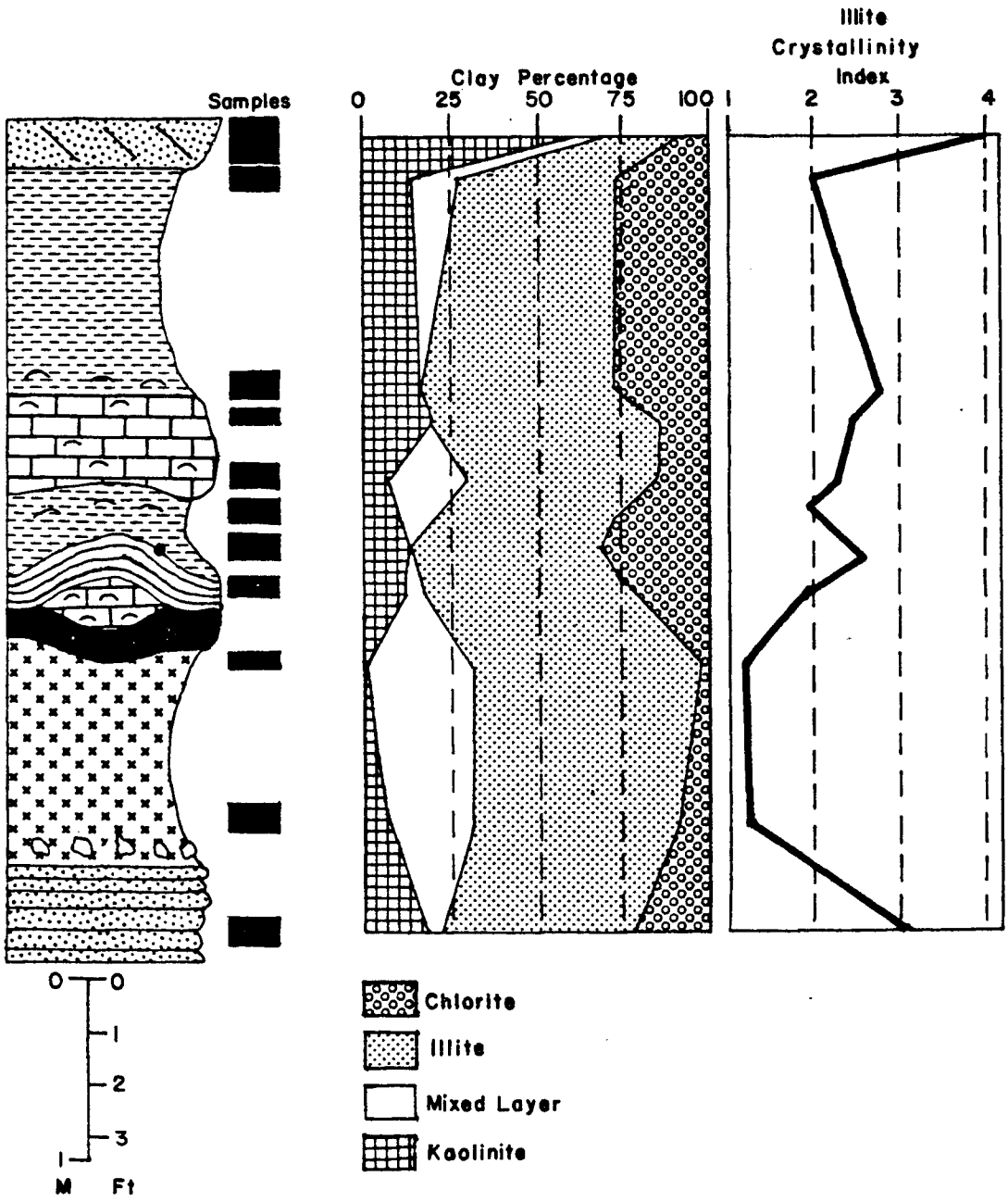



Figure 30. Clay mineralogy profile of the Fithian cyclothem (Ftl).

Galesburg-equivalent horizon in the Charleston, Illinois, core, although it was thinner. However, the Illinois underclays contain some kaolinite, probably reflecting their derivation from more kaolinitic sediments than the northern Galesburg.

Eudora Shale

The Eudora Shale is discussed first here, because it is a better example of several patterns found in the core shales.

The fissile black Eudora Shale everywhere examined is an illite-chlorite shale, with relatively well crystallized illite and almost no kaolinite. Indeed, the abrupt loss of kaolinite from the underlying Vilas to the Eudora places severe constraints on the interpretation of the depositional system. Kaolinite generally not only decreases, but usually disappears in the upward transition. Since kaolinite is essentially associated with clastic influx, this means clastic influx came to an end before Eudora deposition. Climatic change would be insufficient to explain this, as previously produced kaolinite could still be eroded. Lateral delta migration is unlikely, as it would have difficulty completely eliminating kaolinite. A shallow lagoonal environment, even one covered with a flotant mat, would have difficulty excluding kaolinite for even airborne kaolinite from the adjacent land settling on the mat would eventually settle into the sediment as the mat decayed, and some sort of current would be required to bring in illite-chlorite mud from elsewhere. The best explanation of the observed kaolinite-free pattern of the Eudora is for land-derived sediments to be trapped much farther away, such as would occur during a pronounced transgression of the sea.

The Eudora provides a good example of a curious phenomenon. The fissile black shale (B unit) has slightly less crystalline illite than either the underlying or overlying grey shale (Fig. 31). If the black shale represents very slow offshore deposition during the greatest transgression of the sea, and if the dominant clays provided are stripped clays that reconstitute themselves upon entering the ocean, then the clays in the black shale should be the best-crystallized.

Possible explanations are readily available. Clay minerals have long been known to adsorb organic materials (Grim, 1947). Whereas kaolinite and illite are not marked in this tendency, smectite has a great affinity for organics (Grim, 1947), especially in preference to $K^+$ (Whitehouse and McCarter, 1958). Furthermore, the presence of organics in the smectite retards the change of smectite to illite or chlorite (Grim, 1947, 1968; Twell, 1958). Because the black shale environment was doubtless rich in organics, its clay would have absorbed enough organics that the stripped illite (or smectite) in it was unable to crystallize as well as that in the relatively organic-poor adjacent grey shales.

The illite crystallinity pattern in marine black shales is the result of two processes: decreasing rate of sedimentation allowing better illite crystallization, and presumably increasing amounts of organics blocking illitization. Changes in the rate of change of one or the other could account for local variation.

There is also another possible explanation. Roberson and Lahann (1981) noted that the presence of $Ca^{+2}$ and $Mg^{+2}$ in the pore fluids significantly slow illitization. Although there is no evidence at

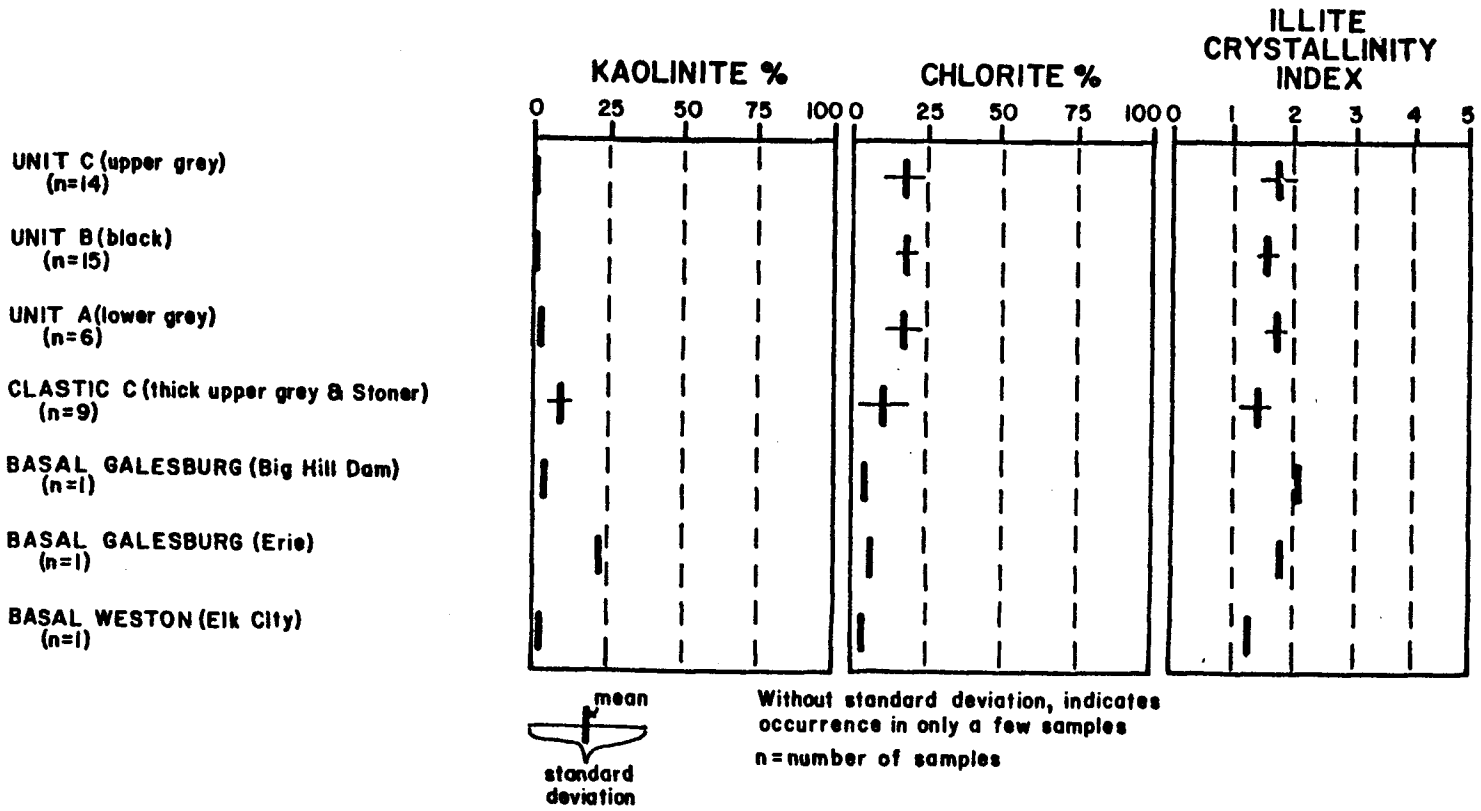



Figure 31. Clay mineralogy of the Eudora Shale and analogous units. The basal Galesburg at Big Hill dam and Erie may be the core horizon of the Swope cyclothem where the Bethany Falls Limestone is absent; the basal Weston at Elk City may be the core shale horizon of the South Bend cyclothem.

this point to support an abnormal level of either ion in the original depositional environment of the black shale, the possibility cannot be entirely discounted.

The Eudora also serves as a good example of another variation in the pattern of core shales. In southeastern Kansas and northeastern Oklahoma, stratigraphic and paleontologic evidence indicates that a clastic wedge prograded into a basin during maximum transgression, producing an anomalously thick upper grey unit of the Eudora. Clay mineralogy confirms this, as kaolinite is present in this sediment, whereas it is rare in the normally thin upper grey unit farther north (Fig. 31). While not as markedly kaolinitic as the typical outside shale, it clearly represents a major pulse of land-derived sediment. The illite is also less crystalline than that found in either the typical Eudora or the typical outside shale of the region. This may reflect significant weathering, perhaps of the original detrital material, or possibly Recent weathering (in these samples, unfortunately, natural exposures predominate, and the possible effect of Recent weathering is unknown).

For comparative purposes, several other examples of clastic influxes at core shale positions were examined (Fig. 31 ). These included a sample of the basal Weston Shale in southeastern Kansas (which truncates the South Bend cyclothem) and the basal Galesburg in the same region, where it apparently truncates the Swope cyclothem. The two samples of basal Galesburg show an even more pronounced influx than the Eudora, with kaolinite and well crystallized illite. The single sample of Weston, on the other hand, does not particularly look

like a core shale environment obliterated by terrigenous clastic influx. In particular, it is only weakly kaolinitic. However, this could simply reflect development of a minor shaly interval before the main clastic pulse, and does not necessarily indicate a different environment.

Stark Shale

Overall, the Stark is generally similar to the Eudora in clay mineralogy and patterns. One notable exception, however, is that the lower grey (A) unit has less well crystallized illite than the black (B) unit, in contrast to the pattern found in the Eudora. This is probably attributable to the rapidity of the Dennis transgression and to more clastic influx during lower grey unit deposition (which permitted less time for reaction of the illite) than in the lower Eudora. Here, as in the Eudora, the upper grey (C) unit has better crystallinity than the black unit.

Overall, the Dennis cyclothem in the Forest City Basin displays a remarkable, readily explained pattern (Fig. 27 and 32). The Galesburg is an underclay, and displays increasing weathering upwards. The clays are markedly more weathered than those of the Bethany Falls, from which the Galesburg may be derived. The Stark is a marine shale in which illite crystallinity progressively increased. Presumably, if organic-rich conditions hadn't interfered, maximum illite crystallinity would have been achieved in the black unit of the Stark. Instead, maximum illite crystallinity occurs in the upper grey transition, then decreases in the Winterset. This decrease may have

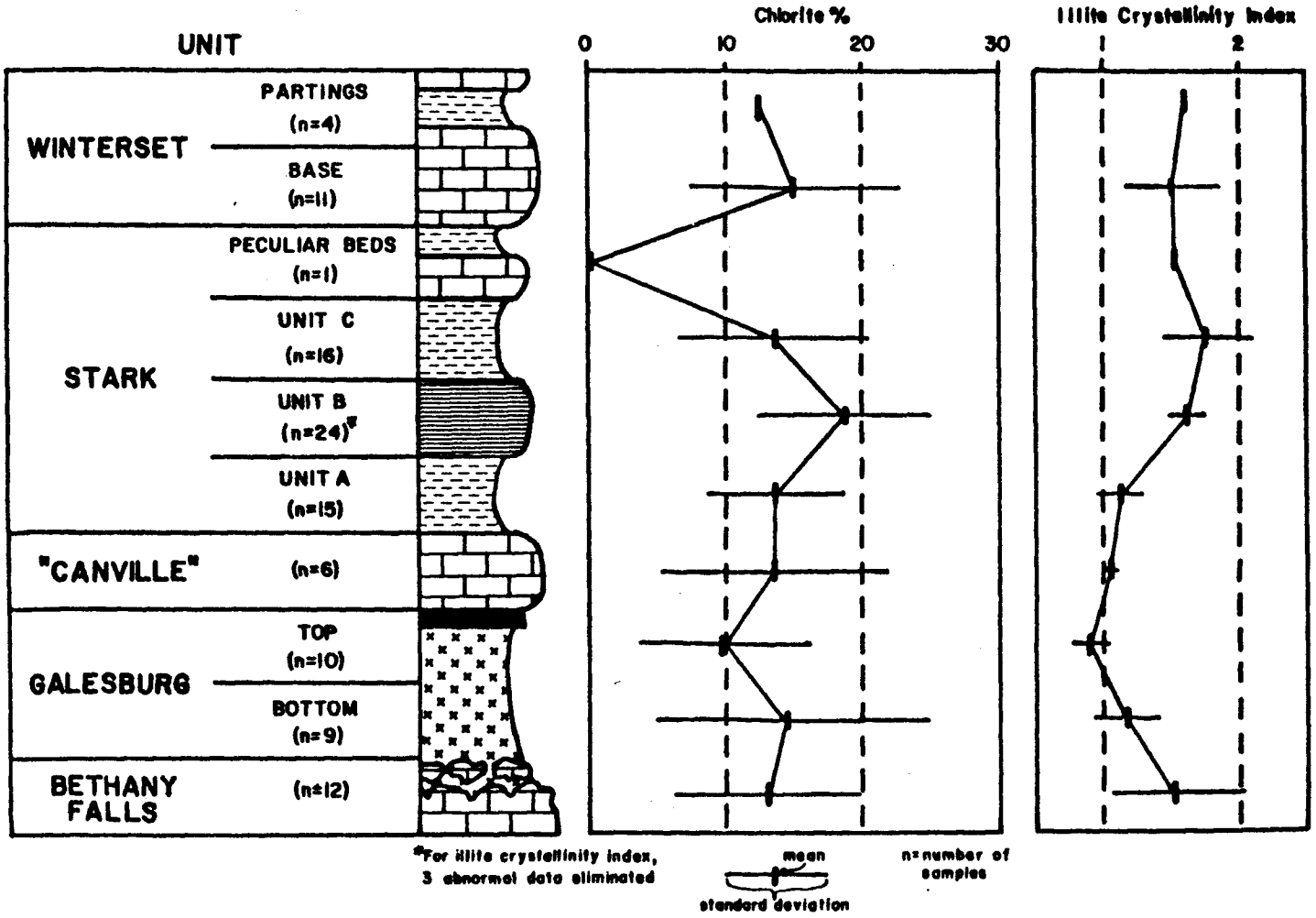



Figure 32. Clay mineralogy of the Galesburg-Dennis interval (Forest City Basin).

been due to somewhat faster deposition and/or a somewhat increased influx of weathered illite.

Chlorite in the black facies of the Stark displays a curious feature. The Forest City Basin black shale has chlorite contents typical of black shales, whereas the average Stark from southeastern Kansas and northeastern Oklahoma is markedly low (Fig. 33). While this may be a function of distribution in a relatively small data set (the standard deviation is remarkably large), it could also be a function of some yet-unrecognized phenomenon.

Fissile Black Shales of the Illinois Basin

The fissile black shales of the Illinois Basin differ from the black Stark and Eudora in one significant feature: they invariably contain kaolinite. In other respects, they are similar, with much the same chlorite content and with good illite crystallinity, which is actually slightly higher in general than in the Midcontinent black shales, although possibly much more variable (Fig. 33). Notably, however, kaolinite content in Illinois black shales is usually near a minimum for the cyclothem, often much lower than the adjacent marine grey shales. This pattern is similar to that found in the cyclothems of the southern Midcontinent. An exception to this trend occurs when there is a soil-profile underclay present, as it may be quite low in kaolinite due to chemical conditions (Fig. 30). The probable explanation for more kaolinite in Illinois black shales is that they were subject to somewhat greater clastic influx, even during black shale deposition, than those of the Midcontinent, or at least subject to an influx different in clay composition.

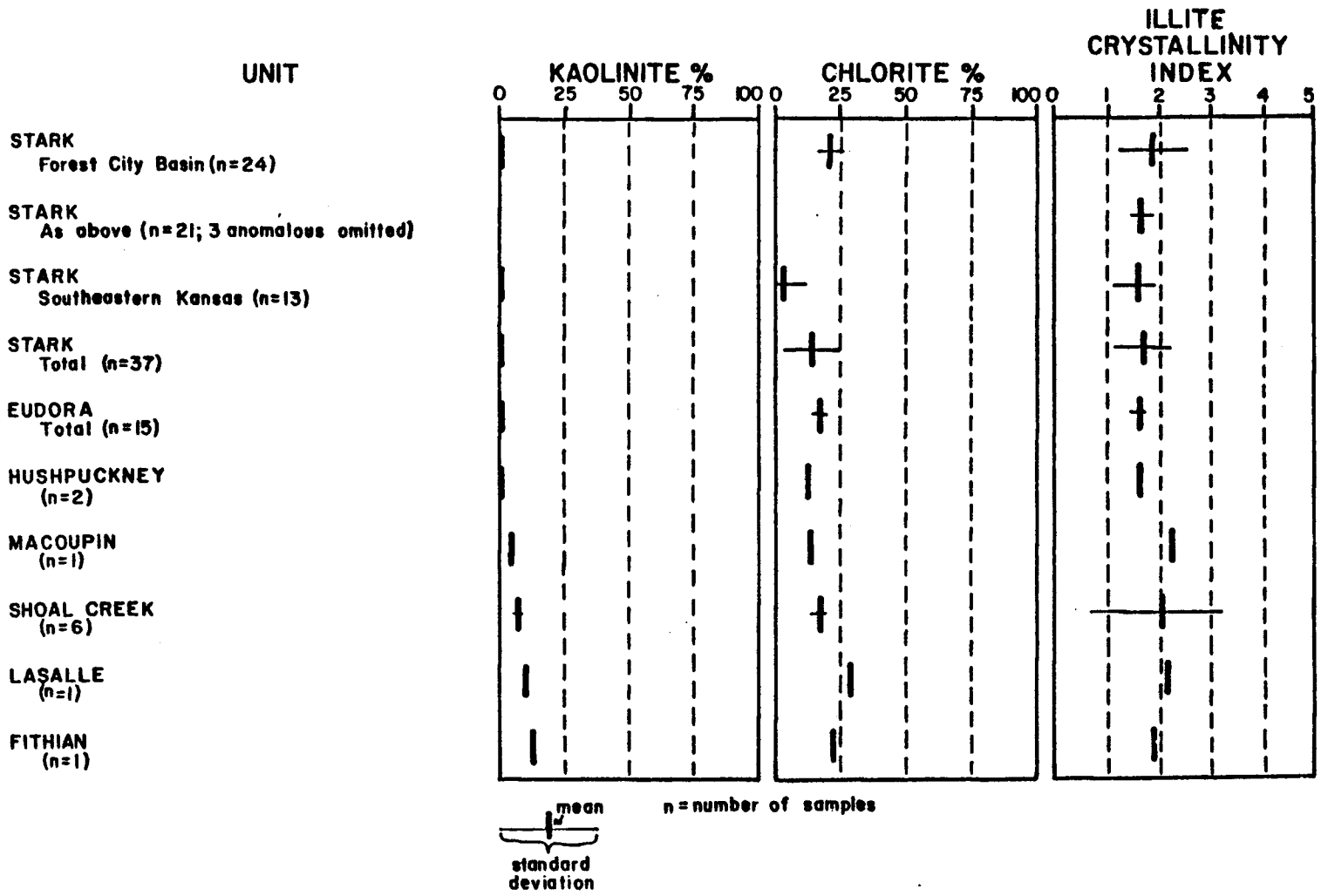



Figure 33. Clay mineralogy of the black facies (Unit B) of core shales.

Clay Minerals and Shale Partings in Limestones

Weaver (1960) noted that the clays in carbonates are generally similar to those in shales, and Millot (1970) observed that most of the clays in marine shales and limestones are detrital. Weaver (1967) added that the clays in carbonates tend to be dominated by illite. This appears to be the case in the Upper Pennsylvanian limestones of the Midcontinent and Illinois. The clay mineral patterns in the limestones follow trends consistent with those in the adjacent shales; apparently treatment with weak formic acid did not affect them to any noticeable degree. Only where the limestones had remnant porosity during later burial did authigenesis significantly affect the clay suite, usually by filling voids with kaolinite, or, more rarely, dickite (Schroeder and Hayes, 1968).

By all the parameters used in this study, the limestone clays are similar to the shale clays. Detrital kaolinite is absent in Forest City Basin limestones, but it is present in the Illinois Basin limestones. Chlorite and illite follow similar patterns in limestones as in shales. Because there are no major changes in the clay suites from shale to limestone, as would be expected in the case of the loss of a major detrital influx from distant, often kaolinitic, sources, it is possible to conclude that carbonate deposition was probably not simply a function of delta migration, but rather a change in other environmental conditions. It cannot be ruled out that a change in the volume of clay is a contributing factor to the onset of a carbonate-producing environment, but apparently the presence or absence of a major deltaic

system did not directly affect initiation of carbonate deposition (although it often contributes to its termination). If clastic influx were the principal control, then limestone formation should have begun earlier in the Forest City Basin than to the south of the Bourbon Arch; this is not the case.

In both the Dennis and Stanton cyclothems, where they overlie clastic outside shales, kaolinite rapidly disappears from the clay suite about the onset of carbonate deposition in the middle limestone. However, this is viewed as a result of the same cause (i.e., loss of kaolinite and initiation of carbonate deposition stem from a common phenomenon) and are not directly related to each other. Kaolinite may disappear significantly before limestone deposition begins, when it begins, or well after it begins; indeed, in Illinois and northeastern Oklahoma it never disappears at all. Thus, there is not an interrelation of these two trends, but rather they are two results of the same general process. If kaolinite is viewed as an indicator of major clastic influx, this lack of correlation indicates other factors besides clastic influx are important controls in the onset of limestone deposition.

An interesting variation appears in southeastern Kansas and northeastern Oklahoma, where the relationship of the Winterset Limestone to the underlying units becomes variable. Both of the middle limestones, the Canville and the equivalent Lost City, have significant kaolinite in their clay suites, with the Lost City being very markedly kaolinitic (perhaps due in part to the vagaries of the clay calculation process, and/or diagenetic kaolinite in the abundant

voids). The Winterset, where it overlies a normal cyclothemic sequence, nearly completely lacks kaolinite. However, in areas where the Stark Shale is absent, the basal Winterset is quite kaolinitic. This is consistent with the interpretation made elsewhere that where the lower part of the Dennis cyclothem is missing, it is due to erosion of those units during early Winterset deposition. Where reworking of the underlying detrital material was significant, the Winterset has incorporated detrital clays. Where presence of the Stark Shale indicates prevailing quiet conditions and a lack of reworking, the Winterset had little clastic input, and lacks kaolinite (Table 4).

An important consideration in determining the depositional history of the cylothems is the origin of the shale partings and beds in the limestone units. Obviously, they represent some sort of a depositional change. Whether it is a minor return to a core shale environment, a brief pulse of terrigenous material, or some other failure of carbonate deposition is fairly significant to the understanding of the depositional history.

The available evidence points in more than one direction, suggesting that the various shale beds may be products of more than one type of event. A good example of the equivocal nature is the Kiewitz Shale in southeastern Nebraska and southwestern Iowa. The Kiewitz in Iowa is kaolinitic, suggesting that it represents a terrigenous pulse. The Kiewitz in Nebraska has no kaolinite, and is rather chloritic, thus it could represent a minor return to a core shale environment of very slow deposition or a terrigenous pulse with a different source. It is possible that the two are unrelated, but are simply

Table 4

Dennis clay mineralogy, southeastern Kansas and northeastern Oklahoma

| | C% | K% | IXI |
|---|---|---|---|
| Basal Winterset without Stark n=5 | m= 6.5 | m=20.5 | m=1.63 |
| Canville n=5 | m=10.4 | m= 4.7 | m=1.42 |
| Lost City n=3 | m= 5.6 | m=32.5 | m=1.91 |
| Basal Winterset over Stark n=4 | m= 4.5 | m= .3 | m=1.67 |
| Winterset shale partings n=4 | m= 9.7 | m= 4.1 | m=1.58 |
| Winterset above basal limestone bed n=4 | m=10.0 | m= 2.0 | m=1.34 |

C%=chlorite %; K%=kaolinite %; IXI=illite crystallinity index; n=number of samples; m=mean

similar-appearing shales in similar stratigraphic positions, although the problems of measuring clays might permit them to be part of the same system.

The various partings in the Winterset Limestone in the Forest City Basin are likewise equivocal in their mineralogy. They are similar to the clays of the upper grey unit of the Stark Shale, and it would be tempting to relate them to a similar environment. However, since Missourian sediments in the Forest City Basin have very little kaolinite, it would be expected that even a terrigenous pulse produced from these sediments would not be kaolinitic; likewise, given a modicum of exposure to seawater, even degraded land-derived illites would achieve the crystallinity observed. On the other hand, the shaly beds in the Winterset of southeastern Kansas and northeastern Oklahoma are kaolinitic (Table 4), regardless of whether the underlying Winterset beds are or not. Also, the kaolinite percent tends to be fairly constant and is greater than the Winterset limestone beds interlayered with the shales. This supports the interpretation that these partings are terrigenous pulses, as they much more closely resemble land-derived clays than clays deposited well offshore.

## Clay Mineralogy in Correlation

In many cases, it would be very useful if a particular unit in this study could be distinguished from another by its clay mineralogy. Unfortunately, the mineralogy mainly reflects broad regional clastic sources and the depositional phase; no stratigraphically diagnostic suite of clay characteristics was recognized. The outside shales have

a wide range of variability, but apparently no unique characteristics. The core shales are less variable, although not completely consistent; they all resemble one another, with no unique features. Frequently, a sample from a core shale would more closely resemble a core shale sample from a different cyclothem than an adjacent sample from the same outcrop.

Nevertheless, as an example of the stratigraphic potential of clay mineralogy, it was applied to the Dennis-Swope problem in eastern Nebraska, where two different correlations have been applied (Heckel and Meacham, 1981). In Iowa the two cyclothems in question are labelled successively Swope and Dennis, whereas in Nebraska they are labelled Dennis and Sarpy.

In Figure 34, clays from similar stratigraphic positions from each cyclothem are compared to the average of the analogous Dennis strata in the Forest City Basin. Note that generally both lower and upper cyclothems in Nebraska usually fall within the range of the Dennis cyclothem elsewhere, and therefore are not diagnostic. When they do fall outside the standard deviation of the average Forest City Basin equivalent, it's not consistently one cyclothem or the other. However, there is one feature that is suggestive. The outside shale of the lower cyclothem is relatively thin, and its illite crystallinity increases from bottom to top, neither of which are characteristic of the Galesburg. However, the outside shale of the upper cyclothem is similar to the Galesburg elsewhere, with a generally similar thickness and a weak upward decrease in illite crystallinity. While this is

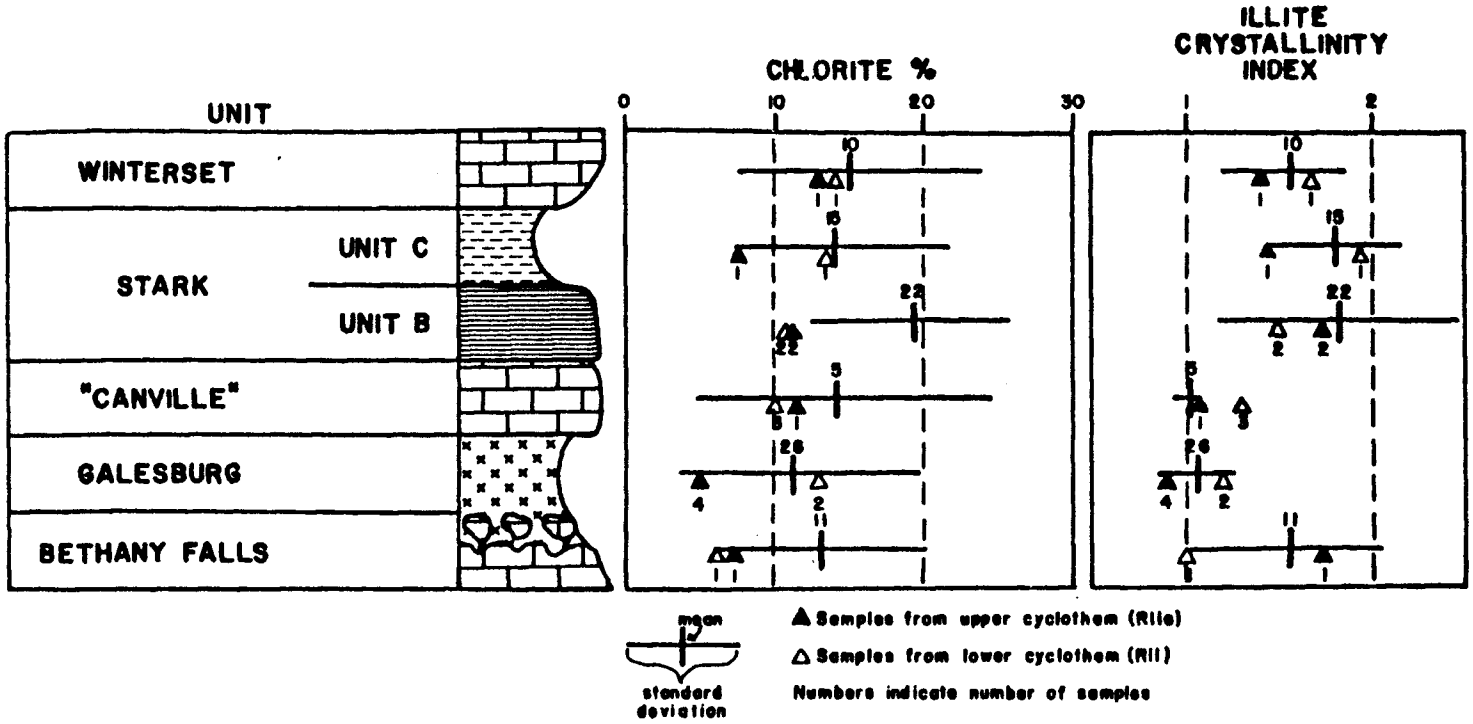



Figure 34. Clay mineralogy comparisons of successive cyclothems at Richfield, Nebraska, compared with average Dennis values in the Forest City Basin. The mean and range are for the units at left from the Forest City Basin; the values from analogous cyclothem units at Richfield are shown by the triangles.

suggestive, there really isn't a firm enough statistical base to make unequivocal statements from the clay patterns.

## Depositional Environments Indicated by Clay Mineralogy

The clay mineral suites of the Missourian strata of the Midcontinent may be broken into several broad provinces, which reflect the nature of the source area. The clays are dominantly detrital, and reflect the weathering history and erosional regime of their source area; alteration in the area of deposition consists chiefly of regrading of stripped illite and chlorite.

Kaolinite is produced in well-drained soils evolved in tropical or subtropical uplands. The marked decline in kaolinite in the Missourian sediments may reflect a decline in the level of orogenic uplift during that stage, something which may be confirmed by the widespread marine nature of Missourian strata. Or it may reflect a gradual migration of climatic belts, with less intense weathering producing less kaolinite; this would agree well with the evidence for a gradual drying out of the climate during the Late Pennsylvanian and into the Permian. It may be significant that Pennsylvanian sediments west of the Midcontinent area are only spottily kaolinitic, and in those cases it may be related to favorable source rocks, such as exposed granite; this would also support climate as a major factor in the change in mineralogy, as the western United States was in an arid climate during the Late Pennsylvanian.

Nevertheless, in the Midcontinent and the Illinois Basin kaolinite did not completely disappear in the Missourian. This

indicates that while climate might have been significant in limiting kaolinite production farther west, the level of tectonic activity (and hence, production of kaolinite) was the determining factor in the Midcontinent and Illinois Basin as clastic influxes from uplands still carried kaolinite, indicating the climate was still favorable for its formation.

Another major indicator of the nature of clay mineral environment is the degree of weathering of illite. In many cases, this is a mirror image of kaolinite. Where drainage was poor and there was little clastic transport, illite crystallinity is low. Often, the distribution suggests a downward leaching of the underlying strata in conjunction with a soil profile. Thus, the Galesburg underclay, forming on what may have been a particularly impermeable limestone, strongly suggests weathering in a swampy environment, with the possibility that much of the clay present is residuum derived from weathering of the underlying calcilutitic Bethany Falls; where the Bethany Falls is a clay-poor, permeable oölite, soil development is negligible. On the other hand, well-crystallized illite is either due to marine regradation or rapid erosion (without significant weathering) and transport of preexisting marine sediments.

It should be noted here that Missourian sediments of the Midcontinent were not likely to contain original true montmorillonite. The leaching climate and erosional regimes, chiefly rapid erosion of leached or unweathered material from the uplands or no erosion in stagnant swamps, were unfavorable to its production, and any potential detrital source from magnesium-rich parents was minor. Those clays

present that are normally described as smectite were probably weathered illite and chlorite, which probably did not undergo the extensive transformation into montmorillonite.

From these principles, broad depositional regimes and source areas can be worked out. For example, during the Missourian, the area in Oklahoma and southern Kansas was dominated by sediment derived from the Ouachitas. The clays were kaolinitic, with significant chlorite and well-crystallized illite, indicating derivation from an uplifted source. This pattern of southern kaolinite enrichment was apparently persistent, as Whitcomb (1965) also found it in the Missourian Bonner Springs Shale, and Toomey (1964) and Crouch (1971) noted it in the Lower Virgilian Oread cyclothem. The northern boundary of this clay province corresponds to the approximate position of the Bourbon Arch. Whether this was a barrier to sediment transport or simply a coincidence with the margin of nearshore clastic-dominated sediment is not known.

The clays of the Illinois Basin closely resemble those of the Ouachita terrigenous wedge. Like the southern clay province, that in Illinois is also persistent; Potter and Glass (1958) noted that the same illite-kaolinite-chlorite suite persisted throughout the Middle and Upper Pennsylvanian. In Illinois, these clays presumably came principally from the Appalachians; locally underclays developed on exposed muds. Apparently, if the Illinois Basin filled with sediment to the point of overflowing, it did not spill into the Forest City Basin, which has a different clay suite. If sediment spilled into the Midcontinent at any point, it probably made its way east and south of

the Ozark Uplift into the Anadarko Basin, where it would have mixed with the similar Ouachita sediments.

Terrestrial and Nearshore Clay Patterns in the Forest City Basin

The two Missourian outside shales examined in this study display contrasting patterns in the Forest City Basin. The Galesburg is apparently entirely a weathering profile, with no apparent clastic influx from anywhere. It developed on the Bethany Falls Limestone, and thus is in marked contrast to the Illinois underclays, which developed on clastic shales and sands. The Galesburg is principally weathered illite and chlorite, with no kaolinite.

The Vilas in the central and northern parts of the Forest City Basin is also dominated by illite and chlorite, but the illite is essentially unweathered. Kaolinite is present only in local areas, which may represent minor pulses of sediments from local sources. The good condition of the illite may be attributed to the apparently marine deposition of the Vilas; if the clays were originally weathered, most of them quickly regained their lost ions. In any event, these clays were not derived from the Ouachitas or the Appalachians.

In the southern Forest City Basin around Kansas City, the Vilas has a kaolinite-illite clay suite, with chlorite lacking. Thus, it is distinct from that of the Ouachitas and Illinois. Notably, this is north of the Bourbon Arch, and stratigraphically and sedimentologically there are suggestions of a local clastic influx. The most likely source appears to be the kaolinite-rich Lower Pennsylvanian clays on the Ozark Uplift, which demonstrates the local significance of a distinctive minor sediment source.

Offshore Clay Patterns

The mineralogy of the fissile black facies of the core shales is characterized by lack of kaolinite in the Midcontinent except in the most marginal areas nearest to detrital sources. For example, kaolinite in the black facies of both the Stark and the Eudora is found only in extreme southeastern Kansas. Crouch (1971) also found this pattern in the black fissile Heebner shale. This is comparable to the black shales in Illinois, which generally contain some kaolinite. During high stands of the sea, nearshore terrigenous clastics were not entirely excluded from the margins of the widespread black shale environments. Nevertheless, the strong illite dominance is consistent with an open marine interpretation of the black shale; continental or lagoonal black shales would be expected to be kaolinitic (Strahl, 1958; Weaver, 1960; Parham, 1966; Grim, 1968). Particularly in areas where illitic non-kaolinitic black shales overlie kaolinitic outside shales, it is difficult to ascribe a nearshore origin to the black shales. The kaolinitic clays would have to be excluded somehow and replaced by marine illitic clays. Possibly, diagenetic destruction of kaolinite in marine waters could account for the difference, but this would be extremely unlikely with a model such as that of Zangerl and Richardson (1963), which envisions a very high rate of deposition. Furthermore, their model for black shale deposition is particularly difficult to reconcile with observed patterns, as they argued that most of the clay in the black shale should be

stream-derived, and thus should be even more strongly kaolinitic than the adjacent marine beds, rather than less kaolinitic, as is the case (Fig. 30, 31).

Related to this problem is a phenomenon that borrows its principle from the work of Griffin and Parrott (1964) on the St. Bernard delta of the Mississippi, where they determined when Mississippi or local clays were dominant by the different clay mineralogy. This variation showed whether local or distant clastic sources were important. Similarly, in some cases in the Missourian strata it is possible to determine when a particular area had clays entering from a distant source (kaolinitic) or local source (illitic, often partially weathered). Typically, this change takes place relatively early in the marine transgression, often considerably before the onset of black shale deposition. Presumably, this transition is due to the trapping of kaolinitic clays near the retreating shorelines by rising waters of the transgression. This upward change from nearshore to offshore clay suites consistently below the base of the black shale in both the Stark and Eudora not only strongly supports an offshore origin for these black shales but also is incompatible with any type of nearshore environment envisioned by Zangerl and Richardson (1963, 1975), Merrill (1975), or Merrill and Martin (1976).

Finally, the glaucony in the lower Winterset Limestone of northeastern Oklahoma and southeastern Kansas indicates that deposition in that area was dominated by active, frequently erosive forces, which permitted little deposition. The interpretation is partially based

on the formation of glaucony only in environments with little or no net deposition.

## Micas

Mica flakes are very abundant in Missourian sediments of the Midcontinent and the Illinois Basin, especially in the sandstones, siltstones, and sandy shales, although they are often common in sandy limestones and some other shales as well. The bulk of the mica flakes are muscovite, although biotite and chlorite are also common (Wenberg, 1941; Clark, 1950; Siever, 1957; Verhulst, 1970).

The significance of the mica has been subject to varying interpretations. El-Zouki (1971) considered the muscovite to be an alteration product of the clays present. Stobbe (1971) stated that it was authigenic because the particles were elongate and excellently cleaved. Kotrous (1978) followed this interpretation, stating that the muscovite in a Virgilian red shale was diagenetic.

This concept has some merit. Muscovite and chlorite are common sedimentary minerals and may form authigenetically; biotite may also (rarely) do so (Beall, 1962). Roeschmann (1971) stated that muscovite may form in underclays during diagenesis.

However, some thought favors a detrital source for the micas (e.g., Verhulst, 1970). The micas are usually found in coarser, proximal sediments, although hydrodynamic considerations could permit their presence in finer-grained material. The major objection to a secondary origin is that diagenetic conditions are unlikely to produce several different micas, particularly with one or more clay minerals.

The common co-occurrences of several micas with several clays is highly unlikely thermodynamically, and is not likely to be an equilibrium assemblage.

Table 5

Correlation of muscovite and kaolinite in the studied samples

| | Muscovite | No Muscovite | Total |
|---|---|---|---|
| Kaolinite | 116 | 59 | 175 |
| No Kaolinite | 19 | 195 | 214 |
| Total | 135 | 254 | 389 |
| | $\chi^2$=140.18 | | |

A major contribution to this argument is the co-occurrence of muscovite and kaolinite. Pearson (1979) stated that kaolinite and muscovite in British coal measures were inversely proportional to each other, which he attributed to size separation during deposition. This is not the case here, as kaolinite and muscovite are strongly correlated, using a chi-square statistical test (Table 5). Kaolinite and muscovite are found together in 116 of 389 samples; if they were independent, they should occur together in only 61 samples.

Kaolinite can also form diagenetically, but not when muscovite is forming. It is possible that the minerals did form diagenetically, with the interstitial solutions undergoing significant shifts in

chemistry. However, the co-occurrence of these minerals in clastic sediments, in marine environments where kaolinite cannot form, together with several other micas and clays, suggests strongly that they are indeed detrital in origin. When the alternatives are wide-scale fluctuation of interstitial solutions, or simple erosion and deposition of different clays and micas, the latter interpretation is favored, as it agrees with the sedimentological features of the rocks.

This interpretation is significant, as Mathews and Shepard (1962) concluded that detrital micas (especially muscovite) were river-mouth indicators; they noted that large rivers (such as the Mississippi and Orinoco) carry detrital micas and plant fragments. Nearshore they are diluted by other sediments, but offshore they mark prodeltaic sediments. This interpretation is notably consistent with other features of the Missourian sediments studied.

## Pyrite

Pyrite is very common in the Missourian sediments studied, especially in the middle limestones and adjacent shales. Toomey (1964) noted that the Leavenworth (a Virgilian middle limestone) was dark because of pyrite, rather than organics. The Canville also is typically dark, although its color may be from both organics and pyrite, as they are usually both abundantly present. Where the middle limestone is missing, the shelly, coaly shale present is typically very pyritic, often with the fauna heavily pyritized.

Berner (1970, 1971) noted that three variables control pyrite formation, assuming a reducing environment: (1) organics for

sulfate-reducing bacteria to metabolize; (2) sulfate diffusing into the sediment; and (3) iron from reactive iron-rich minerals. All of these can be limiting factors.

Sulfate normally is derived from seawater, as fresh water generally has too little sulfate to form a significant amount of pyrite (Berner and others, 1979). Diffusion into the anoxic, organic-rich sediment is necessary, as simple burial of mud and reduction of the contained seawater will yield only 0.3% pyrite sulfur in the sediment (Berner, 1970). Rapid sedimentation and burial will cut off sulfate from the underlying sediment, causing an end to sulfate reduction and often to initiation of fermentation and siderite formation. Conversely, prolonged exposure of organic-rich sediments to seawater generally produces high sulfur values. Williams and Keith (1963) demonstrated a correlation between pyrite in coal and overlying marine roof beds, and Gluskoter and Hopkins (1970) showed that rapid deltaic deposition over coals prevented pyrite formation. They also noted that in some cases the stratigraphic equivalent to the deltaic wedges was a thin pyritized shell layer between the coal and the overlying black shale. Banaszak (1981) stated that enough sulfate is present in a 10-meter column of seawater to produce a 1.5% pyrite concentration in a 1-meter thick coal seam of equivalent area.

Berner (1970) stated that in terrigenous clastics iron-rich minerals are usually present to excess (compared to other limiting factors), but that lack of iron can be a limiting factor in carbonates.

Usually, iron is available from the reduction of hydroxides or detrital clays (Pearson, 1979; Banaszak, 1981).

The correlation between the amount of pyrite in a sediment and its organic content has been frequently noted (Strahl, 1958; Williams, 1978). Usually, the quantity of organic material is the limiting factor in pyrite formation (Berner, 1970, 1971; Williams, 1978). Thus, it is surprising that the fissile black core shales are relatively low in pyrite. Coveney (1979) reported that framboidal pyrite may constitute up to 7 percent of the rock, and S.P. Martin (oral presentation, North Central GSA, May, 1981) stated that pyrite was easily the most abundant sulfide present, but this is still anomalously low for shales that are often 30 or 40 percent organic material.

A number of possible variables can be considered. Lack of a suitable iron source is possible. Wedepohl (1971) suggested that open circulation into sapropelic sediments is actually quite rare, and that such sediments would be quite low in pyrite. Demaison and Moore (1980) noted that lack of bioturbation inhibits diffusion, which would in turn inhibit the sulfate-reducing bacteria. Kirkland and Evans (1981) noted that unsuitable organics may also limit the sulfate-reducing bacteria. They observed that the bacteria are actually very restricted in their requirements, and need other saprophytes to prepare the organics for them. Disruption of this chain (i.e., loss of one of the precursor saprophytes) could restrict the sulfate-reducers. Kirkland and Evans (1981) suggested that high-salinity bottom conditions could be one possible restriction. A high proportion of biologically inert organics (such as fusain) could also affect the results. Degens and Mopper

(1976) suggested that heavy metal complexing of the organics may also render them less susceptible to microbial attack. Thus, the problem is to decipher which mechanism is the cause of low pyrite values in the black shale. As yet, no answer is readily apparent.

Curtis (1980) provided a link between pyritic shales and a lack of calcareous benthos. He noted that in some cases pyritization increases bottom acidity, and observed that decalcified shells are common in black shales. He noted that when the zone of pyrite formation is open to circulation (as it must be to continue the process), $CO_2$ is lost to the water column, and this may promote dissolution of the carbonates. Horizons of such molds were observed near the black shales in a few cases in this study, but it was not possible to exclude recent weathering as a cause.

## Siderite

Siderite is common in many Pennsylvanian sediments of the Midcontinent and the Illinois Basin, and those studied were no exception. Siderite occurred both in spherical to flattened clay-ironstone nodules in the shales and as cement in some sandstones.

Siderite formation poses some problems in interpreting the depositional and diagenetic history of the enclosing rock. First, since it involves $Fe^{+2}$, the environment must be anoxic. Second, the $Fe^{+2}$ concentration must be greater than 5 percent that of $Ca^{+2}$ (Berner, 1971; Blatt et al., 1980); in seawater it rarely exceeds 0.1 percent that of $Ca^{+2}$ (Berner, 1971). Third, $CO_2$ levels must be well above seawater concentrations and above calcite saturation

(Curtis and Spears, 1968). Finally, virtually no sulfide may be present, as pyrite formation is strongly favored over siderite (Curtis and Spears, 1968; Berner, 1971). Given these parameters, siderite cannot form in contact with marine waters.

Thus, it was long thought that siderite indicated nonmarine conditions. Berner (1971) stated that siderite is common in nonmarine beds, especially in lakes and swamps. He believed that siderite in marine beds was due to uplift and freshwater flushing. Roeschmann (1971) noted siderite nodules forming in underclays, although not necessarily during soil formation.

However, co-occurrences of marine faunas and siderite are common. Westoll (1968) noted such co-occurrences in British Carboniferous strata, and compared them to similar richly fossiliferous, sideritic, nearshore marine shales of the Eotriassic of Madagascar. Similar co-occurrences are known in the Missourian of North America (Newell, 1933; Degens, et al., 1957; Donahue et al., 1972; Donahue and Rollins, 1974a; Lipp, 1975). Such an association was particularly pronounced in this study in the Eudora section at Copan, Oklahoma (Locality Cp1), where the siderite formed early enough to keep many of the molluscs and brachiopods from being crushed by compaction.

This apparent contradiction has been solved by recent work in diagenesis. Essentially, if a sediment accumulates rapidly enough in a marine environment, the sulfate in the sediment may not be replenished and may be used up before the organics are consumed. This permits initiation of siderite formation (Curtis et al., 1972; Coleman et al., 1979; Berner et al., 1979). If sufficient organics are left,

fermentation begins, producing $CO_2$ for carbonate formation and biogenic methane (Coleman et al., 1979). This would also help reduce any oxidized iron present, particularly that in hydroxides carried by clays (Carroll, 1958; Curtis et al., 1975). Siderite formed at this stage is usually rich in manganese, which is often associated with the soil-formed hydroxides on the clays. Vivianite, rhodochrosite, and organic matter may also be found in the sediments (Berner, 1981).

During later burial, geothermal heat may begin to break down organics (decarboxylation), which produces more $CO_2$ for siderite, as well as mature hydrocarbons. Siderite formed during this phase is poor in manganese and enriched in Mg and Ca (possibly due to breakdown of aragonite and high-Mg calcite), as well as much lighter in its $C^{13}$ ratio, as the $CO_2$ is formed inorganically, rather than organically (Curtis et al., 1972).

That at least some of the siderite present formed in this way rather than by freshwater flushing is shown by the occasional occurrence of pyrite at the core of some of the siderite nodules. This would indicate initial sulfate reduction from seawater, followed by siderite formation when the sulfate was exhausted. Such nodules were observed in the Vilas Shale near Altoona, Kansas (Fig. 35).

MacDonald and Byers (1981) stated that carbonate nodules can reflect the depositional environment. It is possible that siderite nodules may do so indirectly, reflecting different sedimentary conditions, with flattened or spherical shapes indicating lateral and vertical homogeneity.

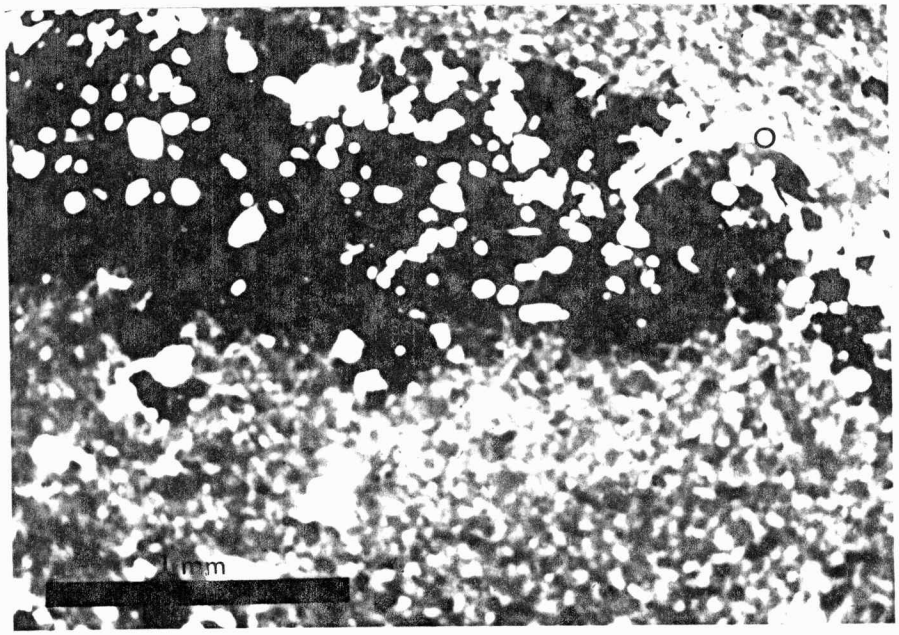



Figure 35. Thin section of siderite nodule from the Vilas Shale near Altoona, Kansas (Locality A11). Note the concentration of pyrite (opaque) in the sandy zone at the core of the nodule, surrounded by siderite (grey). Also note the ostracode (O). This shows the early formation of pyrite with the later formation of siderite when sulfate was no longer available.

Weeks (1957) cited unflattened siderite nodules around fossils as an example of early siderite formation. He cited a personal communication from A.C. Tester that the low Eh due to the decaying organism may help nodule formation. This concept was supported by Zangerl (1973), who noted that decomposition gases from the organism helped nucleate nodule formation. This may well apply at Copan, where fossils are frequently filled with and often enclosed by siderite.

Another possible control is horizontal permeability. Curtis and others (1972) cited this as a control in the formation of flattened siderite nodules. This may apply at such localities as Altoona, Kansas (Locality All), where the nodules are flattened along slightly shelly horizons in otherwise homogenous shale (Fig. 35). It may also explain the preferential cementing of sandstone layers by siderite, as in the Galesburg near Cherryvale, Kansas (Locality BC1) or the sandstone above the Macoupin at Charleston, Illinois (Locality Ch1). (Whether the siderite in the sandstones formed during initial burial or more recently is not known. Nesbitt (1980) indicated that in the Illinois Basin the solutions at depth are in equilibrium with siderite. However, it is not clear whether the waters equilibrated with pre-existing cement, or the cement precipitated from the waters.)

In the sediments studied, those that contain siderite apparently formed in regions of rapid burial. Early siderite formed around fossils, producing round nodules. Later, during compaction and dewatering, siderite formed preferentially along permeable horizons, producing flattened nodules. Siderite indicates that the sediment

produced biogenic methane, and that it may have produced mature hydrocarbons.

## Apatite

### Description

Apatite is a common mineral in the Pennsylvanian cyclothems. Although frequently referred to as "phosphate", this is somewhat misleading, as both monazite and vivianite are phosphates that may occur in the cyclothems (Finkelman et al., 1979; Berner, 1981). "Phosphorite" is not an applicable term, as it applies to a rock type that is rarely present. Most of the phosphate in the sediments here is francolite, a carbonate fluorapatite with some substitution of carbonate for phosphate. Although not verified by chemical tests, X-ray diffraction patterns were consistent with francolite.

The basic form of discrete apatite other than unequivocal fossils is small grains along partings in the black core shales, a form of apatite common in pre-Miocene phosphorites (Bentor, 1980). These are small spherical to irregular light grey particles, generally ranging from 0.1 to 0.5 mm in diameter. When freed from the shale matrix, they compose a poorly sorted sand. Often a small amount of calcium carbonate is associated with the particles, giving the horizons a distinct reaction to acid, in contrast to the organic-rich shale matrix, which does not react.

Generally, the apatite-rich laminae are quite thin, seldom more than one or two millimeters thick. However, they may be quite numerous, particularly near the contact between the fissile black and

upper grey transition in the core shale. A sample processed in this study (the Eudora at Louisville, Nebraska--Locality Lol) produced over 10% sand-sized apatite grains per unit of shale; Merrill and others (1978) reported that some black shales are up to 25% phosphate, and suggested that the fissility of the shale is due to these laminae.

These grains are probably equivalent to the "peloids" of francolite described by Soudry and Nathan (1980). Their peloids are structureless brown ovoid grains, in almost the same size range found here, and almost always associated with organic matter.

The most commonly noticed apatite form in the black shale is the nodules, which are usually spherical or discoidal and up to several centimeters in diameter. Generally, they also are commonest near the contact between the fissile black shale and the upper grey transition of the core shale (e.g., Crouch, 1971; Kidder, 1982).

In thin section and in some hand specimens, the nodules often display a microconglomeratic texture, appearing to be built of a framework of apatite peloids cemented by later generations of apatite as noted also by Hanson (1957), Knowles (1964), Cronoble and Mankin (1965), Evans (1966), and Kidder (1982) (Fig. 36). The interstices among the peloids may be filled with calcite or glaucony as well as apatite (Hanson, 1957; Cronoble and Mankin, 1965). Pyrite, sphalerite, and chalcopyrite may occur disseminated in the nodules (Schenk, 1967; Cassidy, 1968; Martin and Coveney, 1981); Malinky (1980) also reports sphalerite filling cracks in septarian-like apatite nodules. (Although Cassidy, 1968, reported finding kaolinite as the only clay in the nodules, this could be a result of dissolving

Figure 36. Apatite nodule structure

a. Thin section (plane light) of apatite nodule from the top of the Stark Shale, near Bartlesville, Oklahoma (Locality Bt2). Note the microgranular apatite structure in with overgrowth rims of secondary apatite. This apatite is in turn surrounded by fine-grained calcite (C) and quartz (Q). The entire structure is enclosed in more microgranular apatite.

b. Thin section (crossed nichols) showing an apatite nodule in the basal Winterset, near Coffeyville, Kansas (Locality Cf4). Note that the enclosing skeletal calcarenite has abundant quartz sand (white) which is absent from the apatite nodule (dark).

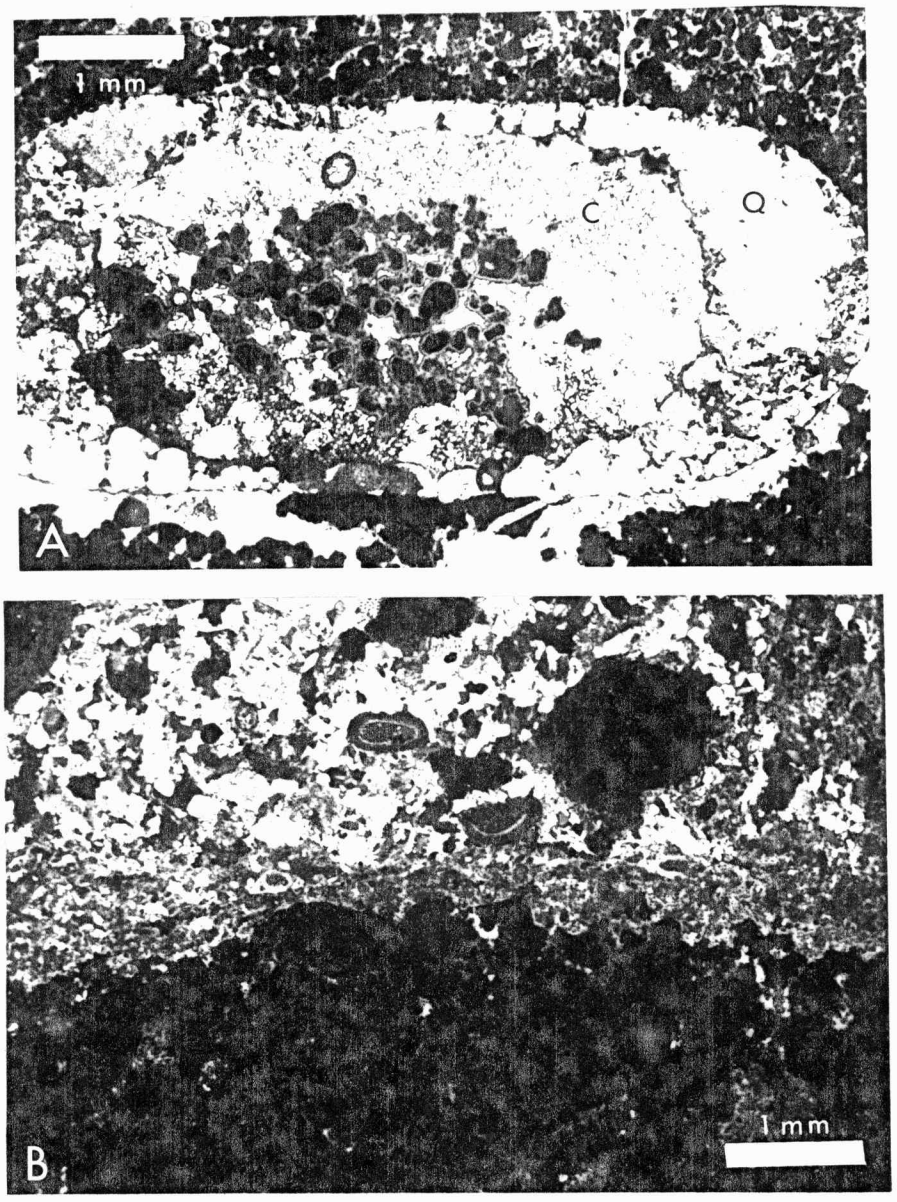



Figure 36.

them with acid to release the clays.) Evans (1966) stated that the nodules apparently grew by pushing aside the surrounding shale, and noted that some of the larger nodules have slickensided surfaces and an equatorial keel. He noted further that many of the larger nodules have a rind of increasing impurities, suggesting increasing difficulty of growth, which was also observed in some of the nodules studied here.

Uranium is frequently strongly associated with the apatite, both in nodules and in the peloidal laminae (McKelvey and Nelson, 1950; Runnels et al., 1953; Ponsford, 1955; Evans, 1966). This is not only because uranium is adsorbed to the enclosing organic material, but chiefly because it readily fits into the apatite lattice. As a consequence, the phosphatic black shales are usually remarkably "hot".

The relationship between nodule nucleation and organic material is not clear. Kenny (1968) stated that the nodules in the Eudora often nucleated on fossil fragments, and Schenk (1967) listed orbiculoids, fish teeth, phosphatized cephalopods, and wood as nuclei. In this study, phosphatic inarticulate brachiopods were occasionally found in nodules, but the valves were usually tangential to the circumference of the nodule. Whether the nodule grew preferentially from the inner curve of the brachiopod valve, just happened to intersect the brachiopod in that fashion, or was actively encrusted by the brachiopod is not known (Fig. 37c and d).

In some cases, non-nuclear fossils are known from the nodules. Berendsen and Nodine-Zeller (1978) noted that many nodules contain radiolarians and sponge spicules, with the opaline silica replaced by

Figure 37. Apatite nodule growth relationships
a. Nodule from the top of the Stark Shale at Cedar Bluff, near Coffeyville, Kansas (Locality CB1). Note the vague concentric growth pattern of the nodule.

b. Nodule from the top of the Stark Shale near Bartlesville, Oklahoma (Locality Bt2). Note the apparently bone-like structure in the center of the nodule.

c. Lingula on apatite nodule, from the top of the Stark Shale near Jingo, Kansas (Locality Ji1). Note the single valve, which conforms to the shape of the nodule. The nodule is visible (dark) where the shell has broken away.

d. Orbiculoidea on apatite nodule, from the top of the Eudora Shale, Malvern, Iowa (Locality Ma1). Note the irregular shape of the nodule.

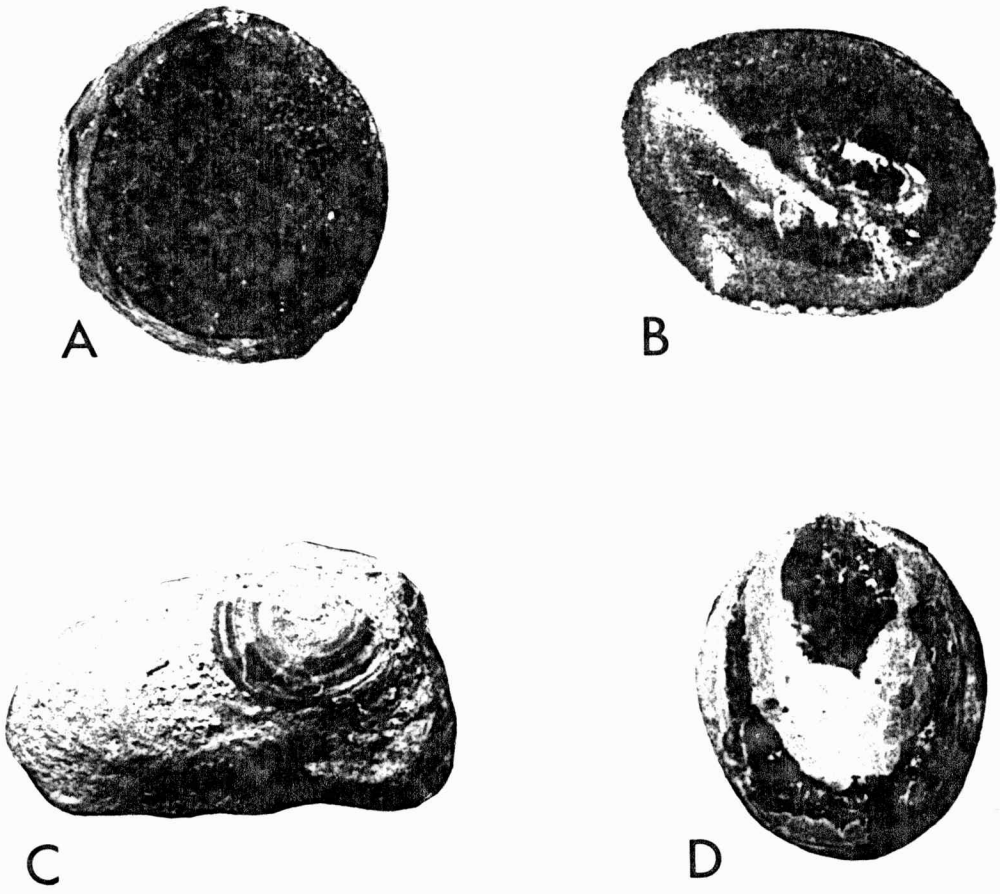



Figure 37.

apatite. Bromley (1967) stated that Cayeux (1950) also reported radiolarians in Dinantian phosphate nodules in Europe, and Deflandre (1952) described radiolarian faunas from Visean nodules. Kling and Reif (1969) reported a radiolarian-sponge assemblage from apatite nodules in the Upper Carboniferous strata of Uruguay. Kidder (1982) suggested that degraded radiolarians may have served as loci for peloid formation.

However, generally the phosphatic fauna of the black shales is little affected by the nodules. Schenk (1967) noted that the microfauna is the same within the nodules and without; Evans (1966) noted that the presence of well preserved conodonts and phosphatic inarticulates in the surrounding shale demonstrates that they were not the source of nodular apatite; likewise, they (especially the conodonts) rarely serve as nuclei and rarely have overgrowths.

At least some of the nodules were exposed for a time at the sediment-water interface. Malinky (1980) cited some nodules in the Eudora with encrusting agglutinated forams and an encrusting sponge; Merrill (1979) cited some that were bored, supposedly by barnacles.

Around Coffeyville, Kansas, and in large areas to the south, the basal Winterset contains apatite nodules where the underlying Stark is missing; these nodules are very similar to those found elsewhere in the upper Stark. In some cases, these nodules lack quartz sand, which is very common in the surrounding limestone; however, in others the later stages of apatite formation incorporated quartz and mica.

A similar situation exists in the basal Galesburg at Erie, Kansas (Locality Er1), where the sandy layers contain abundant apatite

peloids (weathered brown) along with sparse conodonts (including Gondolella). This horizon may represent the core shale of the Swope cyclothem or may be material reworked from it.

Phosphatized wood is occasionally reported from the fissile black shales, e.g., in the lower Bond Formation of Illinois (Gluskoter et al., 1970) and in the dark grey Eudora at Tyro, Kansas (Locality Ty1) (Malinky, 1980).

In addition to the Midcontinent, apatite nodules are known from many black shales in the Illinois Basin, where this study noted both peloids and nodules in the black shales below the Shoal Creek and Macoupin limestones. Merrill (1979) reported apatite nodules in the Appalachian Basin, and they are known from black shales in Britain (Knowles, 1954; Ponsford, 1955).

Apatite steinkerns of micromolluscs are discussed in the paleontology section. They usually consist of a very fine-grained homogenous infilling of the molluscs, sometimes including small shell fragments or fine terrigenous detritus. Presumably, these do not indicate the same type of large-scale environment as do the apatite nodules and granules. Small dead animals would have a different chemical microenvironment than the overall environment, and might maintain it for a significant time, especially if buried. Such carcasses could favor apatite precipitation, even while the general environment does not. However, the closer the general environment is to apatite precipitation, the easier it would be to make steinkerns. Notably, these steinkerns are often found in glauconitic carbonates, and some microgastropods are filled with glaucony (Hanson, 1957). Odin and

Letolle (1980) noted that the conditions for glaucony and apatite formation are quite similar, though not identical, and the two minerals often alternate.

In some cases, an unusual and little-noted form of apatite occurs outside the black shale, usually in the limestones. This is fine-grained, amorphous, apatite, often chalky in appearance. It is light grey in color, and indistinguishable from micrite. X-ray diffraction often indicates it is associated with silica, clays, or dolomite. It is apparently secondary in origin, as it is usually shapeless and irregular, and sometimes engulfs (without replacement) various fossil fragments. Among other localities, it was identified in the top of the Bethany Falls at Princeton, Missouri (Locality Pr1), the lower Stoner at Louisville, Nebraska (Locality Lo1), and the basal Winterset at Atlantic, Iowa (Locality At1). Unfortunately, there is no effective way to identify it, except by X-raying light grey masses left by acidization.

## Environmental Significance

The simple presence of apatite in substantial quantities in the core shale is not significant. Apatite is known in a large variety of environments, including coals (Cook, 1962; Finkelman et al., 1979). Cook (1962) stated that it apparently formed while the material was still peat. Deans (1938) reported it in a "freshwater" Carboniferous oölitic ironstone, and suggested that it might be present in the sideritic black-band ores of the cyclothems. However, these occurrences do not closely match the petrology and stratigraphy of the

apatite found in the Midcontinent core shales, and are not considered to be closely related.

The major problem with explaining the occurrence of apatite is how the $PO_4^{-3}$ ion in seawater becomes concentrated enough to precipitate. This could have occurred because of organic or inorganic processes. Kazakov (1937) first proposed that apatite could be precipitated inorganically in the oceans where cold, phosphate-rich deep water upwelled. Rising temperature and pH would cause apatite to precipitate at depths estimated from 50 to 200 meters (below that pH would be too low, while above that organic consumption would extract the phosphate). Furthermore, the phosphate could be enriched in bottom waters by the decay of organic matter. Phosphate is a limiting nutrient in the ocean, and in abundance it may produce rich organic production. Thus, areas of upwelling rich in inorganic phosphate also produce organic material rich in phosphate, and settling and decay of the organisms further enriches the bottom (Heckel, 1977). Moody and others (1981) cited settling carcasses as a principal phosphate source; Merrill and others (1978) cited "fin, flesh, and feces". Phosphate-rich feces are favored as possible nucleation sites for peloids (Bushinski, 1964; Cook, 1976; Soudry and Nathan, 1980). Due to this persistent association with organic material, phosphorites are often associated with black shales. In deep water, however, only stable organics (such as fusain) reach great depths (Bushinski, 1964); thus phosphate-rich unstable organics would be expected only in relatively shallow water.

Many additional local chemical factors may govern apatite precipitation. Eh is related in several ways. Veeh and others (1973) noted

that apatite nodules off Peru form at the upper and lower boundaries of the oxygen-minimum water mass (where most decay takes place) because apatite precipitation is favored by fluctuating near-zero Eh conditions. This corresponds well to the occurrence of nodules in the core shales at the boundary of the anoxic, strongly reducing black facies, rather than within it. Goldberg and Parker (1960) argued conditions around decaying organics could be critical, e.g., a slight reduction in pH (rather than an anticipated increase) might lower the activity of $CO_3^{-2}$ sufficiently to favor apatite precipitation while limiting $CaCO_3$ formation. Cook (1976) provided a supporting argument: while noting that pH is a control of $PO_4^{-3}$, he noted that alkalinity (a measure of activity of weak acids such as $HCO_3^-$, $CO_3^{-2}$, $OH^-$, and others) is perhaps a more direct and important control, and that their activities are closely tied to the organic matter present.

The activity of $Mg^{+2}$ is also an important control. Martens and Harriss (1970) noted that in seawater, magnesium poisoning of apatite crystals permits only amorphous calcium phosphate to form. With the removal of magnesium from the environment, calcium phosphate quickly crystallizes into apatite. Burnett (1977) believed that formation of Mg-rich clays and/or dolomite permits a favorable interstitial environment for apatite precipitation, and noted that every apatite-rich sample examined off Peru contained at least small amounts of chlorite, sepiolite, or dolomite. Bentor (1980) added that adsorption onto opaline silica is another possible $Mg^{+2}$ sink. However, Cook (1976) cited some modern interstitial phosphate precipitation as soft peloids and nodules of gel-like calcium phosphate; presumably, these could

diagenetically invert to apatite whenever the magnesium was removed from the system.

There are apparently several ways that apatite can form in relation to the sediment. In some cases, apatite could precipitate directly from seawater, producing apatite crusts and hardgrounds (e.g., Bromley, 1967; Soudry and Nathan, 1980; Sheldon, 1980). Ames (1959) stated that this is usually difficult, as phosphate cannot become sufficiently concentrated if calcite is stable, although apatite often replaced calcite under these conditions. This does not seem applicable here, as such crusts and hardgrounds are unknown in the black shales.

Ames' (1959) proposal that apatite nodules form by replacement of pre-existing calcite was cited by Cronoble and Mankin (1965) to explain the apatite nodules in the basal Winterset in northeastern Oklahoma. Ames noted that phosphate replaced carbonate in calcite at much lower concentrations of $Ca^{+2}$ and $PO_4^{-3}$ than are required for direct apatite precipitation, and also that fine-grained calcite was more readily replaced than coarser material.

Although such a mechanism may explain the apparently secondary masses of apatite found in the limestones, it does not explain the formation of apatite in the core shales, as many nodules lack calcite, and the calcite that is present may be secondary (Kidder, 1982). The peloidal structure of some nodules, with multiple generations of apatite growth, is more easily explained by direct precipitation of apatite.

Marlowe (1971) suggested that phosphatization of a carbonate may free $Mg^{+2}$ to produce dolomite elsewhere. He found dolomite where

phosphatization had taken place in rocks rich in high-Mg calcite, but where phosphatization had occurred in low-Mg calcite rocks, dolomite was absent. If this process had operated during apatite formation in the core shales, it would provide a possible explanation for the dolomite often found at the base of the upper limestone.

A large body of opinion favors direct precipitation of apatite in an interstitial environment, with the necessary high levels of $PO_4^{-3}$ provided by organic decay (d'Anglejan, 1967; Cook, 1976; Burnett, 1977; Kolodny, 1978, 1980; Soudry and Nathan, 1980). Burnett (1977) noted that such an environment could also limit $Mg^{+2}$ activity and provide suitable nucleation sites, as well as permit concentration of phosphate.

This process gives rise to features much like those found in the core shales. Burnett (1977) and Kolodny (1980) stated that it produces first-stage apatite granules that occur as somewhat discrete levels of peloids formed in place; these could be analogous to the laminae in the black shales. Soudry and Nathan (1980) listed several possible origins for the granules: (1) from fecal pellets, (2) from ripped-up apatite mud and laminated crusts, (3) from aggregates, (4) from phosphomicritization of bone, and (5) around grains. In the modern environments and in core shales, more than one mechanism may work.

Apatite formation requires changing conditions, from an anoxic environment to a more energetic, possibly oxygenated one. Veeh and others (1973) and Bentor (1980) stated that apatite precipitation takes place most readily at the upper and lower boundaries of the

oxygen-minimum layer where the Eh is not too low. This corresponds well to the usual stratigraphic position of the nodules at the transition from the anoxic black facies to the transitional grey facies. The direction of the change required would also explain why apatite nodules are rarely developed at the lower transition from grey facies to black facies where the Eh declined.

Reworking to form nodules is a commonly supported concept. Burnett and others (1982) observed that modern apatite nodules grow at a rate several orders of magnitude slower than the local rate of sediment accumulation, and in an undisturbed state form flattened, downward-growing masses. Kolodny (1978, 1980) noted that $U^{+4}/U^{+6}$ patterns in nodules indicate an initial anoxic environment overprinted by an oxygenated environment of reworking. The frequent association of apatite nodules with sandy or pebbly cross-bedded deposits (Bushinski, 1964) and the microconglomeratic or aggregate texture of the nodules in both modern and ancient examples (Knowles, 1964; Burnett, 1977; Soudry and Nathan, 1980; Kolodny, 1980) support this concept. In at least some of the sediments studied here, this is clearly the case. The apatite nodules in the base of the Winterset are clearly reworked, occurring in arenaceous fossiliferous limestone. However, the nodules often lack the angular quartz and mica abundant in the surrounding rock, indicating that they formed under different conditions. They also generally display a well-developed aggregate texture. In the Winterset in particular and in the Middle and Upper Pennsylvanian of the Midcontinent in general, the best development of apatite nodules generally coincides with shelf edges and topographic

highs (such as the Bourbon Arch). This may be due to either locally more intense currents (to aid in reworking) or more extensive interaction with fluctuating oxygen levels. Kidder (1982) presented several possible arguments for poorer development of nodules toward the north: (1) a decrease in available phosphate, (2) decreased or less regular upwelling, and/or (3) variations in sedimentation rates and the dilution of apatite. However, some shales (especially the Eudora) do not appear to be less phosphatic to the north, but only to contain fewer nodules. The form, but not the proportion, of the phosphate varies; this would argue for a change in post-depositional conditions (such as reworking) rather than pre-depositional conditions.

It should be noted that upwelling with quasi-estuarine circulation may not be the only way to produce a phosphatic marine black shale. Pevear (1966) noted that estuarine circulation could also produce sufficient phosphate enrichment for apatite formation, although detrital dilution would inhibit formation of discrete apatite in most estuaries. However, transgressing seas might trap the clastics in the rivers, while permitting the phosphate to concentrate seaward and produce unmasked apatite. This might also occur if the rivers carried mostly dissolved solids and little clastic material.

Henderson and others (1979) provided another mechanism, noting that brines can hold a much higher amount of phosphate than normal seawater; seawater concentrated to a tenth of its original volume can hold a hundred times as much phosphate. When such a brine is diluted, phosphate may be precipitated in large amounts. If a portion of the Midcontinent seas was an evaporative environment, phosphate-charged

brines could form and mix with less saline waters from elsewhere in the basin, producing apatite.

Kidder (1982) presented an argument limiting possible depositional environments for the Upper Pennsylvanian apatite. He noted that the evidence of both the sedimentology of Missourian core shales and possible modern analogs supported slow deposition and formation. This is inconsistent with the rapid deposition required in Zangerl and Richardson's (1963) model for black shales.

## Organic Material

The quantity and nature of the organic material in the fissile black core shales is of major interest, both economically and depositionally. The shales often contain 30 to 40 percent organic carbon (Evans, 1966); Merrill and others (1978) stated that they may reach 50 percent carbon (by volume), and argued that they should be considered coals. However, most consist largely of terrigenous clastic particles, and are true shales.

The shales yield small quantities of oil upon destructive distillation; several to 10 or 15 gallons per ton is the usual value reported for the shales under study (Bloesch, 1930, citing pers. comm. from R.H. Dott; Runnells et al., 1952; Lamar et al., 1956). Thus, the shales may be considered low-grade oil shales; here, they are simply called black shales, both because of their marginal economic importance and doubt surrounding their origins.

A major question is the origin of the organic material. It has long been noted that a major component is apparently land-derived

humic material, which is an unfavorable source for hydrocarbons. Twenhofel (1915) observed that Kansas black shales are poor in hydrogen, and stated that they contain principally non-marine material. More recently, Hatch and Leventhal (1981) elaborated upon this, stating that Cherokee (Desmoinesian) black shales were dominated by either humic organics or reworked oxidized material. However, it may be that the humic component of black shales diminishes in younger cyclothems. Applying Swanson's (1960) graph of uranium content versus humic and/or sapropelic material to Evans' (1966) data on the Eudora and Heebner black shales, the Eudora plots at approximately 75% sapropelic organics (Fig. 38), and the Virgilian Heebner plots close to 90%. (Although this is a simplistic model, it is useful as a first approximation.) This pattern is not surprising, as with the demise of the huge Desmoinesian coal swamps, humic material flushed into the epeiric seas would have become markedly less abundant.

Although a high humic content would appear to place severe constraints on the environment of the black shale, land-derived organics can reach the open ocean in a number of ways, often in considerable quantity. Godwin (1934) noted that peat ("moorlog") forms the bottom of large areas of the North Sea; it was submerged by transgressing seas at the end of the Pleistocene, without being overlain by strandline or shallow marine sediments. Tietjen (1971) reported large areas off North Carolina at depths of 800 to 1500 meters where the Western Boundary Current has accumulated organic muds with a large component of salt marsh grass, insect remains, and Thalassia. Demaison and Moore (1980) noted that the Arctic Ocean north of the USSR is accumulating

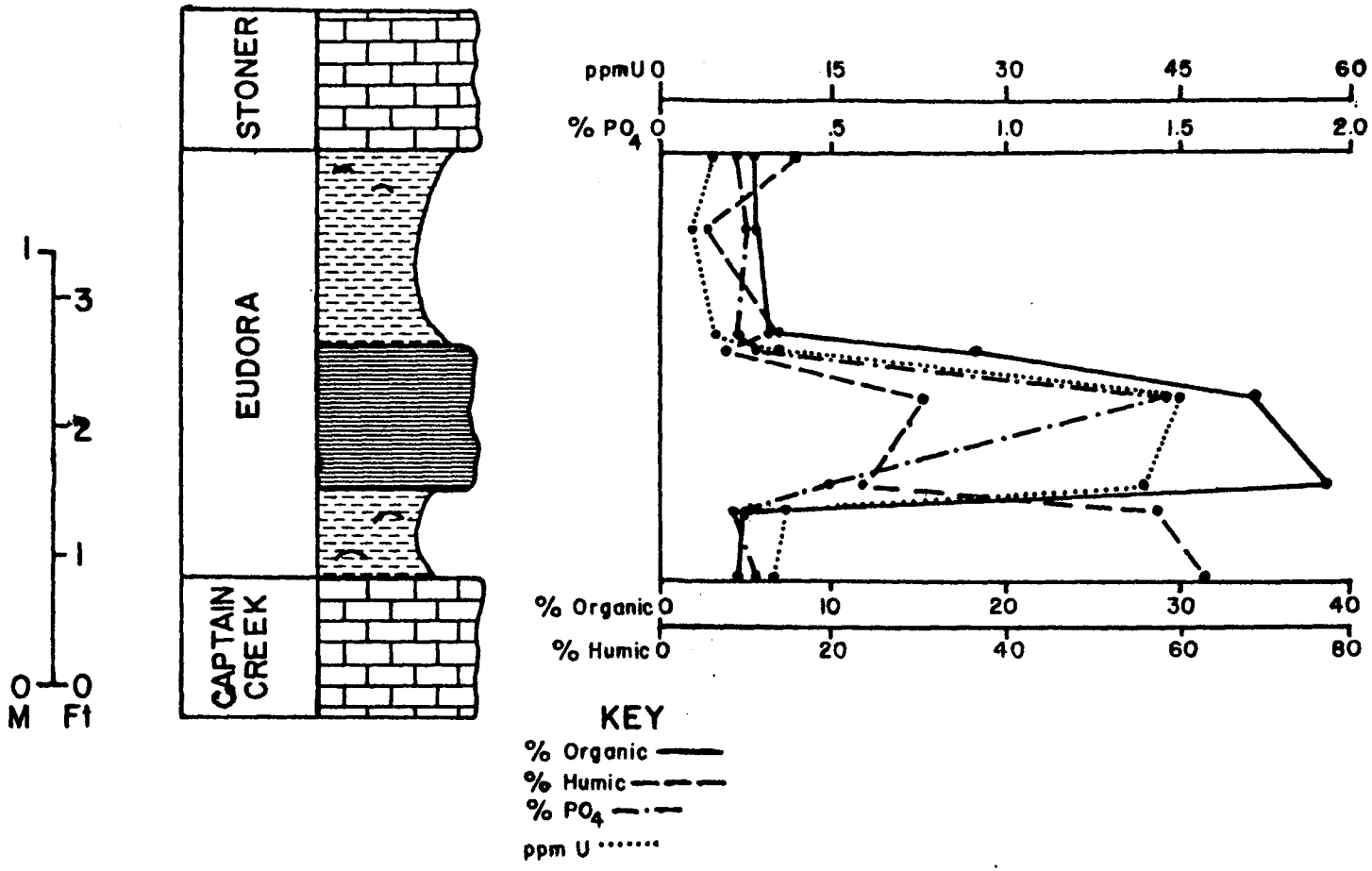



Figure 38. Core shale chemistry, Eudora Shale near Winterset, Iowa (Locality Wi2). Data from Evans (1966)

large quantities of river-borne organic detritus. Berner (1981) noted that carbonized wood is refractory, and can persist in oxic environments. Summerhayes (1981) elaborated upon this, stating that fusain and structured terrestrial organics are more resistant to oxidation than are marine organics, and are proportionally more common in more oxidized environments. Such terrestrial organics may be transported as airborne charcoal from forest fires, or, more importantly, as suspended material in the near-bottom nepheloid layer. Demaison and Moore (1980) also included reworked organics with such material, but they concluded that in marine sediments, "...organic carbon contents rarely exceed 3% when transported humic material of terrestrial origin is predominant" (p. 1187). (As this imposes rate on uniformitarian principal, it is suspect as a generalization, but may be useful as a starting point.)

As well as being found in modern oceans, open marine black shales with high terrigenous organic contents are known from the past, e.g., the Cretaceous black shales in the North Atlantic (Demaison and Moore, 1980; Summerhayes, 1981). Thus, it is not surprising that an epeiric sea fringed with coal swamps may contain organic sediments composed largely of terrestrially-derived material.

Several other factors affect the accumulation of organic material, including Eh of the environment, rate of deposition, and bioturbation of the bottom. As noted above, some terrestrial organics are resistant to oxidation, and can accumulate in sufficient quantity to produce a black shale under oxygenated bottom conditions. However, anoxic conditions markedly enhance preservation of organics,

especially the amorphous marine types. Summerhayes (1981) noted that although in such environments the total amount of terrestrial organics may increase, it decreases as a percentage of the total organic content. Müller and Suess (1979) noted that the permanently anoxic Black Sea has a rate of organic accumulation 5 or 6 times greater than periodically anoxic ocean areas (such as the Baltic or offshore Peru), but they suggested that an increased terrestrial component may explain part of this. Evans (1966) attributed the variation in the Heebner to a similar process: increasing oxygenation decreased the total organic content, but decreased the sapropelic component more quickly. (Curiously, he observed this trend areally, with a decrease in organics toward the south, but only once did he note a similar vertical pattern in a section.)

Müller and Suess (1979) noted that in an open, oxygenated ocean, the percent of organic material preserved depends on the rate of sedimentation and organic productivity. They stated that with all else equal, the percentage of organic carbon doubles for every ten-fold increase in sedimentation. (They noted that the seasonally anoxic areas of offshore Peru and the Baltic conformed to this generalization.) Coleman and others (1979) noted that rate of burial was also important; with greater accumulation, the organics were more rapidly removed from the realm of biologic degradation (including sulfate reduction and fermentation).

However, stratigraphic and sedimentologic considerations make it unlikely that the Missourian black shales are rich in organics (and poor in pyrite) because of rapid deposition. It appears more likely

that they were deposited in an effectively starved basin, with minor clastic influx. Curiously, their description conforms to that which Kirkland and Evans applied to Pennsylvanian black shales of the Paradox Basin, where normally masked sedimentary sources may become important:

> Such materials may make up more than 50% of a meso-saline sediment and may include wind-blown clay, silt, and fine-grained sand; silica precipated by diatoms and radiolarians; calcium phosphate from fish, etc.
> Kirkland and Evans, 1981, pp. 188-189

The type of biologic bottom activity is an important consideration. Demaison and Moore (1980) observed that a lack of bioturbation will preserve organic materials (and limit pyrite formation). Hallam (1967) and Byers (1977) noted that unbioturbated organic sediments are usually laminated, indicating oxygen limitation of benthos. However, Hallam added that some black shales have benthos but no burrowers, as the water column is not always completely anoxic at the base.

Hallam (1967) elaborated upon some of his biological interpretations, stating that lagoonal black muds with circulation restricted by algae should have abundant shelly epibionts, and should lack laminae. However, he did not generally accept laminated black shales as deep water deposits because they usually lack transgressive sediments. He suggested instead that they represent stagnation in tropical waters due to poor circulation through the low-energy shoreline model of Keugelan and Krumbein (1949).

Byers (1977) suggested another possibility for the black shales of the Paradox Basin, where high salinities could limit infaunal

invertebrates either directly or indirectly, as dissolved oxygen decreases with increased salinity.

Although the overall significance of the organic-rich black shales will be discussed in the context of the depositional systems, it is noted here that the admixture of a significant component of terrestrial organics can be expected in a marine environment. Furthermore, this high content organic content in the sediment may be attributable to (1) a large component of refractory terrestrial organics, (2) rapid sedimentation, or (3) anoxic bottom conditions. The first may apply in some cases, but the very high organic content, the production of some distillable hydrocarbons, and the interpretation of Evans' (1966) data indicate that sapropelic material is important. Rapid sedimentation is not justifiable on stratigraphic and petrographic grounds; the black shales are thin, and display only limited wedging over great areas. The very fine laminae also require a great deal of time, as fluctuating deposition of very fine sediments requires a long interval of change to produce discrete layers. Anoxic bottom conditions (at least within the sediment) in conjunction with long-term stability over a large area appear most likely to preserve a larger fraction of the dead organisms that would have rained down upon the bottom, ultimately to produce thin, finely laminated, widespread black shales.

## Trace Metals

### General Mechanisms of Enrichment

Trace metal distribution can provide valuable information on the depositional environment and diagenetic history of sedimentary rocks.

The sediments studied are no exception. The fissile black core shales contain anomalous concentrations of many metals, while the adjacent sediments contain others.

The black shales are enriched in Ag, Cd, Cr, Cu, Mo, Ni, Pb, V, U, and Zn (Heckel, 1977; Coveney, 1981). The uranium especially has attracted attention, since the black shales are often quite radioactive. This is true not only in Kansas (Swanson, 1960) and Illinois Ostrom et al., 1955), but also in the black shales in the British cyclothems (Ponsford, 1955; Knowles, 1964).

The distribution of uranium in the black shales provides useful information on the origin of the shales. Uranium can enter the sediments in three ways: (1) substituting in the apatite lattice, (2) tied to organics, and/or (3) adsorbing to clays (Angino, 1964). $U^{+4}$ substitution for $Ca^{+2}$ in apatite is very important in the black shales; apatite nodules and laminae in the black shales are usually sites of high radioactivity (Runnels et al., 1953; Knowles, 1964). Uranium is also proportional to organics in some cases (Payton and Thomas, 1958; Strahl, 1958; Evans, 1966). This feature helps to distinguish the black shales from coals. According to Swanson (1960) and Angino (1964), uranium fixes to humic organic material more readily than to organic material. However, coals are usually noted for their exceptionally low levels of radioactivity (McKelvey and Nelson, 1950; Breger and Deul, 1956); in fact, geophysical logging of coal is usually done by finding "cold" spots (Reeves, 1976). This is because coals usually form very rapidly in freshwater environments, allowing little time to collect uranium from a medium with low concentrations. Marine black

shales, particularly those that are slowly deposited and have a high admixture of land-derived humic organics, are particularly high in uranium. Evans (1966) disagreed, stating that uranium concentration is dependent on amount, but not type of organics.

Adams and Weaver (1958) noted that in slowly deposited marine black shales, there is usually a low Th/U ratio, as uranium is preferentially enriched by organics, whereas thorium is usually dependent on the siliciclastic component. They cited as an example of this relationship the Heebner Shale, the core shale of the Virgilian Oread cyclothem. Little is known about the significance of clay transport of uranium, although it is frequently cited (Adams and Weaver, 1958; Angino, 1964; Knowles, 1964).

The concentration mechanisms of the other trace elements are important, because without knowing their original concentration mechanism, the diagenetic remobilization (if any) is difficult to decipher. Krauskopf (1956) noted that adsorption must be a primary control of trace elements in the ocean, with apatite, hydroxide coatings, clay, and terrigenous organics all being effective at removing trace metals (especially Zn, Pb, and Cu) from seawater. Hydroxide coatings may be particularly important, as Patin and others (1978) noted that $Fe(OH)_3$ can concentrate many trace elements, and Gibbs (1976a) stated that this is one of the most important mechanisms for transporting mobile metals to the ocean. In a reducing environment, the hydroxides, usually $Fe(OH)_3$, would be broken down, releasing the metal ions to the pore water.

Organic reactions are frequently called upon for concentration of trace metals. Many organisms concentrate them biologically (Angino, 1964; Patin et al., 1978). Post-mortem reactions are also important; Gibbs (1976a) cited metal transport by solid organics as second to hydroxide coatings in importance. Watney and Lemish (1979) and S.P. Martin (oral presentation, North Central GSA, May, 1981) noted that many of the heavy metals were strongly correlated with organics. Elderfield and others (1981) noted that organics were probably the principal mechanism for delivering trace metals to the sediment in a modern anoxic environment. But Wedepohl (1971) stated that organics alone were insufficient to account for the concentration of metals in bituminous shales, and that additional processes were required.

Adsorption of trace metals onto clays is a possible transport mechanism; however, little work has been done either on the mechanism or on the correlation between clays and metal content. Gibbs (1976a) noted that for some metals (e.g., Cr, Cu) it may be significant.

Apatite also may be a significant sink for trace metals. Bentor (1980) noted that it may concentrate Mo, Pb, and Zn among other metals.

Many of the metals occur in the black shales as sulfides. Watney and Lemish (1979) noted that Co, Cu, Ni, Pb, and Zn covary with pyrite; some are discrete minerals, such as sphalerite (Coveney, 1981), while others are in solid solution in other sulfides. Luther and others (1980) cited a modern example in anoxic sediments, including sphalerite formation and Ni enrichment in pyrite. Significantly, Krauskopf (1956) noted that sulfide formation alone was insufficient as a direct

control on trace metal ions in seawater, although he stated that Cu, Pb, and Zn were possible exceptions.

It is important to note that direct precipitation may not be a primary control mechanism for trace metal distribution. Early diagenetic reactions involving the reduction of hydroxides, reaction of organics, and/or exchange reactions with the clays may serve to release metals into the sediments (Angino, 1964). Indeed, Elderfield and others (1981) thought that scavenging by sulfides of metals either diffusing into the sediment or transported by organics accounts for the base metal sulfides in their modern example. R.M. Coveney (written comm., 1981) agreed that diagenetic remobilization from clays and organic ligands may account for the present trace metal distribution in Missourian sediments.

Several minor variations on trace metal patterns should be noted. Gallium is generally preferentially enriched in freshwater shales (Degens et al., 1957); Cubitt (1979) noted that low gallium values in Upper Pennsylvanian shales (including outside shales) indicates they are of marine origin. Manganese is typically depleted in marine bituminous shales (Wedepohl, 1971).

Zangerl (1980) noted that the Mecca Quarry Shale contains exceptional levels of metal such as Co, Cr, Cu, Mo, Ni, and U. These were generally correlated with the organic-rich layers; the adjacent grey shales were lower in trace metals. Since he interpreted the black shale as brackish to freshwater in origin, he suggested that the water draining from the hinterland might have been rich in those

elements, whereas the marine waters of the basin were depleted in trace metals.

Hite (1974) mentioned another mechanism that might have enriched bottom waters and sediments in various metals. He noted that brines formed in near-evaporitic conditions could react with detrital silicates to mobilize Cr, Fe, Ni, and U. Long and Angino (1977) noted that a $Ca^{+2}$-rich brine, such as one close to gypsum precipitation, was particularly effective at releasing Pb and Zn from argillaceous sediments, while $K^{+}$ was effective at removing Cu. If descending brines were involved in water stratification in the Midcontinent, it would provide an additional and/or alternative mechanism for enriching the bottom sediments in trace metals.

## Sphalerite

Sphalerite is common in the residues of Upper Pennsylvanian sediments, occurring in 72 of 385 counted samples, or 18.7%. When statistically weighted to compensate for variable sampling of different units, it averaged 20% of the samples through the two cyclothems. It shows no geographic trend (Fig. 39). Stratigraphically, the sphalerite tends to occur in horizons close to the black core shale, and to be much less common in outside shales, stray limestones, and tops of upper limestones (Fig. 40). Toomey (1964) found sphalerite in 39.3% of the middle limestone samples he studied.

The sphalerite is usually idiomorphic with common cleavage and crystal faces. It is usually a pale resinous yellow, although colors ranging to dark brown are common, sometimes with zoning. In some

cases, it is zoned with pyrite; the pyrite rims a burrow or productid spine, with sphalerite filling the interior. Sphalerite usually replaces fossil fragments, particularly ramose bryozoans and the bases of productid spines. The base of the Winterset at Bedford, Iowa (Locality Bel), provides an extreme example. The sulfide present is almost entirely sphalerite, replacing ramose bryozoans; pyrite is rare. Calculations show the rock is 0.6% sphalerite by weight, or 0.4% zinc. Gastropods and ostracodes (especially geisinids) are also occasionally replaced by sphalerite; Toomey (1964) added that the foraminifer Hemigordius is another favored locus.

It is not known whether the control of sphalerite deposition is a calcite or organic structure that favors atom-by-atom replacement, or if the sphalerite is actually filling voids of those animals that are preferentially dissolved. Notably, the sphalerite shows no evidence of "ghost" structures, and Graffham (1946) reported it forming in large cavities possibly associated with bryozoans in the Spring Hill Limestone.

The sphalerite is occasionally associated with apatite. Martin and Coveney (1981) noted that most of the sphalerite in the black core shale is associated with the apatite nodules and laminae. Malinky (1980) noted that cracks in Eudora apatite nodules are sometimes filled with sphalerite.

Note that the low value of sphalerite listed for the core black shale (Fig. 40) does not reflect low content. Coveney (1979) reported values of Zn in both the Stark and Eudora shales of over 2,000 ppm; Martin and Coveney (1981) observed that sphalerite composed 0.2 to 5

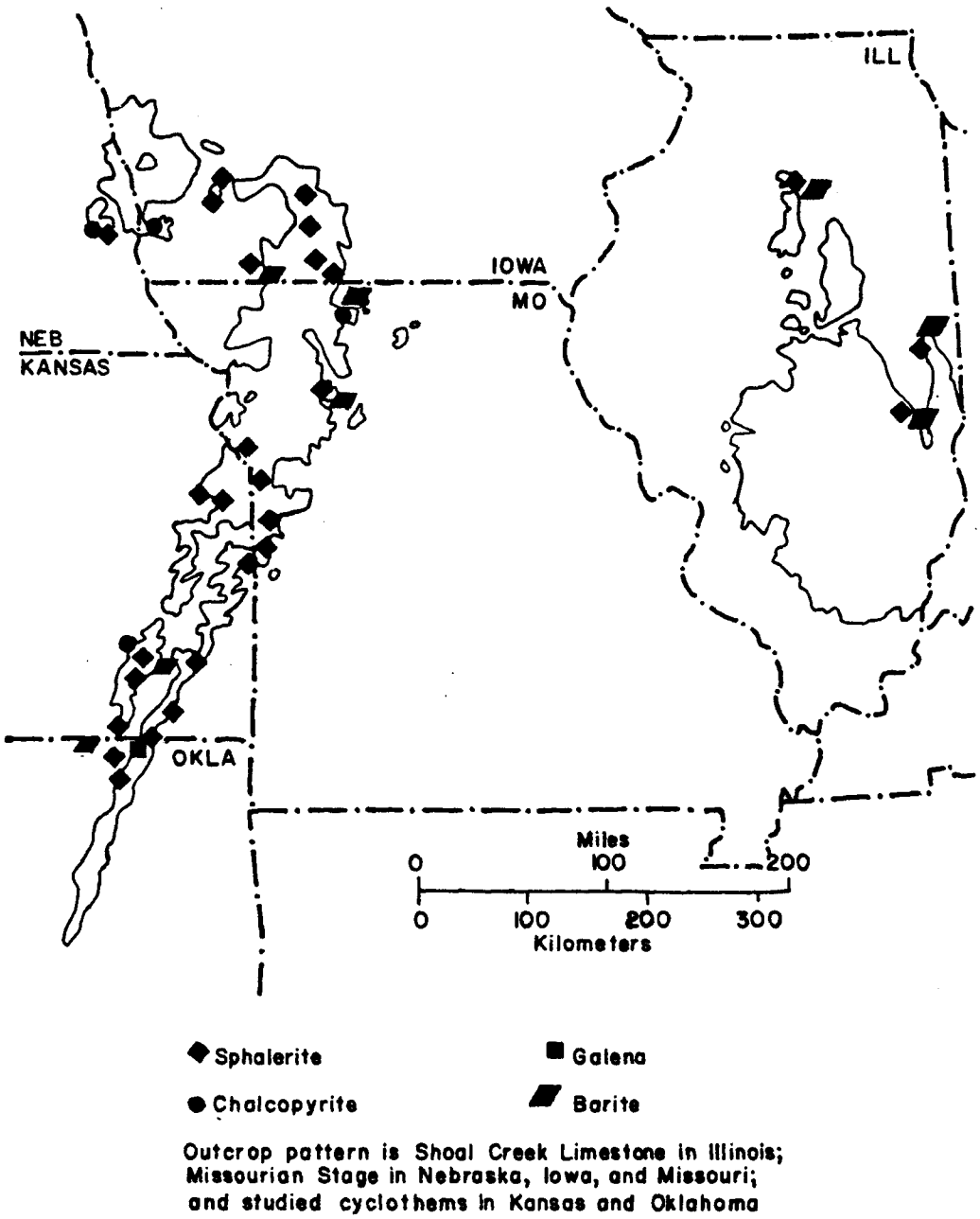



Figure 39. Occurrences of minor metal minerals in studied sediments.

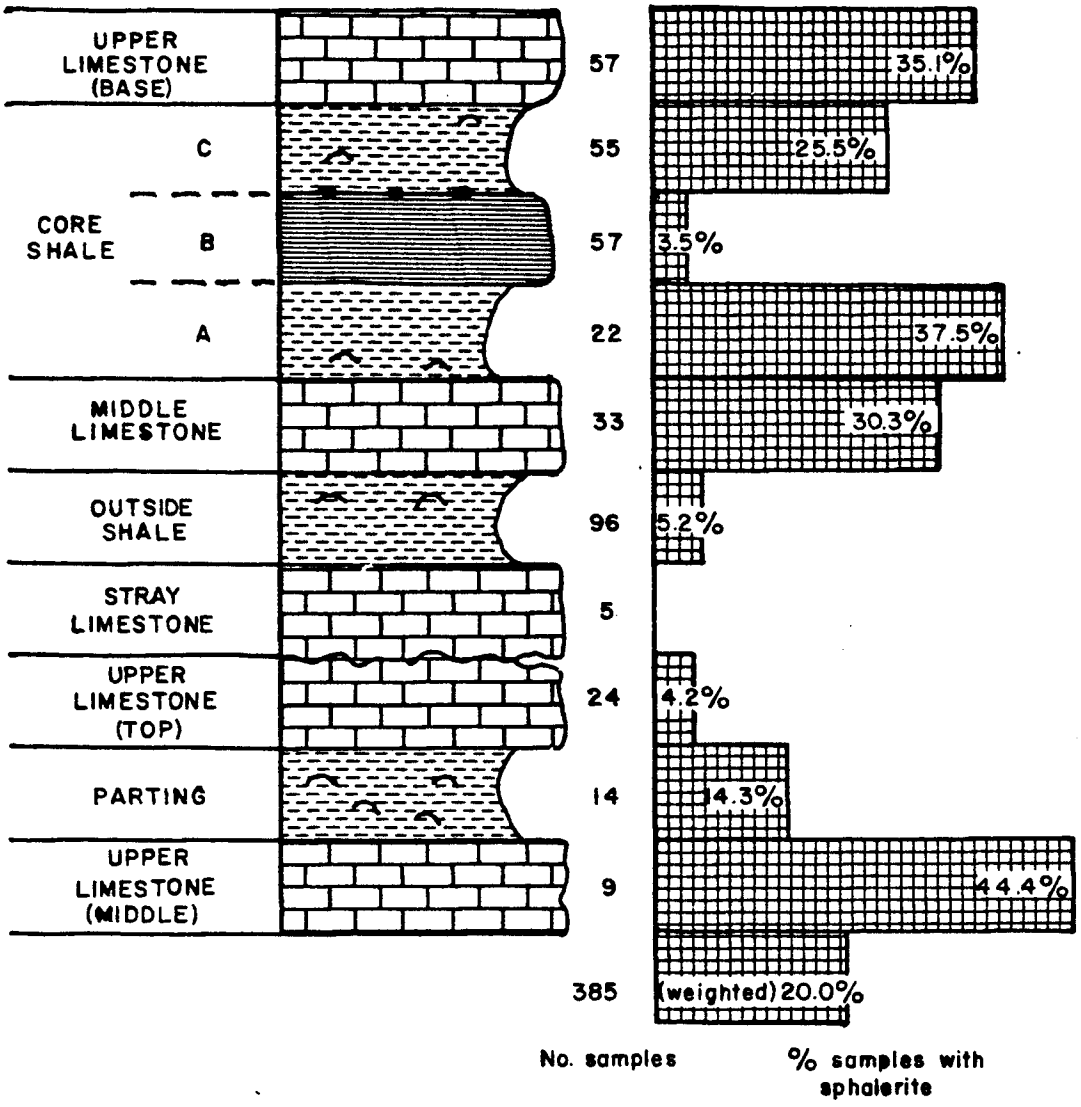



Figure 40. Stratigraphic distribution of sphalerite greater than 125 microns in the Dennis and Stanton cyclothems.

percent of the sulfides in the black shales, but in very fine euhedral crystals or replacing sponge spicules and rarely of a size large enough to be seen and recorded in this study.

The sphalerite is certainly diagenetic, but its ultimate source and timing of emplacement is much debated. Mossler (1970) thought that it was very early, before most of the carbonate diagenesis, but noted that it accompanied ferroan dolomite in fracture fillings in the upper mottled calcilutite of the Bethany Falls Limestone. Martin and Coveney (1981) associated it with late-stage calcite in the black shales. However, Pingitore (1978) stated that calcite crystallization during diagenesis is a Zn sink, which would work against sphalerite formation.

Toomey (1974) thought that the sphalerite was derived from solutions generated near the Ozark Dome; Leach (1979) thought that the Zn-bearing fluids were generated in the Ouachitas during metamorphism.

However, the zinc could also be associated with the sediments. Knight (1957) suggested that burial could cause remobilization and concentration of base metals in sediments. Luther and others (1980) observed sphalerite formation taking place in a modern, seasonally anoxic estuary. The lateral and vertical relationships here support diagenetic remobilization from the black shales, as the sphalerite is uniform areally throughout the Midcontinent and the Illinois Basin, suggesting that it is not associated with a local magmatic or regional metamorphic source. Vertically, it occurs closest to the black shales, which was noted by Mossler (1970) in the Bethany Falls as well as in this study (Fig. 40).

A series of fluid inclusion studies suggest the temperature of sphalerite emplacement was fairly high, about 60°C in eastern Nebraska and northeastern Kansas, and 70°C to 80°C in central Missouri (Coveney and Goebel, 1981). Roedder (1966) found indicated temperatures of 100° to 150°C in Zn-rich fluorite fluid inclusions in Illinois.

This distribution poses some interesting thermal problems. The area affected by sphalerite formation is large enough that there is little question the metal-bearing fluids must have been essentially equilibrated with the surrounding rock. Leach (1979) estimated that the geothermal gradient in the Midcontinent at the time was from 10°C to 30°C per kilometer; this would require the sediments in question to have been insulated by two to four kilometers of overburden, now stripped away, or to have a higher gradient. (The modern gradient according to Combs and Simmons', 1973, data is 10°C to 15°C per kilometer in Iowa and Illinois.)

Two possible explanations exist. One is that a thinner veneer of shale covered the sediments; Combs and Simmons (1973) measured gradients in shales as high as 70°C per kilometer. The other is that the temperature values are anomalous; R.M. Coveney (oral presentation, North Central GSA, May, 1981) noted the potential for hydrocarbons to distort the data. Gasses, especially methane, can be included in the fluid inclusions during formation; homogenization of such inclusions would produce anomalously high temperature values. The fluorite fluid inclusions studied by Roedder (1966) in Illinois commonly contained an oily, organic phase and methane, as well as yielding high temperatures of formation.

The possibility of this is supported by Hitchon (1981), who compared values of Zn, $CO_2$, and $H_2S$ in two sets of petroleums from the same region, and discovered that the older, more deeply buried petroleum and associated formation fluid was richer in all three, whereas the associated shale was poorer in Zn than its younger counterpart. Hitchon concluded that the mechanism responsible for releasing $CO_2$ and $H_2S$ also released Zn, with the breakdown of the organics providing a satisfactory mechanism.

Degens and others (1957) suggested a related mechanism for sphalerite in siderite nodules above a coal: the acids and gasses from the coal leached and redeposited the Zn upwards. Notably, their sphalerite was enriched in gallium.

Long and Angino (1977) provided an alternate mechanism, that of leaching by brines. Significantly, they observed that $Ca^{+2}$-rich brines were particularly effective at mobilizing Zn and Pb in shales. Thus, brines at or near gypsum precipitation could readily carry Zn and precipitate sphalerite. Roedder (1966) noted that fluid inclusions in Illinois fluorite contained up to 20% Ca and Na chlorides and were also up to 1% Zn. Davidson (1966) suggested that such brines might form during the early diagenesis of evaporites. However, equilibrium dynamics might permit such brines to form at surface conditions as well as through burial.

## Galena

Galena is far less common than sphalerite in the Upper Pennsylvanian sediments studied. However, the basal Winterset around

Coffeyville, Kansas, provided several examples of galena (Fig. 39), including ramose bryozoans replaced by galena. Galena may possibly have been present in the base of the Winterset at Bedford, Iowa (Locality Bel).

Virtually all the observations on the chemical behavior of zinc also apply to lead. Most of the processes that move and precipitate zinc do so with lead, as well. Notably, the brine-leaching model of Long and Angino (1977) will concentrate both Zn and Pb from the sediment by the same mechanism. Luther and others (1980) noted in their modern example a difference between the two metals: sphalerite is apparently a primary mineral in the sediment, whereas Pb remains attached to clays.

Martin and Coveney (1981) noted that Pb occurs as clausthalite (PbSe) as well as small galena crystals in the black shales. S. P. Martin (oral presentation, North Central GSA, May, 1981) stated that the pH and Eh conditions for clausthalite precipitation were less extreme than those required for galena, so that conditions for its formation were less abnormal.

Davidson (1966) provided another line of evidence that Pb distribution is often tied to sedimentary processes. He noted that stratabound lead deposits in Europe (such as the Permian Kupferschiefer, which is similar to the Missourian black shales) have radiometric ages consistent with the host strata.

## Chalcopyrite

Chalcopyrite was identified in residues by its marked yellow color, contrasting with the much darker, greener color of the co-occurring pyrite, although no diagnostic X-ray pattern was produced.

Chalcopyrite tends to occur in shales; the base of the Vilas at Louisville, Nebraska (Locality Lol) was relatively prolific in small aggregates, although they were not common. A few larger cyrstals were found at the top of the Bethany Falls at Princeton, Missouri (Locality Prl), while several less certain occurrences were found in the Malvern core in Iowa (Locality Mal) and at Tyro (Locality Tyl) and Buffalo (Locality WCL1) in Kansas (Fig. 39).

It is uncertain how much the geochemistry of copper differs from that of lead and zinc. Martin and Coveney (1981) noted the presence of chalcopyrite in the apatite nodules of the black shales, although it is less common than galena. Graffham (1946) reported chalcopyrite from vugs in the Spring Hill Limestone at Ottawa, Kansas. However, the distribution of chalcopyrite found here was different from that of galena and sphalerite. Cu can be concentrated by the same processes that concentrate Pb and Zn in the black shales, but it can also be concentrated by redbed processes, which may explain its presence in the outside shales. Long and Angino (1977) noted that Cu is mobilized more effectively by $K^{+}$-rich brines, rather than the $Ca^{+2}$-rich brines that mobilize Pb and Zn, although all the metals can be moved by either brine to some extent.

## Barite

Barite is a common minor mineral in Pennsylvanian sediments. Wenberg (1941) noted it with celestite in southwestern Iowa shales. Clark (1950) reported it as authigenic cement in Desmoinesian sandstones in Iowa, and Potter and Glass (1958) reported similar occurrences in Illinois. It has been reported in limestones in Illinois (Shrode, 1952), Kansas (Graffham, 1946), Missouri (Gentile, 1979), and Oklahoma (Cronoble and Mankin, 1965; Heckel and Cocke, 1969).

Barite was found in both shales and limestones scattered across the area of this study (Fig. 39). It occurs as pink laths, which may reach several centimeters in size, as well as glassy, crystalline masses (especially in limestones), occasionally replacing fossil fragments, and as white to grey amorphous masses.

The occurrence of barite is not very surprising, as Nesbitt (1980) noted that many formational fluids in the Illinois Basin were close to saturation in respect to barite, which has a very low solubility. He calculated that in a solution saturated with $Ca^{+2}$ (which would determine whether barite or gypsum precipitates), barite would precipitate if $Ba^{+2}$ values rose above 0.2 ppm.

Several sources for the required $Ba^{+2}$ are readily available. Turekian and Armstrong (1960) noted that the average modern mollusc is 10 ppm Ba, with older fossils higher. Liberation of the barium during aragonite inversion could easily provide the necessary ions for barite precipitation. Turekian and Armstrong also noted that

infaunal forms may be higher in barium, which could explain Gentile's (1979) observation of barite in pelecypod burrows.

$Ba^{+2}$ may also come from clay diagenesis, as Murray (1954) suggested that it could substitute for $K^{+}$ in illite, since it has a similar ionic size. Cubitt (1979) called upon this mechanism to explain the tendency of Ba to follow the distribution of illite and chlorite in Upper Pennsylvanian shales, rather than carbonates as he expected. Removal of the barium from the clays could be achieved by brine leaching, as suggested by Hite (1974) and Long and Angino (1977).

Revelle and Emery (1951) cited igneous brines as the Ba source for barite nodules on the sea floor off California, since they believed the solubility of barite could not be exceeded in seawater. Davidson (1966), however, noted that Ba is rare in igneous emanations, and concluded that it must come from brines associated with evaporite formation.

Barite can occur in marine sediments. In addition to the report of Revelle and Emery (1951), Wedepohl (1971) reported it in deep Pacific sediments, and Dean and Schreiber (1978) reported it in the Atlantic. Dean and Schreiber noted that Ba was higher in the sediments than in seawater, and suggested it was released by decaying organics. During hiatuses, it combined with sulfate which came from (1) upward diffusion from associated evaporites, (2) oxidation of pyrite, or (3) diffusion of seawater. Thus, barite formation was associated with low or non-deposition.

## Summary

A number of metals are concentrated in the reducing environment of the black shales, probably brought in by a number of transport and concentration mechanisms. Although the concentrations could be achieved by other mechanisms, the common occurrence of sphalerite and lesser amounts of galena in the strata next to the core shales can be explained by diagenetic release, either by breakdown of transporting hydroxides, organics, or clays and/or release of saturated fluids during compaction. Chalcopyrite may also be explained by such a mechanism, although other variations are possible.

Barite precipitation is not necessarily associated with the black shales, but may be dependent only on local minor concentrations of $Ba^{+2}$, which can be released by diagenesis of either clays or biogenic material.

Note that none of the reactions described depend on temperature or pressure, but relate largely to ionic concentration and/or time. There is no necessity to postulate significant burial and/or heating in order to explain the observed trace mineral occurrence and distribution.

# CHAPTER III

# PETROLOGY

## Soils

If the outside shales of the cyclothems include subaerial deposits, it is probable that they contained functional soils. This is undoubtedly the case below autochthonous coals and where rooted horizons are present, and probably also is true for texturally similar horizons elsewhere. Thus, it is reasonable to examine such soils for characteristics that would produce information of the nature of the weathering environment. However, two important variables must be considered: 1) Not all soils are alike, and as Missourian soils developed in different areas under different conditions, there probably are several different soil types present. 2) A mature soil is a near-equilibrium feature, and a paleosol preserves the last environment present, unless buried before it achieved equilibrium; thus, a paleosol does not necessarily represent the entire range of conditions present during a weathering episode.

### Physical Descriptions of Possible Soils

#### Galesburg Type

The commonest type of possible soil in the outside shales studied is that represented by the Galesburg Shale north of the Bourbon Arch,

and by two of the examined cyclothems in Illinois (the Fithian cyclothem at Fithian and the Shoal Creek cyclothem in the Charleston core). A typical example of the Galesburg type at Davis City, Iowa (Locality DC1), covers the entire interval between the Davis City Coal and the Bethany Falls Limestone. The Illinois subtype (without underlying limestone) is illustrated at Fithian, Illinois (Locality Ft1), where it extends down from the base of the Flannigan Coal to the nodular horizon just above the lower siltstone.

The outside shale in the Galesburg profile is actually a blocky mudstone, sometimes with low-angle intersecting slickensided surfaces near the base. It is usually grey, grey green, or yellowish grey in color. Pyrite aggregates are common, particularly near the top, which is usually overlain by either a banded coal or a coaly shale. In a few cases (e.g., at Princeton, Missouri, - Locality Pr1), probable pyritized roots are present. The mudstone is generally noncalcareous, although it may become somewhat calcareous toward its lower contact. Usually there's no evidence of a gradational upper contact, as marine invertebrates in the overlying shale and limestone make the overlying beds calcareous. Where the Galesburg overlies massive mottled calcilutite of the Bethany Falls, the top of the Bethany Falls is nodular and brecciated, with the particles of limestone becoming smaller upward, and sometimes badly discolored. The limestone is frequently penetrated by fine, branching calcite- or clay-filled tubules (e.g., Welp et al., 1957); occasionally larger holes up to several centimeters across are present, as well as possible solution pitting (Fig. 41). Where the Bethany Falls has an oölitic facies present at

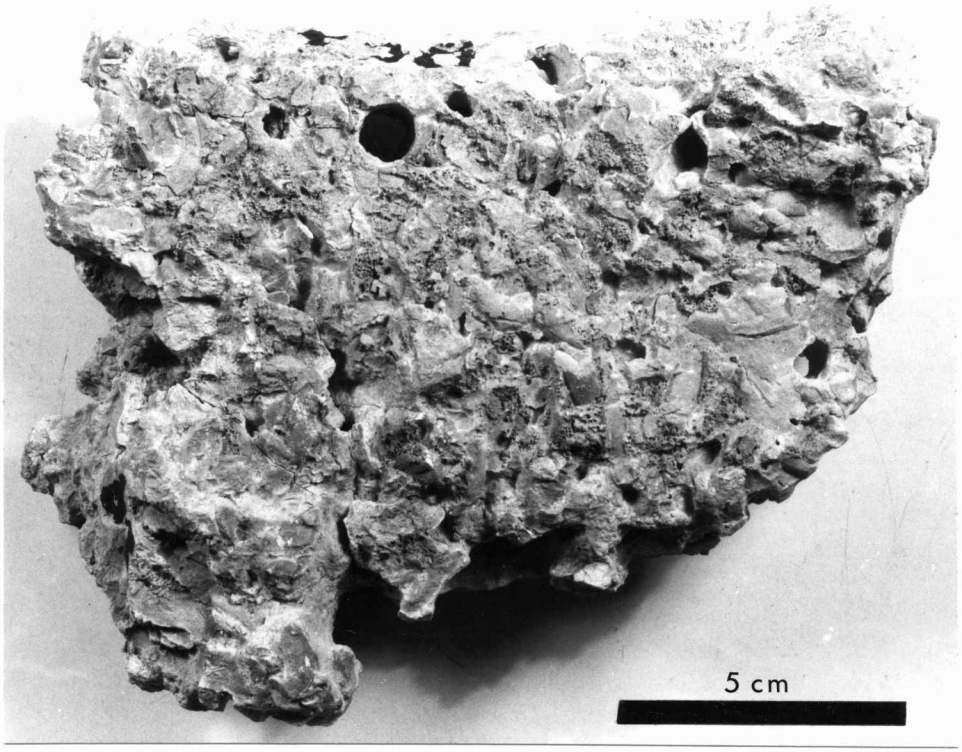



Figure 41. Upper surface of the Bethany Falls Limestone at Davis City, Iowa (Locality DC1) showing solution pitting and possible root holes. Thin section is shown on Fig. 42a.

the top, a thin layer of small angular oölite fragments may be present. The upper Bethany Falls is usually a calcilutite with restricted nearshore lithologies and faunas (Fig. 42).

In Illinois, where there is no underlying marine limestone, but only a considerable thickness of weakly fissile grey shale, the "underclay limestone" may be present. At the sections studied, this consisted of small ameboid nodules of dark-colored micrite. The nodules were often fractured, filled with branching microtubules, and with blocky calcite spar filling the voids.

At one Galesburg section (Unity Village, Missouri - Locality UV1), small septarian microconcretions are present. These are reddish brown rough spheres up to 5 mm in diameter. X-ray diffraction indicated that the spheres are largely manganoan calcite with the internal cracks filled with kaolinite.

The clay mineralogy in the Galesburg (which see) shows a downward increase in the crystallinity of the illite; upward toward the coal more and more randomly interstratified expandable layers are present. Chlorite is present to a limited degree, but kaolinite is only authigenic in the Forest City Basin.

This mudstone ranges in thickness from virtually nothing to about 6 feet, with an average of 3 feet. Neither sedimentary structures nor quartz sand were encountered in any of the sections examined; mica was rare.

Vilas Type

An example of the Vilas type of soil is in the quarry at Stanzel, Iowa (Locality St1) where it includes the interval from the top of the

Figure 42. Restricted marine facies of the upper Bethany Falls Limestone.

a. Calcilutite from Davis City, Iowa (Locality DC1), showing abundant unidentified microspheres, scattered ostracodes (O), and apparent root holes (R) with brown (organically-stained?) micrite. From the same horizon as the sample in Fig. 41. (Plane light.)

b. Calcilutite from Richfield, Nebraska (Locality Ri1a), made largely of mollusc fragments, ostracodes, and foraminifers. (Plane light.)

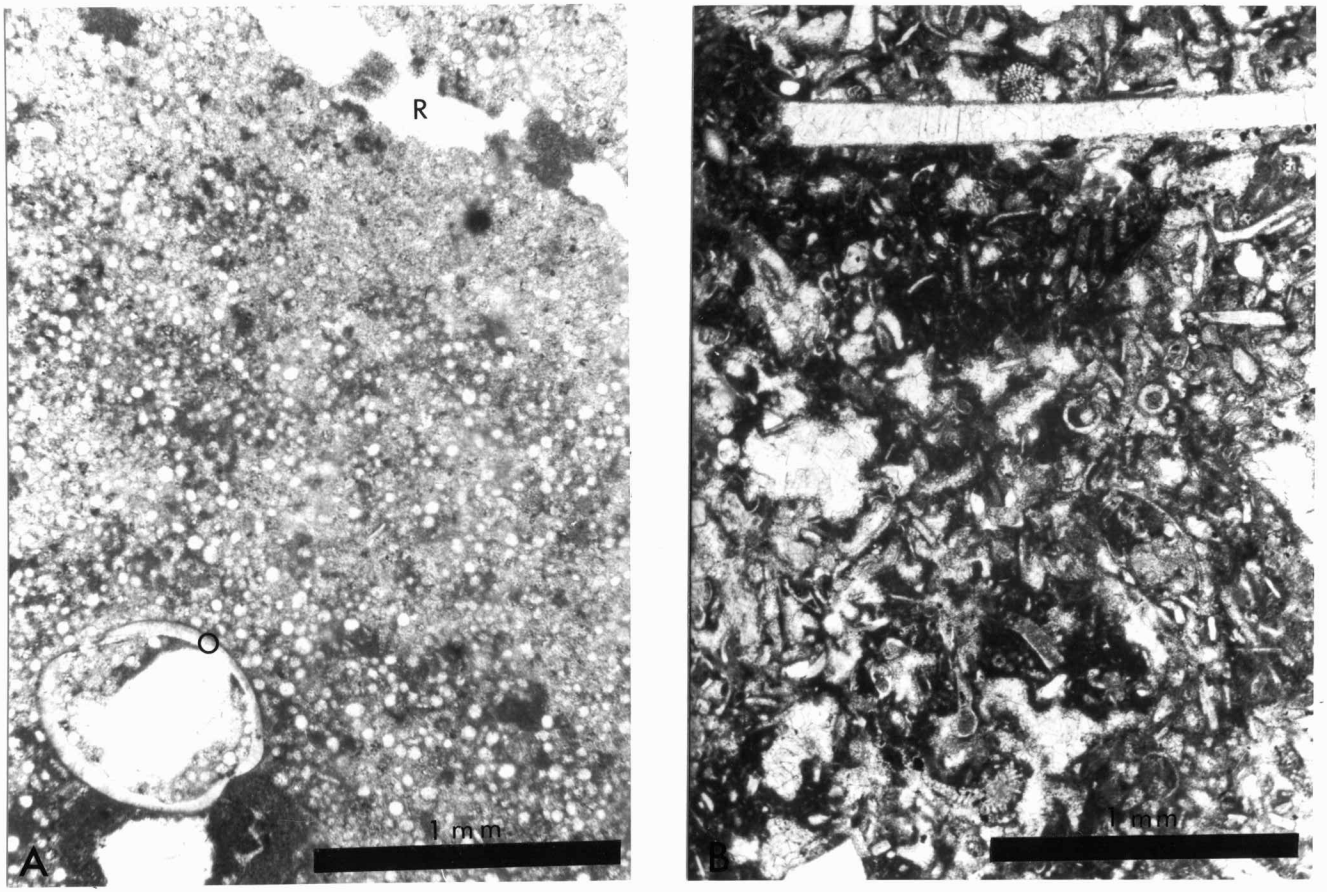



Figure 42.

Spring Hill Limestone to the base of the fossiliferous grey upper Vilas. The Vilas type is blocky and slickensided, as is the Galesburg type, but often includes reddish brown horizons, which are variably calcareous and often have small (2 to 3 mm) lumps of dark reddish brown calcite. The contact with the underlying skeletal calcilutite of the Spring Hill Limestone also is rubbly; occasionally more resistant fossil fragments weather free and are present without matrix in the mudstone. Caliche may be present on top of the Spring Hill. The reddish color penetrates down into and through the Plattsburg cyclothem, where the underlying Bonner Springs Shale also is reddish brown. Upwards, the Vilas is greenish grey, eventually grading into dark, coaly, fossiliferous shale.

Like the Galesburg, sedimentary structures and quartz sand are absent, and mica is rare. Fine grains of pyrite are disseminated in the grey green mudstone. The clay mineralogy, however, does not exhibit a distinct profile; the Vilas section at Stanzel, Iowa (Locality St1), is principally illite (including some random mixed layers) and chlorite and exhibits a rather high proportion of expandable clays, but this is not known to be characteristic.

The original colors of the Vilas mudstone are uncertain. Buol and others (1980) noted that goethite may diagenetically dehydrate to hematite, so it is possible that the red mudstone was originally yellow. The upper grey green portion may have been reduced later by the organic material deposited above; the gradational, mottled contact between the red and green mudstone together with the continuity of fabric support this. This is further supported at the outcrop at

Louisville, Nebraska (Locality Lol), where grey green slickensided Vilas overlies rubbly Spring Hill with reddish brown mottles, and the basal Vilas also contains a few dark reddish brown nodules. Johnson (1982) described a possibly analogous situation in Australia, where a redbed delta was submerged by the post-Pleistocene sea level rise. On the top of the delta, marine organics worked into the mud, reduced the iron, and turned the mud green. The relationship of colors, textures, and fossils in the sediment in the Vilas at Stanzel suggest a close parallel.

Thickness is variable. At Louisville, the blocky mudstone is less than three feet thick, whereas at Stanzel it is at least ten feet thick (more if it is counted as extending down into the Bonner Springs Shale beneath the Plattsburg Limestone).

Coffeyville Type

The Coffeyville type is poorly defined in a stratigraphic sense, consisting principally of the rooted zones of coal seams in thick shaly and/or sandy sections, which do not normally extend more than a foot below the coal seam. The Coffeyville type is exemplified by the horizon below the thick coal (Cedar Bluff Coal?) at the outcrop near Cherryvale, Kansas (Locality BC1). Unlike the other types, detrital quartz sand and mica are usually abundant. The clays are usually unweathered illite, abundant kaolinite, and some chlorite, exhibiting no distinctive development. The horizon may contain some pyrite, where it's unweathered. Some platiness or fissility may be present, but generally the sediment is massive.

The profile may locally develop a calcareous horizon below it. At Liberty, Kansas (Locality Lil), the Cedar Bluff Coal has an argillaceous nodular limy horizon a few inches below a basal bone coal bed.

At Canville Creek, near Stark, Kansas (Locality Cal), the basal Galesburg Shale, about 6 feet below the lower coal seam, contains abundant small (less than 1 cm) laths of selenite. Whether these developed in the original depositional environment (only a few taxa of marine invertebrates were found in that horizon) or from weathering (either Pennsylvanian or modern) is not known.

## Interpretation of Features

### Massiveness

The massiveness of soil zones is usually attributed to bioturbation by roots and/or burrowing organisms (e.g., Roeschmann, 1971; Visher and Rennison, 1978; Watney, 1980). This seems to be generally applicable in the possible soils here, particularly as many do have roots or root-like structures preserved, and/or are overlain by an autochthonous coal.

However, other possibilities exist. Buol and others (1980) noted that soils with expandable clays can have their structure disrupted by repeated wetting and drying, in what is known as an "argillopedoturbative" phenomenon. This may be applicable to the Galesburg and Vilas type horizons. Rhodes (1982) suggested that dry season desiccation and salt wedging on the mudflats of a chenier plain would destroy any sedimentary structures; such a model may also be applicable.

The proponents of a depositional origin for underclays (e.g., Parham, 1964) argued that the massive structure is due to flocculation. This seems unlikely in view of the vertical change in the units and a complete lack of any associated depositional structures or fossils.

Slickensides

Several mechanisms have been proposed for the formation of the slickensides found in many of the Pennsylvanian underclays. White (1961) thought that during the volume changes of dewatering, the various clay domains moved past each other, producing slickensides. Roeschmann (1971) attributed slickensides in Carboniferous underclays in the Ruhr to tectonic stresses. Buol and others (1980) explained them in terms of modern vertisols: where the soil has a large component of expandable clays, drought dries them and forms deep cracks in the soil. Loose soil falls into the cracks, and when the soil is rewetted, the swelling clays create pressure, which is released by low angle slickensiding, and formation of gilgai relief where the surface buckles. Both the Galesburg and Vilas types have slickensides (and expandable clays), whereas the Coffeyville type essentially lacks both, supporting the latter explanation for slickensides.

Pedotubules

Brewer (1964) defined pedotubules as tubular forms in soil material, either as simple tubes or branching systems. Teruggi and Andreis (1971) stated that they were roughly cylindrical or irregular holes, made by either roots or burrowing organisms. They can be microscopic, but are generally megascopic.

These features have been recognized in Carboniferous soil profiles. Walls and others (1975) found sinuous circular to elliptical molds in a Mississippian profile, and Riding and Wright (1981) found sinuous, spar-filled fenestrae in a profile of similar age. Watney (1980) found pedotubules 1 to 5 mm in diameter in the red mudstones above the Missourian limestones in western Kansas, as well as in the tops of the upper limestones, filled by either clay or sparry calcite.

Pedotubules were not found in the mudstones in this study, but were fairly common in the top of the calcilutitic Bethany Falls Limestone, with both clay- and spar-filled forms, some quite large. Pedotubules were also found in the nodular limestones at the base of the Fithian-type profiles, as well as in the clasts above the Bethany Falls.

Glaebules

Brewer (1964) defined a glaebule as a three-dimensional soil unit, usually prolate to equant, distinguished from the surrounding soil material by a different composition and/or a distinct boundary. He included in his definition nodules, concretions, and septaria. Structures that fit the definition are common in Carboniferous rocks, although only Riding and Wright (1981) denoted such structures by that term.

Glaebules are common in the sediments studied, as well. Glaebular structure very similar to that shown by Riding and Wright (1981, p.1331, Fig. 17) was found in the nodular limestone in the

Fithian-type profiles. Glaebules would also include the pyrite nodules found in the grey-green mudstone, the septarian microconcretions mentioned, and the small reddish-brown calcite nodules in the red mudstones.

Leaching

Leaching of mobile ions and soluble organic materials is common in soils that have active transport of water through them. This is particularly important in respect to the common active ions, such as $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, and $K^{+}$. Millot (1970) noted that leached clay profiles that produce mixed layer clays are characteristically pedogenic in origin. With progressive leaching, the clays become more open, as is found in the Galesburg-type profiles (see clay mineralogy). If the process continues efficiently, mixed layer clays yield smectites (as may occur in some sections here), and continued leaching could produce kaolinite. Strakhov (1967) noted that completeness of the leaching sequence depends on the efficiency of the process. In humid tropical climates, it terminates with the residual oxides of iron, aluminum, and titanium.

A few inhibitions to effective leaching may apply here. Leaching cannot proceed when abundant $Ca^{+2}$ remains in the soil, so carbonates tend to inhibit it (Millot, 1970). Soils derived from argillaceous limestone or shale tend to have poor permeability, and are usually only weakly leached (Buol et al., 1980). A high water table would also inhibit leaching.

It has been recognized that many underclays have the upper portions leached of carbonate (e.g., Allen, 1932; Stepusin, 1978). This is generally true of the Galesburg-type profiles, as very few are significantly calcareous. The clay mineral profile suggests that other ions, especially the $K^+$ from the illite, has been progressively removed. However, leaching has been only moderately effective, due to the reasons outlined above.

Organics and Redox

When discussing soils, a general expectation is to find an organic-rich A horizon, and a classical well-developed profile. But the Working Group on the Origin and Nature of Paleosols (1971) and Yaalon (1971) stated that absence of the A horizon is rarely important, as A horizons are principally composed of mobile organics, and are commonly and quickly lost during diagenesis.

However, the presence or absence of a significant amount of organic material during soil formation and weathering is important. Usually, this shows up directly in soil color. Red, oxidized soils are (and were) poor in organics, either due to lack of accumulation or complete leaching; dark soils are rich in organics, and were usually poorly drained (Loughnan, 1969).

Poor drainage and reduction of metals (especially of iron) produce mottled grey soils called "gleys" (a term that is widely used, although Bates and Jackson, 1980, called it obsolete). McMillan (1956) stated that a gley forms from downward movement of organics (with concomitant reduction); however, ions are not removed (except for

some $Ca^{+2}$. Buol and others (1980) noted that parts of the profile subjected to prolonged saturation develop gley colors with a chroma of 2 or less; seasonal fluctuation of the water table promotes development of mottles.

Buol and others also noted several mineral reactions important in relation to redox changes. If the Eh is low, iron sulfides and lepidocrocite may develop in the soil, while high Eh promotes goethite, which "ages" to hematite. Oxidation-reduction cycles from fluctuating water tables are important in poorly drained soils, especially on coastal lowlands. The alternating exchange of $Fe^{+2}$ and $Al^{+3}$ can destroy the clays present, producing degraded clay and amorphous material.

The effects of these processes can be seen on the profile types discussed here. The Galesburg type was subject to a low Eh environment, with drab colors developed, mostly green and grey, and pyrite is common. The Vilas type apparently had relatively little organic material available, and is usually red, although a green color may be overprinted.

Illuviation

Illuviation is the process of forming a horizon mechanically enriched in clay, that is, an argillic horizon or hardpan. This takes place by the process of "lessivage", the washing of fine clays down pores in the soil (Buol et al., 1980).

In the profiles studied, no argillic horizon was evident, but there was evidence of illuviation. The pedotubules and voids in the

underlying limestone were frequently filled with clays apparently washed down from above, plugging the pores. Dubois (1979) and Watney (1980) noted this phenomenon in the tops of the upper limestones in western Kansas and Nebraska.

Caliche

Caliche is a micritic carbonate deposit, formed when percolating groundwater evaporates and precipitates $CaCO_3$. If carried to completion at a stable horizon, this will produce a calcrete or petrocalcic horizon.

There are a number of criteria for recognizing caliche deposits. The most widely observed is repeated fracturing (usually filled by coarse blocky calcite spar or vadose silt and clay) due to desiccation (Reeves, 1970; Walls et al., 1975). Often, these are curved and without orientation, producing circumgranular cracks (Watney, 1980; Riding and Wright, 1981). Pedotubules are also common (Walls et al., 1975). The particles and voids in caliche are often coated with brown microcrystalline calcite, apparently stained by soil organics. The laminae produced in this fashion are usually diffuse, in contrast to algal laminae, which are typically sharp.

Stratigraphic relationships are important, as they determine relative permeabilities and sources. Well-developed caliche horizons form most readily in thick calcareous sands (Reeves, 1970) but are also common as crusts on brecciated limestone. Longman (1980) noted that caliche formation takes place at the air-water interface; if this fluctuates through porous rock, caliche crusts can develop through

a vertical range, and dissolution above the water table can produce vugs, pitted surfaces, and brecciation (Walls et al., 1975; Longman, 1980; Riding and Wright, 1981). Walls and others also noted that such horizons often have mottled blocky mudstones above them, and that laminated algal horizons rarely form on brecciated limestone with a paleosol over the top.

Caliche in shale sometimes produces nodules that are ameboid or spherical in shape (McBride, 1974). These can be found in red, green, or grey mudstones and shales.

Reeves (1970) developed a scale for describing the evolution of a petrocalcic horizon, including (1) young, characterized by white carbonate enclosing masses of parent material), which still retains its structure and is only poorly cemented; (2) mature, characterized by a profusion of large or small nodules, cemented by competent carbonate, often with lenses and blocks of the parent material; and (3) late mature, with the parent almost gone, original structure lost, and the nodules well-cemented.

The nodular limestone below the blocky mudstone at Fithian, Illinois (Locality Ft1) (where Filewicz, 1980, called it a "vestigially present lacustrine limestone") and in the Charleston, Illinois, core (Locality Ch1) fit many of the criteria for caliche well. They are dark, micritic, ameboid, nodular limestones, showing abundant random cracks, pedotubules, and a glaebular structure in thin section (very comparable to that illustrated by Riding and Wright, 1981, p. 1331, Fig. 17) (Fig. 43). These horizons occur below blocky noncalcareous mudstones, which contain poorly crystalline clays that

Figure 43. Thin sections of Illinois soil nodules.

a. Nodule from the base of the blocky mudstone, Fithian (Locality Ft1). Mostly brown and black micrite apparently from organic staining. Note the probable root holes (some bifurcating) lined with multiple generations of calcite growth. (Plane light.)

b. Nodule from the base of the blocky mudstone below the Shoal Creek Limestone, Charleston core (Locality Ch1, -740' level). Note the dark areas, variably stained by organics. Also, observe the multiple layers of growth of calcite in voids, and extensive (including circumgranular) fracturing. (Plane light.)

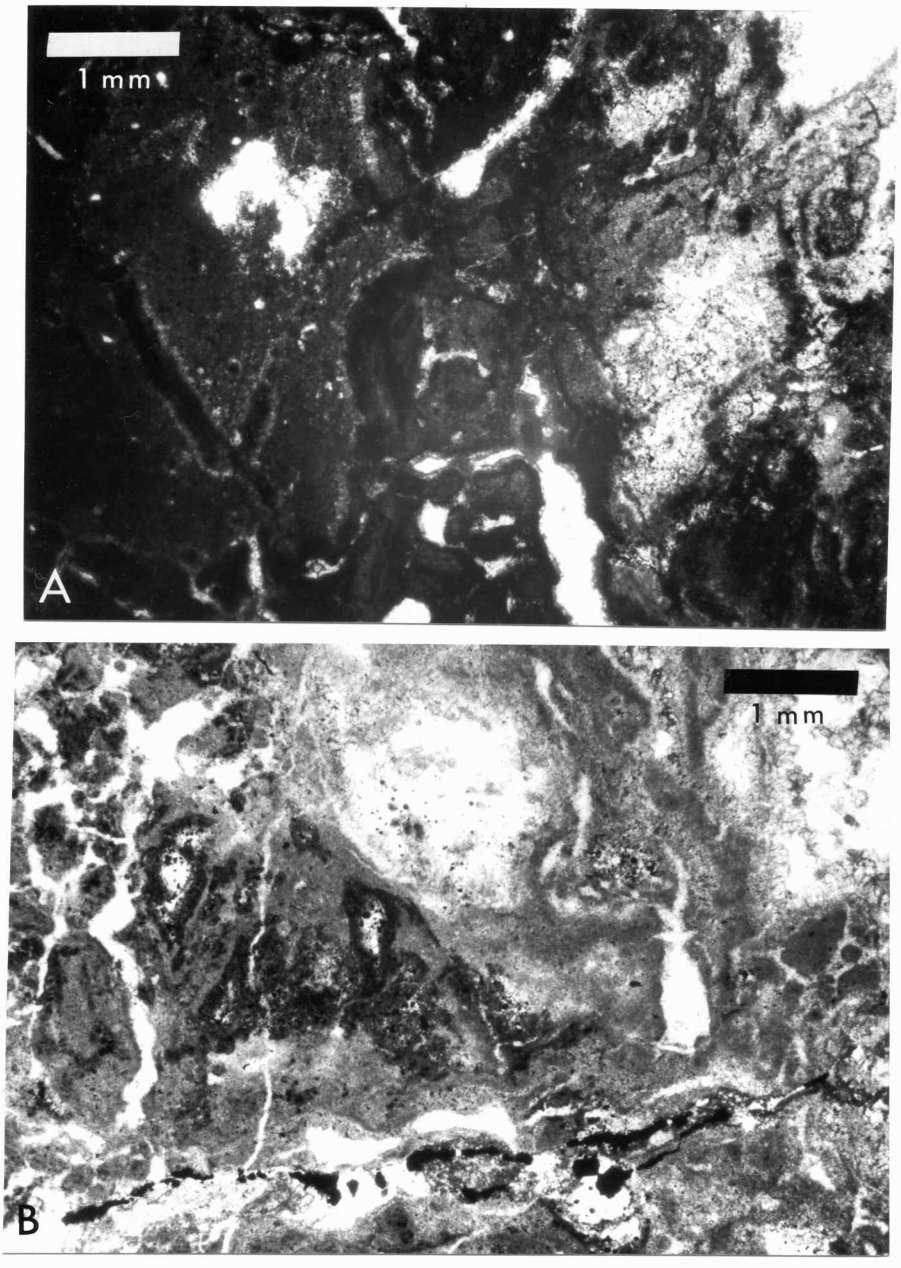



Figure 43.

become more degraded upwards. Below the nodular horizons are laminated grey shales with well-crystallized clays. Using Reeves' (1970) classification, the horizon at Fithian could be described as mature, while that below the Shoal Creek horizon in the Charleston core may be near late maturity.

The nodular horizon below the Cedar Bluff Coal at Liberty, Kansas (Locality Lil) may also be a petrocalcic horizon, although it is too argillaceous to be easily analyzed. Since it is poorly cemented, with much parent material retaining its original structure, it would qualify as a young horizon, in Reeves' terminology.

This interpretation is only partially at odds with the historical view of the "freshwater" or "underclay" limestone in the Illinois and Appalachian basins. Scott (1944) called the thin, nodular, discontinuous limestones freshwater because of local occurrences of ostracodes. Willman and others (1975) stated that the nodular underclay limestones are usually nonfossiliferous, but some contain ostracodes, algae, and Spirorbis; these were interpreted as freshwater deposits, although some grade laterally into marine deposits. Peppers (1964) noted that they contain no spores, although some have abundant cuticular material. Donahue and Rollins (1974) described a lower Conemaugh lake facies of rhythmic alternations of coarsely- and finely-crystalline laminated limestone, with the finely crystalline layers tending to be dolomitic, and with intraclasts and possible desiccation cracks; the coarser layers contain fish fragments and ostracodes. Donahue and Rollins attributed this to seasonal deposition.

Weller (1957) perceptively stated that not all underclay limestones originated the same way. Some are probably primary, as they are well-bedded and fossiliferous, containing leaves, small gastropods, rare pelecypods, ostracodes, shark teeth and Spirorbis. Others are unfossiliferous nodules concentrated along joints in the shale and almost certainly secondary.

Caliche is widespread in Upper Pennsylvanian deposits in the Midcontinent. Mudge and Yochelson (1962) described their shale "biotope" 13 as varigated nonfossiliferous shale, with or without beds of impure clayey nonfossiliferous limestone. Donahue and Rollins (1974) described Conemaugh redbeds as paleosols with caliche horizons. Donovan (1978) and Dott (1981) also noted paleosols with caliche nodules in the Missourian strata of central Oklahoma. Knight (1929) and Loope and Schmitt (1980) noted caliche in the Fountain Formation of Colorado. Kotrous (1978) found caliche in eastern Nebraska, and Dubois (1979) reported caliche soils above the Winterset in western Nebraska. Watney (1980) reported caliche in the Kansas City Group (which includes the Bronson Group of this study) in northwestern Kansas; Heckel (1977, 1978) reported a caliche crust on the top of the Bethany Falls (at the base of the Galesburg) close to the Jingo, Kansas (Locality Ji1), outcrop studied. A similar caliche crust may occur on top of the Spring Hill Limestone at the base of the Vilas at the Stanzel, Iowa, outcrop (Locality St1).

Caliche is normally interpreted as representing at least seasonal aridity of the climate. Reeves (1970) cited a personal communication from Arkley that caliche could form in climates getting more

than 25 inches annual precipitation if it was hot enough to cause significant evaporation. Robbins and Stipp (1979) found a calcrete crust forming in the Florida Keys, where soil carbonate (from storm wash and weathered pieces of bedrock) was dissolved, carried down, and precipitated on the top of the bedrock, plugging the pores and accreting upward. Notably, the overlying soil is mostly humic material.

Thus, caliche represents a climate at least seasonally dry, requiring that deposition exceed dissolution, but not necessarily marked aridity. Donovan (1978) stated that development of a caliche horizon also required tectonic stability and relatively slow rates of sedimentation to allow accumulation of carbonate in one horizon.

Brecciation

Brecciation of underlying limestones (the parent material) is characteristic of soil formation. Riding and Wright (1981) noted that the larger fragments are angular, although the smaller ones may be somewhat rounded by solution. The particles are not sorted, indicating little if any movement. The limestone clasts may be discolored or have a progressive alteration rim; they may be veneered with caliche, which sometimes laminates the clasts together (Walls et al., 1975; Riding and Wright, 1981).

This feature is common on the upper surfaces of the upper limestone in the subsurface Missourian of western Kansas (Watney, 1980). Huddle and Patterson (1961) noted it often in limestones below underclays, observing a decreasing number of pisolites, spherules, and irregular masses upwards toward the coal. Dubois (1979) stated that

brecciation and fracturing were most intense in topographic lows and that some solution features extend 30 feet below the original surface.

The "rubbly zone" in the top of the Bethany Falls across most of the Forest City Basin is a good example, as is the top of the Spring Hill in western Iowa and adjacent Nebraska. Oölite at the top of the Bethany Falls is less obviously weathered and only a few sharp chips are present in the overlying shale.

Other Features

Other features are observed in the profiles examined. G. Retallack (oral comments, North Central GSA, May, 1981) stated that roots were the best evidence of paleosol horizons. Coals in both the Coffeyville-type and Galesburg-type profiles locally have rooted zones; in the Coffeyville type, they were unequivocal carbonized impressions; the Galesburg type commonly contained pyritized root-like structures in the mudstone and pedotubules in the underlying limestone and caliche nodules.

Lack of marine fossils is another characteristic of the profiles. The only occurrence of marine fossils in any of the samples (uncontaminated by float) was at the base of the Vilas at Stanzel, Iowa (Locality St1), where fossil fragments were weathering free of the underlying argillaceous Spring Hill Limestone. Phosphatic as well as calcareous fossils disappear in the soil profile. Even where the underlying limestone contains a significant number of conodonts, they are not found in the overlying mudstone. A comparative study on a

modern weathering profile on the Winterset showed that conodonts disappear quickly in a subaerial weathering environment.

Color can be a misleading indication of subaerial weathering. Although a red-brown color may indicate exposure, the diagenetic dewatering of goethite (Buol et al., 1980) suggests that it is not necessary. The converse is not necessarily true, either. Many green, grey, or drab mudstones and underclays in the Pennsylvanian may be soils (G. Retallack, oral comments, North Central GSA, May, 1981).

The Working Group on the Origin and Nature of Paleosols (1971) and Yaalon (1971) observed that A horizon features are rarely preserved in paleosols, and that B horizon features are the most useful indicators of soil development, as they are usually preserved; the Working Group stated that argillic and petrocalcic horizons are extremely useful. However, they noted that one character by itself is rarely diagnostic, but that an analysis of carbonate distribution, clay mineralogy, and granulometry and other micromorphic procedures are important sources of information on soil profiles.

## Interpretation of Profiles

Logan (1842) first promoted the idea that underclays are soils. Since then, the concept has been refined. Potonie (1910) suggested that they were waterlogged soils, like modern moors. Weller (1930) and Wanless (1931) also thought that they were poorly drained profiles, but not necessarily related to the development of the overlying coal swamps. Allen (1932) stated that they were very young profiles, which is compatible, as poorly drained soils mature very slowly. Ferm (1970)

noted a range in seat rocks, from poorly drained and developed paleosols to well-developed ones. Dubois (1979) recognized a similar range and found that in low areas, the underlying limestone was far more brecciated and leached than in higher areas where the rock interacted less with groundwater (Fig. 44).

In the following descriptions, the nomenclatural system of the United States Comprehensive Soil Classification (Soil Survey Staff, 1975) is used. This divides soils into orders and suborders, with various descriptive prefixes and roots. This is more systematic and useful than other terms that might apply. Laterite, for example, is a broad term that describes a host of soils derived under intense weathering conditions. Rendzina (used in the FAO/UNESCO classification) is any thin soil over a limestone, and has no genetic or physiologic implications. Terra rossa means much the same thing, although it generally implies that the soil is a red residuum leached from limestone.

Galesburg-type Profile

The Galesburg-type profiles probably fit best in the order of entisols; that is, recently formed soils. Buol and others (1980) noted that entisols can form in three principal ways: (1) cumulation may add new material to the surface as fast or faster than it can be assimilated by pedogenic processes (such as in floodplains and deltas); (2) saturation with water prevents development of soil horizons; and (3) lack of time for soil formation, for example, on newly exposed

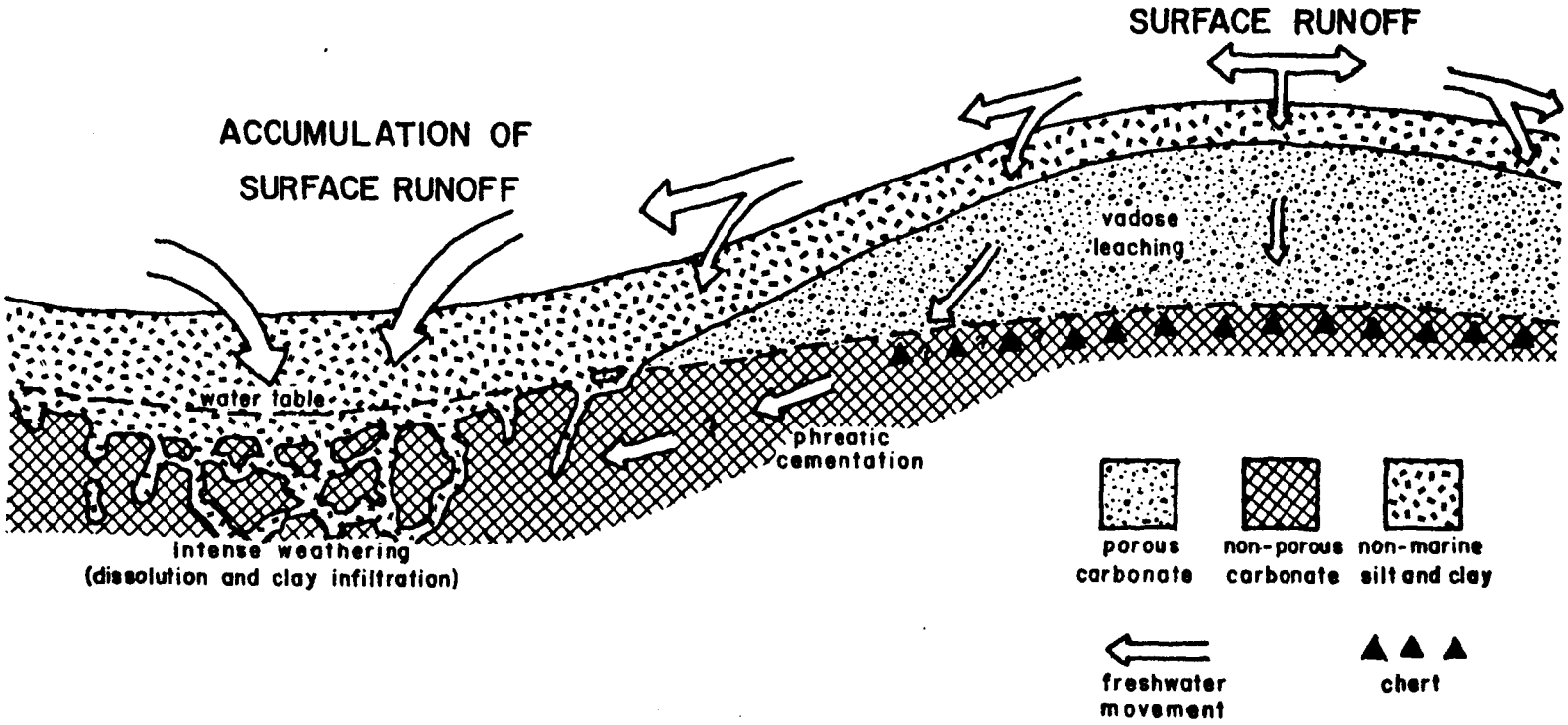



Figure 44. Subaerial diagenetic model of Dubois (1979).

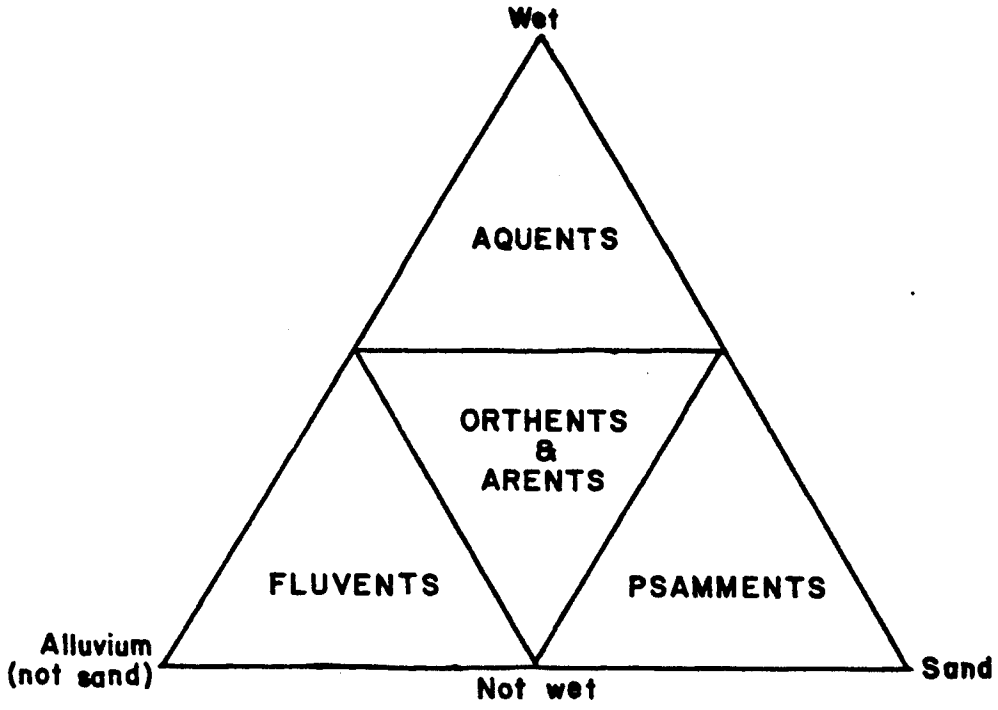



Figure 45. Relationships of entisol suborders,
From Buol and others (1980)

sea floor. In all cases, soil processes are curtailed enough to prevent formation of all but the most rudimentary horizons.

Within this group, the aquent subgroup includes soils that are permanently or seasonally saturated. They are usually bluish-grey or mottled. A further subdivision is that of the sulfaquents, which includes those with sulfidic materials (such as pyrite) within 50 cm of the surface. Modern examples include tidal marshes.

A somewhat overlapping group that may be applicable is the inceptisol group (Buol et al., 1980), which includes embryonic soils with a few diagnostic features. These generally occur in extreme

landscape positions, such as depressions, and can occur on very young geomorphic features. The aquept subgroup has some leaching, but lessivage is retarded (since the soil doesn't dry out, the clays can't wash very far). Aquepts may develop a cambic (surficial) horizon, but other horizons are lacking. They do not have argillopedoturbative features, both because they have poorly leached clay and because they rarely dry out.

The Galesburg-type profiles are most readily placed in the sulfaquents, on the basis of poor horizon development, implied retarded development (expressed by thinness and modest clay evolution), and the presence of pyrite throughout the profiles. However, this may represent only the final phase of their development. In some places, they have argillopedoturbative features (slickensides) and caliche horizons, which may be relicts from previous soil environments.

Coffeyville-type Profiles

The Coffeyville-type profiles can readily be assigned to one of the several subgroups of entisols (as described in Buol et al., 1980). Orthents are lithic soils, which are eroded too quickly to achieve a more distinct profile. Fluvents are loamy or clayey alluvial soils, with irregular organic content at depth (due to frequent burial). Psamments are loamy or sandy soils, better drained than aquents. Coffeyville-type profiles are generally fluvents, although some may edge over into psamments. Locally, it is possible that they merge with orthents, although none were recognized.

Strakhov (1967) made a pertinent observation about tropical weathering, stating that mechanical weathering was more important than chemical weathering in tectonically uplifted regions. In humid tropical areas with relief, denudation is about 6 to 20 times more effective than in areas where chemical weathering alone is active. As a result, much of the debris from orogenic belts in tropical areas is incompletely weathered (producing unweathered illite, among other products). Where the soil is in place for a short time, it leaches very quickly (producing the associated kaolinite). Thus, such areas produce the materials typically found in the Coffeyville-type profiles. (Strakhov, 1967, also felt that such clastic pulses, producing unweathered debris, could explain Pennsylvanian cyclothems.)

Vilas-type Profiles

Buol and others (1980) mentioned two other soil groups that may be applicable to the Vilas-type soils, and might have been a precursor for the Galesburg-type in some cases. Vertisols are soils homogenized by argillopedoturbation. They are over 35% clay, mostly expandable clays. Alkaline reactions are a common feature, and they are often derived from calcareous sedimentary rocks. They show no evidence of illuviation or eluviation (as they are continally churned up), and are usually over 75 cm thick. $Ca^{+2}$ and $Mg^{+2}$ are the dominant exchange cations. Their ultimate fate is for the expandable clays to become nonexpanding when exposed to ions (such as $K^{+}$) that close the structure. Vertisols are characteristic of savanna regions.

Aridisols may overlap with vertisols, as they are often found together. They are usually illitic, although some smectite may be present lower in the profile. Aridisols are usually low in organics, and typically have argillic horizons, although the orthid suborder does not. Paleorthids have a petrocalcic horizon within a meter of the surface.

The Vilas-type profile verges on these. Some examples do have a significant amount of expandable clays, and are extremely slickensided, as well as rather homogeneous. Vilas-type profiles have much less obvious organic material, and are sometimes red, although this may be due to diagenesis. All types of profiles in this study (Vilas, Galesburg, and Coffeyville) locally display some petrocalcic features.

## Significance of Profiles

The features of the profiles can be explained by a continuum of variables. The caliche formation in the profiles, as well as the vertisol and other aridisol characteristics, are consistent with a climate that is seasonally dry; e.g., a tropical savanna climate. With transgression of the sea, a tidal swamp environment may have been overprinted, producing a drab, reduced soil, with local peat formation as in the Galesburg across the Forest City Basin. Transgression might reduce just the upper portion of thick profiles, leaving the lower portion oxidized as in the Vilas in Iowa. Alternately, in some areas the soil may have never become sufficiently emergent and/or developed to progress beyond the inceptisol stage.

In areas of rapid deposition from actively uplifted areas, fluvents with poorly developed soils rich in unweathered minerals

could accumulate. These would be characteristic of most alluvial plains and deltas of major river systems, as in the Coffeyville.

A brief comparison with modern examples of stratigraphic analogs is in order, at least for some soil types. The Florida Everglades have been compared to the terrestrial portion of the Midcontinent Pennsylvanian cyclothems, and some aspects of the comparison are apt. Everglades soils are peats lying directly on the limestone or with an intervening residuum weathered from the limestone; since the Tamiami Limestone is sandy, this residuum is usually a sand layer (Univ. Fla. Agri. Exper. Sta., 1948). The peats sometimes have lenses of fresh-water marls in them. Eventually, with marine transgression, the peats are overlain by marine deposits (Scholl, 1969).

Ruhe and others (1961) noted that where the regosols of Bermuda were well developed, the soils were leached of carbonate, which was deposited as a crust on the bedrock surface. These soils were derived from the insoluble residues, wind-blown material, and/or sheet wash.

The Pennsylvanian paleosols, at least the Galesburg type, are probably analogous to the above examples. Stratigraphically, they are quite similar. A notable point of comparison to the Everglades is the lack of any evident channel system associated with them. The clays in the profiles may have been derived, possibly in large part, from the underlying argillaceous limestone; it is not possible to state this conclusively, for whatever precursor material gave rise to them is now gone. Although wind-blown material may have contributed to the Galesburg soil, more efficient littoral transport or sheet-wash drainage would be more likely.

## Sedimentary Structures

Sedimentary structures are not commonly observed in the studied shales, although they are common in the adjacent limestones and sandstones. A principal reason is that shale structures are difficult to observe, as weathering destroys them quickly, and lab work to enhance them is difficult. Also, some of the outside and core shales are truly mudstones, with most structure destroyed by bioturbation, either by marine burrowers or terrestrial plant roots. But some structures are visible and provide useful information. These include the structures in interbedded limestone and sandstone lithologies. Discrete ichnofossils are considered in a separate section under paleontology.

## Fissility

Fissility is a common characteristic of shales, yet little is known about its origin and significance. It is not even certain whether it is a result of deposition or diagenesis, or a combination of the two.

The black shales of the Eudora and the Stark are particularly fissile, and are good examples of "paper shales", which are common in the cyclothems. Away from the black portions, organic-rich laminations become more widely spaced and prominent; Payton and Thomas (1959) referred to those in the upper Stark as "varves". Weaker development of fissility is found in the outside shales, where rock cleavage surfaces may be about a centimeter apart, with the roughly planar surface often marked with a concentration of muscovite flakes and/or

plant material. When weathered, the outside shale becomes more and more finely "chippy", as opposed to the sheety weathering of the black shale.

There is a basic disagreement on the origin of the fissility in such shales; one group holds that it is due to the parallelism of the clay flakes, while the other believes the organic laminae are principally responsible.

Odom (1967) stated that the primary control of fissility in Pennsylvanian shales in Illinois is the parallel orientation of clay flakes, although he admitted that organic laminae could be a controlling factor. O'Brien (1970) also observed the close correlation of clay parallelism and fissility.

If the fissility is due to clay orientation, there is the additional question of when it is produced. White (1961) and Odom (1967) thought that it was a primary depositional feature, noting that fissility did not increase with increasing burial and overburden pressure. White (1961) and O'Brien (1970) stated that fissility in marine shales is due to unflocculated deposition, with the clays either too diluted to flocculate or organically coated which would prevent electrostatic interaction and flocculation. O'Brien (1970) observed that only a very little organic material was necessary to prevent flocculation. Gibbs (1977) supported this concept, illustrating that flocculation was not a control in the deposition of Amazon clays, and noting that virtually all clays entering the ocean had organic or hydroxide coats that prevented electrostatic interaction.

Blatt and others (1980) favored another model, stating that clay flakes with aliphatic organics attached might have the non-polar ends oriented outward, and thus be only weakly attracted. They felt that this was a major cause of fissility in paper shales.

Alternately, orientation of the clays may be due to compaction. Hedberg (1936) stated that mechanical rearrangement of clays could take place in the top 5 to 10 cm of sediment; O'Brien (1970) noted that incipient fissility could be produced by clay orientation under a few feet of overburden pressure. Rieke and Chilingarian (1974) stated that clays could be reoriented by overburden pressures of less than 100 bars. Blatt and others (1980) attributed most fissility to compaction and diagenesis. Curtis and others (1970) noted the development of clay orientation during growth of a siderite nodule, with clays in the core of the nodule randomly oriented, while those on the outside were more compacted and oriented. Spears (1976) noted that in many shales, the clays are well-oriented, but felt that fissility was not dependent on it.

Whittaker and Dyson (1980) felt that fissility was indirectly related to diagenesis. They stated that the water released by the conversion of smectite to illite generated both fissility and jointing as it was squeezed out of the rock.

Ingram (1953) and Hallam (1980) stated that fissility is due to organic laminations. Curtis and others (1980) cited a paper shale where the clay particles were not well oriented, due to fine quartz grains. But Lundegard and Samuels (1981) noted that laminated mudrock is not always fissile, and cited a Pennsylvanian black mudrock that

didn't develop fissility when weathered. Cluff (1981) stated that fresh, unweathered black shale is never fissile. Ingram (1953) noted that moderate weathering enhances fissility, and Spears (1981) supported this, noting that fissility is a secondary feature based on laminations. The studied black shales are equivocal. Thin sections (Fig. 46) show the organic material and associated clays to be strongly oriented in horizontal laminae; however, lenses of quartz silt have more poorly oriented clay. Empirical observations also confirm that weathered black shales are often, but not always, more fissile than fresh shales.

Merrill and others (1978) added another possible cause, noting that fissility in black shale developed because of stringers of apatite. This feature was frequently observed in the northern Eudora (Fig. 47) and the northern Stark.

Whittaker and Dyson (1980) proposed that fissility and joints developed when water was diagenetically forced from clays by illitization, changing from the denser aligned interlayer water to less dense pore water. However, this is unlikely in the Pennsylvanian of the Midcontinent, since the shales probably did not reach the level of diagenesis needed for such dewatering.

Lack of fissility in massive mudrock can also tell a great deal about the environment. Frequently, this is attributed to bioturbation by marine burrowers, and Byers (1974) cited evidence that burrowers can rework sediments one to several times in a year; Blatt and others (1980) suggested that it is important in most depositional areas, as sedimentation is rarely rapid enough to exceed bioturbation. Byers

Figure 46. Base of the fissile black Stark Shale, Atlantic, Iowa (Locality Atl).

a. Thin section showing strong parallel orientation of organic layers; clays are also strongly oriented. The lenses contain fine quartz silt and poorly oriented clays (not visible). (Plane light.)

b. Conodont (probably an idiognathodid) in the fissile black shale. Note the draping of organic layers around the conodont. (Plane light.)

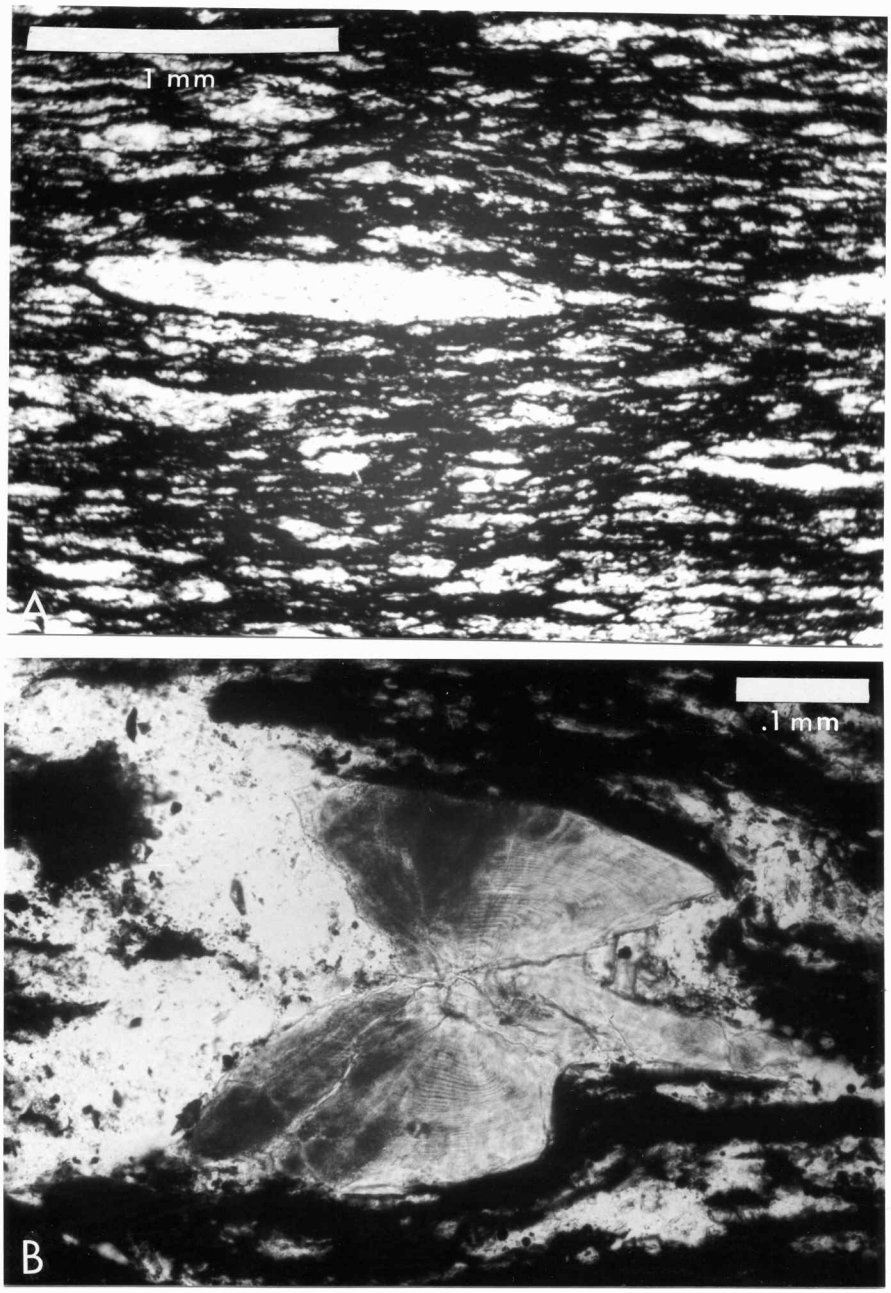
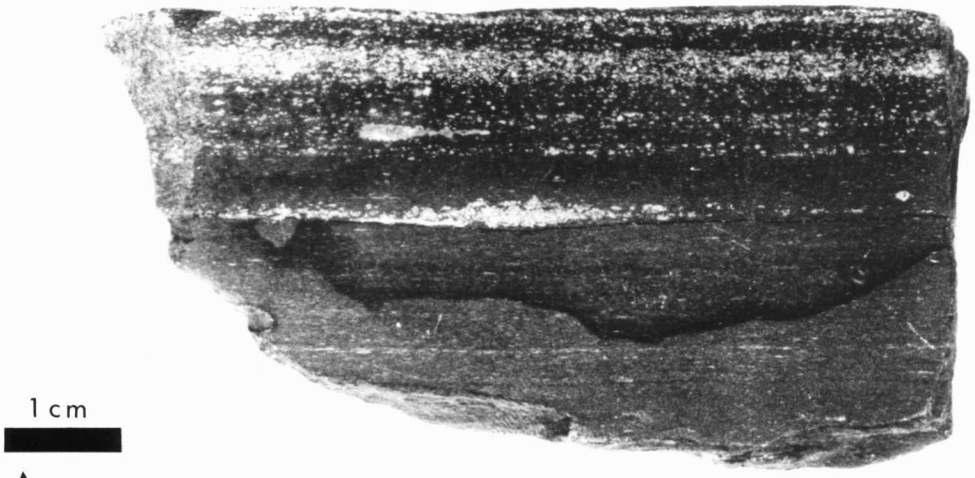



Figure 46.

Figure 47. Apatite peloids in the Eudora Shale, Lewis, Iowa (Locality Le1).

a. Hand specimen showing strong lamination of the Eudora and horizons of grey apatite peloids. The irregular pattern at the bottom is an artifact of the acrylic coating.

b. Thin section of the specimen shown in a. Note the variable size of the grey apatite peloids (A) and the draping of the organic layers around them. Compare to the Stark in Fig. 46a. (Plane light.)



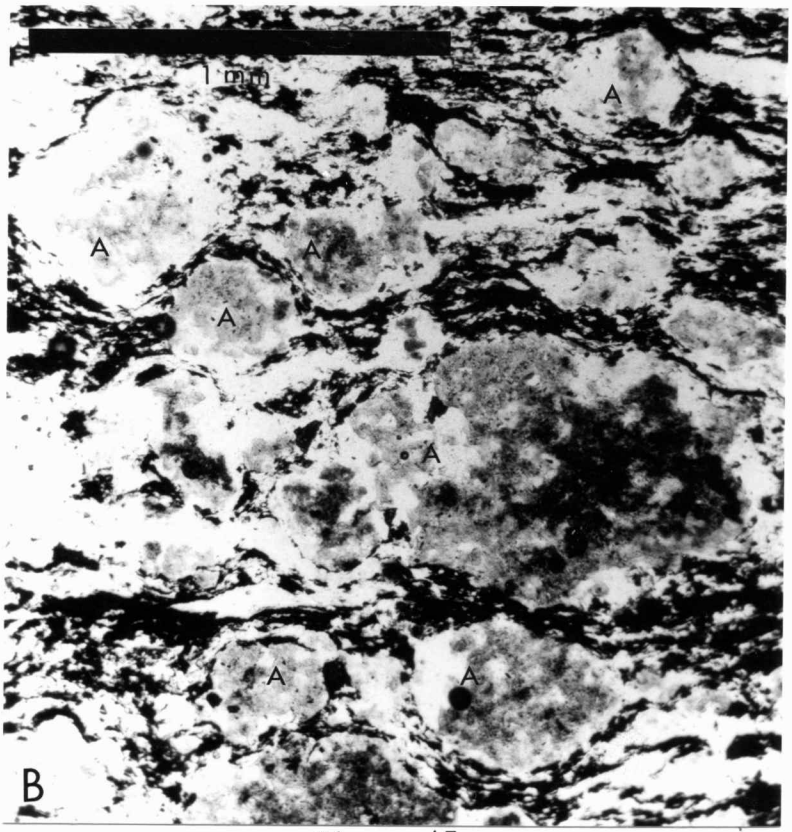




Figure 47.

(1974) stated that protobranch pelecypods (e.g., Nucula, Yoldia), polychaete worms, and holothurians are the principal agents of bioturbation. All are present in the shales studied.

Massive structure can also result from flocculation (Blatt et al., 1980). In the outside shales, root churning may also homogenize the mudrock (Huddle and Patterson, 1961), or the volume changes of expandable clays (argillopedoturbative action) may destroy previous structure (Buol et al., 1980). Byers (1974) was careful to note that lack of laminations and/or fissility in mudrocks does not necessarily indicate bioturbation, but rather that the presence of laminations means lack of bioturbation.

The fissile black shales studied are finely laminated and clearly not burrowed. Some of the outside shales are also somewhat fissile, which could be due to compaction superimposed on clays flocculated from turbid waters, or simply unflocculated clay deposition from more diluted or coated clays. Because burrowing animals are fairly common in the transition grey core shales and some outside shales, compaction may account for the fissility present, or deposition may have been rapid enough to negate the activity of the infauna. At this point, neither the evidence nor the knowledge of fissility are sufficient to resolve these possibilities.

## Siltstone Lenses and Laminae

Whitcomb (1965) described many small cross-stratified, light-colored siltstone lenses interbedded with shale in the Bonner Springs, the outside shale one cycle below the Vilas. The Vilas also

frequently has these lenses, particularly in the Forest City Basin. These are seldom more than one or two centimeters thick, and when freed from the shale show an asymmetrical ripple form.

The correct term for this structure is debatable; they would fit Pettijohn and Potter's (1964) definition of flasers, and Whitcomb (1965) and Shabica (1978) use the term in that sense. However, Blatt and others (1980) and Bates and Jackson (1980) restricted flaser beds to those that are dominantly sand with mud lentils, and use "lenticular bedding" for the type described here. To avoid confusion, the latter usage will be followed here.

Hawley (1981) noted that many shale layers in lenticular (or flaser) beds were over 3 mm thick, but noted that to prevent re-erosion, the mud had to be consolidated, chiefly by overburden pressure. He cited Owen (1970) as stating that in new mud layers, the upper two-thirds of the bed was not resistant, but the lower third was. Hawley stated that crushing of flocs was most important during the first ten hours; further consolidation took place by water loss (mostly during a period up to three weeks). In any case, he concluded that the minimum thickness of a preservable mud layer was 3 to 10 mm. He calculated that even if only one sand-mud couplet was produced every two weeks, the net deposition would be a half meter a year, which is very high. He also calculated that the necessary concentration of suspended mud to form a layer in a short time (e.g., 4 hours) would require phenomenal mud concentrations, on the order of kilograms per cubic meter of water. Hawley concluded that such structures must be formed by episodic storm activity, as normal currents were also

unacceptable as a mechanism, because they are not unstable enough to produce alternating sand and mud layers. He also observed that for the sand to be effectively transported a substantial distance from a source, it would have to be suspended. Such energy levels would require well-compacted bottom muds, which would require considerable time to consolidate, such as the interval between major storms.

There are examples of such bed forms in the modern environment. Nelson and Creager (1977) discussed an area near the Yukon with such structures, and concluded that the small ripples formed by reworking of storm-deposited layers by contemporaneous storm-related currents. This occurred in an area of little net deposition, where sediment was chiefly in transit. Also notably, the primary storm layers were thin laminae of silt with shale, a feature very much like the thin siltstone laminae associated with the lentils in the Vilas. The structures are also comparable in size.

Thus, the lenticular bedding appears to indicate a shallow bottom that occasionally interacted with storms. Net deposition was probably not high. The bottom, at least below the top few millimeters, was reasonably firm, and consolidated enough to resist erosion. It is conjectural whether the surface was firm enough to support epifauna.

## Current Structures

Current structures are rare in the shales, but more common in the adjacent limestones and sandstones. Whitcomb (1965) noted that the ripples in the Bonner Springs showed a mean transport direction of

N33°E. Similar ripples were found in washed residues of the Vilas, but none were observed in place.

The sandstones, mostly channel sands, of the outside shales have various cross-bed directions. Visher and Rennison (1978) showed that paleocurrents in the Coffeyville delta are all to the west or southwest, and illustrate radiating channels and crevasse splays. Hall (1961) showed that the cross-bedding in the Kansas City Group was all to the southwest, even in southern Kansas, indicating a cratonic source; Hamblin (1969) showed that they were to the north in south-central Oklahoma, to the west and northwest in southeastern Kansas, and to the southwest only in northeastern Kansas. Moussavi-Harami (1980) found that trough bedding in the Rock Lake sandstones of southeastern Kansas reflected the northwestward progradation of delta lobes, while ripples in the sands reflected the southwestward movement of the prevailing currents.

Moussavi-Harami (1980) also provided a rare report of evidence of high energy rapid deposition. The Rock Lake has medium-grained sands, some with herring-bone cross bedding, clay rip-ups, and load casts on the soles of some sands. Other places have isolated carbonate-cemented sand and oölite ripples 3 or 4 cm high. These features are found in the Rock Lake above the Eudora near Tyro, Kansas (Locality Ty1). The marine Eudora at Walker Mound (near Independence, Kansas (Locality WM1) contains a sandstone with undulatory ripples, indicating a somewhat higher (but still modest) flow regime compared to that characteristic of Missourian sands.

The Dodds Creek Sandstone above the Cedar Bluff Coal near Cherryvale, Kansas (Locality BC1) shows a number of sets of straight oscillation ripples, all with their crests trending N10°E. No bedforms other than ripples were observed in the Dodds Creek or related sandstones.

Missourian sands pose a problem in interpretation. Southard (1975) stated that sands with a grain size of less than 0.1 mm do not form large structures, but only ripples at low velocities and flat beds at high velocities. Such fine-grained sands are common in the Missourian, making the flow regime difficult to analyze.

Certain limestones in Missourian strata are cross-bedded. Hall (1961) stated that the crossbeds are trimodal, dipping toward the southwest, northeast, and southeast, and concluded that the bedding was from tidal and longshore currents. Hamblin (1969) found bimodal cross-bedding in oölites, with currents indicated to the northeast and southwest. The southwesterly direction was dominant, with megaripples at right angles to this. In the Tyro oölite all cross-beds dipped toward the southwest, in the same direction as the oöids apparently accreted (Heckel, 1978).

The lower Winterset in southeastern Kansas and adjacent Oklahoma shows large scale cross-beds. First noted by Frost (1968), the sets west of Coffeyville are three feet high with an apparent dip to the east. P. H. Heckel (pers. comm., 1981) believes that these are accretional rather than a product of current activity. Cronoble and Mankin (1965) stated that the flanks of the reef at Ramona, Oklahoma

(Locality Ra2), were winnowed by currents, to form a biosparrudite reef talus.

Zangerl (1980) stated that the Mecca Quarry black shale showed no evidence of currents, as the Listracanthus spines and orthoconic cephalopods were randomly oriented. Donahue and others (1972), however, reported oriented pelecypods from the Brush Creek black shale in the Appalachian Basin, but it is not certain if this is the same type of black shale as in the Midcontinent.

## Other Structures

An unusual feature occurs in the Naish Sandstone near Stanton, Kansas (Locality Sn1). There, the Naish is a massive, clean, calcite-cemented sandstone. However, it has local thin undulatory layers, rich in organics and apparently in pyrite, as the layers are marked by heavy limonite stains on outcrop. The organic material is apparently reworked peat, perhaps derived from the nearby coal swamp in the Vilas reported by Kenny (1968). Buller and Green (1976) noted that peat fragments could be sorted and reworked along with comparable crystalline clastics. The organics could make structures similar to those of the inorganics, although with post-depositional biologic breakdown, the resulting horizons could appear misleadingly fine-grained. This is probably what happened with the Naish; however, the exact structures are not very well preserved.

White (1961) suggested that synaeresis cracks are an important feature in Pennsylvanian shales. They form when flocculated muds dewater due to a salinity gradient, clumping the muds and cracking the

sediments. White felt this was also the cause of the small scale slickensides found in homogenous mudstones, as movement during dewatering rubbed adjacent mud masses past each other, producing slickensides. The cracks opened by synaeresis closed by compaction, but rebounded open when exposed. Plummer and Gostin (1981) discussed the distinction between synaeresis and dessication cracks. Both are usually short and curved, and are both pull-apart structures usually filled by another material.

However, neither structure was observed in the shales studied. In contrast, the cracks seen in fresh outcrops were straight and continuous across the outcrops. Usually, they had a preferred orientation. Larger ones also often had a thin (several centimenter) marginal oxidized zone, suggesting movement of groundwater or other fluids. These cracks are probably joints, although they may have functioned as drains for excess fluid during diagenetic dewatering.

## Scarcity of Shoreline Deposits

A persistent problem with interpreting the Upper Pennsylvanian sediments has been the lack of evident wave-built structures. Keugelan and Krumbein (1949) noted widespread evidence (in their estimation), for shallow water, such as ripples and cross-bedding, but were puzzled by the lack of an identifiable strand line. They concluded that the Midcontinent epeiric seas were very shallow and waveless, with a miniscule bottom slope. Tidal currents could not be important as they needed waves to help them to be effective. They noted a lack of lagoonal shales and linear sand bodies associated with

coastal deposits, as well as the lack of erosion and distortion when marine beds were laid over the coals, and concluded that there must have been a very gradational transition from alluvial plain to offshore deposition.

Both Shaw (1964) and Irwin (1965) followed part of this reasoning, and believed the epeiric seas to be tideless. Shaw compared the situation to Florida Bay, which is tideless in its northeastern inland portion.

Klein and Ryer (1978) and Cram (1979) took issue with that position, noting that tides generally increase in magnitude with increasing shelf width, although this relationship is less certain in epeiric seas than on open coasts. Klein and Ryer (1978) cited evidence that there were Pennsylvanian tides in the Midcontinent, such as herringbone cross-bedding. They also argued that without the strong interchange of water, many areas of the epeiric seas would become strongly schizohaline, as is northeastern Florida Bay. Although there is some evidence of faunal restriction in the shallow water deposits, the widespread diverse faunas are difficult to explain without adequate circulation. Finally, such paleotopographic features as the Wilson and Woodson County channels in the Stanton Formation of eastern Kansas correspond well to modern tidal channels (Heckel, 1978).

The lack of obvious strand line deposits may be largely a red herring. There are unequivocal coastal sand bodies, such as the Naish. Its shape is unknown, but it is a fossiliferous, carbonate-cemented, well-winnowed sand, which is uncharacteristic of any Missourian fluvial sand.

There is now a model for a waveless coast fronted by terrigenous mud. Rine and Ginsburg (1978) and Wells and Coleman (1981) studied the Guiana coast of South America, where mud from the Amazon plume is pushed onshore by quasi-estuarine Ekman transport. This produces large migrating mud banks, each about 10 by 20 kilometers in area, and up to 25 meters thick, although Rine and Ginsburg stated that 2 to 5 meters is average for an active mound. They are usually separated by gaps 30 to 60 kilometers wide.

Wells and Coleman (1981) determined that the fluid mud of the banks absorbed wave energy without breaking them. The waves expended all their energy by suspending the fluid mud, which quickly settled to provide drag on the next wave. No wave energy, even storm waves, reached the shoreline.

The passage of a mud bank leaves a firm clay bottom, colonized by benthic forams, ostracodes, worms, pelecypods, and crabs. The waves reaching the shore may build a small beach berm from shells or minor, locally derived sand. Eventual accretion of mud banks produces a mud-dominated chenier plain.

If such a system were preserved in the rock record, it would probably be a thick shale with sparse shelly horizons. Wells and Coleman (1981) stated that the system needs a high rate of sedimentation to maintain itself. However, because the critical feature is fluid mud to absorb wave energy, possibly a well-burrowed low density bottom would be just as effective, assuming animals could live there. Other alternatives may be possible, such as a greater spacing between active mud banks. This might occur if mud bank formation required a

critical mass, but sediment input was less. Thick shales such as the Vilas in southeastern Kansas would have little difficulty providing as much bulk as the modern system, and thinner areas might represent interbank areas, where the banks are not preserved. If the banks are as thin as Rine and Ginsburg (1978) suggested, they may compact to only one to three meters thick.

The Midcontinent sea either had very little sand emptied into it around much of its perimeter, or it had an effective system for concentrating mud on the coast. A few possible shoreline shell lenses can be found, such as the ostracodite lenses at Davis City, Iowa (Locality DC1). It may also be that the ultimate locus of mud deposition has little to do with where it entered the sea; Nelson and Creager (1977) noted a modern situation where the muds are deposited 500 to 1,000 kilometers from where they entered the shallow coastal sea, with negligible deposition over large parts of the intervening area.

Thus, the nearshore shale can be explained in terms of a mud-dominated system, with only a few storm deposits, where sand was available to produce them, and a rare coastal sand body. The variable shales may fit either a rapid depositional rate model or simply reflect a near lack of any materials suitable for expression of higher energy processes. The system can be patterned after modern models, rather than requiring unique conditions in the past.

## Calcite Concretions

Carbonate concretions, especially calcite, are common in black shales (Weeks, 1957). The Stark Shale frequently has such concretions in southeastern Kansas and adjacent Oklahoma (Hanson, 1957; Cronoble and Mankin, 1965). Cronoble and Mankin reported some concretions reaching bedlike dimensions up to 20 feet long and a foot thick, although commonly they are much smaller.

The concretions are very fine-grained calcite, cementing the shale into a dense black limestone. Finely disseminated pyrite is present in the concretions in the Stark; however, pyrite and/or apatite rinds, such as those found on similar black shale concretions in Illinois, are not known. Cronoble and Mankin (1965) reported that the laminae in the concretions are parallel to and continuous with those in the black shale, which they suggest indicates an epigenetic origin. The concretions rarely exhibit the draping and never the micro-slickensiding associated with the apatite nodules in the black shale.

There is some disagreement about the fauna found in the limestone concretions. Cronoble and Mankin (1965) reported only one concretion that produced spores, hystricospheres, and algal fragments. Weller (1957) and Johnson (1962) noted that the concretions in Illinois often contain a fauna related to, but distinct from, that in the black shale. In addition to the typical black shale fauna, it also contains a number of molluscs, some of which are common elsewhere in the cyclothem, but some of which are unique to the concretions. The

burrowing pelecypods include Cardiomorpha, Clinophistha, and Solemya. G. K. Merrill (1981; oral presentation, North Central GSA, May, 1981) found phosphate fillings of acrothoracic barnacle borings, encrusting agglutinated foraminifers, radiolarians replaced by calcite, exquisitely preserved (although rare) conodonts, and "algal stromatolites" in nodules from Illinois. Burrows or borings were found in the calcite nodule in the Stark at Bartlesville, Oklahoma (Locality Bt2). These sand-filled structures are larger and deeper than those of acrothoracic barnacles. In the studied concretions, only a few (but well-preserved) conodonts were found.

Holdsworth (1966) described British Namurian (Lower Pennsylvanian) black carbonate lenses in black shales, with the lenses commonly of ankeritic or calcitic dolomite. Pyrite was rare. Cephalopods were common in the nodules, as were radiolarians and sponge spicules (both often replaced by calcite). Gastropods, pectens, and brachiopods were rare.

G. K. Merrill (oral presentation, North Central GSA, May, 1981) interpreted the concretions as the nodular remnants of a once-continuous limestone layer. He cited the encrusting foraminfers and barnacles as requiring a shelly substrate. Evidence for the "stromatolites" were structures with domed organic-rich laminae (which may simply be preservation of limited compactional draping in the outer portions of the concretions). He also cited occurrence of radiolarians in the concretions, stating that they were not found in the surrounding black shale (although Berendsen and Nodine-Zeller, 1978, found the imprints of radiolarians in similar black shales in

Kansas). Merrill suggested that the majority of the original limestone was lost to acidic water associated with organic decay. Nevertheless, D. R. Hickey (oral comm., 1981) noted that black shales in Illinois sometimes have myalinid shells preserved in them, without discernible etching. It's difficult to see how certain shells would be preferentially eliminated, while nearby ones would be preserved untouched.

The majority of workers favor nucleation mechanisms for concretion formation, usually centered on decaying organisms. Weeks (1957) noted that such concretion formation could take place swiftly, and cited post-Pleistocene fish-bearing concretions in Canada. Berner (1968, 1969) stated that with the decay of vertebrates, $Ca^{+2}$ reacts with long-chain fatty acids to produce stiff Ca-soaps (adipocere), which are supersaturated in respect to $CaCO_3$. During later stages of decay, ammonia production becomes dominant over acid production, and the environment becomes alkaline, permitting calcite to form from the decaying soaps, which maintained the shape of the animal during early burial. Berner noted that invertebrates may take a different course: if the environment is undersaturated with $Ca^{+2}$, organic acids (other than carbonic) may drop the pH to very low levels and destroy the shell. If $Ca^{+2}$ is sufficient, pH levels will rise after a brief initial drop, and carbonate may be precipitated. Zangerl (1971) also called on the decaying organisms to locally alter their environment, citing release of $CO_2$ and $NH_3$ as favorable to nucleation of early concretions.

Wiggins (1981) found microspar concretions in the dark Mississippian Barnett Shale of Texas, which are apparently similar to those under discussion, with undeformed organic-rich and phosphate laminae continuing through the concretions. Bacterial sulfate reduction is indicated by the presence of pyrite and sphalerite. Wiggins' stable isotope work indicated that the carbon in the calcite is from the organics, while the oxygen is from seawater. He hypothesized that local phosphatization of pre-existing carbonate would produce $CO_2$, which could in turn concentrate to produce microspar concretions.

Possible reactions involving phosphate make the chemical equilibria extremely complex. If phosphate is present to excess in the environment, $Ca^{+2}$ will be removed by apatite precipitation. This may lower $Ca^{+2}$ levels below equilibrium with respect to $CaCO_3$, causing dissolution of calcite to restore the equilibrium. (This is the reaction Ames, 1959, cited to replace calcite with apatite.) This will continue until either the $PO_4^{-3}$ level drops to equilibrium, and/or $HCO_3^-$ becomes high enough to stabilize calcite. It is possible that carbonate concretions (and any shells present) must exist in the face of such an environment.

The concretions represent anomalous local chemical conditions, particularly in a dominantly noncalcareous shale. Their localized distribution suggests that appropriate conditions of formation are not widely met; possibly they are related to marginal areas of black shale deposition. The conditions appear to be most readily met by fortuitous dead animals, although such animals are not always

apparent. At present, the concretions are fertile ground for further research.

## Coal

Coal has been reported in every Missourian outside shale of the Midcontinent, but it is generally very minor and local. Only the Thayer Coal of the Chanute Formation has ever been mined on a commercial scale. The Vilas Shale has very minor coals reported, and locally contains driftwood and reworked peat, but is generally poor in coal. The Galesburg/Coffeyville, on the other hand, has named coals (e.g., the Cedar Bluff and Davis City) of regional extent; although not thick enough to be mined, they are of stratigraphic and depositional significance.

The Missourian cyclothems of Illinois also have thin coals, which are locally thick enough to be mined. Although the New Haven Coal, in the Shoal Creek cyclothem, was not seen during this study, the LaSalle Coal in the LaSalle cyclothem, the Flannigan Coal in the Fithian cyclothem, and the Womac Coal in the Macoupin cyclothem were examined, to make some comparisons with the Midcontinent.

Examination of the coals was handicapped by the lack of mining. Although some exposures were in active quarries and rapidly eroding stream banks, others were badly weathered. Weathering generally oxidized the coal, and converted the iron sulfides present to goethite, imparting a brown color to an otherwise black coal. Weathering usually also made the coal finely blocky to granular in texture.

Generally, the coals found are autochthonous, black, bright coals with a blocky fracture. The thermal values of Desmoinesian coals below and Virgilian coals above suggest the Missourian coals in the Midcontinent are mainly high volatile bituminous C in rank.

The coals are generally finely banded, normally 1 to 2 millimeters, although bands a centimeter or more thick are not rare. This banding supports the conclusion that the coal is autochthonous, since the variation in coal lithotypes reflects variation in the relative height of the water table (Stach, 1975). If the coal were allochthonous or sapropelic, it should not be banded. In several cases, the autochthonous nature is supported by the presence of rooted zones below the coal, and by pedotubules in the top of the subjacent limestone.

The coals are usually rich in vitrain and clarain, indicating moist conditions (Stach, 1975a); durain is not common and fusain is rare. However, locally durain-rich and fusain-rich coals do occur. The Davis City Coal tends to be durain-rich, and at Decatur City, Iowa (Locality DeCl), appears relatively rich in fusain. The LaSalle Coal and the top seam in the Coffeyville at Tulsa are also durain-rich. Whether this represents wetter or drier conditions is not certain; Stach (1975a) indicated that this depended on the type of durain. However, the indicated conditions varied, and may reflect intermittent flooding.

Locally, some coaly material was transported. The uppermost Coffeyville north of Coffeyville, while quite shelly, has local lentils of vitrain about a centimeter thick; the shale above the

LaSalle Coal may have similar lentils. The Vilas has pieces of carbonized wood with bleached shale haloes, which was apparently driftwood.

The coals generally contain some pyrite. Pyrite and goethite are occasionally found in cleats, and occasionally on weathered outcrops the adjacent shale will be bleached or have small sulfur blooms from oxidizing pyrite. The spores and associated macerals also show frequent impressions of small, disseminated pyrite crystals.

The presence of the pyrite is readily explained. Most of the coals are overlain by marine deposits. With a plentiful organic supply, the sulfate-reducing bacteria produced abundant $H_2S$, yielding abundant pyrite. In many cases, even the fluvial coals have been affected, as there was not enough overlying sediment to protect them from the seawater and bacteria.

Banaszak (1981) determined an idealized equation:

$$7CH_2O + 4SO_4^{-2} + 2Fe^{+2} \rightleftharpoons 2FeS_2 + 3H^+ + 7HCO_3^- + 2H_2O$$

Not only is pyrite produced, but the lowering of pH would make kaolinite the only stable clay. If and when the system becomes buffered, the bicarbonate produced will favor calcite precipitation, possibly as cleat fill. Both calcite and kaolinite are common in coal-bearing strata.

The coal seams are usually relatively free of clastic deposition. While multiple seams several feet apart are common, thin partings within the coal are not. Only at Bartlesville in northern Oklahoma

(Locality Btl) do significant partings occur in the "Cedar Bluff". Bone coal also is rare; fissile, shaly coal or coaly shale appears below the Cedar Bluff near Liberty, Kansas (Locality Lil).

## Sandstones

Sandstones in the Missourian units of the Midcontinent and the Illinois Basin form only a very small part of the sedimentary sequence. Bennison (1981) noted that they occur in a variety of stratigraphic positions, and represent a number of different environments. However, certain patterns may be used to formulate a coherent system for interpreting the features present.

Missourian sandstones have several dominant characteristics. One is that most are fine to very fine grained, with those of the Midcontinent being finer than those of Illinois. (In Illinois, Andresen, 1961, stated that the median grain size of the Trivoli Sandstone is 0.17 mm, while Siever, 1957, found that in the Mt. Carmel and Shoal Creek sandstones the modal size is 0.25 mm; Verhulst, 1970, reported that in the sandstones of the Kansas City Group the mean size is 0.078 mm, and Seale, 1981, reported the Marchand sands of the Anadarko Basin are mainly fine to very fine grained.) The sands are usually matrix-rich, particularly those in Illinois and the finer-grained examples in the Midcontinent. Quartz, usually monocrystalline, is the dominant detrital mineral. Other minerals, including mica, are usually minor (Table 6). Among the heavy minerals, zircon and tourmaline are usually dominant, and garnet may be locally important (Table 7). Verhulst (1970) argued that the presence of garnet in

Table 6

Major grains of selected Pennsylvanian sandstones

| Unit and Area | Grain | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | Quartz | Feldspar | Mica | Matrix | Rock Fragments | Chert | Calcite Cement | Glaucony | |
| Bartlesville SS, SE Kansas | x | m | m | | x | x | | x | Bass et al., 1937 |
| Hoxbar SS, S Oklahoma | 90+ | x | x | | | x | | | UnKauf, 1970 |
| Dodds Creek SS, SE Kansas | 53-58 | 2 | 2-7 | 3 | 37-44 | | | | Stobbe, 1971 |
| Marchand SS, SW Oklahoma | 89-97 | 2-8 | x | | | 5-10 | | x | Seale, 1981 |
| Noxie and Cottage Grove SS, SE Kansas | 90-95 | x | x | | | x | x | | Haggiagi, 1970 |
| Bonner Springs Siltstone, SE Nebraska | x | | 20 | 22 | | | | | Whitcomb, 1965 |
| Rock Lake SS, SE Kansas | x | m | m | | | m | | | Moussavi-Harami, 1980 |
| Kansas City Gp SS, E Kansas | 36 | 11 | 4 | 2.8 | 42 | | | | Verhulst, 1970 |

Table 6 (cont'd.)

| Unit and Area | Grain | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | Quartz | Feldspar | Mica | Matrix | Rock Fragments | Chert | Calcite Cement | Glaucony | |
| Trivoli SS, Illinois | 54.7 | 3.6 | 1.9 | 7.2 | 9.6 | .5 | 6.2 | | Andresen, 1961 |
| Mt. Carmel and Shoal Ck SS, Illinois | 64 | 4.5 | 1.8 | 1.0 | 26 | | 2.4 | | Siever, 1957 |
| Missourian SS, Illinois | 60-80 | 2-5 | 1-5 | 15-30 | | | | | Potter and Glass, 1958 |

Numbers = percentage average; "x" = present; "m" = minor

Table 7

Heavy minerals of selected
Pennsylvanian sandstones

| Unit and Area | Heavy Minerals | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | Zircon | Tourmaline | Rutile | Garnet | Spinel | Staurolite | Magnetite | Apatite | Others | |
| Minturn Fm Cent Colorado | | x | | x | | | | | | This study |
| Bartlesville SS, SE Kansas | x | | x | | | | x | | Epidote | Bass et al., 1937 |
| Cherokee SS, N Iowa | x | x | x | x | | | | | Leucoxene, chlorotoid, ilmenite | Lindsay, 1981 |
| Desmoinesian and Ladore SS, S Iowa | x | x, | m | | | m | m | m | Leucoxene, chlorotoid, anatase | Clark, 1950 |
| Marchand SS, SW Oklahoma | x | x | | | | | | | Sphene | Seale, 1981 |
| Hoxbar SS, S Oklahoma | | | x | | | x | | | Kyanite | UnKauf, 1970 |
| Dodds Creek SS, SE Kansas | m | Up to 18.3 | | | Up to 26.3 | | x | | Ilmenite | Stobbe, 1971 |
| Kansas City Gp SS, E Kansas | 24.9 | 18.3 | | 30.7 | 1.0 | 1.0 | | 3.3 | | Verhulst, 1970 |
| Tyro Oölite, SE Kansas | x | x | | ? | | | x | | | This study |

Table 7 (cont'd.)

| Unit and Area | Heavy Minerals | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | Zircon | Tourmaline | Rutile | Garnet | Spinel | Staurolite | Magnetite | Apatite | Others | |
| Rock Lake SS, SE Kansas | m | m | | | | | | | | Moussavi-Harami, 1980 |
| Trivoli SS, Illinois | 54.2 | 21.6 | 10.0 | 7.4 | | | | 4.8 | Epidote, andalusite, sillimanite | Andresen, 1961 |
| Shoal Creek and Mt. Carmel SS, Illinois | 30 | 30 | 10 | x | | | | | | Siever, 1957 |
| Missourian SS, Illinois | 15-65 | 20-70 | 0-5 | 0-15 | | | | | | Potter and Glass, 1958 |
| Cambridge LS, Ohio | | x | x | m | | | | | | Bradley, 1964 |
| Ames LS, Ohio | x | x | x | | | | x | | Leucoxene | Bradley, 1964 |

Numbers = average percent; "x" = present; "m" = minor

Midcontinent sandstones and its absence in the eastern Illinois Basin indicated that the sands were from different sources, with those in the west derived from the Canadian Shield. However, this may be complicated by Clark's (1950) observation that garnet can be lost by intrastratal solution.

The sands are derived principally from the adjacent positive areas: from the Ouachitas in the Anadarko Basin (Seale, 1981); from the Canadian Shield in the northern Midcontinent (Verhulst, 1970; Lindsay, 1981); and from the eastern shield and Appalachians in the Illinois Basin (Wanless, 1957; Potter, 1963). The grains in all areas indicate derivation from older sediments and low-grade metasediments; first cycle igneous grains are rare (Clark, 1950; UnKauf, 1970; Graham et al., 1976; Moussavi-Harami, 1980; Lindsay, 1981).

Sandstone diagenesis is very instructive, especially in sandstones with calcite cement, which may be derived from carbonate fossil fragments (Moussavi-Harami, 1980). Dutton (1981, 1982) reported that only the distal, fossiliferous sands of the Anadarko Basin have calcite cement, and UnKauf (1970) noted that the Hoxbar shallow marine orthoquartzites are calcite-cemented. Donahue and Rollins (1974) stated that lower Conemaugh marine sands are calcite-cemented, in contrast to the matrix-rich fluvial sands.

An apparent corollary is that the marine sands are usually orthoquartzites, in contrast to the fluvial-deltaic sands in the same region, which are usually subgreywackes. UnKauf (1970) reported this feature in the Hoxbar, and Moussavi-Harami's (1980) orthoquartzites are marine. Donahue and Rollins (1974) reported that the

delta-destructive sands of the Conemaugh are better sorted and lighter in color than contemporary channel sands. Ferm (1974) attributed this pattern to coastal reworking of fluvial sands, which removed the unstable minerals and clays to produce orthoquartzites.

Although it is not the only possible explanation for this characteristic pattern, marine reworking of the sand is compatible with the origin of the calcite-cemented orthoquartzites found in this study. The Naish in the Kansas City area (Fig. 48a) is petrographically similar to the marine Rock Lake sandstone described by Moussavi-Harami (1980) (Fig. 48b).

Most of the Midcontinent and Illinois Basin sands do not follow this pattern, however. Most are subgreywackes, rich in clay matrix and poor in calcite cement (Fig. 48d). Much of the clay is derived from alteration of unstable mineral grains, and occurs when ground water moves through the sands. Dutton (1981, 1982) stated that clay formation took place after principal calcite cementation, and did not occur if the rock was already cemented.

The vast bulk of the authigenic clay in the Illinois Basin subgreywackes is kaolinite (Potter and Glass, 1958; Millot, 1970), and the data of Verhulst (1970) and Visher and others (1971) indicate that this is probably true in the Midcontinent as well. Nesbitt (1980) stated that the detrital fragments in the sandstones are too rare to control the equilibria, and that they should react to produce stable clays. Hurst and Irwin (1982) stated that due to low pH and low ion activity, freshwater flushing through the sandstones would be expected to produce abundant authigenic kaolinite. They noted that

Figure 48. Midcontinent sandstones.

a. Orthoquartzitic Naish Sandstone, near Stanton, Kansas (Locality Sn1). Note the poikilotopic calcite cement and fossil fragments (f).

b. Orthoquartzitic Rock Lake Sandstone, near Tyro, Kansas (Locality Ty1). Note the relatively coarse grain size compared to the other sands, the lack of mica, matrix, or cement, and the widespread pressure-solution grain contacts.

c. Orthoquartzitic sandstone below the Eudora ("Torpedo Sandstone") near Copan, Oklahoma (Locality Cp1). Note the mica grains (m) and the common pressure-solution grain contacts.

d. Subgreywacke siltstone near the top of the Galesburg Shale, near Stark, Kansas (Locality Ca1). Note the abundant mica, possibly on the bedding surfaces of the ripple cross-bedding.

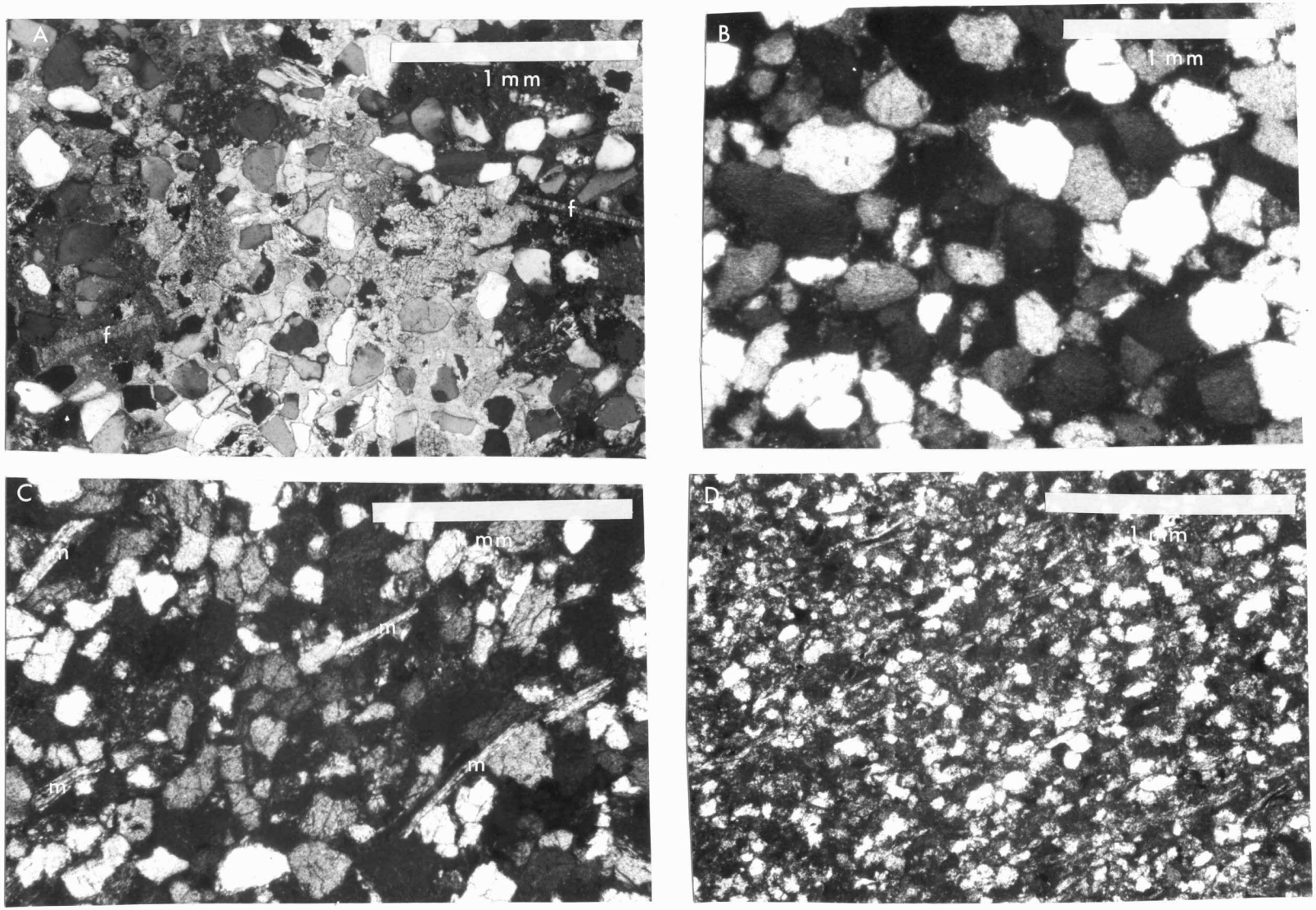



Figure 48.

changes in sea level and hydraulic head would be important in determining which authigenic clays formed at a particular time. Thus, the abundant authigenic kaolinite in the sandstones might reflect rapid degradation of unstable grains in a freshwater phreatic environment.

The formation of kaolinite contrasts with that of chlorite. Chlorite requires a higher $Mg^{+2}$ or $Fe^{+2}$ activity, and may form from marine pore waters (Weaver and Pollard, 1975; Hurst and Irwin, 1982) as well as during later diagenesis.

The relationship between the authigenic clays and the surrounding shales is intricate. Hurst and Irwin (1982) stated that the shales control the pH, silica concentration, and cationic activity in the sandstones, and thus the clays that form there. In the Midcontinent and Illinois Basin, the clays in the shales appear to be essentially at equilibrium, with little diagenetic mobilization of ions; thus, the authigenic clays in the sandstones are kaolinite, with relatively little illite and chlorite.

The tendency for kaolinite to form in the sandstones complicates the interpretation of detrital clays. With increasing clastic influx from well-drained uplands, presumably the amount of detrital kaolinite should increase. However, with increasing grain size and increasing porosity, the amount of authigenic kaolinite would also be expected to increase. The increase in kaolinite in sandy and other shales can be attributed to detrital sources, as the units are essentially all clay, but when the unit is grading into a sandstone, either mechanism may explain the increase in kaolinite.

When considered as part of the overall pattern of Upper Pennsylvanian sedimentation, the sandstones systematically fall into two groups: (1) the proximal sandstones, rich in unstable mineral fragments and often subject to fresh water, are matrix-rich, kaolinitic subgreywackes, and (2) the distal marine sands, with most of the unstable grains and clay removed, are orthoquartzites, which may be calcite-cemented if the content of shelly material is large enough. In some cases, if burial is significant, mobilization of $Fe^{+2}$ with diagenetically released $CO_2$ may produce siderite cement. This pattern suggests that the amount of reworking (i.e., the depositional environment) is a principal control of sandstone petrology.

It should be emphasized that this model is not the only one possible for Upper Pennsylvanian sandstone deposition. However, variation in parent sand sources appears unlikely. Most sands in the Midcontinent and Illinois Basin came from broadly similar sources, and the occurrence of orthoquartzites and subgreywackes in the same area and apparently originating from the same direction suggest other variable controls the petrology. Environmental control is consistent with the sandstone petrology observed in this study, and requires no abnormal conditions.

## Diagenesis and Catagenesis

> Apparently early diagenesis is a relatively uninteresting period during the geological history of clay minerals.
>
> Berner, 1971, p. 185

After the initial formation and burial of a sediment, it can be extensively modified by the effects of burial-dependent temperature and pressure increases and changes in chemical equilibria. In shales, these changes may not be physically apparent, but often the net results of changes in the shales may have profound effects on the adjacent lithologies.

The usage of various terms to describe early burial processes is confusing, as there is little agreement on precise terminology. The chief distinctions come from organic geochemistry, since the processes of coalification and hydrocarbon generation are more pronounced at lower temperatures than are the commonly recognized mineral transformations. Whittaker and Dyson (1980) defined organic diagenesis as taking place below 50°C, where catalytic reduction, stripping, and reforming of organics take place. They defined catagenesis as the zone of thermocatalytic processes, roughly from 50°C to 200°C, where higher temperatures cause the decarboxylation, cracking, and hydrogenation of organic material. Whittaker and Dyson recognized that temperature exposure time is critical, as did Heroux and others (1979), who used catagenetic boundaries related to coal rank. Catagenesis began at the rank of hard lignite and extended to meta-anthracite, where the realm of anchimetamorphism begins.

Important mineralogical changes also begin to take place within this range, and since the rocks studied were apparently subjected to these conditions, the processes are significant. In this discussion, the changes are limited to those that may be dependent on burial

conditions, especially temperature. Those that are chiefly dependent on changes in chemical activity regardless of temperature are discussed elsewhere, especially when pertinent to lithology.

## Level of Organic Metamorphism

The level of organic metamorphism (LOM) is a widely used scale to describe the catagenetic "grade" of various reactions. The widely published LOM scale is that of Hood and others (1975), developed for Shell Oil Company. Because of some peculiar complications and inconsistencies, a brief discussion is appropriate.

Hood and others based their scale on thermodynamic principles, especially that rates of organic reactions would increase with increasing temperature; specifically, reaction rates should double with each $10^{o}C$ rise in temperature. They then composed a linear LOM scale from 0 (earth surface conditions) to 20 (meta-anthracite rank). Crudely, each step increase in LOM should equal about $10^{o}C$ increase in burial temperature.

However, Hood and others recognized that in organic metamorphism time can partially substitue for temperature, so they attempted to correlate their scale to a time-temperature graph. They correlated their data with the temperature-rank relationship found by Suggate (1959) in Tertiary coals in New Zealand. They rejected the similar temperature-rank (or burial-rank) relationship found by Bostick and Damberger (1971) in the Illinois Basin, because Bostick and Damberger's data could not be plotted quite so lineraly, and a given coal rank at the lower rank end would have a lower LOM than if

Suggate's data were used. (For comparison, high volatile bituminous C coal, which is common in Illinois and the Midcontinent, has an LOM of 7.2 to 8.5 using Suggate's data, but 5.5 to 7.2 using Bostick and Damberger's data.) This bears directly on the problem at hand. Hood and others (1975) chose to illustrate their principle with the increasing LOM of organics in Permian and Upper Pennsylvanian strata in the Anadarko Basin. They noted good agreement in deeper strata and at higher LOM (where Suggate's and Bostick and Damberger's data are comparable) but noted that at shallower depths the coals plotted at a higher LOM than would be expected if the system were strictly linear with a uniform geothermal gradient. They added no further comment, but it is apparent that if Bostick and Damberger's data had been used, the coals would have been assigned a lower numerical LOM, and the anomaly might have been largely eliminated. The significance of this is that in low ranks, where Suggate's and Bostick and Damberger's data diverged, time is a bigger factor in organic reactions than Hood and others calculated. Thus, to reach a given LOM on their scale, less heating is required with longer times (e.g., since the Pennsylvanian) than they calculated.

Kisch (1969) observed that there are no retrograde reactions in organic metamorphism. The reactions are effectively irreversible, as equilibrium of products and reactants are never achieved.

In spite of the apparent flaws, the LOM scale of Hood and others (1975) was applied to coals in the Midcontinent to estimate the effective burial temperatures to which the studied shales have been exposed. This is possible because Hood and others provided a

comparison to both the heat (BTU) value and the fixed carbon:volatile matter ratio of coals (Fig. 49 shows the LOM calculated on the basis of BTUs; the values derived from the fixed carbon:volatile matter ratio are comparable, but slightly lower and more variable). Because very few Missourian coals could be plotted, much of the data is derived from Desmoinesian coals, with a few Virgilian (Nodaway) values. Two trends are apparent: LOM of the coals generally increases toward the south, and also is higher lower in the section. Both trends are compatible with overall Midcontinent patterns.

(A few notes on the calculation of LOM values are appropriate. Vassoyevich and others, 1970, used the heat values and fixed carbon:volatile matter ratios of whole coals as a scale. Teichmüller, 1974, reporting on the Shell LOM scale, noted that the heat value was calculated on the basis of moist, ash-free coal, the standard basis for rank calculation used by the ASTM. The fixed carbon:volatile matter ratio is calculated on a dry, ash-free basis. This procedure was apparently followed by Hood and others, 1975. However, whole coal values are subject to considerable variation, so many scales of organic diagenesis are standardized to less variable vitrinite alteration. However, vitrinite values are not available for the Midcontinent.)

Using the estimated LOM values and Hood and others' (1975) chart, an approximate effective temperature can be determined. (Bear in mind from the previous argument that the potential error exceeds the actual one.) Using an age of 275 million years and an LOM of 7.2, an

Figure 49. LOM (Level of Organic Metamorphism) values for Midcontinent Coals.

Calculated using the scale of Hood et al, 1975. BTU values of coal calculated on a moist, ash-free basis using the equation of Amer. Soc. Testing and Materials, 1978.

Data from Fieldner et al., 1926 (Missouri); Fieldner et al., 1928 (Oklahoma); Fieldner et al., 1929 (Kansas); Olin and Kinne, 1930; and Cooper et al., 1949 (Iowa).

Coals

■ Desmoinesian

● Missourian

◆ Virgilian

Outcrop pattern is Missourian strata in Nebraska, Iowa, and Missouri; Galesburg Shale and Vilas Shale in Kansas; and Coffeyville Formation in Oklahoma.

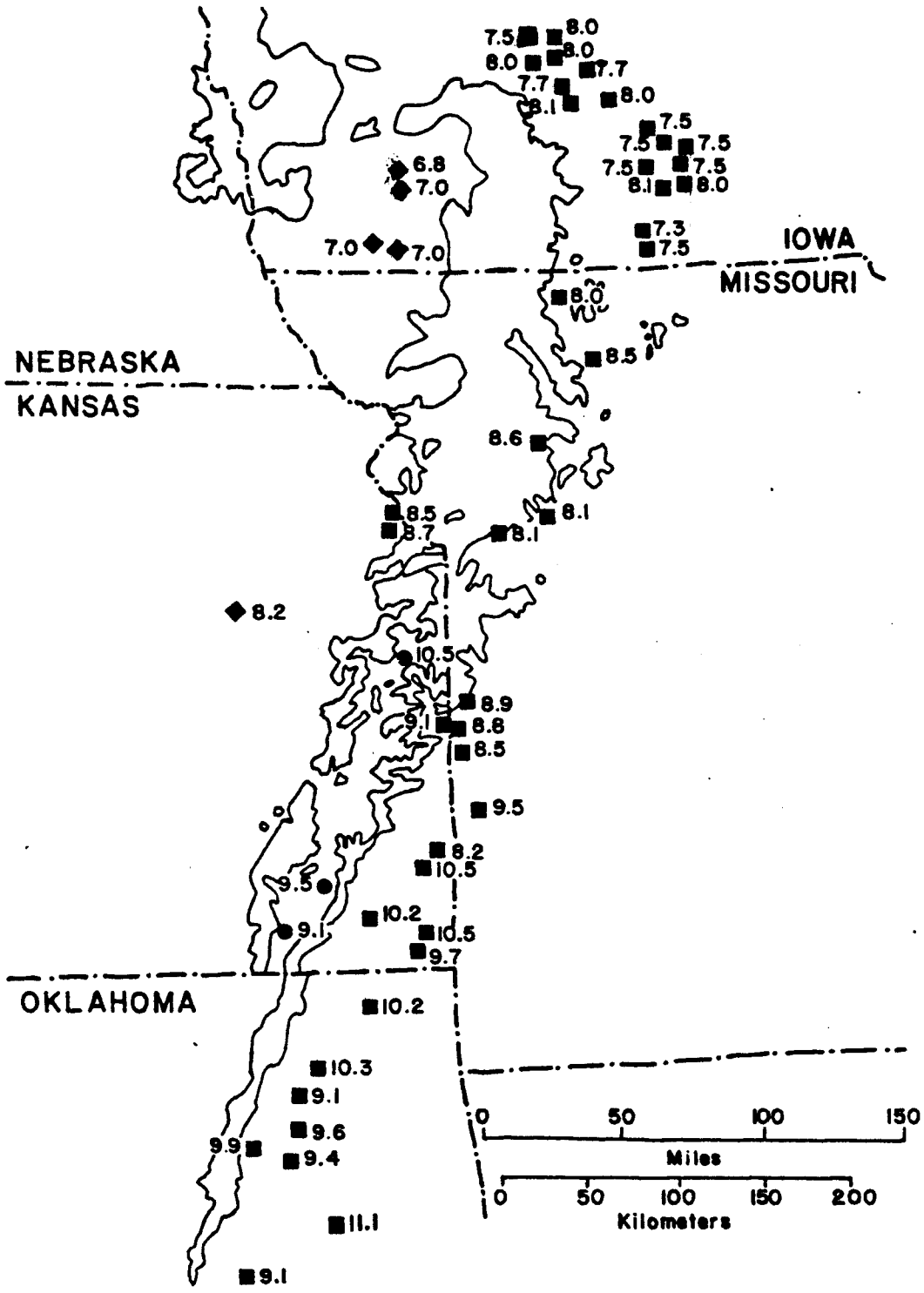

IOWA
MISSOURI
NEBRASKA
KANSAS
OKLAHOMA
0 50 100 150
Miles
0 50 100 150 200
Kilometers

Figure 49.

effective temperature of 25°C is required; for an LOM of 8.5, the effective temperature is 40°C.

These values are important in terms of oil generation. Vasseyovich and others (1970) determined hydrocarbon generation in relation to coal rank; by tying coal rank to LOM, Hood and others (1975) also tied in hydrocarbon formation. They calculated that diagenetic methane would be produced below an LOM of 7.8, and the oil generation window would range between 7.8 and 11.6, with the principle pulse at an LOM of 9 to 10. Thus, the organic-rich sediments throughout the Midcontinent should have produced diagenetic methane, but only those in the south would have produced much oil. Those in the Forest City Basin would be verging on oil production, but given the limited source rock potential and low level of maturity, little Pennsylvanian oil would be expected in the Forest City Basin (although it is possible).

Correlative to this observation, Hatch and Leventhal (1982) noted that the organic signatures of the Cherokee crude oils in northeastern Oklahoma and southeastern Kansas are similar to the patterns found in the contemporary black shales. Thus, there is supporting evidence that when the necessary heat and time are available, the black shales can produce oil.

## Conodont Color Alteration

Epstein and others (1977) provided an independent estimate of the thermal history of the Midcontinent sediments. They devised a conodont color alteration index (CAI) that is dependent on both time

and temperature. Table 8 lists some selected values from studied conodont collections. Both the Midcontinent and the Illinois Basin CAI values are 1.5 or less. Given 275 million years, this would indicate a burial temperature of less than 50°C. If a short period of high temperature in a generally low temperature regime is assumed (e.g., a brief hydrothermal pulse), the conodont colors could be accounted for by $10^5$ years at 100°C; greater lengths of time and/or greater temperatures would exceed the observed values.

There is a curious anomaly in the Eudora Shale, with the CAI of the conodonts suggesting a westward decrease in alteration from Iowa to Nebraska. It is not known if this significant, due to the sparse data and the nature of the color determinations.

For comparison, a conodont sample from a black shale of the Paradox Formation of Colorado is included. These shales are source rocks for considerable oil fields in the Paradox Basin. However, a temperature cannot be estimated from the CAI, as the effective time of burial and thermal metamorphism is not known.

## Palynomorph Color

Gutjahr (1966) compared coal rank to the color alteration of spores and pollen. His method was quantified, using consistent large, smooth palynomorphs and measuring light transmittance. This was not formally carried out in this study, but the spore colors observed were consistent with other indicators of LOM and temperature. Most of the spores observed prior to staining were light yellow to yellow. According to Hood and others (1975), spores begin to turn noticeably

Table 8

Studied samples - selected conodont color alteration indicies*

| | Unit | Sample | CAI |
|---|---|---|---|
| COLORADO | Paradox Fm | BGV1/top | 4.0 |
| ILLINOIS | Black shale below Shoal Ck | Ch1/-737.1' | 1.5 |
| | " | Cl1/scbs | 1.5 |
| | " | Oa1/-11 | 1.3 |
| | Black shale below LaSalle | LS1/58 | 1.0 |
| | Black shale below Macoupin | Cr1/mabs | 1.3 |
| | Black shale Fithian cyclothem | Ft1/4 | 1.5 |
| IOWA | Stark Shale | DC1/67 | 1.5 |
| | " | Be1/-513'8½" | 1.5 |
| | Eudora Shale | Wi2/126 | 1.3 |
| | " | Le1/4 | 1.2 |
| KANSAS | Stark Shale | Bartosovsky -4194' | <1.5 |
| | Canville Ls | De1/c | 1.5 |
| MISSOURI | Stark Shale | UV1/41 | 1.5 |
| NEBRASKA | Eudora Shale | Lo1/90 | 1.0 |
| OKLAHOMA | Stark Shale | Bt2/7 | 1.5 |
| | Lost City Ls | Tu1/1c | 1.3 |
| SOUTH DAKOTA | Minnelusa Fm | Grey | 1.0 |
| UTAH | Honaker Trail Fm | Go1/1st Ls | 1.7 |

*Technique from Epstein and others, 1977.

amber to brown at an LOM of 9.5, and the spores observed were generally a little short of that level.

## Silification

Quartz appears in the studied rocks in a variety of non-detrital forms. Most prominent are the periodic horizons of chert nodules, which are particularly widespread in the Winterset. However, quartz also appears as originally opaline fossils that have inverted (e.g., sponge spicules and radiolarians), as replacements for calcareous fossils, as the small botryoidal and discoidal accretions known as beekite, and rarely in small, discrete, dipyramidal prisms of crystalline quartz.

The quartz distribution suggests several possible origins. Silification in the base of the upper limestone is quite common; Mossler (1970) noted that bryozoans and brachiopods at the base of the Bethany Falls are often silicified, and a similar pattern is evident in the Winterset. Price (1977) noted that the brachiopods in the Winterset at Winterset, Iowa (Locality Wil) are often silicified, and many acidized samples of Winterset processed in this study produced silicified fossils, especially brachiopods. In one instance (Locality Cal), the basal Winterset was pervasively silicified, with the matrix being replaced, rather than the fossil material.

Toomey (1974) observed the distribution of beekite in the Virgilian Leavenworth Limestone. He noted that it is rare in Kansas, and more common in Iowa and Nebraska. He also noted that in areas of abundant sphalerite in the limestone (e.g., southeastern Kansas) the

calcareous foraminifers were silicified. Neither observation was confirmed in this study, since systematic observations were not made, but either may be generally applicable.

Berner (1971) suggested that much of the silicification in fossiliferous carbonate rocks could be attributed to the mobilization of the silica of opaline sponge spicules. He stated this could produce local shell silicification, as well as chert nodule formation. This may be an effective mechanism in at least some silica formation in the studied rocks. Wenberg (1941) noted that some chert in Upper Pennsylvanian strata in southwestern Iowa grades into sponge spicules, and petrographic evidence from some examined chert nodules (Locality Lel/sc) supports this. The example of pervasive silicification mentioned above has associated abundant large sponge spicules, and siliceous sponge spicules most commonly appeared at the base of the upper limestone. Silica also may have been remobilized from within the black core shales; both sponge spicules and radiolarians are replaced by carbonate and apatite in nodules in the shale (Kidder, 1982), and molds of radiolarians exist in the shale proper (Berendsen and Nodine-Zeller, 1978).

Formation of chert nodules, especially those that occur in persistent horizons, may be due to other processes. Dubois (1979) observed such horizons in the Winterset, and cited Wilson (1975) as suggesting that this marked the level of the water table. Knauth (1979) provided thermodynamic evidence supporting this, demonstrating how marine and meteoric waters, both saturated with $CaCO_3$ and undersaturated with $SiO_2$, can be mixed to produce a solution undersaturated

with $CaCO_3$ and supersaturated with $SiO_2$. In such an environment, calcite would dissolve and be replaced by chert. Knauth stated that the silica would be from largely biogenic material dissolved in meteoric water, and noted that isotopic data supports this conclusion.

Thus, it appears that some chert formation in the studied rocks may be due to the influence of meteoric waters while other silicification may be due to local supersaturation by unstable opaline silica. The former is generally found in horizons in the upper limestone, whereas the latter is more dispersed, but appears to be more common at the base of the upper limestone.

## Tourmaline

Small, dark-colored, euhedral tourmaline (probably schorl) grains were observed among the heavy sand grains in the Tyro oölite near Tyro, Kansas (Locality Tyl/oo). These are apparently similar to the overgrowth-bearing tourmaline reported in the Canville and lower Winterset limestones of northeastern Oklahoma by Cronoble and Mankin (1965).

Such tourmaline has long been known, although the chemistry is poorly understood. Krynine (1946) stated that tourmaline overgrowths formed before cements and were usually clear, Mg-rich dravite. He stated that they formed penecontemporaneously with the ocean-bottom sediments, and were not related to igneous activity. Gautier (1979) documented formation of authigenic tourmaline in a sandstone, and noted that reports of overgrowths were fairly common. His tourmaline occurred in a fine-grained feldspathic, lithic arenite, and was

associated with authigenic quartz, Fe-rich chlorite, and slightly expandable illite-smectite mixed layer clay. It preceded formation of calcite cement.

Although the occurrence of euhedral tourmaline is little more than a curiousity, it is important to note that it does not indicate hydrothermal activity or short transport and immaturity of the sand in which it is found. However, it is not possible to say when, or under what prevailing conditions, the tourmaline acquired its overgrowths.

## Kaolinite and Dickite

Kaolinite is common in the studied sediments not only as a detrital mineral, but also as an authigenic one. It usually occurs as a white, powdery void filling. Payton (1966) observed kaolinite filling oöid molds in the Bethany Falls and Winterset limestones. Mossler (1970) noted kaolinite replacing oöids in the Bethany Falls, but noted that authigenic kaolinite was rare in the phylloid algal calcilutite due to lack of voids. Authigenic kaolinite also was observed in several places in this study. Kaolinite is quite common in oölites with oömoldic porosity, and occurs less frequently in other environments where porosity was developed. In the Bedford, Iowa, core, the rubbly calcilutitic top of the Bethany Falls (Be1/-522.3') has a few voids (possibly birdseye structures) filled by kaolinite. Kaolinite also occurs as crack fillings in septarian microconcretions in the Galesburg Shale at Unity Village, Missouri (Locality UV1).

Kaolinite, accompanied by minor quartz, also replaces echinoderm fragments in the top of the Ladore Shale near Cherryvale, Kansas (Locality BHC2).

Two models of kaolinite formation may be applicable here. Hayes (1963) suggested a model for kaolinite formation in the Mississippian Warsaw geodes of southeastern Iowa, which occur in argillaceous dolomitic mudstone; the clays in the host rock include chlorite, illite, and mixed layer illite-smectite, but no kaolinite. Hayes proposed that original calcitic concretions were dissolved, leaving silicate "wreckage" in an acid environment. Then $Al^{+3}$ was brought in, producing kaolinite. Hayes noted that the kaolinite was very early, and is found in the quartz and calcite of the geode fillings. He also noted that relict calcitic concretions found with the geodes lack kaolinite. Such a model may explain some of the kaolinite found in this study.

Hurst and Irwin (1982) produced a different model for kaolinite formation in sandstones that may apply to kaolinite in limestones and shales as well. They recognized two modes of kaolinite formation: flux-dominated and diffusion-dominated. Flux-dominated kaolinite precipitates from fresh water, where low pH and low ion activity favors formation of kaolinite over other clays. Diffusion-dominated kaolinite forms in marine rocks without flux, depending on low pH from $CO_2$ formed during decay to produce a favorable environment. Such marine kaolinite would be uncommon and perhaps better crystallized than the flux-dominated kaolinite.

Under this model, kaolinite would be most common where fresh water was actively flushing through the rock; thus, it most likely

would form in the upper portions where there was significant permeability. Although it might be found elsewhere, it would be less common.

Dickite is generally considered to be a high-temperature polymorph of kaolinite. It commonly occurs in hydrothermal vein deposits, and has been synthesized in the lab only at 350°C (Hayes, 1967). Among other Midcontinent occurrences, it is reported from the lead-zinc ores of southeastern Missouri and with cinnabar in the Arkoma Basin in southwestern Arkansas (Tarr and Keller, 1936).

Hayes (1967) and Schroeder and Hayes (1968) reported dickite from Upper Pennsylvanian strata in eastern Kansas. Among other localities, they noted dickite in the South Bend Limestone west of Altoona (Locality All) and in the Captain Creek Limestone at Neodesha (Locality Nel) and near Independence. The dickite usually fills voids in the phylloid algal mound facies; other, less permeable lithologies usually lack dickite and have only diagenetic kaolinite. Schroeder and Hayes attributed the dickite occurrences to hot waters emanating from the Late Cretaceous diatremes in Wilson and Woodson counties. The hot waters supposedly moved updip in the permeable algal mound facies, and precipitated dickite up to 60 miles updip.

However, this interpretation is based on interpretation of dickite as a high-temperature mineral; Hayes (1967) admitted that this is speculative and open to debate. For example, Bayliss and others (1965) described a Triassic freshwater sandstone in Australia with widespread dickite, but no evidence of hydrothermal activity. They also cited similar examples from England, Wales, and Pennsylvania.

(Oddly, many of the reports of dickite are from Carboniferous rocks.) They cited a personal communication from W. D. Keller, who found dickite in Upper Mississippian chert nodules near Columbia, Missouri, where he attributed it to intense weathering at the end of the Mississippian. Heroux and others (1979) stated that based on their own and other observations, dickite becomes common at about the conditions necessary to produce high volatile bituminous B coal, which is slightly above the prevailing conditions found in the Midcontinent. Thus, it may be that dickite formation is governed by yet unknown chemical parameters, and is not necessarily attributable to elevated temperatures.

## Clay Transformations

In recent years, there has been a growing awareness that clay mineral diagenesis and catagenesis represent part of a continuous sequence of events from deposition into the metamorphic realm. Smectite and kaolinite are relatively unstable, and with increasing burial convert into chlorite and illite. (Chlorite is also a principal low-grade metamorphic mineral, and illite is closely allied to and intergrades with muscovite.) Thus, there is a question of how intensively the clays in the rocks studied have been influenced by burial. This is important for two reasons: (1) could the clays in the original detrital suite have been extensively modified, and would it cause problems in interpretation, and (2) were possible reactions not isochemical; that is, were fluids produced or required that might have reacted with and significantly modified the adjacent rocks?

The second possibility may provide some indication of whether the clays have been modified. Alteration of the carbonates near the shales in the Pennsylvanian strata has been attributed to modification of the clays. A prominent example is the frequent occurrence of a thin zone (usually a foot or less) of dark, fine-grained, argillaceous ferroan dolomite at the base of the upper limestone. This usually represents a gradation from the underlying grey upper transition of the core shale to skeletal calcilutite above. The dolomite is usually soft (apparently due to the high clay content) and often weathers into a reentrant. Megafossils are not common and consist of unaltered original calcite. Mossler (1970) reported such a horizon at the base of the Bethany Falls, Price (1977) observed it at the base of the Winterset, and Siebels (1979) observed it at the base of the Stoner. Price (1981) also noted the phenomenon in the basal Myrick Station Limestone in the Desmoinesian Pawnee cyclothem. All three workers and Price and McHargue (1982) attributed the dolomitization to $Mg^{+2}$ moving out of the underlying core shale. Mossler observed that dolomite was also common along stylolites, clay seams, and diagenetic fractures (i.e., routes of fluid migration).

Reactive ions can be derived from clays in three ways: (1) with the loss of original interstitial fluid during compaction, (2) by cation exchange with exchangeable ions, and/or (3) by structural changes in the clay structure during diagenesis. The third mechanism has received a great deal of attention, as it is a profound process that greatly affects many of the diagenetic processes in the rock. Furthermore, such structural alteration could markedly alter the basic

clay suites present, and thus their interpretation. Because of its importance, it will be discussed first.

Smectite to Illite Transformation

There is considerable disagreement over which processes are important in the transformation of smectite to illite, and the relative significance of each. The basic nature of the reaction has been disputed, with a potentially broad impact.

Most of the important parameters are related to burial, although some are chemical. Availability of necessary ions, such as $Al^{+3}$ and $K^{+}$ can be determining factors (Heling, 1978; Srodon, 1979; Whittaker and Dyson, 1980), as well as the nature and size of the initial material (Heling, 1978; Srodon, 1979). Time for the reaction to proceed also may be important (Eberl and Hower, 1976; Heling, 1978). However, temperature appears to be the most important variable. Karpova and others (1969) estimated the onset of alteration to be at 70°C to 100°C, Perry and Hower (1970) stated the reaction takes place mainly between 55°C and 95°C, while Whittaker and Dyson (1980) stated that the range is 80°C to 200°C, with maximum alteration taking place at 100°C to 110°C. Van de Kamp (1976) noted that in Tertiary sediments mixed layer illite-smectites formed in the range of LOM 7 to 10, with only illite above that.

Eberl and Hower (1976) pointed out a basic difficulty in determining the meaning of the reaction. They stated that the available data could be interpreted in two ways. Either the reaction involved could be kinetic, and balanced on the prevailing temperature, or it

could be an equilibrium reaction, dependent on achieving activation energy. If the latter is applicable, it permits the drawing of a time-temperature diagram, similar to that used for LOM determinations. If this is applied to the studied clays, it allows some interesting conclusions. If a starting clay consisting of 100% expandable layers were assumed, to collapse it to a clay with only 20% expandable layers, given 250 million years, would require a temperature of only 5°C; if a temperature of 50°C were assumed, it would take only 1 million years. Since there are some clays present in the studied samples that are still essentially 100% expandable, this mechanism seems unlikely. However, Eberl and Hower stated that competing ions could slow the transformation. They also noted that empirically on the Gulf Coast the transformation takes place in the 50° to 100° range.

Perry (1974) suggested in the radiometric dating of clays that the age of the fine illite fraction (usually authigenic) reflected the time of diagenesis; he also noted that the rate of formation was temperature-dependent. Bailey and others (1962) attempted radiometric dating of Desmoinesian clays in southern Iowa and northern Missouri, where the detrital 2M illite yielded an age of about 390 million years, and the finer, supposedly authigenic 1Md illite produced an age of 120 million years. Superficially, it would appear that authigenic clay formation was a slow process or considerably delayed. However, 1Md crystallites are considerably smaller than the detrital illite flakes, as well as having more disordered crystal structures, and could be expected to give far less reliable dates than the 2M illite flakes.

If illitization of smectites takes place, can it produce $Mg^{+2}$ to dolomitize the basal upper limestone? A superficial consideration would support that possibility. The average montmorillonite (the smectite group usually considered) averages considerably more Mg than the average illite. However, montmorillonites come in two groups: the larger Cheto type, which averages 5 or 6 percent Mg by weight, and the smaller Wyoming type, which averages about 2 percent Mg. Most natural montmorillonites are physical mixtures of the two. The value for the Wyoming type is not significantly different from the low-Mg illites derived from feldspars, which average 1.7 percent Mg and overlap in composition with low-Al muscovites (data from Weaver and Pollard, 1975). The finer montmorillonites would yield little, if any, $Mg^{+2}$ if converted to illite.

Weaver and Pollard (1975) noted that in order for both illite and montmorillonite to be stable structures in alkaline conditions at surface temperatures (where both form), a certain amount of Mg is necessary in the octahedral layer to allow it to match the tetrahedral layer. This structural Mg is conserved or even increased during illitization. Hower and others (1976) stated that the basic process of illitization is the addition of $K^{+}$ to the interlayer sites of a three-layer clay structure. This requires a negative layer charge, which is usually achieved by replacing $Si^{+4}$ with $Al^{+3}$ in the tetrahedral layer, although replacing trivalent ions (such as $Al^{+3}$) with divalent ions (such as $Mg^{+2}$) in the octahedral layer would also suffice. (Note that the latter process would require an input of $Mg^{+2}$.) The reaction is a solid state one, as far greater energy is required to

destrcy and rebuild a clay lattice. Hower and others (1976) did note that empirical evidence shows a slight, but not signficant, loss of $Mg^{+2}$ during illitization, but suggested that it goes into chlorite formation.

Roberson and Lahann (1981) added an important observation on the role of $Mg^{+2}$ in illitization, noting that cations competing with $K^{+}$ had an inhibiting effect. $Ca^{+2}$ could markedly inhibit the process, and $Mg^{+2}$ was even more potent. Thus, $Mg^{+2}$ in the pore fluids would inhibit the reaction; effectively, illitization would proceed more readily if a pre-existing Mg sink (such as dolomite or chlorite) removed it. Any loss of Mg from the clay structure into the interstitial fluids would also tend to slow the process.

Kahle (1965) suggested an alternative reaction: reacting montmorillonite with calcite and $CO_2$ to produce dolomite, kaolinite, quartz, and water. This is unlikely, as it would not only require the energy input necessary to destroy a clay structure and rebuild it, but it is not supported by empirical evidence, especially in the studied rocks. The core shales that supposedly would be the source of $Mg^{+2}$ are frequently completely devoid of kaolinite, as are the overlying and underlying strata.

Kahle (1965) also suggested a simpler possibility: substituting $Ca^{+2}$ for $Mg^{+2}$ in the montmorillonite. This is a more reasonable concept, but available evidence suggests that it doesn't occur. Nesbitt (1980), working with Pennsylvanian rocks in the Illinois Basin, found that both Ca-smectites and Mg-smectites are far out of equilibrium with the pore waters, but that Na-smectites were in equilibrium.

(Notably, the last finding indicates that there is little, if any, geochemical pressure to convert a Na-smectite to illite under prevailing conditions.)

Chlorite Formation

Alternately, destruction of Mg-chlorite might be called upon to produce the necessary $Mg^{+2}$ for dolomitization. This is even less likely than getting the $Mg^{+2}$ from illitization. Hower and others (1976) noted that chlorite increases with depth. This is probably Mg-chlorite, as Weaver and Pollard (1975) noted that the smaller $Mg^{+2}$ ion strains the chlorite structure less than the $Fe^{+2}$ ion. The lower temperature chlorites are usually more Fe-rich and more poorly crystalline. Empirically, Karpova and others (1969) and Ostrowski (1980) reported increasing Mg and decreasing Fe in chlorite with depth. Weaver and Beck (1971) believed that the necessary $Mg^{+2}$ (as well as $K^{+}$ and $Al^{+3}$ for illitization) came from greater depths, where silicates are more soluble; Dunoyer de Segonzac (1964) and Perry and Hower (1970) argued that both Mg-chlorite formation and illitization are chemically conservative, and derive their ions from destruction of unstable detrital minerals originally present in shales.

Kahle (1965) suggested that a reaction involving the destruction of chlorite forms kaolinite and liberates $Mg^{+2}$, but the same arguments apply that applied to the montmorillonite-to-kaolinite transformation he suggested. Diagenetically, the reverse is true; kaolinite is destroyed and chlorite is formed (Karpova et al., 1969; Weaver and Beck, 1971). Weaver and Pollard (1975) stated that this happens at

about 150°C, while Karpova and others (1969) observed that it occurred at a somewhat greater depth than illitization.

Nesbitt (1980) noted that in the Illinois Basin, pure Mg-chlorite was not in equilibrium with the pore waters. However, since chlorite was ubiquitous, he suggested the possibility that the reaction was slow, but favored the possibility that solid solution (presumably with $Fe^{+2}$) enlarged chlorite's stability field.

Ion Exchange

Weaver and Pollard (1975) stated that in dispersed montmorillonites, $Mg^{+2}$ is the favored exchange cation. But with burial and loss of much of the pore water, exchange sites and exchange cations become more abundant than ions in the pore water (Weaver and Beck, 1971). This favors more mobile ions, with $Na^{+}$ replacing $Mg^{+2}$. The expelled $Mg^{+2}$ is flushed from the system or forms dolomite; Weaver and Beck stated that this process is dominant from near the surface to about 6,000 feet, where illitization becomes important.

Compaction

Organic-rich muds are water-rich, and contain much pore water that is lost during compaction. Holdsworth (1966), working with a carbonate nodule similar to those found in the Stark, calculated that the original mud was 75 percent water-filled pore space. Compaction during the first few thousand feet of burial expels this water and the accompanying ions (Burst, 1969). Wedepohl (1971) suggested that the $Mg^{+2}$ in such connate fluids could produce chlorite or dolomite.

Iron from Clays

The frequent occurrence of ferroan dolomite in Pennsylvanian rocks has led some workers to associate the source of $Mg^{+2}$ with the source of $Fe^{+2}$. Oldershaw and Scoffin (1967) observed that ferroan calcite in limestones they studied was associated with clay seams and stylolites, and occurred in argillaceous limestones. They attributed this to $Fe^{+2}$ movement from the clays to the limestones. Mossler (1970) favored this explanation for the ferroan dolomite in the Bethany Falls.

Siever and Glass (1957) suggested an alternate model, in which $Fe^{+2}$ was mobilized by humic acids in coal swamps, then carried into the limestones to produce ferroan dolomite. In the Illinois Basin, they found the coal-rich Desmoinesian strata to commonly have ferroan dolomite, while the coal-poor upper Missourian strata has almost none. They also noted that ferroan dolomite is equally common on the shelves and in the deeper basin, making it unlikely that it is a product of significant diagenesis. Mossler (1970) argued that this model could not apply to the Bethany Falls, as there were no coals in the overlying Galesburg (in fact, coals and coaly horizons are widespread in the Galesburg).

Hower and others (1976) favored some diagenetic mobilization of $Fe^{+2}$, perhaps lost by smectites during illitization. However, they thought that such $Fe^{+2}$, along with $Mg^{+2}$, would be consumed by chlorite formation.

Carroll (1958) provided a simpler mechanism. He noted that much iron oxide and hydroxide is transported adsorbed onto clay particles. If such clays are deposited in a reducing environment, the iron is reduced from $Fe^{+3}$ to $Fe^{+2}$ and becomes mobile in solution. Drever (1971) added that Fe-chlorite functions as an iron source for anaerobic bacteria, which release $Fe^{+2}$ (much of which, however, would be scavenged by $H_2S$ to produce sulfides). In any case, biologic or inorganic reduction of iron in or attached to the clays could easily provide $Fe^{+2}$ for ferroan dolomite, and further diagenesis is not necessary.

Organic Material and Clay

The accumulation and diagenetic history of organic material is closely tied to clays, especially when the history of petroleum is concerned. The presence of smectites is important: Grim (1947) noted that organics have a high affinity for smectites, and Whittaker and Dyson (1980) noted that smectites could remove organics both by ionic and by hydrogen bonding. During burial, the nature of these bonds affects the history of both the clays and the organics; Whittaker and Dyson noted that smectites lost organics during illitization. When the smectites change charges to become illite, the $K^+$ moves in, and there is no longer the charge or the space to hold the organics However, this does not take place until a thermal level sufficient to crack the organics and make long-chain hydrocarbons has been achieved. Burst (1969) also stated that contemporaneous water loss flushes the petroleum from the source rock. However, Grim (1947) stated that organics

would inhibit illitization, but the exact relationship is unclear. Thus, the presence and nature of the smectites are important; Whittaker and Dyson (1980) stated that in contrast illitic shales lose organics during physical dewatering, too early to generate petroleum. Among the studied clays, however, it is possible that stripped illites absorb and expel organics in the same manner as smectites.

## Conclusions on Diagenesis

The general agreement of the various lines of evidence presented is that burial diagenesis was probably not a significant factor in the history of the studied rocks. Most of the alterations from the original mineralogy can be explained in terms of changing near-surface chemical environments or in terms of time elapsed since the Late Pennsylvanian. The temperatures were very low (Table 9), which is consistent with the probability that they were not significantly buried.

The clay mineralogy has probably not changed much due to diagenesis. The vertical trends within the cyclothems would indicate that burial has done little to homogenize the clays, or push them toward illite formation. Mixed layer clays are abundant, and in some cases completely swelling clays are present. Original montmorillonite was unlikely as there is little evidence that the necessary environment was ever present. Neither is there any evidence of kaolinite converting to chlorite, as kaolinite is common in all of the deepest sections (e.g., the Charleston core).

Table 9

Diagenetic parameters and
indicated conditions

| Parameter | Temperature |
|---|---|
| Level of metamorphism (LOM) | $20^{\circ}$ - $50^{\circ}C$ |
| Conodont color alteration index (CAI) | $<50^{\circ}C$ |
| Clay mineralogy | $<50^{\circ}C$ |
| Fluid inclusion thermometry | $60^{\circ}$ - $80^{\circ}C$ |
| Dickite | $>350^{\circ}C$ |

The systematic variation of clay mineralogy in the cyclothems is probably the strongest evidence against diagenetic modification. Roeschmann (1971) cited Teichmüller (1962) as stating that the upward movement of water during burial removed soil components (presumably such as $K^{+}$). However, the symmetrical increase in illite crystallinity away from the coals indicates that this is unlikely. The pattern is readily attributed to the original depositional environment.

Srodon (1979) noted that organic diagenesis proceeded more readily than clay diagenesis. Thus, the coals of the studied strata probably rank at least high volatile bituminous C or above (by interpolation). In the Forest City Basin, it is possible that the organic material has reached the threshhold for petroleum formation, and apparently has passed it farther south. It is possible that methane

has already been generated, both through fermentation and possibly decarboxylation (Tourtelot, 1979). This is particularly likely where siderite nodules occur.

Many of the apparent anomalies of mineral distribution can be explained by simple burial and compaction. First, it should be noted that connate waters are in or close to equilibrium with the minerals present. So the connate fluids in the limestones should be considerably different from those in the shales. The carbonates would be expected to have $Ca^{+2}$ and little else, while the core shales would be expected to be enriched in silica (from opaline radiolarians and sponges), phosphate, $Mg^{+2}$, $Fe^{+2}$, and trace metals (such as $Zn^{+2}$, $Pb^{+2}$, and $Cu^{+}$). When these shales (which may have been very water-rich) underwent compaction, the connate fluids would have been driven out, principally up (Levorsen, 1967). They would have followed available channels, such as fissures, stylolites, and more permeable argillaceous horizons. Reaching an environment with a different Eh, pH, and ion concentration, many of these materials could precipitate. This would explain the formation of dolomite, some apatite, some silicification, sphalerite, and possibly pyrite, galena, chalcopyrite, and some clays. It would also explain why many of these are common above the core shale, but rarely found associated with the outside shale. This process would not require any thermal diagenesis, although early breakdown of some of the organics might enhance it by releasing ions attached or absorbed to their structures. Thus, all the features in

the rocks examined could be explained by temperatures less than $50^{o}C$, and greater temperatures or depth of burial are not indicated.

# CHAPTER IV

# PALEONTOLOGY

## Paleozoology

> Many of the lithologic and all of the biologic attributes of sedimentary rocks are related to features of the depositional environment.
>
> Purdy, 1964, p. 238

### Introduction

Upper Pennsylvanian cyclothems provide an almost ideal situation for the study of faunal and floral ecological relationships, as the orderly alternation of lithologies reflects an orderly sequence of environments. If the origin of the rocks is known, then it should be possible to decipher the significance of the appearances of various fossil groups. However, since some of the depositional environments in the studied rocks are subject to debate, the purpose here is to attempt the converse, by evaluating the distributions and modes of occurrence of various fossils, and by deciphering their relationships to their environment, and so determining the nature of that environment.

Paleontologists have long recognized various associations of fossils in the Midcontinent cyclothems. Many attempts have been made at analyzing scaled associations within specific lithologies, often with only limited success. But a framework exists for evaluating the relationships of the fossils across lithologic boundaries, as they appear in groups and in an orderly fashion. The fossil patterns

present not only provide direct information about the depositional environment, but may also yield indirect evidence on both depositional and post-depositional phenomena. The absence of an expected faunal group might be due to an environmental variable, loss through reworking in a low-deposition environment, or diagenetic loss. Thus, paleontology not only yields direct information, but also provides data on sedimentologic and petrologic aspects of the rock's history.

The overall nature of this study largely dictated the manner in which the fossils were evaluated. First, a wide range of lithologies was examined, involving a wide range of techniques and variation in the type of information provided by the fossils. Johnson (1962) observed that it is difficult to evaluate the meaning of relative abundance due to the many factors of biology and taphonomy, and noted that presence/absence studies are much easier to interpret in respect to the depositional environment. This principle was generally applied (with the exception of conodonts, which were consistently recovered from all lithologies), both due to the inherent problems of comparing disparate organisms (does one Juresania equal two rugose corals?) and the problems of simply counting fossils (how do you count bryozoans?). This was also simple expediency, as many samples were so fossiliferous as to preclude any hope of efficiently sorting them.

An attempt was made to analyze fossil groups as thoroughly as possible; however, expediency again was a counterbalancing consideration. Thus, groups that required extensive preparation (e.g., fusulinids and bryozoans) were generally not subdivided, as were those groups where preservation generally precluded much meaningful information

e.g., echinoderms and sponges). However, in most of the other groups, some attempt was made to identify specimens to the generic level. In some ways, this was more desirable (as well as more practical) than carrying identification to the specific level. Simpson observed:

> Sampling at a few restricted localities certainly reveals a much higher percentage of the genera than of the species that existed at any one time.
>
> Simpson, 1953, p. 53

Johnson (1962) noted that use of genera introduced some blurring, as species within a genus can have quite different habits, but added that different morphologies recognized as species may not be separate. Admittedly, it would be preferable to look for distributional patterns at the specific level; Raup (1972) noted that the effects of biogeography and endemism are most marked at that level, and decrease with higher taxonomic levels. But practicality dictated that the genus be used for identification. Due to the necessity of covering a large number of samples, none of them could be very large. As Simpson (1953) noted, this does make use of the genus rather than species more logical. Sampling theory also plays a large role - in relatively small samples, less common forms, although present, may not be found. In a study comparable to this one, Lane (1964) noted that splits of fossiliferous samples often omitted rarer forms, and stated that complete picking was a necessity. In this study, that is impractical, and evaluation is restricted to those groups that are common in the rock. The rarer forms are noted when present, but their evaluation is left to future workers with the capacity to effectively deal with them. While it is probable that many of the rarer, more specialized forms may

fill in important details of depositional environment and stratigraphy, it is first necessary to find the overall pattern.

In dealing with congeries of diverse fossils, it is not possible to winnow all the pertinent systematics. Identification of most taxa was done by comparison with published faunal studies of similar rocks, together with appropriate reference works. It was impractical to pursue each taxon for published synonymies, let alone make independent judgments on their appropriateness. Thus, the taxonomy leans heavily on the published forms. For purposes of comparison, however, Appendix B is provided explaining the diagnostic criteria used in the identification of many of the common taxa, together with plates illustrating many of the recognized forms.

The format implemented will treat each group separately, first describing the distributions, then providing some evaluation of each taxon. Conodonts, ostracodes, and forminifers will be considered first, because they occur most frequently and often have marked patterns of occurrence, and thus they form a framework for comparison with other groups. The discussions of taxa will be followed by comments on the mass aspects of the fossils, then by a consideration of the overall implications of the fossil patterns.

The principal statistical measure used in evaluating the distribution of each taxon is its rate of occurrence with other taxa. This is expressed as a percentage level of co-occurrence. For example, if Taxon A occurs in 12 samples, and Taxon B is found with it in 8 of those samples, A occurs with B in 75 percent of the samples in which A is found. (For brevity in the text, the last part will be implicit;

when A is discussed, the set of occurrences used will be those in which A is found.)

Another statistical measure will be used to describe stratigraphic distribution. On the charts showing the stratigraphic distribution of various taxa, each will have a figure which expresses how frequently the taxon occurs in the samples from a given stratigraphic horizon; for example, Taxon A may occur in 5 of 10 shale partings in limestone, or 50 percent of them. Because the various horizons were not sampled with equal frequency, the average frequency of a taxon in the cyclothem is based on a weighted value, where each horizon is assumed to have been sampled with equal frequency. The assumption is then made that the average frequency for the cyclothem would approximate random distribution; that is, if the taxon were completely independent of lithology, it would be expected to occur in all horizons at the same frequency. If the frequency of occurrence in horizon deviates significantly from the assumed random distribution, a positive or negative correlation with that horizon (and the environment it expresses) is established.

## Conodonts

### Empirical Observations

Conodonts are the most common fossils in the marine Missourian sediments of the Midcontinent. In this study, they were found in 300 samples, yielding 34,000 platform elements for examination. Because conodonts could be consistently recovered from all lithologies,

relatively complete and continuous examination of their patterns was possible.

Because conodonts can be recovered in a consistent fashion, they were evaluated quantitatively as well as qualitatively. Counts were made of the platform elements found in a known sample size, and expressed as a fraction of the total number of platforms present. Because various apparatuses have variable loss rates for the associated ramiform elements (Baesemann, 1973; Merrill and Powell, 1980), a count of total elements present would give misleading results, particularly in those cases where winnowing was probable. Although it is probable that the various platforms are not strictly comparable in durability, and comparability is even less likely with elements of apparatuses lacking platforms, platform comparability was considered a reasonable working hypothesis for this study.

Since conodont apparatuses were bilaterally symmetrical, theoretically the number of platforms found could be divided by two to produce the number of animals involved. For simplicity, though, the numbers were left unchanged. For the apparatuses without platforms (e.g., Idioprioniodus, Aethotaxis) all the elements found were totaled, then divided by half of the total of elements known to be in the apparatus for comparison to the other apparatuses.

The abundances of conodont platforms within a cylcothem are systematic. The outside shales and associated stray limestones have relatively low abundances, typically ranging up to 20 or 30 platforms per kilogram of sample. As the core shale is approached stratigraphically, numbers begin to rise. In the core shale, abundances

generally range between 200 and 1,000 platforms per kilogram (Fig. 50). However, the highest abundances occur in those limestones where the core shale is missing, and where the basal bed may be a lag deposit. There, platform abundances average over 2,000 platforms per kilogram, and ramiform elements are not present (Fig. 51). Most limestones are intermediate in abundance between the outside shale and the core shale. The upper limestone, which is thicker, can be subdivided to show the upward decrease in abundance from the core shale to the outside shale.

Gondolella

Gondolella generally has been recognized to be associated with the black core shales, where it is found with plentiful associated conodonts, occasional fish fragments, phosphatic inarticulate brachiopods, and occasional horizons of pectinids. Gondolella was first recognized and named from such a black shale in the upper Desmoinesian strata of northern Texas (Stauffer and Plummer, 1932).

However, this is a simplification. Gondolella's distribution within the cyclothems of this study ranges essentially from the base of the core shale into the basal beds of the upper limestone (Fig. 52). Within the black shale, however, it is not associated with the blackest, most fissile basal layers, but rather the softer, blocky upper portion that grades into the overlying grey shale (Fig. 53). Here it is frequently found with small, pyrite-cored burrows, a restricted calcareous benthic fauna, and occasional apatite nodules. It also reaches its highest percentage of the conodont fauna, occasionally

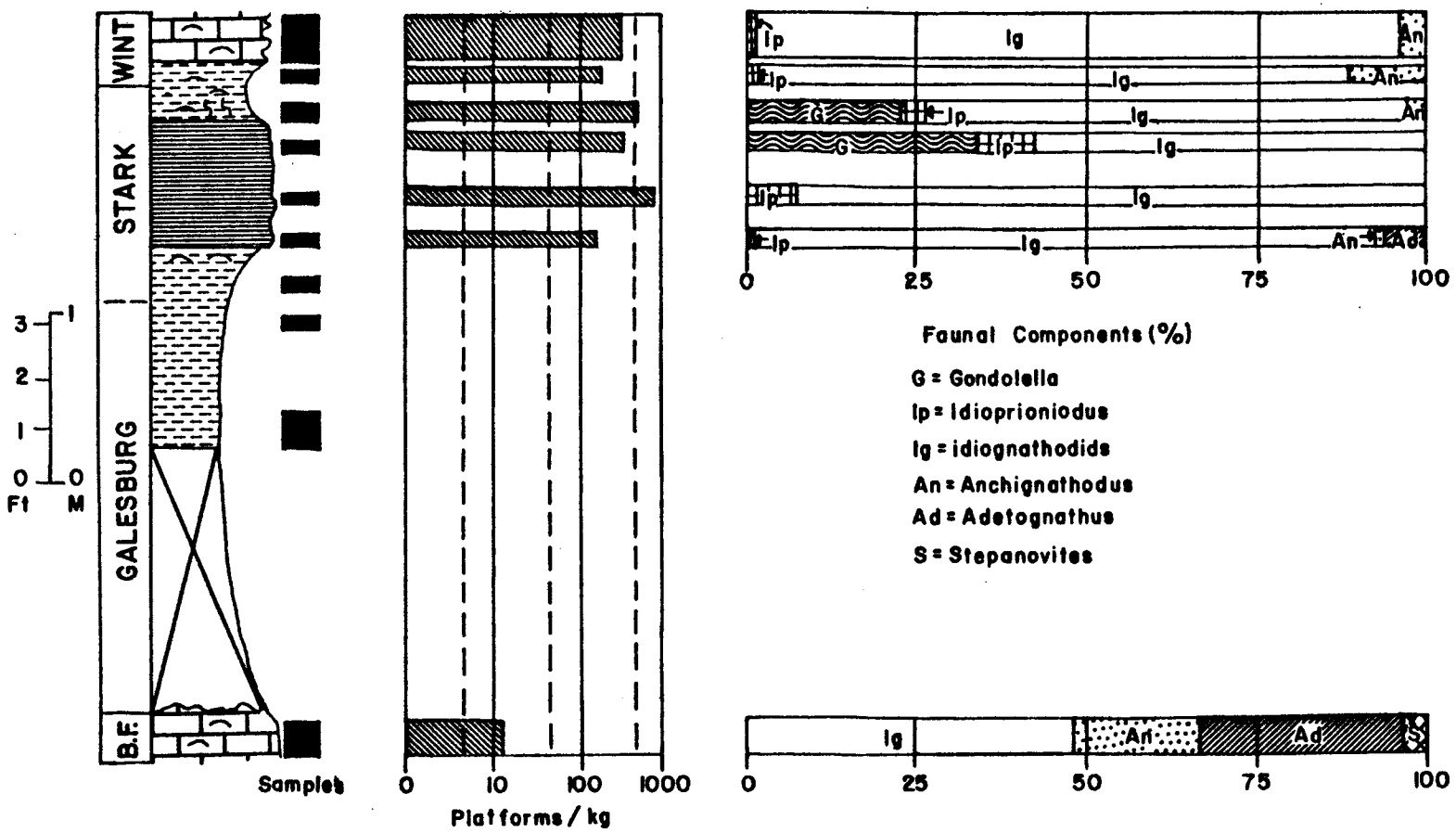



Figure 50. Conodont distribution--Dennis cyclothem, Winterset, Iowa (Locality WI1).

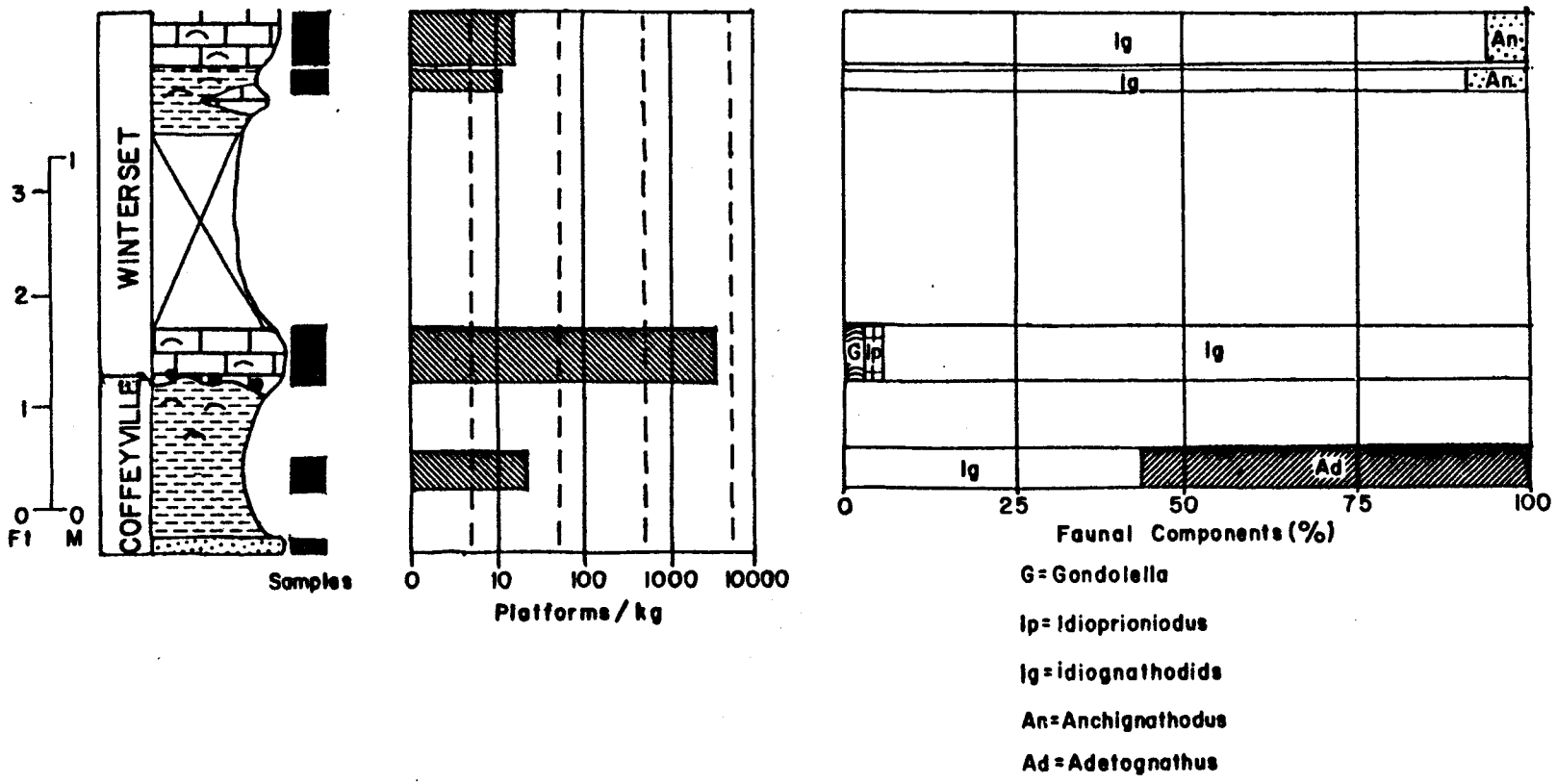



Figure 51. Conodont distribution--Dennis cyclothem, Coffeyville, Kansas (Locality CB2).

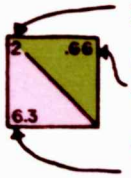
Figure 52. Stratigraphic distribution of conodonts in the Dennis and Stanton cyclothems.

KEY

Genera present = number of genera of fossil group identified in stratigraphic unit

Total samples = number of samples of stratigraphic unit containing fossil group

Percent = percent of total samples

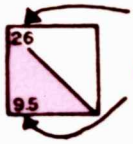



Number of occurrences in stratigraphic unit

Occurrence percentage compared to weighted average percentage for cyclothem

Occurrences as percentage of total sample of stratigraphic unit

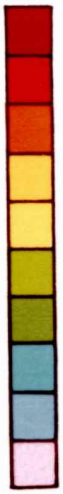
On total line




Total occurrences

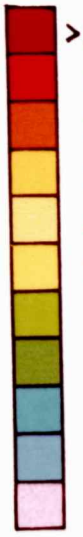
Weighted average percentage (adjusted to theoretical equal sampling of all units)

Percentage Code



| |
|---|
| 90.0 - 100.0 |
| 80.0 - 89.9 |
| 70.0 - 79.9 |
| 60.0 - 69.9 |
| 50.0 - 59.9 |
| 40.0 - 49.9 |
| 30.0 - 39.9 |
| 20.0 - 29.9 |
| 10.0 - 19.9 |
| 0.1 - 9.9 |

Ratio Code



| |
|---|
| >2.00 |
| 1.80 - 1.99 |
| 1.60 - 1.79 |
| 1.40 - 1.59 |
| 1.20 - 1.39 |
| 1.00 - 1.19 |
| .80 - .99 |
| .60 - .79 |
| .40 - .59 |
| .20 - .39 |
| .01 - .19 |

Note that the term "Core A (undifferentiated)" is applied to the lower grey shale where the middle limestone is absent, and the A core shale unit grades into the outside shale.

| | Genera present | Total samples | % of samples | Gondolella | Idioprioniodus | idiognathodids | Anchignathodus | Adetognathus | Stepanovites | Aethotaxis |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ls - Base | 6 | 39 | 13.4 | 13 1.66 33.3 | 23 1.53 59.0 | 38 1.11 97.4 | 26 1.35 66.7 | 7 .46 17.9 | | 5 3.58 12.8 |
| Core C(grey) | 6 | 47 | 16.2 | 24 2.56 51.1 | 40 2.20 85.1 | 46 1.11 97.9 | 18 .77 38.3 | 3 .16 6.4 | | 2 1.10 4.3 |
| Core B(black) | 5 | 60 | 20.6 | 41 3.45 68.3 | 58 2.51 96.7 | 58 1.10 96.7 | 9 .30 15.0 | 2 .08 3.3 | | |
| Core A(grey) | 5 | 17 | 5.8 | 4 1.19 23.8 | 7 1.07 41.2 | 16 1.07 94.1 | 9 1.07 52.9 | 5 .78 29.4 | | |
| Core A(undifferentiated) | 4 | 20 | 6.9 | | 7 .91 35.0 | 17 .97 85.0 | 10 1.01 50.0 | 15 1.91 75.0 | | |
| Middle Ls | 7 | 30 | 10.3 | 2 .34 6.7 | 7 .80 23.3 | 27 1.02 90.0 | 22 1.48 73.3 | 18 1.53 60.0 | 5 2.98 16.7 | 2 1.72 6.7 |
| Outside | 6 | 36 | 12.4 | 2 .28 5.6 | 2 .15 5.6 | 24 .78 66.7 | 12 .87 33.3 | 27 1.91 75.0 | 2 1.00 5.6 | |
| Stray Ls | 4 | 5 | 1.7 | | | 2 .45 40.0 | 2 .81 40.0 | 4 2.04 80.0 | 2 7.14 40.0 | |
| Upper Ls - Top | 5 | 18 | 6.2 | | | 11 .69 61.1 | 7 .79 38.9 | 13 1.84 72.2 | 6 5.95 33.3 | 1 1.44 5.6 |
| Ls Partings (shale) | 6 | 11 | 3.8 | 1 .46 9.1 | 3 .71 27.3 | 10 1.03 90.9 | 7 1.28 63.6 | 3 .70 27.3 | | 1 2.31 9.1 |
| Upper Ls - Middle | 4 | 8 | 2.7 | | 1 .32 12.5 | 8 1.14 100.0 | 5 1.26 62.5 | 2 .64 25.0 | | |
| Total | 7 | 291 | | 87 19.8 | 148 38.6 | 258 88.0 | 127 49.5 | 99 39.2 | 15 5.6 | 11 3.9 |

Figure 52

Figure 53. Distribution of conodont acmes in the Dennis and Stanton cyclothems.

Position in the cyclothem of the highest population percentage of the conodont, based on the raw number of total sections in which it occurs.

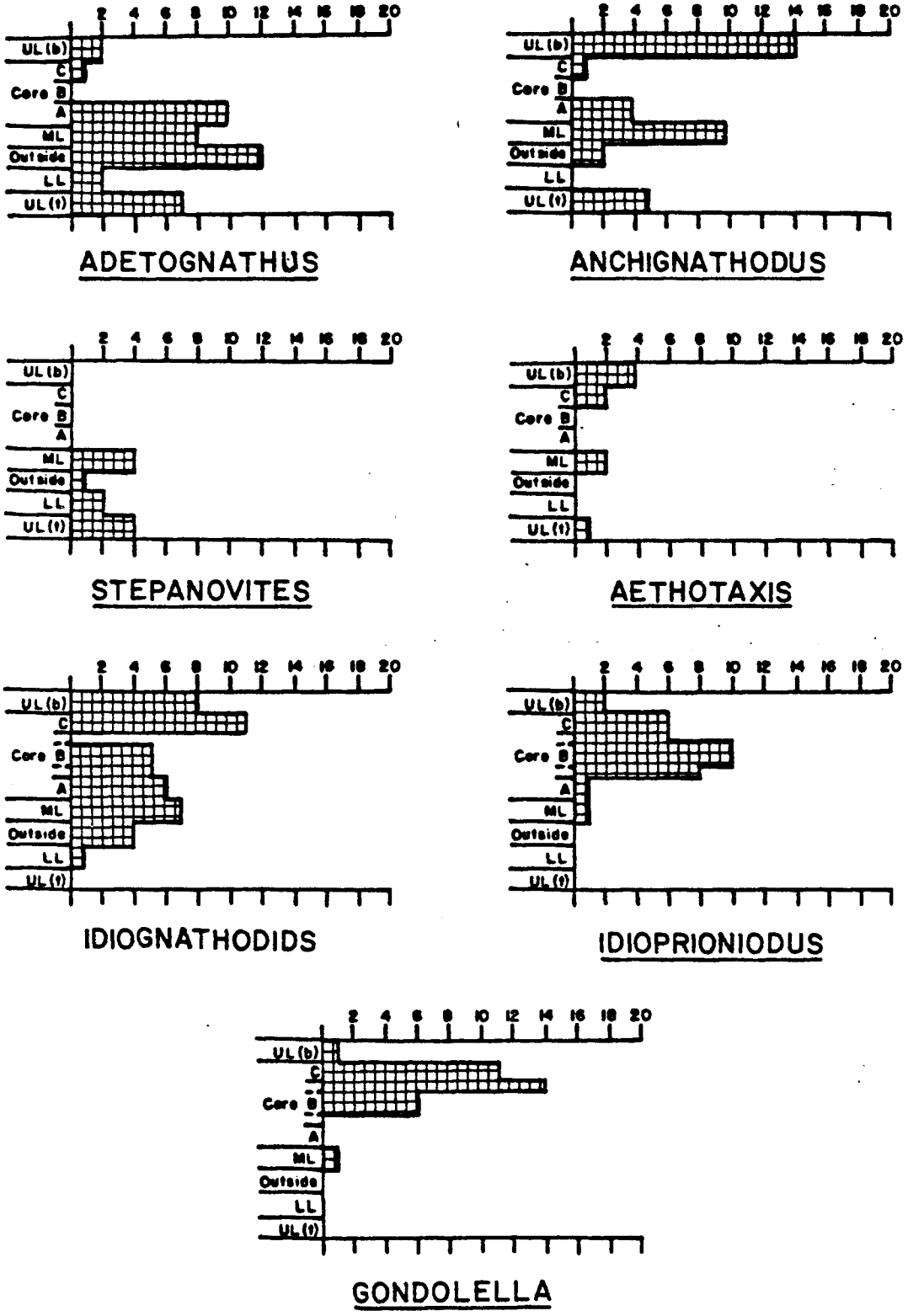

2 4 6 8 10 12 14 16 18 20
UL(b)
C
Core B
A
ML
Outside
LL
UL(t)
ADETOGNATHUS
ANCHIGNATHODUS
STEPANOVITES
AETHOTAXIS
IDIOGNATHODIDS
IDIOPRIONIODUS
GONDOLELLA

Figure 53.

approaching 75 percent of the platforms present. This distribution is consistent with the observations of Baesemann (1973) and Wood (1977), although their data were much more sparse. This might also explain the attributed irregular occurrence of Gondolella in the black shale (Merrill, 1973; Merrill et al., 1978); it is indeed irregular in occurrence in the lower, blackest portion, but is remarkably consistent in its appearance in the transitional zone.

Mitchell (1981) noted a southward decrease in the abundance of Gondolella in the Muncie Creek Shale. That observation cannot be substantiated in either the Stark or Eudora Shales (Fig. 54 and 55); in the southern samples, reworking and/or sedimentary dilution distort the data. Beyond the regions of distortion, no consistent trend can be discerned. Unfortunately, such a trend must be substantiated by very careful sampling (due to the vertical distribution of Gondolella), something which has not yet been done.

Heckel and Baesemann (1975) and Heckel and Swade (1977) stated that Gondolella occurs with a more diverse conodont fauna, and attributed this to environmental effects. However, since Gondolella occurs in samples with very high abundances of conodonts, it is statistically probable that the diversity would be greater, without involving any environmental change. It also cannot be ruled out that some of that apparent diversity is due to transport of rarer forms. The fauna is simple in its gross aspects, with Gondolella always found with idiognathodids, and almost always with Idioprioniodus. In the faunas where they occur, these three compose the vast bulk of the conodonts, though other taxa occasionally co-occur. Merrill (1980) stated that

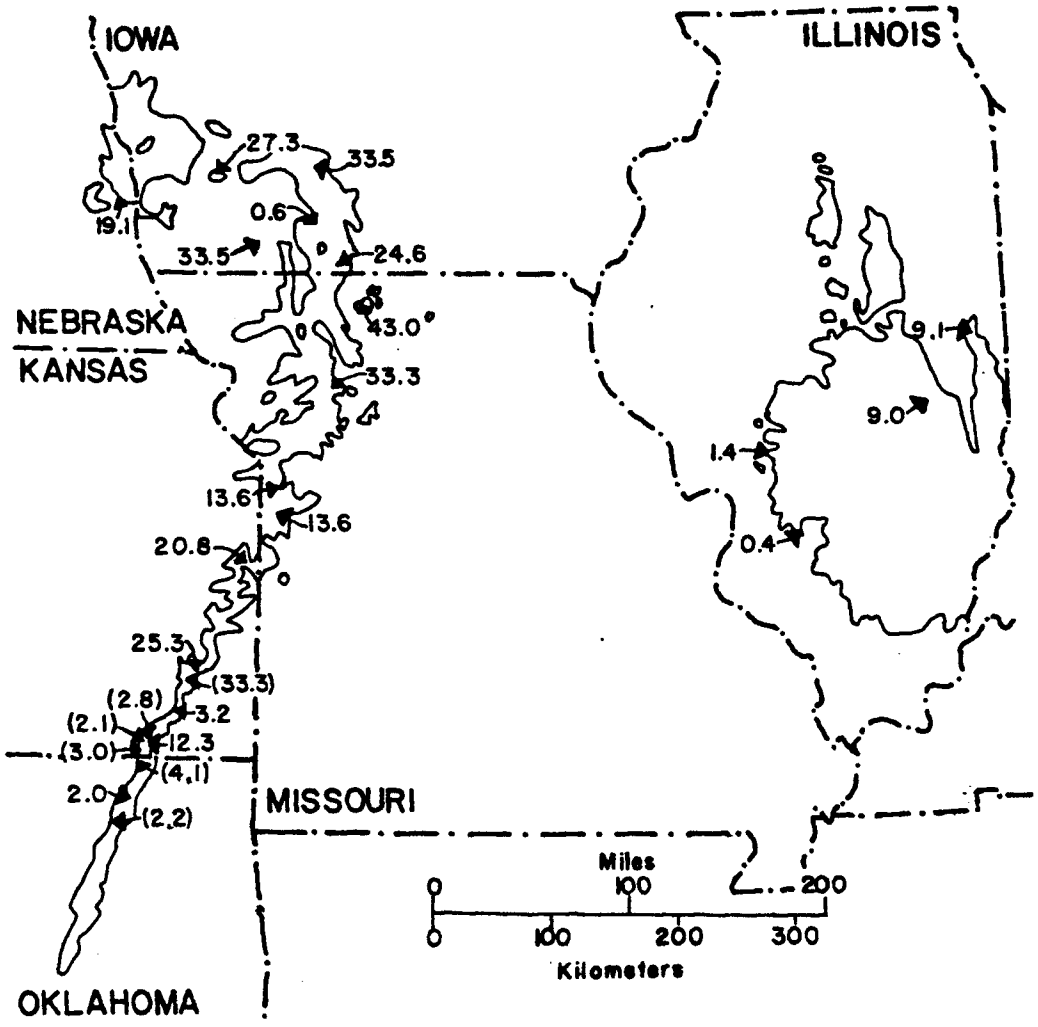



Figure 54. Maximum Gondolella abundances in the Stark Shale.

Numbers indicate maximum percentage of Gondolella found in each section; numbers in parentheses indicate lags. Outcrop pattern is Coffeyville Fm. in Oklahoma; Galesburg and Dennis in Kansas; and Kansas City Group (including Bronson Group as used here) in Missouri, Iowa, and Nebraska; outcrop of Shoal Creek Limestone is indicated in Illinois.

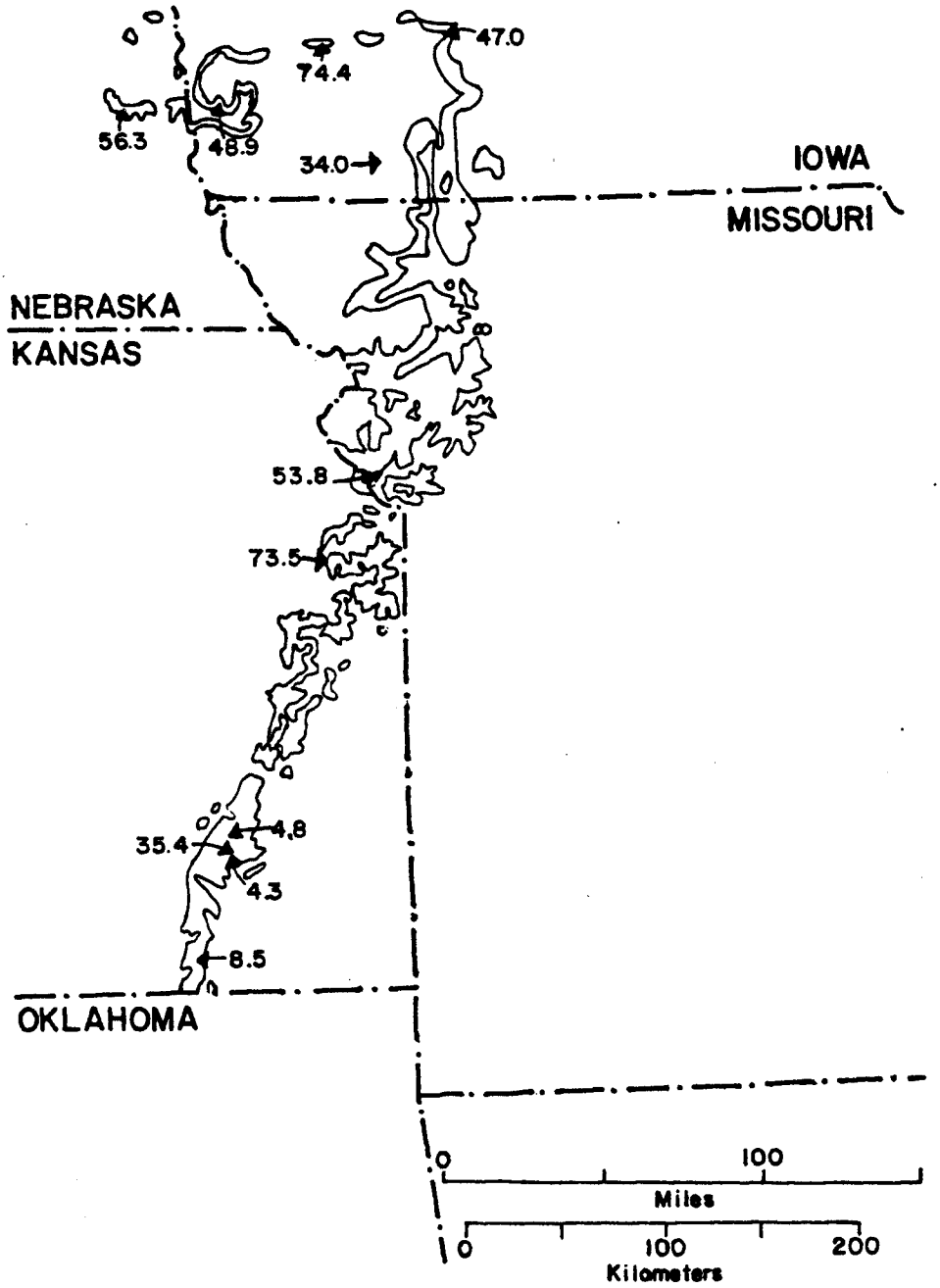



Figure 55. Maximum Gondolella abundances in the Eudora Shale.

Numbers indicate maximum percentage of Gondolella found in each section. Outcrop is Lansing Group.

Anchignathodus rarely is found with Gondolella; however, in this study just over 30 percent of the Gondolella occurrences had co-occurring Anchignathodus (28 out of 88 Gondolella occurrences). Gondolella is found far less frequently with Adetognathus; only 11 cases in 88 occurrences. Some of these co-occurrences suggest the possibility of transportation, such as that in the Altoona channel, where effective currents may have operated (a possibility supported by the clay mineralogy). Since the two genera do not normally occur together, and never with both in significant numbers, transportation should be considered in such anomalous situations. Heckel and Baesemann (1975) alternately proposed that Gondolella and Adetognathus lived in different, vertically stratified water masses. Given the relative abundances of the two conodonts in the black shale, the water mass where Gondolella lived would either be more productive by several orders of magnitude, or, if equally productive, more voluminous by several orders of magnitude. Since Adetognathus usually does not occur with Gondolella, even where conodonts are most abundant, an areally disjunct distribution seems more likely. In any case, the black shale environment and its associated water column were not optimum environments for Adetognathus, and in its occurrence there is an unusual event, possibly due to either physical transport or temporary conditions permitting a brief invasion.

Another type of Gondolella occurrence is in the encrinites of southeastern Kansas and northeastern Oklahoma. There, where the black shale is missing, Gondolella forms a small percentage (usually 2 to 4 percent) of the very abundant conodont fauna, which is chiefly

idiognathodids and Idioprioniodus (Fig. 51). Since this is an unusual fauna (in terms of quantity) in an anomalous stratigraphic position, it suggests an unusual depositional environment.

Idioprioniodus

The distribution of Idioprioniodus is similar to that of Gondolella, but varies in several respects. Like Gondolella, Idioprioniodus is essentially restricted to the middle limestone, the core shale, and the base of the upper limestone (Fig. 52). However, it does not have the skewed distribution of Gondolella, as it is most common in the blackest core shale and becomes less abundant as the shale becomes lighter (Fig. 53). Idioprioniodus is more likely to be found in the lower transition to the black shale than Gondolella, which is relatively rare there.

Idioprioniodus occurs almost twice as frequently as Gondolella in the sampled rocks (151 times versus 88 times), but seldom makes up a large percentage of the conodont fauna, in keeping with the observation of Merrill and others (1978). The low abundances for such common fossil are surprising. Part of this anomaly may be due to the method of evaluation, as Idioprioniodus has no platform element, but each of its elements features similar large, robust cusps. These elements are readily counted, but less readily differentiated, particularly since the diagnostic processes are usually missing. Thus, Idioprioniodus must be evaluated by counting all the elements. Because the Idioprioniodus apparatus has 13 elements (J. W. Swade, pers. comm., 1981), each roughly comparable in durability, the total number of

Idioprioniodus elements must be divided by 6.5 for comparison with apparatuses containing platforms. As a consequence, the number of Idioprioniodus elements in a sample may be substantial, but the ratio of Idioprioniodus apparatuses present compared to other apparatuses is usually low. On an apparatus basis, Idioprioniodus usually makes up 1 to 5 percent of the conodont fauna, only very rarely exceeding 10 percent.

Idioprioniodus, as might be expected, has more overlap in range with other conodonts than does Gondolella. On rare occasions, it occurs without the nearly ubiquitous idiognathodids, and occurs with Anchignathodus and Adetognathus much more frequently than does Gondolella.

Idiognathodids

The idiognathodid conodonts are not specialized in their occurrence. Idiognathodids are the most frequently occurring fossil group in the marine Missourian sediments studied. They occur in 260 samples, just over 75 percent of the fossil-bearing samples studied. 88 percent of the samples with conodonts include idiognathodids. They occur throughout the cyclothem, although they are less common in the outside shales, the stray limestones, and the tops of the upper limestones (Fig. 52, 53).

Not only are the idiognathodids pervasive, but they are also abundant. In the middle limestone, the core shale, and the base of the upper limestone, they dominate the faunas, usually composing 75 percent or more of the conodont fauna. They occasionally dominate the fauna

in the outside shale and adjacent units, but far less completely, and are occasionally absent.

Anchignathodus

Anchignathodus (here = Ozarkodina, Hindeodus; see Appendix B) has a different distribution. It is a common conodont, ranking behind the idiognathodids and Idioprioniodus in the samples examined. It tends to occur most frequently in the middle and upper limestones, becoming less frequent toward both the core and outside shales, although its overlap with both is considerable (Fig. 52). Its abundance is highest in the limestones, where in rare instances it dominates the conodont faunule and declines symmetrically away from them (Fig. 53). Significantly, it is also common in the shale partings within the limestones. It is least frequent and abundant in the black core shale, but does occasionally occur there, an observation consistent with that of Wood (1977).

Anchignathodus often occurs with all of the conodonts but less often with Gondolella, due to its marked depletion in the black shales. It occurs much more frequently with Adetognathus, the conodont characteristic of the outside shales.

Adetognathus

As observed by Heckel and Baesemann (1975), Adetognathus (here = Cavusgnathus; see Appendix B) is found mostly in the outside shale, the middle limestone, and the top of the upper limestone (Fig. 52, 53). However, it does occur throughout the cyclothem, though rarely in the black core shale. Wood (1977) observed that

Adetognathus was sparse throughout its range. In a few cases, however, the numbers of Adetognathus become moderately high, 50 or 60 per kilogram. In one case, the abundance reaches approximately 300 per kilogram, but as this is in a fine-grained sandstone, it may be a lag concentration. In such cases, Adetognathus dominates the fauna, and sometimes occurs alone.

Adetognathus rarely occurs with Gondolella (only 11 times in 100 occurrences), but occurs with increasing frequency with Idioprioniodus and Anchignathodus. The idiognathodids, being nearly ubiquitous, occur very frequently with Adetognathus, but Adetognathus occurs less frequently with them (on a percentage basis) than does any other conodont. As mentioned above, Adetognathus has a disjunct distribution in respect to the other conodonts, most strongly in respect to Gondolella. The pattern cannot be explained by additive dilution, but is compatible with a series of overlapping environments, with the environments favored by Gondolella and Adetognathus farthest apart in the continuum.

The arrangement of conodonts within a cyclothem provides a very useful framework for the placement of other fossils. Gondolella is strongly associated with the core shale, so a fossil that tends to occur with Gondolella should have a tendency to occur in the core shale, too. Adetognathus is strongly associated with the outside shale, so fossils that tend to occur with Adetognathus tend to be associated with the outside shale. A statistical fluke simplified evaluation in this study. In the total samples, Gondolella and Adetognathus occur subequally (88 times for the former, 100 times for

the latter) so that it is not necessary to make relative proportions of occurrence with an investigated fossil for comparison; it can be done directly. Thus, a ratio of Gondolella co-occurrences versus Adetognathus co-occurrences would serve as a rough index to the preferred position of a fossil in the cyclothem relative to the two end points.

Aethotaxis

Aethotaxis is a comparatively minor constituent of the conodont fauna, and is difficult to identify consistently, especially from fragments. Like Idioprioniodus, it lacks a platform; unlike Idioprioniodus, it is not robust, and tends to fragment into ramiform-like pieces. However, on the basis of its few occurrences, some statements are possible about its empirical distribution and probable factors in its environmental control.

Aethotaxis has a distribution strongly associated with limestones similar to that of Anchignathodus (Fig. 52, 53). Furthermore, every occurrence of Aethotaxis is with Anchignathodus, a co-occurrence percentage not reached even with the idiognathodids. This would support Merrill's (1980) conclusion that the two have similar environmental requirements, but perhaps that Aethotaxis is more specialized (i.e., restricted).

Aethotaxis never becomes very abundant, and no more than one or two elements were recognized in any sample. Usually, this worked out to a very small percentage of the apparatuses present.

Stepanovites

Stepanovites (may = Ellisonia; see Appendix B), like Aethotaxis, is a relatively rare conodont and has no platform. Unlike Aethotaxis, however, it is moderately robust, and has a peculiarly recognizable element morphology. Thus, it is more consistently identifiable.

Stepanovites has a marked tendency to occur with Adetognathus, and is found with it even more frequently than it is with the idiognathodids. Thus, its relationship to Adetognathus is analogous to that of Aethotaxis and Anchignathodus in some ways. However, rather than being most common where Adetognathus is most common (as is true of the Anchignathodus-Aethotaxis pair), Stepanovites is most common in the base of the middle limestone and top of the regressive limestone (Fig. 52, 53). Thus, it is also frequently found with Anchignathodus. Although it is not abundant in terms of total numbers, it occurs in sparse faunas and thus it can make up a fair percentage of the conodont fauna (5 or 10 percent is normal). The distribution of Stepanovites also contributes to an interesting assemblage found near the tops of upper limestones, including idiognathodids, Adetognathus, and Anchignathodus, in which total numbers are moderate, and no form is strongly dominant. Little else is found in these rocks except a few molluscs, an abundance of encrusting agglutinated foraminifers, and certain kinds of fish fragments.

Interpretations

Because of the marked association of lithologies and conodont assemblages, many attempts have been made to link various conodonts to depositional environments expressed in the rocks, and in some cases, the reverse has been attempted, i.e., to determine the depositional environments based on the occurrence of conodonts. While some of these efforts may be valid, not one is yet beyond debate.

The least controversial environmental assignment is that of Adetognathus to the shallow, nearshore environment. This is reasonable, as it occurs in shales and limestones associated with coals and various sandstones. Merrill (1973) concluded that Adetognathus must be nearshore, in part because of its association with "brackish" animals such as chonetids, lingulids, and pectinids. Later, Merrill (1974) suggested that it was dominant in areas of high deposition, where sedimentary dilution accounted for its low numbers, and suggested salinity as a control on its distribution. Heckel and Baesemann (1975) also concluded that Adetognathus was a shallow-water form, because of its association with shallow water carbonate facies, such as oölites or tidal-flat carbonates. This association was also noted by Wood (1977). Heckel and Baesemann (1975) also felt that Adetognathus was restricted to areas of fluctuating salinites.

Such observations are supported by this study. The relatively high abundances of Adetognathus in regions where deposition would be expected to be low supports Merrill's (1974) concept that its general

low abundances are partly a function of sedimentary dilution. And the occurrence of Adetognathus comparatively close to coals, and occasionally in monotypic faunas, favors distribution in nearshore environments with some type of restriction. However, its broad significant overlap in distribution with other conodonts, its occurrences with a broad range of invertebrates, as well as its absence from those deposits closest to the coals suggest that it was not confined to restricted environments, although it was opportunistic in some (but not all) nearshore conditions.

Wood (1977) suggested that Stepanovites might have been sedimentologically controlled, which is supported by its restricted occurrence in this study. Its distribution is apparently a subset of that of Adetognathus, perhaps to those areas where terrigenous clastic influx was low enough to permit carbonate sedimentation to continue in shallow water. If true, this would explain the rarity of Stepanovites in Illinois, where the favored shallow-water carbonate facies were less frequently permitted to develop.

Anchignathodus has a distribution that is conceptually similar to that illustrated by Merrill (1973), Merrill and von Bitter (1976), and Merrill (1980) (Fig. 56). There, it is illustrated as the third vertex of a triangle, with Adetognathus and Gondolella in the other corners. Wood (1977) suggested that Anchignathodus had no depth-related environmental control; this is possible, but some factor apparently favors its success in the lime-producing environment. Probably the two (Anchignathodus and limestone) are not directly related, but may occur in similar ranges of conditions and/or depth,

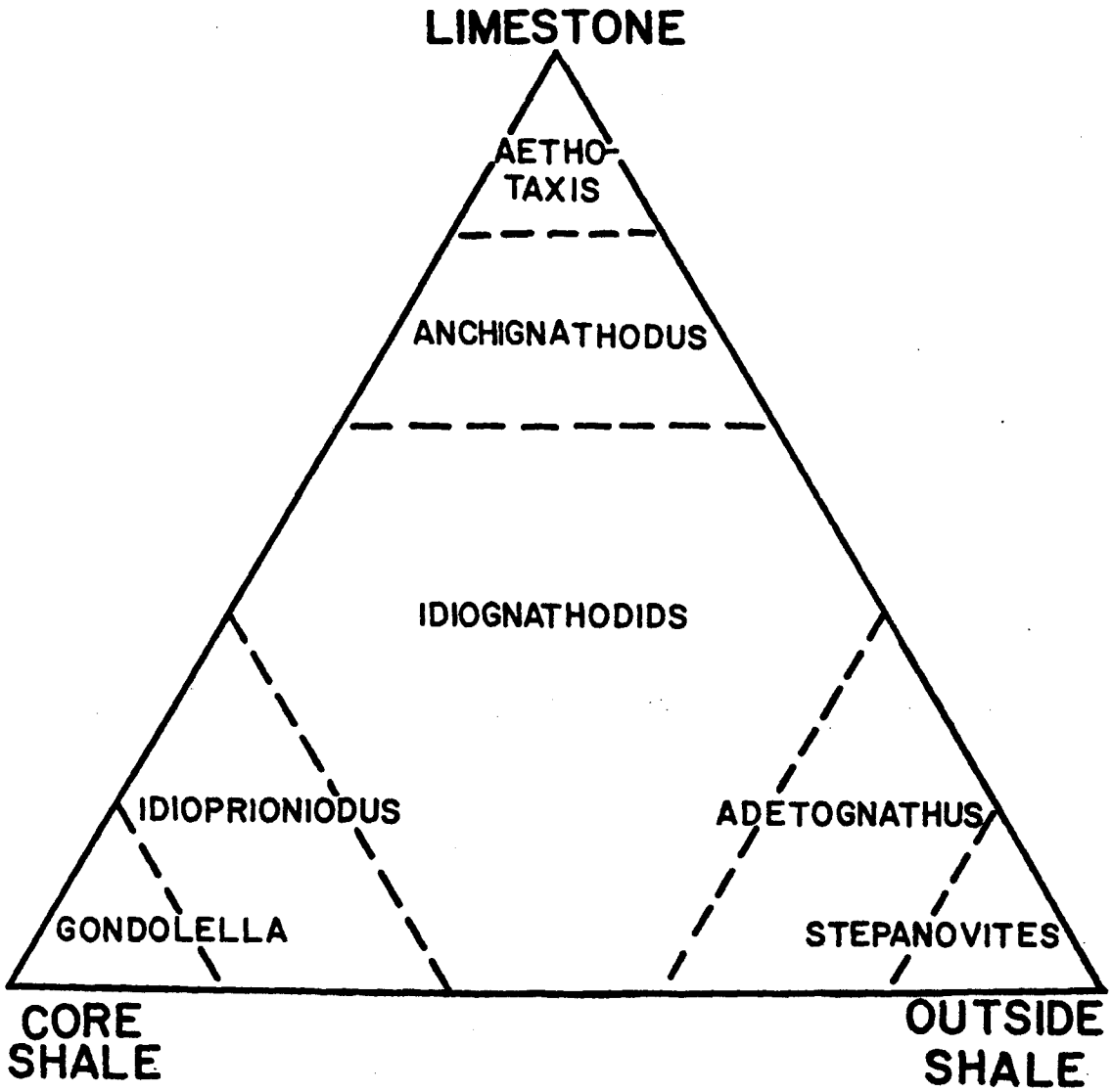



Figure 56. Conceptual diagram of conodont distribution, Missourian cyclothems.

Modified from Merrill, 1973;
Merrill and von Bitter, 1976;
Merrill, 1980.

so that their distributions are similar. But because both sometimes occur without the other, the conditions for either are unlikely to be the same or directly dependent.

Merrill (1980) suggested that the distribution of Aethotaxis may be parallel to that of Anchignathodus, rather than nested as a more restricted subset. Although possible on statistical grounds, the available evidence in this study suggests nesting.

The idiognathodids do not have strongly developed distributional trends, and apparently were adapted to a broad range of environments or to a ubiquitous water mass (Swade, 1982). The only place where they are significantly restricted is where their range overlaps that of Adetognathus. Heckel and Baesemann (1975) suggested that the idiognathodids were limited by salinity fluctuations, and that the mixing of Adetognathus and the idiognathodids was due in part to post-mortem onshore transport of idiognathodids. When salinity was stable, the idiognathodids outcompeted Adetognathus and replaced it. However, other possibilities exist, such as simple overlap in range of non-competing taxa. The zone of overlap may also represent a zone of instability, with the fauna being the time-averaged result, even though the animals did not live under the same conditions.

A seemingly key question in determining the meaning of conodont distribution in the core shales is the manner of life of the conodonts. Ellison (1950), working with similar black shales in West Texas, suggested that the conodont animal was probably pelagic, although he admitted some chance of them being benthic. Heckel and Baesemann (1975) also thought the conodont animal was pelagic, based on the high

organic content of the black shale, which they stated indicated anoxic bottom waters. With this as a premise, they applied Seddon and Sweet's (1971) model of depth zonation for the distribution of conodonts, producing an additive arrangement of conodonts in increasing water depth. Klapper and Barrick (1978) argued that such a distribution could be explained by either pelagic depth zonation or by a nektobenthic habit with overlapping ranges, stating that the only evidence for a pelagic habit was presumably anoxic bottom conditions. However, the anoxic conditions may have been restricted to the sediment, while the water column above, though dysaerobic, was oxygenated enough to permit growth of soft-bodied non-burrowing invertebrates. Such an arrangement can produce laminated black muds. It is also possible the bottom was only periodically anoxic, and epifauna could be present during aerobic episodes. In any case, however, the distribution would in fact support the depth interpretation.

Heckel and Baesemann (1975) based their interpretation of the (relatively) deep-water origin of the black shale not only on accompanying stratigraphic and petrologic grounds, but also on conformability with the Seddon and Sweet model. They claimed to find increasing diversity in the conodonts offshore, something that would be expected with an unstressed situation in deeper water. However, as noted above, the diversity is weakly developed, and is possibly an artifact of higher conodont numbers in the core shale. Heckel and Baesemann (1975) also thought that the high conodont abundances were the product of long-term deposition in a sediment-starved (probably offshore) environment.

Merrill (1973), however, began with Zangerl and Richardson's (1963) model for rapid black shale deposition in a restricted environment. Merrill and Martin stated:

> It is worth noting, however, that the black shale directly below the LaSalle Limestone also lies directly above an autochthonous coal and cannot possibly be interpreted as of deep water origin.
>
> - Merrill and Martin, 1976, p. 245, 249

From this evidence, Merrill (1973) argued that the conodonts did not live in a starved environment, but rather in a rapidly accumulating one. Merrill and Martin (1976) explained that the black shale formed beneath a mat of floating vegetation (the flotant of Zangerl and Richardson, 1963), and that this was true not only in the Illinois Basin, but also in the Midcontinent, where there are frequently extensive open marine deposits between the coals and nearshore shales and the black shales.

Thus, there is a dichotomy in interpretation of the black shale conodonts. Heckel and Baesemann (1975) held that Idioprioniodus and Gondolella were relatively deep-water pelagic forms, with abundant idiognathodids in the surface waters above, all raining down into a starved, anoxic bottom. Merrill (1973) felt they accumulated rapidly in a restricted environment, where the conodont animals would have had to be incredibly fecund to enrich a rapidly accumulating black shale. Merrill (1973) stated that Gondolella lived in a shallow, detritus-poor, organic-rich, low pH, generally low salinity environment.

While the depth zonation evidence of Heckel and Baesemann (1975) is somewhat equivocal, the model of Merrill (1973) has several

difficulties. Beyond the stratigraphic and petrologic problems, the nature of the conodont pattern through the cyclothem is not consistent with Merrill's model. The distribution of conodonts in the cyclothem is essentially symmetrical about the black shale (Heckel and Baesemann, 1975), which would mean that similar conditions prevailed both before and after black shale deposition. Merrill and Martin (1976) attempted to avoid this problem by calling for widespread formation of a flotant mat, which would produce an influx of coaly material, and poison the bottom environment.

However, coaly material will not poison the environment. In Iowa, there is frequent development of coaly shale with abundant marine invertebrates; often even coaly skeletal calcarenites will develop (e.g., the Decatur City beds). The characteristic conodont found in this environment is Adetognathus. This is also true of the Illinois example cited by Merrill and Martin (1976) above (Fig. 57). The coal is actually about four feet below the black shale, with the interval between occupied by coaly grey shale with scattered marine invertebrates; some of the coal fragments have Spirorbis attached to them. Only Adetognathus appears in the transition to the black shale.

Thus, there is usually a distinct, shallow-water phase below the black shale, frequently fulfilling the conditions invoked for shallow-water formation of the black shale. The fauna of the black shale is dependent on its environment, and not on its position in the cycle; that is, all fissile black core shales have a fauna of Gondolella and Idioprioniodus, regardless of the underlying strata, but not all basal or near-basal coaly black strata above coal seams or underclays

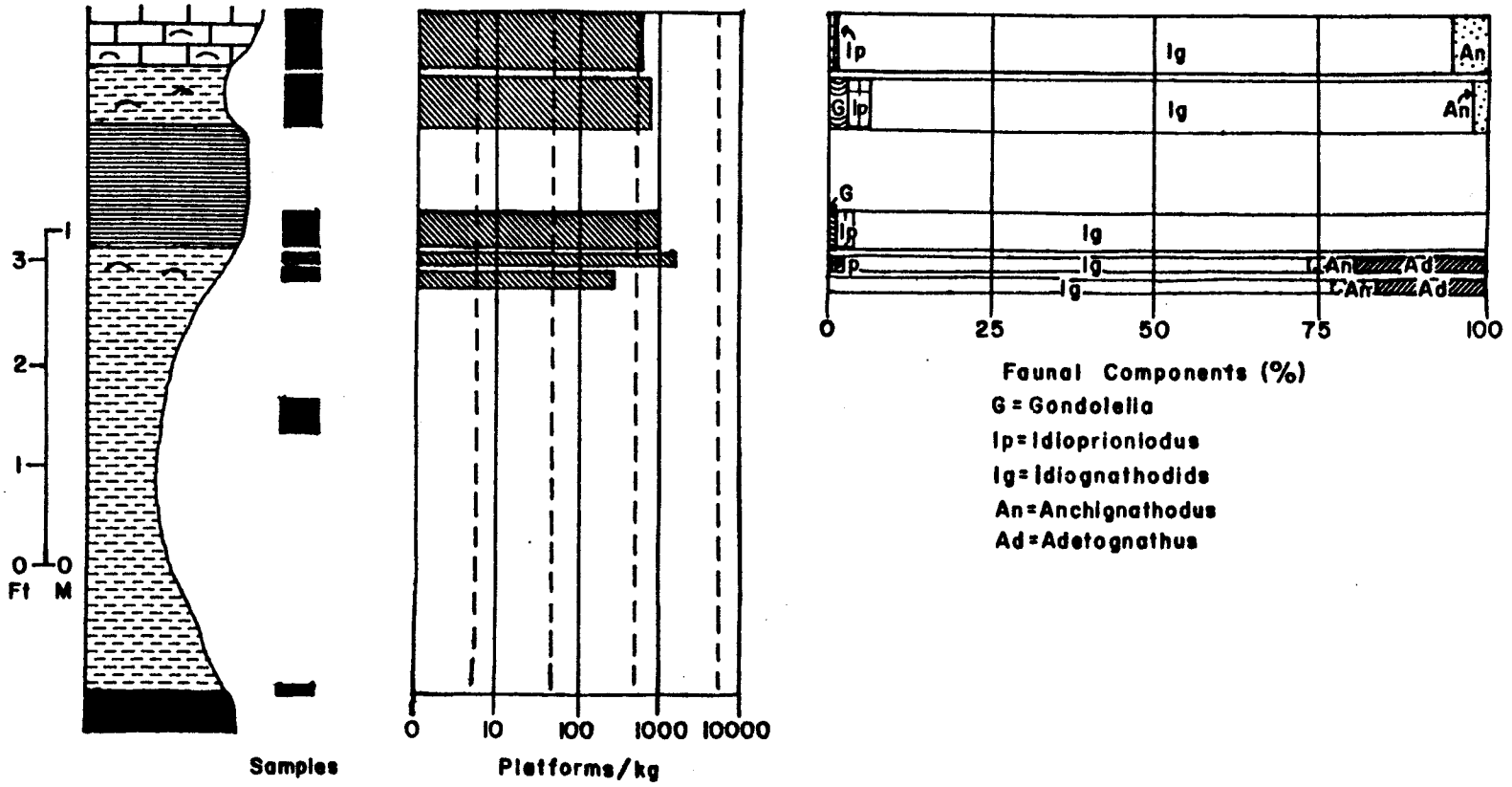



Figure 57. Conodont distribution - LaSalle cyclothem, Oglesby, Illinois (Locality LS1).

have such a fauna. Clearly, there is a progression from a nearshore environment (characterized by Adetognathus) to another one, apparently with a low-oxygen bottom, then back to a shallow one. Deviation from geometric (thickness) symmetry of the strata is attributable to variations in rate of deposition. While this symmetry could be due to other causes, the most probable mechanism is a simple rise and fall of relative sea level, which is probably responsible for the transition from nearshore, low diversity, coaly shales with Adetognathus to offshore, diversely fossiliferous limestones with idiognathodids, Anchignathodus, and Aethotaxis.

There are several non-diagnostic lines of evidence that lend support to the deep-water interpretation of the Gondolella-Idioprioniodus fauna, rather than to the restricted nearshore anoxic interpretation. One is the occurrence in the Black Hills of Missourian grey shales with abundant idiognathodids and Gondolella (Jennings, 1958), where the water apparently shallowed enough over the Black Hills Uplift to prevent black shale from forming, but was still deep enough for Gondolella. In the Paradox Basin, Stone (1968) reported Gondolella from the black shales in the evaporite cyclothems. There, too, the black shales are in the cores of the cyclothems, in what is interpreted as the deepest water. The overall faunal characteristics described are remarkably similar to those of the Midcontinent, including domination of the conodont fauna by idiognathodids. However, in both regions coals and nearshore shales are absent from the section, being replaced by shallow-water carbonates and evaporites. Heckel and Baesemann (1975) reported that G. Klapper found Gondolella

in upper Desmoinesian strata of West Texas in a crinoidal facies, there interpreted as the deepest-water carbonate facies.

Further suggestive evidence comes from Europe. Upper Carboniferous black shales in Great Britain, otherwise similar to those in the Midcontinent, are reported to contain only idiognathodids (Edwards and Stubblefield, 1947; Clarke, 1960). However, the cyclothems in the Moscow and Donets Basins, where the strata are much more open marine with extensive development of limestones, Adetognathus, idiognathodids, and Gondolella (many of the species the same as in North America) are reported (Barskov et al., 1979; Kozitskaya et al., 1979).

It may be that the faunal stratification model of Ellison (1951) (Fig. 58) describes the conodont distribution better than that of Seddon and Sweet (1971). The principal difference is that Ellison included a nearshore zone, with a nektic fauna distinct from that which is vertically stratified in deeper water. Ellison's model, which also applies to benthic microfauna, points out that shallow water forms, nektic or benthic, are occasionally carried into deeper areas. If the Missourian conodont distribution followed Ellison's model, Adetognathus would be the principal shallow-water, nearshore conodont, while the idiognathodids, Idioprioniodus, and Gondolella were vertically zoned in deeper water.

Another pertinent problem relating to Gondolella is the distribution of Gondolella denuda, a "naked" form without a platform on the P element. It is uncertain whether this is a stratigraphic or environmental problem. Gondolella denuda has been used as a stratigraphic marker, although the validity of this is uncertain. Ellison (1941)

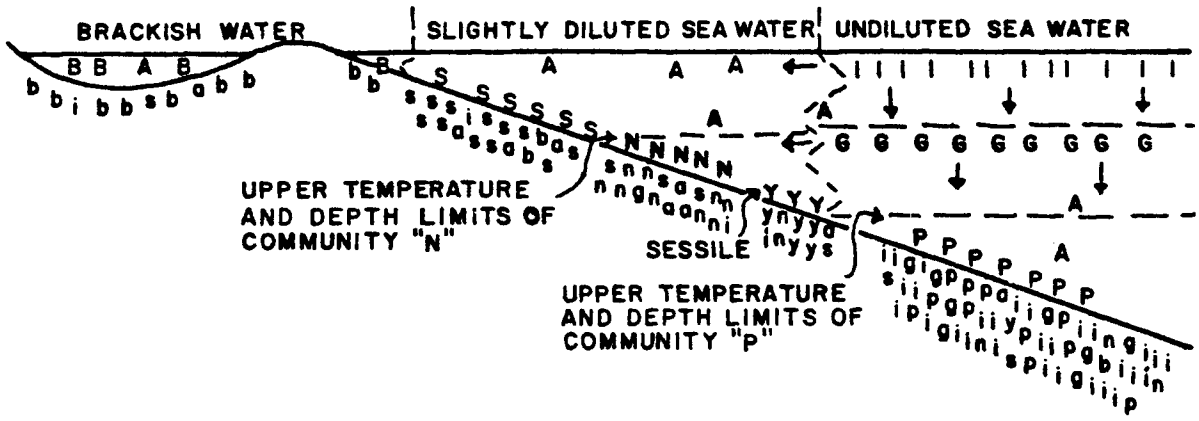



Figure 58. Theoretical distributions of marine microfossils.

From Ellison (1951)

reported G. denuda only from the Hushpuckney Shale of the Swope cyclothem and from the Queen Hill Shale of the Virgilian Lecompton cyclothem. Von Bitter and Merrill (1978) noted G. denuda principally in Lower Missourian black shales and the Queen Hill, and also rarely in the Heebner Shale of the next lower Oread cyclothem. Von Bitter and Heckel (1978) used this pattern to distinguish between the Heebner and the Eudora, because the Eudora lacks G. denuda. This use of G. denuda for de facto stratigraphy was also applied by J. W. Swade (pers. comm., 1981) when he observed a conodont faunule from the black shale below the Macoupin Limestone of Illinois closely resembled that of the Hushpuckney, apparently confirming traditional correlations.

This use of G. denuda runs into problems on several fronts. There is no theoretical basis for this application, only a potential empirical one. Clark and Mosher (1966), in addressing gondolellid evolution, stated G. denuda is the supposed ancestral form, which

von Bitter and Merrill (1978) supported. However, von Bitter and Heckel (1978) implied a reverse evolutionary trend, noting wide-platformed Gondolella in the Eudora, and narrow-platformed Gondolella (including denuda) in the younger Heebner. Since they reasoned the two black shales were environmentally similar, they felt that an evolutionary trend was the probable explanation.

Other reports of G. denuda also cloud the picture. Biesiot (1950) reported it from the Hushpuckney and the Eudora in Nebraska. However, in light of Heckel and Meacham's (1981) reassessment of lower Missourian stratigraphy in Nebraska, the first assignment is uncertain. Baesemann (1973) reported G. denuda from the Muncie Creek Shale of the Iola cyclothem, but none from the Hushpuckney. Von Bitter and Merrill (1978) also reported G. denuda from the Cramer Limestone of Illinois and the Lower Brush Creek cyclothem of the Appalachian Basin. While the latter may be equivalent to the Swope cyclothem and the Hushpuckney Shale (keeping G. denuda essentially restricted to one horizon), correlations based on fusulinids may suggest otherwise (see Appendix C). Also, in the course of this study, G. denuda was found in the black shale below the Shoal Creek Limestone near Oakwood, Illinois (Locality Oal). Again, this suggests that G. denuda is an unsound basis for correlation, or that the outcrop itself was miscorrelated.

A possible explanation to this was provided by another set of outcrops studied. At Richfield, Nebraska, two successive cyclothems were studied, since the stratigraphic assignments were questionable. Only the lower cyclothem yielded G. denuda; this would confirm Heckel

and Meacham's (1981) assignment of it to the Swope cyclothem and the Hushpuckney Shale based on fusulinids. But the distribution of Gondolella within this cyclothem is suggestive. G. denuda occurs near the base, in the very fissile portion of the black shale, where Gondolella is a very small percentage of the total conodont population. Upward, near the transition, where Gondolella becomes abundant, the platforms are all broad. This suggests that G. denuda was environmentally controlled, and occurs only in the blackest part of the black shale where it is relatively rare, being replaced by more typical Gondolella as conditions improved. Von Bitter and Heckel's (1978) observations somewhat confirm this, as they noted that in the Heebner, where they found G. denuda, Gondolella was rare; while in the Eudora, where they didn't find G. denuda, Gondolella was common.

The possibility exists, then, that G. denuda may occur in more cyclothems, but only in horizons that are very restricted and difficult to sample. Only careful vertical collecting of black shales can resolve this question.

Another possible environmental control on conodonts may be connected to clastic influx. In an attempt to measure this, co-occurrences of the various conodonts were plotted with kaolinite and muscovite, which serve as indicators of land-derived clastics. Potential results could be interpreted in two different ways, as a lack of co-occurrence could indicate either an intolerance for terrigenous clastic influx or a simple preference for a deeper water, offshore environment.

For the most part, the co-occurrences are consistent with the hypothesis that depth is the principal control of conodont distribution. Adetognathus occurs with the two minerals in almost exactly the ratios predicted by random co-occurrences. However, lack of a strongly positive correlation suggests that Adetognathus does not actively prefer areas of clastic influx. The idiognathodids have a somewhat lower co-occurrence, as might be expected with an animal living farther offshore. However, since they do occur in the vastly thickened Eudora of northeastern Oklahoma and southeastern Kansas, albeit in much lower numbers due to apparent sedimentary dilution (Wood, 1977; this study), it would seem that clastic influx is not the determining factor. Gondolella also follows this pattern. It occurs with kaolinite and muscovite slightly less often than the idiognathodids, but still co-occurs frequently enough that it seems unlikely that clastic influx controls its distribution.

Idioprioniodus represents a possibly anomalous situation, however. It occurs with the two minerals less frequently than any of the other major conodonts; indeed, it exhibits a more marked tendency to avoid them than virtually any other organism in this study. Since the distribution is not completely disjunct, however, it may be that the control on Idioprioniodus' distribution is only indirectly related to clastic influx. At present, this is an unanswered question.

One other possibly significant correlation between kaolinite and conodonts is found in the Altoona (Kansas) channel. There the Eudora contains Gondolella and a notable admixture of Adetognathus. The Eudora is also anomalously kaolinitic. Both conditions suggest some

transport of nearshore material down the channel, even during the period of black shale deposition.

Another aspect of conodont distribution supports an important stratigraphic and environmental interpretation. Mitchell (1981) noted that in the Raytown Limestone, the upper limestone of the Iola cyclothem, northward development of a tidal flat facies at the top corresponds to a loss of conodont fauna. Generally, a similar tendency can be seen in the top of the Bethany Falls Limestone. However, at several localities, the calcilutitic top of the Bethany Falls contains a numerous and diverse conodont fauna, with Adetognathus, numerous or dominant idiognathodids, Anchignathodus, and Stepanovites. This could indicate a locally more open environment, or it could indicate loss of the tidal flat facies through weathering and development of the overlying Galesburg Formation. No positive petrologic evidence for either possibility was found.

## Ostracodes

Ostracodes are the commonest calcareous microfossils found in the Missourian shales studied. They occur in 154 or just over 64% of the fossiliferous shale samples. 20 genera were identified with varying degrees of certainty, but the faunules were dominated by five abundant forms. The ostracodes display a well-developed, orderly sequence through each cyclothem, which appears more sensitive than the conodont distribution.

In order to discuss ostracode distribution in the shales, it is necessary to comment first on the overall features of ostracode

distribution in general and in the cyclothems in particular. Comments on the individual genera will be made within this framework, then some overall remarks interpreting and summarizing their distribution will be made.

General Aspects of Ostracode Distribution

Ostracodes are capable of living in fresh, brackish, or marine waters, and on a wide variety of substrates. As a consequence, they show a wide range of adaptations to their environment, and a wide assortment of faunal associations.

According to Benson (1961), pelagic ostracodes are rare in the fossil record; most of the forms seen are benthic, which either crawl on the bottom or burrow into the substrate. Thus, either directly or indirectly they are dependent on bottom conditions. These bottom dwellers are divided into groups; since sandy substrates are rare in the shale units dealt with here and produced no ostracodes, they will be disregarded.

Ostracode carapaces are generally considered to reflect the substrate on/in which they live. The smooth forms are commonest in fine muds, while more ornate forms are found in the more calcareous or coarser sediments (Benson, 1961). Agnew (1957) stated that ornamentation occurs on the crawlers, to serve as support on soft substrate. Brasier (1980) elaborated on this, stating that soft substrate crawlers were often flattened ventrally, with fine projections for support, e.g., alae, frills, keels, and lateral spines. Those that live on coarser substrate with more turbulence have thicker shells, with coarse

sculpture of ribs, reticulations, or robust spines. Those that burrow into the mud are smooth and elongate. Benson (1961) also observed that swimming forms are generally smooth, high in proportion to length, and with simply-hinged thin, lightweight valves. Pokorny (1978) noted that soft substrates are generally more conducive to ostracodes, where they are abundant and diverse; whereas sandy sediments have only sparse faunas.

Brasier (1980) noted that unlike most faunal groups, which only have euryhaline forms close to shore, ostracodes have distinct nearshore assemblages. Benson (1961) stated that these fall into a series of distinct zones, based on persistent salinity limits. Ostracodes are often the most abundant fossils in brackish environments, although like most groups they become more diverse in deeper water. (Benson noted that many of the brackish water forms are truly euryhaline, also becoming abundant in hypersaline lagoons.) Generally, ostracodes also seem to become more ornamented offshore (Benson, 1961; Pokorny, 1978); Benson attributed this to increased ease in extracting ions from the water, making construction of heavy, ornamented shells practical.

Benson (1961) summarized several other major controls of ostracodes. Depth, for example, is not a direct control, but may be an indirect one, because many ostracodes are dependent on plant life. In many modern cases, there are specific associations between particular ostracodes and particular plants, which produces a patchy ostracode distribution. Ostracodes also reflect the nutrient content of the water, and, as with many other animals, nutrient-rich upwellings produce large populations. In warm shallow waters low in nutrients,

ostracodes are depleted, except near river mouths draining limestone and/or phosphate-rich terranes. Ostracodes do tend to increase in diversity in warmer waters, but this is largely dependent on adequate nutrients. Benson noted that little is known about the relationship of ostracodes to oxygen, but also noted that ostracodes are not found in euxinic muds, but are found in glauconitic sediments.

All these parameters are reflected in ostracode distribution in the rocks. Benson (1961) noted that ostracodes are rare in well-sorted sands and evaporites, as well as euxinic deposits. Most recovered fossil faunas are from calcareous shales and sands; due to problems of recovery, limestone faunas are poorly known except where replaced by insoluble minerals.

This pattern of occurrence relates to Midcontinent cyclothems in several ways. But before considering the finer aspects of ostracode distribution, two things must be noted. First, most ostracodes found in Missourian strata are long-ranging, often from the Lower Pennsylvanian through the Lower Permian (Johnson, 1936) so that absence of a taxon from a cyclothem is usually for environmental, rather than evolutionary, reasons. Second, Moore (1950) observed that ostracode assemblages did indeed reflect the phase of the cyclothem, which would be expected if the environment changed significantly.

Most of the known faunas were collected from calcareous shales and argillaceous limestones (Johnson, 1936; Cooper, 1946), especially near the marine limestones in the upper part of the cyclothem (Cooper, 1946). Johnson (1936) noted that ostracodes were sparse in pure

limestones and in dark grey shales while black shales lacked them completely.

General trends are instructive. Hattin (1957) found diversity increasing from a red mudstone toward a limestone, which he interpreted to reflect increasing stability of the marine environment. In a series of studies on the Virgilian Beil Limestone, the upper limestone of the Lecompton cyclothem (Brondos, 1974; Kaesler et al., 1977; Haack and Kaesler, 1979, 1980), the reverse was reported, with a decrease in diversity with an increase of clay, with both attributed to increasingly shallow-water deposition. Bate and Robinson (1978) noted similar patterns in the British Carboniferous (which shares virtually all of its ostracodes with North America). They found the greatest diversity in fully marine conditions, with reduction in diversity attributable to changes in depth and/or salinity.

A pertinent faunal association deserves comment. Benson (1961) stated that ostracodes tend to be inversely proportional to conodonts, but that both are common in the transition. Johnson (1936) stated that ostracodes often occur with conodonts, and this was found to be true in this study.

## Empirical Distributions

### Geisinids

The geisinids here include Hastifaba and may include Jonesina (see Appendix B). They are relatively smooth ostracodes with an extremely marked distribution in the cyclothem. Johnson (1936) noted that Geisina is the only ostracode to occur by itself, and when it does, it is very

numerous. Geisina was reported by Johnson from the Vilas Shale and Captain Creek Limestone in great numbers, but was nearly absent from the Galesburg Shale.

In general, observations here confirm this. Geisinids are absent from the blocky Galesburg mudstone, but are very abundant in the basal grey Stark Shale above the Davis City Coal, and are the only ostracodes present. They are associated with myalinids, fish fragments, and scattered lingulids in very coaly shale and limestone. In the Vilas Shale, geisinids are not as numerous, but are often present in significant numbers. The geisinids' distribution also extends into the adjacent limestones as they are preferentially pyritized in relation to other ostracodes, and are frequently recovered from the limestone residues.

Geisinids are strongly associated with the outside shale and never occur in the core shale when the core shale can be distinguished from the outside shale (Fig. 59). Geisinids occur with no other ostracodes in about 40 percent of the samples. Of the other significant ostracodes, geisinids are most frequently associated with Cavellina (in about 50 percent of its occurrences), less often with Bairdia (in about 35 percent and least with Amphissites (in about 20 percent) (Fig. 60). They are also frequently associated with the conodont Adetognathus, but are never found with Gondolella. Notably, they are found with Adetognathus more often than with idiognathodid conodonts.

## Amphissites

Amphissites (may include Shleesha; see Appendix B) is a heavily-carapaced, reticulated ostracode, with several nodes and carinae. It

Figure 59. Stratigraphic distribution of ostracodes in the Dennis and Stanton cyclothems.

Key as in Figure 52, p. 326.

| | Genera present | Total samples | % of shale | geisinids | Cavellina | Bairdia | Hollinella | Amphissites | Roundyella | Kirkbya | Knightina | Kellettina | Kegelites |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ls - Base | 8 | 14 | | | 4 | 6 | 1 | 2 | | | 1 | 1 | |
| Core C (grey) | 13 | 41 | 26.6 | | 32 1.84 78.0 | 21 .96 51.2 | 11 1.11 26.8 | 19 1.66 46.3 | 5 3.05 12.2 | 6 3.40 14.6 | 1 .89 2.4 | 5 3.13 12.2 | 1 1.20 2.4 |
| Core B (black) | 3 | 3 | 1.9 | | | 1 .68 33.3 | 1 1.38 33.3 | | | | | | |
| Core A (grey) | 11 | 13 | 8.4 | | 7 1.27 53.8 | 7 .99 53.8 | 3 .95 23.1 | 6 1.66 46.2 | | 1 1.79 7.7 | | | 1 3.85 7.7 |
| Core A (undifferentiated) | 13 | 32 | 20.8 | 18 3.70 56.3 | 16 1.18 50.0 | 16 .94 50.0 | 3 .39 9.4 | 4 .45 12.5 | 2 1.58 6.3 | | 1 1.15 3.1 | | |
| Middle Ls | 4 | 7 | | 5 | 1 | 4 | | | | | | | |
| Outside | 14 | 56 | 36.4 | 20 2.33 35.7 | 28 1.18 50.0 | 23 .77 41.1 | 17 1.26 30.4 | 10 .64 17.9 | 3 1.35 5.4 | 2 .84 3.6 | 6 3.96 10.7 | | 1 .90 1.8 |
| Stray Ls | 2 | 2 | | 1 | | | 1 | | | | | | |
| Upper Ls - Top | 4 | 7 | | 1 | 4 | 1 | | | | | | | |
| Ls Partings (shale) | 5 | 9 | 5.8 | | 2 .52 22.2 | 6 1.67 66.9 | 2 .92 22.2 | 4 1.59 44.4 | | | | 1 2.85 11.1 | |
| Upper Ls - Middle | 1 | 1 | | | | 1 | | | | | | | |
| Shale - Total | 20 | 154 | | 38 15.3 | 85 42.3 | 76 52.9 | 37 24.2 | 43 27.9 | 10 4.0 | 9 4.3 | 8 2.7 | 6 3.9 | 3 2.0 |
| Total | 20 | 185 | | 45 | 94 | 88 | 39 | 45 | 10 | 9 | 9 | 7 | 3 |

Figure 59.

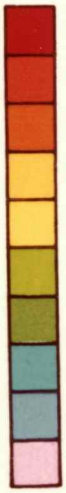
Figure 60. Co-occurrence patterns of ostracodes in the Dennis and Stanton cyclothems.

KEY

Number of co-occurrences

Percentage of total occurrences of taxon at left

Percentage Code



90.0 - 100.0
80.0 - 89.9
70.0 - 79.9
60.0 - 69.9
50.0 - 59.9
40.0 - 49.9
30.0 - 39.9
20.0 - 29.9
10.0 - 19.9
0.1 - 9.9

| | none | geisinids | Cavellina | Bairdia | Hollinella | Amphissites | Roundyella | Kirkbya | Knightina | Kellettina | Kegelites |
|---|---|---|---|---|---|---|---|---|---|---|---|
| geisinids | 15<br>38.5 | | 17<br>43.6 | 14<br>35.9 | 9<br>23.1 | 6<br>15.4 | 2<br>5.1 | | 2<br>5.1 | | |
| Cavellina | 14<br>16.3 | 17<br>19.8 | | 45<br>52.3 | 27<br>31.4 | 29<br>33.7 | 10<br>11.6 | 4<br>4.7 | 7<br>8.1 | 3<br>3.5 | 2<br>2.3 |
| Bairdia | 11<br>13.9 | 14<br>17.7 | 45<br>57.0 | | 28<br>35.4 | 31<br>39.2 | 9<br>11.4 | 7<br>8.9 | 5<br>6.3 | 4<br>5.1 | 3<br>3.8 |
| Hollinella | 2<br>5.3 | 9<br>23.7 | 27<br>71.1 | 28<br>73.7 | | 19<br>50.0 | 5<br>13.2 | 5<br>13.2 | 4<br>10.5 | 4<br>10.5 | 2<br>5.3 |
| Amphissites | 2<br>4.8 | 6<br>14.3 | 29<br>69.0 | 31<br>73.8 | 19<br>45.2 | | 8<br>19.0 | 5<br>11.9 | 1<br>2.4 | 3<br>7.1 | 1<br>2.4 |
| Roundyella | | 2<br>20.0 | 10<br>100.0 | 9<br>90.0 | 5<br>50.0 | 8<br>80.0 | | 2<br>20.0 | 1<br>10.0 | 1<br>10.0 | 1<br>10.0 |
| Kirkbya | | | 4<br>50.0 | 7<br>87.5 | 5<br>62.5 | 5<br>62.5 | 2<br>25.0 | | | 2<br>25.0 | |
| Knightina | | 2<br>25.0 | 7<br>87.5 | 5<br>62.5 | 4<br>50.0 | 1<br>12.5 | 1<br>12.5 | | | | |
| Kellettina | | | 3<br>60.0 | 4<br>80.0 | 4<br>80.0 | 3<br>60.0 | 1<br>20.0 | 2<br>40.0 | | | |
| Kegelites | | | 2<br>66.7 | 3<br>100.0 | 2<br>66.7 | 1<br>33.3 | 1<br>33.3 | | | | |

Figure 60

is strongly associated with the grey shales transitional to the fissile black core shale, although absent from the black shale itself. However, it is also found occasionally in the outside grey shales, as well as shale partings in the limestones and in the limestones themselves (Fig. 59). It is generally not common (and never dominant) within its assemblages, but is a frequent constituent of relatively diverse faunas. Of the significant ostracodes, Amphissites is found most frequently associated with Bairdia (in just over 70 percent of its occurrences), slightly less frequently with Cavellina (just under 70 percent) and only occasionally with geisinids (about 15 percent). It is almost never (5 percent of its occurrences) the only ostracode present (Fig. 60). It is found almost equally as often with the conodont Gondolella as with Adetognathus. Its percent occurrence with idiognathodids is greater than that of any other major ostracode, in over 90 percent of the samples in which it occurs.

Cavellina

Cavellina is the most common ostracode in the shales. It is found in over half the samples with ostracodes present, and in over a third of all the fossiliferous shale samples. Cavellina is often abundant where it is found, as well. It is a simple, unornamented, bean-shaped ostracode. Cavellina is common throughout the shales, but is particularly common in the upper grey transition from the black core shale. It is least common in the shale partings of the limestones (Fig. 59). It is also frequently found replaced and as steinkerns in the limestone.

Of the significant ostracodes, over half of Cavellina's occurrences are with Bairdia, about a third are with Amphissites, and about 20 percent with geisinids (Fig. 60). It occurs with the conodont Adetognathus as frequently as do geisinids (on a percentage basis), and with Gondolella about a quarter as often as with Adetognathus. Cavellina has a particularly striking relationship with geisinids. In several cases, where the core shale is approached stratigraphically, abundant geisinids will be joined by Cavellina and gradually be replaced by it. Then, in turn, Cavellina is joined by (but generally not replaced by) other ostracodes (Fig. 61).

Bairdia

Bairdia is a heavily-carapaced smooth ostracode, somewhat pointed on the ends. It is only slightly less common than Cavellina. Generally, its distribution is like that of Cavellina, and consistent through the shales of the cylcothem. However, it almost always occurs in the shale partings in the limestone, where Cavellina is uncommon (Fig. 59). It is also often found in the limestones, which is consistent with Johnson's (1936) observation that Bairdia is the most common ostracode in them.

Bairdia may be well-represented in the ostracode faunas, but it is seldom dominant. Its distribution is instructive when compared to Cavellina, with which it occurs in about 60 percent of its samples. It occurs with Amphissites more often and with geisinids less often than does Cavellina (Fig. 60). With respect to conodonts, it occurs with Gondolella more often and with Adetognathus less often than does

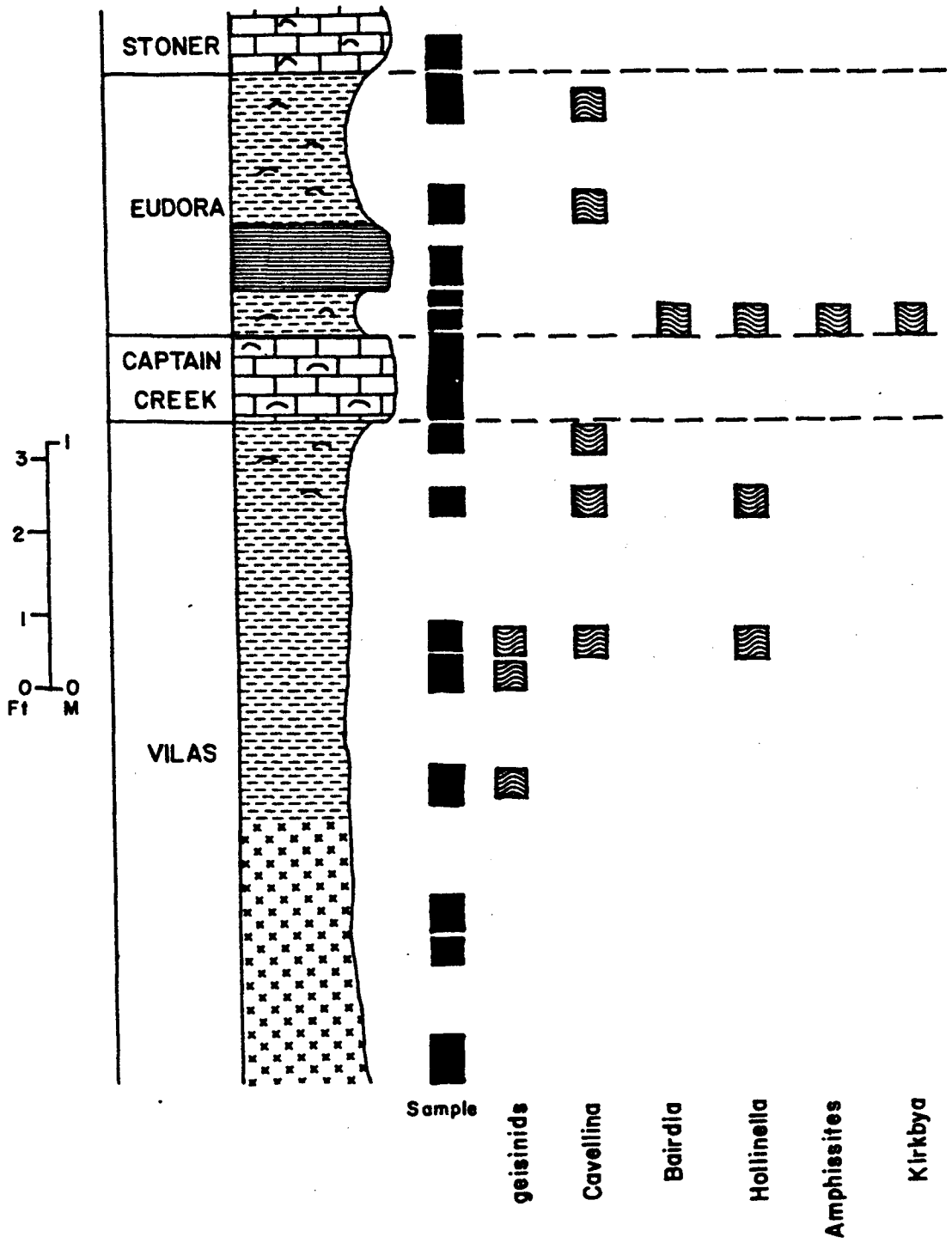



Figure 61. Ostracode distribution - Stanton cyclothem, Winterset, Iowa (Locality Wi2).

Cavellina, although it is still with Adetognathus about 2½ times as often as with Gondolella.

Hollinella

Hollinella has a well-developed velum (frill) and pair of nodes on each valve. It occurs roughly as often in the shales as are Amphissites and geisinids, but it is never particularly abundant.

Hollinella has a distribution that is difficult to analyze. It occurs with both Cavellina and Bairdia in about 70 percent of its samples, with Amphissites in about half of them, and with geisinids in about a quarter of them (Fig. 60). It rarely occurs with Gondolella (in only 5 percent of its samples), but occurs with Adetognathus more frequently (over 50 percent) than any other major ostracode, and with Anchignathodus in over 55 percent of its samples, again more than any other ostracode. It occurs with Stepanovites more than any other ostracode, but as the total occurrence is so small this may not be significant. Hollinella occurs with fish more frequently than do the other major ostracodes; it also does so with respect to gastropods, and only Geisina has a higher percent occurrence with pelecypods. Hollinella occurs with the encrusting agglutinated foram Ammovertella more often than any major ostracode except Amphissites, although the percentage is rather low (22 percent).

Kirkbya

Kirkbya is much less common than the principal genera, but may give some indication of its environmental preferences. Kirkbya is a reticulated ostracode, similar to but less ornamented than

Amphissites, also a kirkbyacean. It bears a single marginal carina, and has a long, straight hinge line. Stratigraphically, it usually occurs in the transition grey shales of the core shale, especially the upper transition. It does occur in the outside shale, but infrequently, and is absent in the outside-core transition when the middle limestone is absent (Fig. 59). Kirkbya occurs with Amphissites in 60 percent of its samples, but never with geisinids. It occurs with Bairdia in nearly 90 percent of its samples, Hollinella in 60 percent of its samples and Cavellina in half of its samples (Fig. 60). Among the conodonts, idiognathodids are always found with it, Anchignathodus accompanies it in three-quarters of its samples, and both Gondolella and Adetognathus equally, in about a quarter of the samples in which it occurs.

Roundyella

Roundyella is a simple lozenge-shaped reticulated kirkbyacean. It occurs in both the core shale transitions and the outside shale, but is most common in the upper grey transition (Fig. 59). Among the ostracodes, 80 percent of its occurrences are with Amphissites, 90 percent with Bairdia, and all of its occurrences are with Cavellina. Half of its occurrences are with Hollinella, and 20 percent are with geisinids (Fig. 60).

Kellettina

Kellettina is another kirkbyacean of secondary importance; it is also reticulated, and bears two very prominent, almost horn-like, nodes on each valve. In this study, it was found only in the upper grey

transition of the core shale and in the shale partings in the limestones, the only ostracode other than the principal genera found there (Fig. 59). Kellettina is accompanied in 80 percent of its occurrences by Bairdia and Hollinella, and somewhat less often by Amphissites and Cavellina. It does not occur with geisinids (Fig. 60).

Knightina

Knightina is yet another kirkbyacean of minor importance; like the others, it is reticulated, and is ornamented by a simple marginal carina. However, it has a markedly different distribution, unlike that of the other kirkbyaceans. It occurs sparingly in the grey transitions of the core, but relatively frequently in the outside shale (Fig. 59). Cavellina accompanies it in about 90 percent of its samples, Bairdia and Hollinella in about half of its samples, geisinids in 20 percent of its samples, and Amphissites in 10 percent of its samples. Knightina has the conodont Gondolella with it in only 10 percent of its samples, but Adetognathus in 70 percent of its samples, even more frequently than with idiognathodids. Among other groups, it is always accompanied by gastropods and usually by fish (in 85 percent of its samples).

Other Ostracodes

Most of the rest of the ostracodes present were infrequent and/or without discernible patterns of occurrence. Brief mention is made of them here, chiefly of those that other workers found frequently.

Kegelites is yet another kirkbyacean ostracode. It is generally ornamented like the others, and what distribution it has suggests it

generally occurs in much the same environments as the others (excluding Knightina).

One isolated occurrence of an ostracode may be more significant. In the fissile black Stark Shale at Dennis, Kansas (Locality Del), a number of small carbonate spheres occur, each divided into two halves by an equatorial rim of sparry calcite; on this basis they were interpreted as being bivalved, although no other details are visible. These fossils are very tentatively assigned to Cypridinella. They were found only at this locality; only two other occurrences of ostracodes (one each by Bairdia and Hollinella) in the black shale are known.

Interpretations

When discussing the distribution of the ostracodes, a summary of the interpretation of each genus is in order. This includes how other workers have interpreted it, and how that relates to interpretations here. Then, an overall summary of distribution can be made.

Geisinids are clearly shallow water, nearshore ostracodes, as indicated by their occurrence in low diversity, high abundance faunas directly above coal or coaly horizons. They often form "ostracodite" lenses, which Brasier (1980) noted are usually of brackish or freshwater origin. Lane (1964) decided Geisina was a freshwater form, as it was associated with Candona and Darwinula, both extant freshwater ostracodes. Bless (1969) reached a similar conclusion, based on the overlap of distribution of Geisina with the freshwater ostracode Carbonita, and Calver (1968a) placed Geisina in the fresh to brackish range. But geisinids may have been more marine than suspected; in this

study, they were always found with marine fossils, often with abundant and diverse faunas, and occasionally in fossiliferous limestones. However, the possibility of transport cannot be excluded in many of those samples.

Cavellina is also a nearshore form, although less clearly so than geisinids. It occurs in great numbers and in low diversity faunas, but often only after succeeding geisinids. But it is also common with other ostracodes; in many ways, it is the ostracode analog of the idiognathodid conodonts.

The nearshore placement of Cavellina is prevalent among ostracode workers. Bate and Robinson (1978) stated that it was brackish; Brondos (1974) and Haack and Kaesler (1980) stated that it lived in shallow, unstable environments.

Bairdia increases in importance farther offshore, but not as far offshore as Amphissites. This is reflected in Bless's (1969) distribution pattern. Bairdia was placed in a deep, stable environment by Brondos (1974), but Haack and Kaesler (1980) concluded that this was an oversimplification. They noted bairdiids both increased and decreased close to shore, depending on the species. In the Lower Permian Red Eagle cyclothem, McCrone (1963) noted that Cavellina and Bairdia were the commonest and most eurytopic ostracodes present, paralleling the observations here.

Amphissites and the associated kirkbyacean ostracodes (Roundyella, Kegelites, Kellettina, and Kirkbya) occur in diverse ostracode assemblages (e.g., Imbrie, 1955; Hattin, 1957; Ottum, 1969). Bless (1969) placed Amphissites in an offshore position, but stated

that the control was probably higher turbulence. He felt that Amphissites and Roundyella were creepers with heavy carapaces to protect them in such an environment. Brondos (1974) placed Kellettina in a deep, stable environment, and Lipp (1975) noted that Amphissites was restricted to the most diverse fauna in the Cambridge cyclothem of Ohio. Siebels (1981) provided some confirmation, finding Amphissites only in the center of the Forest City Basin, and not in equivalent rocks around its perimeter. Thus, Amphissites appears to be a relatively offshore ostracode, living in deep, stable environments, but may not be controlled by turbulence, as most occurrences here are in shale. This agrees with McCrone's (1963) assessment of Amphissites as a stenotopic form; his data also places it close to the core shale. The related kirkbyaceans have similar patterns with minor variations: Roundyella is broadly adapted, and somewhat more shallowly distributed; Kirkbya is very similar to Amphissites in distribution; and Kellettina displays a tendency toward the same environment occupied by Hollinella.

Knightina is a kirkbyacean with a tendency toward shallow water. This shows that the apparent morphology does not reflect the gross environment, as Knightina is similar to the other kirkbyaceans, and also that the level of taxonomy does make a difference in these studies. If a higher level had been used here, Knightina's trend would not have been recognized, and kirkbyaceans would've been assumed to be all deeper water (since a few Knightina would not have noticeably altered the results).

Imbrie (1955) provided support for the relatively shallow-water distribution of Knightina, by noting that Knightina became a dominant ostracode upward from the most diverse fauna in the lower Florena Shale (Permian). McCrone (1963) found that Knightina overlapped significantly with Kirkbya in Lower Permian rocks, in contrast to the data here. This may be a result of sparse data in this study, or of niche enlargement by Knightina, which is reported more often and in greater numbers in Lower Permian rocks.

Hollinella favored an environment like that favored by the conodont Anchignathodus. In many ways, this can be thought of as a limestone or near-limestone environment, perhaps shallower than the depth favored by most animals in the cyclothems. This is essentially the environment that Calver (1968) and Bless (1969, 1969a) placed it in. Bless interpreted it as a near-bottom swimmer, with velae to keep it from sinking into the mud. He stated that it is associated with pelecypods, which have a tendency to be found away from the core shale.

Cypridinella (?) is apparently a pelagic form, closely resembling what Bless (1969) called Cypridina. He stated that it is nektic, based on its morphology. Its possible occurrence in a black shale here supports that interpretation.

The ostracodes in the Missourian shales produce a very distinct sequence from the outside shales to the grey transitions. Geisinids are most strongly associated with the outside shale, appearing in faunas and stratigraphic positions that strongly suggest it was a nearshore euryhaline form. Amphissites represents the other end of the spectrum, as it occurs in diverse faunas associated with the transition grey

shales of the core shale. Cavellina appears closer to geisinids, while Bairdia is closer to Amphissites. Thus, a series is produced, from the outside shale toward the core black shale: geisinids, Cavellina, Bairdia, Amphissites. Hollinella occupies a position in the sequence analogous to that of Anchignathodus and the other conodonts; indeed, Hollinella and Anchignathodus favor the same environment (Fig. 62). Other ostracodes can be fit into this scheme, as can other animals; the principal ostracode with which they occur most frequently would serve as a signature of a particular environment.

Some caution must be applied in interpreting individual ostracode assemblages, however. It must be remembered that all the ranges overlap to some degree. However, certain co-occurrences are more likely at a certain stage than others. Abundances do not offer a clear-cut way to avoid this, as the ranges do not reflect numbers; Amphissites, for example, is rarely dominant, even in the strata where it is most likely to occur. But the potential exists for a rough zonation based on appearances and co-occurrences of the various ostracodes. Notably, this zonation would be an overlapping set in relation to the conodonts. Geisinids occur closer to the coals (in shallower water?) than does Adetognathus. Even Amphissites, which has Gondolella with it more often than does any other ostracode, still is found with Adetognathus more often. And even though it is the major ostracode most closely associated with the core shale, Amphissites sometimes appears in the outside shale before the onset of limestone deposition.

McCrone (1963), in a study of the Lower Permian Red Eagle cyclothem, noted patterns in ostracode occurrences generally very similar to

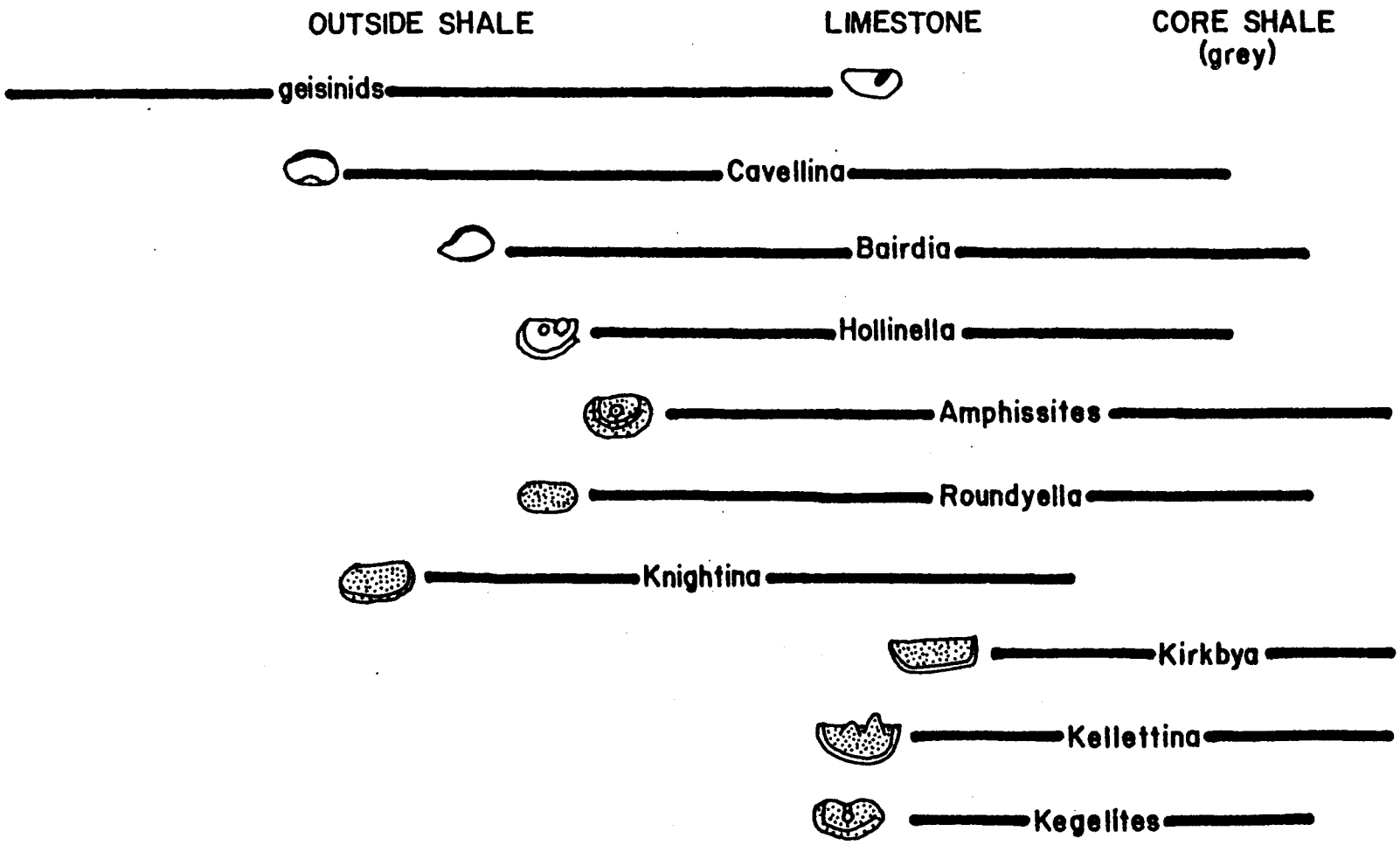



Figure 62. Conceptual diagram of ostracode sequence - Missourian cyclothems.

those here. Some details vary, due either to sampling and statistical effects, or to environmental niche drift by the ostracodes. Notably, he found very few ostracodes in the core black shale, and observed the relative restriction of Amphissites.

Several important pieces of evidence regarding the depositional features of the Missourian strata can be gleaned from the ostracode data. One is on the nature of the fissile black shale. Ostracode diversity increases fairly steadily from the nearshore outside shale toward the black shale, until it drops precipitously just before the shale is reached. This would indicate increasing environmental stability, and presumably, deeper water offshore. The black shale itself is distinctly anomalous if an attempt is made to interpret it in light of Zangerl and Richardson's (1963) model. Ostracodes tend to be plentiful in brackish water, and plentiful where there are abundant plants (Benson, 1961). A shallow lagoon, covered with a flotant mat, should be an ideal environment for ostracodes. Yet the only ones that are found there are what may be some scattered pelagic forms. Thus, the ostracodes are consistent with Heckel and Baesemann's (1975) model, with steadily deepening water until the bottom became anoxic, although pelagic ostracodes continued to survive in the surface waters. This would match Benson's (1961) observation that ostracodes aren't found in euxinic shales.

There appears to be no distinct "limestone fauna" of ostracodes. Of 31 occurrences of ostracodes in limestones, all were of forms found in the shales, usually of those ostracodes that were most common elsewhere. It appears carbonate deposition did not noticeably influence

ostracode distribution, and the ostracode sequence is apparent regardless of whether carbonate deposition occurred or not. Indeed, this phenomenon produces a scale for determining when carbonate deposition normally began. The evidence points to carbonate deposition as being an independent event, one that doesn't require conditions of a specific depth (or some other variable) to begin deposition. Limestone production commences in different places at different stages of the cycle, depending on other local conditions. However, since it occurs more frequently in the more stable portion of the sequence, the ostracode most characteristic of that phase (usually Bairdia, which agrees with the suggestion of Johnson, 1936) is characteristic of the limestone.

Ostracode distribution is apparently not influenced by clastic influx, either. None of the ostracodes express marked tendencies with respect to kaolinite and muscovite; all of the relationships may be explained by random distribution. The conclusion here must be either that the ostracodes were less sensitive to bottom conditions than is assumed, or that detrital deposition was equitable enough that it did not significantly alter the characteristics of the bottom sediments.

## Foraminifers

Foraminifers are very abundant in Upper Pennsylvanian marine sediments. These include not only the well-known fusulinids, but also the smaller calcareous and agglutinate forams. These latter two groups may be rock-formers in the Upper Pennsylvanian. Udden (1903) reported a foraminiferal ooze from southwestern Iowa, where the rock was

composed entirely of endothyrid (calcareous), ammodiscid, and textularid (agglutinate) forams, cemented with sparry calcite. Ireland (1956) reported that in some Virgilian limestones of Kansas, agglutinate forams compose 1 to 3 percent of the rock. In this study, forams were nearly as common as conodonts. 18 genera were recognized in 263 samples, or about 77 percent of the fossil-bearing samples. Agglutinate forams composed the bulk of the specimens, as they could be recovered from limestones, where calcareous forams weren't recognized. Because calcareous forams were rare in the shales, most of this analysis is based on agglutinate forams.

Moore (1950) noted that foraminifers, like ostracodes, were related to the phases of the cyclothems. This proved true in this study, although some of the relationships were less evident than with ostracodes and conodonts.

## Empirical Data

### Hippocrepina

Hippocrepina is a small, vase-shaped, attached agglutinate foram. It is rarely reported from Upper Pennsylvanian strata (Cushman and Waters, 1930; Pabian, (1970a), probably because of its occurrence pattern. It has a strong affinity for the fissile black shale and the grey transition shale above it, although scattered occurrences are found in other lithologies (Fig. 63). Frequently, in the black shales it is the only fossil found other than conodonts. This is expressed by frequent association with the core shale conodonts, Gondolella (in half of Hippocrepina's occurrences) and Idioprioniodus (in nearly 80

Figure 63. Stratigraphic distribution of foraminifers in the Dennis and Stanton cyclothems.

Key as in Figure 52, p. 326.

| | Genera present | Total samples | Percent | Hippocrepina | Ammodiscus | Tolypammina | Hyperammina | Ammovertella | Textularia | fusulinids |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ls - Base | 7 | 32 | 12.2 | 2 .66 6.3 | 15 1.33 46.9 | 31 1.19 96.9 | 9 .90 28.1 | 16 1.52 50.0 | | |
| Core C (grey) | 11 | 51 | 19.4 | 13 2.68 25.5 | 39 2.17 76.5 | 34 .82 66.6 | 14 .88 27.5 | 5 .30 9.8 | 4 3.00 7.8 | 2 .49 3.9 |
| Core B (black) | 5 | 23 | 8.7 | 5 2.28 21.7 | 10 1.23 43.5 | 15 .80 65.2 | 1 .14 4.3 | | 1 1.65 4.3 | |
| Core A (grey) | 5 | 12 | 4.6 | | 3 .71 25.0 | 10 1.02 83.3 | 4 1.07 33.3 | 2 .51 16.7 | | 2 2.09 16.7 |
| Core A (undifferentiated) | 4 | 26 | 9.9 | | 7 .76 26.9 | 22 1.04 84.6 | 10 1.23 38.5 | 3 .35 11.5 | | |
| Middle Ls | 8 | 30 | 11.4 | | 3 .28 10.0 | 28 1.14 93.3 | 9 .96 30.0 | 10 1.01 33.3 | 2 2.58 6.7 | 1 |
| Outside | 15 | 43 | 16.3 | 3 .74 7.0 | 5 .33 11.6 | 33 .94 76.7 | 7 .52 16.3 | 14 .99 32.6 | 3 2.69 7.0 | 4 1.18 9.3 |
| Stray Ls | 3 | 5 | 1.9 | | | 3 .73 60.0 | | 2 1.22 40.0 | 1 7.69 20.0 | |
| Upper Ls - Top | 6 | 22 | 8.4 | | 1 .13 4.5 | 13 .72 59.1 | 1 .14 4.5 | 18 2.49 81.8 | | 1 |
| Ls Partings (shale) | 7 | 11 | 4.2 | 1 .96 9.1 | 5 1.29 45.5 | 10 1.11 90.9 | 6 1.75 54.5 | 2 .55 18.2 | | 2 2.28 18.2 |
| Upper Ls - Middle | 6 | 8 | 3.0 | 2 2.63 25.0 | 5 1.77 62.5 | 8 1.22 100.0 | 6 2.40 75.0 | 6 2.28 75.0 | | |
| Total | 18 | 263 | | 26 9.5 | 93 35.3 | 211 81.7 | 65 31.2 | 78 32.9 | 11 2.6 | 12 (10) 8.0 |

Figure 63.

percent of them). Among the agglutinate forams, it occurs with Ammodiscus in nearly 90 percent of its samples, and Tolypammina in three-quarters of them.

Ammodiscus

Ammodiscus is a planispiral agglutinate foram. It is fairly common throughout the cyclothem, but its distribution is biased toward the black fissile core shale, the grey transition above, and the lower part of the upper limestone (Fig. 63). It varies in abundance from numerous in the upper grey shale to markedly depleted in the outside shale and adjacent limestones.

Ammodiscus' co-occurrences reflect this. It is found with Gondolella in about a third of its samples, and with Idioprioniodus in 60 percent of them. In the grey shales, it occurs with Amphissites in about 30 percent of its occurrences, but with geisinids in only 6 percent of its samples.

Tolypammina

Tolypammina (may equal Minammodytes and Serpulopsis; see Appendix B) is the second most common fossil in the strata examined. It is an encrusting, tube-like foram. It occurs in nearly 60 percent of the fossiliferous samples, and is found uniformly throughout the cyclothem, with a slight increase in the carbonate units (Fig. 63), and is the most common foram in the fissile black shale. It is fairly uniform in its occurrence with other animals, but occurs somewhat more often with Anchignathodus.

Hyperammina

Hyperammina is a relatively large agglutinate foram, shaped like a long, slightly flaring and curved tube with a proloculus at the apex. It is found in most strata of the cyclothem, but more frequently in the lower transition to the black shale and the middle part of the upper limestone. It is less common in the outside shale and the top of the regressive limestone (Fig. 63).

Hyperammina has a puzzling pattern of co-occurrences. While it is depleted in respect to Gondolella (occurring with it in only 10 percent of its occurrences) and Idioprioniodus (in just under 20 percent of its occurrences), it does not show an increased tendency to occur with the other conodonts and other fauna. It does occur with gastropods as often as with brachiopods, both of which occur with Hyperammina more often than do bryozoans and crinoids.

Ammovertella

Ammovertella is an encrusting agglutinate foram, with a compact growth form in which it doubles back on itself, rather than randomly meandering as does Tolypammina. It is strongly depleted in the core shale, and moderately depleted in shale partings in the upper limestone. When the middle limestone is not developed between the outside shale and the lower grey core transition, the shale is more depleted in Ammovertella than otherwise (Fig. 63).

Ammovertella's co-occurrence pattern is anomalous in some respects. It occurs with the conodonts Gondolella and Idioprioniodus

less by about one-half and one-third, respectively, than would be expected were they randomly distributed. It occurs more frequently than would be expected with Anchignathodus and Adetognathus. It has a higher proportion of occurrence with the major ostracodes (excluding Cavellina) than any other agglutinate foram studied; this is also true of its relationships with fish, articulate brachiopods, ramose and fenestrate byrozoans, pelmatozoans, gastropods, and pelecypods. It also has an unusual relationship with the detrital minerals, with which it occurs far more frequently than expected: in 70 percent of the shale samples in which it is found, it occurs with muscovite, and in 90 percent with kaolinite.

Textularia

Textularia is a biserially chambered agglutinate foram. It is not common, and does not clearly favor a horizon in the cyclothem. It occurs less than expected with most fossils, but it is accompanied by Adetognathus more often than any other conodont, Hyperammina more than any other form, and Cavellina more than any other ostracode. It also co-occurs often with gastropods. It has a rather high correlation with the detrital minerals, but not so pronounced as Ammovertella.

Other Agglutinate Forams

The encrusting Ammodiscella and Thurammina, the paleotextularids Ammobaculites and Bigeneria, and the coiled Glomospira occur in a very irregular fashion, so no attempt will be made here to generalize on them.

Fusulinids

Fusulinids were not sought in the limestones, so the data here applies only to the shales. Fusulinids were found in about 4 percent of the shales, but rarely in great numbers or very frequently. Stratigraphically they were found in most of the shales except the fissile black core shale. Fusulinids appear to have a positive correlation with the conodont Anchignathodus, the ostracodes Amphissites and Cavellina, chonetid brachiopods, Punctospirifer and Derbyia, bryozoans, pelmatozoans, and trilobites. Fusulinids were not found with Ammovertella or geisinids.

Other Calcareous Forams

Small calcareous forams were very uncommon in the shales, being abundant only in the base of the Vilas at Altoona, Kansas (Locality A11). Calcareous forams observed in shales included Endothyranella, Endothyra, Cyclogyra, Polytaxis, Tetrataxis, and Nodosinella.

Interpretations

According to Phleger (1960), depth is the most important control on foram distribution. To illustrate this, he cited the distribution of modern forams, and produced an idealized diagram remarkably similar to the theoretical microfossil pattern of Ellison (1951) (Fig. 58). Loeblich and Tappan (1964) agreed with this, but applied it only to open shelves; in restricted shallow basins they thought other variables, such as salinity, substrate, oxygenation, and food could be limiting factors, but they considered temperature to be unimportant.

Diversity of forams was linked to depth by Stevens (1971), who established a depth gauge based on the number of foram types present. For comparison, the highest number of genera in the strata studied here is in the outside shale, although this is probably skewed by the occurrence of many forms only in one anomalous sequence where a limestone was overwhelmed by clastic influx. The second greatest diversity is in the upper grey transition of the core shale.

Substrate has been the variable that has received the most attention. Phleger (1960) considered it unimportant except for encrusting forams, but other workers have disagreed. Waters (1928) stated that agglutinate forams liked bottoms with much quartz sand in the mud, while calcareous forams preferred calcareous muds, but he must not have included encrusting agglutinate forams in his estimation. Croneis and Toomey (1965) noted a relationship of substrate to test material; they also noted that Hyperammina and Textularia selected different-sized grains, and suggested that it might be a limiting factor. In this study, both were observed in remarkably non-sandy shale, so they must be very efficient at finding what is available. Loeblich and Tappan (1964) also noted effects of substrate, citing several studies indicating that fine-grained bottoms had fewer forams than coarse-grained ones. They noted that foram shape was determined by substrate: (1) soft muddy bottoms produced flattened or discoidal forms (here, presumably Ammodiscus and Cyclogyra); (2) firmer sandy bottoms produced forms with a thickened central area (as in Tetrataxis and Polytaxis); (3) firm mud produced forms attached to algae (such as

Ammovertella, Ammodiscella, and Tolypammina; and (4) planktonic forms, often have globular chambers (such as Endothyra and Endothyranella?).

Chemical properties may be important, especially salinity. Ellison (1951) noted that some forams were limited in distribution by fresh-water influx which produced brackish water, in contrast with normal salinity, where forams were found to the shore. Bandy (1960) noted that low coastal salinities and pH would favor agglutinate forams. Murray (1973) noted that agglutinate forams were also dominant in deep water, below the carbonate compensation depth.

In some cases, temperature influences distribution. Loeblich and Tappan (1964) noted that on open shelves, broad latitudinal trends were shown, and they also noted depth-related temperature zones for forams: (1) a shallow zone with variable temperature, (2) the permanent thermocline, with gradual change, and (3) the deep bottom layer.

Finally, Loeblich and Tappan (1964) also recognized simple geography as a variable, citing a comparison of the Sea of Okhotsk and the Gulf of Mexico, which are both of similar depth and size. However, the Sea of Okhotsk has no planktonic forams, supposedly because the Kurile Islands act as an effective barrier.

The encrusting agglutinate forams, the most commonly found, are straightforward in their distribution. Ireland (1956) stated that Ammovertella was the commonest form, with Tolypammina next; Toomey (1974) stated that Tolypammina was the most common, which agrees with this study. The discrepancy could be attributed to weighting the samples, for instance, more upper limestone samples would favor Ammovertella.

Ireland (1956) also noted that processing could have an effect, and noted that shale samples could be preferentially depleted in Ammovertella, Tolypammina, and Thurammina. The first two are fairly robust, and should not be significantly depleted, but Thurammina is very fragile, and could be drastically limited. In this study, only one was recovered, and that from a limestone.

Encrusting forams require something to encrust. Henbest (1958) stated that tolypamminids (which includes Tolypammina, Ammovertella, and Ammodiscella were generally found in shallow water, where they encrusted stones, algal blades, metazoans, each other, and formed parts of aggregates such as Osagia and Ottonosia. However, he felt that rafting by encrusted plants limited their usefulness. Nevertheless, such a distribution conforms with that found here. In the limestones, where both shelled metazoans and possibly algae were most common, the encrusting forams were, too. With a shortage of substrate in the adjacent shales, the encrusting forams were less common. The distribution is like that found by McCrone (1963) in the Lower Permian.

An inexplicable feature of tolypamminid distribution appears in the middle limestone. Ireland (1958), working with Virgilian rocks, noted that tolypamminids were uncommon in the middle limestone. Toomey (1964), working on the Leavenworth Limestone, a middle limestone of a Virgilian cyclothem, established an encrusting foram biofacies but found it only in Iowa. However, later work by von Bitter and Heckel (1978) established the Iowa outcrops as belonging to the Stanton cyclothem, and so Toomey's encrusting foram biofacies is in the Captain Creek Limestone. This study found no noticeable lack of

encrusting forams in either the Captain Creek or the analogous Canville Limestone. This suggests that some limestones (such as the Leavenworth) may lack encrusting forams, or perhaps that the range of tolypamminids became reduced in the Virgilian.

Ammodiscus commonly occurs in some black shales in the Appalachian Basin. Ottum (1969) found it to be abundant in the Brush Creek dark shale (which also yields Idioprioniodus and Gondolella, along with Ammodiscella. Norton (1976) placed such occurrences in a distinct biofacies, and stated that it was a brackish lagoonal or estuarine environment, with the Ammodiscus following an opportunistic habit. McCrone (1963) found Ammodiscus in the black core shale and adjacent transitional shales.

Ammodiscus is a foram living today (Lane, 1964), which may or may not shed much light on its ancient ancestor (or homeomorph). Although Ammodiscus is reported in fresh and brackish water (Loeblich and Tappan, 1964), Lane (1964) noted that it is not restricted in depth. Murray (1973) noted that in the abyssal Pacific, below the carbonate compensation depth, astrorhizids and ammodiscids are dominant, but he suggested that they may have evolved from shallow water forms. All this indicates that modern analogs of fossils can be extremely hazardous for interpretation of past environments.

Hippocrepina is even more strongly associated with the black fissile core shale, which apparently accounts for the infrequency of previous reports. It may have been one of the very last benthic animals to be eliminated by black shale conditions.

Here it is appropriate to mention a possible modern analog, based on similar depositional characteristics and faunal distribution rather than on similar taxonomy or morphology. Sen Gupta and others (1981) described areas of upwelling off the east coast of Florida, where the organic production on the surface produces muds rich in organic matter, especially hydrocarbons. The benthos fauna is generally restricted to high-density faunas of a few species of benthic forams, which are generally rare elsewhere. The authors suggested that ancient upwellings might be identified by similar patterns. The black shales in the cyclothems fit this pattern, with Ammodiscus and Hippocrepina occupying the niche of the benthic forams. Coincidentally, Sen Gupta and others (1981) also noted that the upwellings sometimes have opportunistic invasions of the calico scallop; this could be analogous to the episodic appearance of the pectinid Dunbarella in the Pennsylvanian black shales.

The available literature is no more helpful in interpreting the environment of Hyperammina than the inconsistent patterns of the collected data. Weller (1957) stated that hyperamminids were abundant with Crurithyris in the thin middle limestones of the Illinois cyclothems, but in this study Hyperammina shows neither similar distribution to nor exceptionally frequent occurrence with Crurithyris. Croneis and Toomey (1965) associated Hyperammina with Textularia and placed them in an assemblage; while that assemblage does seem to be reasonably valid for Textularia, the data here suggests that Hyperammina is not notably associated with the animals in it. Toomey and others (1977) found a Hyperammina assemblage in a Virgilian algal

mound; an accompanying photo (Figure 9, p. 2125) indicated that this assemblage overlapped with the conodonts Stepanovites, Anchignathodus, Adetognathus, and an idiognathodid, as well as fish "scales", paleoniscid teeth, and Styptobasis. Here again, none of these are associated in this study with Hyperammina on a consistent basis. It would seem from all this that Hyperammina is controlled by some unknown factor unrelated to lithology or faunal association, or that Hyperammina is actually a polygenetic group of homeomorphs, each with different distributions.

Textularia also is an extant foram which is not restricted in depth (Lane, 1964), although classified as a shelf form by Bandy (1960). Ireland (1956) listed it as a common Upper Pennsylvanian foram, but it is not particularly so in the sediments studied here. Toomey (1974) called it one of the most diagnostic agglutinated foram, while placing it in several assemblages. In 1965, Croneis and Toomey associated it with calcisponges, Cavellina, Bairdia, Hollinella, and Amphissites. Later, Toomey and others (1977) associated it with Ammovertella in a shallow water facies at the top of an algal mound. From the sparse data collected, these seem to be valid although not exclusive associations. Textularia is also frequently associated with Adetognathus; the sum of its co-occurrences suggests that Textularia had a fairly broad range, but favored shallower water.

Glomospira, which Ireland (1956) listed as common, and which is frequently mentioned in the literature, was rare in the studied faunules. Norton (1976) assigned its calcareous homeomorph,

Hemigordius, to a black shale biofacies with Ammodiscus. Thus, although it may be an environmentally significant form, it may have been inadvertently overlooked in the coarser residues examined for forams due to its very small size.

Fusulinids are often a prominent fossil in Upper Pennsylvanian sediments, and are important in their biostratigraphy. The first appearance of Triticites in the Winterset (Thompson et al., 1956) is an important biostratigraphic marker. Thus, it is important to understand the ecology of fusulinids, and many attempts have been made.

The most important attempt was by Elias (1937) who concluded that by their cyclic position they must have lived farthest offshore. (Notably, he was working with Lower Permian cyclothems, which rarely have black shales.) He then analogized on their distribution with that of modern large foraminifers, and estimated that most fusulinids lived at a depth of 160 to 180 feet, which he concluded was the deepest water in the cyclothem. The concept that fusulinids marked the deepest part of the cyclothem has been employed by many workers since then. However, disagreement on interpretation of fusulinids has not disappeared. Henbest (1958) stated that they were not strongly depth-restricted. Mudge and Yochelson (1962) noted that modern large forams were too widely distributed to justify the original analogy, and stated that fusulinids were not depth-dependent. They concluded that fusulinids had wide tolerances, as they were found in many lithologies. Imbrie and others (1964) found some fusulinids in what they interpreted to be shallow water carbonates, based on stratigraphy and petrology.

Toomey (1964) commented on fusulinids, and associated them with paleotextularids (which is not supported here). Stevens (1969) also concluded they were not controlled by substrate, and went on (1971) to calculate that they lived in at least 40 feet of water. Lipp (1975), in contrast, found Triticites in the early phases of the Cambridge transgression, and concluded that it must have been opportunistic. Payton (1966) concluded that fusulinids were not depth-controlled, and occurred in lithologies at the same depth as adjacent, non-fusulinid-bearing lithologies.

Based on the lack of agreement among the workers, and the ambiguous evidence found here, it appears that fusulinids did indeed live in a wide range of environments. It may well be that gross morphology does not reflect a particular environment, but by more sensitive subdivision of the group, various fusulinids might be assigned to various environments.

## Radiolarians

Radiolarians occurred in two localities in the studied units, both in the Stark Shale. Near Coffeyville, Kansas (Locality CB1), numerous small silicified spiralled cones were recovered from a carbonate nodule in the fissile black Stark. These were identified as albaillellid radiolarians. Apatite nodules from the upper Stark near Dennis, Kansas (Locality De1) contained abundant entactiniid spumellarian radiolarians, as well as some possible albaillellids (this occurrence was also described by Kidder, 1982).

Such radiolarian occurrences are fairly common in Carboniferous strata, especially in apatite nodules (e.g., Cayeux, 1950; Deflandre, 1952; Kling and Reif, 1969; Berendsen and Nodine-Zeller, 1978). Holdsworth (1966) described radiolarian faunas from Lower Pennsylvanian carbonate nodules in British black shales, and G. K. Merrill (oral presentation, North Cent. Geol. Soc. Amer., May, 1981) reported finding replaced albaillellids in carbonate nodules in Illinois. Berendsen and Nodine-Zeller (1978) also reported radiolarian imprints in Upper Pennsylvanian black shales in Kansas.

The occurrence of radiolarians may have environmental significance. Bromley (1967) cited Cayeux (1950) as noting the deep sea aspect of the radiolarian-bearing apatite nodules of the Dinantian of the Pyrennes. Holdsworth (1966a), based on his studies of British Namurian marine bands, identified an onshore-offshore continuum of faunal assemblages, and placed the radiolarians in the most offshore assemblage. He noted that they occurred in strata with no benthos, except that albaillellid radiolarians may have been benthic (Holdsworth, 1966a). He also noted that albaillellids apparently occurred in even deeper water than the entactiniids, and marked the most offshore, deepest water biofacies that he recognized. It is possibly also significant that Holdsworth (1977) described the Upper Pennsylvanian or Lower Permian radiolarian fauna from Uruguay as very similar to that of the British Namurian. He noted that the Uruguayan fauna must have lived at a paleolatitude of $50^{o}$, compared to the equatorial British fauna. This implies a widespread persistent

environment, which is consistent with a deep marine habitat for the radiolarians.

In addition to the environmental significance of radiolarians, their occurrence may have petrologic importance. The opaline silica may have been remobilized and provided a source for the silification found in both the chert and silicified fossils in the cyclothems. This would be especially likely where the radiolarians are replaced by other minerals.

## Brachiopods

Brachiopods are the commonest macrofossils in the examined Missourian shales. They were found in 130 of 240, or about 56 percent of shale samples. They are also typical constituents of the limestones, but those were not studied sytematically here. 31 genera were recognized in this study, although fragmentary evidence suggested the presence of more.

Brachiopods are widely distributed throughout the cyclothems. They tend to be most abundant in limestones, where they are commonly associated with bryozoans and pelmatozoans, but less prominent forms were scattered in other portions of the cyclothem. Notably, articulate brachiopods are particularly well-represented in the shaly partings in the limestones. In these shales, spiriferids were most common, followed by strophomenids. The former group has a few common taxa: Crurithyris, Punctospirifer, Composita, and Hustedia. The strophomenids are mostly productids and chonetids. Inarticulate brachiopods are also common; the other orders of articulates (orthids,

rhynchonellids, and terebratulids) are all represented by only one or two genera, and are relatively uncommon.

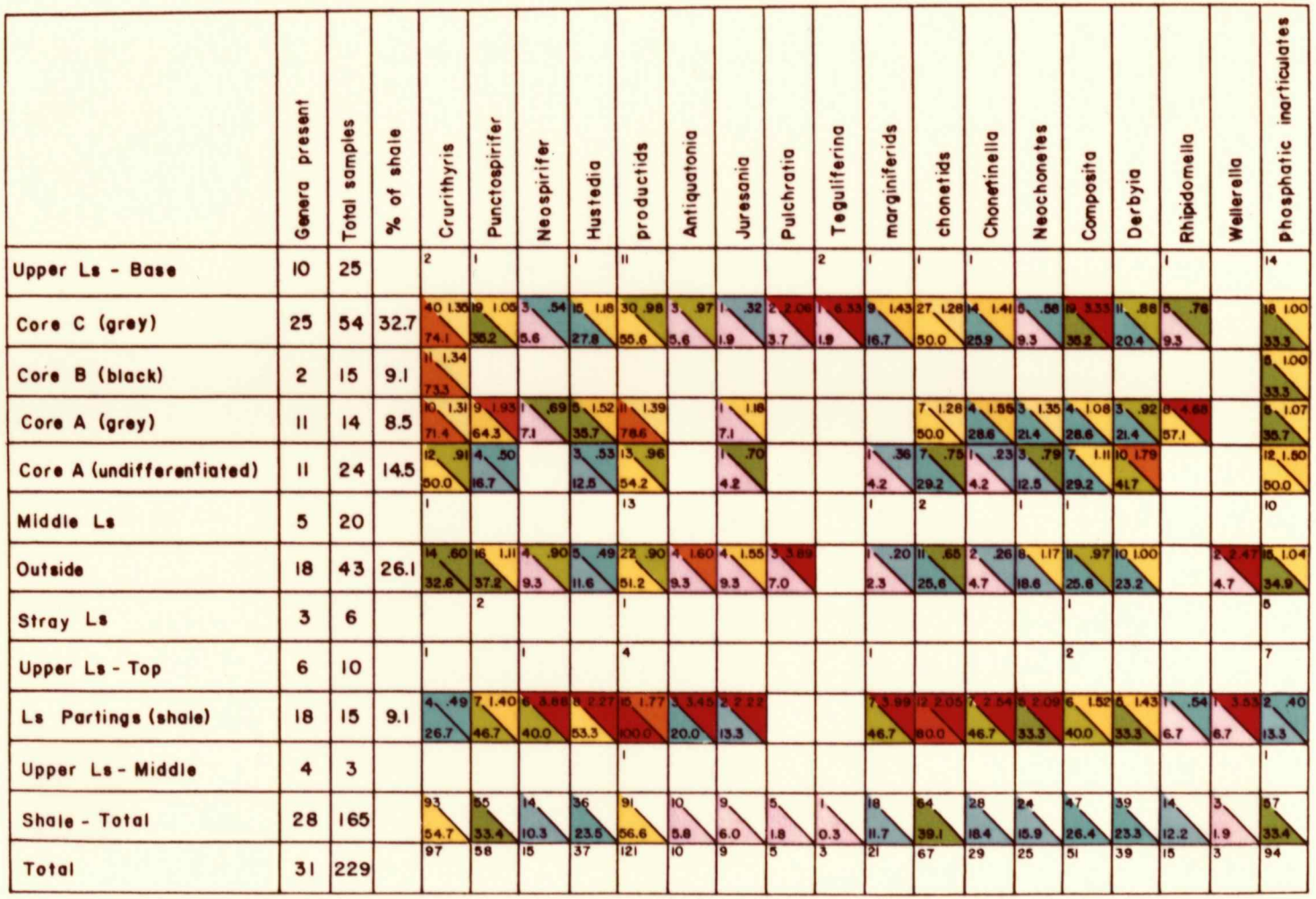
## Empirical Data

### Crurithyris

Crurithyris is a small spiriferid; although sometimes described as being thin-shelled, it has a rather thick shell in relation to its size. Crurithyris is the most common brachiopod in the shales of the cyclothems studied, occurring in slightly more than half the samples containing brachiopods. Its frequency is roughly that of all the productids combined. Crurithyris is fairly common in all the shales, regardless of the stratigraphic position, although it becomes more conspicuous adjacent to the fissile black shale. There, it often forms thin beds of nearly solid, somewhat crushed shells. These beds are found both above and below the black shale, and mark the first and last appearance of macrofauna in many cases. Thus Crurithyris statistically displays a marked affinity for occurring with black shale organisms, such as Gondolella and Hippocrepina. Crurithyris is also found less frequently elsewhere, although it's still very common. For example, in the outside shale, it occurs in nearly a third of the samples; only productids and phosphatic inarticulates (both as groups) and Punctospirifer are more common (Fig. 64). Nevertheless, Crurithyris has a tendency not to occur with muscovite and kaolinite, about as much as Gondolella.

Figure 64. Stratigraphic distribution of brachiopods in the Dennis and Stanton cyclothems.

Key as in Figure 52, p. 326.



| | Genera present | Total samples | % of shale | Crurithyris | Punctospirifer | Neospirifer | Hustedia | productids | Antiquatonia | Juresania | Pulchratia | Tegulifera | marginiferids | chonetids | Chonetinella | Neochonetes | Composita | Derbyia | Rhipidomella | Wellerella | phosphatic inarticulates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ls - Base | 10 | 25 | | 2 | 1 | | 1 | 11 | | | | 2 | 1 | 1 | 1 | | | | 1 | | 14 |
| Core C (grey) | 25 | 54 | 32.7 | 40 1.35 74.1 | 19 1.05 35.2 | 3 .54 5.6 | 15 1.18 27.8 | 30 .98 55.6 | 3 .97 5.6 | 1 .32 1.9 | 2 2.06 3.7 | 1 6.33 1.9 | 9 1.43 16.7 | 27 1.28 50.0 | 14 1.41 25.9 | 5 .58 9.3 | 18 3.33 33.2 | 11 .88 20.4 | 5 .78 9.3 | | 18 1.00 33.3 |
| Core B (black) | 2 | 15 | 9.1 | 11 1.34 73.3 | | | | | | | | | | | | | | | | | 5 1.00 33.3 |
| Core A (grey) | 11 | 14 | 8.5 | 10 1.31 71.4 | 9 1.93 64.3 | 1 .69 7.1 | 5 1.52 35.7 | 11 1.39 78.6 | | 1 1.18 7.1 | | | | 7 1.28 50.0 | 4 1.55 28.6 | 3 1.35 21.4 | 4 1.08 28.6 | 3 .92 21.4 | 8 4.68 57.1 | | 5 1.07 35.7 |
| Core A (undifferentiated) | 11 | 24 | 14.5 | 12 .91 50.0 | 4 .50 16.7 | | 3 .53 12.5 | 13 .96 54.2 | | 1 .70 4.2 | | | 1 .36 4.2 | 7 .75 29.2 | 1 .23 4.2 | 3 .79 12.5 | 7 1.11 29.2 | 10 1.79 41.7 | | | 12 1.50 50.0 |
| Middle Ls | 5 | 20 | | 1 | | | | 13 | | | | | 1 | 2 | | 1 | 1 | | | | 10 |
| Outside | 18 | 43 | 26.1 | 14 .60 32.6 | 16 1.11 37.2 | 4 .90 9.3 | 5 .49 11.6 | 22 .90 51.2 | 4 1.60 9.3 | 4 1.55 9.3 | 3 3.85 7.0 | | 1 .20 2.3 | 11 .65 25.6 | 2 .26 4.7 | 8 1.17 18.6 | 11 .97 25.6 | 10 1.00 23.2 | | 2 2.47 4.7 | 15 1.04 34.9 |
| Stray Ls | 3 | 6 | | | 2 | | | 1 | | | | | | | | | 1 | | | | 5 |
| Upper Ls - Top | 6 | 10 | | 1 | | 1 | | 4 | | | | | 1 | | | | 2 | | | | 7 |
| Ls Partings (shale) | 18 | 15 | 9.1 | 4 .49 26.7 | 7 1.40 46.7 | 6 3.86 40.0 | 8 2.27 53.3 | 15 1.77 100.0 | 3 3.45 20.0 | 2 2.22 13.3 | | | 7 3.89 46.7 | 12 2.05 80.0 | 7 2.54 46.7 | 5 2.09 33.3 | 6 1.52 40.0 | 6 1.43 33.3 | 1 .54 6.7 | 1 3.85 6.7 | 2 .40 13.3 |
| Upper Ls - Middle | 4 | 3 | | | | | | 1 | | | | | | | | | | | | | 1 |
| Shale - Total | 28 | 165 | | 93 54.7 | 55 33.4 | 14 10.3 | 36 23.5 | 91 56.6 | 10 5.8 | 9 6.0 | 5 1.8 | 1 0.3 | 18 11.7 | 64 39.1 | 28 18.4 | 24 15.9 | 47 26.4 | 39 23.3 | 14 12.2 | 3 1.9 | 87 33.4 |
| Total | 31 | 229 | | 97 | 58 | 15 | 37 | 121 | 10 | 9 | 5 | 3 | 21 | 67 | 29 | 25 | 51 | 39 | 15 | 3 | 94 |

Figure 64.

Punctospirifer

Punctospirifer is a small costate spiriferid. It also is common in the shales, particularly those adjacent to limestones. It is strongly concentrated in the lower grey shale of the core shale if there is a middle limestone below it, and somewhat concentrated in the outside shale if a middle limestone is present above. However, if no limestone is present, Punctospirifer is significantly depleted. Punctospirifer is also concentrated in shale partings in the upper limestone. Overall, Punctospirifer (weighted) occurs in a third of the shales that contain brachiopods (Fig. 64).

Punctospirifer's pattern of occurrence with other animals reflects this distribution. With respect to conodonts, it occurs with Gondolella and Idioprioniodus less frequently than would be expected from random distribution, and more frequently with Anchignathodus. It occurs with Amphissites, Hollinella, and Bairdia more often than expected, and about at the expected levels with Cavellina and Geisina. It also exhibits a marked correlation with Composita, which accompanies it in half of its occurrences. It also is accompanied more frequently by gastropods than any other common brachiopod, and shows a tendency to be found with sponges. It has a rather high correlation with muscovite and kaolinite.

Composita

Composita is a large, heavy-shelled athyrid spirifer. Its distribution closely parallels that of Punctospirifer, which occurs

in two-thirds of Composita's occurrences. The only major difference is that Composita is not depleted in the shale when the middle limestone is missing. Composita is also fairly common, occurring (weighted) in about a quarter of the shales with brachiopods (Fig. 64).

Composita also shows a pattern of co-occurrences similar to that of Punctospirifer, from which it varies by occurring slightly more often with the core shale fossils such as Gondolella and Ammodiscus than does Punctospirifer.

Neospirifer

Neospirifer is a large, heavy-shelled alate spiriferid. It is comparatively uncommon, occurring (weighted) in only ten percent of the shales with brachiopods. Like Composita, it frequently occurs with Punctospirifer (in 80 percent of its occurrences), but surprisingly, it doesn't often occur with Composita. Neospirifer's distribution is like that of Punctospirifer, including absence in the lower grey shale sequence if the middle limestone is not present (Fig. 64).

Neospirifer's other co-occurrences are erratic. It occurs with Anchignathodus in 80 percent of its samples, and with Hollinella and Cavellina in 70 percent of its occurrences, and it is always accompanied by paleoniscid teeth. It also occurs with chonetids in 80 percent of its samples, and has a higher proportion of occurrence (70 percent) with trilobites than does any other taxon. Oddly, it is not enriched in respect to Ammovertella, which occurs in the same horizons and with many of the same animals.

Hustedia

Hustedia is a small costate retziid spirifer, which occurs (weighted) in a quarter of the brachiopod-bearing shales examined. It is found to some extent throughout the shales of the cyclothem (except the fissile black shale), but it occurs much more frequently in the lower grey transitional shale of the core and in shale partings in the limestones (Fig. 64).

Hustedia's pattern of co-occurrence is ambiguous. It occurs less frequently with Anchignathodus and Adetognathus than most other brachiopods do, but occurs no more frequently with the black shale conodonts than is average for brachiopods. Among the forams, it occurs more frequently than average with Ammodiscus, Hyperammina, and Ammovertella but less than average with Tolypammina. With the ostracodes, it shows a preference for occurring with Amphissites and Bairdia, and a tendency away from Cavellina and geisinids. Among the other groups, it is found notably often with Punctospirifer (in three-quarters of its occurrences), gastropods (also in about three-quarters of its occurrences), sponges, and trilobites (the last two both in about 40 percent of its samples).

Hustedia also has a remarkably high correlation with muscovite and kaolinite, occurring with the latter in nearly three-fourths of its samples.

Productids

Productids must be considered as a group, because of their low probability of being preserved in any identifiable form. The large productids are especially prone to crushing, and frequently the only evidence for their presence are spines and shell fragments. A few, such as Juresania, have distinctive features, and can be identified from fragments, while others, such as the margini ferids, are much smaller and less likely to be crushed. But most are encountered only fortuitously, and the data presented mean little except when strongly skewed.

Overall, productids occur (weighted) in about half the brachiopod-bearing shales (except the black core shale), but are particularly common in the lower grey transition to the core (where they are found in nearly 80 percent of the brachiopod-bearing samples) and in the shale partings in limestones, where they occur in every sample. Evidence of productids is also frequently recovered from limestones, as the bases of the spines are often sphaleritized (Fig. 64).

Productids as a group show few marked trends in co-occurrences, but a few are worthy of note. They have an elevated rate of occurrence with Anchignathodus, and they occur more frequently than expected with Amphissites, Hollinella, and Bairdia. Most other co-occurrence rates are within expected limits.

Most of the large productids do not occur frequently enough in identifiable condition in shale to make statements regarding their

distribution, but two are worthy of mention. Antiquatonia is probably the most common of the large productids, and was the most frequently recognized large form. It occurs (weighted) in about 6 percent of the shales, especially in shale partings in the limestones and in outside shales (Fig. 64). Antiquatonia also has a remarkable co-occurrence distribution with conodonts: out of seven assignable occurrences, three were with Adetognathus, one with Idioprioniodus, and none with Gondolella. Although the total number of occurrences is low, other co-occurrences may be significant: six out of the seven are with gastropods, which is a higher frequency than with bryozoans or pelmatozoans. Three of the seven are with pelecypods.

Juresania was identifiable even when crushed by its characteristic double-pronged cardinal process. It occurred as frequently as Antiquatonia, and had a remarkably similar distribution (Fig. 64). Like Antiquatonia, there were 7 assignable occurrences. With conodonts, 6 were with Anchignathodus, and 5 were with Adetognathus, but there were no occurrences with either Gondolella or Idioprioniodus. Other unusual occurrences included those with Punctospirifer and Derbyia (5 each). In reference to observations by other workers, it was found in 3 samples with pelecypods, but only twice with gastropods. In 4 of the 7 samples it occurred with trilobites.

The marginiferids (mainly Kozlowskia and Hystriculina) have a different distribution from the large productids. The marginiferids are found (weighted) in about 10 percent of the brachiopod-bearing shales, but have a strongly skewed distribution. They are rare in the outside shales and lower grey transition of the core shale, but

common in the upper grey transition and particularly common in the shale partings in the limestones. Marginiferids are accompanied by Gondolella in 20 percent of their samples, Idioprioniodus in nearly half of them, always by idiognathodids, Anchignathodus in 60 percent of them, but never by Adetognathus. Among the forams, marginiferids occur with Ammodiscus in 60 percent of their samples and with Ammovertella in 40 percent of them. Among ostracodes, the marginiferids occur with Amphissites in 60 percent of their occurrences, with Bairdia in 80 percent (twice as often as with Cavellina), and even with Kirkbya in almost 30 percent of them. Other notable co-occurrences include nearly 90 percent with chonetids and Hustedia, 75 percent with Punctospirifer, 60 percent with trilobites, nearly 50 percent with corals, and 40 percent with sponges. Of special interest is their co-occurrence with fenestrate bryozoans, and they occur only slightly less often with ramose bryozoans and pelmatozoans.

A productid worthy of special note is Teguliferina, even though it was not found often enough to oompile statistics. Teguliferina is a small, basket-shaped productid with a habit much like that of the related richtofenids; however, Teguliferina does not produce bioherms. It is rarely reported in Upper Pennsylvanian rocks; the only Missourian reports are from the base of the LaSalle Limestone in Illinois (Hickey and Younker, 1981) and the Stoner and Eudora in Kansas (Newell, 1933). In this study, silicified specimens of Teguliferina were found only at the base of the Winterset in two localities (Jil and Eul) in the central Kansas-Missouri border region, and possibly at a third nearby locality (Pql). An unreplaced Teguliferina was also found just

below the Winterset in the top of the Stark Shale at Locality Jil. The specimen may be attached to a marginiferid, although the relationship is not clear. The matrix in these cases was calcareous shale (top of the Stark) or argillaceous calcilutite (base of the Winterset).

Chonetids

Chonetids are frequently observed brachiopods in Upper Pennsylvanian shales. In some cases, they are so abundant that they pave the outcrop upon weathering. In this study, they were never so abundant, but did constitute a persistent portion of the brachiopod fauna, and occur (weighted) in nearly 40 percent of the shales with brachiopods.

Although other chonetids are occasionally present (e.g., Lissochonetes), most of the chonetids are either Chonetinella or Neochonetes. The principal distinction between the two is that the former has a marked fold and sulcus, while the latter doesn't. The two occur subequally, but seldom together. Thus, the distribution of chonetids as a group can be approximated by the sum of the two, which have remarkably different distributions. For practical purposes here, the two will be contrasted, and overall patterns for chonetids will be mentioned only when necessary.

Stratigraphically, chonetids as a group have few exceptional characteristics. They do tend to occur most frequently in the shale partings of limestones, where both Chonetinella and Neochonetes are relatively abundant. Chonetids are also concentrated in the transitional grey shales of the core shale, principally because Chonetinella

is strongly concentrated there. Neochonetes is present in these shales in varying numbers, but is best-represented in the outside shale, where Chonetinella is rare (Fig. 64).

The patterns of co-occurrence are instructive. Chonetinella is accompanied by Gondolella about twice as often as is Neochonetes (33 versus 18 percent). The opposite trend appears with Adetognathus, which co-occurs with Neochonetes more often (40 percent versus 25 for Chonetinella). Both occur very frequently with Anchignathodus (in about 70 percent of their samples) and both are virtually always accompanied by idiognathodids. Among forams, Chonetinella occurs more frequently with Ammodiscus (45 percent versus about 30 percent for Neochonetes) and is found on rare occasions with Hippocrepina, which is not found at all with Neochonetes. Neochonetes occurs twice as often with Ammovertella (18 percent versus 8 percent for Chonetinella, which is not often for either one). Both occur very frequently with major ostracodes, about 50 percent each with Amphissites and Hollinella. Chonetinella is also found with Cavellina in about half its occurrences, and in about two-thirds of its samples with Bairdia. Neochonetes is found with Bairdia in almost three-quarters of its samples and in two-thirds of its samples with Cavellina. Neochonetes occurs with geisinids three times, whereas Chonetinella is found with geisinids only once. The opposite is true versus Kirkbya; Chonetinella has 5 co-occurrences, while Neochonetes has only two.

With other groups, the patterns are similar. Chonetinella occurs with marginiferids twice as often as Neochonetes. It also occurs

more frequently with Crurithyris: in nearly 90 percent of its samples, versus 70 percent for Neochonetes. Both occur with Punctospirifer in about three-fourths of their samples and with Derbyia in about half of them. Chonetids are almost invariably found with bryozoans and pelmatozoans. Neochonetes is accompanied more frequently by gastropods (in over 60 percent of its samples, versus 40 percent for Chonetinella), while Chonetinella has trilobites for company more often (55 percent, versus 30 percent for Neochonetes).

Finally, with respect to the detrital minerals, Neochonetes occurs more frequently with both muscovite and kaolinite than does Chonetinella, although neither departs much from random rates.

Derbyia

Derbyia is a medium-sized costate strophomenid brachiopod. It occurs fairly uniformly in all the marine grey shales, but is exceptionally concentrated in shale partings in limestones and the lower grey transition of the core shale where no middle limestone is present (Fig. 64). Derbyia, like chonetids, can be abundant enough to pave the outcrop, but did not do so in any studied here. Derbyia occurs (weighted) in about a quarter of the brachiopod-bearing shales.

Derbyia's pattern of co-occurrence is very pronounced. It occurs with Gondolella only twice (6 percent of Derbyia's occurrences). It occurs with Adetognathus in half of its samples, and is accompanied by Anchignathodus in 80 percent of its occurrences. Among ostracodes, Amphissites and Hollinella are found with it in about 40 percent of its samples, Bairdia in about 60 percent of them, and Cavellina

70 percent. Derbyia has a higher occurrence rate (18 percent) with Geisina than any other articulate brachiopod. Derbyia is accompanied by chonetids in 80 percent of its samples, by Punctospirifer and gastropods in 60 percent of them, and by pelecypods in 40 percent of them. Derbyia shows little affinity for detrital minerals, occurring only infrequently with either muscovite (18 percent) or kaolinite (27 percent).

Rhipidomella

Rhipidomella is a small, circular, biconvex, costate orthid. It occurs (weighted) in about 10 percent of the brachiopod-bearing shales. It is rarely found in the shale partings in limestones, and is moderately common in the upper grey transitions of the core shales, but is strongly concentrated in the lower grey transitions. It was not found in the outside shales (Fig. 64).

Rhipidomella has a strongly skewed occurrence with conodonts. It is accompanied in half of its samples by Gondolella and Idioprioniodus, but in only 20 percent of them by Adetognathus. Among forams, Ammodiscus is found with it in 40 percent of its samples, and Hippocrepina in 14 percent of them. Among the ostracodes, Amphissites and Bairdia are found with it in 60 percent of its samples and Cavellina in 70 percent, but it never occurs with geisinids. Among brachiopods, it is accompanied by Crurithyris in 70 percent of its samples, and chonetids, Punctospirifer, and Composita only a little less frequently.

Wellerella

Wellerella is mentioned here only because it is the most common rhynchonellid in the shales. However, Wellerella was found only in three samples: two outside shales and one shale parting in a limestone. If its distribution is weighted, it should be found in about 2 percent of the brachiopod-bearing shales.

Inarticulate Brachiopods

Most of the discussion here centers on the phosphatic forms, as only one Crania was found, adhering to a Neospirifer in an upper grey transition of a core shale.

Phosphatic inarticulate brachiopods occur (weighted) in about a third of the brachiopod-bearing shales, including the fissile black shale. They are exceptionally common in the lower grey transition shales when the middle limestone is absent, and depleted in the shale partings in limestone (Fig. 64).

The phosphatic inarticulates do show a pattern of co-occurrence, although they occur with most fossils fairly often. In the shales, they are accompanied by Gondolella in about a quarter of their samples, but by Adetognathus in 40 percent of them. When the limestones are added in, the co-occurrence rates with Idioprioniodus, Anchignathodus, and idiognathodids rise, but those with Gondolella and Adetognathus stay about the same. A similar trend appears with ostracode co-occurrences: Amphissites, 20 percent; Bairdia, 30 percent; Cavellina, 50 percent; and geisinids, 30 percent. The last is a

higher frequency of occurrence with geisinids than that displayed by any articulate brachiopod.

The phosphatic inarticulates occur less frequently with articulates than do most other groups, and they also occur less frequently with bryozoans and pelmatozoans. Nevertheless, this rate is 50 to 70 percent, rather than the 90 to 100 percent as is true with other groups. Phosphatic inarticulates are accompanied by gastropods in 60 percent of their samples, and by pelecypods and Crurithyris in about half of them.

## Interpretations

### Mass Aspects

Before describing the significance of each brachiopod's distribution, a consideration of the common features the brachiopods share is in order. Fagerstrom (1964) stated that most post-depositional alteration stems from replacement, leaching, and crushing. Presumably, within a group with similar composition, the first two should be relatively uniform, and not skew the population without leaving noticeable evidence. Both have occurred in the brachiopod faunas here, but are fairly obvious in their results; e.g., sphaleritization of the productids. Perhaps the most significant factor in the shales studied is post-depositional crushing, as this can influence interpretation of relative abundances and other faunal characteristics. Unfortunately, workers do not agree on the results. Large, relatively thin-shelled brachiopods are particularly at risk in shales. Fagerstrom (1964) noted that almost all the large productids in the Bonner Springs Shale

were crushed post-depositionally; he concluded this because the spines were broken, but the shells themselves were not scratched, pitted, or bored, and the fragments were unsorted. On the other hand, Carew (1978) stated that spiriferids and chonetids were more subject to crushing than productids and that in Crurithyris and Neospirifer the brachial valves seemed to be preferentially destroyed.

Crushing is nearly ubiquitous in the shales studied, and uncrushed specimens are rare. There may be preferential destruction of valves, as brachial valves of Crurithyris are generally not evident. However, productids, especially large ones, seem to be crushed far more than spiriferids. Chonetids are rarely crushed at all. Thus, there is a skew to the analyzed population, since many of the productids are crushed beyond recognition and can be classified only in very general terms. The spiriferids, on the other hand, are readily recognizable even from most fragments. This results in misleading correlations in occurrences, as most productids occur far more frequently than represented. All this would make any attempt at quantitative analysis meaningless.

Perhaps closely related in effect to post-depositional crushing is pre-depositional crushing, by predation or other reworking. Evidence for this is surprisingly scant among the brachiopods. Rudwick (1965) cited studies of productid injuries in the Carboniferous, and noted three types of predator damage: 1) sharp bites, possibly from cephalopods (cephalopods are moderately common in the shales studied here); 2) broader, crushing bites, possibly by fish such as Petalodus (fish debris, including Petalodus, is very common in the shales and

limestones); 3) circular borings with beveled edges, probably due to carnivorous gastropods (these are known, particularly in derbyiids, but are not common). Sturgeon and Hoare (1968), working with Conemaugh (Missourian) brachiopods in Ohio, also noted acrothoracic barnacle borings on some shells; these are not known from the shales studied, but were noted in some specimens from shaly beds in the Spring Hill Limestone, directly below the Vilas.

In general, evidence of predation or epibiotic activity is minimal among the brachiopods studied. Very few had much encrustation by tolypamminid forams or bryozoans, and only one Crania was found; however, a few horizons, especially just below the middle limestones, showed evidence of algal growth on the brachiopods. But the general trend is in keeping with the postulated modes of life of the brachiopods: most, especially the productids, were "mud floaters", often almost completely buried in mud, which would minimize epibionts. This is in marked contrast to the contemporary faunas of Sturgeon and Hoare (1968), who noted an unusual amount of epibionts.

A final consideration is whether there is a regional trend that might color interpretations. The consensus is that brachiopods, like other groups, show an increase in diversity to the south and west. Sturgeon and Hoare (1968) noted an increase in both specific (about 40%) and generic (about 10%) diversity from Ohio to the Midcontinent. Mudge and Yochelson (1962) also noted that abundances generally seem to increase in that direction, with a few individual exceptions. Due to the small sample size used here, these trends do not show up clearly, but rarer forms do show up more often toward the south.

Crurithyris

Crurithyris is the most common brachiopod in the Midcontinent shales (an observation supported by Mudge and Yochelson, 1962, and Carew, 1978), and has the most instructive distribution. Its characteristic of forming virtual coquinas, usually just above and less often just below the fissile black shales, has been widely recognized (Mudge and Yochelson, 1962; Winkler Prins, 1968; Senich, 1978; Carew, 1978. In Illinois, the middle limestone between the lower grey shale and the black fissile shale is often composed essentially of lenses of Crurithyris (Weller, 1957; Johnson, 1962). Usually, few other animals are associated with Crurithyris in such environments; phosphatic inarticulate brachiopods are the most frequent. Because of this high abundance and low diversity, Crurithyris is readily recognized as having lived in a high stress environment (Mudge and Yochelson, 1962). It has been widely recognized as opportunistic in character (Sarg, 1979), but this has generally been coupled with an interpretation of shallow and/or brackish water (Mudge and Yochelson, 1962; Winkler Prins, 1968; Carew, 1978; Hickey and Younker, 1981).

It is appropriate here to review the characteristics of opportunist (or r-strategist) animals (Pianka, 1970), and note how Crurithyris relates to them: Pianka lists the following characteristics: (1) found in variable, unstable environments; low diversity generally implies an unstable environment. (2) Little interspecific competition. (3) Highly variable populations. (4) Usually subject to

catastrophic, density-independent mortality. (5) Stresses adapt the r-strategist for rapid growth, high reproductive potential, paedomorphism, and small size. Crurithyris is obviously small, and may be paedomorphic. Perhaps significantly, Crurithyris in grey shale at Copan, Oklahoma (Locality Cp1) are larger than those found in the coquinas immediately adjacent to the black shales.

Levinton (1970) added several criteria for recognition of r-strategists in the rock record: (1) overwhelming numerical dominance (85 to 100%) of the fauna, (2) presence in thin, isochronous units, (3) a tendency to occur in size-group aggregations without evidence of physical reworking, (4) often found in several otherwise distinct faunal assemblages, and (5) appearing in great numbers in a facies it's normally not associated with. Crurithyris fulfills the last two qualifications, as it is often found in other horizons with other assemblages.

Levinton (1970) went on to make several pertinent observations about r-strategists. For example, they are characteristic of high stress environments, where physical variability controls the fauna. Opportunists are physiological generalists, with very high rates of population increase. The coquinas suggest that Crurithyris was very prolific, provided low sedimentation rates didn't concentrate them. However, there is sedimentological evidence that the black shales were indeed very slowly deposited. Thus, it may be possible that other stress conditions and concomitant adaptations account for Crurithyris' distribution, although an r-strategist adaptation is most likely, particularly in view of its distribution beyond the horizons where it is

most abundant. Carew (1978), for example, cited similar horizons, but in proximity to sandstones, which he attributed to fresh water.

Other features of Crurithyris may be used to help interpret its occurrences. Gilliam and Schram (1975) noted that it is small and light, an adaptation for a soft bottom. Thayer (1975) noted that a lack of costae in low-energy environments also reduces weight. However, Hallam (1965) noted that low-oxygen conditions also favor small forms, as it would increase the surface to volume ratio of the animals, and produce more efficient gas exchange. The lack of other expected soft-sediment adaptations suggests that low oxygen is the controlling factor. Thayer (1975), for example, listed flattening to spread the weight as another adaptation for soft sediments, but Crurithyris is relatively high in relation to its width and length. Shells in soft-sediment dwellers are also usually thin, whereas Crurithyris, although small, has a relatively thick shell.

Other stress conditions can produce small size in a fauna. Gunter (1947) noted that size is generally inversely proportional to salinity variation, and Hallam (1965) noted that abnormal salinity strongly stunts organisms, while decreasing diversity and increasing abundance.

Thus, it would appear Crurithyris is probably an opportunist, based not only on its distribution near the black shales, but on its distribution in a wide range of environments. McCrone (1963) considered it eurytopic, because it appeared in a wide range of environments in a Lower Permian cyclothem. It also appears to be physiologically simple and quite small, both adaptations characteristic of r-strategists. Its remarkable occurrences close to low-diversity fissile

black shales suggest physical stress, which would be compatible with a fluctuating low-oxygen environment, although on paleontological grounds alone, salinity cannot be ruled out as a possible control.

Punctospirifer

Punctospirifer, unlike Crurithyris has received relatively little attention. Senich (1978) concluded that it was eurytopic and ubiquitous. Mudge and Yochelson (1962) had noted that it occurred with pelecypods on occasion; the co-occurrence values indicate this happens no more frequently than with other brachiopods.

Punctospirifer's dominant characteristic seems to be association with carbonate deposition, both in its stratigraphic and paleontologic associations. It occurs frequently with Anchignathodus, which is generally associated with limestones. Generally, it overlaps the faunal group that associates with muscovite and kaolinite, and is characterized by Wewokellid sponges. However, Punctospirifer is more widespread and is eurytopic.

Composita

Composita has been widely described as eurytopic and/or ubiquitous (Sloan, 1955; Stevens, 1971; Carew, 1978). Senich (1978) called it one of the most abundant brachiopods in the Stanton cyclothem, and also labelled it eurytopic. Lipp (1975) stated that it was opportunistic (largely because it is common in strata without the most diverse fauna) which implies that it is eurytopic. Mudge and Yochelson (1962) noted that Composita is common in limestones and calcareous shales, but rare in pelecypod-bearing shales.

Composita's distribution in this study supports most of these observations, except that it is opportunistic. Like Punctospirifer, it prefers carbonate-rich environments, as indicated by both its stratigraphic and paleontologic associations. However, it appears that Composita is more likely tied to the depth range that the limestones typically occur in than to the carbonate substrate. This is evidenced by its presence in the lower transitional shale even when a limestone is not developed, in contrast to Punctospirifer. Its range is stratigraphically somewhat broader than that of Punctospirifer, as it is found with a higher level of occurrence with the black shale fossils but without diminishing levels of occurrence with nearshore forms.

Neospirifer

Neospirifer is not a very common brachiopod, particularly in shales, but its presence is often noted, as it is a large, robust form. Mudge and Yochelson (1962) noted that it occurred mostly in limestones and in calcareous shales. Senich (1978), working principally on the limestones of the Stanton cyclothem, called it ubiquitous and eurytopic, which it may be in respect to limestones. It also shows evidence of depth control: Stevens (1971) calculated that it appeared offshore in water at least 15 to 20 meters deep, and Spencer (1967) noted that of the outside shales in Kansas, it was known only from the Cherryvale, a finding that is consistent with Siebel's (1981) conclusion that the Cherryvale is an incompletely developed cyclothem. (On the other hand, Sloan, 1955, concluded it was eurybathic.) Its avoidance of nearshore areas subject to detrital influx coincidentally explains its association with limestones.

In addition to distribution, Neospirifer's morphology has contributed to environmental interpretations. Rudwick (1970) suggested the flat interarea on spiriferids such as Neospirifer served as a stabilizing base, with the commissure up. The alae served as further stabilizers, both adaptations serving to stabilize the animal on a soft substrate. Rudwick also added that a thickened umbo helped to counterweight the posterior into the mud, while a deep sulcus served to increase circulatory efficiency in quiet water.

Alexander (1975) agreed that it was possible that alation may have helped stabilize an animal on a soft substrate, but suggested that it would also be useful for stabilization in a regime with active currents. This makes more sense in the case of Neospirifer, whose shell is robust, and not differentially thinned to reduce weight. It also has a large foramen, suggesting a large, muscular pedicle, which would be useful in currents. A large foramen is not useful to an animal resting on mud. Finally, it would also help explain Neospirifer's rarity in shale, as it would require a firm substrate to support a large, heavy shell. A large shell would suffice, but would not be too common, so that Neospirifer would be controlled by availability of substrate.

Hustedia

Hustedia has received less notice than its larger or more abundant kin. Those observations that have been made are somewhat contradictory. Senich (1978), working principally with limestones, stated that it was eurytopic and ubiquitous. Carew (1978) stated that it preferred

terrigenous clastics dominated by molluscs. Mudge and Yochelson (1962) stated that it favored calcareous shales; Gilliam and Schram (1975) noted that it was small and light, well adapted for soft bottoms. As it turns out, Hustedia essentially follows the other spiriferids, and shows a preference for limy units. Like Composita, it may range more toward the black shales.

Other Spiriferids

Brief mention should be made here of Cleiothyridina and Phricodothyris. Both are widely reported in some Upper Pennsylvanian rocks, but are largely from limestones. Only one Cleiothyridina and three Phricodothyris were found in this study. The explanation appears to be that both are closely tied to limestones. Stevens (1971) noted that both lived offshore in deeper water. Senich (1978) reported Phricodothyris to be one of the most eurytopic, abundant brachiopods in the Stanton limestones. Toomey (1980) added that he found Phricodothyris in an algal mound.

Productids

The productids are morphologically adapted for life in muddy environments. With thin shells, a broad, compressed body, and a concavo-convex shape, they are designed as "mud floaters", with the spines adding stability (Rudwick, 1970). However, within this muddy range, productids are found in a variety of environments. Several factors suggest that the muddy environment was fairly stable. Diversity is often substantial, and the productids meet several of the criteria for K-strategists (Pianka, 1970). They invest considerable energy in

larger size, and their populations are usually quite low. This would suggest that there were few, if any, significant short-term physical pressures in the environment.

The best-known productid group, the margginiferids, are clearly associated with the portions of the cyclothem closest to the black shale. However, they are found in limestones as well as in the grey shale transitions to the fissile black shale.

Grant (1968) noted that the ears and spines stabilized the margginiferids, helped by the concave brachial valve filled with mud. He also noted that the ears and trail were divided from the visceral mass by marginal internal ridges, which helped to trap excess mud. He concluded that they lived in slightly turbid water. He also stated that they probably spent their juvenile stages attached to bryozoa or similar substrates, dropping off into the mud as they matured. In support of this observation, several juvenile margginiferids were found attached to bryozoans in this study and margginiferids were always found with fenestrate bryozoans.

Juresania is clearly associated with the shallower environments, including the outside shale. Because of this, margginiferids and Juresania rarely occur together, as observed by Mudge and Yochelson (1962). This is also why Juresania is often found with molluscs (Elias, 1937; Mudge and Yochelson, 1962). Overall, Juresania is of intermediate abundance, but can be the dominant element in some faunas (Fagerstrom, 1964).

Antiquatonia is an abundant productid, especially when reports of dictyoclostids (largely Antiquatonia) are included (Mudge and

Yochelson, 1962). It is often reported from calcilutite (Mudge and Yochelson, 1962; Toomey, 1980), as well as from shales (Lipp, 1975). This, coupled with its lack of depth control (Stevens, 1971), suggests that Antiquatonia is widely adapted to a number of environments, and is rather eurytopic. (Notably, Berendsen and Nodine-Zeller, 1978, reported dictyoclostids from black shales with phosphate nodules.)

Most other productids are ambiguous in their distributions, both in the material found here and in reported occurrences. Linoproductus, which Mudge and Yochelson (1962) stated is one of the most common productids in the Upper Pennsylvanian, is linked with both argillaceous (Mudge and Yochelson, 1962) and algal calcilutite facies (Senich, 1978; Toomey, 1980). The more uncommon related Cancrinella (Mudge and Yochelson, 1962) has even been reported from the black core shale (Scheihing and Langenheim, 1980), as well as from algal calcilutite near the core shale (Senich, 1978). Pulchratia is associated with shales dominated by molluscs (Carew, 1978) and with limestone (Moore, 1964; Winkler Prins, 1968). These distributions can be explained in several ways: (1) preservation does not permit a sufficiently complete distribution to be recognized, (2) the forms involved are actually eurytopic, and/or (3) they are variously restricted by factors not evident in the lithology. In any event, no environmental assignments can be made.

Teguliferina is of special interest, even though it has a limited distribution. Unlike other productids, it would appear to require a firm substrate, and to be poorly adapted to deal with significant turbidity. Both features suggest that a muddy environment would be

unsuitable. However, muddy bottoms do not imply high turbidity. And Teguliferina seems to have solved the substrate problem by colonizing isolated shells. Thus, it was able to survive in the upper grey transition of the core shale and the adjacent calcilutite.

Chonetids

The chonetids have a pronounced dichotomy in distribution, with Neochonetes most common in the outside portion of the cyclothem, and Chonetinella closely associated with the core shale. Both are apparently similar in habit, however. Rollins and others (1979) described Chonetinella as a "mud floater", which would also apply to Neochonetes. They are both small, thin, concavo-convex, and possess spines to help support them on the mud. Both are apparently opportunistic: Sarg (1979) concluded that Neochonetes' distribution in the Ames cyclothem of Ohio supported this interpretation, and Jacobs (1976) demonstrated it in the Virgilian Stull Shale of southwestern Iowa. He noted that it composed 95 percent of the brachiopod fauna, and that it was associated with Crurithyris. He concluded that the stress was due to soft bottom conditions. Winkler Prins (1968) noted a similar distribution, and also concluded that it indicated shallow water with soft bottom conditions.

Chonetinella has a less pronounced distribution. Rollins and others (1979) stated that it is eurytopic, but Senich (1978) noted its tendency to occur close to and in the core shale. He also described a shale parting in the limestone a few feet above the core shale, dominated by Chonetinella and Rhipidomella. Lipp (1975) stated that it

is opportunistic in the Cambridge cyclothem of Ohio, as it occurs alone in a fauna just above the coal. He also cited Moore's (1964) statement to the same effect.

Spencer (1978) compared two species of Chonetinella, and determined that the characteristics of each reflected their position in the cyclothem. He found that the species closer to the core shale was more convex, and had a greater sulcus definition. The form closer to the outside shale was more alate, with lower convexity. This trend was attributed to quiet water and soft bottom conditions near the core shale, with the opposite near the outside shale. Notably, Chonetinella and Neochonetes share this same distributional and morphological relationship.

Derbyia

Derbyia has been described as being ubiquitous and eurytopic (Senich, 1978). Mudge and Yochelson (1962) noted that it was common not only in limestones and calcareous shales, but was also associated with pelecypods and Juresania in more marginal marine shales, an observation confirmed by this study. Derbyia often produces coquina-like horizons below the limestones (Winkler Prins, 1968), which may stabilize the substrate for more diverse faunas (Rollins et al., 1979). Winkler Prins (1968) noted that Derbyia usually produces the basal bed of the transgression, and while dominated by Derbyia, it is often diverse in faunal composition.

Actually, Derbyia is most closely associated with limestone, although common in both outside and core shales, and is very common at

the position of the middle limestone where it is absent. This eurytopic distribution is evidenced by its occurrence with a wide range of organisms. Derbyia's characteristic occurrence at the "base" of the marine portion of the cyclothem simply marks the first occurrence of prominent marine fossils; often, an extensive sequence of ostracodes, small molluscs, and other fauna is present in strata immediately below.

The possible roles of other physical characteristics in Derbyia's distribution are not well known. Muir-Wood and Williams (1965) stated that Derbyia was cemented to a firm substrate by its ventral umbo, and Gundrum (1980) suggested that it may have used sponges for that purpose. Gilliam and Schram (1975) found Derbyia to be generally free-lying, which is the usual case with the Derbyia seen in this study.

Derbyia also may have been sensitive to clastic influx. Exclusive of the animals associated with the black shales (e.g., Gondelella, Crurithyris), Derbyia has the lowest correlation with the detrital minerals of any taxon studied. However, this sensitivity is not yet verified by extensive field observations.

Meekella

Meekella is a significant strophomenid although only one occurrence (in an upper limestone) was found in this study. Senich (1978) found it only in algal-rich limestones close to the core shale, but Mudge and Yochelson (1962) reported it from calcareous shale, although noting that it was more common in limestone. West (1977) reported it in growth position in a limy bed of the Decatur City beds very close to

a studied section (Locality DeCl); he attributed the control on its occurrence to fluctuations in rate of sedimentation producing a favorable attachment site.

Rhipidomella

Very little has been written about Rhipidomella. Senich (1978) noted that it was common in and near the core shale, but was essentially restricted to the clastic facies belt. The restriction to near-core environments is verified here, but it occurs more widely, as several grey core transition shales in Iowa have abundant Rhipidomella.

Enteletes

Enteletes is largely restricted to limestone (Winkler Prins, 1968; Senich, 1978), and was seen near the base of the Captain Creek Limestone in this study.

Wellerella

According to Mudge and Yochelson (1962), Wellerella prefers red calcareous shales. This is generally verified by observation: Carew (1978) stated that it preferred molluscan shales, and Senich (1978) reported it only from the fossiliferous upper grey transition shale of the Eudora. In this study, Wellerella was found in outside shales and shale partings in limestones. Thus, Wellerella may be more closely tied to gross lithology than to position in the cyclothem.

Terebratulids

According to Senich (1978), Dielasma, the commonest terebratulid in the Upper Pennsylvanian, is ubiquitous and eurytopic. However,

since his study largely concentrated on limestones, and since only one terebratulid was found in a shale in this study, it would appear terebratulids are largely confined to carbonate facies.

Phosphatic Inarticulates

Phosphatic inarticulate brachiopods are common in Upper Pennsylvanian marine units, and have long been used as keys in the interpretation of the depositional environments. Many of these interpretations have been based on analogies with modern lingulids, even though not all the Pennsylvanian forms are Lingula. Orbiculoidea is also common, and there is fragmental evidence that the prominently ridged genera Trigonoglossa and/or Lindstroemella are also present. Paine (1970) noted that the assumption of similarity between modern and ancient forms is based on the apparent evolutionary conservatism of the group. However, such assumptions are hazardous, and must be recognized as such. However, an assumption of evolutionary conservatism may be useful, if it is recognized as just a hypothesis and is found to be compatible with the evidence.

The assumptions made about lingulids apply to several aspects of their existence. Substrate conditions would seem to be most unequivocal. Craig (1952) noted that modern lingulids live on all manner of substrate, from sands to muds, but that even in mud they need a solid substrate, either a shell or a buried sand layer. Weller (1957) suggested that Lingula might be either epiplanktonic or a resistant bottom dweller. Ferguson (1963) demonstrated that Carboniferous lingulids were indeed burrowers, like their modern descendants. Paine

(1970) noted that modern lingulids have a substrate gradation with nearshore forms living in sand, and offshore forms living in mud; he noted this was compatible with the fossil record.

It is not clear if this generalization also applies to Orbiculoidea. Weller (1957) stated that Orbiculoidea was epiplanktonic, and Rudwick (1970) noted that not all inarticulates could be assumed to be burrowers, as many (such as Orbiculoidea) lacked a linguloid shape.

In any case, substrate may be a factor in the distribution of phosphatic inarticulates. Ottum (1969) noted that the Brush Creek cyclothem, even the black shale, lacked inarticulates, and attributed it to a lack of suitable substrate.

Another key characteristic of modern lingulids is the ability to live in fluctuating conditions, especially in the intertidal zone. Craig (1952) noted that Lingula could tolerate brackish and/or fetid water conditions, and could even tolerate fresh water, although it was not known to occur naturally in freshwater environments. Manwell (1960) explained the physiological mechanism for this; modern lingulids possess a blood pigment that stores oxygen, permitting it to close itself off from its environment for long periods when the environment becomes inimical. This permits Lingula to cope with remarkable temporary extremes in salinity and oxygen levels.

This trait, combined with the previously known shallow occurrences of inarticulate brachiopods (Elias, 1937; Craig, 1952), led to the placing of inarticulate brachiopod occurrences in shallow water, especially in the intertidal zone if phosphatic inarticulates were the

only fossils present. Winkler Prins (1968) placed the black shale Lingula-Orbiculoidea assemblage in shallow water, beneath an algal mat. Paine (1970) also assigned such occurrences to shallow water, for lack of a deep water mechanism for oxygen fluctuation. However, this restriction was not uniformly recognized: Rollins and others (1979) noted that Lingula was eurytopic, and Ellison (1950) noted an occurrence of Lingula in a black shale assemblage very similar to those of the Upper Pennsylvanian, and interpreted it as occurring in relatively deep water.

The application of these observations has led to important results. Elias (1937) noted that most modern lingulids occur in less than 60 feet of water. He also observed that in Lower Permian cyclothems, the most nearshore stages were marked by faunas of phosphatic inarticulates. He also noted that in modern and Permian examples, increasing depth produced intergradation with molluscan communities. Thus, he established the shallowest phase of the cyclothem as characterized by simple faunas of phosphatic inarticulates.

This has had a remarkable repercussion. Although the cyclothems Elias worked with generally did not have a black core shale, his assignment of inarticulate faunas to shallow water correspond well to the accepted model that such black shales formed in shallow, nearshore conditions. Thus, it was viewed as reinforcing evidence, and strengthened the shallow water model for the black shale.

However, this overlooks the eurytopic nature of lingulids, which occur throughout the cyclothem, not just in the black shale, where they are most easily observed. Although Mudge and Yochelson (1962) stated

that Orbiculoidea was restricted to the black shale and dark limestones, this may be only a function of preservation; in this study, orbiculoids were also found in the outside shale. In fact, phosphatic inarticulates tend to occur frequently in association with shallow-water conodonts and ostracodes, near the terrestrial portion of the cyclothem. They also frequently occur with molluscs, both gastropods and pelecypods. They follow Elias' (1937) zonation, but with a modification: they are eurytopic, and occur in all horizons. In the black shales, where other organisms cannot survive and conditions for preservation are good, they are much in evidence, but that does not mean that they lived only in that environment.

While it cannot justifiably be assumed that ancient phosphatic inarticulates were equipped with the same blood pigment as modern ones, it can serve as a supporting observation. Some lingulids obviously lived in an environment at least periodically low in oxygen. Coupled with the distribution of Crurithyris in the same horizons, they would support the concept of episodically unfavorable conditions, although whether due to abnormal salinity or oxygen conditions cannot be conclusively demonstrated.

In several places, the top of the Spring Hill Limestone beneath the Vilas Shale was characterized by large lingulids, with rugose black periostracums. At present, the potential stratigraphic and/or environmental significance of this is not known.

Environmental Implications

The overall distribution of brachiopods in Upper Pennsylvanian cyclothems gives some information on the depositional environment. Bretsky and Lorenz (1970) noted that diversity correlates with environmental stability, in this case, presumably to increasing water depth, which would stabilize temperature and salinity fluctuations, and protect bottom communities from frequent storm damage. Diversity within the shales may illustrate this theoretical trend: the most diverse fauna occurs in the upper grey transition of the core shale. The shale partings in limestones may be comparable, but this is not possible to say on statistical grounds: the gross diversity is lower, but fewer samples were collected. Since rare forms are increasingly likely to be collected with more samples, gross diversity increases with sampling. Some 54 upper grey transitions produced 25 genera, whereas 15 shale partings produced 18 genera.

The other shales are also difficult to determine, but appear to be less stable. The lower grey transition contains far fewer taxa, perhaps due to greater environmental instability. The aggregate outside shales yielded 18 genera in 43 samples, for less diversity than the upper grey transition and the shale partings. It is probably generally lower than that, as some "outside shales" are simply limestone environments with excessive terrigenous mud; these shales show much higher diversity than is typical, and often contain taxa that are not present in other outside shales. The fissile black shales, of course, have very low diversity.

The nature of the brachiopods also indicates something about the environment. In both the outside shales and the grey transition shales closest to the black fissile shale, many of the brachiopods show evidence of being opportunists, adapted to unstable conditions. Many of the other species are also generalists; Watkins (1974) noted that the range of taxa through different communities reflects niche size, so that wide-ranging forms are generalists. Most of the brachiopods are found in both limestones and shales, and thus cover a wide range of environments. They do not appear to be dependent on specific uncommon environmental conditions. Increasing stability toward the limestones accounts for the addition of some taxa. This trend, rather than a niche-specific trait, may account for those brachiopods effectively limited to limestones; there are few brachiopods limited to shales.

Sloan (1955) noted that brachiopods increased offshore relative to molluscs. Carew (1978) stated that brachiopods were more common in carbonates, and reflected a clear-water environment. This would follow the logical interpretation that high rates of sedimentation would inhibit brachiopods. Rudwick (1965), however, noted that both modern and ancient brachiopods are fairly tolerant of turbid water for feeding purposes, although they are unable to avoid burial. However, most brachiopods apparently require a firm substrate to initially settle upon (the adaptations of margini ferids and the presence of cicatrices on many productids reflect this). Rudwick added that it is also possible that brachiopod-bearing sediments reflect episodic deposition,

with generally clear-water conditions interspersed with periods of turbidity.

Thus, the presence and nature of brachiopods in the shales studied reflect increasing stability of environment from the outside shale toward the limestones. The bottoms were generally muddy enough so that productids and chonetids were favored, with only small or uncommon pediculate brachiopods present. However, the rate of sedimentation is not indicated, as it could be slow enough to not affect brachiopod growth, or simply episodic.

The reduction of brachiopod diversity in the grey transitional core shales toward the black shale also reflects varying stress conditions. Notably, the large productids are less common in these shales; the smaller margiferids are more common. The fact that the sequence toward the black shale involves different brachiopods with different features indicates that the source of stress is different from that in the outside shales. The stress sources in the outside shales are presumably those associated with nearshore conditions; the stress in the core shale is most likely related to basin-wide conditions.

## Bryozoans

Bryozoans are very common in the shales examined. They were found in 117 of the 230 shale samples, or just over 50 percent. However, little was done toward recognizing various taxa, because it was impractical here to do a thorough study. Subdivision was limited to categorization as fenestrate, ramose, and fistuliporid bryozoans.

Empirical Data

Fenestrate and ramose bryozoans constitute the bulk of bryozoan occurrences. The two groups have virtually identical occurrences, and co-occur much of the time, so the co-occurrences of bryozoans as a group, fenestrate bryozoans, and ramose bryozoans with other animals can all be described together.

Fenestrate bryozoans occur in nearly 40 percent of the fossiliferous shale samples, and in about three-quarters of those containing bryozoans. They were with ramose bryozoans in about 85 percent of their occurrences.

Ramose bryozoans were slightly more common, occurring in over 85 percent of the samples containing bryozoans. They were accompanied by fenestrate bryozoans over three-quarters of the time.

Bryozoans have few notable distributional characteristics. They occur with Adetognathus 40 times in 117 occurrences, or about 35 percent, but with Gondolella only 23 times, or about 20 percent. Among ostracodes, bryozoans occur with both Cavellina and Bairdia in a little over half of their samples, with Amphissites in about 35 percent of them, and with geisinids in about one-eighth of them. Bryozoans are accompanied by articulate brachiopods in over 90 percent of their samples, by pelmatozoans in about three-quarters of them, and by gastropods in about 70 percent of them. They are also accompanied by inarticulate brachiopods in about 30 percent of their samples, by pelecypods in about a third of them, by sponges and trilobites in about

a quarter of them, and by corals in about one-eighth of them. Bryozoans tend to occur in sediments containing muscovite and/or kaolinite insignificantly more often than expected.

The same co-occurrence rates generally apply to both the fenestrate and ramose bryozoans, with the ramose bryozoans generally having a slightly higher percent co-occurrence, due to their slightly greater frequency. One exception is with pelmatozoans, which accompany fenestrate bryozoans in nearly 90 percent of their samples, versus a 75 percent level for ramose bryozoans and bryozoans in general.

Fistuliporid bryozoans are much more restricted in their distribution. They occur in only 16 (7 percent) fossiliferous shale samples, which is only 14 percent of bryozoan occurrences. Fistuliporids occur with Adetognathus about as frequently as do bryozoans in general, but more often with Gondolella (30 percent versus a 20 percent average). With respect to ostracodes, fistuliporids occur more frequently with Bairdia (in 60 percent of their samples) and less with Cavellina (in 25 percent of their samples). Fistuliporids are always accompanied by articulate brachiopods, notably including Punctospirifer and Hustedia (each found with fistuliporids in 75 percent of their samples). Fistuliporids occur with trilobites and corals twice as often as do bryozoans in general, with sponges 50 percent more frequently, and with pelmatozoans 25 percent more often. They are accompanied by echinoids in about 60 percent of their samples, or about three times the average rate for bryozoans. Fistuliporids occur slightly less frequently with pelecypods (about one-third as often). Fistuliporids occur in shales containing muscovite about as often as bryozoans in general, but in

kaolinite-bearing shales in about 75 percent of their samples, or about 30 percent more often than other bryozoans.

Interpretations

The bryozoans found in the fossiliferous shales are relatively common and broadly adapted as a group. They generally occur with articulate brachiopods and pelmatozoans, and together make the basis for the diverse faunas found in most limestones and adjacent shales. As a consequence, bryozoans are generally found with those animals most closely associated with the limestones, and are relatively seldom found with those characteristic of extreme conditions.

The gross morphology of bryozoans (e.g., ramose versus fenestrate) does not reflect kinetic conditions. McKinney and Gault (1980) noted that fenestrate bryozoans are found in both quiet and agitated conditions, and the same conclusion appears to be applicable to the ramose bryozoans. Indeed, the usual co-occurrence of the two forms would suggest that gross morphology is not a characteristic that gives one form an adaptive advantage over another in a particular environment. McKinney and Gault (1980) suggested that intergeneric variations are adaptive, and would correspond to various environments, but environmental associations would have to be done at that more refined level.

Fistuliporid bryozoans, however, show distinct trends within the cyclothem, appearing somewhat more toward the core environment than the outside shale environment.

Bryozoans presumably are closely related to their environment, especially in respect to the substrate. Rollins and others (1979)

suggested that a bryozoan community in the Cambridge cyclothem developed after the substrate was stablized by development of a pavement of Chonetinella valves. A similar situation may have occurred in the Missourian strata studied, where Derbyia valves may have provided a substrate for a dense growth of Rhombopora (identified by F. K. McKinney, pers. comm., 1980) at the top of the Vilas Shale near Winterset, Iowa (Locality Wi2). This kind of association with Derbyia is fairly common, and may be an early step in establishing carbonate production.

Broadhead (1976) suggested that in a bryozoan-dominated community, fallen fronds would act to limit infaunal burrowing. Thus, the bryozoans would be self-perpetuating in their environment, and burrowers should be rare with such a fauna.

## Echinoderms

Because most echinoderms disintegrate into discrete plates upon death, taxonomic problems are rampant. Effective taxonomy relies upon the fortuitous preservation of critical features. Thus, most of the observations about echinoderms are confined to those that can be made about the group in general, with few specifics.

### Pelmatozoans

#### Empirical Data

Pelmatozoans were generally represented in the sediments by abundant discrete plates. They were found in 101 (near 45 percent) of the

230 fossiliferous shale samples. Identifiable calyx material was found in only ten samples (Table 10).

Pelmatozoans have almost identical co-occurrence patterns as the bryozoans (which see). The only noticeable difference is that pelmatozoans occur more frequently with gastropods (44 percent of the time, versus 35 percent) than do bryozoans. Pelmatozoans occur with detrital minerals at the same rate as do bryozoans.

Interpretations

Pelmatozoans are usually associated with bryozoans and articulate brachiopods, the three groups making up the bulk of the fossils found in most limestones and adjacent shales in the cyclothems. Thus, pelmatozoans as a group display no discernible tendencies in relation to other animals, except a disjunct relationship with those related to extreme facies.

One feature of pelmatozoan distribution should be mentioned. South of the algal mound facies in southeastern Kansas and adjacent Oklahoma, the basal portions of the Winterset consists of beds of pelmatozoan debris interlayered with shaly horizons that also contain abundant pelmatozoans. These beds are locally cross-bedded (Frost, 1968; 1975), with abraded grains (Cronoble and Mankin, 1965), possibly indicating active currents during their deposition. The limestones also contain some glaucony (Cronoble and Mankin, 1965; Frost, 1968; 1975), indicating a low net rate of deposition. The volume of such limestone present suggests that such an environment favors pelmatozoan growth.

Table 10

Crinoid occurrences*

| Crinoid | Unit | Locality |
|---|---|---|
| Aesiocrinus | Eudora | Copan, Oklahoma (Cp1) |
| Anchicrinus | Vilas | Bedford, Iowa (Be1) |
| Apographiocrinus | Kiewitz | Louisville, Nebraska (Lo1) |
| | Winterset | Coffeyville, Kansas (Cf1) |
| Delocrinus | Kiewitz | Louisville, Nebraska (Lo1) |
| | Spring Hill | Altoona, Kansas (Al1) |
| | Winterset | Coffeyville, Kansas (Cf4) |
| Erisocrinus | Kiewitz | Louisville, Nebraska (Lo1) |
| | Stoner | Buffalo, Kansas (WCL1) |
| | Spring Hill | Altoona, Kansas (Al1) |
| | Winterset | Coffeyville, Kansas (Cf1) |
| Exocrinus | Eudora | Altoona, Kansas (Al3) |
| Exoriocrinus | Winterset | Coffeyville, Kansas (Cf4) |
| Galateacrinus | Eudora | Copan, Oklahoma (Cp1) |
| Graffamicrinus | Kiewitz | Louisville, Nebraska (Lo1) |
| | Eudora | Copan, Oklahoma (Cp1) |
| Kallimorphocrinus | Eudora | Copan, Oklahoma (Cp1) |
| Oklahomacrinus | Weston | Elk City, Kansas (Weston ECQ) |
| | Kiewitz | Louisville, Nebraska (Lo1) |
| Paradelocrinus | Stoner | Buffalo, Kansas (WCL1) |

Table 10 (cont'd.)

| Crinoid | Unit | Locality |
|---|---|---|
| Stellarocrinus | Vilas | Bedford, Iowa (Bel) |
| | Spring Hill | Altoona, Kansas (All) |
| Stenopicrinus | Kiewitz | Louisville, Nebraska (Lol) |
| Triceracrinus | Kiewitz | Louisville, Nebraska (Lol) |

*Identifications by H. L. Strimple and T. J. Frest.

It is not clear in what relative water depth the encrinites formed. Heckel and Baesemann (1975) stated that G. Klapper found Gondolella in similar rocks in West Texas, which were interpreted as the deepest carbonate facies. In this study, Gondolella was found in the facies, but only in a basal conodont lag. Toomey and Winland (1973) found similar encrinites over and in front of algal mounds in New Mexico, and interpreted them as forming in shallow water. The relative depth is thus uncertain, but is probably intermediate, rather than near an extreme.

Crinoids have distributions that reflect the stages of the cyclothems. Pabian and Strimple (1969) recognized two assemblages: a warm, shallow water assemblage ("Type I") with large, ornate species, and a cold, relatively deep water assemblage ("Type II") with small, simple species. The abundance and diversity of crinoids increases

toward the core shale, until core conditions begin to limit them. According to Heckel and Pabian (1981), the cold water associated with core shale formation would make it more difficult to precipitate calcium carbonate, leading to smaller crinoids. By this reasoning, the Winterset encrinite probably formed in relatively shallow water, as it contains rather robust crinoids.

Of the identifiable calyxes found, the most frequently occurring were Delocrinus and Erisocrinus. Although unlike most other Upper Pennsylvanian invertebrates, crinoids show evidence of provincialism (Pabian, 1979), Delocrinus and Erisocrinus were relatively cosmopolitan, at least in the Midcontinent.

## Echinoids

### Empirical Data

Echinoids are far less common in the fossiliferous shales than are pelmatozoans. Echinoid plates and/or spines were found in 28 (about 12 percent) of the 230 fossiliferous shale samples.

Echinoids show a distinctive pattern of co-occurrences. They occur less frequently with all the major conodonts than do pelmatozoans; for example, they only occur in 10 percent of their samples with Gondolella (versus 20 percent for pelmatozoans) and in less than 30 percent of them with Adetognathus (versus more than 30 percent for pelmatozoans). Echinoids occur more frequently with all the foraminifers, especially with Hyperammina and Ammovertella; they likewise are accompanied more frequently by the ostracodes Amphissites, Bairdia, and Cavellina (nearly 60 percent for each, versus 40 percent,

50 percent, and 50 percent, respectively, with the pelmatozoans). Echinoids occur with articulate brachiopods about as often as do pelmatozoans (in nearly 90 percent of their samples), but with different ones, especially Punctospirifer and Hustedia. Echinoids also occur with bryozoans and pelmatozoans in about 90 percent of their samples. Echinoids display relatively high rates of occurrence with gastropods (70 percent), pelecypods and trilobites (50 percent), sponges (30 percent), and corals (nearly 20 percent). Echinoids occur relatively frequently in shales containing muscovite (50 percent) and kaolinite (75 percent of the samples).

Interpretations

Senich (1978) noted that echinoids were most common in the early phases of the transgression; i.e., the base of the Captain Creek and the South Bend limestones. The co-occurrence patterns found would support this interpretation, especially the occurrence with such animals as Punctospirifer. While it is unlikely echinoids are restricted to that phase, they may be most common near that horizon.

Holothurians

Only two identified holothurian spicules were recovered, both from the grey Eudora shale at Walker Mound, near Independence, Kansas (Locality WM1). Byers (1977) suggested that dysaerobic conditions might favor holothurians. This, together with other features (e.g., other animals that may be favored by similar conditions, proximity to a black core shale), is compatible with a dysaerobic environment

for deposition of at least part of the southern Eudora; however, it is not the only possiblity.

## Molluscs

### Preservational Problems

Before discussing the distribution of various molluscan groups, it is necessary to consider the potential impact of diagensis on their record. Scavenging, predation, and mechanical reworking are also factors, but presumably would not selectively act on particular taxa without evidence. Here, preferential loss due to chemical characteristics will be considered; biologic and depositional factors will be discussed elsewhere. Recognition of this problem not only includes comparison of dominantly aragonitic molluscs to calcitic groups, but may also apply within the molluscs, as they vary considerably in their relative calcite and magnesium contents (and thus in their capacity to be preserved).

Chave (1964) took note of the "generally unwarranted assumption" that most mineralized fauna is preserved in marine units. He observed that chemical alteration of aragonite and high-magnesium calcite may lead to preferential loss, as they are often not stabilized by inversion, but frequently dissolved, with low-magnesium calcite reprecipitating in the void. Chave further cited an example where a calcitic fauna was locally preserved as an "insoluble residue" of a dominantly molluscan fauna. He stated such a process could badly warp an ecologic interpretation based on its results.

Koch and Sohl (1981) also noted the results of faunal skewing due to poor preservation of certain components. They observed that without ideal preservation, some taxa are preferentially preserved. Thus, taxa preserved only under ideal conditions would appear erroneously uncommon, endemic, and stenotopic; this would work against meaningful results of studies of diversity, abundance, and distribution in the total fauna.

Is there any evidence of this happening in the Upper Pennsylvanian sediments studied? Studies of mollusc distribution should provide a clue, and perhaps do: molluscs seem to be reported more frequently from detrital facies, where they would be rapidly buried. However, the low-magnesium calcite faunas they are associated with are remarkably like those in thinner, stratigraphic equiavalents elsewhere, where molluscs are rare. Furthermore, the molluscan fauna is often in strata where unusual mineralogical conditions (such as precipitation of siderite) could indicate rapid deposition and favorable preservation.

Lintz (1958) noted that Upper Pennsylvanian faunas in the Appalachians were mostly molluscan, while equivalent faunas in the Midcontinent were dominated by brachiopods. Carew (1978) noted a similar trend in Texas: the mollusc-dominated clastic wedges had a more diverse fauna, mostly by addition of taxa, with siderite deposition as a frequent indicator. In the Appalachian Basin, Lipp (1975) noted that above a limestone and fossiliferous shale (containing mostly brachiopods) both the abundance of molluscs and of siderite increased upward. Newell (1933) noted a lateral example of the same transition in the Eudora: to the north, it was dominated by brachiopods and crinoids; to

the south, as it thickened, it was dominated by molluscs and siderite nodules. Senich (1978) also noted this trend, and stated that a number of animals, mostly molluscs, were apparently restricted to this southern terrigenous clastic facies where the Eudora became very thick.

The siderite provides a clue. As is described elsewhere, siderite requires rapid sedimentation to form in marine sediments. The sediments must be thickly covered in order to prevent an influx of sulfate from seawater, while retaining enough organic matter to permit bacterial $CO_2$ production to continue via fermentation. This requires rapid burial.

An example of how this might work is provided by the fauna at Copan, Oklahoma (Locality Cp1). Here, the Eudora is very thick, and contains a great deal of siderite. Most of the siderite is in nodules, filling and/or surrounding fossils. Molluscan fossils are plentiful and diverse, usually filled with siderite, with the original shell material replaced by coarsely crystalline calcite. Siderite formation was early, as many of the molluscs are uncrushed. The brachiopods and crinoids found here are taxa also common to the thinner shales to the north where molluscs are rare.

Is there evidence of preferential preservation? Some taxa are found elsewhere, where fortuitous preservation preserves them. The cephalopod Eoasianites is an example. Senich (1978) found it only in the thick clastics, where it is preserved as calcite, often with a siderite filling. He concluded that it was restricted to that facies. However, it has been found to the north, when preservation permitted:

in oölites (where deposition is rapid) in Kansas, and pyritized in limestones in Kansas and Iowa (Fig. 65). The depositional environments are different, but diagenetic conditions are favorable.

Senich (1978) provided another example where fortuitous preservation may distort interpretation. He found the pelecypod Edmondia associated only with skeletal calcarenites, particularly in the Altoona channel, and stated that this indicated the animal preferred such an environment, even though its shell shape suggested it was a shallow burrower and poorly adapted to life in a high-energy environment. However, most other reports of Edmondia report it from shales, many dark grey and black (Lintz, 1958; Mudge and Yochelson, 1962; Hoare et al., 1979).

Hakes (1976) also provided evidence that molluscan fauna may be largely lost in some cases. Working with trace fossils in the outside shales, he noted that the shales frequently have abundant and diverse ichnofossils, many made by shelled invertebrates, especially molluscs. However, body fossils are rare, which he attributed to post-depositional leaching.

Other processes may also work to preferentially preserve molluscs. Hallam (1965) observed that some fossil populations could be skewed by preferential preservation of the smaller members or portions of them. He mentioned pyritization as an example; glauconitization could act in a similar fashion. But it seems that phosphatization is most prevalent in Upper Pennsylvanian sediments. Apatite steinkerns of microgastropods are widespread. Bradley (1964) noted that most of the phosphate in the Cambridge Limestone of Ohio consists of such

Figure 65. Cephalopod distribution in strata related to the Dennis and Stanton cyclothems. Terrigenous detrital facies limit from Heckel (1979)

Pattern is Kansas City Group (includes Bronson Group as used here) in Iowa, Missouri, and Nebraska, Vilas and Galesburg shales in Kansas, and Coffeyville Formation in Oklahoma.

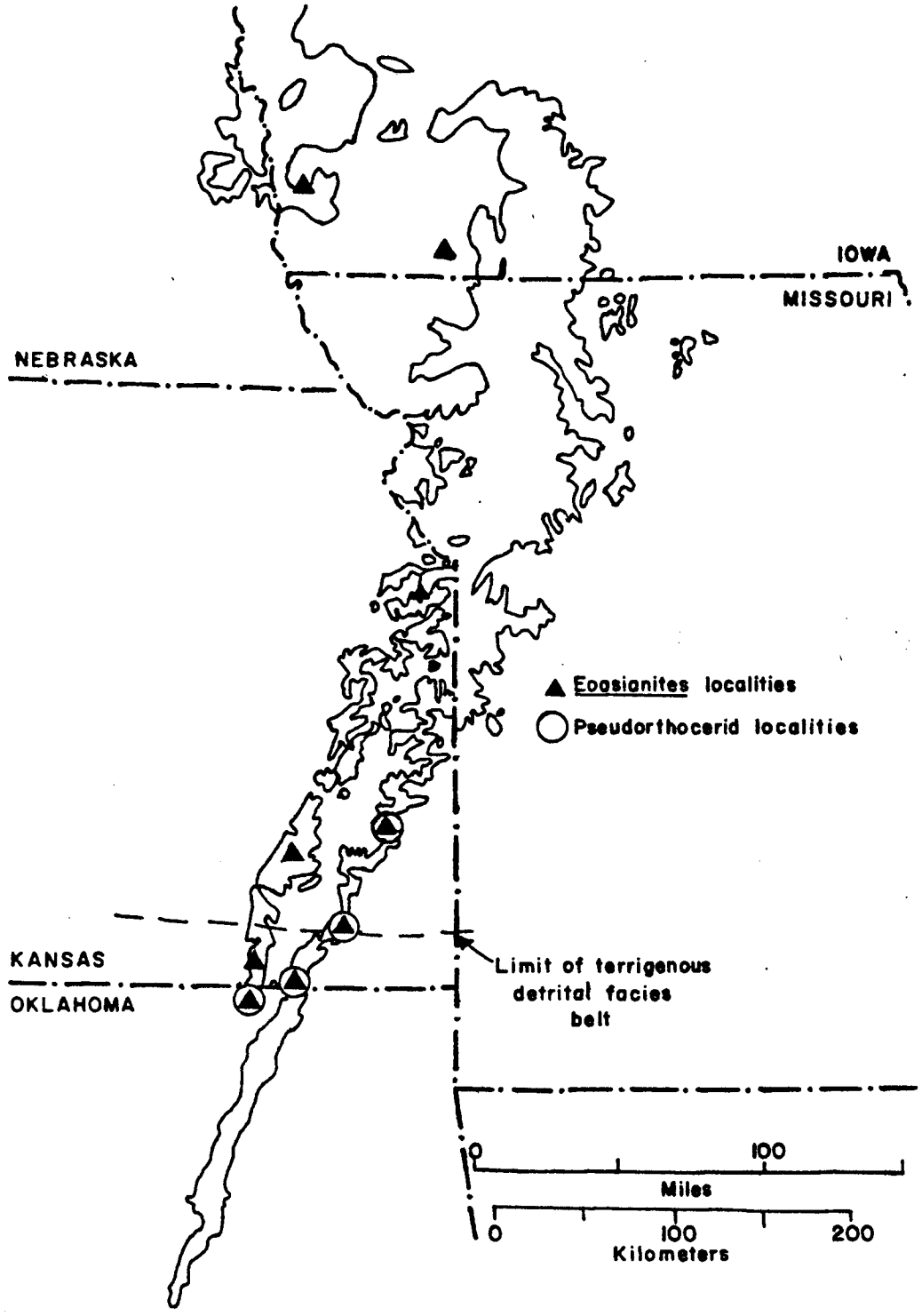

IOWA
MISSOURI
NEBRASKA
▲ Eogasianites localities
◯ Pseudorthocerid localities
KANSAS
OKLAHOMA
Limit of terrigenous detrital facies belt
0
100
Miles
0
100
200
Kilometers

Figure 65.

steinkerns; Cronoble and Mankin (1965) noted them in the Lost City; and Toomey (1980) noted them in a crinoidal grainstone in New Mexico. Hanson (1957) reported them from the crinoidal grainstone base of the Winterset in Oklahoma, accompanied by some filled with glaucony. They are so common that Merrill (1980) expressed surprise when a sample lacked them.

The steinkerns are common in most of the basal upper limestones and adjacent shales. They form by a process somewhat different from that of the apatite grains and nodules, as they are massive and lack microconglomeratic structure. They probably form as a result of a process similar to glauconitization, where the microchemical environment within a small shell locally favors precipitation. Notably, glaucony forms under conditions similar to those that produce apatite, particularly in respect to rate of sedimentation. Thus, small molluscs, particularly burrowing forms (which would more readily maintain the necessary chemical conditions) would be preferentially phosphatized. The large scale depositional environment would not need to be extreme for such phosphatization to take place, although obviously the higher the concentration of phosphate in the water and sediment, the more readily phosphatization could take place.

Such steinkerns often make up a significant portion of the rock. They are mostly high-spired gastropods, but bellerophontids and pelecypods are also common; ostracode and brachiopod steinkerns are less frequently preserved. They are common in sediments from Iowa and Illinois, as well as farther south. The crinoidal grainstones in the base of the Winterset in northeastern Oklahoma and adjacent Kansas are

particularly rich in the microgastropods; in one case, they were also silicified, so that the silica preserved the external form, while phosphatization preserved the interior (Lost City Limestone, Ramona, Oklahoma, Locality Ra2). They occur often enough that no attempt was made to systematically record their presence as apatite.

Molluscs can be lost by preburial solution, as well. Bosellini and Winterer (1975) noted that before the Cretaceous, the compensation depths for aragonite and calcite were much closer to the surface. These compensation depths also vary locally, depending on carbonate production. It is possible that during the Pennsylvanian, water undersaturated with respect to aragonite and possibly calcite invaded the shallow coastal waters. Alexandersson (1976) noted that cold water, limitation of photosynthesis, and organic decay may all contribute to dissolution of carbonate by raising the level of $CO_2$ in the water. Degens and Stoffers (1976) noted that carbonates eventually dissolve in strongly reducing waters, and Curtis (1980) suggested that pyritization would also cause dissolution by increasing acidity. Aragonitic fossils would be much more susceptible to loss. Since many of these processes should have been active in the Missourian depositional environments, dissolution of shells should be expected. However, few of the fossils found are etched, crumbly, chalky, or frosted, as would be expected if dissolution were important. Only near the black core shales is there any evidence this may have occurred; there, molds of fossils are locally common, but even there preservation suggests diagenetic, rather than syndepositional, loss.

Thus, extensive suggestive evidence exists that molluscs may be variably preserved or removed; it is difficult to determine on the basis of negative evidence. In some cases various Midcontinent units away from the environments outlined above do contain well-preserved molluscs; this could mean that if present, they are preserved one way or another, or it could be just lucky chance in a generally unfavorable environment.

Even though the loss rate is not known, enough data may be preserved to provide distributional trends. With enough data from favored areas where molluscs are preserved, coupled with fortuitous occurrences elsewhere and with co-occurring calcitic organisms, some inferences may be possible about areas where the molluscs are missing.

## Gastropods

### Empirical Data

Despite the potential problems with preservation, gastropods were remarkably common in the sediments studied, although a large proportion were either steinkerns or calcite replacements in rapidly deposited units. In the shales, evidence of gastropods was recovered from 110 (nearly 48 percent) of 230 samples. Gastropods as a group exhibit distinct trends in co-occurrence. Among conodonts, they are accompanied twice as often by *Adetognathus* as by *Gondolella* (35 times versus 17 times). Among the ostracodes, *Cavellina* is found with gastropods more than twice as often as *Amphissites* (60 times versus 27 times), and geisinids co-occur more frequently than they do with many

other groups (24 times, or 22 percent). Gastropods also often occur with calcitic groups. Articulate brachiopods, bryozoans, and pelmatozoans are found with gastropod faunas in between 60 and 75 percent of their samples. Pelecypods accompany gastropods in half of their samples, and inarticulate brachiopods in 30 percent of them.

An effort was made to determine if high-spired gastropods had a distinct environmental preference. Most of the high-spired forms were preserved as steinkerns, so that little could be determined of their taxonomy. Most were simple spires with a circular cross-section, but a fair number had a flattened cross-section, suggesting internal molds of gastropods such as Bulimorpha or Soleniscus. These high-spired gastropods occurred in three-quarters of the total gastropod faunas, but varied very little from the overall distribution of gastropods as a group.

An effort was also made to determine the distribution of bellerophontid gastropods, which were also often steinkerns. Bellerophontids occurred in 24 shale samples, or just over 10 percent. Their co-occurrence patterns are instructive, especially when compared to gastropods as a group. For example, with conodonts: bellerophontids were never found with Gondolella, but occurred more frequently with the other major conodonts than did gastropods in general. Bellerophontids are accompanied by Idioprioniodus in over 40 percent of their samples, and Anchignathodus and Adetognathus in over half of them. The same shallow-water relationship generally holds true with ostracodes, except that all the major ostracodes co-occur more frequently by about 50 percent with bellerophontids than with gastropods in general.

Brachiopods (articulate and inarticulate) and bryozoans follow generally the same rate of co-occurrence as with gastropods in general; but pelmatozoans occur with bellerophontids about 25 percent more often than they do with gastropods as a group, and pelecypods occur about 80 percent more often (or in nearly 90 percent of bellerophontid occurrences).

Interpretations

Although individual taxa were generally too sparsely distributed to undergo quantitative evaluation, a few qualitative comments are appropriate here.

Glabrocingulum.--Glabrocingulum is perhaps the commonost gastropod found in the Upper Pennsylvanian. Several workers have commented on its distribution, but with little agreement. Sloan (1955) stated that it was abundant at all depths, but that it was most abundant in shallow water. Petty (1975) also linked it to shallow water, while Carew (1978) stated that it was ubiquitous. Senich (1978) felt that it was restricted to the terrigenous clastic facies, and there only in the grey core shales and adjacent limestones. MacLeod (1982) found Glabrocingulum in a predeltaic shale in Texas, and used it, together with Trepospira, to characterize a mollusc-dominated faunal association.

Glabrocingulum was identified with some certainty in a dozen samples, largely from shales in the terrigenous clastic belt, mostly from the thick sections of Eudora Shale at Copan, Oklahoma (Locality Cp1) and Independence, Kansas (Locality WM1). However, it was found

elsewhere, such as in the Stark Shale at Jingo (Locality Ji1) in east-central Kansas. It was also found in outside shales and shale partings in limestones. The dominant feature of its distribution is that it always occurs in very diversely fossiliferous units, which would imply offshore conditions.

Trepospira.-- Trepospira has generated less comment and less disagreement. Petty (1975) placed it in an intermediate depth range; Senich (1978) felt that its distribution was similar to that of Glabrocingulum.

Reasonably identifiable Trepospira appeared in four Iowa samples of this study, and as surface specimens collected at Copan, Oklahoma (Locality Cp1). Two samples were from just below the black fissile Stark Shale in fairly diverse faunules (Localities DC1 and DeC1), and two were from the Vilas Shale at Bedford (Locality Be1). Depending on the interpreted depth of Vilas deposition, an intermediate depth is reasonable, but the facies restriction seems unlikely.

Worthenia and Hypselentoma.-- Worthenia and Hypselentoma are morphologically similar, but differ from each other principally in the greater ornamentation of Worthenia. Without ideal preservation, it is difficult to distinguish the two, but there are probably environmental distinctions.

Disagreement stalks Worthenia, but not the less frequently observed Hypselentoma. Sloan (1955) stated that Worthenia was restricted to intermediate depths; Petty (1975) thought that it lived in shallow water, and Senich (1978) restricted it to the grey core

shale in the terrigenous clastic facies. Newell (1933) observed Hypselentoma in the Vilas in eastern Kansas; Senich (1978) found it only in a quartzarenite.

In the samples studied, Worthenia appeared only as a surface grab specimen at Copan, and in a diversely fossiliferous shale at the top of the Spring Hill Limestone in the core at Bedford, Iowa. Hypselentoma occurred once in the coaly lower grey Stark Shale at Decatur City, Iowa (Locality DeCl) with little else but myalinids, and twice in the Vilas shale near Altoona, Kansas. One of the Kansas occurrences was in a continuous horizon of large (to several centimeters) limy "biscuits" in non-calcareous, coaly shale. The horizon was crowded with Hypselentoma, a few pelecypod fragments, and geisinid ostracodes. It appears to be an opportunistic outburst by Hypselentoma when a temporarily abandoned delta was the site of abundant algal growth. Hypselentoma apparently occurs in simple, nearshore faunas, while Worthenia is found in more diverse, more offshore faunas.

Bellerophontids.-- The bellerophontid gastropods appear to have a more discrete distribution than the other gastropods. Among the various bellerophontids, Sloan (1955) assigned Euphemites to relatively deep water, while stating that Bellerophon (Pharkidonotus) was a eurytopic minor form. Calver (1968) assigned bellerophontids to a biofacies just onshore of that characterized by productids, chonetids, and crinoids. Senich (1978) thought that Euphemites was restricted to the grey core shale of the Eudora in the terrigenous clastic facies,

but also correlated bellerophontids to the basal middle limestones, where they were most abundant. MacLeod (1982) also recognized that bellerophontid-rich faunas were distinct from those with an abundance of other gastropods.

The data collected agrees with these observations. Both individual taxa and steinkerns of bellerophontids are comparatively restricted to the most diverse faunas, centered around the limestones.

General Observations

Gastropods occurred more frequently than might have been expected, which argues against much diagenetic loss. However, relatively useful specimens were restricted to the areas where the rate of deposition was high and preservation good. It was surprising that gastropods were more likely to be associated with calcitic animals (articulate brachiopods, bryozoans, and pelmatozoans) than with pelecypods or inarticulate brachiopods. In general, it would appear that gastropods were relatively eurytopic. Many were probably grazers (Tucker, 1976a), and tended to be associated with algae (Payton, 1966; Carew, 1978), but carnivorous forms were probably also present: some had shell shapes that suggested a carnivorous habit (Carew, 1978), and there are some borings in brachiopods that suggest such activity. The grazers would be most abundant in the photic zone, with the predators and scavengers more eurytopic. This would suggest bellerophontids were grazers, an interpretation supported by shell morphology (Signor, 1981); other shell shapes are less related to environment and so less restricted to facies.

## Pelecypods

In the sediments studied, pelecypods are preserved: (1) as calcite mold fillings (usually in grey shales, with or without siderite); (2) as apatite steinkerns; (3) as simple molds; or (4) as original material, particularly myalinids, which have a heavy outer ostracum of prismatic calcite. Such a variety of preservational modes can greatly influence the observed distribution of pelecypods in the cyclothems.

### Empirical Data

Fossil pelecypods are considerably less common in the Missourian sediments than are gastropods. Pelecypods were found in 70 (about 30 percent) of the 230 fossiliferous shale samples.

Pelecypods as a group have distinctive co-occurrences. They do not occur often in the core shale, or in association with fossils that characterize it. For example, pelecypods were found with Gondolella only twice, but occurred with Adetognathus 27 times, or nearly 40 percent of the pelecypod occurrences. They occurred less often (by 30 percent) with Anchignathodus. With respect to foraminifers, Ammodiscus and Tolypammina occurred with pelecypods less frequently than they did with the calcitic groups (articulate brachiopods, bryozoans, and echinoderms), but Hyperammina and Ammovertella co-occur at similar rates in pelecypod and calcitic faunas. Among ostracodes, pelecypods also show a marked trend, occurring with Cavellina over half the time, and occurring more often with geisinids (30 percent) than with Amphissites (20 percent). Pelecypods do occur often with calcitic

forms, about 60 percent of the time each with bryozoans, articulate brachiopods, and pelmatozoans. Nearly 80 percent of pelecypod occurrences also include gastropods, and phosphatic inarticulate brachiopods co-occur nearly 40 percent of the time, a higher rate than with calcitic groups.

Pelecypods also have notable co-occurrence rates with detrital minerals, as over half the shale occurrences of pelecypods also contain muscovite and kaolinite.

Nuculids were found in nearly 10 percent of the fossil-bearing shales, and present co-occurrence patterns somewhat more extreme than those of pelecypods in general. Nuculids were never found with Gondolella, and nearly half the time were accompanied by Adetognathus (a higher rate than with idiognathodids). Nuculids occurred slightly more often with all the major forams than did pelecypods in general. With ostracodes, they presented an odd pattern: they occurred with both Amphissites and geisinids about 15 percent less frequently than the pelecypod average, but 30 percent more often with each Hollinella, Bairdia, and Cavellina. The nuculids reflected the average pelecypod in occurrence with bryozoans and pelmatozoans, but occurred somewhat less often with brachiopods and more often with gastropods. Nuculids also are found more often in kaolinitic and/or muscovitic shales than is the average pelecypod.

Myalinids were found in 11 fossiliferous shale samples, or about 5 percent of those examined. They also did not co-occur with Gondolella, while about half the time Adetognathus was found with them. Among the foraminifers, Tolypammina accompanied them 80 percent of the

time and Hyperammina did so 35 percent of the time, but the rest were relatively uncommon. Among the ostracodes, myalinids occurred most often with geisinids (in 60 percent of their occurrences); with Cavellina and Bairdia 45 percent of the time, and only 30 percent of the time with Amphissites. Myalinids occur often with other groups; with gastropods and articulate brachiopods, 80 percent of the time, with inarticulate brachiopods and bryozoans 70 percent of the time, with pelmatozoans 60 percent of the time, and with trilobites nearly 40 percent of the time. Myalinids are found less often (only 45 percent of the time) in shales with kaolinite and muscovite than the average pelecypod.

Interpretations

Paleotaxodonts.-- The paleotaxodont pelecypods were the most common identifiable forms found in the sediments studied; Hoare and others (1979) found them to be the commonest Upper Pennsylvanian group. Most of the specimens were nuculids, and were usually found as small calcite mold fillings which preserved external ornamentation and occasionally dentition. In other cases, apatite steinkerns were preserved which showed taxodont dentition and an outline generally like that of Nuculopsis; since these were not distinguished in co-occurring similar preservational modes, it is possible these are simply differently preserved specimens of one genus.

Nuculids have a morphology suggesting an infaunal habit, but apparently were slow burrowers, as they are poorly streamlined (Kauffman, 1969). They generally show a strong tendency to occur with

those animals that are characteristic of shallow water. They also show a marked tendency to occur in thick clastic units, characterized by muscovite and kaolinite. Because nuculids clearly occur in rapidly accumulating units, where preservation is favorable, it is not known whether they were restricted to that environment, or occurred elsewhere and are not preserved.

The same may be true of the other paleotaxodonts. Paleyoldia, Phestia, and Paleoneilo were found in the grey Eudora Shale at Copan, Oklahoma (Locality Cp1), where they were favorably preserved by siderite filling and calcite replacement. Senich (1978) noted similar occurrences in the area. Notably, the faunas are similar to those reported from the Appalachian Basin (Lintz, 1958; Hoare et al., 1979). Here, it may be reasonable to assume these pelecypods were originally restricted to the environment they are now found in; unlike nuculids, they appear to be rapid burrowers, with a compressed, streamlined shape (Stanley, 1970), and thus more compatible with an area of rapid deposition. However, they may have been simply migratory deposit feeders, as many of the co-occurring faunal elements are less clearly adapted to a turbid environment with rapid deposition; in any case, rapid deposition may have been only episodic, and not a continuous control.

Byers (1977) and Morris (1979) suggested that the infauna of restricted dysaerobic muds may be dominated by protobranch pelecypods (which includes the paleotaxodonts). This could be compatible with the shales in which the paleotaxodonts are common, but more evidence is necessary to eliminate other possiblities.

Mytilids.-- Mytilids were represented by two occurrences of Modiolus in northeastern Oklahoma. One was a small individual recovered from the grey Eudora Shale at Copan, while the other was a collection of molds in a fine-grained sandstone from the top of the Coffeyville Formation at Ramona (Locality Ral), where it was accompanied by Aviculopecten. In notable contrast to these occurrences, Hoare and others (1979) stated that mytilids are usually found in dark limestones.

Kauffman (1969) stated that Modiolus was streamlined for life in a high-energy environment in shallow water, either completely exposed to currents or somewhat countersunk in a small depression.

Myalinids.-- Myalinids have robust shells largely of prismatic calcite, and thus are less likely to be destroyed by diagenetic processes.

There is little argument regarding the characteristic environment of Myalina and its subgeneric form, M. (Orthomyalina). Newell (1942) observed that myalinids lived in shallow, nearshore environments similar to those inhabited by related mytilids today. He also noted that some myalinid beds are traceable for over 100 miles. Myalinids in general and Orthomyalina in particular are often the first fossils appearing at the base of a transgressive sequence: Toomey and others (1977) noted them above an unconformity in New Mexico, accompanied by Spirorbis, charophytes, and ostracodes; Searight and Howe (1961) observed persistent myalinid beds at the base of the Merriam Limestone

(Plattsburg cyclothem), and Hakes (1976) noted similar layers ("plasters") at the base of the South Bend Limestone. They also occur at the tops of cyclothems: Welp and others (1957) found abundant Myalina in the top of the Bethany Falls in Iowa, while Rollins and others (1979) stated that Orthomyalina produced "banks" like oyster banks during late regressive stages. The pattern is marked enough that Calver (1968) used myalinids as an indicator in cyclothems; except for lingulid brachiopods, it was the shallowest water macroinvertebrate.

This distribution is supported by both statistical distribution and field observation. Myalinids occur consistently with those fossils associated with shallow conditions (e.g., Adetognathus, geisinids). A curious detail is the comparatively high co-occurrence of typically stenohaline calcitic forms, such as articulate brachiopods, bryozoans, and pelmatozoans. However, they are not common, and may be reaching the limits of their environmental ranges. Another feature is the low co-occurrence of myalinids with clastic minerals, which is surprising for a nearshore form. It may be that myalinids also lived in relatively clear water, away from active deltaic areas.

Nevertheless, while the vast bulk of them did live under such conditions, there were apparently a few exceptions. Sloan (1955) stated that Myalina was eurybathic, and Senich (1978) stated that Septimyalina was ubiquitous and eurytopic. Hoare and others (1979) stated that Myalina and Septimyalina usually occur together in limestones. Septimyalina was found during this study in the grey Eudora Shale at Copan.

The apparent answer is that Myalina occurs in abundance in shallow water, but is not persistent vertically. Septimyalina, on the other hand, is much more eurytopic, but unlikely to form a significant portion of the rock. (A possible alternative is that myalinids are eurytopic, but are usually out-competed except under extreme shallow-water conditions.)

Myalinids seem to be analogous to modern oysters in a number of ways. Mudge and Yochelson (1962) added an interesting ecological footnote: myalinids in shales have thicker shells and are more frequently bored than those in limestone. The first feature coincides nicely with an oyster analog. Since the shales in question are outside shales, they presumably are generally closer to shore than the limestones, and thus were subject to greater salinity variations. Like modern oysters, myalinids may have acquired thicker shells to insulate them from brackish conditions. The amount of boring would reflect a lower rate of deposition, and would be consistent with myalinids not living in active deltaic areas.

Pteriids.-- Pteriids, represented by several specimens of Leptodesma, were recovered from the grey Eudora Shale at Copan, Oklahoma (Locality Cp1). This is compatible with the observations of Hoare and others (1979), who noted that it sometimes occurs in dark shale, although limestone is typical.

Pectinids.-- Although one of the most common Upper Pennsylvanian pelecypod groups (Mudge and Yochelson, 1962), pectinids were uncommon in the Missourian sediments examined here. The only probable

pectinids were molds of Aviculopecten found in fine-grained sandstone at the top of the Coffeyville at Ramona, Oklahoma (Locality Ra1), where they were accompanied by Modiolus and other pelecypods. A small, poorly preserved specimen, possibly of Euchondria, was found in the top of the Coffeyville Formation at Coffeyville, Kansas (Locality CB2). Acanthopecten may be represented by a rather poor impression in the reef rock at Ramona, Oklahoma (Locality Ra2).

Little can be said about the significance of pectinid distribution solely on the basis of these occurrences, but in light of the importance often attributed to them in the environmental interpretation of the cyclothems, more discussion is appropriate.

Aviculopecten appears to be a shallow water, nearshore form, which would conform with its sole occurrence here. Elias (1937) noted that its distribution appeared to extend into shallower water than most pectinids, as it often was found with only inarticulate brachiopods. Newell (1937) stated that it was most common in argillaceous limestones, but was occasionally found in sandy, shaly beds or in oölite. Mudge and Yochelson (1962) verified this, stating that it was most common in argillaceous sediments. Hakes (1976) added that Aviculopecten was found in the basal beds of the South Bend Limestone, along with Orthomyalina; a similar occurrence was reported from the sandy top of the Bonner Springs Shale by Gentile (1969). Kauffman (1969) stated that Aviculopecten was a byssate, free-swinging, hydrodynamically streamlined form, which would adapt it for turbulent shallow water. This would correspond well to its occurrence with the similarly adapted Modiolus.

The environmental significance of Dunbarella may depend on whether it was motile or sessile. Dunbarella, like most Upper Pennsylvanian pectinids, was possibly byssate (Hoare et al., 1979). Dunbarella lacks the auricular symmetry that Stanley (1970) stated was a characteristic of swimming pelecypods. However, Weller (1957) suggested that it could possibly be epiplanktonic; and Kauffman (1969) stated that most pectinids are byssate only during their juvenile stage, becoming free-swimming adults.

Newell (1937) observed that Dunbarella (and Euchondria) normally occur in black fissile shale or black limestone, occasionally in grey shale, but never in argillaceous or pure limestone or oölite. Dunbarella is quite common in the black shales of the Midcontinent, the Illinois Basin, and the Appalachian Basin, where it often occurs in great numbers in thin horizons.

Zangerl and Richardson (1963) found Dunbarella only in the basal horizon of the fissile black Mecca Quarry Shale. Zangerl (1980) later stated that this stenohaline form was subjected to mass mortality by freshening of the seawater during later black shale deposition, thus tying its occurrence to the brackish, nearshore depositional model of black shale deposition. In contrast, Calver (1968) stated that Dunbarella was characteristic of the portion of the cyclothem deposited in deepest water, typically a black shale with only cephalopods, conodonts and fish. However, he noted that Dunbarella's range might extend landward to nearly the environment of Myalina.

On the basis of its typical episodic distribution, Hickey and Younker (1981) concluded that Dunbarella was probably opportunistic.

Two models for this currently exist. (1) Clark (1978) worked with Dunbarella in plant-rich grey shales, where it occurred on "varve" surfaces. He interpreted Dunbarella as a seasonally opportunistic byssate scallop, attached to floating vegetation. He drew a parallel with the modern byssate Leptopecten latiauratus, which colonizes in enormous numbers and matures in a few months. (2) Sen Gupta and others (1981) described a modern area of coastal upwelling off the east coast of Florida, where organic-rich sediments contain only a few opportunistic benthic foraminifers with large numbers of calico scallops, which live on periodic algal blooms.

The opportunistic nature of Dunbarella may explain why it was not present in the shales studied; opportunism is a threshold phenomenon, and here the threshold was not reached. Opportunism would also reinforce the concept that the black shale environment was episodically unstable, or at least some portion of the water column above it was. This would agree with similar observations made elsewhere, particularly in respect to Crurithyris.

Veneroids.-- Astartella is widely reported, especially from those basins where deposition is rapid enough to favor good preservation. Carew (1978) stated that Astartella was the most abundant and ubiquitous pelecypod in the Upper Pennsylvanian of north-central Texas.

Astartella was found only in three localities in this study. It was well-preserved and abundant in the grey Eudora Shale at Copan, Oklahoma (Locality Cp1), but rather poorly preserved, with much

adhering material, in the top of the Coffeyville Formation near Coffeyville, Kansas

According to Hoare and others (1979), Astartella occurs most often in black shales, less often in dark limestone, and infrequently in light limestones and shales. Sloan (1955) stated that it was ubiquitous, but most abundant in shallow water deposits. Astartella was probably a feeble burrower, as adult forms tend to be nearly globose, and they are heavily ornamented with thick concentric growth lines, both of which inhibit burrowing (Stanley, 1970). Kauffman (1969) suggested that such a morphology could be consistent with either a feebly burrowing infaunal form or a free-living epifaunal form, with heavy ribbing to protect it from abrasion if rolled. This could be interpreted to indicate the environment was not subject to much clastic influx that would bury Astartella. Curiously, Astartella is found at Copan with such rapid-burrowing forms as Paleyoldia and Phestia, an association also reported by MacLeod (1982) in his study of a prodeltaic shale in Texas. But the other forms present (numerous brachiopods, bryozoans, and echinoderms), suggest that deposition was not remarkably fast, and the rapid burrowers were adapted for migratory deposit feeding, rather than unburying themselves.

Cypricardella was tentatively identified from small silicified specimens in poorly fossiliferous massive calcilutite at the top of the Bethany Falls at Jingo, Kansas (Locality Ji1) and Davis City, Iowa (Locality DC1). It is possible that they represent part of a restricted fauna living in shallow subtidal or intertidal carbonate muds.

Pholadomyoids.-- Edmondia was the only member of this group seen during this study, only in the Stoner calcarenite of the Altoona channel. Its significance has been discussed previously.

General Observations

Elias (1937) placed a pelecypod-dominated biofacies onshore from his articulate brachiopod-dominated biofacies in Lower Permian cyclothems. He also noted an inarticulate brachiopod facies even more landward, but recognized overlap among all these facies. Hoare and others (1979) cited the same general pattern. Many specific examples exist where this pattern has been applied. The data collected here seem to support this, although the reason for such a distribution is not clear.

The pattern could simply be a product of preservation. The pelecypods would be more likely to be preserved in a nearshore setting where deposition was more rapid, or it could be that they were more suited for such an environment. Hoare and others (1979) stated that few pelecypods were found with epibionts: they rarely had encrusting forams or Crania, and had no bryozoan encrustations or barnacle borings. Since these are more common on articulate brachiopods, it could indicate pelecypods were buried rapidly after death (including such weak or non-burrowing forms as Astartella and the myalinids) or simply that most pelecypods spent more time buried in mud than many brachiopods. The different distributions of gastropods and pelecypods suggest that gastropods would be preferentially preserved over

pelecypods, but characteristics of both groups and diagenesis do not permit ready evaluation.

Other factors probably have some influence on this general pattern. Dodin (1974) stated that molluscs tend to be more diverse and abundant close to shore (his "molluscan reversal"). He noted that infaunal forms tend to be larger closer to shore, as increased size permits them to burrow faster; while epifaunal forms are smaller nearshore, where small size and early maturation are desirable in view of stress conditions. Note that larger infauna closer to shore could produce a greater likelihood of preservation of those forms close to shore, whereas epifaunal offshore forms might be lost. But there are exceptions to the generalization, as myalinids are large, nearshore epifaunal forms.

Purdy (1964) noted an inverse relationship between organic matter in the sediment and deposit-feeding pelecypods, due to a loss of oxygen and an increase of toxic products. This would serve to limit such pelecypods (and most other infauna) in sediments deposited under dark-grey or black-shale conditions.

Broadhead (1976) worked with a similar Upper Mississippian pelecypod-rich fauna, which included Phestia and Aviculopecten, as well as some productids and spiriferids. He suggested that freshwater influx may have limited most stenohaline forms; alternately, soft substrate may have limited larval development of the calcitic forms.

It seems, for whatever reason, that Upper Pennsylvanian pelecypods are preferentially found in particular environments. However, automatically restricting them to the environments in which they are

preserved, or lumping all their occurrences into one environment, is ill-advised. Stanley made a pertinent observation:

> Most bivalve species show tolerances for more than a single type of habitat and exhibit some variation in mode of life.
>
> - Stanley, 1970, p. 6.

Cephalopods

Cephalopods suffer from the same theoretical preservational problems as do the other molluscs. However, since cephalopods are probably nektic predators, presumably they should be widely distributed, and only indirectly (through their prey) be controlled by bottom conditions. Thus, their distribution should serve as a partial measure of the problem of preservation versus original distribution in molluscs. The cephalopods, however, are really too sparse to give much more than a suggestion. Preservation is much like that with the other molluscs: siderite and calcite molds and casts in the terrigenous detrital facies, pyrite and apatite steinkerns elsewhere, and in some cases, molds in limestone, especially oölite.

Empirical Data

Small cephalopods were recovered from many washed residues, plus a number of localities produced specimens grab-collected on outcrop. Of the washed shale samples, 12 (just over 5 percent) of the 230 samples produced confirmed cephalopods.

The co-occurrence pattern of cephalopods does not indicate any marked faunal relationships; all are essentially independent and randomly distributed. For example, with the conodonts, cephalopods

were found with Gondolella twice and Adetognathus three times. Every cephalopod occurrence in shale was accompanied by idiognathodids. Ostracodes were similar, with three occurrences with Amphissites and two with Geisina. With foraminifers, some pattern was shown: cephalopods were accompanied by Hippocrepina three times (for 25 percent), a higher percentage occurrence with Hippocrepina than any other fossil except Ammodiscus, Orbiculoidea, or siliceous sponge spicule B. Cephalopods also occurred with Ammodiscus 7 times, or nearly 60 percent of the time. Cephalopods occurred with articulate brachiopods, bryozoans, and pelmatozoans in between 80 and 90 percent of their sample time, but in only half of them with pelecypods, and in a quarter of them with inarticulate brachiopods and trilobites. No fossil is accompanied by cephalopods in more than 20 percent of that fossil's occurrences. Cephalopod distribution is random with respect to muscovite and kaolinite, and so is not related to clastic influx.

Interpretations

Eoasianites.-- Eoasianites was by far the most common cephalopod found in the Missourian sediments examined. It was found at 9 localities in 11 different horizons; several of these were found only as grab samples (Fig. 65).

Senich (1978) stated that Eoasianites, with rare exceptions, was found only in the terrigenous detrital facies belt, and in the core grey Eudora Shale and adjacent beds. He felt that Eoasianites was controlled by depophase within the cyclothem.

Due to the common occurrences of cephalopods, including Eoasianites, in the southern terrigenous detrital facies, it is easy to reach this conclusion. However, when other occurrences are added in, the generalizations become shaky. Only about half of the Eoasianites occurrences in this study come from the southern terrigenous detrital facies, and less than half come from the core shale. The other occurrences are either steinkerns or molds from oölite. Thus, common occurrence of Eoasianites would seem to be largely a matter of favorable preservation in areas of rapid deposition.

Pseudorthocerids.-- Pseudorthocerids, especially Pseudorthoceras, are the commonest orthoconic nautiloids in Pennsylvanian strata, both reported in the general literature and recognized in the samples studied here. Four localities produced pseudorthocerids, three in southeastern Kansas and one in adjacent Oklahoma (Fig. 65). However, here, as with Eoasianites, the data is insufficient for generalizations.

Bactritoids.-- In addition to occurring in the Eudora Shale at Tyro, Kansas (Locality Ty1, with bactritoids described by Mapes, 1977), a probable pyritized immature bactritoid was recovered from the basal grey shale of the Eudora at Lewis, Iowa (Locality Le1).

Soleniscus.-- A large specimen of Soleniscus, oriented with its plane of symmetry vertical, was recovered from the top of the Bethany Falls oölite at Canville Creek (Locality Ca1), near Stark, Kansas. According to Raup (1973), the orientation of the Soleniscus would indicate it died less than 10 meters above the bottom; this would be

compatible with a shallow-water environment, although the cephalopod may not have been close to surface when it died. The cephalopod was accompanied in the rock by myalinids.

General Observations

Cephalopod distribution does not link readily with many things. In general, they seem to follow a distribution that would be expected of nektic predators, especially if modified by diagenesis. They clearly occur outside the terrigenous clastic belt often enough to demonstrate that they are not restricted to it. There is some possibility that cephalopods are more common toward the core of the cyclothem, which could be due to a genuine correlation (that they preferred that environment) or simply to a greater water column containing a greater number of cephalopods.

Zangerl and Richardson (1963) stated that cephalopods were euryhaline, based on their occurrence in fissile black shales that they had interpreted as being deposited in fresh or brackish water. If this interpretation is rejected, the distribution of cephalopods becomes more consistent with usual patterns.

Cephalopods do not provide a ready answer to the question of possible molluscan skewing by diagenesis, but make it more obvious. The same taxa are generally widespread, but numbers and preservation are much superior where detrital influx helps preserve them. Cephalopods do occur outside that area, but how they relate to original distribution and numbers cannot be determined.

In any event, this study did point out where and how to look for cephalopods. Obviously, rapidly accumulating open marine detrital facies, especially those that are sideritic, are good; oölites are also good places to look for molds; and many other sediments stand some chance of producing pyritized or phosphatized microcephalopods, although rarely in quantity.

## Minor Molluscan Groups

Several minor groups of molluscs often reported in Upper Pennsylvanian sediments were recovered during this study.

### Scaphopods

Scaphopods are frequently observed in Upper Pennsylvanian sediments (e.g., Watkins, 1973; Donahue and Rollins, 1974; Petty, 1975). Senich (1978) stated they were restricted to the Eudora in the terrigenous clastic facies. MacLeod (1982) reported them from the Missourian Wolf Mountain Shale of Texas, where they commonly accompanied mollusc-dominated faunas, although they also occurred in productid-dominated faunas.

Six localities in this study produced specimens that could be assigned to Plagioglypta with varying degrees of certainty. Most were tapered shells, with inclined annular rings, characteristic of the genus. Two of the localities were replaced material found in limestones, and the others were from three outside and one core shales. Two were from Oklahoma, two from Kansas, one from Iowa, and one from Illinois. Plagioglypta probably suffers from the same problem found with the other molluscs, that of spotty preservation.

Rostroconchs

Rostroconchs also have been widely reported across the continent in Upper Pennsylvanian strata (Griffin, 1931; Petty, 1975; Carew, 1978). Hoare and others (1979) and Bonem (1981) labelled them as active deposit feeders, found in somewhat silty light brown to dark grey shales. This conforms well with Senich's (1978) statement that they, too, were confined to the grey core Eudora Shale in the terrigenous clastic belt, probably by substrate conditions. Fragments of rostroconchs were collected only from the Eudora at Copan, Oklahoma, in this study, which agrees well with previous statements and interpretations.

Hyolithids

Hyolithids were recovered only from the grey Eudora Shale at Copan, Oklahoma (Locality Cp1). Little is known about the environmental controls of these animals at this time.

## Sponges

Sponges were moderately common in the fossiliferous shales studied, being found in 26 (about 11 percent) of the 230 shale samples. Most were spicules of various kinds; few whole sponges were recovered.

Empirical Data

Sponges as a group exhibit few extremes. Although they occasionally occur with fossils characteristic of extreme environment

(e.g., the black shale), they are usually found with the median (limestone) elements.

For example, sponges occur with both Gondolella (in 27 percent of their samples) and Adetognathus (15 percent), but not exceptionally often with either. Among foraminifers, sponges occur often with Ammodiscus and Tolypammina, largely because those forams occur in a number of environments. Sponges also display some positive association with Hyperammina, Ammovertella, and Textularia. Among ostracodes, sponges occur particularly often with Amphissites and Bairdia, with the others are far less often.

Sponges occur regularly with the major megafossils. They occur with articulate brachiopods in almost 90 percent of their samples, especially with Punctospirifer and Hustedia. Sponges are always accompanied by bryozoans, by pelmatozoans in 85 percent of their samples, by gastropods in three-quarters of them, by pelecypods in 30 percent of them, by inarticulate brachiopods and trilobites in a quarter of them, and by corals in one-eighth of them.

Sponges show a surprising association with terrigenous clastics. Over 60 percent of sponge specimens were found in shales rich in muscovite, and over three-quarters were in shale containing kaolinite.

Several individual sponge taxa were recognizable. Wewokellid calcisponges were identified from spicules in 15 shales, or nearly 60 percent of the samples in which sponge material was found.

The co-occurrence pattern of the wewokellids was generally similar to that of sponges as a group. However, all major conodonts occurred with them less frequently. Among the forams, Tolypammina,

Hyperammina, Ammovertella, and Textularia occurred more often than with sponges in general; Ammodiscus was less frequent. Among the ostracodes, Amphissites occurred with the wewokellids more than twice as often as Hollinella, Cavellina, or Geisina; Bairdia co-occurred four times as frequently as those three. Wewokellid occurrence with macrofossils is similar to the general pattern of sponges, but with slightly higher co-occurrence frequencies. The major exception is that of inarticulate brachiopods, which occur with wewokellids about half as often as with sponges as a group.

Wewokellids, like sponges as a group, are found in muscovitic sediments in about half of their occurrences, and in shales containing kaolinite in about 95 percent of them.

Interpretations

Hyalosponges will be discussed separately because calcisponges and demosponges compose most of the evidence of sponges, and consequently obscure the information from the hyalosponges.

The wewokellid spicules resemble those illustrated by Croneis and Toomey (1965; plate 5, fig. 8 - 11), and the general characteristics of the assemblage in which they occur are the same. Croneis and Toomey found their wewokellids in a grey shale, with the agglutinated forams Hyperammina and Textularia; and a diverse ostracode fauna with Amphissites and Bairdia the common forms. These trends are parallelled in the fauna studied here.

MacLeod (1981, 1982) also found a similar calcisponge community, localized and possibly restricted to a delta top. Along with the

sponges were bryozoans, articulate brachiopods (including Crurithyris and Punctospirifer), large echinoderms, and rugose corals.

The overall aspects of the sponge patterns indicate a relatively offshore position, but one with a substantial amount of terrigenous clastic material. Conodonts do not indicate a trend toward a particular environment, but are generally depleted in number, as though by clastic dilution. Associations with the agglutinated forams are not definitive, but generally favor encrusting forms. The ostracode association clearly favors the coreward portion of that sequence, with Amphissites and Bairdia much in evidence. All the major calcitic groups are well-represented (even corals and trilobites are relatively common); the presence of Punctospirifer and Hustedia is characteristic. Gastropods are also well-represented; only pelecypods and inarticulate brachiopods are not particularly enriched in the fauna.

The high occurrence with detrital minerals would be compatible with MacLeod's (1981, 1982) association of calcisponges with submerging deltas. However, another possibility is that calcisponges are provincial, as they occur predominantly in or near the terrigenous clastic facies, and in many different positions in the cyclothem. Finally, they also occur in an area where Midcontinent faunal gradients tend to peak, and in shales enriched in a broad diversity of elements. Thus, principal occurrence of calcisponges in the terrigenous clastic belt would match the recognized evidence. The sponges would be controlled by clastic influx, or, more likely, by proximity to the stabilizing influence of the open ocean.

In addition to the wewokellid spicules, a pair of sponge genera was observed in the shale. Girtyocoelia was only found in the lower Eudora Shale at Tyro, Kansas (Locality Ty1), where its presence is consistent with Senich's (1978) observation that it occurs in the cyclothem during the late transgressive phase (just before the black shale).

Specimens assigned to the demosponge (?) Coelocladia were found in five locations in relatively similar horizons: grey core shales, including those expanded by clastics, and shale partings in the limestones just above the core shales. Gundrum (1980) reported Coelocladia in the base of the Bethany Falls in north-central Missouri. She interpreted the environment as one of low energy and deposition, but normal salinity. She also noted that the sponges needed a solid substrate--in this case, probably productids or algal blades, since the bottom gives evidence of being soft. Tall, slender sponges (such as Coelocladia are well adapted for such an environment.

Hyalosponges have a different distribution. Two types were distinctive enough to recognize consistently. Spicule A is a small hexacton with secondary spikelets on the axes. It was found in seven samples, all from limestones. Most of these were from the Captain Creek and Stoner, but one was from the basal Winterset. Areally, the occurrences were in Iowa, Missouri, and east-central Kansas.

Spicule B is a robust, simple hexacton, often accompanied by similar monaxons. It was found in six localities, usually in the basal Winterset Limestone or adjacent beds, although one locality is from the top of the Eudora Shale. Areally, these are distributed from Oklahoma

to Iowa. Spicule B was not found frequently, but could be abundant when it appeared.

In four of its occurrences, Spicule B is accompanied by Ammodiscus. Of its two occurrences in grey shales, it is accompanied in both by Bairdia and Punctospirifer. Amphissites is the only other ostracode known to occur with it. Hustedia also co-occurs once, as do wewokellid sponge spicules. Thus, on sparse evidence, there is a suggestion that the "sponge" association may extend beyond calcisponges, or that calcisponges overlap with hyalosponges.

Hyalosponge distribution may be tied to local silicification in the limestones. This is particularly evident at Canville Creek (Locality Cal), near Stark, Kansas, where the basal bed of the Winterset Limestone is almost completely silicified, and the adjacent beds produce large numbers of Spicule B. Spicule B is frequently found in the base of the Winterset, a unit notable for its abundance of chert and silicified fossils. This may extend to such silicification throughout the Missourian cyclothems. Wenberg (1941) noted that some chert in the Upper Pennsylvanian graded into bundles of sponge spicules; he also noted siliceous spicules (mostly monaxons, with some hexactons) in the Winterset. Price (1977) noted brachiopod silicification in the Winterset, and Mossler (1970) noted similar silicification in the base of the Bethany Falls. Berner (1971) backed the general principle, noting that much of the silica in carbonate rocks and chert probably came from siliceous sponge spicules, producing local shell silicification and nodule formation. Spicule B especially seems to be locally abundant enough to easily provide such a silica source,

and its apparent affinity for the basal beds of the upper limestone correspond well to the apparent frequency of silicified fossil material there. It may also be significant that Berendsen and Nodine-Zeller (1978) noted that some apatite nodules in the black shale and the black shale itself contain possible sponge material.

If certain hypotheses are accepted, sponge distribution in Missourian sediments shows a remarkable correlation with the general characteristics of sponge distribution as summarized by de Laubenfels (1957):

(1) Sponges require protection from burial or smothering; thus, they live in fairly clear water with suitable attachment sites; nearly all of them require a solid substrate.

(2) Sponges prefer moving water, but not excessive current; ones in strong current regimes are encrusting and small.

(3) Most sponge species have narrow salinity and temperature tolerances.

(4) Calcisponges live only in completely marine waters.

(5) Calcisponges live principally in shallow water, and are abundant at less than 10 meters; hyalosponges are found only in deep, cold water.

(6) Ideal conditions for sponge growth would be a limited amount of land drainage into a fairly shallow, enclosed area of moderate current activity.

This corresponds well to the general depositional patterns postulated. Calcisponges show evidence of being more common in the southern

terrigenous clastic belt where evidence of current activity is more apparent and where salinity may have been more stable, as well as possibly having some land-derived nutrients available. The distribution of calcisponges in the limestones and outside shales, with hyalosponges associated with the core shales is compatible with the idea that the outside shales were deposited in warm, shallow waters, while the core shales were formed in deep, cold environments. In Pennsylvanian sediments, many occurrences of siliceous spiculites have been found in relatively deep water (with the assignment of water depth based on other criteria). For example, Carothers (1979) noted the Cambridge Limestone of Ohio was spiculitic off the delta lobes that prograded into it. Becker (1978) found spiculites in the most offshore portion of the cyclothems of the Mintum Formation of Colorado. Sponge spicules are often found with radiolarians in black core shales (e.g., Holdsworth, 1966; Berendsen and Nodine-Zeller, 1978). This pattern of occurrence is compatible with Byers' (1977) observation that sponges are very tolerant of low oxygen conditions, and would be among the last sessile benthos to disappear with decreasing oxygen. Thus, sponge occurrences in the cyclothems are consistent with expected patterns, but are not diagnostic themselves.

## Trilobites

Trilobites are surprisingly common in the fossiliferous shales, as trilobite debris was found in 30 (13 percent) of the 230 samples examined.

Empirical Data

Among the major conodonts, trilobites were more frequently found with Adetognathus (a third of their occurrences) than with Gondolella (13 percent). Almost all ostracodes occurred with trilobites rather frequently. Amphissites, Hollinella, and Cavellina each occurred in more than half of the trilobite-bearing samples, and Bairdia co-occurred in 70 percent. Even Kirkbya, found in a total of only 9 samples, occurred with trilobites 5 times. Geisinids and Knightina, however, were unexceptional in their co-occurrence frequencies.

Among the macrofossils, trilobites are accompanied by articulate brachiopods in 90 percent of their samples, and most of the brachiopod genera occur with trilobites quite frequently. Trilobites are also accompanied by bryozoans and pelmatozoans in over 90 percent of their samples, by gastropods in 60 percent of them, by pelecypods and phosphatic inarticulate brachiopods in half of them, and by sponges and corals in about 20 percent of them.

Trilobites occur with muscovite in half of their occurrences, and with kaolinite in 60 percent of them.

Interpretations

Very little has been said about the distribution of trilobites in Upper Pennsylvanian sediments. Mudge and Yochelson (1962) stated that trilobites composed only a minor portion of the fauna, and occurred principally in calcareous shales and shaly limestones. Fagerstrom (1964), working with a restricted association in the Bonner Springs

Shale, noted that cranidia far outnumbered complete free cheeks. Here, the reverse is true, as most of the trilobite evidence consists of free cheeks, with a few pygidia, thoracic segments, and hypostomes and no cranidia. Lipp (1975) suggested Ditomopyge was a burrowing, communal animal. However, the evidence here is that trilobites as a group had a distribution consistent with that of vagrant benthos, occurring relatively frequently with those animals that are common, but rarely in restricted environments. They are most common in faunas dominated by calcitic animals, but appear to range more toward the faunas characterized by pelecypods and phosphatic inarticulate brachiopods than is usual. Thus, they are found over a wide range, excluding only the extremes of the black shale environment and the very near shore environment.

The relatively frequent occurrence of trilobites with terrigenous clastics is reminiscent of that displayed by sponges, and their faunal co-occurrence pattern would suggest the possibility of a provincial restriction to the most diverse faunas in Oklahoma and southeastern Kansas. The faunule described by Pabian (1970) from the Virgilian Stull Shale of southeastern Nebraska contains a number of groups characteristically associated with trilobites (which it contains) and sponges (e.g., Punctospirifer, Hustedia, corals, and echinoids). However, trilobite reports show no tendency toward areal restriction, and the samples from Illinois were particularly productive of trilobite debris. In this case, the association with detrital influx may be simply due to an increased tendency to occur in a more onshore

position, or due to original distribution, with trilobites frequenting areas where land-derived nutrients were plentiful.

## Corals

Corals were the least abundant of the major groups in the fossiliferous shales, found in only 13 (about 6 percent) of the 230 samples.

### Empirical Data

Because of the low occurrence rate of corals in the shales, differences may only be a result of random chance, but significant correlations may be definable.

Although corals were found with Gondolella only once, and with Adetognathus twice, they were found with Anchignathodus 9 times (nearly 70 percent) which suggests a real correlation. In respect to ostracodes, corals were found with Bairdia in 60 percent of their samples, with Cavellina in 45 percent of them, with Hollinella and Amphissites in about 40 percent of them, but with geisinids only once. Corals occurred with articulate brachiopods 12 out of 13 times (over 90 percent), with most of the articulates having a fairly high rate of co-occurrence; chonetids are particularly high (in 85 percent of their samples), as is Punctospirifer (in three-quarters of their samples). Bryozoans also occur with corals in over 90 percent of their samples, and pelmatozoans in 85 percent of them. Gastropods co-occur in 70 percent of them, trilobites in over half of them, phosphatic inarticulate brachiopods in 40 percent of them, pelecypods in 30 percent of them, and sponges in 20 percent of them.

Oddly, corals occur with detrital minerals relatively often, with muscovite in over half their occurrences and kaolinite in 60 percent of them.

Interpretations

According to Mudge and Yochelson (1962) and Cocke and Mossler (1974) only non-dissepimental rugose corals are known from the shales in the cyclothems. These belong to three genera of corals of the family Lophophyllidiidae (Lophamplexus has no columnella; the ends of the septae in Lophophyllidium are enlarged, and not enlarged in Stereostylus). Dissepimental forms are reported only from the limestone members.

These corals apparently are adapted to life on an unstable substrate, repeatedly falling and growing up again, to produce a "cornucopia" shape; the weight distribution along the outer edge of the curve serves to further stabilize the animal on the substrate (Ziegler et al., 1968).

In addition to the lophophyllid corals, four occurrences of the small colonial tabulate Sutherlandia were found in the highly fossiliferous shale layers in the Winterset Limestone in southeastern Kansas and adjacent Oklahoma. These corals colonized local hard substrates (e.g., productid spines) protruding above the bottom.

In general, the lophophyllid corals seem to be relatively eurytopic and eurybathic (Sloan, 1955), but the other corals are restricted both areally and stratigraphically. Bebout (1966) reported that only Stereostylus is known from Missourian sediments in Ohio.

Farther to the west, more abundant and more diverse corals are found. Heckel (1968) noted that corals were rarer in Iowa limestones than to the south, and Cocke and Mossler (1974) added that they were generally smaller in Iowa. In the limestones, not only solitary dissepimental rugose corals, but also colonial tabulates appear. In the "reef talus" at Ramona, Oklahoma (Locality Ra2), Cronoble and Mankin (1965) noted that corals are abundant, the only place in the Winterset Limestone where they are. Strimple and Cocke (1973) reported four genera of colonial tabulates there. (The Winterset was apparently very favorable to coral growth, as Cocke and Mossler, 1974, noted that it had the most diverse coral fauna of any of the cyclothems in Iowa.) The other end of the sequence may possibly be in California, where Watkins (1973) reported Upper Pennsylvanian occurrences of the colonial rugosan Lithostrotion. Thus, like several other groups, corals probably became more diverse in the more stable environments closer to the straits connecting the Midcontinent seas to the open ocean. Clastic influx is not an influence in the overall distribution; as with the sponges, a tendency to occur where salinity conditions would be most stable is also a tendency to occur in the terrigenous clastic facies belt along the Ouachitas. (Lophophyllids also occur in Iowa and Nebraska where there was no clastic influx, as well as in Illinois, where there was.)

## Polychaete Worms

Evidence for polychaete worms comes from both scolecodonts in the sediment and Spirorbis worm tubes. Scolecodonts are fairly common,

occurring in 19 (8 percent) of 230 fossiliferous shale samples and in 13 (12 percent) of 110 limestone samples. Spirorbis are considerably less frequent, and were recovered from only 8 fossiliferous shale samples (3.5 percent).

Empirical Data

The co-occurrence data presented here is based only on the fossiliferous shale samples. For scolecodonts, adding the limestone samples raises the frequency of occurrence with conodonts slightly, and slightly lowers occurrence with foraminifers.

Scolecodonts occur fairly often with conodonts, especially the idiognathodids (in about 85 percent of the scolecodont occurrences). They occur more frequently with Adetognathus (about 30 percent) than with Gondolella (10 percent). Scolecodonts are accompanied by Tolypammina in 95 percent of their samples, but the other forams are not excessively frequent. Among the ostracodes, Amphissites, Hollinella, and Bairdia all co-occur in about 30 percent of their samples, Cavellina in nearly 60 percent of them, and geisinids in 15 percent of them.

Scolecodonts have an interesting occurrence pattern with megafossils: they are accompanied by articulate brachiopods in nearly 90 percent of their samples (usually with Crurithyris, which co-occurs in over 60 percent of them; with bryozoans and pelmatozoans in about three-fourths of them; with gastropods in 60 percent of them; pelecypods in 40 percent of them; and phosphatic inarticulate brachiopods in a quarter of them.

Spirorbis is much less common, and so its co-occurrence pattern is more ambiguous, but a few features stand out. It was never found with Gondolella, and only 3 times out of 8 with Adetognathus (for the highest frequency among conodonts, however). Among ostracodes, it occurs most often with geisinids (6 out of 8 occurrences) and never with Amphissites. Among the brachiopods, it occurs more than once only with Crurithyris and inarticulate brachiopods (3 times each). Spirorbis was accompanied in 5 samples by gastropods, in 4 by pelecypods, in 3 by bryozoans, and in 2 by pelmatozoans.

Both scolecodonts and Spirorbis show a similar relationship to terrigenous clastic minerals. They occur with muscovite about 15 percent of the time, and with kaolinite about 35 percent of the time.

## Interpretations

Polychaete worms seem to have preferred somewhat shallower waters (closer to the outside shales) but ones free from too much terrigenous clastic influx. The polychaetes represented by scolecodonts are widely distributed within those parameters.

However, Spirorbis is far more restricted. The specimens collected here were strongly associated with those fossils found in nearshore environments, and were relatively abundant in the horizons they occurred in, often the first marine beds in a cyclothem.

But Spirorbis may not be confined to such environments. Some workers (e.g., Gundrum, 1980) have observed Spirorbis attached to brachiopods and other substrates in marine limestones. Thus, it could be that Spirorbis is substrate-dependent. In the shallow sediments

studied, coaly fragments are abundant, some with Spirorbis attached. Thus, Spirorbis could be most abundant in shallow water, where such substrates are common, but also found in more offshore deposits, where occasional sites are found. But even with a common nearshore association, Spirorbis was infrequently found with terrigenous clastic minerals.

## Conularids

Conularids were found only in the grey Eudora Shale at Copan, Oklahoma (Locality Cp1) during the course of this study. This is in contrast to the frequent reporting of conularids from fissile black shale (Mitchell, 1981; Wilson, 1981). However, it is compatible with MacLeod's (1982) report of conularids in a mollusc-dominated fauna in a thick prodeltaic shale in Texas. It is possible that conularids are not particularly associated with core shales (as their reports would indicate), but are more easily observed there, and more frequently reported.

## Ichnofossils

Ichnofossils are fairly common in the sediments studied, and some occur in consistent patterns, but their significance and relation to the fauna is generally unknown.

The commonest type of ichnofossil encountered consists of cylindrical burrows 1 or 2 millimeters in diameter, in both shales and carbonates. They are variously and irregularly oriented, but the most frequently observed are essentially vertical, and often they are crenulated by compaction. Most are found above the black shale, with

light-colored clay filling them; these sometimes extend down to, but not into, the fissile black shale. In a few cases, similar burrows appear below the black shale, where they are filled by darker mud in a light-colored matrix. In some cases, the burrows provide evidence of being back-filled by the organism that produced them; in other cases, they are filled by pyrite, apparently due to increased permeability, which permitted more seawater to reach organic-rich sediments, so that sulfate-reducing bacteria could form $H_2S$ and thus pyrite. In their size, orientation, and stratigraphic relationships these burrows resemble the Chondrites described by Shabica (1978) from the Carbondale Formation of Illinois; however, they were not observed to branch as Chondrites does.

These burrows are concentrated in and around the core shales. Their presence would indicate reduced burrowing activity, as intense burrowing would homogenize the sediment.

Many of the siltstone and fine-grained sandstone lenses in some shales are marked on the soles by fine, wandering burrows a half to one millimeter in diameter. Occasionally, vertical cylindrical burrows of similar size are also seen. In some cases, larger burrows (up to 1.5 cm) also penetrate the sediment, and run beneath the lenses. There is little upon which to base an interpretation, but the animals that made them apparently found it profitable to penetrate migrating ripples and burrow along the mud-sand interface. Shabica (1978) suggested that some of the vertical burrow-like structures in the sand layers could also be escape structures.

In a few cases, much larger ichnofossils, up to several centimeters across, are much in evidence. These are large annular swirlings, much like Zoophycos (although they are too incomplete to be assigned properly to that ichnogenus). In the instances where they are evident, the swirls appear as light-colored mud in much darker matrix, just above the black shale as in the upper Stark Shale at Atlantic, Iowa (Locality At1).

Hakes (1976) noted that proper assignment of an environment based on ichnofossils was hazardous unless a whole range of ichnofossils were present. In this case, only one tentatively identified form is present; nevertheless, it is interesting to know Zoophycos is considered characteristic of a circalittoral to bathyal range. Alternately, Shabica (1978) suggested that Zoophycos might be present due to the lack of turbulence in the epeiric seas of the Midcontinent and Illinois Basin, rather than indicating a depth range.

Another ichnofossil present is a small, rod-shaped fecal pellet, generally 1 to 2 mm long and 0.5 mm wide. It is grooved, usually with seven grooves; however, the frequent addition of secondary grooves makes the generalization difficult to support properly. The rods are made of the same mud as the surrounding matrix, and are invariably flattened.

These fecal pellets are found in what appear to be thick, rapidly deposited shales. The Eudora Shale yields specimens from the grey portion in Kansas and Oklahoma (Localities WM1 and Cp1), and the Vilas Shale produces specimens in Kansas (Localities All and Eu1), Missouri (Locality PC1), and Iowa (Locality Be1). In some cases, they

are found when almost no other fossils are present. Whether the animal that produced them preferred a turbid environment with an unstable, rapidly accumulating bottom, or simply that the fecal pellets are preferentially preserved in such an environment is not known.

## Fish

Fish fragments are very common as they were found in 112 (49 percent) of 230 fossiliferous shale samples and 85 (77 percent) out of 110 limestone samples.

### Review of Missourian Fish

Before discussing the interpretations of the various fish fragments, a brief outline of Missourian fish is in order. Most of the following discussion is from Romer (1966) and Moy-Thomas (1971).

Upper Pennsylvanian marine fish belong principally to three groups: acanthodian, osteichthyans, and chondrichthyans. One Upper Pennsylvanian lamprey is known, but is not significant; Upper Pennsylvanian crossopterygians and lungfish were mostly freshwater forms.

Acanthodians began their evolution as mostly small freshwater fish, but by the Upper Pennsylvanian many had migrated into marine environments where some became larger. They were characterized by having all their fins supported by spines and had small, diamond-shaped ganoid scales. Romer (1966) noted that it is generally not possible to distinguish shark and acanthodian spines. They were mid-level feeders, and mostly strainers of microorganisms such as ostracodes.

Most Pennsylvanian bony fish are included in the paleoniscid order; only very aberrant forms have been placed in other orders. Thus, the paleoniscids do not constitute a natural taxon, but rather a taxonomic complex of morphologically similar but unrelated forms. Paleoniscids were generally carnivorous, fusiform fish, with thick, rhomboid, overlapping ganoid scales.

The chondrichthyans were the most important group of fish in the Upper Pennsylvanian. They are subdivided into two groups, the elasmobranchs (e.g., sharks) and holocephalans (e.g., chimaeras or rabbitfish). These two groups may not be directly related, as they may have evolved separately from placoderms (Romer, 1966).

The elasmobranchs, or sharks, were mostly predators. Originally, they were placed in "levels" or "grades", because no lineages could be worked out from scattered fragments. Thus, tooth, brain, fin, and body shape were used for taxonomy, but because of mosaic evolution, and parallel evolution in different stocks, the concept of evolutionary grade was most useful (Schaeffer, 1967). The most primitive grade was that of the cladodonts (or cladoselachians); these gave rise to the hybodonts by the Late Devonian, and eventually to modern sharks. Zidek (1973) argued that this arrangement overlooked a basic dichotomy in sharks, between those with simple or no spines, and those with long, well-ornamented spines. This distinction was largely superseded by Zangerl's (1973) division of sharks into six groups, which lumped cladodonts and hybodonts into premodern sharks.

The sharks are characterized by rapidly replaced teeth, which they produce in great abundance. They frequently have spines, but little

dermal skeleton, with only a few dermal denticles, but no bones or bony tissue; however, most Pennsylvanian sharks had prismatically calcified cartilage (Zangerl, 1973).

According to Shaeffer (1967), cladodonts probably functioned much like modern sharks, but their high-cusped teeth were adapted for seizing and tearing prey, rather than shearing and sawing. Hybodont teeth are generally more for shearing, but range from high-coned cladodont teeth to nearly flat grinders. The crowns are generally striated or crenulated, usually with a short root in high-crowned forms and a deep root in low-crowned grinders.

The other group of chondrichthyans, the holocephalans, is so named because their upper jaw is fused to their brain case for a firmer bite, since they usually ate shelled invertebrates. Many of them were flattened forms, occupying the niche now occupied by skates and rays. However, the group is heterogenous, since it was originally partially defined on the occurrence of "bradyodont" teeth, which are characterized by tubular dentine. Many of these fish had slowly replaced, crushing "dental plates", while others had rapidly replaced teeth. An example of this taxonomic problem is that of the petalodontids, which are flattened forms with rapidly replaced sharklike teeth. Another example is that of the edestids, which have been placed in both groups. For instance, Eaton (1962) noted that while they had "bradyodont" teeth, that was not a taxonomically useful character, and placed them with the sharks. Edestids are nektic forms with shearing dentition; Zangerl (1973) estimated that they were among the fastest swimming Pennsylvanian sharks. Eaton (1962) tried to explain these

peculiar fish, which developed a pronounced symphysial whorl of shearing teeth with lateral grinding teeth (the Permian Helicoprion is an extreme development). He suggested the front teeth were used for shearing off mussels, crinoids, and corals (requiring rapid replacement), while the side teeth were grinders. Some edestids are found with brachiopods in their stomachs.

Another group of some significance is the iniopterygians (Zangerl and Case, 1973), an order of holocephalans. These were originally classified as placoderms, and are morphologically midway between holocephalans and elasmobranchs. These are reported only from black fissile shales in the Midcontinent, including the Stark Shale in Iowa and Nebraska.

Empirical Data

Fish remains are fairly widespread, and occur rather frequently with a number of animals. Among the major conodonts, fish are accompanied in shale by Gondolella in about 30 percent of their samples, and by Adetognathus in a third of them. When limestones are added in, occurrence with all the conodonts rises slightly, except with Gondolella, which drops slightly. Among the forams, occurrence with fish in the shales is lower than is common relative to the other invertebrates, but rises with the addition of limestone samples. Fish occur with Tolypammina in about two-thirds of their samples, with Ammodiscus in about a fourth of them, and with Hyperammina and Ammovertella in about 15 percent of them. Among the ostracodes, fish exhibit little preference. They occur with Bairdia in about 40

percent of their samples, with Cavellina in about a third of them, with Hollinella and Amphissites in about a quarter of them, and with geisinids in about an eighth of them. Among the major invertebrate groups, fish are accompanied in 70 percent of their samples by articulate brachiopods, in 60 percent of them by bryozoans, in half of them by pelmatozoans, in 40 percent of them by gastropods, in 30 percent of them by pelecypods, and in 20 percent of them by inarticulate brachiopods.

Paleoniscid teeth are the most common fish fragments found. In the fossiliferous shales, they are found in 54 (just under a fourth) of 230 samples, and they occur in nearly half of the fish-bearing shales. In the limestones, they occur in 64 (nearly 60 percent) of 110 samples; three-quarters of the fish-bearing limestones include paleoniscids. Stratigraphically, paleoniscids are most common in limestones, less common in the outside shale, and least common in the core shale; especially in the black fissile portion (Fig. 66).

In the fossiliferous shales, paleoniscids were found with Gondolella in a quarter of the occurrences, with Anchignathodus in nearly 60 percent of their samples, and with Adetognathus in 40 percent of them. The latter two frequencies rise a little and the others drop when the limestone numbers are added in. Paleoniscid occurrence patterns with forams are much the same as with fish in general, except that Tolypammina co-occurs in over three-quarters of their samples. With ostracodes, the co-occurrences are also similar to fish in general, except co-occurrence frequencies are higher, up to nearly 60 percent with Bairdia. Paleoniscids occur with macroinvertebrates

Figure 66. Stratigraphic distribution of fish fragments in the Dennis and Stanton cyclothems.

Key as in Figure 52, p. 326.

| | "Genera" present | Total samples | Percent | paleoniscid teeth | Styptobasis | Cladodus | Protacrodus | Orodus | petalodont | altoonodont | Holmesella | Cooleyella | scale? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ls - Base | 14 | 30 | 15.2 | 25 1.33 83.3 | 11 1.79 36.7 | 9 1.85 30.0 | 4 3.59 13.3 | 1 .85 3.3 | 1 1.22 3.3 | 6 2.41 20.0 | 9 .73 30.0 | 9 1.53 30.0 | 5 1.23 16.7 |
| Core C (grey) | 12 | 25 | 12.6 | 12 .77 48.0 | 7 1.37 28.0 | 2 1.03 8.0 | 1 1.08 4.0 | 3 3.33 12.0 | | 1 .48 4.0 | 7 .68 28.0 | 1 .20 4.0 | 5 1.47 20.0 |
| Core B (black) | 7 | 31 | 15.7 | 8 .41 25.8 | 12 1.89 38.7 | | | 2 1.81 6.5 | | | 5 .39 16.1 | 1 .16 3.2 | |
| Core A (grey) | 6 | 6 | 3.0 | 2 .53 33.3 | 1 .81 16.7 | | | | | 1 2.01 16.7 | 4 1.63 66.7 | | 1 1.23 16.7 |
| Core A (undifferentiated) | 10 | 20 | 10.1 | 13 1.04 65.0 | 2 .49 10.0 | | | 1 1.39 5.0 | 1 1.85 5.0 | 1 .60 5.0 | 9 1.10 45.0 | | 3 1.10 15.0 |
| Middle Ls | 16 | 28 | 14.1 | 21 1.20 75.0 | 7 1.22 25.0 | 3 1.37 10.7 | 2 1.92 7.1 | | 4 5.30 14.3 | 3 1.29 10.7 | 11 .96 39.3 | 10 1.82 35.7 | 4 1.05 14.3 |
| Outside | 11 | 22 | 11.1 | 11 .80 50.0 | 2 .44 9.1 | 1 .68 4.5 | 1 1.22 4.5 | 2 2.53 9.1 | 1 1.67 4.5 | 4 2.19 18.2 | 10 1.11 45.5 | 3 .69 13.6 | 1 .33 4.5 |
| Stray Ls | 4 | 4 | 2.0 | 2 .80 50.0 | 1 1.22 25.0 | 1 3.21 25.0 | | | | | | 2 2.55 50.0 | |
| Upper Ls - Top | 5 | 14 | 7.1 | 11 1.26 78.6 | 1 .35 7.1 | | | | | | 2 .35 14.3 | 6 2.19 42.9 | 1 .52 7.1 |
| Ls Partings (shale) | 10 | 12 | 6.1 | 10 1.33 83.3 | 2 .81 16.7 | 3 3.21 25.0 | 1 2.24 8.3 | | | 1 1.00 8.3 | 7 1.42 58.3 | 4 1.70 33.3 | 5 3.07 41.7 |
| Upper Ls - Middle | 4 | 6 | 3.0 | 5 1.33 83.3 | 1 .81 16.7 | | | | | | 4 1.63 66.7 | 2 1.70 33.3 | |
| Total | 20 | 198 | | 120 62.6 | 47 20.5 | 19 7.8 | 9 3.7 | 9 3.6 | 7 2.7 | 17 8.3 | 68 41.0 | 38 19.6 | 27 13.6 |

Figure 66.

more frequently. They are accompanied by articulate brachiopods in over 80 percent of their samples (especially by chonetids and Crurithyris), as well as that often by bryozoans. Pelmatozoans are found with paleoniscids in two-thirds of their samples, gastropods in nearly half of them, and pelecypods and phosphatic inarticulate brachiopods in a third of them.

Styptobasis is a common cladoselachian shark tooth (Zidek, 1973). It occurs in 25 (just over 10 percent) of 230 fossiliferous shale samples and in a quarter of the shale samples with fish debris. It also occurs in 21 (just under 20 percent) of 110 limestone samples. Stratigraphically, Styptobasis is rather erratic. It is most common in the black fissile core shale, and fairly common in adjacent units; it is present but less common in the outside shale and similar horizons (Fig. 66).

Styptobasis has a notable occurrence pattern in the shales. It occurs in over 40 percent of its samples with Gondolella, and in 80 percent of them with Idioprioniodus. It occurs with idiognathodids in 96 percent of its samples, but with Adetognathus only in about 30 percent of them. Among the forams, it occurs with Tolypammina less than any other fish (in slightly less than two-thirds of its samples), with Hippocrepina in over 10 percent of its samples, and rarely with Ammovertella. (Co-occurrences in limestone are similar, except Ammovertella, which leaps from 8 percent to 30 percent.) Occurrences with ostracodes are low. Bairdia is most frequent at 28 percent. Styptobasis' pattern with other megafauna is remarkable for the low level of co-occurrence. Articulate brachiopods accompany Styptobasis

in about two-thirds of the occurrences (with Crurithyris being the most common), bryozoans in about half, pelmatozoans and phosphatic inarticulates in about 30 percent, gastropods in about a quarter, and pelecypods in 15 percent of the occurrences.

Styptobasis is poorly associated with terrigenous detritus. Only 12 percent of the occurrences are with muscovite, and a third with kaolinite.

Cladodus is the "typical" cladoselachian shark tooth. It occurs in only 6 (about 2.5 percent) of the 230 fossiliferous shales, and in 12 (just over 10 percent) of 110 limestone samples. Cladodus occurs in about 9 percent of the samples containing fish. (Since Cladodus is so uncommon, most appropriate comments here will be directed toward its pattern that includes limestone.)

Cladodus is accompanied by Gondolella in about 20 percent of its samples, by Idioprioniodus in half of them, by Anchignathodus in three-quarters of them, and Adetognathus in 40 percent of them. Occurrences with foraminifers are notable in that Ammovertella co-occurs in a third of its samples, while Ammodiscus and Hyperammina are found with it in only 10 percent of them. Cladodus occurs most often with Amphissites and Bairdia among the ostracodes. In the shales, it is always accompanied by articulate brachiopods and bryozoans. It is accompanied by pelmatozoans in two-thirds of its samples, by gastropods and phosphatic inarticulate brachiopods in half of them, and by pelecypods in a third of them.

"Altoonodonts" are tooth-like structures of unknown affinities found in 8 samples (about 3.5 percent) of the 230 fossiliferous shales and in

9 (8 percent) of 110 limestone samples. As with Cladodus, due to improved statistics, the limestones will be included when appropriate.

Altoonodonts occur with Gondolella relatively often, in nearly 30 percent of their samples. They occur with Anchignathodus in three-quarters of them, and Adetognathus in half of them. The altoonodonts' occurrence with forams is unexceptional, except for being accompanied by Ammovertella in half of their samples. Among the ostracodes, the altoonodonts are accompanied most by Bairdia and Cavellina (5 times out of 8 each), with Hollinella slightly less often (4 out of 8), Amphissites co-occurring only once, and Geisina not at all. Among the megafossils, altoonodonts are always accompanied by articulate brachiopods and bryozoans, by gastropods and pelmatozoans in three-quarters of their samples, by phosphatic inarticulate brachiopods in half of them, and by pelecypods in a quarter of them. The altoonodonts' occurrence with other fish is instructive. They are found frequently with paleoniscid teeth (in over 70 percent of their samples), with Holmesella (in 40 percent of them), and occur in over half of their samples with Styptobasis.

Holmesella is by far the most common of the fish scales. It is found in 40 (about 17 percent) of the 230 fossiliferous shales and in 25 (about 23 percent) of the 110 limestone samples. Since the limestone and shale co-occurrence patterns are very similar, shales will be discussed.

Holmesella is accompanied by Gondolella in only 15 percent of its samples, but by Anchignathodus in three-quarters of them and by Adetognathus in half of them. Among the ostracodes, Holmesella

occurs most with Cavellina (in nearly half of its samples), followed by Bairdia (about 40 percent), Hollinella (30 percent), Amphissites (in a quarter of them), and Geisina (about 10 percent). Holmesella is usually accompanied by an array of articulate brachiopods (in 90 percent of its samples), by bryozoans in 80 percent of them, by pelmatozoans and gastropods in about 60 percent of them, by phosphatic inarticulate brachiopods in about half of them, and by pelecypods in 30 percent of them. Among the fish, Holmesella is found with paleoniscid teeth in almost three-quarters of its samples.

Cooleyella is another common dermal denticle. It was found in 8 (3.5 percent) of 230 fossiliferous shale samples and 29 (over 26 percent) of 110 limestone samples. Stratigraphically, Cooleyella is one of the few fish fragments that shows a distinct trend. It is strongly associated with limestones, and uncommon in shales, especially the core shale (Fig. 66). Because Cooleyella's distribution is heavily skewed toward limestones, the limestone data will be included when possible.

Cooleyella occurs with Gondolella in about an eighth of its samples, and with both idiognathodids and Anchignathodus in nearly three-quarters of them (with the latter slightly more often). Adetognathus occurs with Cooleyella in about half of its samples. Cooleyella has an unremarkable pattern with respect to forams, except that Ammovertella occurs with it in about 40 percent of its samples. Among the ostracodes, Hollinella and Bairdia co-occur most frequently. Among the macrofossils, articulate brachiopods, bryozoans, and pelmatozoans occur with Cooleyella in about two-thirds of its samples,

pelecypods, phosphatic inarticulate brachiopods, and sponges in about a third of them, and with gastropods in a quarter of them.

Another fish fragment that frequently occurs is a grooved plate that Gunnell (1933) referred to simply as a "scale". It was found in 15 (6.5 percent) of 230 fossiliferous shale samples and 12 (11 percent) of 110 limestone samples.

The "scale" occurs with conodonts in a typical pattern. Gondolella accompanies it in about 20 percent of the samples, while Adetognathus accompanies it in about a third of them. The "scale" is accompanied by Ammodiscus in a third of its samples, more frequently than is any other fish fragment. The "scale" is found with Bairdia in nearly three-quarters of its shale occurrences; by Cavellina in 45 percent and by Amphissites in 40 percent. Among macrofossils, the "scale" is always found with articulate brachiopods (usually including chonetids), in 90 percent of its samples with bryozoans, and in 80 percent of them with pelmatozoans. It is found with gastropods in 40 percent of its samples, and with phosphatic inarticulate brachiopods and pelecypods in a quarter of them. The "scale" also occurs with paleoniscid teeth in 80 percent of them and with Holmesella in 40 percent of them.

## Interpretations

Fish in Upper Pennsylvanian strata have been studied for some time. Gunnell (1933) did the first detailed work on Missourian fish fragments of Kansas, and introduced many of the organ taxa used for the ichthyodurolites. Biesiot (1950) did a similar study in Nebraska, including the black shales; he observed that the fish genera are

common throughout the Missouri Series. Since that time, most of the work has concentrated on fish in black shales, because whole individuals are found there, rather than scattered fragments. Recently, Tway (1979, 1981) worked on the ichthyodurolites of the Virgilian Series of Oklahoma. She found abundant microscopic teeth, dermal denticles, and mucous membrane denticles, and found that they were not facies dependent as they occurred in a wide range of lithologies. Many of the taxa had short stratigraphic ranges and she felt that they had more stratigraphic potential than conodonts. She also noted they could be used as thermal indicators in the same way as conodonts.

Tway (1979) noted that shales tended to have poorly diverse fish faunas, but often quite abundant forms. Limestones tended to have high diversity, but no form was very common. Pabian (1981) was a little more detailed: the outside shales are characterized by a diverse assortment of sharks and holocephalans, together with some brackish and freshwater fish (i.e., coelocanths, dipnoans, and xenacanthid sharks); the limestones include most of the sharks and holocephalans, plus abundant bony fish (mostly paleoniscids); but the core shales have very limited fish remains, mostly of cladodont and petalodont sharks. The evidence from this study generally agrees with these patterns, except that numbers in limestones are frequently high. The highest abundances are in a few skeletal calcarenite lenses in the transition shale where true middle limestones are absent (such as at Van Wert, Iowa - Locality VW1); there, the rock may reach several percent fish fragments (with considerable diversity) in a coaly limestone composed principally of myalinids and ostracodes.

Holmesella was originally assigned by Gunnell (1933) to acanthodian fish. However, Ørvig (1966) worked with some material from the Muncie Creek black shale of Kansas, and concluded that some Holmesella belonged to elasmobranchs, as he found evidence of prismatic calcified cartilage (known only in elasmobranchs), as well as teeth suggesting such an affinity. He did state, though, that only some Holmesella belonged to sharks; others were clearly acanthodians.

Acanthodians were small fish with numerous scales, and are generally considered to be near-shore forms. If most of the Holmesella scales came from such fish, a near-shore distribution would be expected. This is what was found. Holmesella does appear throughout the cyclothem, but shows marked trends toward the outside portion. It occurs with Adetognathus more often than any other fish fragment, and is the only one to occur with Cavellina more often than Bairdia. Although raw values show that it is more likely to occur in limestones than in shales, those shales include the poorly fossiliferous core shales where Holmesella is depleted. In the outside shales, Holmesella occurs in nearly half of the fish-bearing samples, compared to about 15 percent in the fissile black core shale. Tway (1979) stated that acanthodians are far more abundant in shales than limestones, and suggested that they were substrate dependent. It seems more likely that this is a reflection of their nearshore habitat, where shales are more likely to form.

Paleoniscid teeth are by far the most common ichthyodurolites, and are common throughout the cyclothem, an observation confirmed by Tway (1979). Pabian (1981) also associated paleoniscids with the

limestones, and implied that they were less common in the shales. They do, however, show a preference for limestone environments, where overall faunal diversity (and probably biomass, hence prey) was greater. Indeed, they occur in at least three-quarters of the fish-bearing limestones, including the tops of the upper limestones, which often contain restricted faunas.

The affinities of the furrowed plate Gunnell (1933) referred to as a "scale" are unknown, although it is a common ichthyodurolite. Insufficient correlation exists to tie it to any other organ genus; it would seem most likely that it belongs to a paleoniscid, although it's possibly acanthodian in origin. It's highly improbable that it belongs to a chondrichthyan, as it is a solid bony plate. It shows some affinities for limestones, but is relatively rare in outside shale and the tops of upper limestones.

The evidence for sharks is common, which is not surprising as they shed teeth rapidly. As is true with the paleoniscids, sharks generally seem more common in limestones, because that environment was where most of the food was.

Cladoselachian (or cladodont) sharks are best represented. In addition to Cladodus, other cladodont teeth found were Styptobasis (Zidek, 1973) and Protacrodus (Schaeffer, 1967).

Cladodus and Protacrodus (about half as common as Cladodus) follow the typical fish distribution, but Styptobasis is distinctive as it is the principal ichthyodurolite with a distribution skewed toward the core shale; 40 percent of the fish occurrences in the fissile black core shale include Styptobasis. This trend is also clear from its

co-occurrence pattern, which is strongly associated with typical core shale faunal elements. Other characteristics, such as its low probability of occurring in areas of high clastic influx, also reflect this. This pattern was also found by McCrone (1963) in the Lower Permian Red Eagle cyclothem: Styptobasis is common in the black shale, but rare elsewhere.

Hybodus was the only hybodont shark tooth seen, and both occurrences were in the middle limestone.

Orodus and Agassizodus belong to edestid sharks (Zangerl, 1973). Nine Orodus occurrences and possibly two Agassizodus occurrences showed no evident pattern.

Petalodont teeth were found in seven samples, including four from the middle limestone. This is consistent with a durophagous habit, as Moy-Thomas (1971) noted that many petalodonts are found with brachiopods, crinoids, foraminifers, and crabs in their stomachs.

Ørvig (1966) stated that Gunnell's (1933) genus Kirkella might be petalodont scales, since a similar association is known from the Permian. Kirkella was found in five samples, four from the base of the upper limestone.

One of the commonly reported fish remains of the Carboniferous black shales of both Europe and North America is the spine Listracanthus; this is possibly associated with the dermal denticle Petrodus (Chorn and Reavis, 1978). Two localities were found during this study where the black shale contained Listracanthus, and there were two grey shale occurrences of Petrodus.

The affinities of Listracanthus and Petrodus are not certainly known. Although found close together in some shales, Zangerl and Richardson (1963) felt that the evidence for association was not conclusive, although they felt that both organs belonged to sharks. However, Romer (1966) listed Listracanthus as a possible holocephalan. This interpretation goes along with Zidek's (1977) statement that Listracanthus is not a true spine, but rather a prolonged dermal denticle. Chorn and Reavis (1978) acknowledged this interpretation, and stated that Listracanthus should be regarded as an organ genus. They cited some of the work that connects it to holocephalans, but decided not all Listracanthus can be explained this way; they stated that Listracanthus and Petrodus are apparently associated with a large chondrichthyan, possibly one with edestid teeth. They noted that Listracanthus and Petrodus often correlate in relative abundance in the black shales.

Listracanthus may not be particularly significant environmentally, although it is associated with the fissile black shale. For instance, it may be provincial; Zidek (1977) reported the first occurrence of it in Oklahoma. It may also be that it's preserved only in quiet water, since Petrodus comes from other environments than the black shale.

Physonemus is a shark spine that bears mentioning. Although none were found during this study, they do occasionally appear in Missourian strata. Zidek (1976, 1977) reported it from the Coffeyville Formation in Oklahoma, along with other shark spines. Chorn and Frailey (1978) reported a specimen from the Coffeyville north of Coffeyville, Kansas, and estimated its complete length at 76 centimeters, which would imply

a very large shark. Baird (1957) had found Physonemus in the Ames Limestone (possibly equivalent to the Stanton cyclothem) and noted that most of its occurrences were in marine limestones, except for several in Illinois, which he concluded were brackish-water occurrences.

Holocephalans, which often have large, slowly replaced grinding plates, are not nearly as well represented in the record as are elasmobranchs, even though it has been estimated that holocephalans were much more common. Only two specimens of possibly fused holocephalan teeth were found. Helodus, assigned to an iniopterygian holocephalan (Zangerl, 1973), was found in seven samples, which show no particular pattern. Curiously, none were in black shales, to which Zangerl and Case (1973) said they were restricted. R. K. Pabian (written comm., 1982) reported Helodus from a Virgilian upper limestone. It is possible (1) that preservation only permits their recognition in the black shale, or (2) they are an organ genus without a specific organism associated with them.

Unassigned ichthyodurolites, possibly dermal or mucous membrane denticles, make up a substantial portion of the fish fragments encountered. Most were given names by Gunnell (1933), whose terminology is applied here. The most common of these forms is Cooleyella, which is strongly associated with limestones, and with the animals characteristic of limestone-forming environments: Anchignathodus, Ammovertella, and Hollinella. However, no other ichthyodurolite approximates Cooleyella's distribution, so it's not possible to draw any conclusions on affinities.

The altoonodont ichthyodurolite is of uncertain nature with a root similar to a dermal denticle, but often marginally produced into a tooth-like structure. Altoonodont distribution suggests that they may have preferred limestones toward the core shale, but this is not a marked pattern.

Other dermal denticles(?) occur in the sediments only sparingly. These include Multidentodus, Moreyella, and Cooperella. None occur often enough for useful observations.

Few useful generalizations can be drawn from the distribution of fish in general. As predators, they would be expected to be where most of the prey is found--in the limestone environments. Thus, it is not surprising most fish fragments are found there, and that the highest diversity of fish is there. The patterns found here agree well with those of Pabian (1981); most of the marine fish are spread throughout the cyclothem, although the outside shales are somewhat less diverse (not including introduced freshwater fish) and the core shales are very depleted. Only Holmesella and Styptobasis exhibit tendencies to be found in shales; Holmesella toward the outside, and Styptobasis toward the core.

Some statements have been made about various fish. Zidek (1976), for example, stated that all Pennsylvanian sharks were from shallow marine, deltaic, or lagoonal environments, but did not elaborate. The black shales, where fish are much in evidence, have also drawn much examination and generalization. Olsen (1946) listed the typical fauna of the black shales in Illinois (specifically including the Oakwood Shoal Creek section, Locality Oa1): Petrodus, Listracanthus,

Edestus, Orodus, and Orbiculoidea. He noted some crossopterygian teeth, and suggested that these animals must have lived in brackish water, since there's no evidence for marine crossopterygians until the Permian. However, Baird (1957) noted that the teeth in question were in a coaly matrix, rather than shale, and suggested that they were transported.

Finally, Zangerl and Richardson's (1963) interpretation of the fish fauna in the fissile black Mecca Quarry Shale should be considered. They noted an abnormal concentration of fish without an apparent similar concentration of food, and stated that all the fish died from predation. (However, R. K. Pabian, written comm., 1982, cited a personal communication from J. G. Maisey suggesting that some of the evidence for predation was a result of preservational peculiarities.) Zangerl and Richardson found that modern cartilagenous fish (which are not heavily calcified as are the Pennsylvanian forms) must be buried very rapidly in order to be recognizably preserved, at least if the water temperature is 20°C or more. They also stated that the black shale formed in an environment of little current activity, since the Listracanthus were not oriented. From this, they concluded that the black shales were formed in shallow lagoons, protected by a flotant mat, with periodic fluctuations in water level to trap and kill the fish.

These observations are pertinent to a formulation of the depositional environment of the fissile black shale. Not only do the same ichthyodurolites commonly occur in the black shales of the Midcontinent and Illinois Basin, but the same mode of deposition generally applies.

Pieces of fish are common in the Eudora Shale, and at least one whole small fish was recovered from the Eudora near the type locality in Kansas (Locality Eul). It would appear that whatever the environment was, it was remarkably persistent.

## Paleontology and Sedimentology

Between the death of an organism or assemblage of organisms and its expression in the rock as fossils, many physical and biological processes may operate. That processes must operate is immediately evident; only a tiny fraction of the organisms that lived in one place are preserved as fossils. What governs which are preserved, and how? How do the processes alter the fauna? By deciphering the nature of these processes, a better understanding of the depositional environment can be achieved. In the Midcontinent, where the effects of diagensis are minimized, this is somewhat simplified, but by no means simple.

Tackling the problem of deciphering depositional environments from the physical and biological distribution of fossils requires two assumptions: (1) The biological distribution of organisms in the Upper Pennsylvanian was governed by the same physical and biological processes operating today; that is, the same processes should produce similar general patterns. (2) Post-mortem physical processes (such as winnowing and storm transport) should produce comparable results in the Upper Pennsylvanian and the present.

Study of a changing environment and the fauna associated with it can be approached on two levels: as an aggregate, or average, study of many similar changes, or on an individual, unique basis. Both have

particular features. An aggregate approach to a faunal sequence will produce broad outlines of a pattern. This is because in an area of net deposition, the older deposits are successively less likely to be reworked than the younger ones. While mixing may be extensive and continuous, older deposits will become less and less prone to homogenization as they become incrementally farther from the surface. Thus, if sequential assemblages exist, some crude ordering should persist and be detectable, although the degree of mixing may not be readily apparent. Statistically, a sequence should appear, but the original discreteness of particular assemblages must be approached in other ways.

One way is to compare the sequence found in an outcrop with the statistically developed sequence. Deviations from the expected pattern have a cause, and if the nature of the cause can be determined, it can be factored into the overall depositional model.

The problem involved is essentially multivariate, depending on both biological and physical processes. As such, it is not possible to approach the problem without assumptions. Each of several variables must be tested for its possible effect; in order to do this, certain assumptions about the other factors must be made. The result is something of a "null hypothesis" methodology: for example, the question is asked, "Are the fossils subject to frequent storm reworking?" If there are clearly storm deposits, then the interpretation of both fauna and depositional environment must take this into account. If there are no obvious storm deposits, the lack of storms cannot be postulated, but their significance can be minimized. This approach

can be summarized as making a series of postulates about the fauna and environment, and testing whether they are necessary to explain observed features; if so, why, or if not, why not.

Biological Parameters

The controls on fossil distribution come from two sources: environmental controls (distribution) and later physical processes that modify the original distribution, including diagenesis.

To discuss environmental controls, it is first necessary to establish a general expected pattern, and see if it can be verified. The Missourian shales studied are, of course, clastic rocks. Since there are nonmarine rocks present, it is reasonable to assume some of the shales were deposited in shallow water. So what sort of pattern would be expected?

Johnson (1972) stated that benthic communities on clastic substrates in shallow water are "low-grade" communities, that is, evolutionarily immature faunas, with few interdependent systems, low diversity and low environmental gradients, and that tend to occur in variable combinations. Such communities tend to be continuous and intergrading. They are low grade because they are controlled by physical systems, and nearshore physical parameters vary more than in deeper water. The most unpredictable portions of the environment have the lowest diversity.

Johnson (1972) also observed that such communities tend to be gradational into one another, since they are controlled by physical factors that are not sharply delimited. The more biologically

controlled the community, the sharper its boundaries and the higher the grade.

In shallow water, the fauna is subjected to extremes of physical conditions. As these extremes become less frequent and less intense, usually by increase of water depth with its buffering capacity, the fauna no longer needs to cope with the extremes. Plants and animals that are more sensitive to extremes or that need certain prerequisites can move into an area, and a system of more interdependent relationships may be initiated. But should exceptional conditions return, even briefly, the whole sequence begins again.

Johnson stated it this way:

> Far from attaining some equilibrium state, the community is conceived of as continually varying in response to a history of disturbance. In this view, the community is a collection of the relics of former disasters.
> - Johnson, 1972, p. 153.

In an environment where "disasters" are frequent, the succession never gets very far. As they become less frequent, it develops further and further. Johnson described the benthic community as a temporal mosaic, with each area reflecting how far its succession has progressed since the last "disaster". Under such a regime, the first species in the succession (which must be adjusted to frequent extremes) is generally eurytopic. Additional species join the community one by one, since they are dependent on physical properties and not each other (Fig. 67).

Johnson (1972) noted that a faunal Walther's Law applies in such circumstances. Adjacent communities are those most likely to replace a given community when conditions change. Thus, lateral facies changes

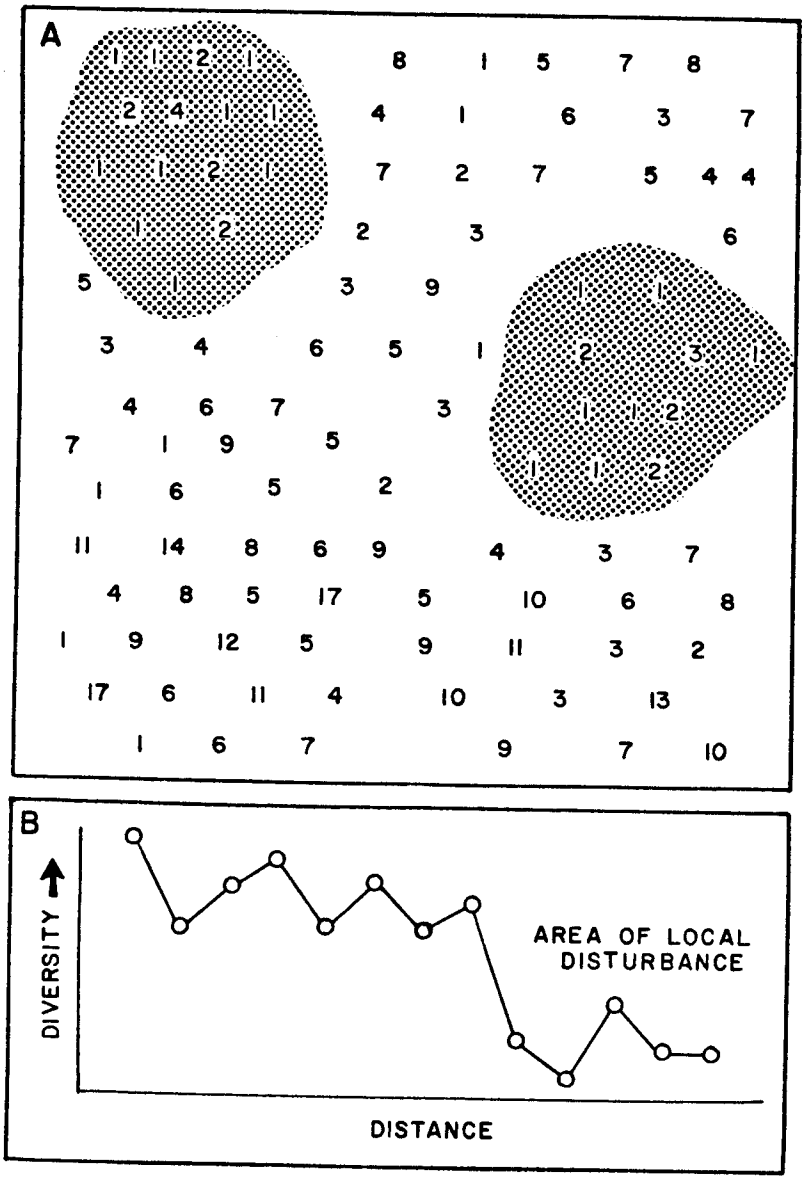



Figure 67. Conceptual relationships of shallow marine organisms (Temporal Mosaic of Johnson, 1972).

A. Areal distribution of fauna on a time plane; numbers represent number of taxa present. Shaded areas are areas of disturbance.

B. Transect across time plane, showing relative diversity (diversity is in number of taxa present).

can be seen in a vertical sequence as environments move back and forth with time.

Johnson (1970) summarized some of the features of benthic communities on clastic substrates: (1) the overall diversity is low; (2) they tend to be gradational, with no meaningful way to subdivide them; (3) diversity increases with higher rank (more biologically interdependent) species, which appear on an individual basis; and (4) the most eurytopic, shallow water forms tend to be present as a minor element in the more diverse faunas (since biologic interaction, such as competition, is not a factor).

Thus, in an environment where sea level is rising, the expected early faunas would be low in diversity, and consist of eurytopic forms. With increasingly stable conditions, due to deepening water, more and more taxa would be added to the fauna. In the rock, this would be expressed as an upward increase in diversity. Since the lateral relations are gradational, it should also appear gradational stratigraphically. This is what is seen in the cyclothems in the Midcontinent and the Illinois Basin.

Eventually, Johnson (1972) observed benthic communities significantly modify their environments, permitting replacement by other species, constituting a true succession. The original sediment may be modified by burrowing, shell accumulation, or microorganic activity. The microhabitats produced yield heterogeneity, which produces increased diversity. If not episodically homogenized, eventually the various niches will become discrete, and be occupied by different organisms, dependent upon the activities of others. Thus, given

enough time in a stable environment, diversity should increase, giving rise to a biologically accommodated stenotypic community, from the original eurytopic, physically controlled, low diversity fauna (Sanders, 1968).

The question now is can we recognize the features of shallow water faunas in the cyclothems? The answer, apparently, is yes. Both the outside and core shales exhibit low diversity, becoming higher toward the limestones. Johnson (1970) noted that shallow-water species in cyclothems are often present in the diverse portion, a function of additive (rather than replacive) diversity. Watkins (1974, p. 311) observed: "Range of a species through one or more fossil communities is a direct measure of niche size...." Thus, the most eurytopic forms should appear in the most samples, at least if they are from an additive diversity gradient.

Are there other ways to recognize physically controlled eurytopic forms? Again, yes. Most such species are opportunists (Levinton, 1970), and the characteristics used to recognize them are applicable. Pianka (1970) noted that r-strategists (opportunists) are found with little interspecific competition, and are often very variable in their populations. Characteristically, they are physiologically general and paedomorphic: the object is to reproduce as rapidly as possible, before the next "disaster". Thus, they are usually small and simple. (In contrast, K-strategists, which live in stable environments, put more energy into a few individuals with a high probability of survival, rather than many individuals with a low probability. They are slow-growing, relatively large, and not very numerous.) Hallam (1980)

noted that such benthos as is found in laminated black shales is generally opportunistic; the diversity is low, with high numbers, while the individuals are usually small due to mass juvenile mortality (rather than stunting).

How well does this work when applied to specific cases? Crurithyris, the articulate brachiopod that occurs most frequently in the cyclothems, occurs throughout them, both in monotypic faunas and as a minor element in more diverse ones. It is a small, simple form, often present in wildly variable numbers--in short, it is a classic eurytopic opportunist. Generally, this pattern can be followed, most graphically among the brachiopods (since they live long enough for larger size to be a viable option for a K-strategist): the smaller, simpler forms tend to be locally common and widespread throughout the cyclothem, while the larger, more complex forms (such as Pulchratia and Juresania) are more restricted in their distribution and are less common when found.

Petty (1975) noted this general pattern in the Missourian Graford Formation of north central Texas (which he observed had a fauna very much like that of the Midcontinent); he found the same species of brachiopods, echinoids, and crinoids in the shale and the overlying limestone, and concluded the animals were probably pioneers, helping prepare the environment for limestone deposition. The same may be true in the Midcontinent.

There is independent verification of this hypothesis. Bretsky and Lorenz (1970) and Jablonski (1980) noted that environmental stability and diversity were negatively correlated with long-term biotic

stability. This means that the least diverse, most environmentally unstable faunal assemblage should be the most persistent through time. (This is reasonable, as any specialization by an r-strategist would restrict its chances of success. On the other hand, in stable environments niche partitioning and sympatric speciation are possible.) Thus, the community represented by the most eurytopic forms should have the longest geological record. Crurithyris, for example, does. It occurs in very similar environments, with similar associations (usually phosphatic inarticulate brachiopods) from the Mississippian through the Lower Permian. Other faunal elements are similarly long-ranging in persistent associations; indeed, many Carboniferous and Permian faunas are quite closely comparable.

Jablonski (1980) noted that the change from an r-selective fauna to a K-selective fauna may reflect an onshore-offshore gradient, not changes from a succession. The faunal patterns found in the studied cyclothems agree very well with this concept.

At this point, it is a valid question to ask if there are exceptions to this pattern; places in the cyclothem where the communities become biologically accommodated and distinct. Since there are two stress environments present (the black core shale and the nearshore outside shale), the logical place to look for biologically accommodated faunas is in the limestone. (As a corollary, the limestones would be the best place to look for index fossils, since they are the most stable environment physically.)

Johnson (1962) suggested several criteria for finding key species in distinguishing separate biologically accommodated life assemblages:

(1) they do not occur together, even though their stratigraphic distributions overlap; (2) they co-occur with other skeletally similar animals at a significant level, forming a pair-linked chain, even though they don't mutually co-occur; and (3) using a Chi-square test, they are negatively correlated at a 0.005 level of confidence.

Thus, we are looking for disjunct distribution, loss of eurytopic forms, high diversity, and rapid faunal change through time to see if biologically accommodated communities exist. The answer, to a degree, seems to be no. In the shales and apparently in the limestones (partially represented by shaly fossiliferous intervals) there are few signs of disjunct distributions in one stratigraphic horizon or lithology (Senich, 1978, did present a possible example with Meekella and Enteletes). Every animal studied occurred with almost every other one at some frequency; the most disjunct tendencies came from those that were stratigraphically extreme. Even in the most diverse faunas in the limestones, the common faunal elements (e.g., Composita, Crurithyris, chonetids, etc.) persist. Turnover in fauna through time is not high, either. Most of the faunal elements, even in the limestones, are comparatively long-ranging. This is not to say biological accommodation did not exist; it clearly did in some cases, and all the features of more stable environments are present in the limestones. The point is that all the environments present in the Midcontinent exhibit some degree of physical control; the trends certainly persist through the shales. This also supports Johnson's (1970) contention that there is no meaningful way to divide such a spectrum into discrete "communities"; they can be divided into grades in a continuum,

with certain faunal elements characteristic of each grade. The grades can recur frequently, and be recognizable units, but are not communities with distinct boundaries.

The mosaic nature of the faunas has been described before, although not interpreted. Lockwood (1972) described it in the Francis Formation (dominantly shale) in southern Oklahoma, where a diverse fauna displayed vertical and horizontal patchiness. More importantly, Senich (1978) observed it in the limestones of the Stanton Formation. He concluded that the faunal pattern was actually a mosaic, rather than laterally continuous and stratigraphically recurrent. He further observed that this pattern was real, and not an artifact of sampling; and he noted that no taxon in the study was strictly limited by paleogeography (this apparently excluded those forms too uncommon to validly judge). Clearly, in both his study and this study, many taxa are very generally recurrent stratigraphically, but they don't appear consistently at a particular horizon. The environment can be degraded and regraded at almost any point.

Since it can be shown that the faunas in much of the cyclothems, and certainly in the shales, are stressed assemblages, the question then arises, what are the stresses? And are the stresses in the core shale and the outside shale due to the same processes? Several possible physical variables should be considered (substrate conditions will be considered with physical variables, as they are partially dependent upon the rate of deposition.)

One possible variable is salinity. Both Gunter (1947) and Hallam (1965) noted that abnormal salinity conditions cause both a

decrease in individual size (stunting) and a decrease in diversity. This would appear to be a reasonable possibility; Ottom (1969) called upon salinity fluctuations as a cause of small faunal size in the Brush Creek cyclothem in Ohio. Lees (1975) noted that a modern control in coral distribution was extreme salinity conditions; such an interpretation would be compatible with the coral distribution observed.

Another possible variable is oxygen saturation. Hallam (1965) observed that low oxygen conditions can cause stunting. He noted that laminated black shales indicate low oxygenation; they often contain thin layers of nektic or benthic epifauna, some of which can be shown to be stunted. This type of deposit would indicate alternation of anoxic and low oxygen conditions. Purdy (1964) stated that such bottom organics restricted burrowers, as oxygen in the substrate decreased and poisonous compounds (such as $H_2S$) accumulated. Sanders (1968) found that faunas in areas of upwelling were depleted due to oxygen stress. More specifically, Malinky (1980) suggested that the stunted fauna he studied in the Eudora Shale was stunted by low oxygen conditions. By way of analogy, he cited descriptions of Baltic black muds (Segerstrale, 1957; Manheim, 1961) with stunted faunas in adjacent muds; the black muds themselves were mainly plant remains with a pelagic fauna.

Clearly, this is applicable to core shales, where laminated black shales grade into grey shales with small and/or stunted individuals. However, it is unlikely to apply to outside shales. The lack of lamination there suggests effective reworking, either by physical or biological agents. Physical agents (currents or waves) would move

oxygen to the bottom; biologic agents would require the oxygen already be present. Another contraindication is the frequent presence of myalinids in the outside shales. Large, heavily-shelled molluscs are poorly adapted to low-oxygen conditions (with low surface area to volume rations), although admirably adapted to salinity fluctuations. Notably, many shelled invertebrates in the outside shales occur abundantly in coaly shales; the apparent explanation is that much of the coaly material is essentially oxidized and inert (in such forms as fusain) and has little biological oxygen demand.

Another possible control is temperature. Heckel and Pabian (1981) attributed the apparent small size of core-shale crinoid taxa to low water temperature. In an attempt to verify possible thermal stratification, the Missourian Midcontinent fauna was generally compared to cold-water, low diversity, high abundance Gondwana faunas from Australia, both a contemporary fauna from New South Wales (Campbell and McKellar, 1969) and a slightly younger, postglacial fauna from the Permian of Tasmania (Clarke and Banks, 1975). Ideally, tropical submergence would cause shallow-water temperate/polar forms to appear in deeper, presumably colder water in the tropical Midcontinent. Unfortunately, little support was produced. The New South Wales fauna had a great deal of overlap, but the forms in common were not restricted in the Midcontinent (e.g., Neospirifer, Punctospirifer, Composita). The Permian fauna produced a few possibilities (Cancrinella, conularids), but most common forms there were also unrestricted in the Midcontinent.

Temperature is unlikely to be a control in the outside shale. Gunter (1947) observed that on shallow shelves there are no distinct gradients attributable to temperature.

Hallam (1965) noted that a lack of food can also stunt a fauna; with less food, it becomes sparser and smaller. As this typically happens in an offshore direction, it is unlikely to have caused stress in the outside shale. However, it is a possible episodic cause in the core shale; the Crurithyris horizons would suggest at least periodic abundance, however.

Physical Parameters

Between the existence of a fauna and its manifestation in the rock today, a number of processes act to determine how and how much of it will be preserved. Most of the processes that operate in the interval are purely physical, with the exception of burrowing (which, while biologic in origin, has both chemical and mechanical effects). Substrate stability is included, both as it relates to original deposition and to burrowing activity.

One of the most important aspects of fossil preservation is the rate of sedimentation. Fürsich (1978) summarized the possible variations: (1) if the rate of sedimentation is greater than net biological shell production, the environment will remain a clastic-dominated system, possibly resulting in a stable community dominated by deposit feeders, which will also act to limit filter-feeding epifauna; (2) if the rate of sedimentation is less than net biological shell production, the community will evolve toward epifaunal filter feeders, with

the shells restricting infauna. Thus, as a first approximation, with constant high rates of sedimentation, a community of organisms that can survive burial would develop; if the rate of deposition were low enough to permit accumulation of shells, a succession would take place. A third possibility (not listed by Fürsich) is that deposition is episodic, permitting sessile epifauna to persist without burial, but frequent enough to prevent a marked accumulation of shells.

The third possibility is related to one of the problems of faunal interpretation: time-averaging. Warme and others (1976) noted this phenomenon in studying benthic foraminifers and molluscs in coastal waters. They noted that the animals had patchy or clumpy distributions, but that the preserved record tended to homogenize them. This homogenization was not due to significant transport or large-scale environmental fluctuation, but simply due to random variation within an environment. They noted that because of time-averaging, fossil assemblages of animals are more useful than living assemblages, because they are less susceptible to variation due to sampling.

McCall and Tevesz (1981) made more pertinent observations on time-averaging in their work with modern soft bottom faunas in Long Island Sound. Like Johnson (1972), they recognized an orderly recovery from a bottom disturbance in shallow water. But they noted two problems with interpretation of the succession from the record. (1) most early colonists lack hard parts, and (2) the succession is difficult to reconstruct from vertical or lateral variation due to the comparative rapidity of recovery. In other words, the animals of the successional series lived and died faster than they were separated by sedimentation;

thus, the death assemblage represented all stages of a succession, and it was more diverse than the fauna living at any one time. (This applied even when only shelled invertebrates were considered.)

Time-averaging is thus a function of the rate of deposition. If the rate of deposition is great enough, the various groups will be separated; if not, the various stages of the succession will be "condensed" (Fürsich, 1978) together, and appear to be one assemblage in the fossil record.

Schindel (1980) summarized the impact of time-averaging on sediments and their faunas. He noted that in almost all environments deposition is too slow or too intermittent to preserve short-term continuous biologic change (such as a succession); compaction and bioturbation usually homogenize sediments faster than they accumulate. Thus, he stated, changes such as the "succession" of Donahue and Rollins (1975) is more likely the result of directional change in environments, which is significantly different from the instantaneous shifts which downgrade the environment and produce a true succession.

The problem of evaluating the record is, in part, one of degree. The distribution of all shallow marine animals and assemblages is, at some level, areally restricted or patchy. An animal that is broadly eurytopic on one scale may be patchy on a much more local scale, either due to random chance or particular aspects of its distribution. A particular community may be a definable entity by itself, or a part of a larger entity.

All this is very important to answer the question, are we looking at a succession condensed into one horizon or a diverse community?

With respect to additive diversification, it's important to know whether the animals were alive at the same time, or simply time-averaged together by low sedimentation rates. The answer lies in how discrete the elements must be. Following Johnson's (1972) concept of an areal (as well as temporal) mosaic, at any one time many different stages of the local succession are in a prevailing larger-scale environment. These coexisting stages would be expected to be time-averaged. On that scale, time-averaging would be no handicap; small scale time-averaging of local patches would not significantly distort interpretation of the general environment. However, if time-averaging (due to low sedimentation) were severe enough to mix the faunas from different environments, problems of interpretation might develop.

More to the point, how do we know the apparent diversity increase toward the limestones is not an artifact of slowdown in deposition and condensation? On a fine scale, the faunas must be time-averaged; it is unlikely all the animals there lived simultaneously, especially if a succession is evident. But on a slightly coarser (and more useful) scale, they lived together, either areally or successionally separated, but within the same general environment.

Fürsich (1978) listed several criteria for identifying condensed faunas. He noted that such faunas would possess abnormally high diversity, and that features such as solution, encrustation, or mineralization were indications. If the mature community existed for a long time, its remains would dominate the fauna, and the precursor communities' contribution would shrink to insignificance and undetectability.

Applying these criteria to the shales studied, few of them possess abnormal diversity. The possible exceptions are (1) the shale partings in the limestones (although this is difficult to judge because it requires comparison to the faunas in the limestones) and (2) the thick grey shales, in which high diversity is possibly a function of diagenetic preservation of a portion of the community normally lost. Solution and encrustation are generally rare in the sediments; only the shells immediately below the middle limestone occasionally show what may be extensive algal coating. Mineralization can be interstitial and rapid (Clark and Lutz, 1980, demonstrated pyritization of a living mollusc), and pyritized brachiopods and apatite steinkerns are common; however, encrusting mineralization, such as that produced by long contact with mineralizing seawater, is rare (pyritic horizons on top of the Coffeyville Formation at Tulsa, Oklahoma, and on the Davis City Coal at Davis City, Iowa, may qualify). (Arguably, a matter of degree exists here. Glauconitization and possibly apatite steinkern formation do require slow sedimentation. However, it's not known if it's sufficiently significant to result in mixed faunas, particularly as both tend to occur where successions are less likely. In any event, they are largely restricted to limestones, and may not have much bearing on the shales.) Finally, no assemblages are known that are dominated by "mature" faunas; if there are separate "mature" faunas, they never lasted long enough to ever form a major component of the fauna. (By the reasoning above, if the mature fauna was present for a significant amount of time, it should dilute the pioneer fauna to the

point of insignificance, and produce a disjunct distribution. This was never found in the shales.)

Lockwood (1972) provided an interesting verification of the premise that the studied faunas were indeed a mosaic, and that they did co-exist rather than succeed each other. She worked with the Francis Formation in southern Oklahoma, a thick grey shale equivalent to much of the Dennis cyclothem. She found both lateral and vertical mosaic patterns, as would be expected if the rate of sedimentation sometimes exceeded the rate of sequencing, while permitting the sequence to culminate at other times. Notably, the associations she found in the patches were similar to those found here, and were generally additive in nature. By extension of the principle, Senich's (1978) mosaic pattern in the limestone may indicate sedimentation there also outstripped the rate of sequencing.

Thus, the distribution of sequential units can be tied to a relative rate of deposition. When deposition episodically exceeds the rate of sequencing, a vertical and horizontal mosaic would develop. With lower rates of deposition, continuous, time-averaged horizons would develop, the degree of time-averaging depending on the rate of net deposition. Virtually all the shales studied did not exhibit a recognizable mosaic (in the nearshore shales, the sequence would not proceed far in any case; in the others, either sampling was deficient or the rate of deposition was indeed low). Most of the shales showed relatively continuous deposition, albeit slow; saltation in the sequence (due to nondeposition or erosion) was rare and readily recognizable. Thus, each unit of the faunal sequence represents a time-averaged

association. With increasing stability, probably due to increasing water depth, new, more stenotopic elements are added to the local successions, and are time-averaged with the pioneer elements. Thus, an additive pattern of faunal occurrence is created, with the most stable part having the highest diversity.

An aspect of time-averaging applies to recognition of opportunistic species. Both Levinton (1970) and Warme and others (1976) recognized the problem: in a time-averaged assemblage, opportunists might not be recognizable due to dilution with later successional elements. Levinton also recognized the opposite problem:

> The presence of a non-transported fossil species in high densities may indicate that formerly it was living in great abundance (assuming sedimentation rates were not inordinately low).
>
> - Levinton, 1970, p. 73.

The operative part is the parenthetical clause, for if sedimentation were low, faunal condensation would result. Curiously, this study provides examples of both cases--true opportunists, such as Crurithyris and Neochonetes that occur in monotypic horizons; and Derbyia, which is noted for forming pavements. However, upon examination, Derbyia horizons are usually fairly diverse, suggesting a degree of condensation (Derbyia is the prominent element because it is a relatively large, robust shell). Notably, Derbyia has a very poor correlation with terrigenous clastic minerals (muscovite and kaolinite), reinforcing the conclusion that the Derbyia horizons are due to condensation.

Factors other than low depositional rates have an influence on the time-averaging of a faunal assemblage. Blatt and others (1980) noted

that in most depositional areas, sedimentation is so slow that infaunal reworking of sediments far exceeds the influx of new sediment. Obviously, this would lead to extensive homogenization of faunas, although any sedimentation at all would help to preserve some degree of discreteness, as the most buried horizons gradually go out of circulation.

Burrowing can introduce other factors into the faunal distribution in addition to homogenization. Aller (1980) noted that in water less than 15 meters deep in Long Island Sound, there was little shell preservation, even in diverse faunas and where the bottom was saturated with respect to calcite and aragonite. He found that burrowing promoted oxidation of bottom sediments, and that carbonic and sulfuric acids formed and caused the pore waters to be undersaturated in respect to the carbonates. He also found that areas of frequent environmental disturbance, where burrowing was inhibited, were far more likely to have shells preserved (as well as retain physical structures) than those in more stable environments. In deeper water, the shells were often chalky and pitted from dissolution; Aller cited evidence by Westrich and Berner (1980) that bioturbation caused oxidation to a depth of 1.5 meters in Long Island Sound. He noted, however, that in some cases, deep burrows may fill with surficial shelly material, enabling it to bypass the zone of dissolution.

Rhoads and Larson (1981) added some interesting information. They noted that by the Late Paleozoic infaunal deposit feeders were well developed, but they also pointed out that pioneer assemblages then,

like those today, probably didn't bioturbate more than about the top 3 centimeters of sediment.

Low oxygen levels in the sediment, of course, also inhibit burrowing and homogenization of the sediment (Byers, 1974). Between low oxygen levels inhibiting burrowing in the core shales and unstable environmental conditions inhibiting burrowing in the outside shales, it would seem that much of the shales deposited should be relatively undisturbed by burrowing (and thus not subject to further fossil loss), as well as retain many depositional features. In large part, the shales appear to reflect this, but it should be less likely with more stable diverse faunas.

How are well-burrowed substrates recognized? Lack of structure, as pointed out by Byers (1974), is one way. Unfortunately, on weathered shale slopes this is frequently not directly observable, and in any case is frequently ambiguous. Using Aller's (1980) observation, lack of pyrite and organic material would be suggestive; this goes along with Rhoads and Morse's (1971) observation that low-oxygen conditions inhibit burrowers, particularly shelled forms. Then, too, one can use the fauna, not only directly observable infaunal burrowers, but also other forms. Burrowing does soften the sediment, permitting water to enter it; potentially, areas of extensive burrowing will have a fauna adapted to a soft bottom. Johnson (1970) observed that soft, shifting bottoms were less stable and had fewer niches; with all else equal, they should have lower diversity.

Shales were originally mud, and were presumably soft in most cases, either from water incorporated during initial sedimentation,

and/or by later burrowing. Thus, the shales studied would presumably be prime candidates for soft-bottom adaptations, either in areas of rapid deposition or in areas of intense bioturbation. A lack of such adaptations, or restriction of their distributions, might indicate that sedimentation was actually slow and/or intermittent, and/or that burrowing was minimal.

Rhoads (1970) and Thayer (1975) listed a number of features that pelecypods and brachiopods might use for soft sediment adaptation. Many of these were discussed in the brachiopod analysis of this study. It is fairly evident that productids and chonetids are adapted for muddy, if not soft, bottoms; in contrast, other brachiopods (such as Composita) are poorly adapted for such conditions. Small size, a possible adaptation for soft bottoms, is fairly common, but Thayer noted that this is also advantageous in low-oxygen conditions, or could be a result of turbidity stunting.

There may be another line of evidence. Purdy (1964) noted that deposit feeders are more common in muddy environments, due to the greater amount of fine organics (food) in muds, and also because suspension feeders do better in currents (which tend to remove mud). Craig and Jones (1966) observed suspension feeders principally on gravelly or shelly bottoms in the North Irish Sea; there, too, the biomass and diversity was higher than in muds. They also noted limitations on epifauna (largely browsers and specialized predators): epifauna tends to be heavily shelled, so the bottom would need to be firm enough to support them or permit movement; for example, Craig

and Jones noted that a soft bottom could restrict gastropods by being too soft for traction.

Rhoads and Young (1970) provided an instructive exception. They studied infaunal burrowing activity in Buzzards Bay (produced mostly by protobranch pelecypods, such as Nucula and Yoldia). The burrowers produced very soft sediment; the sand-sized fecal masses of mud were more easily eroded than unreworked mud, and could easily generate considerable turbidity. However, by a series of experiments and observations, they demonstrated that the principal controls on epifauna were lack of settling sites and turbidity. In areas where epifauna became established, their baffling effects kept down turbidity and maintained a favorable environment, despite the continued intense burrowing activity of the infauna.

Considering the burrowers themselves, Craig and Jones (1966), and Rhoads and Young (1970) noted that burrowers in soft bottoms should be thin-shelled, unornamented, rapid burrowers. Nucula, Phestia, and Paleyoldia would presumably qualify, but Astartella would not. However, Kauffman (1969) implied a morphology adapted for rapid burrowing may simply indicate burrowing to a greater depth below the sediment surface (and thus niche partitioning), rather than soft sediments. Thayer (1981) called upon lower levels of infaunal activity to explain higher levels of soft bottom immobile suspension feeders in the Paleozoic. However, that is not necessary to explain the higher proportions of brachiopods, bryozoans, and crinoids in Missourian shales. As in modern environments, local patches could develop (presumably on locally favorable substrate) where bryozoans and crinoids could baffle

the currents and keep turbidity down. The soft muddy areas would be the domain of the productids and infauna. The whole would then be time-averaged together, especially without very rapid sedimentation. (This could also explain the apparently anomalous co-occurrence of Paleyoldia and Astartella.) Thus, much of the shales studied could have been modified by burrowing, except in areas of high sedimentation and/or stress, caused by low oxygen or fluctuating nearshore conditions. Environmental instability may limit burrowing, but the presence of epifaunal suspension feeders does not preclude it.

One of the physical agents that might be expected to have a profound influence on shallow-marine faunas would be storms. Bambach and others (1978) and Kreisa (1981) stated that storms winnow shells into coquinites that thin offshore down to layers only a valve or two thick, which are readily bioturbated back into the matrix. Kreisa (1981) noted that in shallow-water deposits, the shales generally have all the shells removed and worked into coquinites, whereas in deeper water the muds are incompletely reworked during storms, and the shales remain fossiliferous. Kreisa also noted that storms produce little abrasion; which is principally the province of constant fair-weather processes, an observation supported by Warme and others (1976).

It is possible that storms play a vital role in preserving fossils, especially in shales. Kreisa (1981) noted that below wave base, biogenic degradation of shells is rapid unless they are quickly buried; Aller (1982) additionally suggested that such storm layers may be better protected against chemical attack due to their bulk composition. Warme and others (1976) and Kreisa (1981) also stated that such storms

seldom significantly transport megafossils, except in the shoreface, beach, and intertidal zones. They agreed with Bambach and others (1978) that the fauna in storm deposits are generally the same as in the adjacent shales, although any local succession within those shales may be homogenized (with the exception of preferential loss of fragile or aragonitic forms). Thus, storms may be a contributing agent to the time-averaging of the sediments.

Particularly in view of the low rate of deposition in much of the outside shales, storms may have been an important factor in contributing to the preservation of shells. However, no unequivocal evidence of their existence was seen. Where alternating shales and shelly layers were present (e.g., the Decatur City Beds; the Winterset Limestone in southeastern Kansas and adjacent Oklahoma), none of Kreisa's (1981) criteria for storm deposits were met. At this point, no evidence for storms exists, although the possibility remains, especially if it's required for fossil preservation.

In general, it seems that transport is not a factor in the distribution of megafauna (Johnson, 1972; Stanton, 1976). Purdy (1964) noted a possible exception: diversely fossiliferous oölite (such as the Missourian Drum oölite of southeastern Kansas). He stated that due to unstable substrate, oölites usually had low diversity, although they might have good abundance. So a diverse fauna either had to originate in a marginally oölitic environment or be transported in. However, in oölites and other grainstones, the possiblity of transport should be readily apparent.

Mudge and Yochelson (1962) stated that most Virgilian fossil assemblages in the Midcontinent were biocoenoses; Fagerstrom (1964) reached a similar conclusion about a Missourian shale. Their observations also apply to the faunas examined here. With a few exceptions, there is no evidence of transport or abrasion; many delicate forms are in good shape. The shells are not scratched or pitted, and are rarely bored, and there is no sorting of the fragments of crushed shells.

Post-depositionally, various chemical processes may work to modify the original fauna present (Chave, 1964; Fürsich, 1978). The most obvious possiblity for loss is of the aragonitic molluscs; this was discussed in detail in the introduction to their paleontology. However, Chave (1964) also added that high-magnesium calcite may also be preferentially lost, particularly if it dissolves before replacement, rather than merely losing magnesium in a solid-state process.

The overall abundance of carbonate in the sediment may be important, as well. This would determine how much dissolution would be necessary to bring the interstitial solutions into equilibrium. Generally, dissolutional loss is not an evident problem; however, rapidly deposited sediments with a small proportion of shelled invertebrates could be seriously undersaturated. Hakes (1976) in part called upon this mechanism to explain the discrepancy between the lack of shelled fauna and abundant ichnofossils produced by them in certain outside shales. Without trace fossils, though, this may be a bootless argument; it's difficult to argue something was present when there are no remains, but it is still a possibility.

Summary of Distributional Effects

The faunas found in the studied shales generally conform to a distributional model that involves an increasing physical stress on the environment. This would include both the outside and core shales, although the stresses are obviously different. In the outside shales, a host of nearshore conditions is possible, such as fluctuating salinity, turbidity, and rate of deposition. Conditions in the core shale are not so diverse; low oxygen conditions seem to be the principal variable. The overall effect is a physically-controlled faunal sequence, rather than a biologically-dependent succession. This sequence is evident in the stratigraphic record; although it is probably time-averaged on one scale, those animals averaged together probably lived in an environment where the physical aspects were essentially similar; when physical conditions irreversibly changed, new faunal elements were introduced.

Note that the changes were time-averaged, and in an irreversible sequence, which indicates both a steady change in gross environmental parameters and a low rate of net deposition. In areas where deposition was high, a stratigraphic mosaic pattern is present, due to the temporal mosaic of the faunal sequence.

An important contrast can be found in the differences between the outside and core shale sequences. The sequence in the outside shale has more variation, expressing various influences. There are several pathways present toward a more complex assemblage, and sometimes there

are steps missing. In the core shales, on the other hand, the steps are relatively uniform. Some variation exists, but far less than in the outside shales, and there is no evidence of missing steps, except in extreme cases.

While the evidence is consistent with simple physical controls, even in the limestones, there may be biological controls present. Theoretically, they should be more important in the limestones (if they represent the stablest and most diversely fossiliferous portions of the cyclothems). There may even be biologically controlled assemblages (the phylloid algal assemblage is a possibility), but the general sense is of physical stress gradients.

The animals present are apparently the animals that lived there. Transport was probably not a major factor, especially in the megafauna; with the sample sizes involved, very pervasive transport would be necessary to significantly skew the fauna, for which there is no evidence. The sediment and the fauna may have been extensively modified by burrowing and by storms, but that may have aided fossil preservation, and served to time-average the local fauna; nevertheless, little direct evidence of either is present.

Post-depositional factors are largely a question mark. It can be argued that certain animals must've been present and lost through diagenesis, particularly when co-occurring resistant forms are present. But proof is generally lacking. Molluscs, particularly pelecypods, are more common in environments that would be more hospitable to their preservation, but possibly also to the living animals. Whether they

were so restricted in life is only guessable, but they are now restricted for practical purposes.

Faunal Associations

Many workers have recognized that Upper Pennsylvanian cyclothems have distinctive faunal suites. Many attempts have been made to systematize them and develop relationships, many of which have a considerable degree of validity.

A major stumbling block has been recognition of the degree of continuity involved. Johnson (1970) noted that especially on a soft substrate in shallow water, communities are gradational, and went so far as to state that there was no meaningful way to divide a spectrum into discrete "communities". Rollins and others (1979) observed that faunal boundaries are only as distinct as the associated stress gradients, and used a classification based on "end members". However, the vagaries of deposition and petrology make the problem more complex. In much of the Midcontinent region, the Illinois Basin, and the Appalachian Basin, where much of the paleontological work has been done, periods of little or no deposition have condensed or eliminated faunal patterns, producing anomalies. In many cases, these events are sufficiently consistent that they have frequently gone unrecognized, appearing to be the rule rather than the exception. Thus, many of the faunal units worked out for the Upper Pennsylvanian are unrelated, or represent composite assemblages.

Several European schemes have clarified matters. There, deposition was apparently much more continuous, and faunally symmetrical

cyclothems have been recognized (e.g., Calver, 1968; Bless, 1969; Fig. 68, 69). When applied to the very similar North American cyclothems, many relationships become clear, and a dominant pattern becomes manifest.

From those works and the work undertaken here, it rapidly became evident that Upper Pennsylvanian faunas were parts of gradational sequences, with a dominant control, modified by lesser, more local ones. Thus, it is not really practical to separate them. However, it is useful to be able to express a fauna and its environment in terms of characteristic elements. Thus, a summary of the various associations recognized is presented, together with an assessment of how they relate to each other. It is essential to remember, however, that these are grades (in the sense of Johnson, 1972) or stages in a complete spectrum, and any number of intermediate faunas can exist, particularly when modified by local conditions that may emphasize one or another element. Also, typical elements of one fauna are usually present in others, so that the concept of an "indicator" fossil is inappropriate; they can really be viewed only on the basis of an association.

Moore (1964) recognized many of the characteristic faunal associations, but did not arrange or relate all of them. However, because he named and analyzed many of them, his nomenclature will be followed when possible. He named the associations after a type unit, then modified his name with a characteristic faunal element. Here, the type unit designation will be eliminated, chiefly because most such units exhibit too much lateral and vertical gradation to be strictly

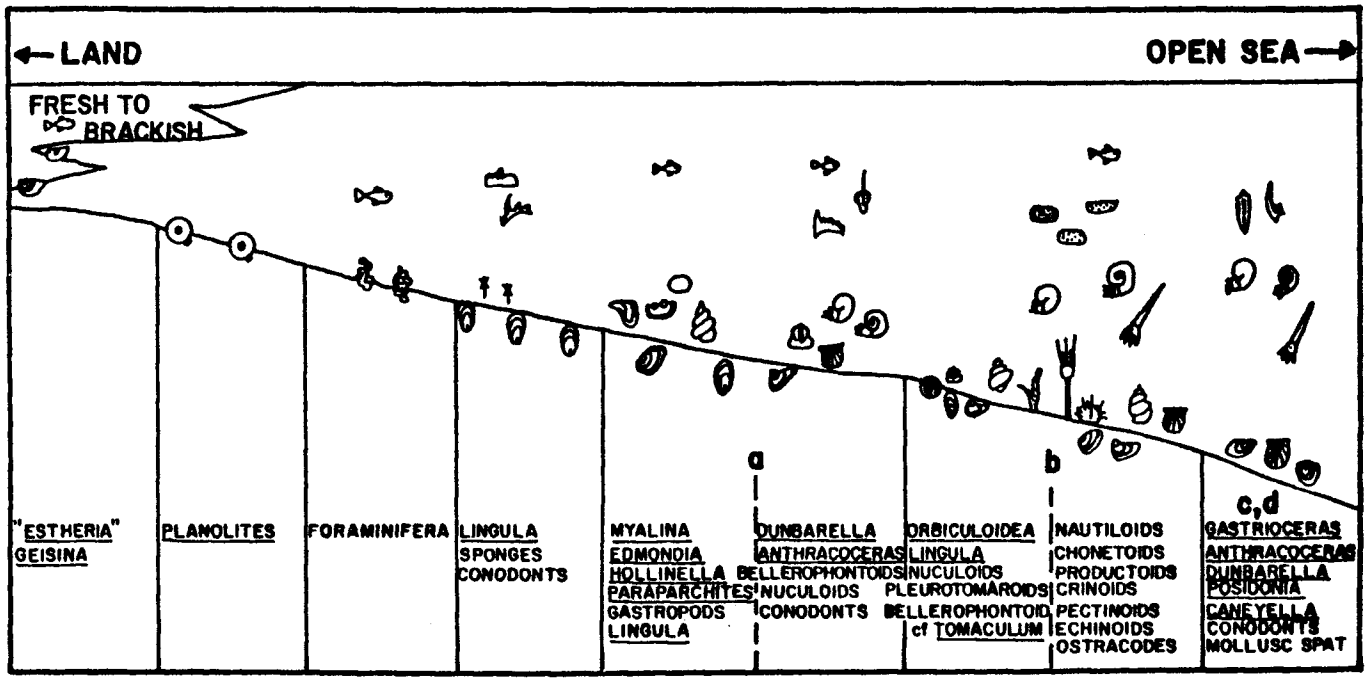



Figure 68. Environmental relationships of Pennsylvanian faunal assemblages (From Calver, 1968).

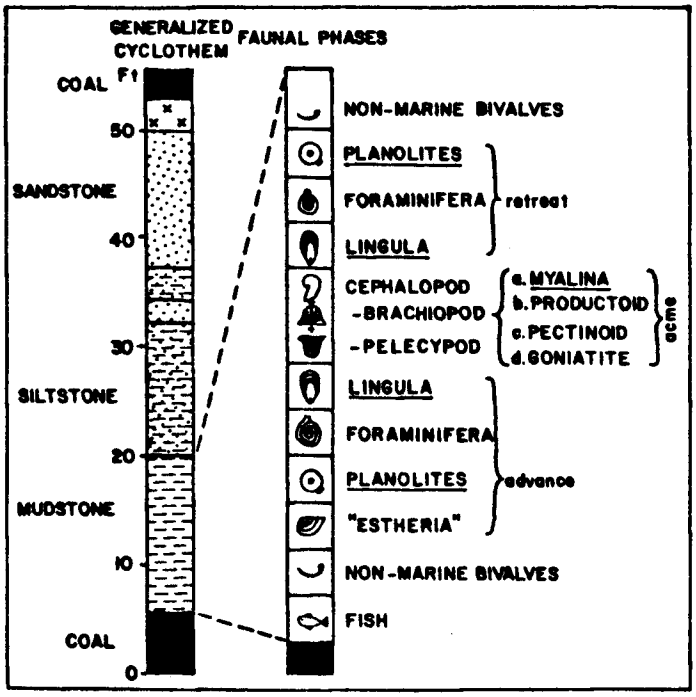



Figure 69. Stratigraphic expression of the Paleontology of a transgressive-regressive cyclothem (from Calver, 1968).

applicable. However, for want of a better system, the practice of assigning a characteristic faunal name will be followed.

The associations described here are based on commonly occurring natural associations and the associations established statistically through co-occurrence patterns. Usually, these are quite similar, as well as coinciding with those described by other authors. The arrangement of the associations is based upon stratigraphic relationships and the stratigraphic distribution of the taxa involved.

Outside Shale Inarticulate Brachiopod Association (I)

The existence of this assemblage as a discrete entity in the cyclothems studied is conjectural, as no specific representative of it

was found. However, it is suggested by statistical patterns, and supported by the literature.

The distributional evidence for this association is based on stratigraphic affinities and co-occurrence patterns. Inarticulates, while found throughout the marine portion of the cyclothem, become more common toward the outside shale, particularly if the intervening middle limestone is not developed. They are found more often with the outside shale end members of the ostracode and conodont sequences (geisinids and Adetognathus) than with the core shale and members (Amphissites and Gondolella). The inarticulates have a relatively low occurrence rate with the calcite fossils (articulate brachiopods, pelmatozoans, and bryozoans) which are characteristic of the limestones and core shales, and a high rate of occurrence with pelecypods and gastropods, which tend to be associated with the outside shales.

Elias (1937) suggested that such a nearshore inarticulate assemblage should exist. Both Calver (1968) and Bless (1969) placed such a biofacies in their sequences: Bless's Biofacies IV and Calver's Biofacies 6 (Fig. 68, 69). Holdsworth (1966) also had an inarticulate brachiopod biofacies in his sequence. In these instances (as in Elias's arrangement), they represent the first appearance of marine megafauna in the cyclothem.

Drawing from Calver (1968) and Bless (1969), such a biofacies would be in silty or sandy shale (although ranging from mud to sandstone) with abundant plant fragments. Lingula and Orbiculoidea would be the principal megafossils; locally small molluscs or sponge spicules might be present. Microfossils would be geisinid ostracodes

Figure 70. Relationship of characteristic associations and depositional environments in Missourian cyclothems.

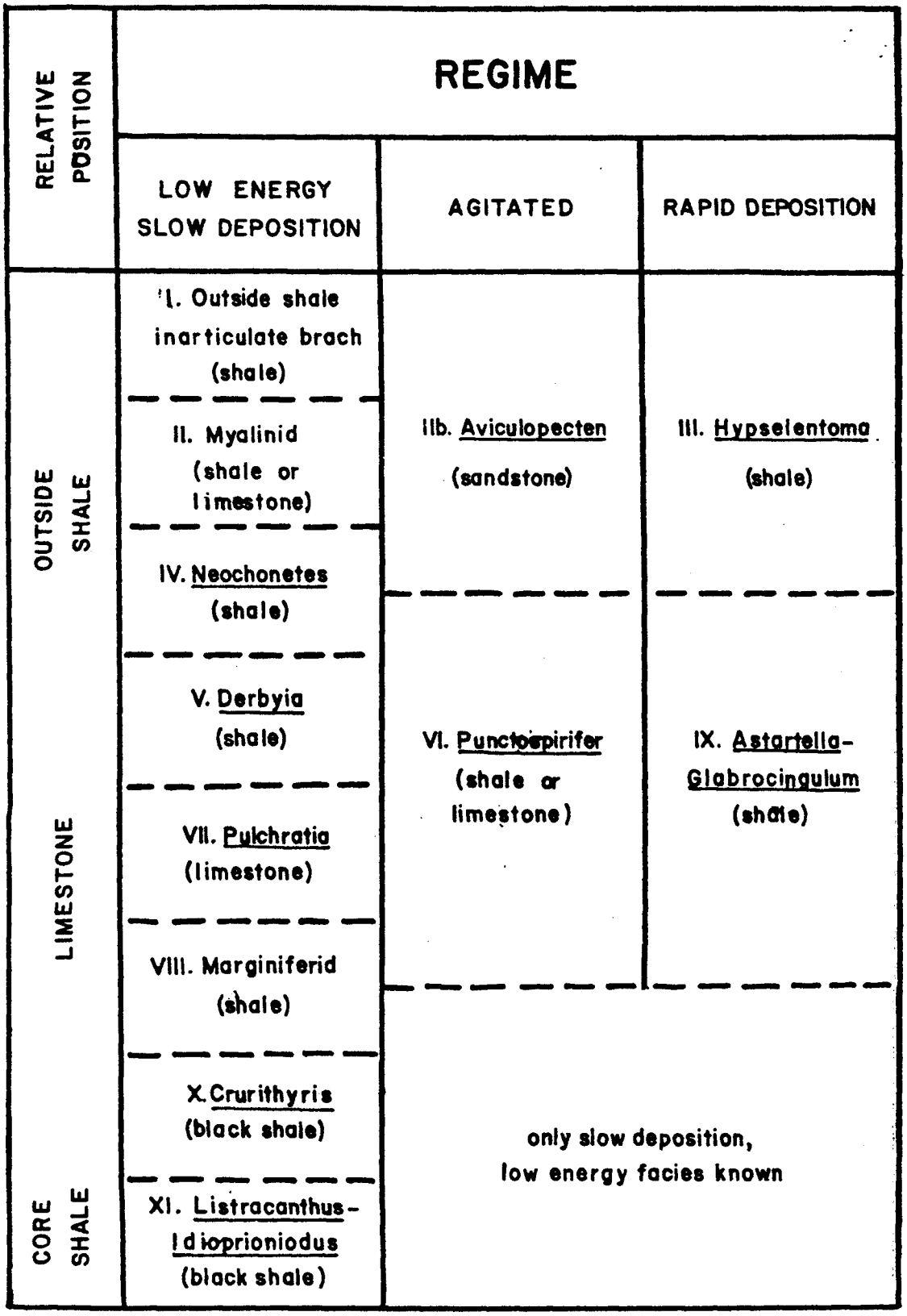

RELATIVE POSITION
REGIME
LOW ENERGY SLOW DEPOSITION
AGITATED
RAPID DEPOSITION
OUTSIDE SHALE
LIMESTONE
CORE SHALE
I. Outside shale inarticulate brach (shale)
II. Myalinid (shale or limestone)
IIb. Aviculopecten (sandstone)
III. Hypselentoma (shale)
IV. Neochonetes (shale)
V. Derbyia (shale)
VI. Punctospirifer (shale or limestone)
IX. Astartella-Glabrocingulum (shale)
VII. Pulchratia (limestone)
VIII. Marginiferid (shale)
X. Crurithyris (black shale)
only slow deposition, low energy facies known
XI. Listracanthus-Idioprioniodus (black shale)

Figure 70.

and perhaps the conodont Adetognathus. Various tracks and trails may be abundant. Generally, faunal diversity would be low, but abundances may be high.

Myalinid Association (II)

Intergrading and perhaps overlapping with the inarticulate brachiopod association is that characterized by myalinids. This approximately follows Elias's (1937) concept of a pelecypod biofacies between the inarticulate and calcareous brachiopod biofacies, but is somewhat more restricted. Calver (1968) recognized such a biofacies in a similar position, characterized by Myalina and other pelecypods (Fig. 68, 69). This generally corresponds to Bless's (1969) Biofacies IVa and V, Mudge and Yochelson's (1962) biotope 8, and Rollins and others' (1979) orthomyalinid bank.

Typically, the fauna consists dominantly or completely of myalinids, often to the extent of forming a shell hash or limestone. In some cases, other elements may form a significant component: various other pelecypods (Schizodus, Edmondia, Pteronites, and nuculids are mentioned by various authors) and/or inarticulate brachiopods are common shelled invertebrates, fish fragments are common, and Spirorbis and ostracodes may be important. Geisinids are the typical ostracodes, but the facies overlaps the transition to others such as Cavellina, Bairdia, and Hollinella.

Where not forming a limestone or in a carbonate matrix, the myalinids are usually in a dark, coaly shale. It is usually the first noticeable biofacies in a cyclothem, commonly at the base; less frequently it may be developed at the top.

In the cyclothems studied, this facies is occasionally developed; the basal beds of the Decatur City Beds, directly over the Davis City Coal, are a good example (Locality DeC1). Frequently, however, condensation combines this biofacies with succeeding ones; the shale just below the black shale in the LaSalle cyclothem at Baileys Falls (Locality LS1) is a possible example.

Geisinid Subassociation (IIa)

It is unclear whether the fauna made up largely of geisinids are significantly different from the myalinid assemblage. Calver (1968) placed his Geisina biofacies in Biofacies 3, with three intervening biofacies before his myalinid biofacies (Fig. 68, 69); Bless (1969) placed it in his Biofacies III, with the intervening inarticulate brachiopod facies before the pelecypod facies. Lane (1964) stated Geisina was always in brackish water, associated with fish fragments and freshwater ostracodes (e.g., Candona and Carbonita).

However, where it was seen in this study, it was intergradational with the myalinid assemblage. At Davis City, Iowa (Locality DC1), the basal Stark contains lenses of ostracode hash, made up of geisinids with minor amounts of myalinids and fish fragments. It occupies the same stratigraphic position as the myalinid facies, and like it, is a very coaly shale.

Geisinids demonstrate a considerable tolerance for nearshore conditions, ranging from coal swamps to limestone environments. They may be concentrated anywhere within that range, so that they don't represent a narrow range.

Aviculopecten Subassociation (IIb)

Aviculopecten is also reported as a pelecypod that forms shell layers at the base of cyclothems, sometimes with myalinids. However, it is also often reported from coarser sediments, such as siltstone or sandstone. Mudge and Yochelson (1962) assigned it to their biotope 7, noting that it occurred with other pelecypods, gastropods, and occasionally fenestrate bryozoans. Wilson (1942) described the sandstone below the Livingston Limestone in Illinois as locally containing Aviculopecten and Lingula. Gentile (1969) described a faunule from the sandy top of the Bonner Springs Shale that included Aviculopecten, Myalina, and nuculid pelecypods; he concluded the association lived in a low tidal flat environment. It is possible that the sandstone at the top of the Coffeyville Formation at Ramona, Oklahoma (Locality Ral) may be an example of this subassociation.

Hypselentoma Association (III)

This assemblage is rarely observed, and has largely been ignored. It is a normally very sparse fauna in the thick grey outside shales. Characteristically, the shales are laminated and micaceous; siderite nodule horizons are common. Siltstone lenses are sometimes present, marked by trails and burrows. Plant debris is occasionally found, including large pieces of coalified driftwood. The fauna consists of the geisinid ostracodes, nuculid pelecypods, and occasional gastropods, mostly assignable to Hypselentoma. The conodont Adetognathus is present in very low numbers, and the small, rod-shaped, grooved fecal

pellet is sometimes present. Occasionally, a stromatolite or oncolite horizon will be present, with an abundance of the characteristic fauna.

The Vilas Shale around Altoona, Kansas (e.g., Locality WCL1) and in southwestern Iowa, provides examples.

Neochonetes Association (IV)

Moore (1964) recognized the Neochonetes association and cited as an example the Virgilian Snyderville Shale described by Toomey (1964). Winkler Prins (1968) recognized the same association in northwestern Spain.

The Neochonetes association is found in shale, and is typically dominated or consists completely of Neochonetes, frequently in great abundance. It is typically the first occurrence of articulate brachiopods in a cyclothem, representing opportunistic colonization of a fluctuating environment. The association intergrades with the myalinid association and with the Derbyia association; Moore (1964) noted that other articulate brachiopods sometimes present include Derbyia, Crurithyris, Juresania, and Antiquatonia.

Moore (1964) stated that in the Missourian, Neochonetes is sometimes replaced by Chonetinella. The significance of this is unknown, since Chonetinella appears to prefer a more coreward association than Neochonetes; however, the two do overlap. Lipp (1975) attributed a fauna completely dominated by Chonetinella (just above the coal in the Cambridge cyclothem of Ohio) to this assemblage.

Derbyia Association (V)

This association includes both of Moore's (1964) Speiser and Florena assemblages. It is characteristically a shale crowded with Derbyia, usually just below the middle limestone; it often represents the most diverse fauna found in the outside shale. Rollins and others (1979) recognized a similar facies in their derbyid pavement of the Cambridge cyclothem, and Winkler Prins (1968) found it similarly expressed in northwestern Spain. Bless's (1969) Biofacies VI and Mudge and Yochelson's (1962) biotopes 3 and 4 probably include this association.

The association has been characterized (Moore, 1964; Winkler Prins, 1968) as the initial transgressive phase of the cyclothem. However, this is unlikely--it has a diverse fauna: not only Derbyia, but also Neochonetes, Juresania, Composita, Antiquatonia, and Reticulatia are present, in addition to diverse gastropods, pelecypods, scaphopods, crinoids, bryozoans, echinoids, corals, ostracodes, and conodonts.

The association is gradational from the Neochonetes assemblage to the Pulchratia association in the (usually overlying) limestones.

The assemblage probably represents the onset of relatively stable conditions. The Derbyia pavement is a result of condensation, inasmuch as Derbyia apparently does not tolerate large amounts of terrigenous clastic materials entering the environment (based on mineralogy). In such a regime, the entire terrestrial to offshore sequence may be condensed, and the Derbyia assemblage would frequently be the first apparent fauna.

A possible exception is in the basal sandstone member of the Shoal Creek cyclothem in southeastern Illinois, where Weller (1957) reported fossiliferous zones with Derbyia the most common fossil. However, it may be that deposition was not rapid and/or was episodic.

Moore (1964) cited the Wolfcampian Speiser Shale (as described by Hattin, 1957) as his type example of the Derbyia association. Hattin had noted as a separate association the myalinid limestone below the Derbyia shale, but Moore included it in the Derbyia association. In the sense of the association used here, it is again restricted to the shale.

Moore (1964) defined the Derbyia-Neochonetes association in the Wolfcampian Florena Shale of the Beattie cyclothem as a distinct association, principally on the basis of its stratigraphic position above a fusulinid-rich limestone. However, its fauna is essentially the same, and represents a transition from more stable conditions (the underlying Cottonwood Limestone) to less stable nearshore conditions (the overlying Morrill Limestone, which consists largely of unfossiliferous dolomitic and osagia limestones), an interpretation supported by Imbrie and others (1964). The fauna would also support such an interpretation. Imbrie (1955) presented data on an ostracode sequence from a basal diverse fauna dominated by Amphissites to an upper restricted one characterized by Knightina. He also noted many horizons where the Derbyia fauna gave way to Neochonetes horizons, indicating fluctuating and unstable conditions. Essentially, the Florena represents the mirror image of the Speiser, in the upper portion of the cyclothem, as

conditions deteriorated, rather than stabilized. On this basis, the two facies are combined into one association.

The association is fairly common in the cyclothems studied. At some localities, no limestone is developed, and it represents the most diverse association in the lower part of the cyclothem below the core shale.

In some cases, a somewhat more complete sequence is evident. The Vilas exposure in south-central Iowa west of Winterset (Locality Wi2) shows a gradational transition from the geisinid subassociation to the Neochonetes association, then to the Derbyia association before being replaced by the Captain Creek Limestone.

Rhombopora Subassociation (Va)

This subassociation is characterized by the dominance of ramose bryozoans, particularly Rhombopora. Moore (1964) listed the Virgilian Doniphan Shale of the Lecompton cyclothem as his type example. Johnson's (1962) Group 5, characterized by Rhombopora and chonetids, may be similar. It represents a variation in the environment locally favorable to bryozoans, as the other elements are generally those of the Derbyia fauna, although less common. The outcrop mentioned above (Locality Wi2) has the Rhombopora subassociation developed as a horizon within the Derbyia association.

Punctospirifer Association (VI)

One of the volumetrically more important associations is the Punctospirifer association. None of the faunal elements are restricted to this association, but all of them show certain common distributional

features, and have a tendency to occur with each other in preference to other animals (Fig. 71). The fauna is quite diverse, and usually occurs in very fossiliferous shales intergrading with argillaceous skeletal calcarenites. The outcrops are usually limonitic and buff in color, reflecting a pyritic unweathered nature. They are found both in the outside shale-middle limestone transition and as a facies of the upper limestone.

The faunal elements are marked by a strong association with muscovite and kaolinite. There are several possible reasons for this: (1) the fauna is dependent on a certain level of terrigenous clastic influx; (2) the fauna is preferentially developed in the southern terrigenous clastic facies belt, where water conditions are more stable; and/or (3) the fauna is dependent on relatively strong current conditions, which rework much of the underlying deltaic material. All of these are possible general considerations, and one or more may explain the occurrence with the clastic minerals.

The fauna is characterized by a high level of occurrence of Punctospirifer, Hustedia and gastropods. Somewhat less strongly related are trilobites, corals, fistuliporid bryozoans, echinoids, and the ichthyodurolite Cooleyella. The sponges are largely calcisponges, especially wewokellids, but some hyalosponges may also be favored by such conditions. (While many of the animals may not occur in the association that frequently, they are included because they are more likely to be found here than elsewhere.) The coreward ostracodes are favored: Amphissites and especially Bairdia. Among the foraminifers, Tolypammina is relatively depleted, but Hyperammina,

Figure 71. Co-occurrence frequencies of characteristic animals in the Punctospirifer association.

Key as in Fig. 60, p.362.

| | muscovite | kaolinite | Gondolella | Idioprioniodus | idiognathodids | Anchignathodus | Adetognathus | Amphissites | Bairdia | Hollinella | Cavellina | geisinids | marginiferids | Punctospirifer | Hustedia | gastropods | fistuliporids | echinoids | sponges | trilobites | corals | Cooleyella | Textularia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amphissites | 13<br>31.7 | 18<br>43.9 | 9<br>22.0 | 19<br>46.3 | 38<br>92.7 | 21<br>51.2 | 12<br>29.3 | | 30<br>73.2 | 19<br>46.3 | 28<br>68.3 | 6<br>14.6 | 9<br>22.0 | 22<br>53.7 | 14<br>34.1 | 27<br>65.9 | 6<br>14.6 | 16<br>39.0 | 9<br>22.0 | 16<br>39.0 | 5<br>12.2 | 1<br>2.4 | 1<br>2.4 |
| Bairdia | 26<br>38.2 | 37<br>54.4 | 10<br>14.7 | 25<br>36.8 | 57<br>83.8 | 27<br>39.7 | 27<br>39.7 | 30<br>44.1 | | 27<br>39.7 | 41<br>60.3 | 12<br>17.6 | 12<br>17.6 | 32<br>47.1 | 21<br>30.9 | 47<br>69.1 | 10<br>14.7 | 17<br>25.0 | 16<br>23.5 | 21<br>30.9 | 8<br>11.8 | 3<br>4.4 | 4<br>5.9 |
| marginiferids | 7<br>46.7 | 10<br>66.7 | 3<br>20.0 | 7<br>46.7 | 15<br>100.0 | 9<br>60.0 | | 9<br>60.0 | 12<br>80.0 | 5<br>33.3 | 6<br>40.0 | 1<br>6.7 | | 11<br>73.3 | 13<br>86.7 | 7<br>46.7 | 5<br>33.3 | 7<br>46.7 | 6<br>40.0 | 9<br>60.0 | 7<br>46.7 | 2<br>13.3 | |
| Punctospirifer | 27<br>51.9 | 33<br>63.5 | 8<br>15.4 | 17<br>32.7 | 42<br>80.8 | 27<br>51.9 | 16<br>30.8 | 22<br>42.3 | 32<br>61.5 | 17<br>32.7 | 24<br>46.2 | 6<br>11.5 | 11<br>21.2 | | 24<br>46.2 | 38<br>73.1 | 12<br>23.1 | 18<br>34.6 | 17<br>32.7 | 18<br>34.6 | 10<br>19.2 | 4<br>7.7 | 3<br>5.8 |
| Hustedia | 19<br>59.4 | 23<br>71.9 | 7<br>21.9 | 10<br>31.3 | 27<br>84.4 | 15<br>46.9 | 5<br>15.6 | 14<br>43.8 | 21<br>65.6 | 9<br>28.1 | 8<br>25.0 | 3<br>9.4 | 13<br>40.6 | 24<br>75.0 | | 23<br>71.9 | 12<br>37.5 | 13<br>40.6 | 14<br>43.8 | 14<br>43.8 | 8<br>25.0 | 3<br>9.4 | 1<br>3.1 |
| gastropods | 48<br>43.6 | 58<br>52.7 | 17<br>15.5 | 34<br>30.9 | 69<br>62.7 | 39<br>35.5 | 35<br>31.8 | 27<br>24.5 | 47<br>42.7 | 29<br>26.4 | 60<br>54.5 | 24<br>21.8 | 7<br>6.4 | 38<br>34.5 | 33<br>30.0 | | 8<br>7.3 | 20<br>18.2 | 19<br>17.3 | 19<br>17.3 | 9<br>8.2 | 2<br>1.8 | 7<br>6.4 |
| fistuliporids | 7<br>43.8 | 12<br>75.0 | 5<br>31.3 | 5<br>31.3 | 14<br>87.5 | 8<br>50.0 | 6<br>37.5 | 6<br>37.5 | 10<br>62.5 | 5<br>31.3 | 4<br>25.0 | 1<br>6.3 | 5<br>31.3 | 12<br>75.0 | 12<br>75.0 | 8<br>50.0 | | 10<br>62.5 | 6<br>37.5 | 8<br>50.0 | 4<br>25.0 | 2<br>12.5 | 1<br>6.3 |
| echinoids | 15<br>53.6 | 21<br>75.0 | 3<br>10.7 | 3<br>10.7 | 18<br>64.3 | 10<br>35.7 | 8<br>28.6 | 16<br>57.1 | 17<br>60.7 | 8<br>28.6 | 17<br>60.7 | 4<br>14.3 | 7<br>25.0 | 18<br>64.3 | 13<br>46.4 | 20<br>71.4 | 10<br>35.7 | | 9<br>32.1 | 13<br>46.4 | 5<br>17.9 | 2<br>7.1 | 3<br>10.7 |
| sponges | 16<br>61.5 | 20<br>76.8 | 7<br>26.9 | 9<br>34.6 | 19<br>73.1 | 8<br>30.8 | 4<br>15.4 | 9<br>34.6 | 16<br>61.5 | 4<br>15.4 | 6<br>23.1 | 3<br>11.5 | 6<br>23.1 | 17<br>65.4 | 14<br>53.8 | 19<br>73.1 | 6<br>23.1 | 8<br>30.8 | | 6<br>23.1 | 3<br>11.5 | 3<br>11.5 | 4<br>15.4 |
| trilobites | 15<br>50.0 | 18<br>60.0 | 4<br>13.3 | 9<br>30.0 | 23<br>76.7 | 14<br>46.7 | 10<br>33.3 | 16<br>53.3 | 21<br>70.0 | 15<br>50.0 | 16<br>53.3 | 4<br>13.3 | 9<br>30.0 | 18<br>60.0 | 14<br>46.7 | 19<br>63.3 | 8<br>26.7 | 13<br>43.3 | 6<br>20.0 | | 7<br>23.3 | 1<br>3.3 | 1<br>3.3 |
| corals | 7<br>53.8 | 8<br>61.5 | 1<br>7.7 | 4<br>30.8 | 12<br>92.3 | 9<br>69.2 | 2<br>15.4 | 5<br>38.5 | 8<br>61.5 | 5<br>38.5 | 6<br>46.2 | 1<br>7.7 | 7<br>53.8 | 10<br>76.9 | 8<br>61.5 | 9<br>69.2 | 4<br>30.8 | 5<br>38.5 | 3<br>23.1 | 7<br>53.1 | | 2<br>15.4 | |
| Cooleyella | 4<br>50.0 | 5<br>62.5 | 1<br>12.5 | 2<br>25.0 | 6<br>75.0 | 5<br>62.5 | 3<br>37.5 | 1<br>12.5 | 3<br>37.5 | 3<br>37.5 | 2<br>25.0 | 2<br>25.0 | 2<br>25.0 | 4<br>50.0 | 3<br>37.5 | 2<br>25.0 | 2<br>25.0 | 2<br>25.0 | 3<br>37.5 | 1<br>12.5 | 2<br>25.0 | | |
| Textularia | 4<br>50.0 | 6<br>75.0 | 1<br>12.5 | 2<br>25.0 | 3<br>37.5 | 1<br>12.5 | 4<br>50.0 | 1<br>12.5 | 4<br>50.0 | 1<br>12.5 | 6<br>75.0 | 1<br>12.5 | | 3<br>37.5 | 1<br>12.5 | 7<br>87.5 | 1<br>12.5 | 3<br>37.5 | 4<br>50.0 | 1<br>12.5 | | | |

Figure 71.

Ammovertella, and possibly Textularia are relatively more abundant. All conodonts are generally less common, although the distributions are not skewed. This last feature suggests the possibility that the rate of deposition was relatively high (compared to more conodont-rich faunas farther north) and that the relative phase of deposition is approximately the same as that for more normal limestones.

In some respects, the environment represented overlaps with that of the Derbyia association. Many of the faunal elements also occur in that association, but are less abundant. In some cases, Punctospirifer is quite common, almost forming shell beds at the base of the middle limestone in place of Derbyia; the rate of deposition and/or turbulence of the environment is likely a controlling factor on whether Derbyia or Punctospirifer is the dominant form.

The association may also overlap and intergrade with the marginiferid association, as marginiferids quite frequently occur with many of the faunal elements present. This may reflect a potential subdivision of the Punctospirifer association, as some elements (such as Textularia) have shallow-water affinities, while others (Hustedia and the marginiferids) are closer to the core environment.

The Punctospirifer association probably roughly matches the sponge assemblage Carew (1978) found in the Upper Pennsylvanian of north-central Texas and the calcisponge community MacLeod (1981, 1982) found in the Missourian Wolf Mountain Shale of the same area. It probably overlaps in part with Calver's (1968) productoid biofacies, which is characterized by articulate brachiopods, crinoids, trilobites, and corals (Fig. 68, 69); it may also generally correspond to Bless's

(1969) Biofacies VII and VIII, the former being characterized by Amphissites and bairdiids, spiriferids, corals, and trilobites, among other diverse elements, and shows evidence of being an agitated environment. Biofacies VIII is largely limestone, but Bless noted that the bases are characterized by prolific spriferids.

Examples of the association are fairly common in the cyclothems studied in southeastern Kansas. At Coffeyville, both the Coffeyville-Canville transition (e.g., Locality CB1) and shaly Winterset beds (e.g., Localities Cf1, Cf4) are examples, while the top of the Vilas near the Benedict Bed north of Altoona (Locality Al2) is an example of the Punctospirifer-rich horizon at the base of the middle limestone.

Pulchratia Association (VII)

Moore (1964) established the Pulchratia association as being characterized by abundance and diversity of fauna more than any particular organism, and established the Virgilian Beil Limestone as the type. He conceived of it as being a limestone facies, but here that should be amended to include shaly limestone partings and shale interbeds. These shales are remarkably fossiliferous, and sometimes have forms (notably large productids, such as Pulchratia and Echinaria) present that are not common elsewhere.

A typical example of this would be the Kiewitz Shale in eastern Nebraska (e.g., at Locality Lo1).

Marginiferid Association (VIII)

The marginiferid association is most evident at the contact of the upper grey transition of the core shale and the adjacent basal upper

limestone. Typically, the lithology is calcareous grey mudstone grading into argillaceous calcilutite.

Although marginiferids are common through much of some limestones, they are prominent elements at the contact mentioned. Statistically, this is closely related to the Punctospirifer association, and is also gradational to the Pulchratia association; indeed, a characteristic is the occasional appearance of large, limestone-associated productids (such as Pulchratia) in the shale beds closest to the limestone.

This association is very persistently developed at the base of the Winterset Limestone where it conformably overlies the Stark Shale. Examples can be found readily in Oklahoma (Locality Bt2), Kansas (Locality Jil), and Iowa (Locality Wil). In the south, it also intergrades with the Punctospirifer association found in much of the adjacent Winterset.

Astartella-Glabrocingulum Association (IX)

This association is diversely fossiliferous and characterized by large admixtures of molluscs, in addition to calcitic faunal elements common in other associations. The association occurs in thick grey laminated shales, frequently with abundant siderite nodules. Sandstone layers and lenses, some with ripple marks, flute casts, or load casts are common.

The fauna is noted for its molluscs: the pelecypod Astartella, the cephalopod Eoasianites, and the gastropods Glabrocingulum, Worthenia, and Trepospira are often abundant; rostroconchs and scaphopods are often found with the other molluscan forms. Calcitic forms are

numerous and diverse: many large pelmatozoans, echinoids, bryozoans, and articulate brachiopods such as Neospirifer, Crurithyris, Punctospirifer, Hustedia, Composita, Linoproductus, and chonetids are common. Hollinella, Bairdia, and Cavellina are common ostracodes; conodonts are very rare, but tend to be of the idiognathodid type.

The fauna appears to differ from the typical Midcontinent fauna principally by the addition of molluscs. As pointed out earlier, this may simply be a diagenetic result of relatively rapid deposition, and may not represent a great variation in the original environment. Carew (1978) essentially observed this when he noted that the molluscan facies was more diverse due to addition of molluscan forms without a corresponding loss of calcitic forms.

The dichotomy between molluscan-dominated shales and the shales and limestones of the Midcontinent dominated by calcitic forms has long been a principal basis for partitioning Pennsylvanian faunal assemblages. Molluscan faunas have been widely recognized as distinct in the areas where relatively high rates of deposition are a factor: in Texas (Petty, 1975; Carew, 1978; MacLeod, 1981, 1982), Oklahoma (Lockwood, 1972; West, 1972), Illinois (Johnson, 1962), and Ohio (Rollins and others, 1979). In some cases (e.g., Lockwood, 1972), attempts were made to subdivide this assemblage; this is probably a valid effort, especially if it is simply a depositional and diagenetic variant of the Midcontinent faunas, but care must be taken to take such variables properly into account. In this study, the association was insufficiently sampled to permit any such attempt, but suggestive evidence was observed for sequential changes in the outcrops.

Typical examples of this facies were observed in the thick grey Eudora Shale at Copan, Oklahoma (Locality Cp1) and at Walker Mound, near Independence, Kansas (Locality WM1).

Crurithyris Association (X)

This association is the same as Moore's (1964) Orbiculoida-Lingula association, but has been renamed here to avoid confusion with the outside shale inarticulate brachiopod association (Association I). Moore cited as a type example the lower black bed of the Bennett Shale in the Wolfcampian Red Eagle cyclothem as described by McCrone (1963).

This association is developed in soft black to dark grey blocky to poorly laminated shale. In well-developed cases, it is transitional between the black fissile shale with the Listracanthus-Idioprioniodus association and the marginiferid association, particularly above the black fissile shale. When present below the black fissile shale, it is usually very thin. In some cases, such as the cited Red Eagle cyclothem, the black fissile facies is not developed; however, Moore (1964) noted that like the black fissile facies it is laterally very persistent (traced over 300 miles in outcrop in the Red Eagle cyclothem) and has a very sharp basal contact.

The fauna consists principally of eurytopic elements, such as Lingula, Orbiculoidea, and Crurithyris, and of distinctive elements associated with the facies, such as the agglutinated foraminifer Hippocrepina, the ichthyodurolite Styptobasis, and the conodont Gondolella. Crurithyris is often common to the point of forming what several authors have called a coquina (Evans, 1966; Crouch, 1971). In

some cases, the small orthid Rhipidomella is also present, occasionally replacing Crurithyris, although never as abundant. Other faunal elements, such as Amphissites, various sponges, productids, echinoderms, and molluscs are occasionally present, probably representing a portion of the transitional fauna. In many cases, small cylindrical burrows, often pyrite-filled, extend down toward the fissile black shale (Price, 1977).

Many workers have recognized this facies, although in many cases it has been lumped with the fissile black shale. Johnson's (1962) Orbiculoidea association was essentially the same, as were Mudge and Yochelson's (1962) Virgilian biotopes 5 and 6 (characterized by inarticulate brachiopods and Crurithyris, respectively). Winkler Prins (1968) recognized the association in northwestern Spain, and West (1972) may have found a similar association at the base of the Wewoka cyclothems in Oklahoma. Other descriptions attributable to the association are widespread (e.g., Cassidy, 1968; Hickey and Younker, 1981).

An obvious problem with interpreting this association stems from its low diversity and eurytopic forms, which include many of those in Association I (Crurithyris is one of the first articulate brachiopods to appear, often with Neochonetes). This is further complicated by the commonly abrupt basal contact of the black shale, often adjacent to very shallow or even terrestrial deposits. Thus, both faunally and stratigraphically it can be quite misleading, and has frequently been misinterpreted as a shallow water, lagoonal deposit (Moore, 1964; Winkler Prins, 1968; West, 1972; Hickey and Younker, 1981).

Examples of this association were very widespread in this study, and encountered in virtually every section where black shale was developed.

Listracanthus-Idioprioniodus Association (XI)

This association is the equivalent of Moore's (1964) Listracanthus association, for which he cited the Virgilian Heebner Shale as a type unit. It is a hard, fissile, noncalcareous, radioactive black shale, characterized by fish fragments (such as Listracanthus and Styptobasis) as well as whole fish (Zangerl and Richardson, 1963). Conodonts are very abundant, sometimes as bedding plane assemblages (DuBois, 1943); most are idiognathodids. Idioprioniodus, although never dominant, reaches its acme in the cyclothem in this assemblage; Gondolella is rare to common, but tends to form the largest percentage of the conodont fauna at the transition to or in the overlying Crurithyris association. Occasionally, other animals are found; Dunbarella horizons are often reported, and scattered Pseudorthoceras, Lingula, Orbiculoidea, and conularids also occur. Generally, however, benthic forms (except opportunistic ones) are lacking.

This association is quite similar to that which Calver (1968) placed in the most offshore, deepest water environment in his cyclothem (Fig. 68, 69). Notably, however, he indicated that he had symmetrical biofacies developed around it, suggesting that it is the acme of cyclothem development. He also noted the general lack of benthic fauna, except for occasional pectinoids. Holdsworth (1966) described a very similar association in the most offshore portion of the

cyclothems, and noted the presence of radiolarians, as well as the lack of benthic megafauna.

The black fissile facies, like that of the Crurithyris association, frequently lies on shallow water or terrestrial deposits, which has often caused trouble in interpretation. However, some faunally analogous deposits might be possible clues. McGugan (1965) cited the Upper Permian Ranger Canyon black shale of western Canada, which unconformably overlies older rocks. The basal radioactive black shale has a phosphate lag of bones and teeth, and a fauna of Lingula, Orbiculoidea, conularids, and the edestid shark Helicoprion. The black shale lacks any other transgressive deposits, stretches from the United States to the Northwest Territories, and is several hundred feet thick. Ellison (1950) described the Mississippian Woodford Shale of West Texas, which is a thick, fissile, radioactive black shale covering a large area. Its organic remains include conodonts, Lingula, Tasmanites, and a crustacean. Ellison concluded it was a euxinic basin, but probably not over 200 meters deep.

These deposits are much like the persistent descriptions of the persistent black shale of the Midcontinent (e.g., DuBois, 1943; Evans, 1966; Schenk, 1967; Mitchell, 1981). This facies and its association were also well represented in the cyclothems studied; it is conspicuous in both the Stark and the Eudora Shales and it is common in the Illinois cyclothems.

Limestone Associations and Facies

Moore (1964) described a number of limestone faunal assemblages, most of which are not applicable here, although they could be readily recognized in the field in the cyclothems. A few, however, bear brief mention in view of their relationships to the adjacent shales.

One is Moore's (1964) Isogramma association for which he designated the Virgilian Leavenworth Limestone as a type example. In fact, Isogramma is very rare in it, and the association is more defined on lithology and stratigraphic position than on a particular fauna. The limestone is the thin middle limestone, typically a single dark grey massive bed, with inconspicuous whole fossils. It is usually markedly pyritic, sometimes with extensive darker burrows. Moore (1964) listed a number of fossils in it, including gastropods and Derbyia (occasionally pyritized), Composita, Antiquatonia, and marginiferids. Over much of its outcrop, the Canville is typical of this facies; locally, the same is true of the thin Lost City Limestone (Locality Ra2).

Moore's (1964) Euconospira association is also developed, for which he cited the Drum Limestone as a type example. It is typically a cross-bedded oölite with an abundant fauna, dominated by molluscs. Cephalopods and myalinids are common, as is a diverse assemblage of bryozoans and articulate brachiopods. Moore noted that many of the outcrops Sayre (1931) attributed to the Drum in his original description have since been found to belong to other units, particularly the upper Bethany Falls.

The Bethany Falls also displays another faunal association farther north. The lithology is a white to mottled grey calcilutite just below the rubbly top of the unit. Fossils are rarely evident, although sometimes high-spired gastropods are present. Microfossils are more common, particularly small silicified pelecypods and ostracodes, the agglutinated foraminifers Ammovertella and Ammodiscella, the conodonts Adetognathus, Anchignathodus, and Stepanovites, and fish fragments (especially paleoniscid teeth and Cooleyella). The top of the Bethany Falls near Jingo, Kansas (Locality Ji1) is a good example.

Another, rather uncommon facies is a sandy dark calcarenite, usually developed at the level of the myalinid assemblage. Identifiable fossil fragments are rare, although that is the source of the bulk of the grains. The limestone is burrowed and homogenized to poorly laminated, often coaly, and sometimes contains abundant fish fragments. Examples are the limestone facies beds of the Decatur City Beds (at Locality DeC1) and lenses in the Vilas Shale at Louisville, Nebraska (at Locality Lo1).

Relationship of Fauna and Lithology

The faunas in the Pennsylvanian cyclothems are closely related to lithology in some ways, but not in others. Some faunas, such as those typical of the black shales, are restricted to those lithologies, and some, such as the Hypselentoma and Astartella-Glabrocingulum assemblages, are found in thick grey shales, often with siderite nodules. However, most of the rest are variably developed, and many can occur either in shales or in limestones. Limestones can be developed in any

assemblage if the rate of clastic deposition is low enough and the rate of biologic accumulation is high enough. Limestones are known to be developed from associations as disparate as the myalinid and the Crurithyris.

Significantly, reaching a particular stage in a cyclothem (as marked by an association) does not ensure that a limestone will be developed, although some associations have a much higher probability than others. Limestone formation with one particular association does not imply that any succeeding associations will also be limestones.

The critical point here is that occurrence of a limestone does not indicate that a particular stage of a cyclothem has been reached, or that the lack of a limestone means it has not been reached. Faunal elements and associations are more dependent on the stage of the cyclothem than is limestone formation, and are frequently developed regardless of gross lithology. This means that the conditions necessary for limestone development are largely independent of the faunas, and that the faunas are not directly dependent on the environmental factor (or factors) required to produce limestone. It is true that certain associations indicate a higher probability of limestone than others, and that there is a tendency for certain associations to occur frequently in limestones, but the two should never be assumed to be interchangeable.

An aspect of this is related to shale partings and beds in limestone units. The shales represent an interruption of limestone deposition, but the mechanism is unclear. The possibilities are either a clastic influx or a failure of carbonate deposition, the latter either

by a brief return to a noncarbonate environment (such as that of the core shale) or some other failure of production. Each type of disruption should ideally produce a distinctive faunal pattern, representing a response to the new condition with a return to normal. In practice, such patterns are difficult to recognize, both due to the small degree of change and the possibility of condensation (the shale may incorporate all the successional changes in the recovery, producing an anomalously diverse fauna). As it turns out, all three types of variation may be exhibited in the cyclothems studied. Some of the dark grey partings in the lower Winterset Limestone may reflect a brief return to core conditions; the Kiewitz Shale may represent either a brief clastic influx or other carbonate failure, but exhibits no sign of a brief return toward core conditions. (It is also not possible to say if the fauna is a single assemblage, present because the disruption was only enough to influence carbonate deposition and not the accompanying fauna, or if the fauna is a condensed fauna representing a successional response to disturbance.) Some shale partings, especially in Illinois and southeastern Kansas, are clastic influxes, as likely is the portion of the Vilas Shale between the Benedict Bed and the Captain Creek Limestone. Other shale partings are less clearly interpretable; some may represent changes in agitation of the depositional environment, as in the southern Winterset Limestone.

## Summary of Faunal Patterns

The cyclothems have a distinctive suite of faunal associations, as well as lithologies. Like lithologies, these associations are

sequentially symmetrical about the black shale, although modest variations do occur. The associations reflect gradation from a near-shore unstable environment with low diversity through an offshore stable environment with high diversity and on to a core environment with a low diversity fauna in an unstable environment; then the sequence is reversed. Johnson (1970) noted that such changes in diversity during transgression are one of the most common patterns of faunal change seen in the rock record. The overall pattern has been attributed to a change in water depth (Elias, 1937; Bless, 1969); Calver (1968) included the black shale as the culminating stage of the transgression.

In addition to providing information on the overall cyclothem, the faunal associations provide more detailed information on aspects of sedimentation, particularly on its comparative rapidity. Certain faunal elements are preserved only when deposition is sufficiently rapid, while others prefer areas of low sedimentation. The faunal associations fall in a distinct sequence, and lack of stages or condensation of several indicate low rates of deposition or erosion. This is particularly true in most cyclothems, which are usually very asymmetric in terms of relative thickness of units, with the lower sequence (below the core) being very much condensed or sometimes truncated, and decipherable only by comparison with more expanded complete sequences.

Many of the faunal elements present did not seem to be greatly affected by the rates of sedimentation. Sedimentation was either not rapid enough or was so episodic as to not effectively restrict their

distribution. Many animals that would be expected to be influenced by bottom conditions apparently weren't, at least to the degree expected, or the bottom conditions weren't what they seem. Another conclusion is that deposition was rarely rapid enough during an individual's life span to significantly inhibit it. Other variables dependent on the gross environment and its stability, apparently controlled faunal distribution, so that the appearance of various animals is dependent on the stage of development of the cyclothem, and not lithology.

Since the same faunas are present in both thick shales and in limestones that are approximately stratigraphic equivalents, finer correlation by stage equivalence can be drawn on the basis of the faunal sequences, and relative rates of deposition determined. For example, when carbonate deposition is overwhelmed by terrigenous clastic influx, it is often possible to determine what stage of the cyclothem was disrupted, as most of the animals appear in the shale. For instance, evidence from the partial cyclothems of the South Bend and Swope in extreme southern Kansas suggest that both were overwhelmed before development of core shale conditions.

Faunal elements displayed a remarkable degree of independence. The ranges (both vertical and lateral) of most forms were independent of others, supporting the idea that they were generally controlled by physical parameters, rather than by biological interactions.

Lane (1964) made some very useful observations on the interpretation of microfauna in shales, which are also applicable to megafauna. He noted there were four types of faunal change in the cyclothems:

(1) range throughout the shale without change

(2) change gradually through the shale

(3) change abruptly between two shales with a thin limestone between

(4) pronounced difference between faunas in shales separated by a thick limestone

The first case simply represents a stable environment, while the second applies to a gradational change, perhaps with a limestone replaced by shale. The third and fourth cases indicate abrupt, pronounced change, and Lane noted that these two changes often involved a fauna including Geisina as one of the two members. These two more obviously apply to a cyclothem; the third change would usually apply to one from an outside shale to a core shale, across the thin middle limestone, while the fourth would generally apply to the reverse pattern across the thick upper limestone.

The faunal patterns also indicate an overall increase in diversity, particularly in those forms likely to be stenotopic, toward the southwest and Oklahoma. This may indicate the direction toward the principal opening into the Midcontinental sea, where water conditions were most stable due to proximity with the open ocean.

The fauna may also reflect the gross nature of the cyclothems in the lack of faunal change from one cyclothem to the next. This would suggest a response to a stress environment, where specialization was not a desirable trait. Even the forms in the diverse environments did not change rapidly. This may reflect the relatively short term nature of the cyclicity, and the necessity to migrate long distances effectively as the environment migrated.

The fauna also provides a lesson on the plasticity of adaptation, at least as related to gross fossil forms. Several groups with a morphology supposedly related to their environment occur in a number of different environments and/or in different stages of the cyclothem (e.g., kirkbyacean ostracodes), or are found with others of contrasting morphologies; thus either the morphological control is apparently not the physical environment, or the forms could functionally converge into the same environment without morphological modification (e.g., bryozoans).

## Paleobotany

The floral assemblages of the Missourian are markedly different from those of the Desmoinesian. Desmoinesian coal swamp floras were dominated by the arborescent lycopods, especially Lepidodendron and Lepidophloios. As the Desmoinesian ended, these disappeared, and the flora became dominated by both true and seed ferns, with some sphenopsids and minor arborescent lycopods, especially Sigillaria. This transition coincided with, and was probably related to, the general loss of major coal-forming environments. Phillips and others (1980) estimated that in the Midcontinent and Illinois Basin, 93 to 99 percent of the Pennsylvanian coal is in Desmoinesian strata. Missourian coals are generally very thin, although they may have significant lateral continuity.

### Megaflora

The Galesburg/Coffeyville strata in southeastern Kansas and adjacent Oklahoma often contain fragments of plant material present,

although these are usually unidentifiable coalified wood fragments. But the material that can be identified corresponds well to the general pattern. For example, at Dennis, Kansas (Locality Del), the upper Galesburg contains silicified Psaronius (true fern) trunks.

The most informative localities are near Coffeyville, Kansas (Localities Cf2 and Cf3), where a well-preserved, diverse compression flora is found in the shaly top of the Coffeyville below the Cedar Bluff Coal. This coal is overlain by about ten feet of sandstone, which is disconformably overlain by the Winterset Limestone.

The flora is composed almost entirely of fragments of sphenopsid and fern-like foliage. The calamite foliage Annularia mucronata Schenk is very common, as is the supposed root structure Pinnularia, which has historically been assigned to sphenopsids (Boureau, 1964). Among the fern-like foliage, Alloiopteris, a true fern, is most common, and Neuropteris, a seed fern, was also identified. Several other fern-like foliage types were also present in low abundance. There were vegetative leaves and sporophylls from aborescent lycopods, although they were relatively minor.

The flora corresponds well to similar floras known in the region. Wilson (1979) reported a sphenopsid-fern flora, including common Annularia and Neuropteris, from the Seminole Formation at the transition from the Desmoinesian to the Missourian in northeastern Oklahoma, about three cycles below the Coffeyville flora. Read (1947) reported a flora from the Chanute Shale (two cycles above the Coffeyville flora) which included nine fern species, among them species of Alloiopteris and Neuropteris, as well as Annularia and Sigillaria.

On a local scale, the Coffeyville flora may be instructive. Although not studied systematically, brief outcrop observations suggested that upward toward the coal, sphenopsid material became more common at the expense of the ferns. This would correspond well with Scott's (1979) observations that sphenopsids were typically water-margin plants, whereas pteridosperms were more common in transition and dry zones (chiefly the floodplain environment). In particular, he cited Teichmüller (1952) as stating that sphenopsids were often associated with delta tops. This would appear to be the case here, as the Coffeyville is a deltaic format, overlain by the marine Winterset Limestone. At the compression flora locality, the upward sequence of events could be interpreted as follows: (1) a floodplain environment, characterized by ferns, which was replaced by (2) a water-margin flora of sphenopsids, then by (3) deposition of the Cedar Bluff Coal itself. This was followed by (4) deposition of the overlying delta-destructive sandstone and eventually by (5) offshore marine deposition.

The Galesburg Shale in the Forest City Basin and similar shales in Illinois, together with the subjacent limestones, often contain pedotubules and pyritized root-like structures, and may have been homogenized by root action. These features are discussed in more detail in the section on soils.

The Vilas Shale produced no identifiable megafloral remains. In several locations around Altoona, Kansas, however, it contained scattered fusainized wood fragments with bleached haloes of shale, which were interpreted as fragments of driftwood.

Malinky (1980) reported abundant remains of conifers, pteridosperms, true ferns, and cordaites in the marine Eudora Shale at Tyro, Kansas (Locality Ty1). Transport and deposition may have been rapid, so the remains could easily be carried in from elsewhere. None of the material was noted during this study, however.

## Palynology

The following discussion is essentially restricted to miospores. Megaspores were frequently observed, particularly in the shallow marine portions of the outside shales, but only occasionally were found closer to the core of the cyclothem (Table 11). The megaspores exhibited little variation, generally being assignable to the form genus Triletes.

Malinky (1980) also reported Triletes and other megaspores from the dark grey marine Eudora Shale at Tyro, Kansas (Locality Ty1).

The miospore flora generally reflects the Missourian megaflora; i.e., ferns, sphenopsids, and scattered lycopods. Generally, Missourian miospore assemblages are of low diversity, as is the Missourian flora when compared to the Desmoinesian.

Most of the spore collections came from the coals in the Galesburg and Coffeyville shales, with a few preparations from other coals and shales. No spore analyses were attempted for the black shales, which do not generally yield useful assemblages. Kosanke (1950) noted that there were few spores in the black shale below the Shoal Creek, and Zangerl (1980) observed that there were very few in the Mecca Quarry Shale. Peppers (1964) found that the black shale at

Table 11

Megaspore occurrences
in studied units

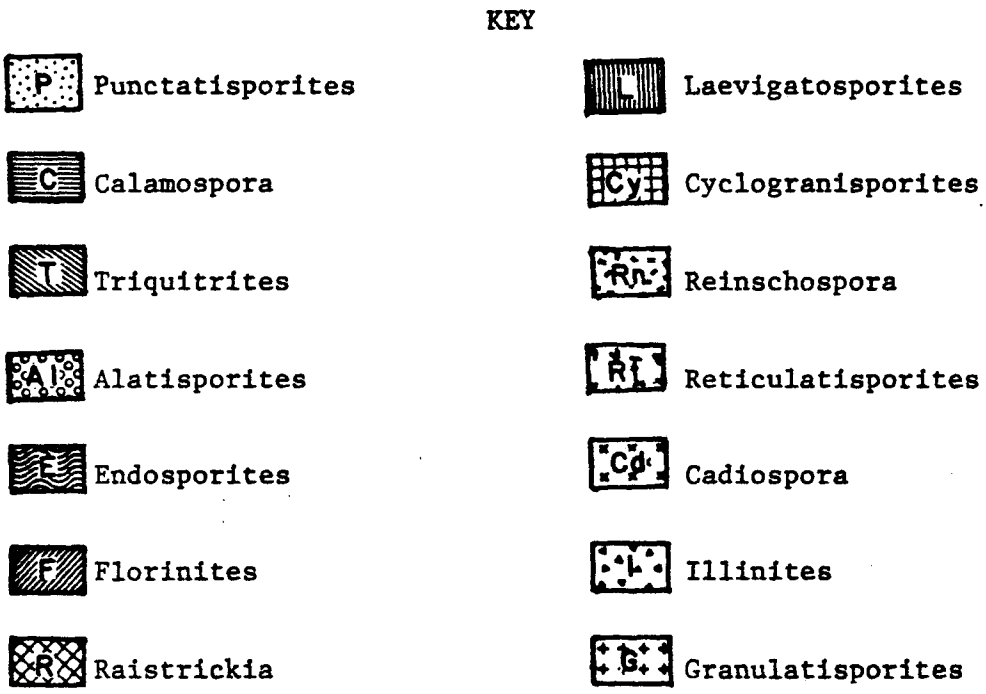
| Unit | Horizons |
|---|---|
| Stark Shale and Decatur City Beds | Pr1/70, Dc1/39, DeC1/63, VW1 |
| Vilas Shale | A11/-27', A11/-14½, Eu1/-36 |
| Captain Creek Limestone | Ma1/155.8' |
| Eudora Shale | Le1/Ø |

Megaspores were noted only from washed residues.

Fithian contained the least diverse spore flora present, and from other work, it can be argued that it is a distal assemblage.

The dominant element in all the coal assemblages studied was the small round spore Punctatisporites, which made up 34 to 89 percent of the microflora. Smith and Butterworth (1967) assigned it to ferns or psilophytes, while Habib (1968) stated that it may have come from an herbaceous fern. He also noted that it was frequently clustered, which was also observed in some of the samples studied here. The dominance of Punctatisporites in Upper Pennsylvanian coals seems to be typical. Peppers (1964) stated that in the McLeansboro of Illinois it was the most abundant genus in all but a few samples. Habib (1968) found that it composed up to 94 percent of some assemblages in a lower Virgilian

Figure 72. Miospore floras of studied and related coals. Original data based on counts of 250 spores.



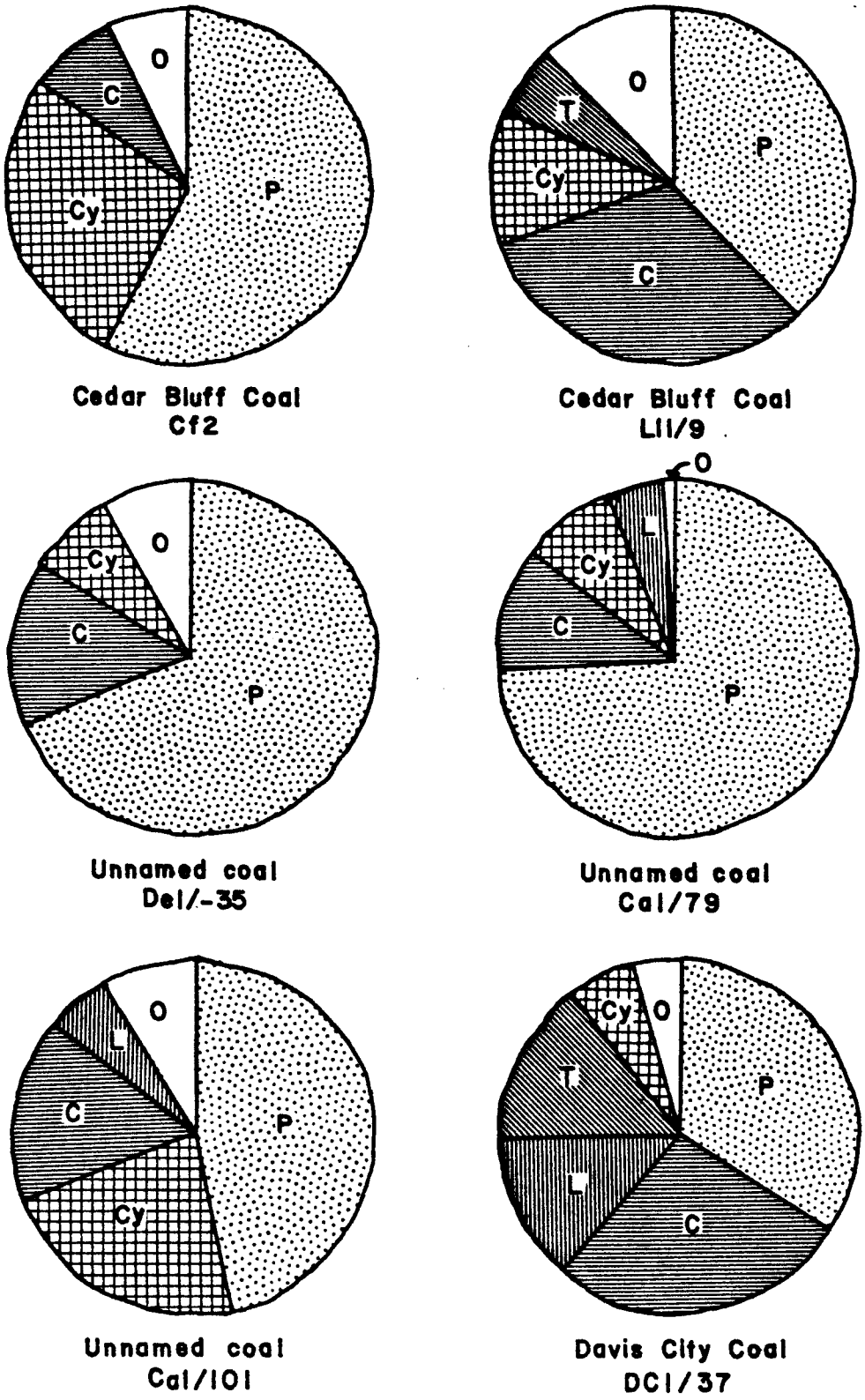

O
C
Cy
P
Cedar Bluff Coal
Cf2
O
Ti
Cy
P
C
Cedar Bluff Coal
LI1/9
O
Cy
C
P
Unnamed coal
Del/-35
O
L
Cy
C
P
Unnamed coal
Cal/79
O
L
C
P
Cy
Unnamed coal
Cal/101
Cy
O
Ti
P
L
C
Davis City Coal
DC1/37

Figure 72

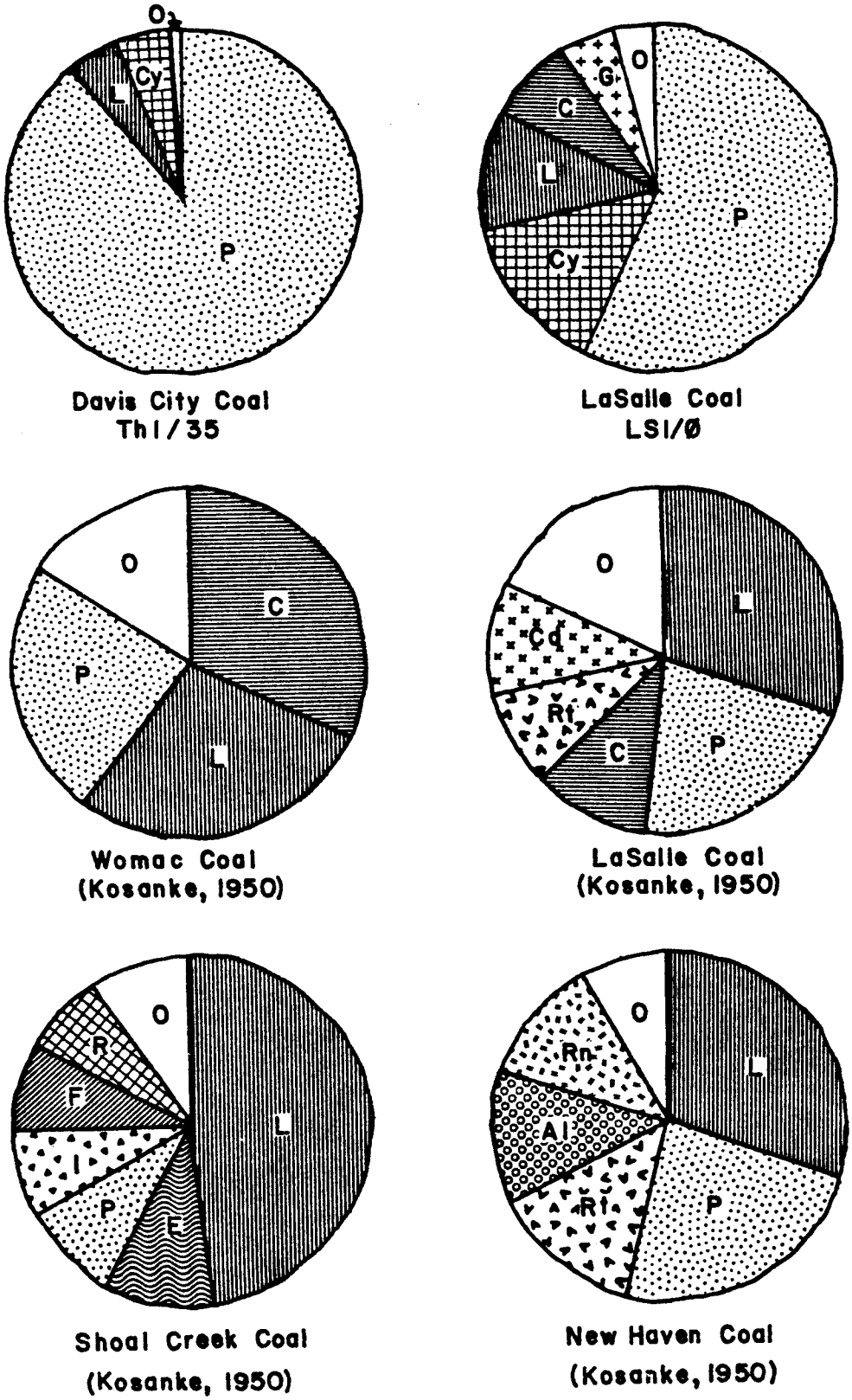



Figure 72 (cont'd.)

coal from West Virginia. Upshaw and Hedlund (1967) found that upper Coffeyville coals at Tulsa were dominated by the small, round, monolete spore they assigned to Latosporites (see Appendix B). Kosanke (1950), however, described somewhat different microfloras in Illinois (Fig. 72). Although he found Punctatisporites in significant amounts in most of his samples, it was usually not dominant. Whether this reflects local environmental variation or some other factor is not known.

Other moderately common fern spores in the coals include Cyclogranisporites (from 5 to 27 percent of the flora) and Triquitrites (up to 15 percent). Less common supposed fern spores included Granulatisporites, Verrucosisporites, Lophotriletes, Apiculatisporis, Raistrickia, and Leiotriletes (assignments from Smith and Butterworth, 1967, and Scott, 1977).

The sphenopsids are also well represented in the coal microfloras. Calamospora ranged from 8 to 32 percent of the flora in the samples studied, except in the Davis City Coal at Thayer, Iowa (Locality Th1), where it composed only 1 percent of the microflora. Laevigatosporites (assigned as a sphenopsid by Habib, 1968, and Scott, 1977) usually constitutes a few percent, ranging up to 17 percent. (Kosanke, 1950, found much higher percentages in his Illinois samples.) These two genera compose only 9 percent of the microflora in the Cedar Bluff Coal at the site of the compression flora, but represent 35 percent of the Cedar Bluff microflora at nearby Liberty, Kansas (Locality Li1).

Lycopods are represented in the microflora by Endosporites and and Crassispora (assigned by Smith and Butterworth, 1967; Habib, 1968;

and Scott, 1977). These form a minor portion of the coal flora, never representing more than a percent or two of the total in the samples studied. Kosanke (1950) reported higher concentrations in equivalent Illinois coals, up to 10 percent for Endosporites.

Florinites is a gymnospermous pollen, usually assigned to cordaites (Smith and Butterworth, 1967; Scott, 1977). In the coal samples studied, it was usually a minor element, composing a percent or two of the total. Kosanke (1950) reported up to 8 percent in equivalent Illinois coals.

Chaloner (1958) explained an important aspect of miospore distribution when he observed that the coal floral assemblages represented essentially the local swamp flora, with a minor admixture of transported spores and pollen. He suggested that Florinites was an element of the upland flora, and was usually widely dispersed. As a consequence, it is usually a minor element in coal floras, but may be dominant in other environments, especially open marine shales. Neves (1958) confirmed this in some Lower Pennsylvanian coal - black shale - grey shale successions. He found the coals to be dominated by Lycospora, Calamospora, and ferns, while the offshore grey shale was dominated by Florinites and Punctatisporites. This is consistent with what was found in this study. Two samples of grey marine Vilas Shale (Wi2/90 and A11/-14½'), with a significant assemblage of various invertebrates, were processed. Both samples produced only a few spores, but Florinites was well-represented. This trend also has a bearing on the microflora of the black shale at Fithian, Illinois (Locality Ft1)

where Florinites reaches a maximum, although Punctatisporites and Crassispora are more common (Peppers, 1964).

Outside of the Illinois Basin, very little work has been done on Missourian microfloras. Upshaw and Hedlund (1967) examined Coffeyville microfloras in northeastern Oklahoma, and concluded that they most closely resembled Kosanke's (1950) Shoal Creek assemblage. All the common palynomorphs were present in approximately the same proportions as found in this study, except they identified the small round spores as Latosporites (composing 15 to 75 percent of the flora), rather than Punctatisporites.

Clendening (1977) examined the microflora of the Bonner Springs Shale in Kansas (the cycle below the Vilas). Most of the genera present were typical forms, such as Florinites, Calamospora, Cyclogranisporites, and Laevigatosporites. However, the flora was dominated by Gillespieisporites, while Punctatisporites was not mentioned.

Habib (1968) studied and interpreted the floral succession in a lower Virgilian coal in West Virginia, and noted the relationship to coal petrography. An early basal phase was dominated by lycopods and gymnosperms and rich in mineral matter and inertinite. A middle transition was dominated by Punctatisporites and Laevigatosporites. In the upper portion, these two dominant spores were joined by other spores, such as Lophotriletes, Triquitrites and Calamospora. Mineral matter and inertinite were generally low and vitrinite high in the upper portion of the seam. Where Calamospora was important, mineral matter, inertinite, and exinite increased. Florinites was a minor

element throughout the seam. Habib interpreted the sequence as a result of flooding. An initial conifer phase gave rise to a wetter, dominantly herbaceous flora, with periodic minor influxes producing local occurrences of other forms.

An important consideration of the microflora is whether the paralic swamp flora varied significantly from the alluvial plain flora. In this study, most of the coals probably formed in paralic swamps, as they are either overlain directly by grey shales containing abundant marine fossils (e.g., the Davis City Coal) or by sandstones that are, in turn, overlain by limestones (e.g., the Cedar Bluff Coal). In contrast, the two coals in the middle of the Galesburg and Canville Creek (Locality Cal) are probably alluvial coals, as they are thin, discontinuous, separated by several feet of sandy shale, and occur in a poorly sorted, mineralogically immature clastic unit. However, their flora is not significantly different from the Davis City and Cedar Bluff microfloras, nor are they too different from each other, although the upper one is more diverse. This suggests either that there was more marine influence than is apparent, or that Missourian coal swamps had low diversity and/or wide-ranging floral elements. This contrasts with Habib's (1968) observation that coals overlain by marine beds had higher diversity than those that were not, because in all the coals studied here, diversity was relatively low.

## Environmental Significance

The floral patterns of the Upper Pennsylvanian are broadly attributed to increasing dryness of climate. This is interpreted as the

principal cause of the loss of most of the aborescent lycopods and the vast coal swamps at the end of the Desmoinesian (Phillips et al., 1980; Phillips and Peppers, 1981; Wilson, 1981). Phillips (1979) stated that the principal aborescent lycopods (e.g., Lepidodendron and Lepidophloios had reproductive cycles adapted to standing water; therefore, with the loss of such swamps, they became extinct. The few other aborescent lycopods not adapted to such an environment, such as Sigillaria, endured as a minor element of the Upper Pennsylvanian flora. The loss of the lycopods made it possible for previously minor elements of the flora, such as the true and seed ferns, to become the dominant groups of Missourian coal swamps. (This floral change was demonstrated at Tulsa, Oklahoma, by Wilson, 1979.)

Scott (1977) partially supported this generalization, noting that lycopods and sphenopsids were generally more adapted to wet conditions, while pteridosperms and some cordaites were more adapted to dry conditions. Phillips (1979) noted that swamp-adapted cordaites died out in the middle Desmoinesian, but that upland forms survived the Pennsylvanian.

The general floral trend toward more xeric forms is important when considered in relation to the Garnett flora found in the Rock Lake Shale, the next cycle above the Vilas Shale. The Garnett flora is characterized by the conifer Walchia and the ginkgo-like Dichophyllum (Baxter and Hartmann, 1954). This flora has often been described as being Permian in aspect, and definitely xeric; Moore and others (1936) attributed it to both drying and an upland habit.

The topographic/floral zonation is important. In Europe, Gothan and Remy (1957) recognized a lowland flora characterized by Calamites and Pecopteris (i.e., sphenopsids and ferns) and an upland flora of Callipteris (a characteristic fern of the Permian) and Walchia. This appears to have been generally the case in the Midcontinent, although Moore and others (1936) stated that sphenopsids and ferns were uncommon in the Missourian.

This floral pattern of more xeric forms corresponds to the eastward migration of drier climate. In the Desmoinesian, the basins of western Colorado were accumulating evaporites. Read (1947) observed that the associated Pennsylvanian floras, while having elements in common with those to the east, suggested relatively dry climates, especially in the relative rarity of lycopods. In the Late Pennsylvanian, orogenic activity produced more upland flora: Walchia appears in Upper Pennsylvanian strata in Colorado and New Mexico, as well as to the east in the Appalachian Basin, where Moore and others (1936) stated that it occurs in upper Conemaugh (upper Missourian) strata.

There is some evidence that the transition from the humid conditions of the Desmoinesian coal swamps did not directly give way to arid conditions, but rather to a monsoonal regime with seasonal rainfall. Baxter and Hartmann (1954) found weakly developed seasonal rings in the Dichophyllum wood at Garnett (and noted that modern Ginkgo has very similar annual rings). Wilson (1981) mentioned the occurrence of Missourian wood in central Oklahoma with seasonal growth bands, and Jensen (1982) described growth rings in cordaitean wood from the Seminole Formation of central Oklahoma. Phillips (1979)

stated that cordaite roots (but not stems) in coal swamps also showed growth rings, but felt that it must have been due to nonseasonal fluctuations in the environment, apparently because he considered availability of water to be an unlikely control.

This type of seasonal climate may explain some of the petrographic features of the coals of the Missourian (and to some extent of the Desmoinesian, as well). Scott (1979) noted that periods of drought could produce a fire hazard, which would make fusain layers in the coals. Burnouts might also be conducive to formation of clastic "splits" in the coal; the whole process would be analogous to that in the modern coastal swamps described by Staub and Cohen (1978).

Phillips and others (1980) noted that other factors might also be related to the floral transition in the Late Pennsylvanian. They noted that differences in basin subsidence, drainage systems, proximity to sediment sources, and relative sea levels would also control formation of swamps. In most of the Midcontinent and the Illinois Basin, the Missourian was a period of reduced clastic influx when compared to the Desmoinesian; it may also have been a period of higher sea levels. These factors would act to restrict development of the broad deltaic plains where the coal swamps developed, and might be a contributing factor in the floral transition.

In general, the Missourian floral patterns may be summarized as "lowland" floras of seed ferns, true ferns, sphenopsids, and some lycopods, growing in areas of high water tables along rivers and in coastal swamps. An apparent "upland" flora characterized by cordaites and possibly Walchia was developed in better drained areas.

As drier conditions migrated eastward, more xeric features and floral elements appeared, and coal swamps became more restricted. In the Missourian, this apparently was a result of developing a monsoonal climate.

An interesting modern analogy was described by Rhodes (1982). A chenier plain in northern Australia is dominantly low coastal mudflats with scattered beach ridges, which resulted from episodic flow and clastic influx of local streams produced by a monsoonal climate. Although only a meter or two higher than the surrounding flats, the beach ridges were high enough to support an "upland" flora characterized by such trees as eucalyptus, in contrast to the mangrove coastal swamps.

# CHAPTER V

# DEPOSITIONAL ENVIRONMENTS

In this section, a synthesis of the diverse lines of evidence relating to depositional processes will be presented. In order to adequately do this, much evidence from outside the study must be considered, particularly that which deals with large-scale influences on sedimentation. Upon evaluating this evidence, it can be shown that the depositional systems found in the Missourian shales of the Midcontinent region and Illinois Basin are compatible with those expected from global patterns. These depositional patterns are also comparable with modern analogues, and do not require extreme conditions.

## Large Scale Influences

Several factors from outside the immediate study area have a profound influence on what is found in the shales. Although these influences are themselves somewhat controversial, those interpretations favored here are compatible with the observed characteristics of the Missourian shales. It is not possible to avoid some judgment of these interpretations and their implications to the Midcontinent and Illinois Basin, so discussion of these interpretations will be presented to aid in understanding the background factors of local depositional systems.

## Tectonic Influences

The global tectonic setting of the Missourian is relatively simple. During this time, the collisional tectonics that marked the assembly of Pangaea dominated the tectonic pattern of North America. The Appalachians and Ouachitas were suture belts that were active throughout the Pennsylvanian and Permian; however, the Missourian was generally a time of reduced activity except in the Ancestral Rockies and New Mexico (Mallory, 1972). Rascoe (1962) noted that marine deposition reached its maximum extent in the Midcontinent at this time, and Kosanke and others (1960) stated that the Missourian Bond Formation had the thickest, best-developed limestones and fewest sandstones of any Pennsylvanian formation in the Illinois Basin. But new orogenic pulses in the Ouachitas marked the close of the Missourian and were probably a factor in Vilas and Stanton deposition. The importance of the Ouachitas as a detrital source in the Rock Lake Shale, which terminated Stanton deposition, has been documented by Moussavi-Harami (1980).

One notable feature of this tectonic activity in North America is that it was essentially amagmatic. The Ouachitas and Frontrange had no contemporary associated intrusives or volcanics, and there was relatively little in the Appalachians. Thus, there was no influx of volcanic ash, in contrast to the numerous volcanically-derived tonsteins of Europe. Most of the tectonically emergent areas shed reworked sediments or low-grade metamorphics. Primary igneous debris came

principally from the Cambrian Wichita granites and the Precambrian granites of Frontrange; minor amounts may have been derived from the very restricted Precambrian rocks of the Ozark and Nemaha uplifts (Horne, 1965), while the Canadian Shield was a distant source.

## River Systems

Because the positions of large river systems should affect the distribution of shale units, it is important to locate the dominant rivers that influenced deposition in the Midcontinent and Illinois Basin.

In the Lower Paleozoic and Mississippian, the evidence points to a major river draining the craton southward along a similar axis as the modern Mississippi. According to Potter (1978), this is in part due to control by recurrent normal faulting in the basement. In the Pennsylvanian, however, this drainage was probably blocked by the rising Ouachitas, and the river diverted.

L.F. Brown (1979) observed that on the craton, long-term distribution of rivers and deltas was controlled by broad, subtle structures. In the Pennsylvanian, drainage across the continent carried clastics from the Appalachians across the Appalachian Basin and into the Illinois Basin (Morris, 1967), where they were diverted to the south to the Black Warrior and Arkoma Basins (Potter and Glass, 1958; Graham et al., 1976). Evidence for this drainage pattern is found in the channel sands, which are southerly in the Illinois Basin (e.g., Palomino-C., 1963) (Fig. 73). The various basins encountered acted as successive sediment traps, filling and spilling into the next basin (Potter,

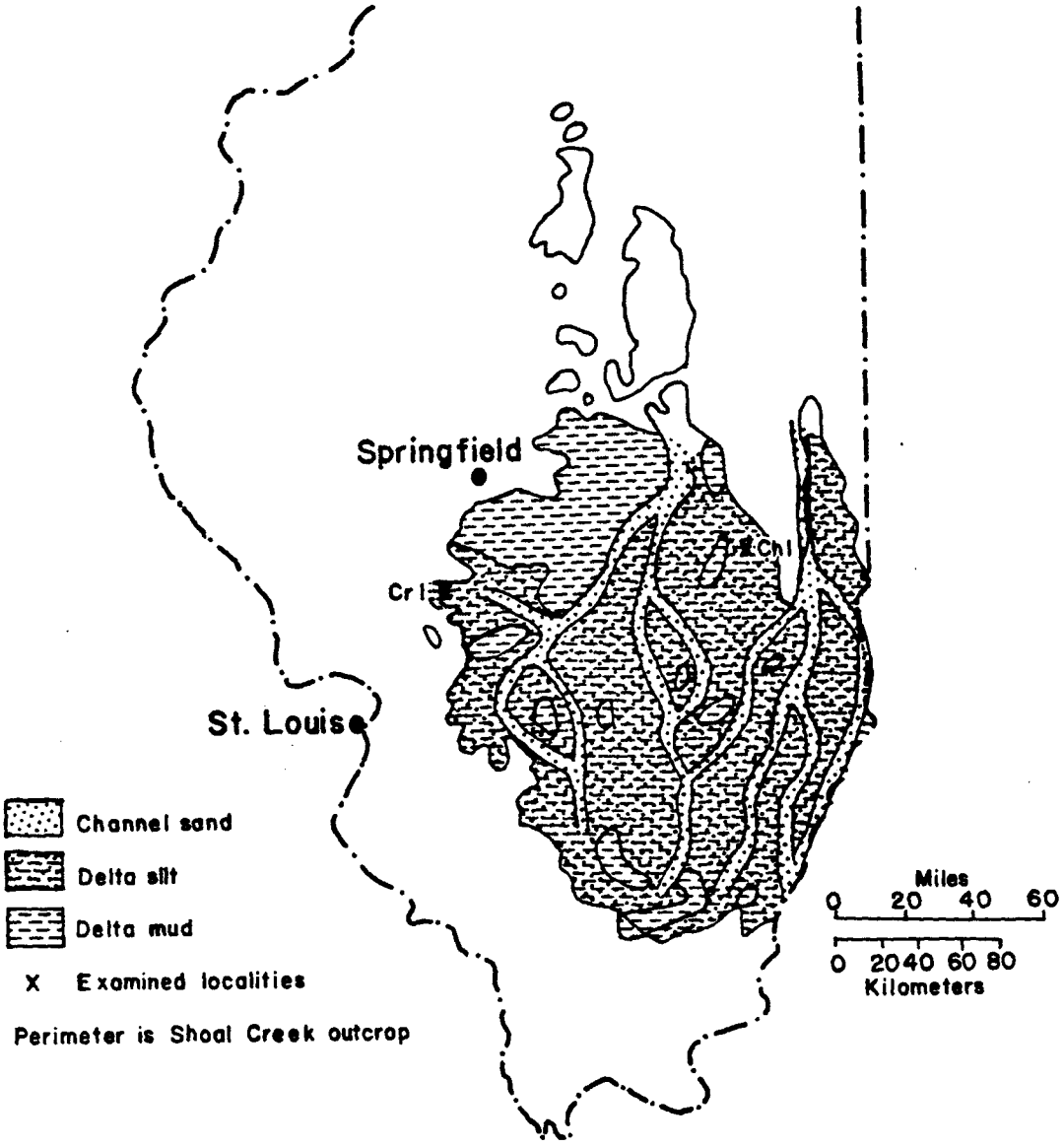



Figure 73. Environmental map of the sandstone interval below the Shoal Creek Limestone (includes only the upper portion of the Shoal Creek-Macoupin interval).
(Facies map from Palomino-C., 1963).

1978). As a result of this study, it can be shown that at least during the Galesburg and Vilas intervals, sediments from the Illinois Basin were not carried into the Forest City Basin; by elimination they must have gone to the Arkoma-Anadarko Basin if they entered the western Midcontinent at all. The major river must've emptied into the eastern end of the Arkoma Basin, eventually filling both it and the Anadarko Basin.

By the Missourian, the Arkoma Basin was essentially full and the Anadarko Basin was filling. Moore (1979) stated that the Ouachitas (to the southeast) were the principal source of Missourian clastics. The Amarillo Mountains to the southwest produced coarse clastics, but volumetrically they did not contribute as much to the filling of the basin (Dutton, 1981a). The pattern of a basin marginal to a foldbelt, with drainage parallel to the fold axes, is one that is quite frequent; Audley-Charles and others (1977) described them as being related to Alpinotype subduction, and noted that if they are on the craton, post-depositional deformation is minimal. Often such a system will have a basinal fan sequence associated with the major delta (Kuenen, 1957); this apparently applied here. The drainage paralleled the front of the Ouachitas and filled in the Anadarko Basin from one end; basinal fan deposits spread westward from the deltaic system.

It is important to note that the sediments examined in the Illinois Basin and in Oklahoma have similar clay suites, which are distinct from those found in the Forest City Basin. Mineralogically and texturally the sands in Illinois and Oklahoma are also similar, but whether they were part of the same system or simply derived from

similar sources was not documented. The relative contributions of the sediment transported long distances from the Appalachians (if the system draining the Illinois Basin spilled sediments into the Anadarko Basin) and those derived nearby from the Ouachitas was not evaluated.

This large-scale river system (or systems) supplied detrital mica to the Illinois Basin and part of the Midcontinent, in much the same way as the modern Mississippi does (Mathews and Shepard, 1962). Where long-distance fluvial influence is absent in the Midcontinent, so are the micas.

It is possible that a large river system was responsible for the clastic wedges in northeastern Oklahoma and southeastern Kansas. Although it would be expected that most of the sediments were funnelled into the Anadarko Basin, if the rate of accumulation exceeded the rate of subsidence, delta avulsion may have occasionally spread sediments over the shallow shelf to the north. Channel patterns and direction of transport in southeastern Kansas are consistent with this. The major river system would probably have served as a principal axis of transgression into Illinois for rising seas, rather than across Iowa as Wanless (1957) believed.

Other, smaller fluvial systems were probably locally significant, although the evidence is much more tenuous. During Vilas deposition, the area around Kansas City received sediment with a different clay suite (illite-kaolinite) than that to the south (illite-kaolinite-chlorite) or that in the Forest City Basin to the north (illite-chlorite). This may have been supplied by a river draining the

kaolinitic (but chlorite-poor) terrain on the Ozark Dome. This is compatible with Kenny's (1968) isopach information on the Vilas.

Outside the study area, the Amarillo-Wichita and Frontrange mountain systems apparently were drained by short, braided fan-delta systems. As both areas emptied into adjacent basins, the arkosic sediments were trapped abruptly and did not influence Midcontinent sedimentation. During low sea level stands the remnants of the Nemaha Uplift may have been locally eroded and produced small deltas in northeastern Kansas (Horne, 1965), but there was no evidence of this in the studied sediments. It may be possible that a river system draining the Williston Basin during low sea level stands produced the clastic wedges prograding southeastward across Nebraska (Horne, 1965), and such a transport system could explain the different clay mineralogy of the Minnelusa Formation in the Black Hills (illite-kaolinite). Facies evidence of Palomino-C. (1963) suggests a possible small delta in the St. Louis region, draining into the Illinois Basin from the Ozark Dome.

It is also important to note where there is no evidence for river systems. During Galesburg deposition, the Forest City Basin was free of any river system active enough to produce significant erosion or build a clastic wedge. Most drainage was probably by overland sheet flow, similar to the modern Everglades. During Vilas deposition, however, there may have been small local systems as the Vilas locally thickens and contains some sand and mica, as well as traces of kaolinite. But since the sections actually examined are marine, it's not clear if the material was produced locally or carried by longshore

currents. If it was produced by local river systems, it is not apparent why the Vilas depositional system should have developed such streams, while the Galesburg did not.

## Cyclothems and Climate

Pennsylvanian cyclothems of similar nature are found in eastern North America and Europe, and contemporary cyclic deposits occur in other parts of the world. The mechanisms that produced them are both regional and global in scale. Thus, it is necessary to interpret deposition in the Illinois Basin and the Midcontinent in terms of large-scale controls.

Various theories of cyclothem development are linked to climate, which in turn influences the depositional environment. Regional models would not markedly alter climate on a global or zonal scale, so the locally prevailing climate between one phase of cyclothem deposition and another would not have been very different. However, if the cyclothems are caused by changes in the global climate, the locally prevailing climate would reflect that change, and may differ considerably at different phases of cyclothem deposition. Global sea level change from whatever cause may itself alter the climate and also have an effect on the local climate, which could vary with the phase of the cyclothem. Regional models for cyclothem development would not have climatic change related to phase, whereas global models might, in some cases by definition.

It is not necessary to discuss the various models in great detail here, since they are all thoroughly presented and discussed elsewhere.

Neither is it necessary to choose one over another. The regional and global models are not mutually exclusive. One process may be locally dominant, and overprint another. Still, some are less likely, and may be discarded as possible mechanisms for cyclothem control; others may be dismissed in some details, but not in toto.

Deltaic Model

The facies deltaic model of cyclothem deposition is one of the newest of the several models, at least in complete form. Moore (1959) proposed it for the Lower Carboniferous of Yorkshire, Ferm (1970, 1974) elaborated it for the Appalachian Basin, Fisher and others (1969) and Galloway and Brown (1972, 1973) have applied it to the Eastern Shelf in Texas, Visher and others (1975) and Visher and Rennison (1978) applied it in northeastern Oklahoma, and Pryor and Sable (1974) believed that it applied to the Upper Pennsylvanian in Illinois. Essentially, it proposes that a prograding delta may build out and up to a point where it avulses and begins deposition elsewhere. When this happens, compaction and/or subsidence act to submerge the abandoned delta. Eventually, the delta system may avulse again, and deltaic deposition may resume over the abandoned submerged lobe. This would lead to a repetitive sequence of shallow marine transgressive and deltaic progradational facies. The notable feature of the model is that the cyclic deposits would be local in nature, and should not be traceable over long distances. However, Fisher and others (1969) and Galloway and Brown (1972, 1973) pointed out that eustatic sea level changes may also be present, although they stated that on the Eastern Shelf of Texas

such changes are dominated by delta migration. Fisher and others (1969) noted that deltaic formats are separated by regionally extensive limestones which mark periods of low sedimentation on the Eastern Shelf; Galloway and Brown (1973) claimed that these limestones can be correlated only as zones, not as units. Galloway and Brown further argued against eustatic sea level change because of the lack of subaerial features such as soils and channeling, without recognizing that these may be lacking if the shelf were only partially emergent at low stand.

This model can be closely tied to the deposition of the shales studied here. In much of the outside shales (Galesburg and Vilas) deltaic or prodeltaic deposition is apparent, but the extent and effect of deltaic migration is variable.

The relationship of the deltaic model to other lithofacies is debatable, especially to the black facies of the core shale. Many workers in the Appalachian Basin assigned this to a lagoonal or estuarine environment, although Ferm (1974) largely ignored it. Brown and others (1977) indicated that in the Cherokee cyclothems in southern Iowa and northern Missouri it is the initial deposit on a subsiding delta. Merrill and Martin (1976) extended this model to the Illinois Basin, and such an interpretation applies to Zangerl and Richardson's (1963) coastal model. In such cases, estuaries rather than lagoons must be invoked, as skeletal calcarenite barrier bars are not apparent, and delta-destructive barrier sands are unknown. (If the black shale represents a lagoonal environment, with water deepening to produce the overlying marine limestone, then following Walther's Law

the barrier environment should be present between them. This situation does not occur in the Midcontinent or Illinois Basin.) Furthermore, strict application of the deltaic model implies that none of the facies are traceable over large distances, and this is just not true in the Midcontinent or the Illinois Basin.

Tectonic ("Diastrophic") Model

The tectonically-controlled cyclothem model was principally advanced by Weller (1956). Although he recognized the regional correlation of cyclothem units, he argued that they must be controlled by linked pulses of uplift and subsidence; e.g., for the Illinois Basin and the Appalachians. He provided no mechanism to power this cyclic diastrophism, and argued for it principally on the basis of negative arguments against other theories. Intrinsically, the theory did not provide environmental parameters for some facies, although Weller believed the core black shale was deposited in nearshore, shallow conditions relative to the upper limestone.

Strakhov (1967) attributed the cyclic paralic sequences (as in the Pennsylvanian) to fluctuating tectonic activity, stating that in the tropics, sedimentation was principally dependent on tectonic activity, which could overwhelm chemical activity in magnitude.

Momper (1966a) suggested that the Pennsylvanian cycles were due to heat-magma cyclicity, which caused changes in the volume of the oceans, in turn causing eustatic sea level change. Sloss and Speed (1974) also provided a mechanism, stating that at certain times a change in spreading rates produced a pulsating disequilibrium of melted material

beneath the continents. When melted material from subduction accumulated beneath the continents, the lighter melt lifted them up. When mantle circulation was more vigorous and melt removed, the continents would deflate and subside. Such a mechanism would provide for global synchroneity, assuming all the mantle convection cells circulated in harmonious fashion. They stated that such activity could produce the yoked basins common in the Pennsylvanian, and that the coal cyclothems could be attributed to such a mechanism. But they did add that such fluctuations could be modulated at even higher frequency by continental glaciation.

Pedersen (1981) studied cyclic anoxic deposits in the Upper Paleocene and Lower Eocene strata of Denmark, where black laminated horizons were interbedded with burrowed diatomite. He compared this with several related cyclic deposits in the Cretaceous and Jurassic, and concluded basinwide anoxic events were caused by tectonic restriction, with climatic variation providing the cycles. Arguably, the principle could apply to the Upper Pennsylvanian.

Glacial Eustatic Model

The glacial eustatic model was first put forth by Wanless and Shepard (1936), who proposed that cyclothems were caused by the fluctuations of the ice cap in the southern continents. They argued this global mechanism was necessary because of the widespread occurrence of cyclic deposits, their great lateral continuity, and because of problems with the complicated diastrophic mechanisms invoked in alternate explanations. The glacial eustatic model would have produced sea level

changes similar to those of the Pleistocene. Weller (1956) argued against this, stating that the synchroneity of glaciation and cyclothems was unproven, and that the number of glaciations did not approach the number of cyclothems. Crowell and Frakes (1975) and Crowell (1978) demonstrated that the glaciation of the southern continents did coincide with widespread cyclic deposition in the northern continents, counting over 100 cyclothems from the Late Mississippian to Middle Permian. Crowell (1978) also noted that the southern ice caps were relatively modest, and fluctuated with changing moisture sources, as well as possibly with the Milankovich effect. Rao (1981) argued that high latitude deposits in Tasmania were related to cyclic glaciation and deglaciation; the number of cycles was similar to the number of cyclothems elsewhere. Crowell and Frakes (1975) observed that glaciation in the Southern Hemisphere reached its acme in the Late Pennsylvanian or Early Permian, when the south pole was in the Transvaal. Ramsbottom (1979) supported the idea of eustatic control for the Westphalian (Desmoinesian) cyclothems of Europe, stating that European, Russian, and North American cyclothems were apparently synchronous.

Eustatic sea level change is readily evident in some carbonate sequences, especially in the algal mounds. Wilson (1975) stated that it profoundly influenced the development of the mounds. A.A. Brown (1979, 1982) found that features of the mounds on the Eastern Shelf in Texas required eustatic change, and Heckel (1980) cited a personal communication from G.A. Risley that there were at least eight episodes of wave-cut erosion and leaching on the Horseshoe Atoll during the

Missourian. Parks (1976) found a horizon of silicified tree stumps between two episodes of phylloid algal mound growth in New Mexico. Cress (1981) found eustatic control in the algal mounds of the Oquirrh Group in Idaho and attributed it to glacial fluctuation. The carbonate cyclothems of the Paradox Basin, also attributed to eustatic sea level change, show a remarkable resemblance to those of Kansas, without the outside shale member, although sometimes with evaporites (Peterson, 1966; Hite and Cater, 1972).

Eustatic sea level change is strongly supported as a mechanism for cyclothem formation in the Midcontinent. Moore (1950) accepted eustatic sea level change as a control for the cyclothems, but rejected glaciation as the agent. Johnson (1971), Heckel and Baesemann (1975), and Heckel (1977) argued that the Midcontinent cyclothems were most simply explained by a single transgressive-regressive event. Stout (1981) agreed with the principle, but disagreed with the interpretation of the evidence. The lateral continuity of several lithofacies in the cyclothems, especially the core black shales, is considerable. Heckel (1980) observed that such continuity is not compatible with rapidly shifting facies, and Dott (1981) stated that persistent thin units of the cyclothems did not support the deltaic model.

In the Forest City Basin, the limestones and shales of the Bronson Group provide a unique sequence through several cycles. Each unit has recognizable, persistent, and unique features, which correlate laterally over the basin; the alternative is to believe that a unique sequence of events can occur randomly through different cyclothems. The Galesburg Shale is important to this, as it is markedly different

from the outside shales separating the cycles above and below it: the Cherryvale (above the Dennis) is a thick partially subaerial shale-limestone unit, whereas the Ladore below the Swope is a sandy shale with marine fossils. The Galesburg further militates against the facies relationships of Ferm's (1974) model as there are no deltaic or prodeltaic facies present in the Galesburg across the entire Forest City Basin. Progradation and subsidence are simply inadequate to explain such a case; the Dennis and Swope cyclothems represent deposition under similar marine conditions, yet the Davis City Coal is an autochthonous, subaerial coal above a soil profile that averages three feet thick. Progradation cannot explain the development of the Galesburg soil upon a marine limestone. Subsidence would have to be episodic and possibly reversed for the Bethany Falls and Winterset to subside to the same extent for the same environments to occur and accumulate to similar thicknesses, while separated by a time of widespread emergence.

Baturin (1971) linked apatite nodule formation to sea level change. He surmised that apatite nodule formation, as an aggradational process from interstitial peloids, might be related to winnowing and aggradation brought about by sea level change; Burnett (1977) suggested that this change could be eustatic. This may well apply in the Midcontinent.

Basinal systems, such as the Anadarko Basin also support eustatic sea level change. Gibbs (1981) noted that sea level rise traps sediments on the shelves, which must prograde across them to feed basinal fans. Eustatic sea level change creates starved basins and

causes deposition on the shelf, a common phenomenon in the Upper Pennsylvanian. Kumar and Slatt (1982) stated that this process was active in the Anadarko Basin.

Thus, in the Midcontinent a non-deltaic model fits the observed data. The glacial eustatic model is most acceptable, since it corresponds well to depositional features both here and elsewhere. However, the activity of deltaic lobes overprinting eustatic changes is readily evident in the Illinois Basin and the southern Midcontinent region, as Wanless (1967) and Heckel (1977, 1980) have noted.

Climatic Effects

In the Missourian, both paleomagnetic determinations (Irving, 1977) and continental positioning based on broad paleoclimatic reconstructions (Heckel, 1977) place the Midcontinent region slightly to the north of the equator, although neither method provides the resolution to determine precisely how far. The overall Pennsylvanian trend, again based on both lines of evidence, shows that North America was moving northward; thus, the Midcontinent would be expected to become increasingly dry. In the Desmoinesian, evaporite precipitation was extensive in the Paradox and Eagle basins of western Colorado; by the Missourian, significant gypsum was precipitating in South Dakota (McCauley, 1956; Mallory, 1972) and sabkha deposition was taking place in western Nebraska (Wilson, 1978); by the Upper Wolfcampian, halite precipitation began in western Nebraska; and by Leonardian, evaporite precipitation was extensive in the Midcontinent and Williston Basin (Rascoe and Baars, 1972). Thus, both

paleomagnetic and climatic reconstructions provide similar broad determinations of climate; more detailed interpretation depends on finding evidence for possible modifications in the sediments.

During the Missourian, the Illinois Basin and Midcontinent probably were significantly beyond the equatorial doldrums belt, due to the proximity of evaporite deposition. Because Europe, which was then presumably across the Appalachians and in the Southern Hemisphere, has abundant volcanic ash in Upper Carboniferous rocks, and the ash clouds apparently were never carried over North America, some sort of atmospheric boundary separated it from North America.

Since the Midcontinent and the Illinois Basin were between the equator and the horse latitudes belt, they would have been in the zone of northeast trade winds. This would mean that the prevailing winds should have blown mainly from what is now the north or northeast toward the south or southwest. Axelrod (1981) noted that with the assembly of Pangaea, the subtropical highs should have been strengthened, which would have increased dry conditions in low latitudes during the warm season; this is compatible with the evidence.

This represents only the simplest case. Due to the axial tilt of the earth (assumed to have been constant in the past), the doldrums belt has a north-south seasonal migration of about $10^{o}$ latitude, giving adjacent areas a seasonal variation in rainfall and wind (Parrish, 1982). Also, the large mass of Pangaea, particularly that portion in temperate latitudes, would provide a strong monsoon effect. In the Midcontinent, which was marginal to the main landmass of Pangaea, winds would be expected to blow seaward in the southern winter and landward

in the southern summer. Parrish (1982) noted that in extreme cases (such as Asia today) the monsoon effect is capable of completely overwhelming zonal circulation.

Orographic effects would be expected to modify atmospheric circulation. The Appalachians, Ouachitas, and perhaps the Ancestral Rockies might have had an effect, but it's not possible to tell to what extent, since there is no way to estimate their elevation. Axelrod (1981) added that major explosive volcanism (common in the Pennsylvanian everywhere but in North America) could have contributed to climate modification.

Thus, the overall climate in the Midcontinent and Illinois Basin would be expected to be a transitional climate with seasonal rainfall; in the Köppen nomenclature system, an Am (tropical monsoon), Aw (tropical savanna), or BSh (hot steppe) climate.

Here, large scale models enter the picture. If the deltaic model alone is applied, no significant variation of climate should occur. Regional tectonic variation may modify the climate slightly, but not significantly unless an orographic barrier was created. However, either global eustatic model (tectonic or glacial) could radically alter the distribution of land and sea. The glacial eustatic model, by definition, would require the further fluctuation between glacial and interglacial thermal regimes. Since the Midcontinent and Illinois Basin were at low latitudes, the temperature might not have changed much between stages, but atmospheric and oceanic circulation would have been expected to be much more vigorous during the glacial stages (when the outside shales were formed). The CLIMAP Project Members (1976) and

Gates (1976) observed that during the last Pleistocene glacial age, the westerlies were displaced slightly equatorward only near the ice sheets. Near the ice sheets, mean annual temperatures were reduced $10^{\circ}$ to $15^{\circ}$C, while the tropical continents were about $5^{\circ}$C cooler, and the average ocean temperature dropped only $2.3^{\circ}$C. By analogy, the low latitude climate in the Midcontinent and Illinois Basin may not have been much affected by glaciation elsewhere, although precipitation may have been affected by the profound change in sea distribution.

These general patterns are confirmed in the sediments. The presence of caliche supports seasonal rainfall, and the occurrence of fan-deltas resulting from flashy discharge along the Amarillo Mountains (Dutton, 1979) can be attributed to this. The decline of hydrophilic plants and amphibians could also reflect a change from a constantly humid climate to one that was seasonally dry. The occurrence of trees with seasonal growth rings would also support seasonal rainfall. In the marine rocks, a dominantly northeasterly current is documented, although this may have alternated with transport from the southwest. Hall (1961) and Hamblin (1969) found these two directions dominant in the limestones of the Kansas City Group; Whitcomb (1965) found that transport was directed N33$^{\circ}$E in the Bonner Springs, and Payton (1966) stated that currents or storms transported oöids northeastward across Missouri during Bethany Falls and Winterset deposition. Southward eolian directions from Wyoming and Utah, determined by Agatston (1954), Opdyke and Runcorn (1960), and Peterson (1966) support such an interpretation. Fluctuation in marine circulation is also supported by the opportunistic fauna, the varve-like lithology, and occurrence of

apatite in the core shales. All would be enhanced by seasonal variation in the intensity of vertical circulation in the seaway, attributable to changes in direction and/or intensity of the prevailing winds.

## Outside Shales

It is essential to recognize that outside shales represent far more than one simple environment, and that they are actually complexes of environments, many of which have only terrigenous clastic composition in common. Some are deltaic, while others are soil profiles developed on limestones in areas without clastic influx. Those that are marine range from shallow to comparatively offshore. These shales probably represent a greater range of depositional environments than the other, more prominent lithologies associated with them.

### Deltaic and Prodeltaic Shales

Deltaic and prodeltaic shales are widespread in the Missourian, but it is a mistake to assign all the outside shales to such environments. Typically, they display some regional wedging, and are composed of poorly fissile grey shale that is usually micaceous, kaolinitic, and occasionally sandy. They often contain plant fragments. More frequently in the Midcontinent they are prodeltaic rather than deltaic, as may be true in the Missourian outside shales of the Illinois Basin. As a consequence, the shales are usually sparsely fossiliferous, often with siderite nodules, and contain thin, often burrowed, fine-grained sand beds or lenses. The ability of siderite nodules to form in rapidly deposited marine muds negates a major argument for subaerial deposition of these shales. Of the studied shales, the

Coffeyville-Galesburg and Vilas south of the Bourbon Arch, and the shale between the Macoupin and Shoal Creek limestones in Illinois fall into this category; the Vilas in the Bedford, Iowa, core and around Kansas City may belong to this facies group as well. The Galesburg-Coffeyville has unequivocally subaerial deltaic facies, in contrast to the Vilas, which did not have any in the study area. The Coffeyville delta conforms to L.F.Brown's (1979) description of a slowly subsiding delta, usually 100 to 300 feet thick, with coals and delta-destructive sands at the top. Bloesch (1930) described the Coffeyville in those approximate terms, while Horne (1965) and Visher and Rennison (1978) showed the clastic wedge and distributary channel patterns developed (Fig. 74). No subaerial deltaic facies were recognized in the examined sections in Illinois.

A significant aspect of this facies group is its ability to overwhelm other facies that might normally develop. At any point, a normally developing cycle may be truncated by a prograding delta; evidence of this comes from the occurrence in a prodeltaic shale of animals normally found at a particular phase of the cyclothem. Often, this is expressed as a thin, shaly upper limestone interbedded with and eventually replaced by prodeltaic shale, in which fossil abundances often decrease with increasing sedimentation. Examples of this are the Vilas at Altoona, Kansas (Locality Al1) and in the Bedford, Iowa, core (Locality Be1), and the shale above the Macoupin in Illinois, both at Carlinville (Locality Cr1) and Charleston (Locality Ch1). In some cases, the prodeltaic muds directly succeed the black fissile core shales, as in the Eudora at Copan, Oklahoma (Locality Cp1) and Walker

Figure 74. Subsurface Coffeyville sandstone isolith map. (From Visher and Rennison, 1978)

Study area is at upper right.

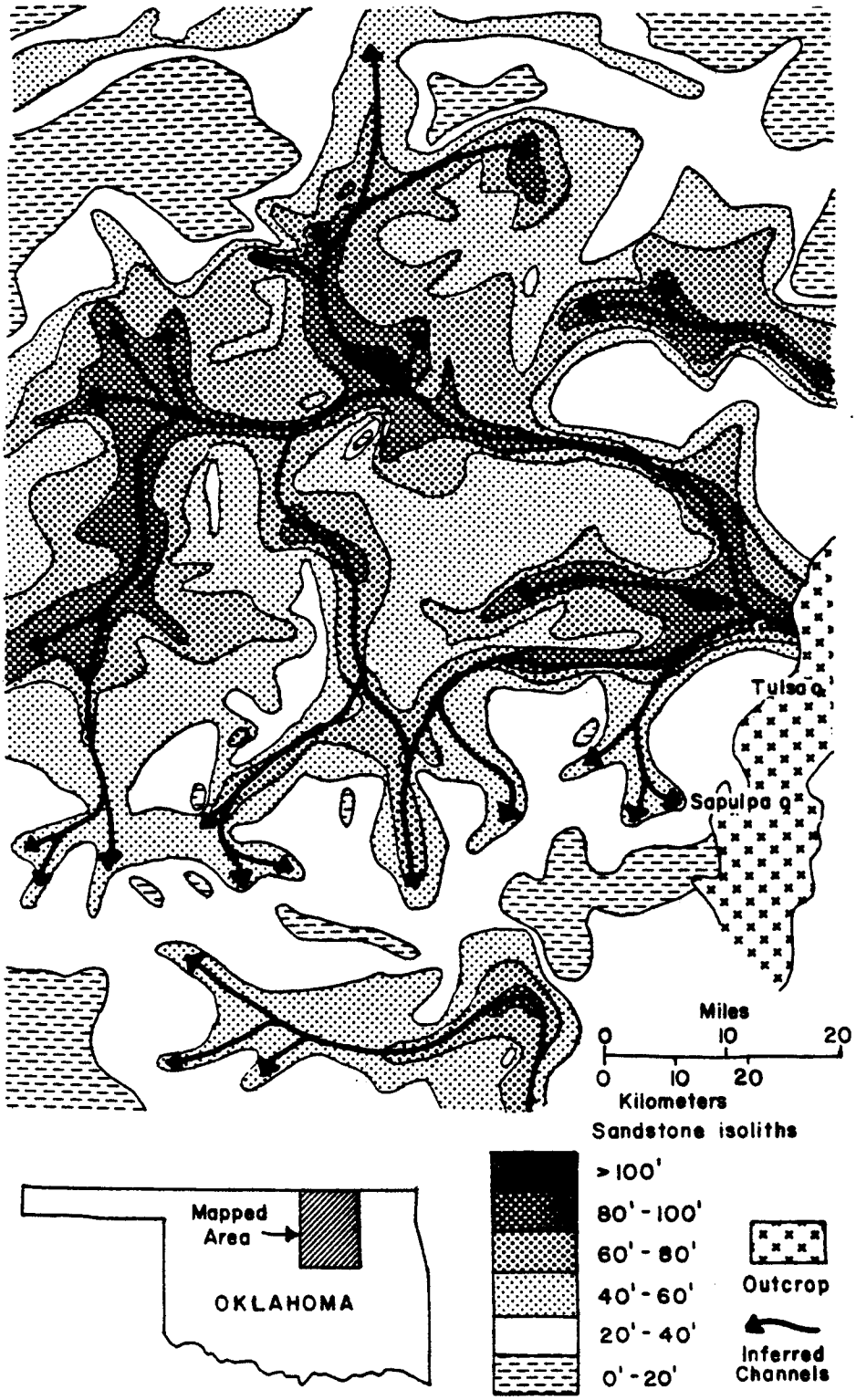

Tulsa
Sapulpa
Miles
0 10 20
0 10 20
Kilometers
Sandstone isoliths
>100'
80'-100'
60'-80'
40'-60'
20'-40'
0'-20'
Outcrop
Inferred Channels
Mapped Area
OKLAHOMA

Figure 74.

Mound, near Independence, Kansas (Locality WM1). In a few cases, the prodeltaic facies may truncate the cyclothems even earlier. At Erie, Kansas (Locality Er1), the Galesburg overlies the Middle Creek Limestone Member of the Swope Cyclothem; the Middle Creek has only nearshore fauna present, while the basal Galesburg contains rare offshore conodonts and scattered echinoderm fragments. Whether this represents clastic progradation during far offshore deposition or some later erosion and reworking is not clear. At the Big Hill Creek damsite (Locality BHC2) near Cherryvale, Kansas, the Galesburg also overlies the Middle Creek, and neither shows development of a core fauna, suggesting that the prodelta started prograding here earlier than at Erie to the north. It is important to recognize that later phases in the cyclothem are much more likely to be eliminated, especially the shoal water carbonates at the top of the upper limestone; when sea level is falling, a delta can prograde much more rapidly than when sea level is rising and trapping sediments in estuaries, filling previously eroded stream valleys rather than constructing deltas. The greater lateral persistence of the core black shales and occasionally the middle limestones (as with the Middle Creek, the Captain Creek, and the South Bend) would tend to argue against the deltaic model for cyclothem deposition as a shallow water black shale would be expected to be interrupted by clastic influx more often than one formed in deep water.

Many prodeltaic facies do not grade upward into deltaic facies, but rather give way to renewed marine deposition or contain intervals of marine carbonate deposition in prodeltaic sequences. This may represent either a eustatic rise in sea level or delta abandonment

within a eustatically controlled cyclic pattern. Examples of this include the Vilas near Altoona, Kansas (Localities A12, WCL1) and Bedford, Iowa (Locality Be1). In some cases, prodeltaic facies develop non-aggrading soil profiles on top, as at Charleston (Locality Ch1) and Fithian (Locality Ft1) in Illinois. This may represent an abrupt drop in sea level, bypassing deltaic facies development.

In addition to recognizing what deltaic progradation may do, it is important to recognize what it may not necessarily do. Many of the thin shale partings in the limestones are likely attributable to failure of carbonate deposition due to local disturbance (e.g., storms) or change in water characteristics rather than to clastic influx, as the partings rarely display prodeltaic features, such as wedging, mica, sand, or kaolinite. Offshore deposition by plumes, extending offshore, such as those suggested by Heckel (1980, Fig. 5), are unlikely. Modern plumes are not known to extend farther than 200 kilometers offshore, even in shallow seas (Gibbs, 1981). Furthermore, the offshore shales in Iowa, Nebraska, and South Dakota (e.g., the Stark, Eudora, and Minnelusa grey shale) have different clay suites than that found in Illinois, indicating a different source. Recognition of this principle is important because Galloway and Brown (1972) argued that such shale splits in limestones indicated deltaic deposition somewhere. Since this does not necessarily follow, the limestones are just as compatible with eustatic sea level change.

Subaerial deposition of some of the outside shales cannot be excluded, particularly in light of the indicated climate. A braided stream, described by Rust (1981), from the interior of Australia, had a

very low channel density, and was a mud-dominated system, probably due to seasonal flow. It probably resulted from a raised base level, which would apply to the studied shales during transgression. Such a system could conceivably be present in the Missourian, but it would be difficult to recognize.

## Residual Soils

Commonly in the Midcontinent, development of blocky mudstone units was completely independent of recognizable clastic influx. These mudstones are leached of carbonates, often have increasingly weathered clays in the upper portions, and lack detrital kaolinite and muscovite. In some cases, evidence of roots is present, and/or they are overlain by coal. The contact with the limestone below is usually composed of a rubble of angular cobbles derived from the limestone below, with frequent holes, cracks, and pits penetrating the limestone. Caliche may be present.

The origin of the clays for these mudstones is unclear, since the original features have been destroyed by soil processes. They may be derived from leaching of the underlying limestone, from longshore transport of clays very late in the regression, from sheet wash of the land, and/or from aerial transport. Although Wanless and Shepard (1936) noted that underclays physically resembled loess, eolian material is probably insignificant, except locally (close to a braided stream feeding a fan-delta, for example), because modern rates of accumulation of wind-borne material at a distance from a source are minimal, and not likely to be important except in sediment-starved

environments. Griffin and others (1968) stated that the modern rates of accumulation of windborne clay from the jet stream in the North Atlantic is .3 to .5 mm/1000 years. With a 50% compaction rate, 1 meter of sediment would take 4 to 6 million years to accumulate. Moreover, Midcontinent deposition was from the trade winds, which are less efficient at dust transport. The close resemblance between the clay suites of the mudstones and the underlying limestones suggests a generic relationship, and the example of residual clastics overlying limestone in the Florida Everglades provides a modern analogue for the possibility. (Scholl, 1969, compared Florida to the Pennsylvanian cyclothems, and stated that the principal difference is that most cyclothems developed on deltaic facies. In the Forest City Basin, where deltaic facies are sometimes lacking, the similarities are even more marked.) The answer probably involves a mixture of several of the mechanisms suggested, but it is clear that deltaic processes are not involved, unless in the most remote fashion.

## Redbeds

Redbeds associated with the cyclothems have been widely overinterpreted, sometimes with conflicting conclusions. Horne (1965) stated that red muds in the Galesburg near the Nemaha Uplift were marine. Ferm (1974) assigned them to oxidized marine environments where wave action provided the oxygen to destroy organics and ferrous iron. More frequently, they have been interpreted as subaerially formed (e.g., Heckel, 1977). Waage (1950) stated that in the Appalachians the redbeds intergraded with seat earths. Burchett (1959)

described them as subtropical lateritic soils, and stated that they resulted from subaerial modification of green shales. Wilson (1981) also described them as rainforest laterites. Subaerial formation is probably often the case, as the organics necessary to reduce the iron are more difficult to accumulate on land. The usual lack of structure could be due to argillopedoturbation, root action, or salt wedging on mudflats during the dry season (Rhodes, 1982). Russell (1974, 1977) argued that redbeds in Nebraska (including the Rock Lake Shale above the Stoner Limestone) were high intertidal mudflats, originally brown and red, representing a diastem in the middle of a regressive-transgressive sequence. The Vilas Shale at Stanzel (Locality St1) and near Winterset (Locality Wi2) in Iowa has red mudstone grading upward into green mudstone, then grey fossiliferous shale. This is closely analogous to a foundered redbed delta described by Johnson (1982), where marine organics reduced the upper redbed. However, in view of the possible diagenetic dewatering of limonite, it cannot be assumed that the mud has always been red. Laminated red shales (such as those mentioned by Kotrous, 1978, and T. M. Stout, oral comments, North Central GSA, May, 1981) are difficult to explain through soil processes, and may be diagenetic.

## Coals

Of the different depositional environments of coal, two or possibly three are represented in the Galesburg/Coffeyville. The Davis City Coal probably developed in a paralic swamp when rising sea level ponded the inflowing fresh water, a common method for forming broad

coal swamps (Heckel, 1980; Heckel et al., 1980). This would be analogous to the Florida Everglades, with broad areas of unchanneled flow backing and spreading over a low-relief terrain. As a facies in a transgressive sequence, such a coal is expected to be laterally continuous, as the Davis City Coal is.

In the Coffeyville, multiple coals would indicate development on a flood plain, with flood deposits interrupting and diluting coal swamp development. Such flood plains would be expected to be laterally discontinuous and of relatively low quality. It is unclear whether the Cedar Bluff Coal belongs to the first or second type, or constitutes a third distinct type. Its position below a regionally significant sheet sand that is overlain by marine deposits suggests it could constitute the initial phase of a delta-destructive sequence; the Dodds Creek Sandstone (sensu stricto) is a delta-destructive sand formed by a barrier bar pushed back over a back-barrier swamp. This system would be analogous to the modern Chandeleur Islands being pushed back over the subsiding St. Bernard lobe of the Mississippi Delta. Immediately behind the Chandeleur sand bars are mangrove swamps, so the sands are deposited over peat by washover (Kolb and Van Lopik, 1966). The Cedar Bluff-Dodds Creek sequence may also be comparable to some of the Cretaceous coals of Utah, which were cyclically overwhelmed, in part by having barrier bar sands retrograde over them (Young, 1955; Bucurel, 1978). Ryer (1981) stated that the Upper Cretaceous coals of Utah were related to eustatic sea level change, with thin coals forming only during periods of sea level change and thick ones during periods of relative stability. By analogy, the thin Missourian coals (such as the

Davis City Coal) may reflect the rapidity of the transgressions. Coals below delta-destructive sands might be expected to be as extensive as the abandoned delta platform; thus, Fisher and others (1969) stated that they are the best marker beds in delta-destructive sequences. It is not demonstrable whether a delta so defined was submerged due to avulsion or rising sea level.

Curiously, despite the stratigraphic evidence for two or possibly three distinct environments, the microflora is not particularly different among the coals. Either the flora involved was broadly adapted to a range of environments, or the environments involved were not as distinct as they appear in the rock record.

In at least one case (Stobbe, 1971, at Locality Lil) flaky, shaly bone coal has been confused with the fissile black core shale. The bone coal is underlain by a possible caliche horizon, which accentuates the resemblance. However, the bone coal was distinguished by its abundant spores and lack of marine fossils, particularly conodonts.

All the coals examined are autochthonous banded coals. None produced any evidence of developing in open water and forming a cannel or boghead coal, as would be expected in a lake or lagoon. Spackman and others (1969) noted that modern coastal transport of peat from the Everglades rarely produces even a "coaly streak" or "smut" on the beach.

Finally, it should be noted that coal formation does not imply a moist climate. Rust (1981) observed that thin peats are forming on the flood plain of a braided ephemeral stream in the interior of Australia. This is not to suggest the rainfall regime in the Midcontinent was so

extreme, but only to point out that a seasonally dry climate is not prohibitive to coal formation.

## Coastal and Shallow Marine Shales

In the shales that are not subaerially deltaic or overlain by coals, marine processes frequently played a major role. A long-smoldering argument of the depositional relationships of cyclothem units relates to the lack of significant, or in some cases any, transgressive deposits. Typically, the marine deposits between the coals and the black shales are quite thin, much thinner than the sequence above the black shale. Indeed, in Illinois the fissile black shale often directly overlies the coal. For this reason, it's often been argued that the black shale must be a shallow water transgressive deposit.

However, this overlooks an intrinsic feature of transgression. Whether it is due to delta abandonment or to eustatic sea level rise, detrital clastic sediment would go elsewhere. With eustatic sea level rise, the sediments would aggrade chiefly in estuaries and lower river valleys, filling pre-existing channels, thus producing many of the channel sands seen today (L.F. Brown, 1979). Emery (1968) noted that many estuaries actually remove sediment from the shelf by estuarine circulation. Other areas of the shelf would thus be starved of sediments. This is closely analogous to modern depositional patterns, where, due to the post-Pleistocene sea level rise, 70 percent of modern coastal shelves are floored with relict, non-equilibrium sedimentary deposits. For example, large areas of the North Sea are floored with peat deposits (Godwin, 1934).

The faunal patterns in the shales support this conclusion. Sedimentation was never consistently high enough in one area to alter the fauna present; indeed, even in prodeltaic areas the fauna was not much affected. Episodic instability, such as storms, was probably the chief influence.

Wedges and lenses also provide evidence that considerable time elapsed between the coals and black shales. Locally, considerable sedimentation did take place where the coals and black shales are separated by several dozen feet of grey shale, which pinches out to an equivalent layer of pyritized fossils between the two (Gluskoter and Hopkins, 1970). This feature is observed to a lesser degree at Fithian, Illinois (Locality Ft1) (Heckel et al., 1980).

An important corollary to starved deposition during transgression is that it neither implies that transgression was more rapid than regression nor precludes that possibility. Thus, it is not possible to simply compare thicknesses to determine whether or not the cyclothem is temporally symmetrical.

Another frequently cited problem in the Midcontinent and Illinois Basin has been the absence of recognizable strandline deposits in the shale between the coal and the black shale. Keugelan and Krumbein (1949) attributed this absence to the lack of effective wave action, brought about by a very low regional slope. Irwin's (1965) model of epeiric sedimentation predicts intervening surf-zone deposits, but this model applies to clear water carbonate sedimentation, and may not apply to argillaceous sediments.

Recent work on mud-dominated coastal environments has provided a possible model for outside shale deposition, particularly thick shallow marine sequences such as the Vilas. Mud-dominated coasts, such as the Guiana Coast of South America described by Wells and Coleman (1981), tend to damp wave action so that wave processes do not operate. In such an environment, rather than the waves removing the mud, the abundant mud removes the waves.

Reineck and Singh (1980) explained that chenier plains developed in response to fluctuating sedimentation. Normal processes produce the muddy tidal flats, while episodic storms produce beach ridges. Alternately, migration of mud banks may provide periodic development of strand deposits (Wells and Coleman, 1981). In many cases (e.g., Wells and Coleman, 1981; Rhodes, 1982), the beach ridges are built of shelly material, as the sands from rivers either may not be present or are flushed offshore, with Ekman transport carrying the mud back onshore.

The principal requirements for development of such a system are a plentiful supply of mud (in the Midcontinent, this could have been supplied by the river emptying into the Anadarko Basin) and a long-shore current, which would help winnow out the sand and, through Ekman transport, carry the mud back to shore. If this model applied to the Vilas and similar outside shales, the postulated long-shore current would flow to the northeast, which is supported by paleocurrent measurements.

As observed above, such systems, particularly in areas of seasonal climates, often develop chenier ridges. The sand-poor chenier systems cited here formed in climates much like those postulated for

the Midcontinent and Illinois Basin: the northern coast of South America ranges from tropical monsoon (Am) to hot steppe (BSh), while northern Australia is tropical savanna (Aw) and hot steppe. Chenier ridges were not identified in the Midcontinent or Illinois Basin. This is not a major problem for two reasons: (1) chenier ridge development is dependent upon the frequency of disruptive, beach-forming processes and the availability of material for beach construction, and (2) most modern chenier plains are progradational; if the mud was introduced during a transgression, it may not build up sufficiently to form beach ridges, so only the offshore mud banks would be preserved in the record. Either or both possibilities could apply to the studied shales.

Spackman and others (1969) stated that shelly storm ridges are occasionally pushed over the peats in the Everglades; such a process may have produced such shelly ridges or lenses like that at Fithian (Locality Ft1).

In such systems today, the terrigenous sand is deposited offshore. In the Missourian, the sand may have either been flushed into the Anadarko Basin from the delta, or it may never have been present.

The southern Vilas Shale could easily fit this model, as it is a thick, sand-poor, largely structureless and poorly fossiliferous shale, such as would be expected to form from mud banks. Much of the thicker Vilas north of the Bourbon Arch and some of the outside shales in Illinois may also fit the model, although the patterns are much more conjectural. The southern Galesburg and the Coffeyville are largely deltaic and prodeltaic in origin; they are rich in sand bodies,

coals, and sedimentary structures that support this interpretation.

Other models apply to other shales. In areas of thin marine grey shales, such as the lower Stark in the Forest City Basin, nondeposition and storm action probably were important; these processes could have produced the Decatur City Beds. Spackman and others (1969) noted that off the modern Everglades storms mix degraded peat with lime mud and deposit it on the in situ peat, much like the muddy layers of the basal Stark.

There is some evidence that other coastal processes may have been active. Spackman and others (1969) described channels at river mouths in the Florida Everglades, often cut down to bedrock. Given a similar situation, the channel described by Kinerney (1961) in the Kansas City area may be analogous. Also, the possible precursor channel in the Vilas to the Stanton channel described by Heckel (1966) may have originated in similar fashion. Heckel (1978) compared the succeeding carbonate channel system to modern Persian Gulf systems. Whether or not similar processes were responsible for the precursor channel in the Vilas is not known.

Most of the shallow marine shales appear to have formed near open shorelines. The physical structures of the shales suggest bioturbation with some over-printing by storm activity. The fauna also supports such an interpretation, with low diversity, opportunistic faunas near the outside, with diversity increasing toward the core, along with an increase in K-strategist organisms.

Three important negative observations should be made in connection with these shales. One is that the presence of coaly debris did not

noticeably inhibit the fauna, as reasonably diverse faunas, including brachiopods and bryozoans, are found in very coaly shales. The principal inhibition is probably proximity to an unstable shoreline environment, rather than to a coal. The principal effect of the coaly debris is apparently to enhance pyritization of the fauna.

Another feature is the lack of identifiable lagoonal environments in the shales. In some cases, the fauna present is low in diversity, but this could be simply proximity to shore on an open shelf. The only shale environment that might possibly be lagoonal is at the base of the Galesburg at Canville Creek, near Stark, Kansas (Locality Cal). This shale is poorly exposed, but if the low faunal diversity and abundant small gypsum laths are in place, it could possibly represent a lagoon.

The third feature is the lack of evidence of extensive restriction and salinity increase. Although Shaw (1964) and Irwin (1965) believed that the epeiric seas were shallow and tideless, Klein and Ryer (1978) not only cited physical evidence contradicting tidelessness, but also argued that such seas would have local salinity variation and restricted faunas. The argument would apply to shallow-water Missourian environments. There is some evidence of restriction in the upper parts of the upper limestones, but only rarely to the extent of salt formation (Mitchell, 1981); much of the rest of the cyclothem shows no evidence of restriction at all, implying that most of the time the water was deep enough to circulate freely. Heckel's (1978) Persian Gulf channel analogy would support the concept of active and effective circulation, even near shore.

## Relationship of Shallow Water Shales and Carbonates

In shallow-water shales, both strandline and storm processes are likely to winnow and concentrate shell fragments. Because low rates of terrigenous clastic influx would also act to limit detrital dilution, skeletal carbonates could develop when conditions were favorable. Because a variety of conditions can produce limestones at a variety of depths, skeletal limestones are not necessarily restricted to a particular phase of the cyclothem. Middle limestones (or the equivalent carbonate facies) can be constructed of very shallow water carbonate particles (Fig. 75) and do not indicate a minimum critical environment.

The formation of large algal mounds is an important phase of cyclothem and carbonate development. However, it is not clear how relevant they may be to the development of the shales in the cyclothems. Davis (1959) stated that the algal mound of the Spring Hill Limestone dammed back the Vilas clastics prograding from the south. Both Horne (1965) with the Coffeyville-Galesburg, and Kenny (1968) with Vilas, indicated that the clastic wedges of the outside shales that prograded into southeastern Kansas were rimmed with phylloid algal mounds, suggesting lateral equivalence and possibly a cause-and-effect relationship. But at this point it is unclear if a significant portion of the algal mounds are lateral facies changes from shales or if deposition was largely sequential and disjunct.

The relationship between the upper limestone and the overlying shale is difficult to evaluate. In many cases, the top of the

Figure 75. Shallow water carbonates in the lower Stark Shale, south-central Iowa.

a. Myalinid calcarenite from Van Wert, Iowa (Locality VW1). Light particles are mostly myalinids; dark particles are coal and fish fragments. The large dark particle is a possible soilstone (caliche) clast. Note inarticulate brachiopod (IB).

b. Ostracodite from Davis City, Iowa (Locality DC1), immediately above the Davis City Coal. The rock is almost entirely flattened geisinid ostracodes. Note the cellular structure of the fusain.

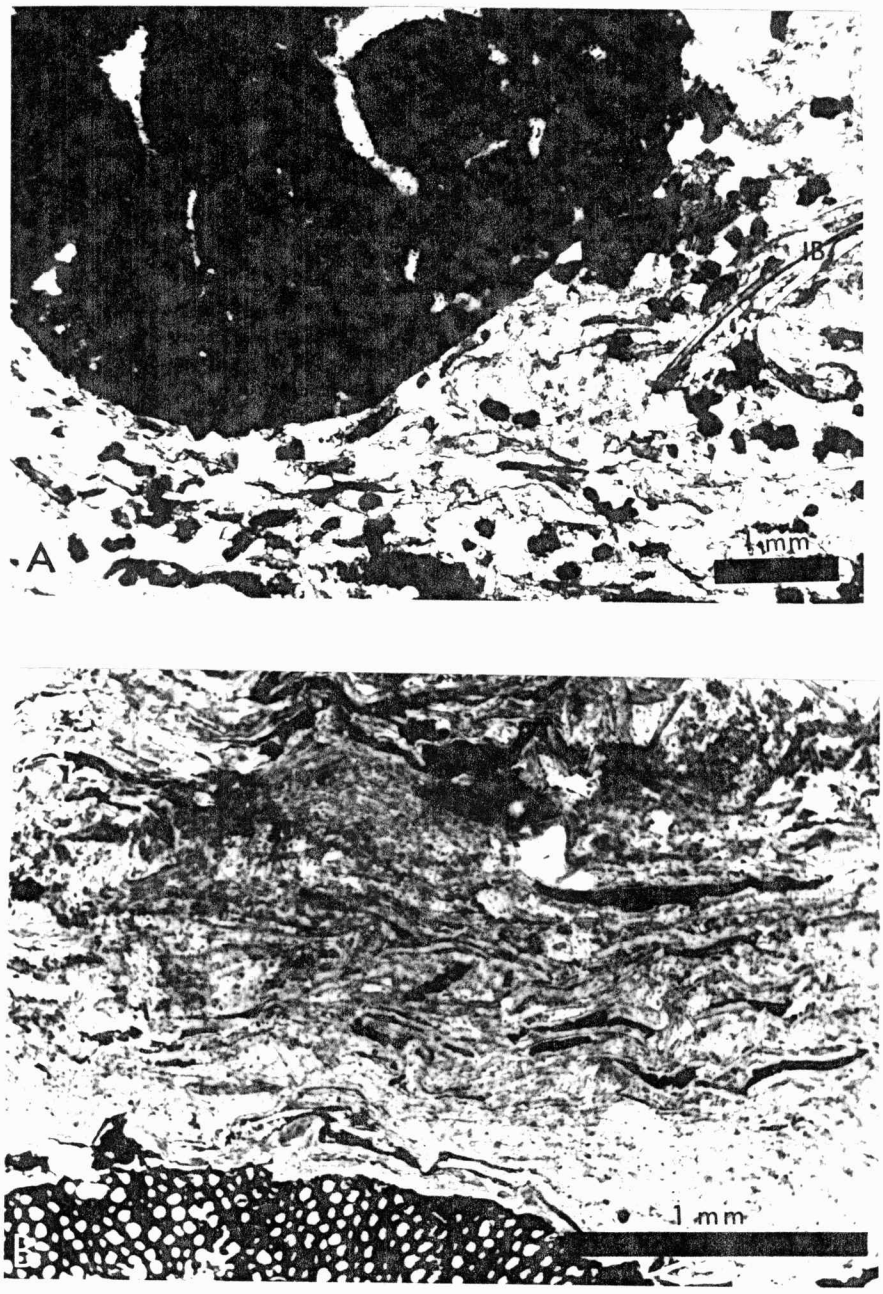



Figure 75.

limestone is brecciated (Kenny, 1968; Heckel, 1980) and karstification and caliche formation are common. Heckel (1980) stated that shoal water facies are widespread at the top of the upper limestones, especially in the Forest City Basin where they are not masked by terrigenous clastic influx. Heckel stated that these carbonate facies prograded southward from Minnesota and South Dakota into Nebraska and Iowa; due to lack of evidence of active outbuilding it is more likely the facies changes were passive, and were simply due to increasing emergence as the sea withdrew.

## Sandstones

Very little can be said about the sandstones in general. In most of the cases examined, the shape of the sand bodies is unknown, the sand size is too small to produce many diagnostic structures, and the mineralogy too homogenous to be helpful. There was, however, one apparent correlation to environment. The clean sands with little matrix are usually marine, and frequently fossiliferous. They are either cemented by calcite or by pressure solution closing of much of the pore space; this apparently was dependent on how much calcareous material was originally present. The fluvial material is much more matrix-rich, possibly from originally containing more labile grains, and from being less winnowed than the marine sands.

Ferm (1974) first suggested that this dichotomy of sandstones was due to environment, rather than source. He noted that both orthoquartzites and subgreywackes occur in the Appalachian Basin, and suggested that it was due to the contrast between marine and fluvial

deposition. This probably applies in the Midcontinent, for two reasons: (1) in any area, the finer sands are generally more matrix-rich, presumably due to less winnowing, and (2) the orthoquartzites show no demonstrable geographic tendencies. To believe that some sandstones are orthoquartzitic because they are derived from the Ouachitas would require the rather anomalous situation of relatively immature sediments from the Ouachitas producing orthoquartzites while the sands derived from the craton produced subgreywackes.

Bennison (1981) indicated that the Dodds Creek is a transgressive sandstone. The sheet sand facies of the Dodds Creek (sensu stricto) is the only sand encountered in this study with strong indication of its specific environment, which is probably a delta-destructive shoreline-barrier complex. It is usually relatively clean and well-sorted, suggesting persistent wave action. Although locally fossiliferous, it apparently had little carbonate cement, and shows substantial pressure solution. This interpretation is at odds with that of Stobbe (1971), who noted that the sand is better sorted than that of most rivers, but thought that it was part of a distributary system, even though he found no channels. He also interpreted it as beveling the Bethany Falls, which may be a product of miscorrelation.

Visher and Rennison (1978) stated that the sandstone developed in the Winterset above the main Coffeyville distributary is a calcareous orthoquartzite, in contrast to the subgreywackes of the Coffeyville.

The Naish was a marine sand body of unknown type. It is moderately fossiliferous, very clean, and relatively well-sorted. Its carbonate cement may have originated from the shelly material.

Although its overall geometry is not known, it does resemble in some respects (e.g., abrupt flat base, planar bedding, and associated plant-rich beds with lenticular starved sand ripples) what Hobday (1974) described as barrier bars in the Black Warrior Basin. The presence of coaly partings in the Naish would also favor a depositional environment close to shore; this may be comparable to what Buller and Green (1976) found on the lower tidal sand flats of an estuary. Visher and Rennison (1978) described subsurface sand bodies off the perimeter of the Coffeyville delta, which they described as barrier bars trending northeast-southwest, parallel to apparent regional circulation.

Other sands encountered locally are less readily categorized, and cover a range of environments from marine to fluvial. Further study is necessary on individual sand bodies to correctly place them.

## Core Shales

### Offshore Deposition

The core shales, found between the middle and upper limestones of the limestone formations of the Midcontinent, and their analogues in the Illinois Basin, have long been controversial as to their significance in the development of the cyclothem. Many arguments have been advanced in favor of shallow water (i.e., lagoonal or coastal) origin. In Illinois, the common occurrence of the core black shale immediately above the coal in the cyclothem led to this conclusion. However, as was argued in the previous section, the lack of deposition during a transgression is not surprising, and the occurrence in Kansas of many feet of marine shale and limestone in this interval would argue that

the core shale is not coastal. Likewise, the premise that the submerged coal swamp poisoned the black shale environment is not empirically supported; in many cases, the overlying shale is quite fossiliferous, and coaly limestones are fairly common.

Several features of the core shales are difficult to explain if they are nearshore deposits. Both the lack of sedimentary structures due to shallow water processes, and a mechanism for restricting oxygenation of the bottom require explanation. Weller (1956) introduced the idea of a kelp-like flotant mat to protect the sediment below, and to provide the organic material necessary to deoxygenate the bottom water. Zangerl and Richardson (1963) concluded the Mecca Quarry black shale had formed in 4½ years, due to mass mortality related to freshening of the water and the alternation of lithologies within the black shale. Zangerl and Richardson (1975) then expanded this mat, having it cover the entire Midcontinent region at one time, regardless of the depth of water beneath. Merrill and Martin (1976) followed this model, and stated that the core shales in Kansas and Illinois originated in the same way.

The shallow water model runs into problems on several counts. Unless Zangerl and Richardson's (1975) vast flotant-matted sea model is accepted, the tremendous lateral continuity of the core shales is difficult to explain (Heckel, 1978). In any case, a flotant appears to be insufficient; Zangerl and Richardson's (1963) modern analogue (which is not even a natural ecosystem) is frequently shredded by storms, even in the limited area it covers (Russell, 1942). Kolb and Van Lopik (1966) stated that flotant marshes usually exceed 50% organics, due to a high

ratio of organic production to clastic influx, whereas the black core shales rarely are that high.

The clay mineralogy does not support a shallow water origin, either (Crouch, 1971). Zangerl and Richardson (1963) suggested that the black shale was produced by a freshening of the water, producing mass mortality. However, in the Midcontinent, the core shales (especially the black facies) lack detrital muscovite and kaolinite, whereas the adjacent outside shales have them (even in the Illinois Basin, where the core shales contain kaolinite, it is usually less than in the outside shales). This pronounced change in mineralogy suggests that the core shales are far removed from direct fluvial input. Heckel (1978) further argued that the fine grain size indicated offshore deposition, and Hallam (1967) noted that coastal black muds are almost never laminated. Kidder (1982) observed that the slow formation of apatite nodules is not consistent with the rapidity of sedimentation required to form a black shale in 4½ years.

Curiously, black shales are often the only facies to extend through the phylloid algal mounds at the shelf edges (e.g., Rall and Rall, 1958; Michlik, 1981; W. L. Watney, pers. comm., 1981), whereas outside shales disappear toward the mounds along the Anadarko rim (Rascoe, 1962). The persistence of the black shales is difficult to explain if the mounds were to have acted as a restrictive barrier.

A further argument is the lack of fauna, especially epibionts (Hallam, 1967). Ostracodes in particular would be expected to be common on an algal flotant mat, yet they are absent. Although benthic fauna is not strictly lacking, the forms present were either remarkably

adapted to low oxygen (e.g., Lingula) and/or opportunists, able to take advantage of fluctuations (e.g., Crurithyris).

All these features are much more effectively explained by offshore, comparatively deep water deposition. In a basin with stratified water, the lower water mass could be extremely persistent laterally; if it was below the photic zone, infalling organic matter would deplete its oxygen without algae to replenish it (Heckel, 1977). Offshore deposition would not be incongruous sandwiched between a middle limestone with petrographic evidence of being formed in deeper water upward and an upper limestone being deposited in increasingly shallow water (e.g., Watney, 1980). Most limestones immediately above and below the core shale lack evidence of algae, and frequently contain the most diverse fauna of the cyclothem (Johnson, 1971; Senich, 1978). Offshore deep deposition would also explain the general lack of terrigenous clastic minerals (i.e., muscovite and kaolinite). Finally, there is the stratigraphic relationship in both the Anadarko (Seale, 1981) and Midland basins (Fisher et al., 1969), where the limestones grade basinward into black shales. This arrangement also strongly suggests eustatic sea level change: during high stand, sediments are trapped in estuaries, permitting carbonates to form on the shelves and starving the deep basins; sea level drop permits clastics to build across the shelves and feed deep water fans. If delta avulsion were the cause, offshore deep water sedimentation should continue without a break. Heckel and Baesemann (1975) observed that black shales grade into dysaerobic but open marine grey shales both laterally and

vertically. Following Walther's Law, this would support the concept of offshore deposition for the core shales.

## Upwellings

Heckel (1977) has suggested that many features in the black core shales are explainable in terms of upwellings occurring when prevailing winds parallel to the coast transport surface water offshore, bringing deeper water to the surface, following the model of Brongersma-Sanders (1970). Brongersma-Sanders observed that seasonally-alternating winds, as well as persistent prevailing winds, can generate upwellings, and cited the example of the Gulf of Cariaco, on the northern coast of South America. Axelrod (1981) observed that intensifying wind circulation (with increasing glaciation in the south) would strengthen wind-driven upwellings, as well as enlarge the regions of drier climate, and the CLIMAP Project Members (1976) found this to be true in the Pleistocene. Upwelling in the Midcontinent would correspond well with Cook and McElhinny's (1979) findings that upwelling is most common at $10^{\circ}$ to $20^{\circ}$ latitude (i.e., slightly equatorward of the most intense desert conditions mentioned by Ziegler and Parrish, 1981). In the Midcontinent seaway, with the wind presumably coming from the northeast, the upwellings would occur along the (now) eastern side of the basin as a zonal upwelling. The Illinois Basin may have functioned as a parallel basin of similar orientation, or may have been part of the same system as the Midcontinent.

Heckel (1977) called upon wind-induced quasiestuarine circulation to drive the upwelling system, although it is possible that true

estuarine circulation (Heckel, 1982) or current meanders (e.g., Kress and Veeh, 1980; Sen Gupta et al., 1981) accentuated or modified the upwelling pattern.

In addition to theoretical expectation, the black shales provide substantial evidence of upwelling. The high concentration of skeletal apatite may have been due to biological enrichment of the bottom sediment resulting from the high biological productivity of the surface waters.

Upwelling is also supported by the type of fauna present. Modern upwellings are seasonally unstable; Degens and Stoffers (1976) observed that the related thermo- or haloclines move up and down on a seasonal basis. Consequently, when the upwellings fail or weaken, mass mortalities of the fauna occur (e.g., Sverdrup et al., 1942). Thus, the overall diversity of the fauna is usually low, and the fauna present is generally dominated by opportunistic forms. The fauna found in or adjacent to the phosphatic zones of the core shales conforms to this (e.g., Crurithyris). Hickey and Younker (1981) described the faunal elements in the black shale below the LaSalle Limestone as r-strategists in an unstable, resource-rich environment. Although they interpreted this as a lagoonal environment, it would also be compatible with seasonal upwelling in an offshore environment.

A modern fauna associated with an upwelling has close parallels with that found in Pennsylvanian core black shales. Sen Gupta and others (1981) described an organic-rich, poorly oxygenated bottom, dominated by a few species of opportunistic benthic foraminifers with occasional explosions of scallops living on periodic algal blooms. In

the Pennsylvanian, Ammodiscus and Hippocrepina may be analogous forams, and Dunbarella may be an analogous pecten.

The seasonal aspect of the upwelling explains several other features. Apatite preciptation is enhanced by fluctuating Eh levels at the margin of the oxygen-minimum zone (Veeh and others, 1973; Bentor, 1980), and the varve-like laminations frequently seen in the transitional shales could also be attributed to this. Analogous modern upwellings are associated with seasonal climates onshore, as along the northern coast of South America. Notably, Birch (1980) observed that upwellings in arid climates can draw water far up onto shelves, actually into restricted estuaries in his example, where temperature fluctuations produced cyclic precipitation in organic-rich rocks.

Degens and Stoffers (1976) observed that deep anoxic waters are enriched in dissolved carbonate. When this diffuses up to shallower waters, carbonate production may be enhanced. This may be particularly true if the $O_2/H_2S$ interface drops, which would produce large amounts of carbonate. Such a mechanism could enhance limestone formation, particularly adjacent to upwellings along basin margins (e.g., algal mounds around the Anadarko Basin).

## Stagnation

It is readily apparent that much of the bottom water in the epeiric seas of the Midcontinent and Illinois Basin must have been essentially anoxic and stagnant. Heckel and Baesemann (1975) and Heckel (1978) stated that the abundance of conodonts in the core shale

was attributable to starved basin deposition with lack of clastic dilution. Texturally, a low rate of deposition is required, as rapidly accumulated organics are usually massive; slowly accumulated ones are laminated or fissile. Partly for this reason, Evans (1966) concluded that the fissile black core shales represented very slow sedimentation with no burrowing. The high metal content also is linked to slow deposition; rapidly accumulating sediments often do not have sufficient time to react with seawater, and are consequently low in metals. Empirically, the black shales show no evidence of current activity. Zangerl and Richardson (1963) noted that the fossils in the Mecca Quarry show no current orientation, and had noted earlier (1955) that they were unsorted.

Simple upwelling as an explanation has constraints as well. Upwellings have some of the highest rates of deposition known in ocean basins (Busch and Keller, 1981). Also, upwellings cannot take place across an entire basin simultaneously. Thus, continual upwelling as an explanation for the black shales is unlikely; however, episodic, scattered upwelling is possible. Between upwelling events, the bottom waters would become stagnant and anoxic.

Stagnation and upwelling are not incompatible; the upwelled water is simply drawn from the stagnant water mass or just above it. Local upwellings would explain the spotty development of phosphatic shale at the dysaerobic margins of the core, whereas the stagnant water would be responsible for the black, fissile portion that generally lacks even an opportunistic benthos, but commonly has higher conodont abundances than the phosphatic portion.

Stagnation is not difficult to initiate, especially in shallow seaways. Fenchel and Riedl (1970) noted that in areas of low energy, where fine-grained sediments accumulate, the $O_2/H_2S$ boundary is usually close to the sediment/water interface; a slight change in density could easily cause stagnation. Manheim (1961) stated that the haloclines at 60 to 80 meters in the Baltic permitted bottom stagnation. Luther and others (1980) cited a modern sulfide-producing, metal-rich black mud forming in a seasonally anoxic estuary. Thus, persistent stagnation is not a requirement, either; seasonal stagnation may suffice.

## Mechanisms

Heckel (1977) called for an influx of cold, low-oxygen bottom water from the open ocean in his model. This was necessary to provide a thermocline to stratify the water column. While the possibility cannot be rejected, three things must be considered. One is that there is no physical evidence of such a low oxygen water mass penetrating into the epicontinental seaway. Since upwelling could not take place everywhere simultaneously, some areas must have been offshore of the nearshore nutrient traps. By Heckel's model, those offshore areas should have been overlain by low oxygen (but not necessarily anoxic) cold deep water. Thus, a low oxygen basinal facies would be expected offshore of the upwelling; stratigraphically, it would be the core of the core shale in the basins. Such a facies is not known from the basins of Texas and Oklahoma. Black, radioactive shales are the lateral equivalents of limestones there, while the thick grey shales represent sediments flushed into the basin during low sea level stand. But the

circulation through the basins may have been sluggish enough to permit anoxia to develop in the basinal water mass.

The second consideration is the nature of wind-driven upwelling. All modern upwellings are local circulation cells, although they may be regional in areal extent. Water is drawn up from depths of 50 to 300 meters, coming from the waters of the shelf (e.g., Sverdrup et al., 1942; Gross, 1972; Bentor, 1980; Busch and Keller, 1981). No areally extensive or basin-wide circulation is established (Parrish, 1982). While there is unquestionably some exchange of water with the open ocean (the volume depending on the water balance of the Midcontinent sea), it is unlikely that a significant percentage of the surface water entrained by the prevailing winds can be forced through the downwind straits. Thus, the entrained water must be largely replaced by water derived within the basin, which is compatible with what is known about modern upwellings. A nominal quantity of deeper water from the ocean may enter the circulation, but it would be volumetrically inconsequential compared to the wind-driven circulation within the basin.

The third consideration stems from Moody and others' (1981) observation that deep ocean waters compete with those on the shelves for phosphate. Phosphate levels in the deep water are proportional to detrital (noncarbonate) influx. During high sea level stands, terrigenous clastics are trapped on the shelves, as is biological production, and phosphate levels in the open ocean decline, as biological productivity is relatively low there. Bushinski's (1964) observation that unstable, phosphate-rich organics do not reach the bottom in deep water may be an additional factor. Thus, during high sea level stands

in the Midcontinent, bottom water from the open ocean would be expected to be relatively phosphate-poor compared to the shallower waters of the epeiric sea. The phosphate and other nutrients required to support an upwelling may all be derived and concentrated within the Midcontinent sea. There is no requirement for nor evidence of significant input of open ocean bottom water into the Midcontinent circulation system.

Heckel's (1977) argument for the presence of a thermocline was largely negative; he argued that a halocline (specifically, a fresh-water surface layer) would not work. (Heckel and Pabian, 1981, did argue that diminuitive crinoids in the grey core shale suggested cold water, but other interpretations are possible. Malinky, 1980, for example, argued that the stunting was directly attributable to low oxygen conditions.) However, other models may apply. Degens and Stoffers (1976) observed that both thermo- and haloclines become very stable in periods of prolonged warmth or in land-locked seas.

One possibility for the black core environment would be relative oceanic stagnation. The core shales developed during presumed inter-glacial epochs. Strøm (1939) argued that without a strong latitudinal temperature gradient and its associated winds, much of the oceans could have become stagnant. It is also possible that with deglaciation, vertical circulation due to loss of descending cold polar water was weakened, leading to basin-wide or global anoxia. This could be analogous to the Cretaceous anoxic events. If sea level rose sufficiently, this anoxic water could penetrate into the epeiric seas, as it apparently did in the Cretaceous. This model would explain the great expanses of black shale found in Europe as well as in North America.

Note that bottom water stagnation occurs because of the lack of descending oxygenated cold water; it could stagnate the bottom water in a warm epeiric sea as well as a warm global ocean. Bentor (1980) observed that such stagnant bottom waters could become exceptionally enriched in phosphate, and suggested the mechanism contributed to Cretaceous and possibly Permian and Cambrian phosphorite formation. (Apatite nodules like those of the Upper Pennsylvanian are reported by Ferrell, 1965, from the Cretaceous Thermopolis Shale, a black shale in Wyoming.)

Various kinds of haloclines cannot be ruled out. Fresh or brackish water wedges could stagnate marine bottom waters, comparable to what may have occurred in the eastern Mediterranean during the Pleistocene (Stanley and Maldonado, 1979), although Schrader and Matherne (1981) argued that at least one of those sapropels was due to upwelling. Heckel (1977) argued against this, stating that a freshwater influx sufficient to stagnate the bottom during high sea levels would freshen the entire sea during low stand of the sea. This overlooks the possibility that climatic change due to change in area and distribution of the seas may have caused a marked increase in drainage into the basin during high stand. Jenkins and others (1981), in modelling the Mediterranean anoxic events, did not even tie them to glacials or interglacials, but only to the periods of marked instability going from one state to the other. It may be possible such a model could apply here. Hatch and Leventhal (1982) favored a freshwater wedge for carrying land-derived organic material out to sea during black core shale deposition. Since a significant portion of these

organics is fairly resistant, such a wedge is unnecessary, a conclusion supported by modern examples. However, a freshwater layer may be incompatible with upwelling; Gross (1972) stated that such a freshwater wedge protects the underlying water from the wind and wind-driven circulation. However, a freshwater wedge in an unrestricted basin is unlikely to be areally significant in stratification of the water column, although the associated river-borne organics may be widely dispersed.

Another possibility is the reverse situation, with brines settling to the bottom of the basin and stagnating. This has been applied to the Paradox Basin, where thick black shales with faunas similar to those of the Midcontinent are interlayered with carbonates and evaporites and are attributed to a salinity-generated stratification controlled by eustatic sea level change (Hite and Cater, 1972).

This might be applicable in the Midcontinent epeiric seaway as the rising sea spread into the Williston Basin, where marginal bedded evaporites of Missourian age are known. Since Missourian strata are erosionally truncated on the north and east, it is not possible to determine how extensive the shallow evaporitic areas might have been. Such areas would have generated dense brines, which could have drained along the bottom, ponding in the deeper parts of the epeiric sea and rising to an equilibrium level (Fig. 76).

Such a model is remarkably compatible with features of the core shales. Highly saline waters have a reduced capacity to carry oxygen, and can also stunt a fauna in a fashion similar to that of cold water (Byers, 1977). The high salinity may also disrupt the biological chain

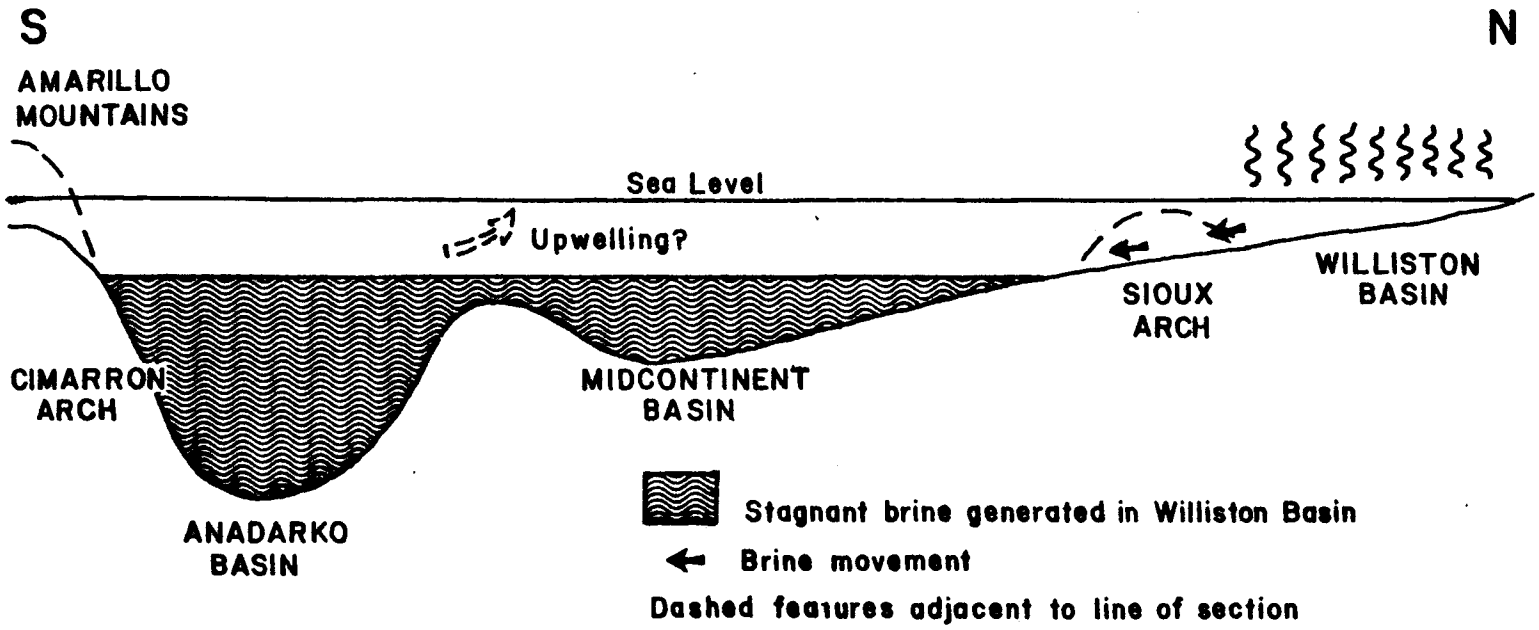



Figure 76. Salinity stratification model for Missourian black core shales.

to sulfate reduction, and thus restrict the amount of pyrite formed in the black shales (Kirkland and Evans, 1981). Such brines have a markedly increased capacity to mobilize and transport metal ions (Hite, 1974; Long and Angino, 1977), especially lead and zinc. They also have a vastly increased capacity to dissolve phosphate, which may be precipitated when the brines are diluted (Hite, 1974; Henderson et al., 1979). Thus, such brines would provide stagnation and stunting of the adjacent fauna, as well as the high metal content of the black shales and the associated apatite deposition. The model could provide the mechanism to explain some other features. While it is apparently not difficult to produce apatite in a normal marine environment, dilution of a phosphate-rich brine would precipitate apatite, while carbonate would become undersaturated. Dilution as a mechanism for apatite precipitation would also explain why the black shales in the Paradox Basin are not phosphatic for in the intense evaporitic environment, dilution did not occur.

Comparison with a nearly landlocked modern sea with vertical density stratification is appropriate. Several features of the Black Sea are closely analogous. Notably, the Black Sea is relatively rich in phosphate. Vertical circulation does exist, at least in part wind-driven. Caspers (1951) cited an example of the prevailing winds blowing surface water offshore and drawing up deeper water along the western side of the sea. Along the Crimea, productivity of the sea increases severalfold, possibly in part due to upwelling (Caspers, 1957).

It is important to note that the Black Sea is actually only a quasi-stable system, and that fluctuations in vertical circulation take place. Cold winters and dry summers both make the surface waters denser, lessening the contrast between surface and deep waters and permitting increased vertical circulation and increased productivity of surface waters (Caspers, 1957). Although cold winters might not apply to the Midcontinent sea, dry seasons might, particularly in a seasonal monsoon-type climate.

An important aspect of the Black Sea data is that upwellings can be generated in landlocked seas, and do not require input from the open ocean. Parrish's (1982) argument against Midcontinent upwellings was that a surfeit of islands would block circulation; since there is no requirement that circulation be connected to the ocean, this is a spurious argument. Pevear (1966) presented evidence that river-derived phosphate was adequate for apatite precipitation, so a source from outside the basin is not necessary.

A brine-controlled circulation may not be too anomalous. Southam and others (1981) suggested that Cretaceous oceanic circulation was controlled by warm salty water generated in epeiric seas and that ocean bottom temperatures may have been as high as 15°C. The same situation may possibly have prevailed during the Late Pennsylvanian interglacials, at least in the epeiric seas.

In conclusion, the core black shales may be explained by formation beneath a stagnant water mass which accumulated offshore below the photic limit. Locally, fluctuating vertical circulation, possibly wind-driven, produced upwellings that yielded enhanced productivity

and phosphate precipitation in the bottom sediments. Stratification of the water column and bottom stagnation may have resulted from several mechanisms including salinity contrasts as well as reduced vertical thermal circulation and temperature contrasts.

## The Basal Winterset Limestone in Northeastern Oklahoma and Adjacent Kansas

Closely related to the problem of the core shales is that of the basal Winterset in northeastern Oklahoma and adjacent Kansas. There, the Stark Shale and Canville Limestone are often missing, and the Winterset directly overlies the Dodds Creek sandstone, sandy Coffeyville, or the Lost City Limestone. However, where this occurs, the sandy basal Winterset contains numerous apatite nodules, which permits its use as a marker bed.

The patchy distribution of the Stark, Canville, and Lost City and their relationship to the Coffeyville delta has been the subject of much debate. Oakes (1940) suggested that minor warping at the close of Coffeyville deposition permitted them to form in lagoons (although not in abandoned channels). He rejected the possibility of erosional truncation of the lower units because they were lithologically more related to the Winterset than to the Coffeyville. Hanson (1957) attributed the Stark to isolated, barred lagoons or patches of algal flotant. Cronoble (1962), noting that patches of Canville and Stark were lensoid in distribution and covered from 1 to 3 square miles, suggested that they were either erosional remnants or local basins. Cronoble and Mankin (1965) compared the Lost City, Canville, and Stark

to Florida Bay, stating that they represented low energy facies baffled by algae. Visher and Rennison (1978) decided that the Lost City is time equivalent to the upper Coffeyville, and accumulated in a restricted nearshore environment.

In addition to the continuous distribution of apatite nodules in the base, the principal clue to the relationships of the units is provided by the conodonts. Where the Canville, Stark, and Winterset occur in normal sequence, the conodonts display the typical Midcontinent pattern with Gondolella and Idioprioniodus appearing in the Stark (e.g., Localities CB1, Bt2); where the Canville and Stark are missing, the basal Winterset contains a conodont lag of forms typical of the Stark, such as Gondolella. In some cases, the basal Winterset is directly above the Dodds Creek (sensu stricto) or over sandy Coffeyville; in other cases conodonts typical of the Canville (such as Adetognathus) show up in the sandy, fossiliferous shales below. The apatite nodules also show evidence of having not formed in the basal Winterset environment as many lack detrital sand, although the surrounding Winterset is rich in it.

It is readily apparent that the Canville and Stark are largely missing due to active processes, either continual winnowing of fines so that the Stark did not form, or submarine erosion. The latter is favored, because the apatite nodules appear to have formed in a different environment from that of the basal Winterset, and because they are reworked into the basal layer, rather than restricted to a single plane.

The patchy distribution of the Stark does not seem to be linked to channels, as it is not linear. Around Hogshooter, it is a lens only a foot or so thick, but covering an area of several square miles (Cronoble and Mankin, 1965). At another place where channel fill is a possibility (Cedar Bluff north of Coffeyville, Locality CB1), neither the underlying Canville nor overlying Winterset show any development of current-influenced facies; if it is a channel, it does not show late regressive current movement as do the Wilson and Woodson County channels in the Stanton Formation (Heckel, 1975).

This patchy development without gradation into a dysaerobic grey facies makes the Stark unique among core black shales, but since it can be demonstrated that Stark deposition was probably originally continuous, this apparent anomaly disappears.

A related feature occurs in the Eudora Shale in the same region. At Tyro, where the black facies is absent, Malinky (1980) described an apatite nodule horizon in the middle of the grey Eudora with some of the nodules encrusted by epibionts. Malinky attributed this to development of a diastem at maximum transgression. This matches well with the conodont distribution, which reaches much greater numbers including the typical core forms at that horizon. Further erosion of the Eudora over a larger area could have produced the situation observed in the Stark.

Both of these features suggest that during or not long after high sea level stand, currents could be locally or regionally important in erosion of bottom sediments, and that the Upper Pennsylvanian seas may have been more energetic than generally credited.

# SUMMARY

The two sets of shales at different positions in the cyclic sequences of the Midcontinent and the Illinois Basin show distinct differences, reflecting deposition under widely different conditions. The outside shales (Vilas, Galesburg/Coffeyville, and equivalent units in Illinois) have both depositional and nondepositional subaerial and shallow marine facies. The core shales (Stark, Eudora, and similar shales in Illinois) are relatively uniform offshore marine units, except where diluted by terrigenous clastic influx.

1. The clay mineralogy of the shales and adjacent rocks reflects the sources and transportational patterns of the original materials. Kaolinite, which forms principally by leaching on well-drained uplands, usually indicates significant erosion and transport of detritus into the basin. Where clastic influx was not important, the clay suite is illite-chlorite. This suite was found throughout the Forest City Basin in both the Vilas and Galesburg shales, indicating that no significant clastic material was brought in during the regressive portions of the cyclothems. The thick shales of the Illinois Basin and the southern Midcontinent are kaolinitic, as are the minor clastic pulses in the Forest City Basin. The principal clastic wedges, derived from the Appalachians and the Ouachitas, are characterized by an illite-kaolinite-chlorite suite. The different clay mineral suites show that the clastics deposited in Illinois were not transported into the

Forest City Basin during the regressive intervals. A small delta near Kansas City, possibly derived from the older Pennsylvanian surface of the Ozark Uplift, has an illite-kaolinite suite.

The general lack or low abundance of kaolinite in all core shales indicates that they were deposited far from clastic influx from the basin margins. Even in Illinois and southeastern Kansas, where some kaolinite is found in the core shales, it is less abundant than in the outside shales of the same regions.

2. Mica in these deposits is a detrital mineral, and its distribution closely parallels that of detrital kaolinite.

3. Siderite nodules in the marine outside shales are probably formed in rapidly deposited muds where access to sulfate from seawater (which would have promoted pyrite formation) was cut off by the sediment. The round nodules formed in a homogenous medium, perhaps by early nucleation around a fossil that locally altered the geochemical environment. Flattened nodules may have developed later after some compaction when lateral permeability of the sediment became important.

4. Barite formation throughout the deposits was a result of local barium supersaturation, possibly brought about by ion exchange with illite or by the inversion of barium-rich aragonite releasing barium to the environment.

5. Authigenic kaolinite occurs in both sandstones and limestones, where its distribution may be compatible with formation in a freshwater environment during emergence at maximum regression.

6. Low-temperature diagenesis and/or compactional loss of interstitial fluids from the core shales probably contributed to

silicification and dolomitization of the adjacent carbonate units, as well as transporting ions for sphalerite, galena, and chalcopyrite formation.

7. Diagenesis had no effect on the bulk of the clays present. Various lines of evidence indicate that the rocks of the Midcontinent were probably not heated to more than 50°C.

8. The black shales of the Forest City Basin are at threshold conditions for liquid hydrocarbon production. The organic matter in the Eudora Shale may be largely sapropelic, which corresponds to the diminished importance of humic material from the limited coal swamps of the Missourian. Diagenetic heating is at the lower end of the liquid hydrocarbon range. However, biogenetic methane may have been produced in areas where deposition was rapid enough to preserve the organics and cut off sulfate diffusion in from the environment. These conditions were probably not met in the Forest City Basin, but were common to the south and in the Illinois Basin.

9. The distribution of pertinent marine fossils supports the interpretation of nearshore variable environments in the outside shales, becoming increasingly stable toward the limestone horizons. The core shale faunas also indicate an unstable environment, especially close to the black facies. The black-shale fauna is a low-diversity opportunistic one that closely resembles those found in modern areas of upwelling. The distributions not only of conodonts, but also of ostracodes, agglutinate foraminifers, articulate brachiopods, and fish supports an interpretation of increasing water depth toward the black shale. Inarticulate brachiopods and sponges also are

compatible if modern analogies are applicable. These distributions found and their interpretations are compatible with those detailed by Holdsworth (1966) for radiolarians, Bless (1969) for ostracodes, Heckel and Baesemann (1975) for conodonts, and Calver (1968a) for Carboniferous faunas in general.

10. The faunas in the outside shale are compatible with a shallow-water environment periodically disrupted by storms, with disruptions becoming less frequent toward the limestones. On a fine scale, the assemblages are probably time-averaged from different stages of local successions, but on a coarser scale they show regular additive increases in diversity, as more and more stenotopic forms are added to the succession. Only in areas of rapid deposition can direct evidence be found for the temporal mosaic of Johnson (1972).

11. The distribution of fauna in the cyclothems suggests that the animals were largely controlled by physical conditions. Distribution of the animals was dependent on cyclothem phase of deposition, and almost no distributions found showed a correlation between two faunal groups. Thus, the faunas conform to models for shallow marine, physically controlled associations, rather than stable offshore marine, biologically accommodated communities.

12. Some correlations suggest a relationship between faunal distributions and clastic influx. Some animals commonly occurring in the outside shales, such as Derbyia and myalinids, were negatively correlated with kaolinite and mica, which suggests that they were favored by low deposition. Other animals exhibited both a negative correlation with clastic minerals and a positive correlation with limestones and

core shales, which suggests that they may have favored a stable offshore environment rather than one with low deposition in a nearshore environment. Most molluscs showed a tendency to occur in the thick grey shales; however, sedimentary features and distribution of co-occurring calcitic forms suggests that many molluscs were not originally restricted to this environment, but simply that rapid deposition favored their preferential preservation.

13. The faunal associations correspond in general features to those of Elias (1937), Johnson (1962), Mudge and Yochelson (1962), Moore (1964), and Calver (1968a). However, since the faunal elements were apparently not dependent on each other, the associations represent common ranges of occurrence, rather than mandatory biological relationships.

14. The flora in the outside shales follows the known trend of reduced diversity in the Missourian possibly reflecting the general drying of the climate and the advent of seasonality.

15. Coals formed in several different environments: alluvial flood plains, behind barrier bars, and on open coasts where fresh water was impounded by rising sea level. The second and third groups are areally extensive, although not thick enough to be of economic value. The first group is represented by multiple thin coals in the Galesburg and Coffeyville. The second group is represented by the Cedar Bluff Coal, while the Davis City Coal is an example of the third group. Although living in different settings, the flora that produced the coals was apparently relatively uniform.

16. Several different types of soil profiles were found in the outside shales. The Galesburg type was a thin, nonaggradational profile developed on a limestone. Its clay mineralogy and carbonate distribution indicate that it was leached, although not extensively or deeply. Generally, it could be described as a sulfaquent, a soil type found in coastal marshes today; this would reflect its modification during transgression when coal swamps formed on it. The Fithian subtype is similar, except that it formed on a thick shale where leaching during regression produced a caliche horizon at the base of the profile.

The northern Vilas type is a much thicker soil, usually including blocky red mudstone. Although the clays may be somewhat more leached than in the Galesburg type, a distinct gradation is not developed. Calcite is present in this soil as small glaebules. The Vilas type is reduced to green mudstone at the top, probably by marine organics introduced during transgression. The Vilas type may have been a variety of vertisol, formed in well-drained, seasonally dry conditions.

The Coffeyville type is a poorly developed flood plain soil found beneath coal swamps. Leaching is not evident, and the clay mineralogy is indistinguishable from the parent material, but in rare cases a poorly developed caliche horizon may be present.

17. The sandstones of the cyclothems include both orthoquartzites and subgreywackes. The only apparent positive correlation suggests that depositional environment is the controlling variable, with fluvial sands rich in matrix, and shoreline sands winnowed

orthoquartzites, which became cemented by calcite if they contained sufficient fossils.

18. The Dodds Creek Sandstone in southern Montgomery County is a delta-destructive sand, conformably overlying a coal and overlain by an offshore limestone with apatite nodules. It is a relatively clean, massive sheet sandstone with no evidence of alluvial sedimentary structures or channel forms. It is possible that the Dodds Creek in its type area and similar facies in Oklahoma are also delta-destructive sands, but the stratigraphic and chronologic relationships among them are unclear.

19. Where the Stark Shale and Canville Limestone are locally missing in northeastern Oklahoma and adjacent Kansas, the basal Winterset Limestone contains a lag deposit of conodonts and apatite nodules normally found in the Stark, which implies a period of winnowing and/or submarine erosion prior to the deposition of the basal Winterset.

20. Sedimentary structures in the marine portions of the outside shales in the Forest City and Illinois Basins support the interpretation of deposition in areas of episodic, slow sedimentation periodically disrupted by storms. Thicker shales in the southern Midcontinent and Illinois suggest deposition in a variety of delta-related environments, including mud banks driven along shore by prevailing currents, prodeltaic muds, and in some cases deltaic muds and sands.

21. Shale partings in the limestones may be due to clastic influxes, temporary failure of carbonate deposition, or the result of some sort of disruptive event. In some cases, the cause can be

determined from paleontological, stratigraphic, and mineralogic evidence.

22. The features of the black core shales can be most readily explained by widespread offshore deposition beneath a largely stagnant water mass during maximum transgression. Locally, upwelling may have enriched the water in phosphate and precipitated apatite. The episodic nature of the upwelling is compatible with modern upwellings, resulting in formation of laminations and apatite nodules, and appearance of opportunistic fauna. The upwellings were probably controlled by seasonally variable winds.

23. Although the stratification of the offshore water column may have been due to establishment of a thermocline in deep water (Heckel, 1977, 1980), locally augmented by a freshwater wedge nearer humid shorelines (Heckel, 1982), development of a dense brine may have been involved, possibly to a controlling extent. Contemporary evaporites along the northern edge of the Midcontinent basin may have been associated with high salinity bottom waters, which in turn contributed to the geochemical anomalies (e.g., low sulfur and high metal contents) of many black shales. Similar cyclic sequences in the evaporitic Paradox Basin contain a similar fauna in the black shales which are attributed to brine stratification. Although the sedimentological and paleontological features are compatible with a brine-stratification model, they do not require it.

24. The depositional features of the shales support the simple mechanism of rise and fall of sea level as the basic control to explain the formation of cyclothems. The outside shales were

deposited mostly during low stand in variable shallow water and subaerial environments, whereas the core shales were deposited at high stand in widespread offshore environments where Eh was the only variable. The prevailing climate was apparently transitional from wet to dry tropical, with seasonal fluctuations in rainfall and wind intensity and possibly direction. This was a manifestation of the gradual drying of the climate in the Upper Pennsylvanian, and this part of North America moved northward through the trade wind belt toward the horse latitudes.

# APPENDIX A

# EXPERIMENTAL PROCEDURES

## Clay Mineralogy

### Sample Preparation

Laboratory procedure for clay analysis included the processing of normal shales, bituminous shales, underclays, argillaceous sandstones, and argillaceous carbonates. The simplest procedure involved the normal shales, underclays, and argillaceous sandstones. After thoroughly air-drying in the laboratory, the samples were crushed with a mortar and pestle, then dry-sieved through a 63-micron (250 mesh) screen. Samples were crushed sufficiently to produce a usable quantity of fine particles, not to completely reduce the sample to powder. Samples were ground as little as possible to minimize strain of the clay crystal lattices.

Bituminous shale samples were processed by first scrubbing the sample to remove adhering weathered material, then soaking in commercial bleach (sodium hypochlorite solution) until all of the organic material was removed, following the procedure of Cassidy and Mankin (1960). They observed that this process did not damage illite, chlorite, or vermiculite, but could potentially damage kaolinite or smectite. However, if this occurred, it was marked by the appearance of X-ray diffraction peaks at 6.3Å and 3.64Å, a characteristic that

was not observed in the course of this study. Due to the extremely bituminous character of many of the samples, it was necessary to bleach them for several months, changing the bleach as necessary. This contrasts with Cassidy and Mankin's bleaching time of three days. This was necessary, however, as excess organic material diluted the clays and did not permit effective orientation of the samples, producing poor resolution of untreated clay samples. Processed samples, however, produced results that were consistent with those of adjacent, nonbituminous sediments. After the samples were bleached, they were rinsed several times to remove excess bleach, then allowed to dry. They were then loosely crushed with a mortar and pestle to disaggregate the mud, then dry-sieved through a 63-micron (250 mesh) screen to remove any unbleached fragments.

In order to obtain clay samples from carbonates, it was necessary to acidize them. Ostrom (1961) noted that other methods were inefficient and not as accurate, due to the low volume of material usually produced and large proportion of carbonate with the clay. Since a considerable volume of carbonate was processed for microfossils, it was economical to remove clay samples as a byproduct. A carbonate sample consisted of a kilogram of washed and crushed rock dissolved in dilute formic acid. When the residue was washed to remove the microfossils, a small jar was placed below the 63-micron (250 mesh) screen normally used in processing microfossils. This caught a representative sample of the fine insoluble residue. This was then washed several times to remove excess formic acid. The sample was then allowed to dry, when it became ready for further processing.

Ostrom (1961) noted that well-crystallized clays were not affected by any concentration of acetic or hydrochloric acids, although poorly crystallized chlorite and illite were somewhat altered by moderate concentrations, with the peaks broadened, apparently by the loss of exchange cations in interlayer sites. Fraser (1970) reported a personal communication from J. L. Eades, who observed that in the case of chlorite time was more important than strength of the acid in destroying the brucite layer. Nevertheless, as a practical matter, acidizing carbonates to obtain clay samples has been generally pursued, and little difficulty is encountered in practical application. Fraser (1970) used a method followed by H. D. Glass of the Illinois State Geological Survey, employing dilute hydrochloric acid. Bradley (1964) reported that use of both acetic and hydrochloric acid sharpened the illite, kaolinite, and smectite peaks in his samples. Toomey (1964) stated that the formic acid frequently used for microfossil processing (as in this case) was even less damaging to the clays than hydrochloric acid.

At this point, all three pathways for sample processing converged. The samples were placed in suitable small beakers, which were then filled with distilled water, to which a few grains of sodium hexametaphosphate had been added as an antiflocculant (this is particularly important to the bleached and acidized samples, as they may still contain enough exchangeable cations to produce a very strong flocculation). The samples were stirred to suspend the material, then allowed to settle briefly to permit the heaviest non-flaky particles to settle out.

At this point, there was a deviation from standard clay mineralogy procedures. Standard procedures are directed toward producing a sample of clays 2 microns or less in size. For this study, however, the object was to produce a sample that reflected the bulk mineralogy of the detrital clays in the specimen, which would most closely reflect the depositional environment. Baker (1973) noted in Columbia River sediments that the less-than-2-micron fraction was not representative of the clays present, whereas the fraction that was 62 microns or less in size closely reflected the actual clay makeup of the total clays carried by the river. Gibbs (1977) noted the markedly different mean sizes and distributions of various clay minerals carried by the Amazon: smectites averaging about .4 micron, kaolinite about 1 micron, illite about 2 microns, and chlorite about 10 microns. Here again a 2-micron cutoff would not reflect the clay assemblage carried by the river. This also applies to ancient sediments. Héroux and others (1979) noted that the greater-than-2-micron clay fraction is generally used for evaluation of the sediments that originally entered the basin, while the finer material gave evidence of the diagenetic history. Mukhopadhyay and Brookins (1976) and Bailey and others (1962), working with Pennsylvanian sediments, concluded that the larger 2M illite polytype was detrital, and the smaller 1MD polytype was authigenic; dividing the sample at 2 microns would skew the sample toward one or the other form. Using coarser grain sizes increases accuracy, as Jonas (1975) observed that the coarser clay particles are better crystallized, and will disproportionately dominate the X-ray pattern.

Once suspended in water, the clay samples were pipetted onto porous ceramic tiles. These were subjected to suction, drawing the water through the tile and orienting the clays parallel to the flat upper surface. Gibbs (1965) considered this to be one of the few useful methods of clay sample preparation, as it did not skew the sample due to differential settling of the various clays.

When the tiles were covered with a sufficient thickness of clay, the samples were dried and run on a Philips APD 3500 Automated Powder Diffraction System, with a peak search program. The samples were subjected to monochromatic CuK$\alpha$ radiation, run at a current of 40 kilovolts and 20 milliamps. The peak search program produced a printout of all the principal peaks, as well as the average background for each peak. Thus, it was possible to approximate the actual intensity of the various clay reflections.

## Semiquantitative Clay Mineral Analysis

The semiquantitative calculations to determine the clay mineralogy were based on a procedure described by G. S. Austin in a written communication to J. Lucas, a copy of which was provided to G. R. McCormick. Four runs on the X-ray diffraction device were necessary for each sample: (1) with the sample dried, run between $2^{\circ}$ and $38^{\circ}2\theta$; (2) at 1/5 normal speed between $24^{\circ}$ and $28^{\circ}2\theta$; (3) with the sample exposed to an ethylene glycol-saturated atmosphere for 24 hours, then run from $2^{\circ}$ to $18^{\circ}2\theta$; and (4) heated to $300^{\circ}$C for 1 hour, then run again from $2^{\circ}$ to $18^{\circ}2\theta$. The following values were then found for the respective peaks (less background): on the untreated run, the value at $12.4^{\circ}2\theta = K_{(1)}$;

at $17.8^{\circ}2\theta = I_{(2)}$; and at $18.4^{\circ} - 18.9^{\circ}2\theta = C_{(3)}$. On the slow run, the value at $24.9^{\circ}2\theta = K_{(2)}$ and at $25.1^{\circ}2\theta = C_{(4)}$. On the glycoated run, values were found at $5.2^{\circ}2\theta = S_{(1)}$ and at $8.8^{\circ}2\theta = I_{(1G)}$; and heated a value was found at $8.8^{\circ}2\theta = I_{(1H)}$. (Often, the peaks do not appear precisely where specified by the procedure. In such cases, the peak value recorded at approximately the correct spacing is substituted.) Values were then calculated by use of the following formulae:

Equation 1. $$T = I_{(1H)} + K_{(1)}$$

or, if chlorite is present,

Equation 2. $$T = I_{(1H)} + \frac{C_{(3)} x I_{(1G)}}{I_{(2)}} + \frac{K_{(2)} x C_{(3)} x I_{(1G)}}{2 x C_{(4)} x I_{(2)}}$$

Equation 3. $$\% \text{ Illite} = \frac{I_{(1G)}}{T} \times 100$$

Equation 4. $$\% \text{ Chlorite} = \frac{I_{(1G)}}{T} \times 100 \times \frac{C_{(3)}}{I_{(2)}}$$

Equation 5. $$\% \text{ Kaolinite} = \frac{K_{(1)}}{T} \times 100$$

or, if chlorite is present,

Equation 6. $$\% \text{ Kaolinite} = \frac{I_{(1G)}}{T} \times 100 \times \frac{C_{(3)}}{I_{(2)}} \times \frac{K_{(2)}}{2C_{(4)}}$$

Equation 7. $$\% \text{ Smectite} = \frac{S_{(1)}}{4T} \times 100$$

Equation 8. $$\% \text{ Mixed layer} = \frac{I_{(1H)} - \left[ I_{(1G)} + \frac{S_{(1)}}{4} \right]}{T} \times 100$$

There are three potential sources of inaccuracy in the evaluation of the clay samples: (1) those intrinsic to the clay samples themselves, (2) those involved with the actual process of X-raying the

samples, and (3) those involved with manipulating the data evolved.

Problems Inherent in Samples

The tremendous amount of solid solution in some clay minerals makes them difficult to analyze and describe. Several clays examined in this study presented major difficulties.

Illite, the most abundant clay, presented chiefly descriptive problems. As the potassium is removed from the illite structure, an increasing number of expandable or partially expandable layers are formed. These weathered clays have been variously described as smectite-illite mixed layer, vermiculite-illite mixed layer, hydromica, or degraded or weathered illite. The last term is preferred here; although it carries a genetic connotation, this is appropriate in this instance.

Vermiculite is essentially stripped illite with the layer charges causing the interlayer water to line up and behave in an orderly fashion. There is some question whether vermiculite proper is present in the sediments. This is unlikely although the weathering process may possibly give rise to some vermiculite-like layers.

Chlorite provides the principal problem as it is very common, and unfortunately very difficult to categorize. Within the chlorite group are iron-, magnesium-, and aluminum-rich end members. The first two are comparatively well known, and usually formed by various depositional and diagenetic processes. Aluminum silicates with a chlorite structure (approaching the end member known as donbassite) apparently are formed by soil processes through the process called the

"antigibbsite effect" by Jackson (1963). In this process, stripped illite has aluminum introduced between the clay layers, building up a gibbsite layer between them and producing a dioctahedral clay with a 14Å basal spacing. For X-ray purposes, this is a chlorite, and it is not possible to distinguish it from other chlorites without chemical tests. This in turn hampers evaluation of the chlorite present, as a continuous intergradation may be present, originating from different processes and perhaps altering from one to another.

Non-clay fines provide another problem. Usually, they include quartz and calcite, but may also include organic material. This leads to poor results for two reasons: (1) the non-platy materials may prevent a significant number of clay flakes from lying flat on the tile, thus cutting down on the intensity of the basal spacing, and (2) the quantity of nonclay material serves to dilute the clays present. In some samples, particularly the bleached black shales, the second problem may be quite severe, as a very large percentage of the clay-sized particles are quartz.

Problems Inherent in Hardware

Difficulties with the hardware principally centers around the ceramic tiles used for the clay samples. These are not high-precision slides, but are porous construction tiles cut to fit in the automatic sample-changing device. As a result, a certain degree of uncertainty is introduced, but this is readily overcome by internal controls. Because the face of the sample tile is often not precisely parallel with the sample holder, the angle produced by the X-ray beam, the clay

lattice, and the recording device is slightly different from that recorded by the X-ray goniometer and the printout. This hampers precise measurement of the diffraction peaks, but this would be important only if precise measurements of the percentage of mixed layer clays were necessary. However, in view of the nature and genesis of the random mixed layers present, this is not useful information. In addition, internal control of variation in peak positions and intensities between runs comes from several sources: the frequent presence of a sharp kaolinite 001 peak, and/or the presence of a moderately sharp chlorite 002 peak at about 7Å, neither of which are significantly influenced by either glycolation or heating to 300°C, provides a control on the low-angle clay data. Quartz is present in all the samples as well, and marked quartz peaks (the 100 peak at 4.26Å - 20.85°2θ and the 101 peak at 3.343Å - 26.66°2θ provide control at the higher angles. The latter peak, used as the calibration peak, is particularly important, as it provides control on the "slow" run from 24°2θ to 28°2θ where precision in determining the position of the kaolinite 002 and the chlorite 004 peaks is particularly important. The amount of machine-produced error in angle measurement is readily determined by examination of the displacement of the quartz peak.

Since the sample tiles often do not sit flush with the sample holder, occasionally very low angle effects (from the X-ray beam grazing the tile) will produce a spurious very low angle peak. This is usually demonstrated to be the case as the peak will not significantly change position or intensity on the normal, glycolated, or heated runs. The occurrence of this phenomenon is not governed by any stratigraphic

pattern, but appears to be random. Potentially, this peak could mask the occurrence of a clay with a large basal spacing, such as corrensite, but the lack of any such clay appearing elsewhere makes this unlikely.

Generally, the X-ray diffraction patterns are very usable. On such occasions as it was necessary to rerun portions of the samples (generally due to miscellaneous hardware glitches), the data was satisfactorily repeated, indicating very little intrasample variation from run to run.

Problems Inherent in Analysis

The problems involved with manipulating the data are probably the largest source of numerical error, but the least readily understood by those unfamiliar with semiquantitative clay mineralogy. The problem arises from the wide variability of clay mineral composition mentioned earlier. These wide variations have a tremendous effect on the relative strengths and shapes of the X-ray peaks. In order to quantify the data to any degree, it is necessary to assume a single stoichiometric formula for each clay, which would produce an ideal X-ray pattern. Unfortunately, even relatively minor variations from the ideal may produce significant variation. Thus, the numbers generated from an X-ray diffraction pattern are usually better thought of as a numerical evaluation of the peaks, and may or may not reflect the actual proportions of the clays present.

Pierce and Siegel (1969) ran comparative tests among five techniques for evaluation of clay mineralogy, and found only modest

consistency at expressing trends. They also found that use of peak areas gave better results than peak heights. However, they did not include heating the sample in their procedure, nor attempt to quantify the percentage of mixed-layer clays present. They concluded that numerical data on clays could only be described as semi-quantitative; that is, descriptive of the X-ray pattern and not necessarily of the clays present. However, they concluded that the methods were all probably internally consistent, but that comparisons between quantitative results of different methods was not a good idea. During this study, a test was conducted with a suite of samples from Fithian, Illinois, with four different methods. The results in Table A1 illustrate the problem. Three of the methods are based on peak heights, while that of Schultz is partially based on area. Austin's method is the one actually used in this study. For this study, the assumption of reasonable internal consistency was accepted, permitting the comparison of a large number of samples.

At this point, it is appropriate to consider the problems inherent in Austin's methodology (many of which are shared with other techniques) used here, and discuss the potential impact on the results generated.

Austin's method is based on comparison of peak heights. While it may not be as accurate as using areas, in view of the large numbers of samples run and the relative uniformity of the clays, together with the assumption of internal consistency, this was a reasonable compromise. However, this involves a flaw common to most semiquantitative techniques, the use of correction constants.

Table 12

Clay mineral percentages by contrasting techniques--Fithian, Illinois

| Illite | | | | | Mixed Layer | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample | 1 | 2 | 3 | 4 | Sample | 1 | 2 | 3 | 4 |
| Ftl/top | 46.3 | 35.1 | 52.6 | 34.8 | Ftl/top | 12.5 | 9.4 | 14.1 | 13.5 |
| Ftl/47 | 56.9 | 41.4 | 62.6 | 43.2 | Ftl/47 | - | - | - | 6.4 |
| Ftl/44 | 64.8 | 33.7 | 55.0 | 45.2 | Ftl/44 | - | .2 | 3.3 | 6.0 |
| Ftl/m | 54.8 | 39.1 | 53.0 | 44.7 | Ftl/m | 21.8 | 16.0 | 21.7 | 18.6 |
| Ftl/19 | 51.6 | 35.8 | 54.3 | 41.8 | Ftl/19 | 12.6 | 9.3 | 14.2 | 18.8 |
| Ftl/12 | 54.6 | 47.4 | 64.5 | 56.6 | Ftl/12 | - | 5.0 | 6.8 | 1.3 |
| Ftl/4 | 60.0 | 48.1 | 65.9 | 50.4 | Ftl/4 | 4.2 | 3.3 | 4.6 | 13.9 |
| Ftl/-12 | 68.3 | 54.7 | 62.0 | 50.6 | Ftl/-12 | 29.2 | 23.3 | 26.5 | 39.7 |
| Ftl/-42 | 55.0 | 44.1 | 54.6 | 42.3 | Ftl/-42 | 29.6 | 23.8 | 29.4 | 40.8 |
| Ftl/sls | 54.1 | 32.2 | 54.5 | 35.0 | Ftl/sls | 6.7 | 4.0 | 6.7 | 8.2 |
| | Chlorite | | | | | Kaolinite | | | |
| Sample | 1 | 2 | 3 | 4 | Sample | 1 | 2 | 3 | 4 |
| Ftl/top | 27.4 | 15.3 | 17.0 | 10.3 | Ftl/top | 13.7 | 40.2 | 16.2 | 41.4 |
| Ftl/47 | 28.1 | 11.8 | 18.3 | 8.8 | Ftl/47 | 15.0 | 46.8 | 19.0 | 41.6 |
| Ftl/44 | 16.9 | 11.8 | 13.4 | 3.8 | Ftl/44 | 18.2 | 52.5 | 28.2 | 45.0 |
| Ftl/m | 16.2 | 11.5 | 13.3 | 5.5 | Ftl/m | 7.2 | 33.3 | 12.0 | 31.2 |
| Ftl/19 | 26.2 | 15.2 | 17.3 | 8.8 | Ftl/19 | 9.5 | 39.6 | 14.3 | 30.6 |
| Ftl/12 | 32.1 | 15.4 | 15.7 | 10.7 | Ftl/12 | 13.2 | 32.2 | 13.0 | 31.4 |
| Ftl/4 | 23.3 | 11.2 | 14.4 | 9.2 | Ftl/4 | 12.5 | 37.4 | 15.1 | 26.5 |
| Ftl/-12 | 1.7 | 2.3 | 5.6 | .8 | Ftl/-12 | .9 | 20.0 | 5.9 | 8.9 |
| Ftl/-42 | 8.5 | 2.7 | 6.3 | 2.1 | Ftl/-42 | 6.8 | 29.4 | 9.6 | 14.8 |
| Ftl/sls | 21.2 | 8.5 | 14.6 | 4.8 | Ftl/sls | 17.9 | 55.3 | 24.1 | 52.0 |

1 - Austin, unpublished

2 - Fraser, 1970

3 - Weaver, 1967

4 - Schultz, 1964

The problem stems from variation in the relative X-ray-reflecting abilities of the various clay minerals. Illite is generally relatively weak, and is thus under-represented by peak strength. Chlorite is slightly stronger, with kaolinite stronger than chlorite. Smectite clays are the strongest of the common clays. So, the problem arises in how to compare the clays. Since the methods attempt to reflect the mineralogy in only an approximate way, and essentially show the results of the numbers used, arbitrary correction constants are acceptable, although these should approach reality as much as possible. Thus, to compare illite and kaolinite, Verhulst (1970) and Crouch (1971) divided the kaolinite peak value by 2.5, while Murray (1954) and Kinell (1964) divided it by 3. To compare kaolinite and chlorite (and thus indirectly to illite) Schultz (1964) divided the kaolinite peak value by 1.5; Glass (in Fraser, 1970) used 2; and Murray (1954) and Kinell (1964) used 2.5. The smectite-illite comparison is more consistent: Weaver (1967), Crouch (1971), and Austin (as used in this study) all used 4 as the divisor, while Schultz (1964) used 4.5. In all cases listed here, the comparison is between the 001 basal reflections; only Austin (used in this study) and Weaver (1967) used other peaks when they compared the chlorite 002 and the kaolinite 004 peaks. Correction constants were also applied here, as Austin divided the kaolinite by two, while Weaver compared them directly.

As is immediately obvious, this can lead to problems. For example, in Austin's method, all mixed layer clays are assumed to have the same reflecting ability as illite, but if they become as expandable as a smectite, the value is automatically divided by 4. In this study,

this is a relatively minor problem, as clays with smectite characteristics are relatively rare in the sediments studied.

Perhaps the principal problem is in comparing chlorite and kaolinite. This is doubly difficult, as frequently the illite 001 peak partially conceals the chlorite 001 peak, while the chlorite 002 and kaolinite 001 peak are superimposed. Austin chose to circumvent the problem by comparing the kaolinite 002 and chlorite 004 peaks, which, although closely spaced, can be resolved in many cases. However, when the chlorite is poorly crystallized and the peak is wide, it is often difficult to tell if kaolinite is present (the reverse may also be true, but far less often). Since Austin divides the chlorite 004 peak value by 2 to compare to the kaolinite, any sample with kaolinite slightly less than half as abundant as chlorite should be treated with some caution.

Austin used chlorite for indirect comparison of kaolinite to illite. The percentage of chlorite present is based on the intensity of the chlorite 003 peak and that of the illite 002 peak. Theoretically, this should work, as Brindley and Gillery (1956) noted that the odd peaks of chlorite vary less with Fe-Mg substitution than the even peaks. However, the 003 peak is a weak peak, and with the large, broad illite 002 peak nearby, resolution is frequently difficult. Furthermore, since the chlorite 003 value is often too small to print out directly, estimation is frequently necessary. Due to the nature of the problem, this then multiplies through the system, influencing the value of kaolinite. Since Weaver (1967) noted in iron-rich chlorites (which many of these may be) the 003 peak is relatively weaker compared

to the 002 peak than in Mg-chlorite, this serves to underestimate both the amount of chlorite and the amount of kaolinite present. All this is further compounded when chlorite disappears from the sample; then, Austin compared the illite and kaolinite values directly. As observed above, most workers employ correction constants, and with the indirect chlorite pattern probably underestimating kaolinite, this can produce drastic swings in kaolinite, depending on whether chlorite is present or not. This artifact should be borne in mind when examining the results produced.

The other major problem involved is quantifying the data derived from the illite 001 peak. As much of the illite in this study is weathered, it produces a substantial "tail" toward the high angle side (Keller, 1964). When glycolated, this "tail" spreads, and occasionally produces a high angle peak. Labelling and evaluating these high-angle, high-basal-spacing clays is difficult and arbitrary. If the clay produced a separate peak at 17Å upon glycolation, it was counted as a smectite; otherwise it was included as part of the mixed layer clays. Vermiculite would also fall into this area, and many workers have reported it (Table 1). However, vermiculite is produced principally by replacing the interlayer metal cations of three-layer clays with $H_3O^+$, principally by weathering. In true vermiculite, the layer charge lines up the water, giving the mineral its unique properties; however, this is not much different from more normal leached illite and chlorite. Stepusin (1978) cited a personal communication from J. Hower that vermiculite derived from illite by leaching expands to 17Å when glycolated, so that dioctahedral vermiculite

cannot be distinguished from smectite. Thus, with glycolation it is not possible to distinguish interlayered vermiculite/illite from smectite/illite. In any event, discrete vermiculite was not present. Several examples were heated to 550°C, where vermiculite loses its 14Å spacing, while that of chlorite intensifies. The behavior expressed indicated that all the 14Å clay present was chlorite. This was supported by the observation that the 7Å (002) peak (when kaolinite did not mask it) was much more intense than the 14Å (001) peak, a characteristic of chlorite; vermiculite is the reverse (Grim, 1968). The lack of vermiculite was helpful, as Austin's method is not set up to evaluate the data for it. Essentially, all the high-angle "tail" to the illite is considered to be mixed-layer clay, with the change in shape with glycolation and heating expressing illite interlayered with smectite (free swelling) layers. Unfortunately, even when heated the peak does not collapse completely and become comparable in sharpness to kaolinite; Stepusin (1978) stated that this is probably due to interlayer precipitation of hydroxides. Because of this, the percentage of mixed layer clay is consistently underestimated; it is also possible that a small percentage of vermiculite interlayers may contribute to this persistent "tail".

Another problem with the evaluation of mixed layer clays centers around dehydration, which collapses all the non-chloritic layers to 10Å. Austin and Leininger (1976) noted that heating to 350°C or less causes incomplete collapse (300°C was used here, following the established procedure), while heating over 425°C caused a loss of intensity. They suggested heating for 5 minutes or more at 375°C, but

noted that cooling below 100°C permitted partial rehydration. Here again it was necessary to rely on some level of internal consistency, as it was not possible to achieve the ideal.

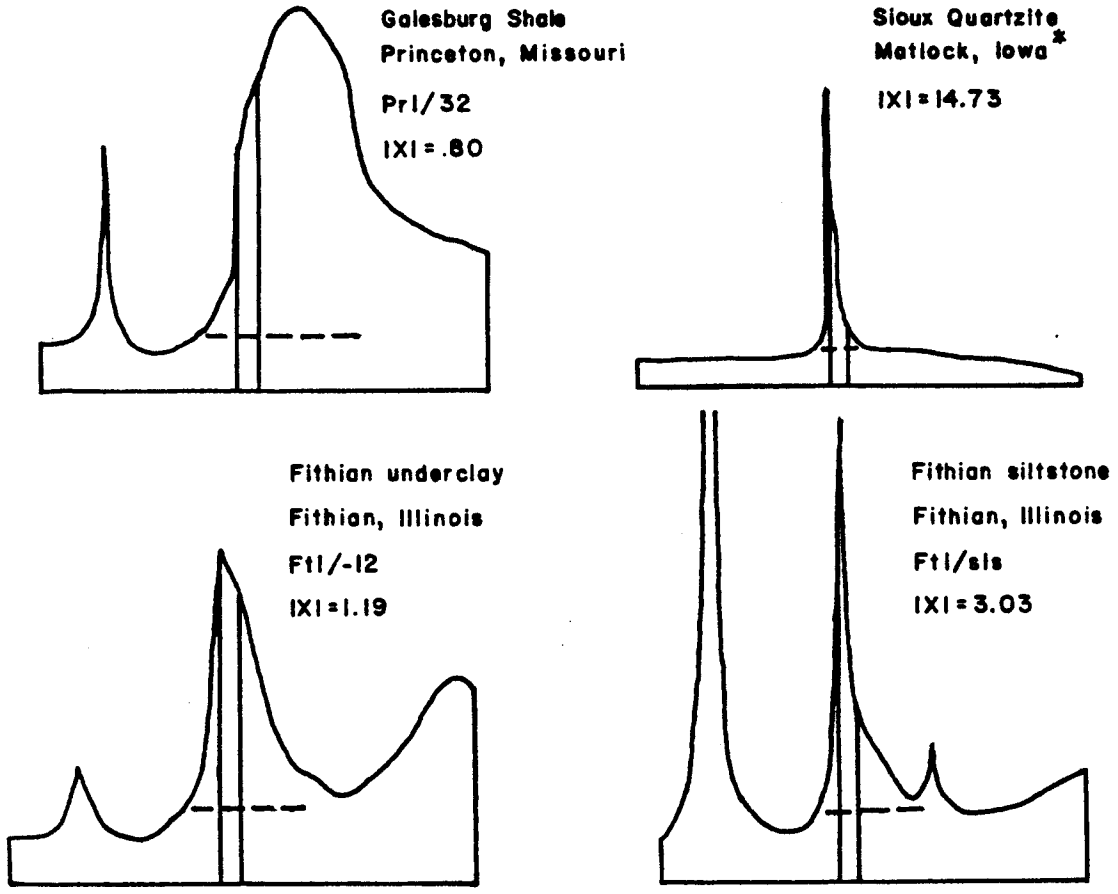
A problem common to all the clays when more than one peak was used, but particularly pronounced in the cases of illite and chlorite, are the differing intensities based on the solid solutions in the structures. It is presumed that such variations are not significant in illite, as the environments producing the clays are not too extreme or variable, but there is a strong probability that a whole range of aluminum, magnesium, and iron chlorites exist. Unfortunately, little can be done to address this problem, particularly as the diagnostic peaks for this series are probably thoroughly obscured, as chlorite is usually only an accessory clay.

At this point, the question, "Then why bother?" should be answered. Because this is semiquantitative, it does not purport to represent the amounts of clays actually present. Attaching numbers to the clay peaks enables some sort of comparison to be made between them, with a system possessing some degree of internal consistency. Even the gross trends expressed may have some significance, although care should be used in their interpretation. Austin and Leininger (1976) stated that no clay data should be reported to more than one significant digit; here, it is reported to the first decimal, with the understanding that it represents the mathematical reduction of the peak data and not the actual percentage of clay present, even though it is expressed in that form.

## Illite Crystallinity Index

Another X-ray peak parameter employed turned out to be much more useful, and not subject to the many failings inherent in the semi-quantitative comparison of clays. This is the illite crystallinity index (IXI), which is essentially an attempt to quantify a shape parameter of the illite 001 peak. Weaver (1960) first suggested using the measurement to express the degree of metamorphism of the illite. Here, however, it was employed to express the degree of leaching to which the illite was subjected. With the loss of potassium, increasing amounts of expandable clays are present, asymmetrically broadening the illite peak, as noted by Weaver (1965). This is expressed as a ratio of the peak height to the height of the peak $\frac{1}{2}^{\circ}2\theta$ to the upper spacings. (Weaver, 1960, suggested using 10Å and 10.5Å values for calculation; due to slight vagaries of the process used here, the illite peak adjacent to the abrupt drop-off on the low-angle side was used, as well as the value $\frac{1}{2}^{\circ}2\theta$ noted above. As it turns out, in this range there is little difference between the values from the two methods, and the results are roughly comparable.) This measurement has the advantage of not requiring comparison to any other clays or peaks; it is a measure of one parameter, not a plethora of them as in semiquantitative measurements. Consequently, changes in the index better define some of the changes in the clay.

However, it does suffer slightly from problems at the extremes. If the illite peak is sharp, it is often difficult to accurately




Dashed line indicates background level

*Sericite from -574', New Jersey Zinc core C-6, T98NR44W32SEI/4SEI/4SWI/4SEI/4

Figure 77. Comparative illite crystallinity.

estimate the secondary, non-peak value; a small error here can produce wide fluctuations in the index value. For this reason, high values should not be taken literally, i.e., values above 2.5 should simply be read as "very high". Weaver (1960) suggested using a ratio of 2.3 as the level of incipient metamorphism, with 12 being approximately the greenschist grade; however, values between 2.5 and 5 are fairly common in the offshore suites of this study, but were unlikely to have been preferentially metamorphosed. Poor peak resolution in some samples may produce similar problems, as very low values may be misrepresented. Typically, in badly weathered illites, the curve separates into a sharp, true illite peak and a peak with a large percentage of expandable layers. Usually, the secondary value for the index will fall in the saddle between, producing a smaller secondary number to compare to the illite peak, while the main peak, at a higher angle, would reduce the ratio further. As a result, an index of about 1.0 or below should simply be viewed as "very low" and the illite as "badly weathered".

## Potassium Percent

A third parameter also was measured, although it is of uncertain value. This is the potassium percentage of the illite, and involves comparing the 001 and 002 illite peaks. White (1962) noted that as illite weathers in the soil and the potassium content decreases, the illite 002 peak becomes less intense relative to the 001 peak. Weaver (1965) also observed this tendency, and plotted the distribution of several clays with known potassium percentages and known 001/002 ratios.

From this data, an approximate equation was calculated, in an attempt to express the determined 001/002 ratio as a theoretical potassium content. This produced the following equation:

$$Y = 11.51 - 1.231X$$

where $Y = K_2O\%$ and $X = 001/002$ ratio. The correlation coefficient of the original data is $r = -.5706$, and is significant to the 99% level of confidence.

Unfortunately, two later pieces of evidence throw doubt on the validity of using this value as a direct measurement of potassium present. Weaver (1965) noted that extrapolation to illites with a large percentage of expandable layers was unexamined, although limited application here seems to indicate it is consistent. White (1962) explained the discrepancy: when a substantial percentage of the $K^+$ is removed and replaced by $H_3O^+$ (at a loss of about half the $K^+$), there is a discontinuity in the curve. The resulting pattern gives the same trend, but values calculated for the $H_3O^+$-dominated illite would give a falsely high $K_2O$ percent. The overall pattern would still be valid, but the low values should actually be lower.

The other problem is that $K_2O$ content is not the sole determinant of the 001/002 ratio. It also depends on the amount and type of solid substitution in the octahedral layer of the illite (Grim, 1968). This may or may not be a large problem; most of the illites studied here are probably aluminous. In the case of dioctahedral illite (which they probably are), if it is assumed that all variation in the 001/002 ratio came from solid solution, between 50 and 90 percent of the dioctahedral

sites would be filled with aluminum, with most of the values in the upper end of the range.

However, at this point it is not possible to say how much variation in the ratio comes from changes in potassium content or changes in solid substitution. Empirically, the patterns produced are sometimes consistent with a simple model, but often they are not. The values are included here only as data, representing a quantification of the interactions of several variables. Although reported as $K_2O$ percent (its original intent), the data may not completely reflect variation in that parameter.

## Further Observations on Technique

Shortly after completing this section, a review of quantitative clay mineralogy by Brindley (1980) became available. Included in his observations are several points that theoretically would make the results of this study less reliable. In particular, one variable not considered above is the effect of grain size. Brindley stated that the optimum size for clay studies is about 1 micron. He noted that surface irregularities can cause significant variation, particularly if the particle size is over 10 microns; this is especially important at low $2\theta$ angles.

Brindley also summarized the value of quantitative clay mineralogy by concluding that it is fairly reliable, provided the mixtures involved are simple and the components well defined. On the other hand, soil clays will always remain difficult to analyze, because this is seldom true with them. He also felt that uniform clay procedure

is an unrealistic expectation, as many mixtures must be treated in regard to their special pecularities.

Obviously, this study violated the precept about fine grain size, but this was necessary on sedimentological grounds, as observed previously. This study is definitely a case where the procedure was based on the desired objective, and was structured to give results with some practical efficiency. According to Brindley, this study would have had little hope for quantitative accuracy, for in addition to everything else, most of the clay mixtures dealt with were probably soil mixtures.

On a theoretical basis, then, the clay mineralogy is quantitatively unreliable, due in large part to the nature and objectives of the study. On an empirical basis, however, useful information was produced, and some questions about the nature and origin of the shales were answered by clay mineralogy.

## Recommendations for Future Clay Mineral Studies

1. For studies of detrital clay suites, the samples should use the less-than-63-micron size fraction. Clay samples ideally should be closely spaced in pairs, as in some units, marked variation can take place in a short distance (particularly in soil profiles). In any event, such pairing can serve as a control on the range of variability in a clay suite.
2. Several modifications may be used to better estimate chlorite percentages. A further course of heating to 550°C will

collapse any vermiculite present; even greater heating to 750°C will collapse the kaolinite and eliminate all but the chlorite 001 peak. However, before these techniques could be used semiquantitatively, some control tests would have to be undertaken, as heating intensifies chlorite peaks by an unknown amount.

3. If practical, conducting runs at ½ normal speed may permit better resolution of the chlorite 003 peak, one of the major sources of error in Austin's methodology.
4. In following Austin's methodology, as presented here, it may be desirable to heat the samples to 375°C, rather than 300°C. Austin and Leininger (1976) noted that this will cause more complete collapse of hydrated layers; unfortunately, little can be done now to prevent some rehydration.
5. Although not certain, it is possible that X-ray intensities may vary somewhat from run to run, as well as due to position within a run. It may be possible to minimize this problem by expressing peak intensities as a ratio to the background, rather than as an absolute value.
6. In such cases where chlorite disappears from some samples of a sequence, it may be possible to interpolate values of kaolinite that are more consistent with those of the adjacent, chlorite-bearing samples. The working assumption is that the relative reflective power of

kaolinite and illite remain the same throughout the sequence, whether or not chlorite is present. If this is assumed, the following procedure may be employed:

Step 1. Determine ratio from known sample of kaolinite/illite+mixed layer percentages; determine ratio of $K_{002}$ peak and $I_{001_H}$ peak. This must be from a sample where chlorite is present.

$$\frac{K\%}{I+M\%} = R_1 \qquad \frac{K_{002}}{I_{001_H}} = R_2$$

Step 2. Determine the ratio of the $K_{002}$ peak and the $I_{001_H}$ peak of the non-chloritic unknown with kaolinite.

$$\frac{K_{002}'}{I_{001_H}'} = R_3$$

Step 3. Determine the multiplier for $R_2:R_3$.

$$\frac{R_2}{R_3} = m$$

Step 4. The multiplier times the known percentage ratio yields the ratio of percent kaolinite in the unknown to the illite + mixed layer.

$$R_1 \times m = R_4 = \frac{K\%'}{I+M\%'}$$

Step 5. $K\%' + (I+M\%') = 100\%$

Using algebra: $K\%' = R_4(I+M\%')$

$$R_4(I+M\%') + (I+M\%') = 100\%$$

Solve for $I+M\%'$

Step 6. To obtain K%', subtract I+M%' from 100%.

Step 7. Illite and mixed layer percentages are determined by proportionally allotting I+M%' between them, based on the values of $I_1$, $I_{1G}$, and $I_{1H}$. $I_{1H}$ is equivalent to I+M%'.

7. The clay samples should be treated with K-saturated solutions (Keller, 1964, used KOH; Jonas, 1975, used KCl). Keller reported that stripped illite collapses more completely than smectite, due to its greater layer charge.
8. The cationic exchange capacity (CEC) should be determined; this is done by determining the volume of methylene blue required to titrate to an endpoint a 100-gram sample of clay. Hang and Brindley (1970) presented a discussion of the methodology and problems of the technique; Karlsson and others (1978) reported good results using the CEC for quantitative clay mineralogy by assigning typical values to various clays.

## Paleozoological Techniques

Samples for paleozoological study were gathered in the field by collecting 1 kg samples of shale. The samples were as fresh as possible; however, as many shale outcrops are slopes, it often was not possible to completely exclude the effects of slumping. Modern roots were also frequently present, but these often penetrated relatively fresh shale, and were not indicative of significant weathering. A few shale samples where the possibility of float contamination was unknown

were collected and processed; due to the large data base, if unrecognized they could not seriously affect the distribution results. It was also possible to exclude from the data base questionable occurrences; if a low probability occurrence appeared in a sample that may have been contaminated, it was excluded. This may be circular, but the final decision was usually based on more than one criterion.

Generally, brief inspections of the outcrops were undertaken for prominent macrofossils, especially exceptionally preserved ones. The data from these searches were included in the stratigraphic associations of the various taxa, but omitted from the co-occurrence studies, as the grab samples were not placed at a specific horizon.

Adjacent limestones were also collected for processing. Normally, a sample adequate to provide a hand specimen, a thin section, and 1 kg of material for microfossils was collected.

Upon return to the lab, all shale samples were thoroughly air dried. Before further processing, 10 or 20 grams were removed for clay mineral analysis.

The samples were then immersed in a light aliphatic hydrocarbon liquid. Layne (1950) used gasoline, Crowley (1952) used kerosene, and Collinson (1963) used Stoddards solvent. The last was used in this study; it appears to have better penetrating ability and is less unpleasant to use. The shales were permitted to stand until the pores were saturated; then the excess solvent was decanted and filtered for reuse. The shales were then submerged in water, where due to the immiscibility of solvent and water, the escaping solvent disintegrated the shale, reducing it to mud. This mud was washed through a series of

screens (1mm, 125 micron, and 63 micron openings), and the debris on the two larger screens examined (the 63 micron material was retained for possible future studies).

Other rocks required varying techniques. Limestone was processed by placing coarsely crushed washed rock in dilute formic acid (in the manner of Toomey, 1964). When decanted, the residue was washed as above. A small amount of the material passing through the bottom screen was recovered, washed, dried, and run for clay mineralogy.

The fissile black shales required another technique. First, the shale was washed to remove adhering weathered material. It was then immersed in sodium hypochlorite (NaOCl) solution (commercial bleach). This procedure was first mentioned by Norby and Avcin (1972), but not completely published until Duffield and Warshaver (1979). The bleach is allowed to oxidize the organics until it turns dark or the sample stops bubbling off $CO_2$. Then it is washed through the screens, with the coarse unoxidized portion returned to fresh bleach for further oxidation. The finer fractions are accumulated; usually, when all the shale practical was reduced to less than 1mm in size, the whole was returned to bleach for several weeks to oxidize the fine unbleached particles normally present. (In the blacker shales, even repeating the process every two weeks, it may take more than a year to oxidize a sample. Biesiot (1950) used a quicker method of boiling the sample in sodium oxalate solution, but this may excessively damage the conodonts and other fauna.)

At this point, the shale residues were scanned for calcareous fossils. A selection of the taxa present among the megafossils was picked out for identification. The calcareous microfossils were also examined, with representative collection made of the taxa present. This produces a cross-section of the most common taxa present; a kilogram sample, incompletely picked, can scarcely be considered to contain all the taxa present in a unit. Lane (1964) noted the problem in picking Lower Permian microfossils, as he tried to examine 1 gram splits from his samples, but found rare microfossils were overlooked, and that even on examination of the entire sample (ranging from 5 to 40 grams) some were missed. He concluded that it was necessary to pick the entire sample. However, this was patently impossible here as many of the samples produced over 100 grams of calcareous fossils, and some over 500 grams. As a compromise, it was necessary to sacrifice the less common forms.

The remainder of the calcareous shale residues was then acidized to release the non-calcareous fossils present. At this point, processing of the shale and limestone became identical. Both were picked for representative agglutinate forams present, plus whatever other non-phosphatic fossils might be present (e.g., hyalosponge spicules, scolecodonts). Then it was frequently necessary to further reduce the sample size. This was done by running the sample through separatory funnels of tetrabromoethane (Biesiot, 1950; Collinson, 1963). Tetrabromoethane has a density of 2.89 g/cc, whereas the apatite of most of the phosphatic animals ranges from 2.84 to 3.1 g/cc, so most of them

settle out. (Biesiot, 1950, hastened the process by centrifuging them.)

The heavy residues were then picked for fish fragments and phosphatic inarticulate brachiopods. If the sample ran too much over 1 gram, it was then split. About a gram (more if the productivity was low) was completely picked for conodonts. All the platform (and appropriate non-platform) elements were totalled, then the theoretical total for exactly a kilogram of original sample was calculated.

All the material collected was identified to the generic level, except when practically precluded by extensive sample preparation requirements (e.g., bryozoans). Simpson (1953) noted that with such a procedure a higher percentage of the taxa (at the generic level) is represented than at a lower level (the specific level). Johnson (1962) noted that this was more ambiguous than use of species, but the taxa involved are more readily identified. Actual identifications were made either by consulting appropriate experts when available or by compiling a list of the reported Missourian taxa, together with a list of diagnostic criteria.

The fossils were then listed on a presence/absence basis by samples, so that each fossil was listed with every other fossil. Johnson (1962) stated the interpretation of this type of data was much more straightforward than those based on abundance. In shale, diagenesis can profoundly alter the relative abundances of taxa, eliminating the possibility of meaningful abundance comparisons between brachiopods and ostracodes, for example.

Conodonts are an exception. Recovery of conodonts was reasonably consistent, so that conodont numbers could be meaningfully compared, particularly in terms of percent of the platforms present.

When these data were assembled, many of them were evaluated in terms of a null hypothesis: if there is no correlation between two taxa, or a taxon and its lithology (i.e., no environmental factor controlling the distribution), the probability of the two occurring together should be random. In some cases, statistical tests were applied, to determine if the actual occurrence varied from randomness beyond the 95% confidence level, or if only lesser degrees of separation were present (which are, nonetheless, separation).

## Palynological Technique

The palynological preparation technique used here is that summarized by Ravn (1979). First, samples of appropriate size (about 10 grams for coal, 50 grams for shales) were prepared by crushing. The samples were then macerated for two days in Schulze solution (1 part saturated potassium chlorate solution, 2 parts concentrated nitric acid). After washing to remove the solution, the samples were treated for 15 minutes with a 10% KOH solution to remove humic acids. The samples were quickly washed; then, if necessary, they were treated with cold 48% hydrofluoric acid to remove any silicate minerals present. The samples were washed through a 250-micron screen to remove the coarser material, then centrifuged to remove very fine debris. They were then washed with ethanol and stained with safranin and mounted on slides in Canada Balsam.

Counting specimens was done by following a grid pattern on slides and counting each reasonably identifiable palynomorph encountered. A minimum of 250 grains were counted, collected from parts of four different slides of the same sample.

# APPENDIX B

## TAXONOMIC USAGE

Many of the fossils referred to in this study are uncertain in taxonomy, and many others may have had their taxonomy altered in publications unknown to this writer. In some cases, usage of particular terms have been modified to fit the requirements of the study and the preservational limitations of the material studied. Thus, it is necessary to review the pertinent taxonomic problems and diagnostic criteria used here.

### Conodonts

Here conodont taxonomy is applied chiefly to platform elements. In most cases, the platform and apparatus taxonomy are essentially synonymous, and will be so used. In those apparatuses which do not have platforms, a brief explanation of usage is included.

Missourian conodonts have numerous taxonomic problems, mostly stemming from disagreement among the various workers about what constitutes a valid generic name. The many synonyms make interpretation difficult, but because the solutions resolving the usage problems are largely subjective, there seems to be little hope in changing the situation in the near future.

An excellent example is Adetognathus. This was originally included in the genus Cavusgnathus (Harris and Hollingsworth, 1933).

However, Lane (1967) later erected the genus Adetognathus from the Pennsylvanian and younger forms. This was based on three criteria: (1) in Adetognathus, the blade is attached to either the left or right side of the platform; in Cavusgnathus only to the right; (2) in Adetognathus, if a fixed blade is present at all, it is less than half the length of the free blade, whereas the opposite is true of Cavusgnathus; and (3) the denticles on Adetognathus' blade are discrete and increase in height toward the anterior half of the blade (except for an anomalous denticle in the posterior half), while Cavusgnathus' blade has fused denticles increasing in height toward the posterior half. There is little disagreement that these distinctions exist; the disagreement is whether they constitute sufficient grounds for a new genus. Thus, there is dichotomous usage of terms among conodont workers.

Anchignathodus is another taxon with severe nomenclatural problems. It has been referred to as Spathognathodus, Ozarkodina, and Hindeodus. The last is currently the most widely used synonym. Anchignathodus was established as a single element apparatus with a platform-like element, but when a complete multi-element apparatus was established, Sweet (1977), who had originally named Anchignathodus, synonymized it with Hindeodus. He stated that the lineage, based on the platform, extends from the Mississippian type species to the Triassic. However, he also noted that the platform appears to be an evolutionarily conservative element, while the other elements show signs of rapid and marked change. He noted that these changes may be sufficient to justify placing some variations of the apparatus in other

genera. J. W. Swade (pers. comm., 1982) stated that this is probably true for the Missourian apparatus, and favors retention of Anchignathodus for it until it can be demonstrated to be closely akin to the apparatus of the type species. This usage is adopted here.

Stepanovites is an apparatus containing only ramiform and simple cusp elements. At present, the elements are not completely known, nor what their ratios are. The elements are all characterized by a prominent curved cusp with a broad basal cavity which extends beneath the processes if present. The denticles along the processes are characterized by marked separation, distinguishing them from Idioprioniodus, where the denticles are much more serrate in appearance and more closely spaced.

Included here in Stepanovites is an unusual bird's-foot-like element consisting of a single long curved cusp with four processes extending from its base, each at approximately a $90^{o}$ angle to the adjacent ones; this produces an anterior and a posterior process in the plane of the cusp, with two lateral processes, one on each side. The processes have no accessory denticles, and are approximately subequal in length. The basal cavity is broad and extends into the adjacent processes. Due to its similarity to Stepanovites elements, J. W. Swade (pers. comm., 1982) recommended placing it in that apparatus as an unknown element.

It may be that Merrill's (1980) Ellisonia is synonymous with Stepanovites. Several Pennsylvanian species of Ellisonia have been transferred from that taxon, some to Stepanovites, while the remaining forms are indeterminate. Merrill did not provide diagnostic criteria,

but his use of Ellisonia and omission of mention of Stepanovites, as opposed to the opposite trend among other workers, suggests that this is the case. Furthermore, he attributed occurrence patterns to Ellisonia similar to those of Stepanovites. Thus, for this study, Merrill's (1980) diagram has Ellisonia relabelled as Stepanovites for conceptual purposes, although it is possible there is a discrete parallel occurrence of a different taxon.

The idiognathodid conodonts have a well-known apparatus, particularly as bedding plane apparatuses from the black shale of one of the sections studied here (LaSalle, Illinois, Locality LS1) first demonstrated that conodont elements are arranged in apparatuses (DuBois, 1943). Very little is clear beyond that, however. Idiognathodus refers to a platform with ridges crossing the platform laterally, while Streptognathodus refers to a platform with a longitudinal trough. Unfortunately, these forms are completely intergradational. Merrill (1974) stated that variations in relationships between the two indicate a biostratigraphic trend, with Streptognathodus becoming relatively more abundant in younger rocks (on this basis he assigned a Middle Virgilian age to the Ames Limestone of Ohio when macrofaunal evidence indicates an Upper Missourian age); he also indicated (1980) that it is due to change in the depositional environment. Observations during this study suggest the difference may also in part be ontogenetic. Ellison (1941) concluded that zonation based on these conodonts was not possible. Merrill and von Bitter (1976) referred to the aggregate taxa as a "plexus", but felt that they could be sorted out. Baesemann (1973) considered the two genera to be congeneric, and this

position is taken here. To avoid any unfortunate taxonomic problems, they are all simply referred to as idiognathodids.

Idioprioniodus does not have a taxonomic problem. Neither does it have a platform, which is a source of difficulty in comparing it to other apparatuses. Idioprioniodus elements have long, curved cusps with triangular bases. Various processes distinguish the elements, but these are usually missing. However, all the cusps are essentially equally robust and equally likely to be preserved. J. W. Swade (pers. comm., 1982) suggested there are 13 elements (6 pairs and a symmetrical element) in an apparatus, so, to compare them with other apparatuses, the total number of elements was counted, then divided by 6½.

Aethotaxis has a similar problem, but is not nearly so robust as Idioprioniodus. Aethotaxis elements are ramiform-like, and are characterized by two 90° bends, giving them an inverted - U shape. J. W. Swade (pers. comm., 1982) suggested that there are nine elements present, so to compare them to other apparatuses the total counted is divided by 4½. However, due to their relative fragility, they are probably underrepresented.

## Ostracodes

The taxonomy applied to ostracodes here was derived largely from published faunal lists and the Treatise of Invertebrate Paleontology (Benson, et al., 1961). Since those publications, revisions have been made to some of the taxa, but as a practical matter it was not possible to search out all of them or to research the specimens to apply corrections. Some problems also arose from persistence of competing terms in the literature.

A case in point are the geisinids. Many workers still use Jonesina for what is apparently Geisina, even though the type for Jonesina was inadequately based on a steinkern that probably belonged to Geisina. I. G. Sohn (pers. comm. to P. H. Heckel, 1980; pers. comm., 1982) assigned many specimens from the studied horizons to Hastifaba, which differs from Geisina principally in being a more inflated form. However, the material available did not always permit the two genera to be distinguished, so the term "geisinid" is used here.

Sohn (1961) also established the genus Shleesha from a portion of Amphissites. Unfortunately, that usage was found only after completion of sample examination, so it is not applied here.

It should be noted that many of the generic assignments made here generally were not made on a complete range of criteria, since many (e.g., hinge teeth, muscle scars) were not adequately preserved. It may be that some minor taxa were improperly identified, due to dubious material, but major taxa are fairly stable. Empirically, this appears justified, as the various taxa separated into distinct entities; this presumably would not occur had overlapping unrelated groups been included together.

However, in similar groups, several taxa may have been included in one group; an example is Cavellina. It is possible that other genera conforming to the general character of Cavellina (a smooth elliptical ostracode) may be included, although when the identification could be verified other similar genera were not found with Cavellina. Bairdia and Bairdiacypris provide another case in point; they are distinguished

here principally by the more elongate form of the latter, since the necessary internal information was not available. This problem frequently applies to the less common genera, so that if they are inadequately preserved, they may be included with similar more common genera because of the lack of diagnostic features.

## Foraminifers

The taxonomy used here for agglutinate forams follows that of Ireland (1956). This is remarkably straightforward, although a few comments on usage are in order.

Tolypammina was long used as a catch-all term for irregularly wandering encrusting forams, and was used as such by Ireland (1956). Henbest (1963) recognized another genus, Minammodytes, which was distinguished from Tolypammina by the orientation of the proloculus and several related traits. He also synonymized Serpulopsis (previously thought to be a worm tube) with Minammodytes. Toomey, in several works on Upper Pennsylvanian algal mounds (e.g., Toomey et al., 1977) recognized Minammodytes as the genus present, with no Tolypammina. However, in a similar work (Toomey, 1980), he found only Tolypammina and did not report Minammodytes. Whether this represents an unexplained change in taxonomy, or a simple dichotomous distribution of taxa is not clear. In any case, the diagnostic traits are rarely preserved, especially in specimens from shale. Thus, Tolypammina is used here in its original sense.

Textularia is another genus of nebulous taxonomic position. Croneis and Toomey (1965) briefly referred to the problem, noting that

Paleozoic forms may not properly be placed in the genus, and are properly referred to as paleotextularids. However, they concluded that some of the Pennsylvanian forms can be assigned to Textularia. For simplicity, all such forms here are referred to as Textularia.

Little was done with the calcareous forams in regard to taxonomy, as most require detailed thin section work for proper identification. Fusulinids were simply treated as a group, while the smaller calcareous forams were generally identified on the basis of their external morphology.

## Brachiopods

Generally, taxonomic problems with brachiopods did not involve diagnostic characteristics but resulted simply from the many synonymies and subdivisions present in the much-studied group. The names applied here are generally the most recent revisions: the most important ones are briefly summarized. (These generally follow usage in the Treatise on Invertebrate Paleontology.)

The genus Marginifera has been subdivided and restricted to the Permian, with the forms in the Upper Pennsylvanian previously referred to that genus now mainly assigned to Hystriculina (characterized by six endospines and multiple broken-off trails).

The genus Dictyoclostus has been similarly treated. The genera Antiquatonia and Reticulatia are distinguished principally in degree: Antiquatonia often has well-developed ears, prominent spines, and less extensive reticulation.

The terabratulids present a different problem. From time to time, attempts have been made to synonymize Dielasma and Beecheria, both of which are present in the Upper Pennsylvanian. However, they belong to separate families, and are only distinguishable by their internal characteristics, so application of a generic name is often questionable.

Other significant nomenclatural features include assignment of Chonetes granulifer to Neochonetes. Phricodothyris has been previously referred to as Squamularia and Condrathyris. Moore (1964) provided a useful list of recent taxonomic revisions.

## Echinoderms

The crinoid calyxes and identifiable fragments found in the course of this study were kindly identified by H. L. Strimple and T. J. Frest.

According to T. J. Frest (pers. comm., 1981), the echinoid genus Archeocidaris can include most Pennsylvanian echinoids, and consequently is of little real taxonomic value. For this reason, Archeocidaris is not used here, as it is essentially synonymous with "Pennsylvanian echinoid".

Included in the echinoid count are spines, spine plates, and a curious small plate with a pair of circular holes through it. These plates are round to polygonal in outline, and are normally smooth, but some have an offset ball, very like the ball joint on an echinoid spine plate. Because of this, the plates are included with the echinoids, as probable ambulacral plates; however, it is possible that they belong to another echinoderm.

## Gastropods

Identification of gastropods was simple when the external ornamentation was present and the shells were uncrushed. However, this situation was relatively infrequent, and in most cases generic assignment could not be applied. The taxonomy follows that used in the Treatise of Invertebrate Paleontology.

A notable exception to this was frequently found in the small phosphatized gastropods. In some cases, the original shell mold was also replaced by apatite, as well as the internal cavity. Thus, in some cases the external decoration was preserved. This was often principally heavy collabral ridges, and the gastropod was assigned to an appropriate genus of pseudozygopleurids (e.g., Helminthozyga or Palaeostylus). Sometimes the ornamentation consisted of a series of spiral threads. In such cases, the gastropods were listed as Aclisina as a matter of convenience; without better preservation, the specimen could belong either to that genus or a number of others (e.g., Stegocoelia or Cyclozyga).

## Pelecypods

The comments applied to the gastropod identification also apply to pelecypods; in cases when sufficient preservation permitted, the taxonomy used in the Treatise of Invertebrate Paleontology generally prevailed. However, a few important problems should be noted.

One is the common occurrence in the shales of small calcite-replaced pelecypods. These have toxodont teeth and a shape very much

like Nucula, but do not have radial ornamentation. Rather, they exhibit only concentric growth lines. This could be attributable to immaturity, and as Nucula is commonly reported as an Upper Pennsylvanian genus, this may be a reasonable assignment. However, there is a fair possibility that these small specimens could simply be immature members of any one of a number of nuculoid genera, so they are simply described as nuculids.

The small apatite steinkerns of pelecypods occasionally found in the sediment also have toxodont dentition, but are somewhat more elongate than Nucula. They also have some of the large muscle scars preserved, and usually have a posterior notch preserved along the commissure in the steinkern, similar to that of Nuculopsis, so the specimens are assigned to that genus. However, it is possible that they are actually congeneric with those assigned generally to nuculids. A generally disjunct distribution in the two groups, as well as in preservation, makes it impossible to make a definitive judgment.

Another problem involves Astartella and Cyprcardella. Morphologically, the genera are identical, except in arrangement of cardinal teeth. When the teeth were present, only Astartella was recognized; by extension and by previously reported trends it is assumed only Astartella is represented.

## Cephalopods

Cephalopod identification was graciously provided by Dr. B. F. Glenister.

## Sponges

There are some difficulties with the proper assignment of Coelocladia. Gundrum (1980) noted that there is a very similar genus, Coelocladiella, distinguished principally on the basis of whether or not it has a perforate dermal layer (according to Gundrum's usage, as the original diagnosis is unclear). In this study, all specimens were arbitrarily placed in Coelocladia on the basis of their resemblance to specimens in the SUI study collections.

Gundrum (1980) also observed that there are difficulties in assigning Coelocladia to the demosponges. She noted that other workers claimed that the sponges were originally hyalosponges, as the spicules have a cental void, a feature of hyalosponge spicules. Gundrum, however, noted that the sponges were bored by acrothoracic barnacles, which she stated are known only from calcareous substrates.

The two hyalosponge spicules recognized are quite distinctive. Spicule A is a small, sharply angular hexacton, with tapered rays. Each ray has a series of spikelets on each side, producing a sawtooth appearance. In some cases, the arms bifurcate, producing two rays diverging at approximately right angles, symmetrical to the axis of the original ray.

Spicule B is a remarkably coarse hexacton. No complete spicule has been found, but measured specimens are a centimeter or more across. The rays are simple cylindrical tubes. Almost invariably, one or more of the rays will be replaced by a short, bulbous protuberance.

Whether this is a beekite-like secondary replacement or a primary structure is not known. Unlike Spicule A, Spicule B is accompanied by numerous monaxons, the morphology and size of which suggest they came from the same organism as Spicule B.

## Fish

The fish fragments were identified principally by use of descriptions and diagrams in a number of reference works. These included Gunnell (1933), Eaton (1962), Romer (1966), Shaeffer (1967), Pabian (1970), Moy-Thomas (1971), Zidek (1973, 1976), and Chorn and Reavis (1978).

Very little can be added to the descriptions and diagrams given, but a short description of distinguishing characteristics can be appended here.

Among the shark teeth, Cladodus is distinguished by its prominent cylindrical central cusp, usually flanked by smaller cylindrical denticles, and its generally broad base. In Hybodus, the denticles are triangular in outline, well-adapted for shearing. Protacrodus is an intermediate form between Hybodus and Cladodus. Styptobasis is considerably different, with a high, recurved cusp, usually with prominent furrows and a thick cushion at the base. It may also appear in multidenticulate forms, although single cusps are the rule. Gunnell (1933) referred to it as Idiacanthus, which Wilimovsky (1954) changed to Gunnellodus; this was in turn amended to Styptobasis by Zidek (1973). Orodus has a strongly crenulate upper surface, often with the ridges outlined with lighter-colored material. Helodus is

essentially a simple triangular cusp with a longitudinal and several cross ridges meeting at the apex. Petalodus is similar, but with a prominent deep root.

Paleoniscid teeth are simple cones, usually of brown or grey apatite, and usually tipped with clear enamel.

Among the dermal scales and denticles, Holmesella is the simplest. It is a simple rhomboid, usually with a flat smooth top. According to Ørvig (1966), those forms with a high crown and a constricted neck belong to acanthodians, while those that show concentric growth and are produced into a spine or platform belong to elasmobranchs. Cooleyella has a sub-elliptical top with a hollow, flared base recessed beneath. It is usually distinguished by a single simple ridge running across it longitudinally, rising from the forward margin and overhanging the rear. In some forms, this ridge may be divided into two or three sharper folds posteriorly. Multiple sharp folds without a well-developed ridge, however, are characteristic of Cooperella. Kirkella is shaped like a mushroom with a fluted stem.

Gunnell's (1933) "scale" is relatively large, and typically rhomboid in outline when complete. The obverse is covered with furrows and rounded ridges, and is usually quite shiny. The reverse is dense, dull, amorphous apatite.

The "altoonodont" (so-called because the first recognized specimen came from the upper Captain Creek Limestone at Altoona, Kansas, Locality A11) was undescribed in the literature. It consists of a rounded triangular platform, with a "root" below. The "root" in plan looks like three sides of a square, open toward the broad base of the

triangle, or a simple bar parallel to the base of the triangle. In well-developed specimens, a small circular node is present beneath the apex of the triangle. Between the node and the bar, or between the node and the arms of the open "box" is a circular pit. Normally, if placed on the flat base of the root, the platform will be inclined at an angle, with the apex being the lowest portion. Usually, the triangular platform will develop a short, cylindrical denticle rising from it, centered on the base of the triangle opposite the vertex with the root, although the denticle is usually broken off. In rare cases, a pair of smaller auxiliary denticles, one on either side of the main one, will be developed. The whole upper surface is smooth and shiny, while the lower side is dull.

## Plants

The megafloral identifications were graciously provided by Dr. J. T. Schabilion.

Palynological identifications were based principally on the descriptions and photographs found in Smith and Butterworth (1967), Ravn (1979), and the unpublished "The Thinking Person's Guide to Pennsylvanian Miospores of Iowa" (produced chiefly by R. L. Ravn, and found in the geology department at the University of Iowa).

Most of the results correspond with other reported microfloras, so there is little need to detail taxonomic oddities here. However, two are pertinent.

The small (25 to 40 microns), round, thin-walled spores posed a taxonomic problem. Since they were the dominant floral element, they

could not be eliminated as "unidentifiable". But frequent folding and tearing of the exine often made positive identification nebulous. Because Punctatisporites was the most commonly reported genus, and because many of the complete specimens conformed to the diagnosis of the genus, it was used as a catch-all term. However, Punctatisporites, especially the pertinent species P. minutus, is quite variable, so overlap with other genera is possible. For example, Upshaw and Hedlund (1967) identified analogous small round spores as Latosporites. This differs from Punctatisporites in that it is monolete, rather than trilete, but may have an incipient third ray. It may also be minutely granulate, while Punctatisporites may be minutely punctate. Punctatisporites may also be confused with the similar monolete Punctatosporites or the alete (but folded) Fabasporites. Preservational features dictate that the absence of any of these cannot be demonstrated, so their presence as part of the Punctatisporites group must be recognized.

The presence of Gillespieisporites (Clendening, 1969, 1977) is difficult to evaluate. Gillespieisporites is commonly a Virgilian and Wolfcampian form, and was not considered a possibility when identification of the spores was carried out. It is morphologically similar to several spores identified, particularly Granulatisporites and Triquitrites (Clendening, 1969). Its presence as part of either taxon cannot be eliminated at this point, but as both are far more commonly reported in Missourian microfloras, Gillespieisporites is likely to be minor.

# APPENDIX C

## APPALACHIAN BASIN CORRELATION OF THE DENNIS CYCLOTHEM

Although not directly the subject of this study, some correlations with the Appalachian Basin raise some difficult questions in respect to the interpretation of the Midcontinent rocks. In particular, two widespread marine horizons of the lower Conemaugh Series raise difficulties.

The Brush Creek cyclothem is one of the most widespread in the Appalachian Basin. In Ohio, it consists of one or two fossiliferous limestones (Morris, 1967), but elsewhere is a dark grey to black fossiliferous shale (Seaman, 1942; Lintz, 1958). Morris (1967) interpreted the shale between the two limestones as a deltaic wedge; it is capped by a coal (below the upper limestone), which suggests a foundering delta.

The Cambridge cyclothem is somewhat more restricted areally than the Brush Creek. In Ohio, it is usually a calcareous sandstone or sandy to argillaceous calcarenite (Kozusko, 1968), although locally phylloid algal mounds are developed (Carothers, 1979). Eastward, the Cambridge is black and much more shaly (Seaman, 1941). Like the Brush Creek, the Cambridge was subjected to prograding and shifting deltas (Carothers, 1979).

Several correlations of these two units to the Midcontinent have been suggested. Generally, that of Moore (1962) is followed, with the Cambridge equated to the Shoal Creek and Dennis cyclothems. According to Lintz (1958), Moore determined that the Brush Creek was the equivalent of the Swope cyclothem, and Lintz noted that the megafauna supported such a conclusion. However, Moore (1962) suggested that the Brush Creek was equivalent to the Trivoli (Cramer) cyclothem of Illinois and the Hertha of the Midcontinent. Curiously, the Brush Creek is the only Appalachian cyclothem known to have a core shale-type conodont fauna, with Idioprioniodus (Merrill, 1974) and Gondolella (von Bitter and Merrill, 1978). The Gondolella is G. denuda, a form characteristic of the nearly restricted to the Swope cyclothem in the Midcontinent and found in the Macoupin cyclothem in Illinois; however, it is also reported from the Cramer Limestone of Illinois (von Bitter and Merrill, 1978), which is compatible with Moore's (1962) correlation.

The fusulinid Triticites is found in both the Cambridge and Brush Creek cyclothems. However, Midcontinent biostratigraphic usage holds that Triticites should appear no lower than the Dennis (Thompson et al., 1956; Heckel and Meacham, 1981). But Thompson (1936) explained the apparent anomaly by stating that the Triticites of both the Brush Creek and Cambridge are more primitive than those of the Dennis cyclothem. From this, however, comes two worrisome possibilities:

(1) Triticites appears lower in the section than the Dennis equivalent. The Brush Creek-Swope correlation as

generally used is correct. But this casts doubt on correlations in the Midcontinent based on fusulinids.

(2) Triticites appears only in rocks equivalent to the Dennis in age. Thus, the standard correlations are wrong, and the Brush Creek is equivalent to the Dennis. This would cast a shadow on the potential usefulness of Gondolella denuda as a stratigraphic indicator, as it would not be characteristic of a particular horizon.

# APPENDIX D

## AGE OF THE MISSOURIAN STAGE AND DURATION OF CYCLES

Several attempts have been made to get useful absolute ages for Missourian deposition. Mukhophyay and Brookins (1976) used Rb-Sr dating on authigenic illite from the Upper Pennsylvanian Madera Group of New Mexico, assuming that the age of the illite approximated the time of deposition. They found an age of 264 $\pm$ 6 or 9 million years. Kovach and Zartman (1981) used U, Th-Pb dating on conodonts from eastern Ohio. Conodonts from the Ames Limestone (possibly equivalent to the Stanton cyclothem of the Midcontinent), produced ages from 268 to 306 million years old. Conodonts from the Brush Creek cyclothem (possibly equivalent to the Dennis or Swope cyclothems) yielded ages of 315 to 341 million years. Bouroz (1978) dated volcanic cinders from within Cantabrian strata of Spain, using Rb-Sr, and obtained an age of 300 $\pm$ 10 million years. He proposed that this was approximately the age of the Westphalian-Stephanian boundary, but noted that it could not be reliably correlated with the Desmoinesian-Missourian boundary. (Bouroz also cited Russian data from granites at the Carboniferous-Permian boundary; a collection of dates by U,Th-Pb centered around 293-287 million years, while Rb-Sr gave an age of 291 million years.)

Heckel (1980) based his estimate for the duration of the cycles on the radiometric data of Bouroz (1978) cited above. Heckel assumed the Upper Pennsylvanian lasted for 10 million years, spanning 25 cycles.

This would produce an average age of 400,000 years, which he noted was similar in periodicity to the Pleistocene glaciations. This figure is the same as that estimated by Weller (1930) for the length of cycles in Ohio.

Weller (1956) later changed his estimate to 150,000 years per cycle, based on 100 cycles in half of the Pennsylvanian. This figure corresponds well to most other estimates for the cycles: Momper (1966a) estimated 100,000 years per cycle, with the periodicity a result of heat-magma cycles changing the volume of the ocean. Donahue and Rollins (1974a) estimated the marine portion of a cycle lasted 10,000 to 100,000 years, based on the type of community succession they found. Bennison (1981) also cited 100,000 years as the length of a cycle.

Sloss and Speed (1974) also contributed an estimate, based on their model for oscillatory plate tectonic conditions. Through this, they estimated a duration of less than 1 million to 5 million years for a plate oscillation, but stated climatic controls could modulate an even shorter frequency.

An attempt was made to judge the capacity of depositional processes to produce a cyclothem in the allotted time. An assumption was made that a river with a drainage basin corresponding to the area of Minnesota deposited sediment in a basin with the area of Iowa. The river was assumed to be carrying mostly suspended load, and to have no highlands in its basin. From the data of Holeman (1968) modern rivers with such a geography in a tropical climate with seasonal rainfall erode about 100 tons of sediment per square mile per year. Assuming an

average density for the deposited sediment of 2 gm/cc, it would take approximately 37,000 years for the eroded material to cover the depositional area with a layer of mud 1 meter thick. This is reasonable in light of deposition in the Forest City Basin.

All these figures and calculations indicate that the range of 10,000 years to 1 million years would be approximately the length of a cycle, but there is little certainty where within that range the average time occurs.

# APPENDIX E

## WATER DEPTHS IN THE MIDCONTINENT EPEIRIC SEA

Although no evidence was collected during this study that indicated absolute water depth during deposition, a brief review of some pertinent estimates is in order, to provide a conceptual framework for depositional models.

Ulrich (1911) and Moore (1929) estimated that the Pennsylvanian epeiric seas did not exceed 600 feet in depth. Elias (1937), using faunal analogies to modern forms, estimated that the deepest water during a cycle was 180 feet. Bless (1969) estimated that the most offshore limestone facies in the Stephanian in Spain did not form at a depth of more than 100 meters.

Carbonate facies were connected with eustatic sea level changes in many places to provide estimates of the magnitude of sea level change. Peterson (1966) calculated the variation in the Paradox Basin to be 100 to 300 feet. Rao (1981) estimated a fluctuation of 150 meters was expressed in the Lower Permian Berriedale Limestone of Tasmania. Rascoe (1978) felt that Virgilian carbonates in the Anadarko Basin showed evidence of a range of 100 to 150 feet. Wilson (1967) found that basinal sedimentation of the Oro Grande Basin of New Mexico alternated between euxinic, starved-basin black shales and limestones with algal laminae, mud cracks, and flat pebble conglomerates, as well as laminated gypsum and caliche zones. The latter facies was also

found on the margin of the basin, permitting Wilson to estimate from depositional relief that the minimum eustatic change in sea level was 115 to 165 feet.

Depositional relief also permitted some other estimates to be made. Galloway and Brown (1972) estimated that the Midland Basin was 600 to 1100 feet deep, while Seale (1981) found 400 to 500 feet of depositional relief in the Anadarko Basin during Coffeyville deposition. Both basins had black shales deposited in them during maximum transgression.

Other methods for finding water depths included that of Wanless and Shepard (1936). They assumed that the cycles were caused by glacial episodes, and suggested that the sea level change was about 450 feet, by analogy with the Pleistocene. Heckel (1980) based his estimate on a model that attributed stratification of the water to a thermocline, and suggested that the thermocline might have been 200 meters deep in Kansas and 50 meters deep in Illinois.

The majority of these estimates suggests that the water of the Midcontinent sea was at least 200 to 300 feet deep, which would easily permit stratification and stagnation of the bottom water in deeper environments. Heckel (1980) observed this range was analogous to that of the Pleistocene, which is compatible with glaciation in the Southern Hemisphere as a control for the cyclothems.

# APPENDIX F

## MISSOURIAN REPTILES

Although no terrestrial vertebrates were found during this study, they should be mentioned because of their possible significance in environmental interpretations.

Reptiles are the most significant component of Missourian terrestrial vertebrate faunas. Peabody (1957) stated that reptiles must have evolved during the Desmoinesian, due to their diversity and abundance in the Missourian. Colbert (1980) thought that the increasingly dry, seasonal environment at the close of the Pennsylvanian promoted the adaptive radiation and dominance of the reptiles.

Cope (1875) described the pelycosaurs from Oakwood, Illinois. They were found in red and grey shales below the Shoal Creek cyclothem (which would be the outside shale equivalent to the Galesburg Shale). The fauna also included amphibians, xenacanthid sharks, lungfish, and crossopterygians (Olsen, 1946; DeMar, 1980).

The Rock Lake Shale (the outside shale a cycle above the Vilas Shale) near Garnett, Kansas, is known for its reptile fauna as well as the associated flora. Four taxa of pelycosaurs and one other reptile are found in the Walchia-bearing horizons (Reisz et al., 1982). Peabody (1957) argued that the association of reptiles and Walchia, which is common in the Upper Pennsylvanian, indicated a dry climate. Reisz and others (1982) stated that the diversity of the flora

indicated that the climate was moist; the environment present was a valley cloaked in a conifer forest that was flooded by the transgressing sea.

Martin (1971) reported finding a pelycosaur vertebra in the Bonner Springs Shale (the outside shale a cycle below the Vilas) of southeastern Nebraska. Lund and others (1979) reported pelycosaurs in the shale below the Ames Limestone in the Pittsburgh, Pennsylvania, region (the shale would be equivalent to the Vilas if the Ames correlates with the Stanton cyclothem).

Thus, it appears that the Missourian forests were haunted by pelycosaurs and other reptiles. Outside shales such as the Vilas and the Galesburg should be closely examined for terrestrial vertebrate localities which could potentially produce valuable information on vertebrate evolution and the environments in which the animals lived.

# APPENDIX G

## RECOMMENDATIONS FOR ADJUSTMENT OF STRATIGRAPHIC NOMENCLATURE

1. Recognize the Bronson Group. It has priority and is readily recognizable. It is even definable in Oklahoma, if the Checkerboard is equivalent to the Hertha, as Ravn (1981) has shown.

2. Adopt Midcontinent core shale names for core shales in Illinois, when equivalence can be demonstrated. Most such shales are currently unnamed, and several of those that are named already have Midcontinent names (e.g., Anna, Excello).

3. Adopt some sort of names for the outside shale units in Illinois. The format concept may prove to be applicable, which would require only informal names, since formats are not formal stratigraphic units. When applicable, formal unit names might be proposed.

4. Adopt a similar formational terminology in Illinois as in the Midcontinent--i.e., an alternation of marine limestone-dominated formations and outside shale-dominated formations. The current formational units could be elevated to group or subgroup status for simplicity. The current names for

the cyclothems could be applied to the new limestone-dominated formations retained for the limestone members alone.

5. Do not recognize the Dodds Creek Sandstone as a formal unit. It is poorly defined, and as currently used represents a multitude of separate sand bodies produced by a variety of environments. It may retain some usefulness as an informal term for any sandstone occurring in the Galesburg Formation.

6. Treat the Naish Sandstone as the Dodds Creek. It has an implicity defined type section, and may have been formed in one or a set of closely related environments, but its lateral continuity is currently unknown.

7. North of the Bourbon Arch, define the top of the Galesburg as the top of the Davis City Coal or its equivalent coaly horizon. This would effectively divide nonmarine from marine strata, and facilitate interpretation.

8. Do not recognize the Canville Limestone in northern Missouri or southern Iowa, where it is little more than random nodules in the basal Stark. This would simplify understanding, and would avoid misleading inferences about its origin.

9. Restrict the Stanton Formation to the lower cyclothem. The Rock Lake Shale and South Bend should be elevated

to formational status; this would permit consistency with taxonomic usage for other formations. However, the Rock Lake and South Bend (and equivalent units) could remain in the Lansing Group.

10. If the Sarpy cyclothem is equivalent to the Dennis cyclothem, the former term should be abandoned, as it is a junior synonym (Heckel and Meacham, 1981).

# APPENDIX H

## PALYNOMORPHS IN STUDIED COAL SAMPLES

Cedar Bluff Coal, Coffeyville, Kansas (Cf2)

| | |
|---|---|
| Punctatisporites | 58% |
| Cyclogranisporites | 27% |
| Calamospora | 8% |
| Laevigatosporites | 1% |
| Florinites | 1% |
| Granulatisporites | 1% |
| Triquitrites | 1% |
| Raistrickia | trace |
| Verricosisporites | trace |
| Leiotriletes | trace |
| Cadiospora | trace |
| Thymospora | trace |

Cedar Bluff Coal, Liberty, Kansas (Li1/9)

| | |
|---|---|
| Punctatisporites | 38% |
| Calamospora | 32% |
| Cyclogranisporites | 12% |
| Triquitrites | 6% |
| Lophotriletes | 4% |
| Laevigatosporites | 3% |

| | |
|---|---|
| Florinites | 2% |
| Granulatisporites | 1% |
| Apiculatosporis | 1% |
| Wilsonites | 1% |
| Vestispora | trace |
| Acanthotriletes | trace |
| Raistrickia | trace |

Unnamed coal, Galesburg Shale, Dennis, Kansas (Del/-35)

| | |
|---|---|
| Punctatisporites | 69% |
| Calamospora | 15% |
| Cyclogranisporites | 8% |
| Laevigatosporites | 3% |
| Apiculatosporis | 1% |
| Endosporites | 1% |
| Lophotriletes | 1% |
| Triquitrites | 1% |

Unnamed coal, Galesburg Shale, Canville Creek locality, Stark, Kansas (Cal/79)

| | |
|---|---|
| Punctatisporites | 74% |
| Calamospora | 11% |
| Cyclogranisporites | 9% |
| Laevigatosporites | 5% |
| Triquitrites | trace |
| Neoraistrickia | trace |

Unnamed coal, Galesburg Shale, Canville Creek locality, Stark, Kansas (Cal/101)

| | |
|---|---|
| Punctatisporites | 47% |
| Cyclogranisporites | 22% |
| Calamospora | 15% |
| Laevigatosporites | 6% |
| Endosporites | 2% |
| Florinites | 2% |
| Cadiospora | 2% |
| Triquitrites | 1% |
| Wilsonites | 1% |
| Lophotriletes | trace |
| Verricosisporites | trace |
| Granulatisporites | trace |
| Apiculatisporis | trace |

Davis City Coal, Davis City, Iowa (DCl/37)

| | |
|---|---|
| Punctatisporites | 34% |
| Calamospora | 24% |
| Laevigatosporites | 17% |
| Triquitrites | 15% |
| Cyclogranisporites | 6% |
| Apiculatosporis | 1% |
| Endosporites | 1% |
| Granulatisporites | 1% |

| | |
|---|---|
| Wilsonites | trace |
| Verricosisporites | trace |
| Florinites | trace |

Davis City Coal, Thayer, Iowa (Th1/35)

| | |
|---|---|
| Punctatisporites | 89% |
| Laevigatosporites | 5% |
| Cyclogranisporites | 5% |
| Calamospora | 1% |
| Florinites | trace |
| Thymospora | trace |

Unnamed coal, LaSalle cyclothem, Oglesby, Illinois (LS1/Ø)

| | |
|---|---|
| Punctatisporites | 57% |
| Cyclogranisporites | 15% |
| Laevigatosporites | 11% |
| Calamospora | 8% |
| Granulatisporites | 5% |
| Apiculatisporis | 1% |
| Leiotriletes | 1% |
| Endosporites | 1% |
| Crassispora | 1% |
| Illinites | trace |
| Triquitrites | trace |

# APPENDIX I

## MEASURED SECTIONS WITH CLAY MINERALOGY AND FAUNAL DATA

The following appendix shows the measured and collected sections examined in this study. The intervals sampled are marked to the right of the lithology column. In some cases, these samples were not completely processed; the data presented is that available.

The samples collected averaged about a kilogram in mass. The clay mineralogy and fossils observed are listed. However, it is important to note that some fossils may occur in a particular sampled horizon, and be apparent on outcrop, but not be sufficiently common to occur in a typical 1-kilogram sample of sediment. Thus, the fauna reported represents the major components of the observed fauna, and should not be viewed as a comprehensive list.

At some outcrops, grab samples and collections were gathered from selected strata. Since these were not systematically examined or assigned to a particular horizon, the results are generally omitted from the measured section diagrams, although some notes are added in significant cases.

In a few cases, the shale samples may be contaminated by float from higher in the section. Every attempt was made to collect fresh material and eliminate contamination, but in some cases minor amounts of spurious material may be present. This is especially true at the

toes of shale slopes immediately above limestones, as the low slope angles make it difficult to obtain fresh, uncontaminated samples. Such contamination can usually be identified by low probability faunal patterns. However, no effort was made here to edit the data; the data reflect observed occurrences.

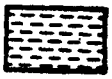
The data from limestone samples systematically include only the results of observations of insoluble residues. The presence of identifiable replaced fossils are noted; in some cases, fossils visible on outcrop are also noted.

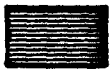
The net processed sample weight refers to the amount of sample actually picked for conodonts; it excludes any undissolved large fragments of sample. It also reflects the total amount picked if a sample was split; when conodonts were too abundant for the whole sample to be reasonably picked, it was split. In such cases, the portion of the kilogram sample picked is reported.

The notation "np" in the conodont section indicates that the sample was not processed or not picked for conodonts. This is in distinction to vacant columns under the conodont data table, which indicate no specimens were found in the examined samples.

In the case of bryozoan data, the number of distinct taxa observed in a sample are reported under the appropriate heading.

KEY TO LITHOLOGIC SYMBOLS

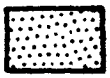
Shale 

Fissile black shale 

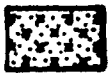
Blocky mudstone

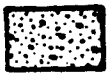
Blocky mudstone (red)

Siltstone

Sandstone 

Sandstone (red)

Ganister 

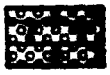
Conglomerate 

Coal

Dolomite

Limestone

Algal limestone

Oölitic limestone 

Stromatolitic limestone

Stromatolites

Shelly fossils 

Plant fossils

Burrows

Chert ▲

Nodules (apatite in limestones and black shales; siderite in grey shales) ●

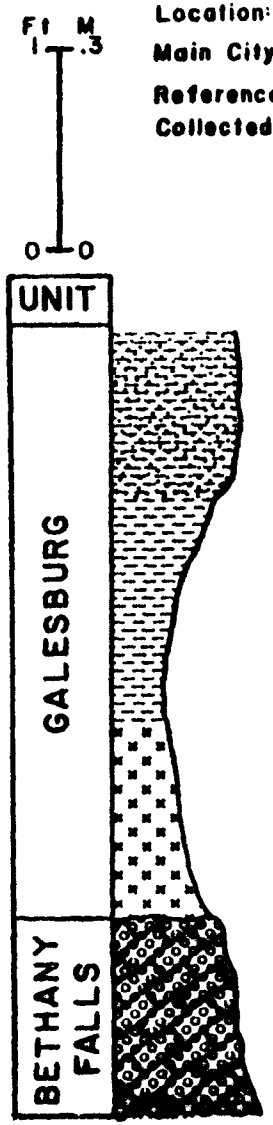
# I.Ad I

Location: Abandoned quarry 5 mi west of Adrion, Missouri

Main City, Missouri, 7 1/2'  T42NR32W33SE1/4NE1/4SE1/4

Reference: Gentile, 1976, Strat. Section 41, p.86

Collected: August 7, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ad1/28 | 1.11 | 9.2 | 42 | 45 | | | 13 | x | | | | | | | | | | | | | | |
| Ad1/0 | .86 | 7.7 | 28 | 46 | | 9 | 18 | x | | | | .80 | | 9 | 14 | | 86 | | | | | |
| Ad1/bf | .98 | 7.9 | 4 | 5 | | | 91 | | | | | 1.50 | | 28 | 41 | 7 | 41 | 12 | | | | |

BETHANY FALLS
GALESBURG
UNIT
0
0
Ft. M
1 .3


Ad1/28
Ad1/0
Ad1/bf
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
unidentified
1.Ad 1

| Sample | Adl/28 | Adl/0 | Adl/5f |
|---|---|---|---|
| GASTROPODS | | | |
| bellerophontids | | x | x |
| other | | | |
| PELECYPODS | | x | x |
| myalinids | | | |
| other | | | |
| ECHINODERMS | | | |
| pelmatozoans | | x | |
| echinoids | | | |
| holothurians | | | |
| BRYOZOANS | | | |
| fenestrate | | | |
| ramose | | | ? |
| fistuliporids | | | |
| encrusting non-fistuliporids | | | |

I.Ad I

I.Ad I
Ft M
1 3
0 0
UNIT
GALESBURG
BETHANY FALLS
Sample
FISH
paleoniscid teeth
allocnodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Ad I/28
Ad I/O
Ad I/bf
x
x
x

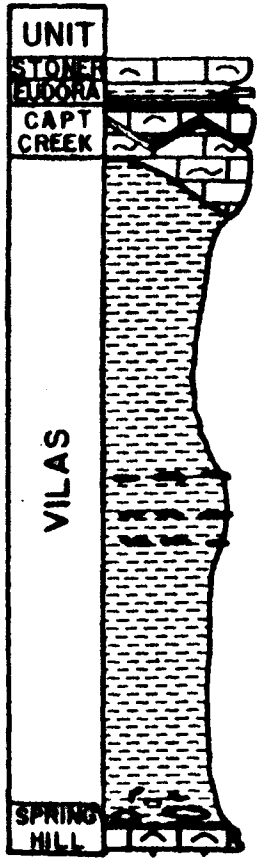
# 2.All

Location: Roadcut on Kansas Highway 47 1 1/2 mi west of Altoona, Kansas

Altoona, Kansas, 7 1/2' T29SR16E18NE1/4NE1/4NE1/4

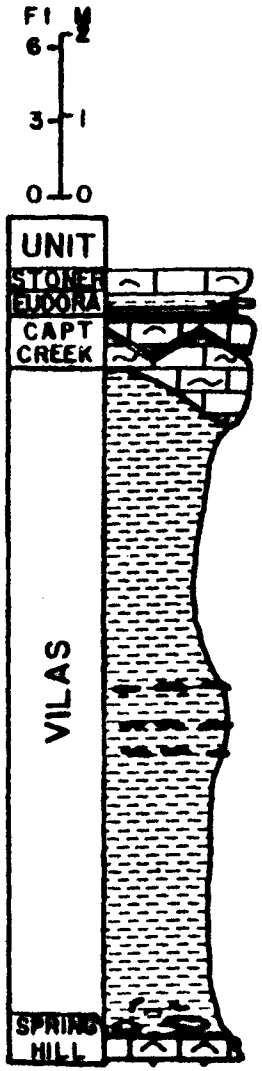
References: Kansas Geol. Soc., 1962, Stop 2, p.36-37; Heckel, 1978, Stop 6B, p.35; Heckel et al., 1979, Stops 6B and 6C, p.31-33

Collected: August 15, 1978, and October 20, 1979

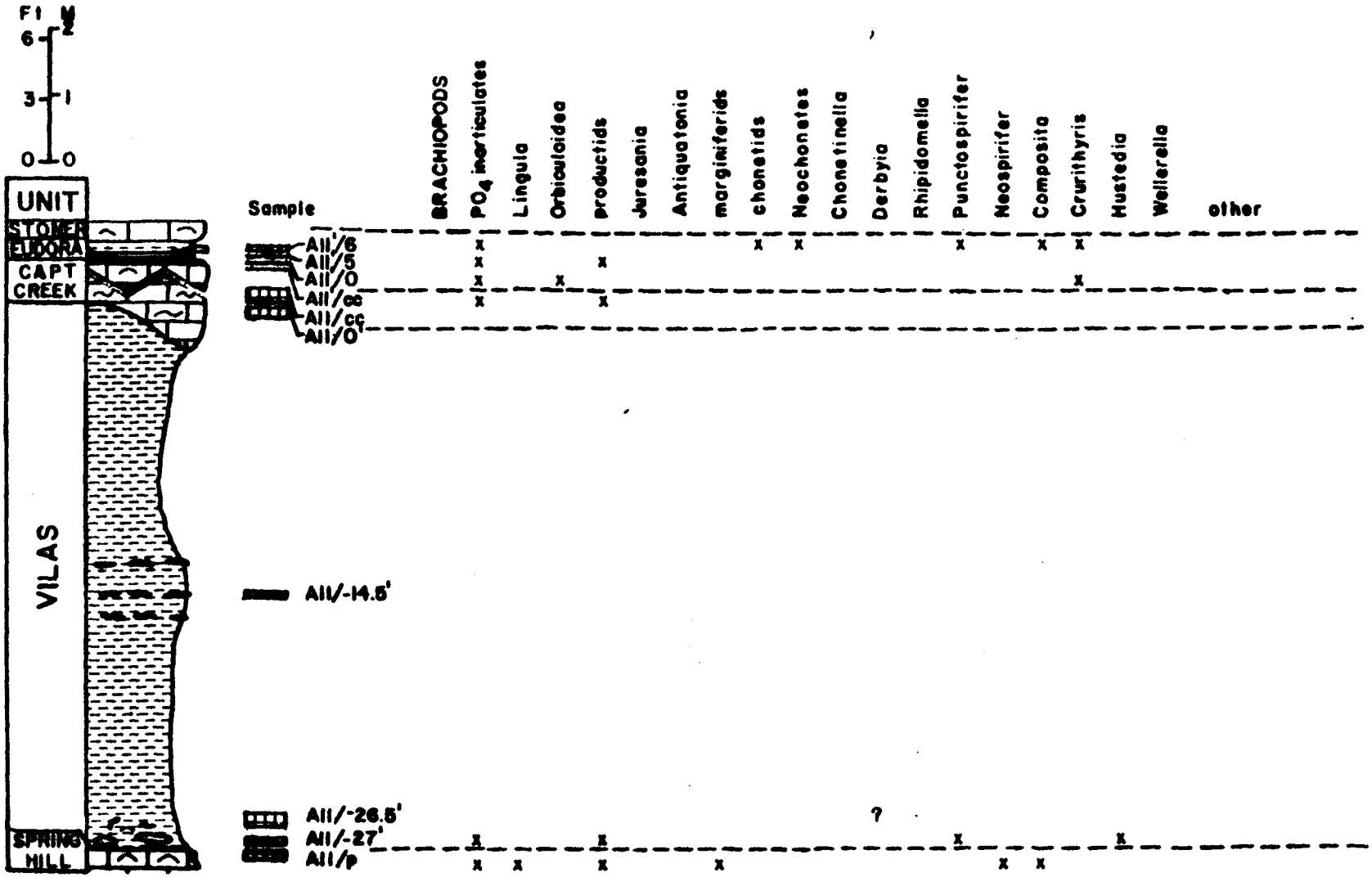



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All/6 | 1.52 | 10.2 | 43 | 21 | | 8 | 28 | x | x | | | .10 | 1187 | | 3 | | 89 | | | 4 | 4 | |
| All/5 | 1.82 | 9.3 | 47 | 11 | | 15 | 27 | | x | | | .27 | 3702 | | 1 | | 97 | 3 | | 1 | 1 | |
| All/0 | 2.33 | 8.9 | 52 | 17 | | 16 | 13 | | | | | .10 | 4849 | | | | 98 | | | 1 | 1 | |
| All/cc | 2.66 | 9.5 | 59 | 9 | | 17 | 15 | | x | | | .98 | 585 | | 1 | | 95 | 4 | | 1 | 1 | |
| All/cc | 2.21 | 9.6 | 59 | 34 | | | 7 | x | | | | | | | | | | | | | | |
| All/0 | 1.43 | 9.7 | 49 | 40 | | 4 | 8 | x | | | | | | | | | | | | | | |
| All/-14.5' | 2.34 | 10.0 | 56 | 24 | | 14 | 6 | x | | | | .85 | | 1 100 | | | | | | | | |
| All/-26.5' | 1.81 | 9.8 | 63 | 21 | | 11 | 6 | x | | | | .96 | | 13 | 33 | | 67 | | | | | |
| All/-27' | 2.24 | 9.8 | 57 | 23 | | 12 | 8 | x | x | | | .82 | | 140 | 20 | | 80 | | | | | |
| All/p | 2.03 | 9.8 | 61 | 22 | | 10 | 8 | x | | | | .36 | | 314 | 23 | | 77 | | | | | |

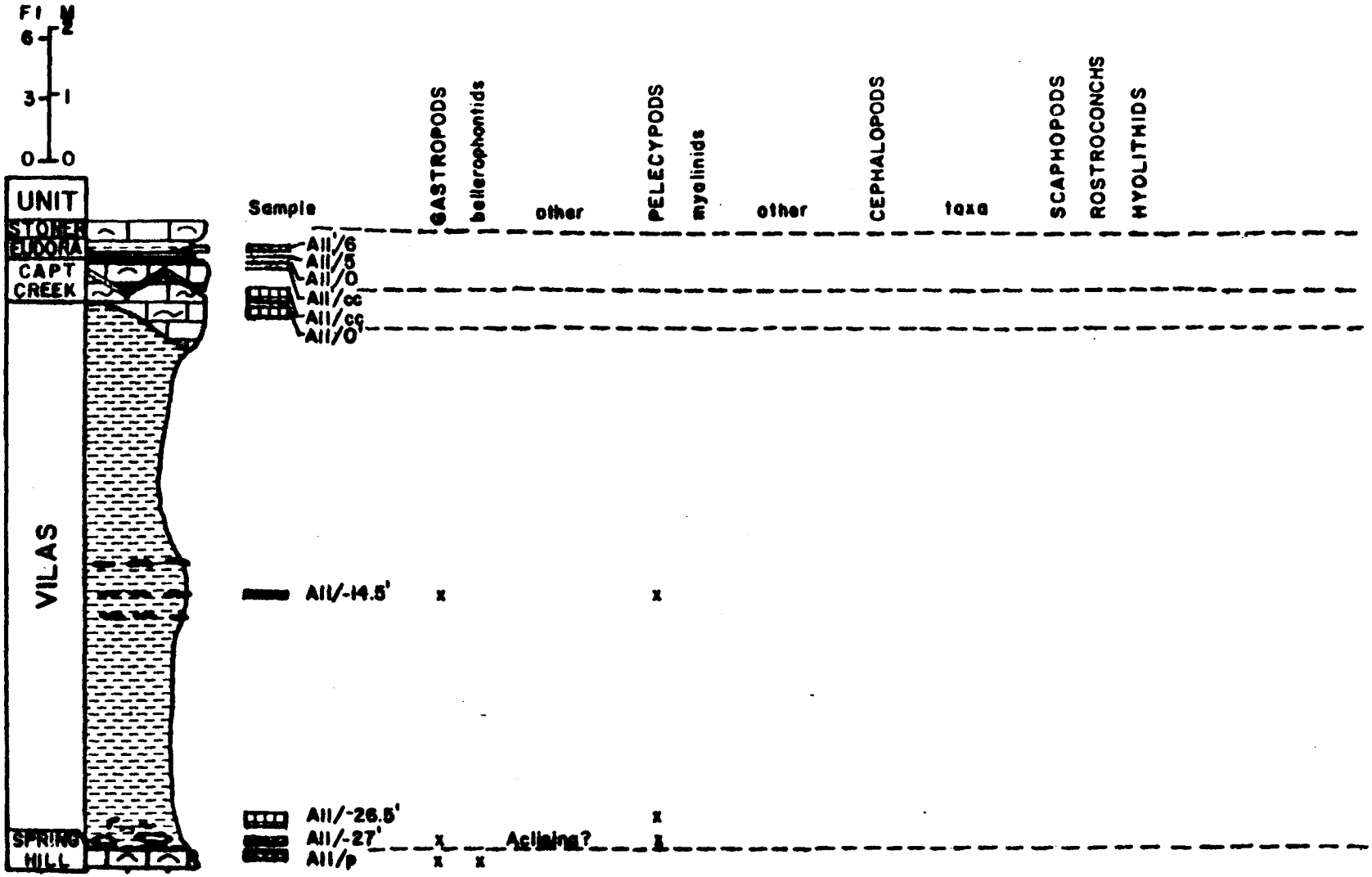
## 2.All



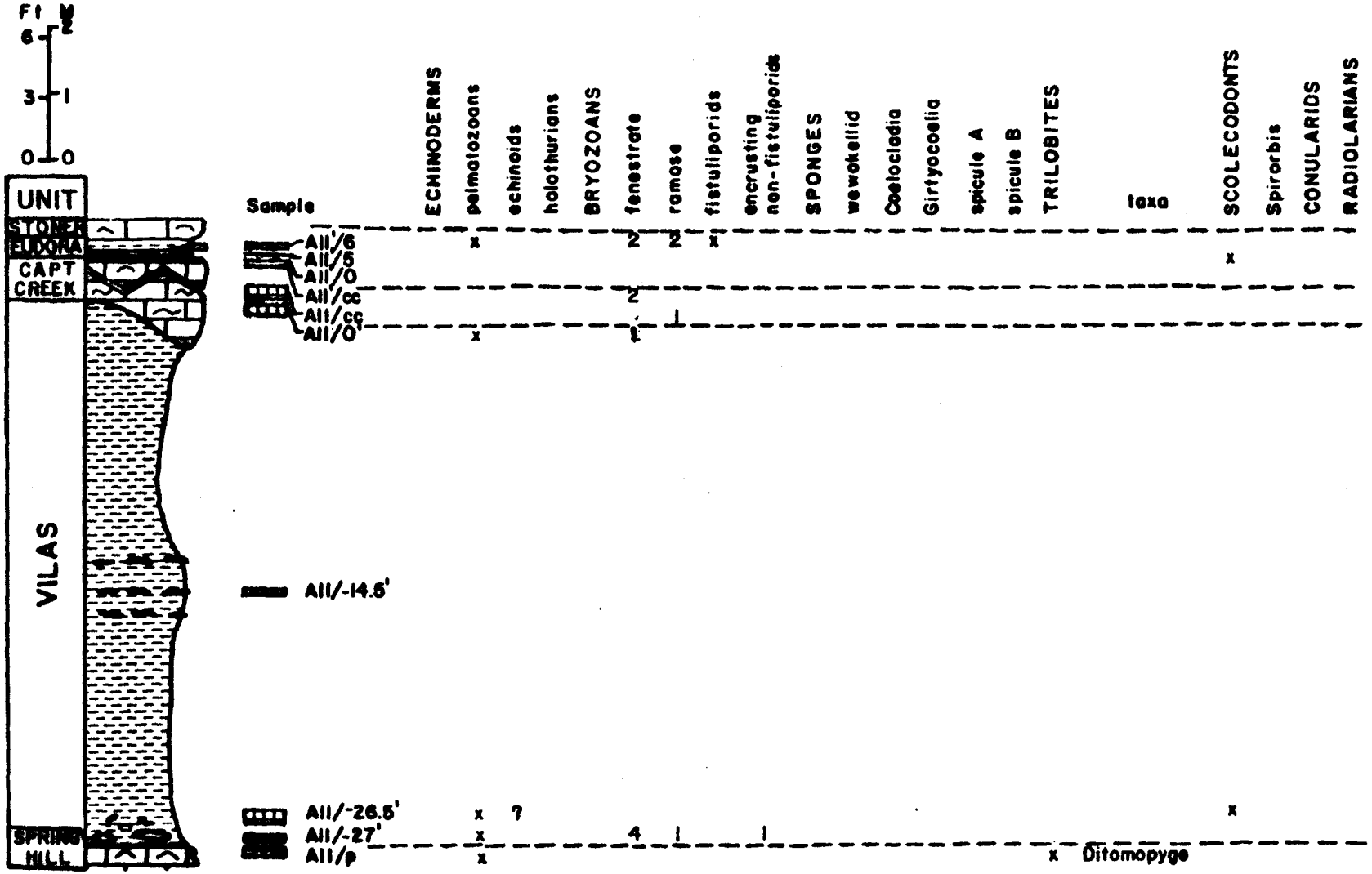

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All/6 | | | ? | | ? | | | | | | | | | | | x | | | | |
| All/5 | | | | | | | | | | | | | | | | | | | | |
| All/0 | | | | | | | | | | | | | | | | x | | | | |
| All/cc | | | | | | | | | | | | | | | | | | | | |
| All/cc | | | | | | | | | | | | | | | | x | x | | | |
| All/0' | | | | | | | | | | | | | | | | | | | | |
| All/-14.5' | | ? | x | | x | | x | | | | | Healdia | | x | x | x | x | x | Cyclogyra, Tetrataxis | |
| All/-26.5' | | | x | | | | | x | | | | | | | | x | x | 26.5 | Ammobaculites, Nodosinella, Endothyanella, Tetrataxis, Cyclogyra, Ammovertella | |
| All/-27' | | | | | x | x | | x | x | | | | | | | x | x | 27 | | |
| All/p | | | | | | | | | | | | | | | | x | x | | | |


FT M
6 2
3 1
0 0
UNIT
STONER
EUDORA
CAPT CREEK
VILAS
SPRING HILL
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
All'/6
All/5
All/O
All/cc
All/cc
All/O'
All/-14.5'
All/-26.5'
All/-27'
All/p
?

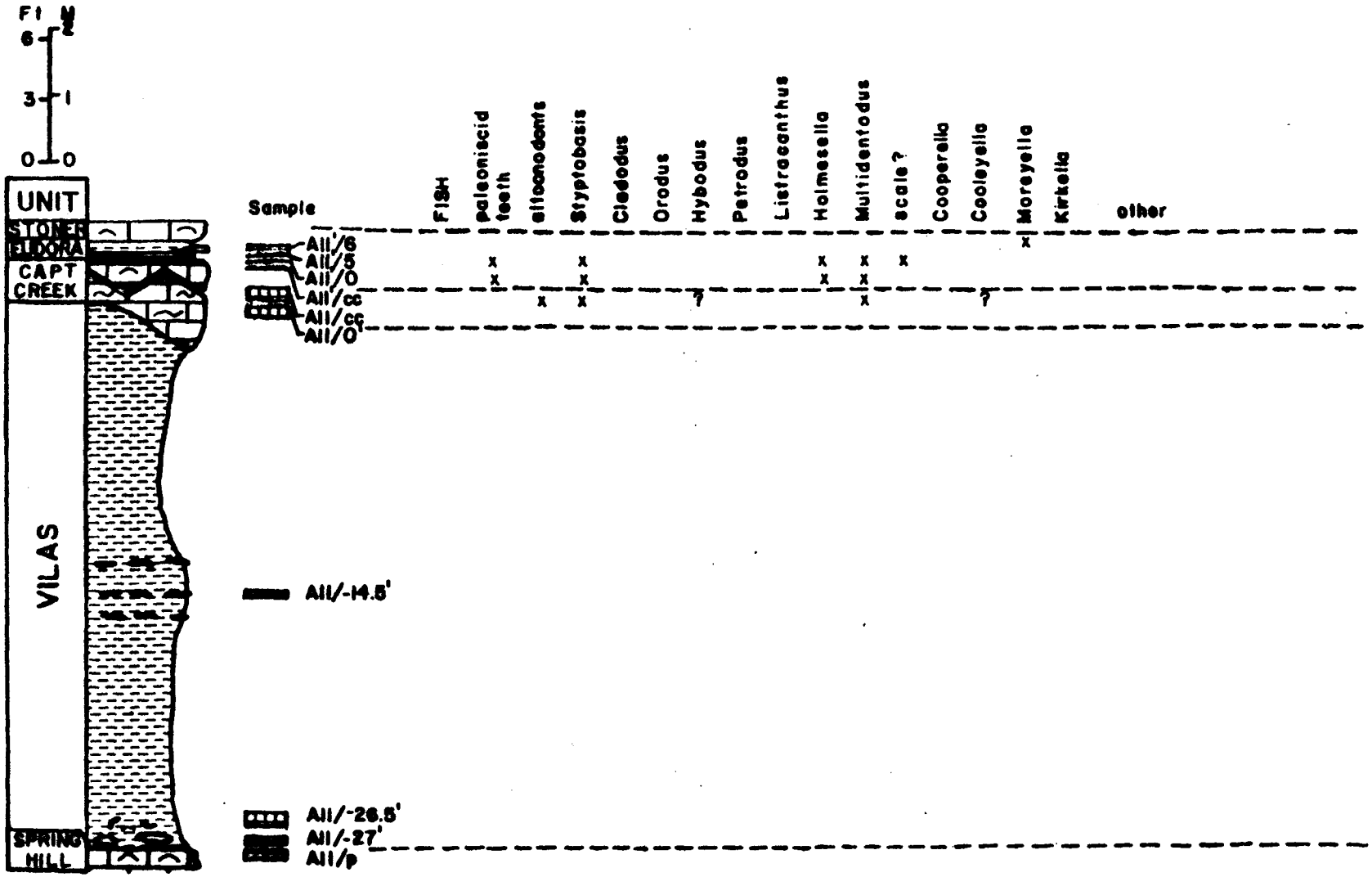
## 2.All


FT M
6 2
3 1
0 0
UNIT
STONER
EUDORA
CAPT CREEK
VILAS
SPRING HILL
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
All/6
All/5
All/O
All/cc
All/cc
All/O
All/-14.5'
All/-26.5'
All/-27'
All/p
Aclinina?

## 2.All


FEET
6
3
0
UNIT
STONER
EUDORA
CAPT CREEK
VILAS
SPRING HILL
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
All/6
All/5
All/O
All/cc
All/cc
All/O
All/-14.5'
All/-26.5'
All/-27'
All/p
?
Ditomopyge

## 2.All

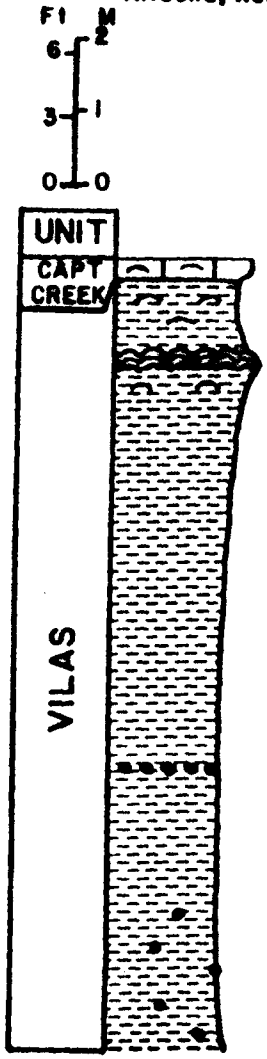

FT M
6 2
3 1
0 0
UNIT
STONER
EUDORA
CAPT CREEK
VILAS
SPRING HILL
Sample
FISH
paleoniscid teeth
elliconodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Mutilidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
All'/6
All/5
All/O
All'/cc
All/cc
All/O
All/-14.5'
All/-26.5'
All/-27'
All/p

# 3.Al 2

Location: Roadcut on US Highway 75. 4 mi north of Altoona, Kansas

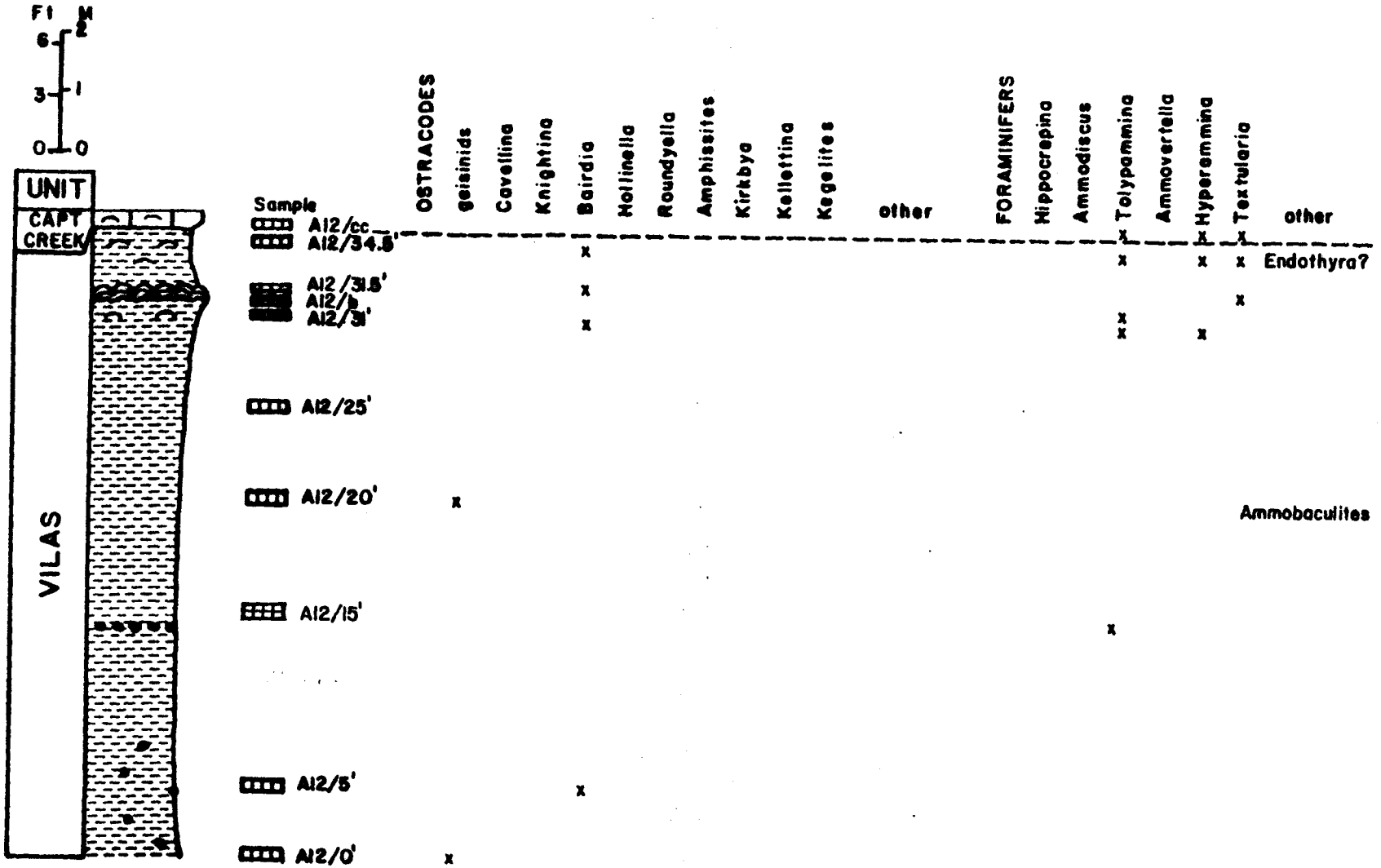
Altoona, Kansas, 7 1/2'

T28SR16E22 NWI/4SWI/4NWI/4

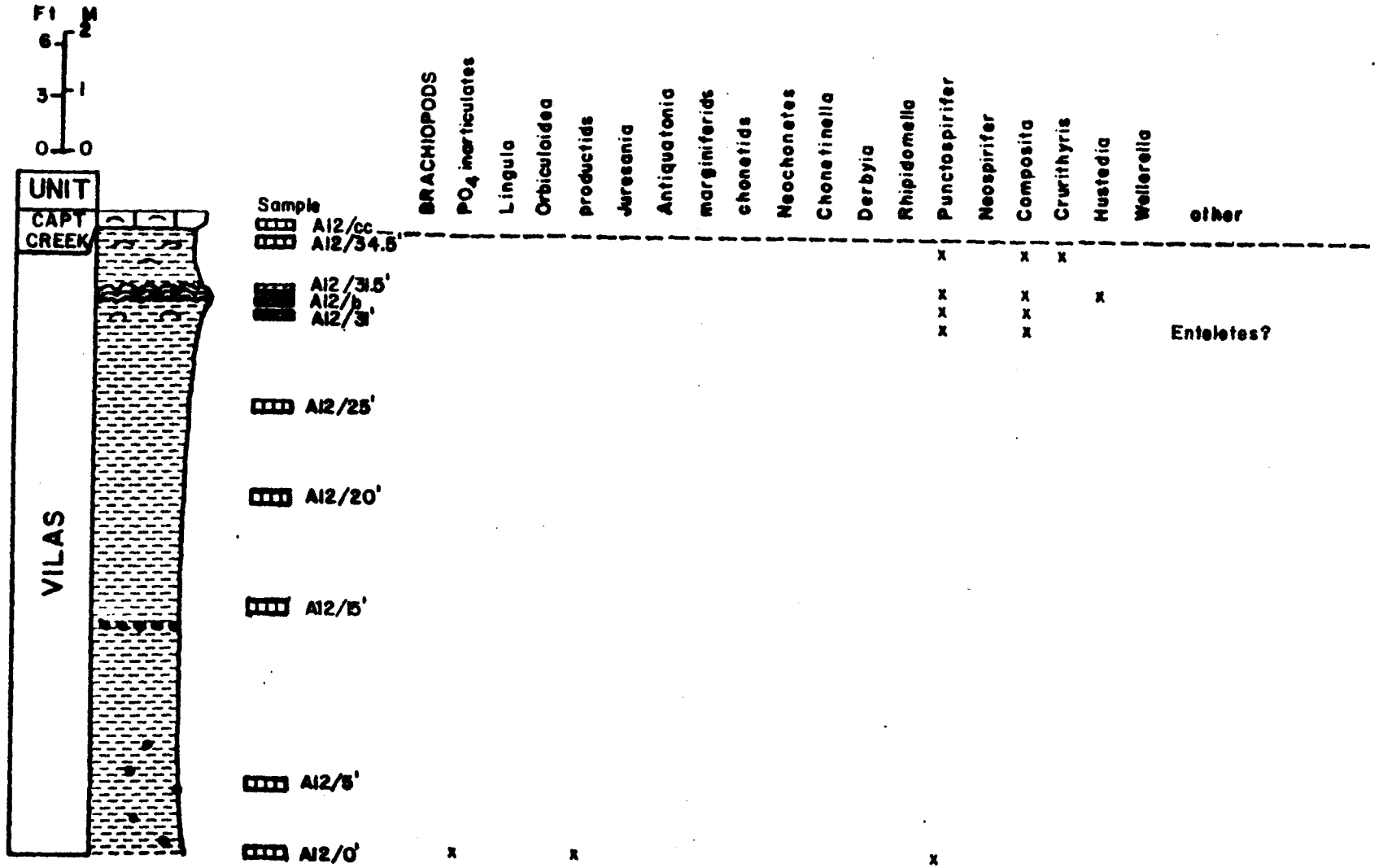



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al2/cc | 1.58 | 9.7 | 47 | 37 | | | | x | | | | | | | | | | | | | | |
| Al2/34.5' | 1.15 | 9.7 | 43 | 39 | | 6 | 13 | x | | | | .73 | | | | | | | | | | x |
| Al2/31.5' | 1.33 | 10.0 | 49 | 37 | | 5 | 9 | x | | | | .89 | | 1 | 100 | | | | | | | |
| Al2/b | 1.93 | 9.9 | 48 | 23 | | 9 | 19 | x | | | | .14 | | 7 | | | 100 | | | | | |
| Al2/31' | 1.32 | 9.9 | 49 | 38 | | 7 | 6 | x | | | | | | | | | | | | | | |
| Al2/25' | 1.80 | 9.9 | 57 | 22 | | 16 | 5 | x | | | x | | | | | | | | | | | |
| Al2/20' | 1.59 | 9.8 | 71 | 12 | | 12 | 5 | x | | | | | | | | | | | | | | |
| Al2/15' | 1.46 | 10.0 | 61 | 26 | | 6 | 7 | x | | | | | | | | | | | | | | |
| Al2/5' | 1.82 | 10.4 | 59 | 21 | | 14 | 6 | x | | | | | | | | | | | | | | |
| Al2/0' | 2.10 | 10.0 | 67 | 16 | | 12 | 5 | x | | | | | | | | | | | | | | |

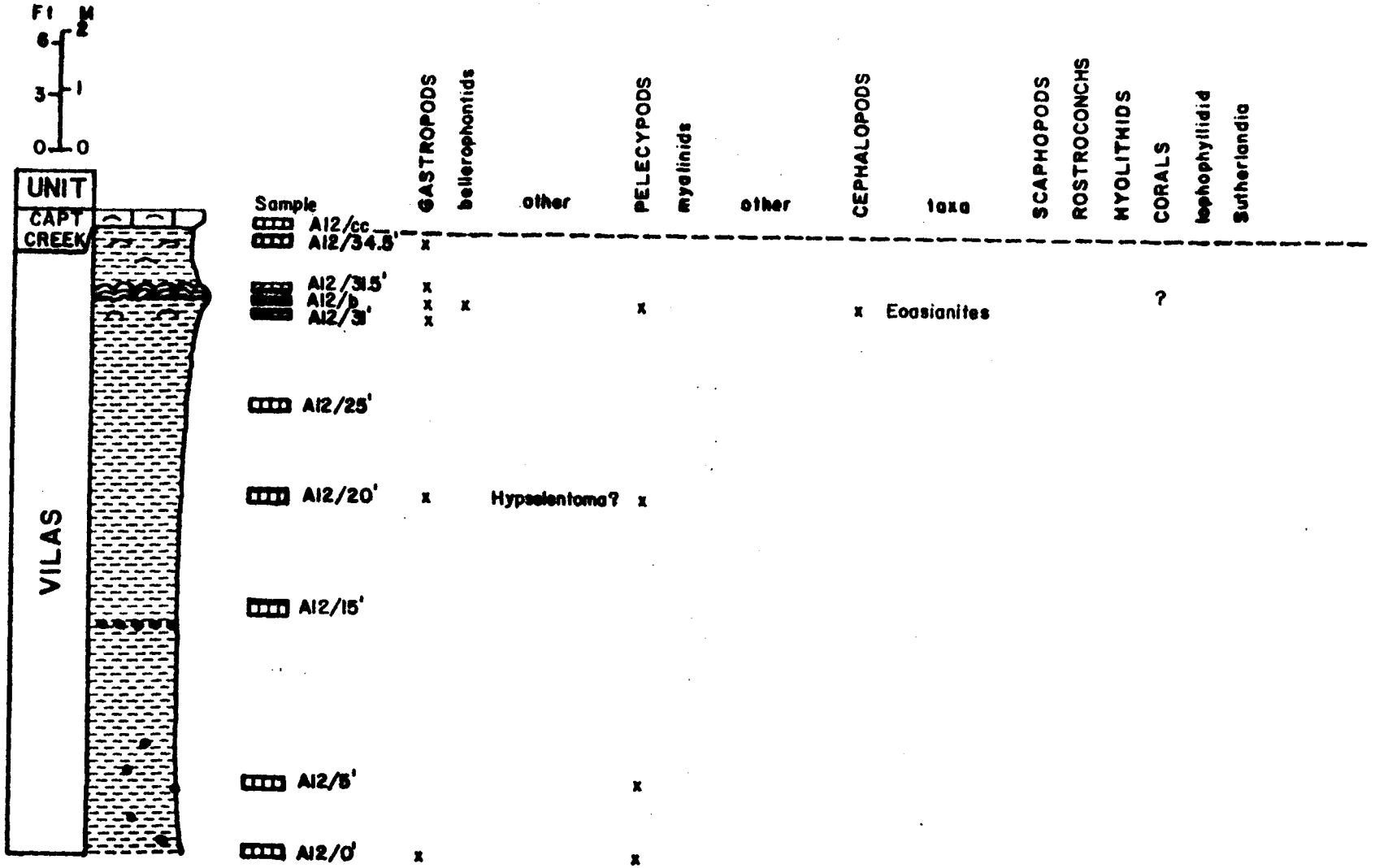
## 3.Al 2


Ft M
6 2
3 1
0 0
UNIT
CAPT CREEK
VILAS
Sample
Al2/cc
Al2/34.5'
Al2/31.5'
Al2/b
Al2/31'
Al2/25'
Al2/20'
Al2/15'
Al2/5'
Al2/0'
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Endothyra?
Ammobaculites

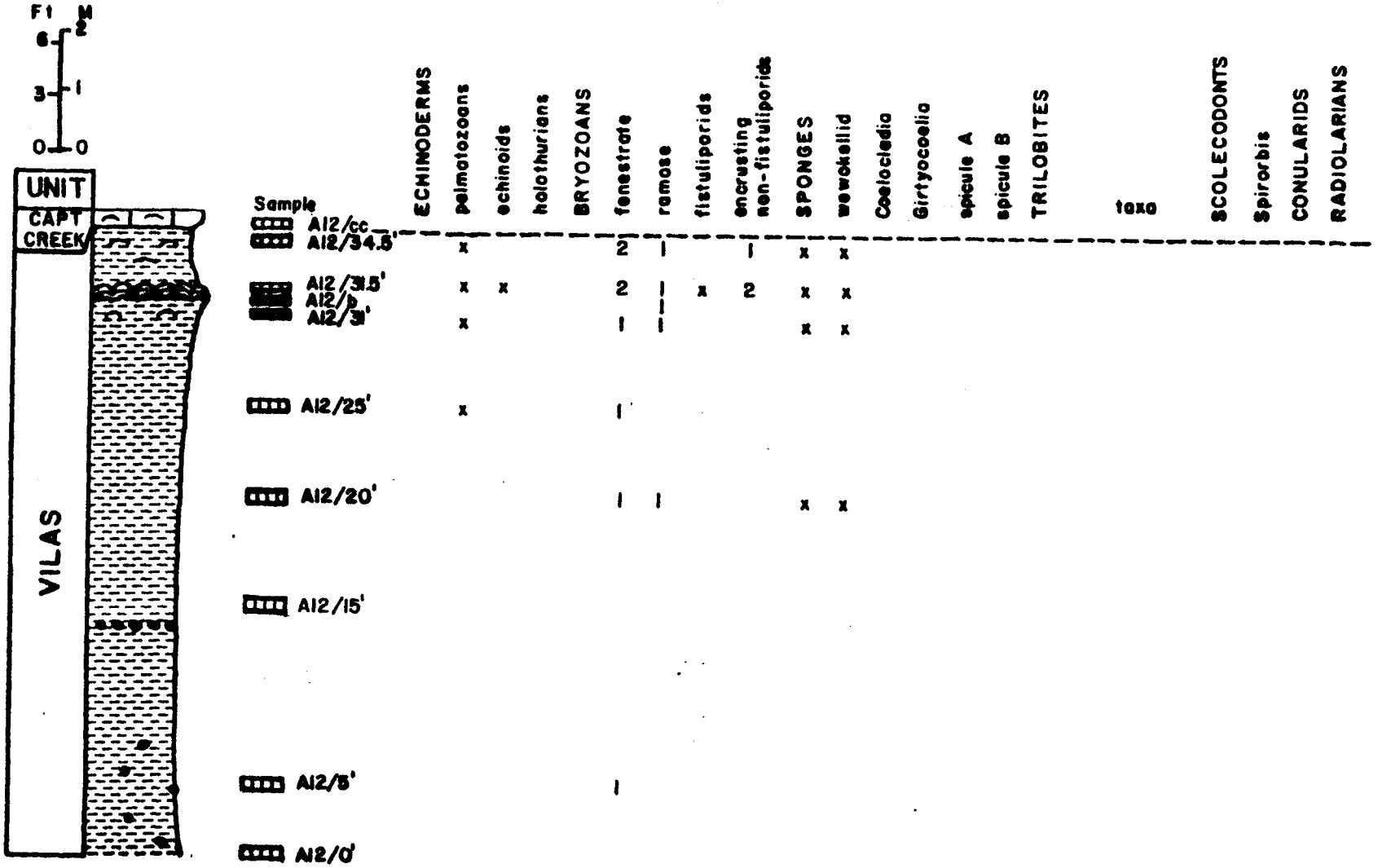
# 3.Al 2


Ft M
6 2
3 1
0 0
UNIT
CAPT CREEK
VILAS
Sample
Al2/cc
Al2/34.5'
Al2/31.5'
Al2/b
Al2/3'
Al2/25'
Al2/20'
Al2/15'
Al2/5'
Al2/0'
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Enteletes?

# 3.Al 2


Ft
M
6
2
3
1
0
0
UNIT
CAPT CREEK
VILAS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Al2/cc
Al2/34.5'
Al2/31.5'
Al2/b
Al2/31'
Eoasianites
?
Al2/25'
Al2/20'
Hypselentoma?
Al2/15'
Al2/5'
Al2/0'

# 3.Al 2


Ft M
6 2
3 1
0 0
UNIT
CAPT
CREEK
VILAS
Sample
Al2/cc
Al2/34.5'
Al2/31.5'
Al2/b
Al2/3'
Al2/25'
Al2/20'
Al2/15'
Al2/5'
Al2/0'
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS

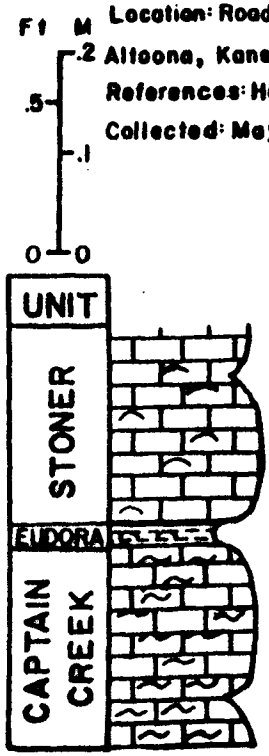
# 4.AI 3

Location: Road cut on county road, 2.2 mi west and .2 mi north of Altoona, Kansas

Altoona, Kansas, 7 1/2'  T29SR16E7SW1/4SW1/4NW1/4

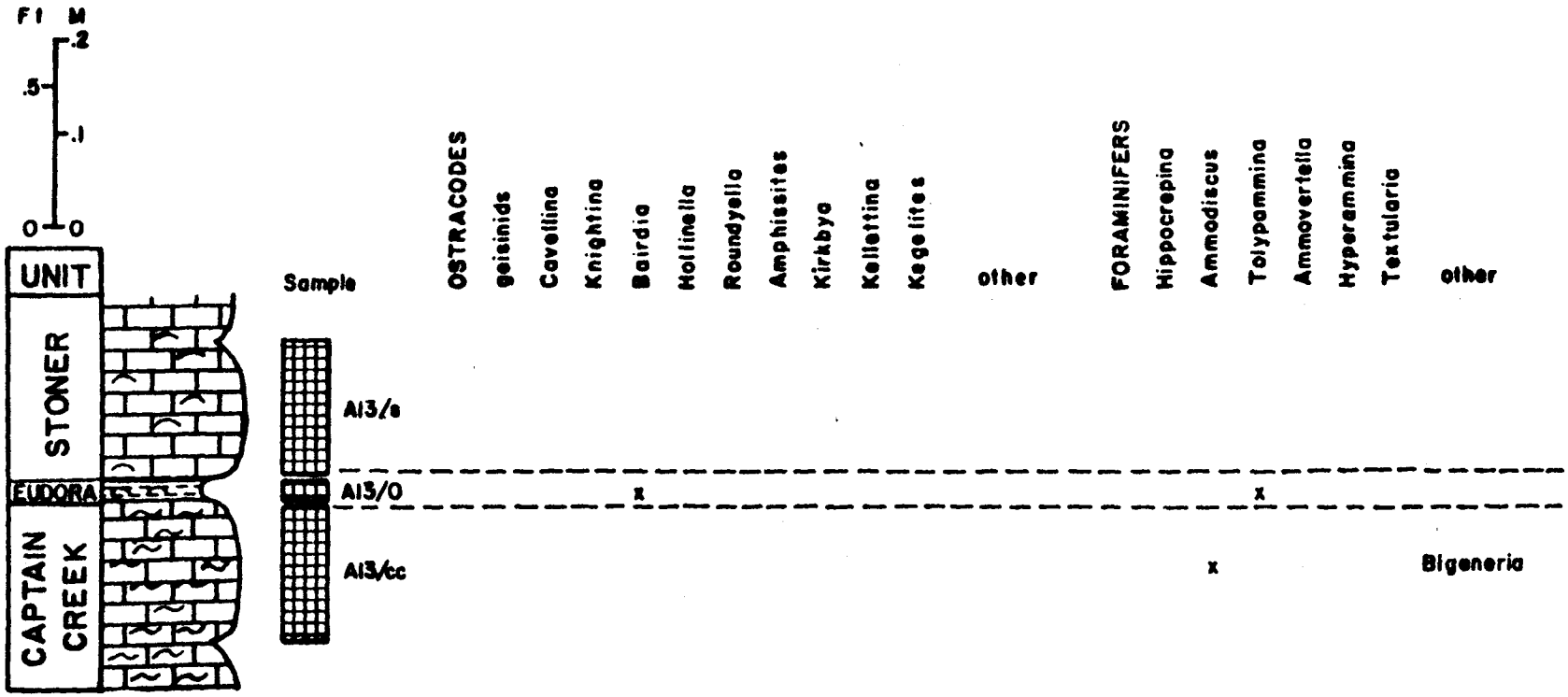
References: Heckel, 1975, Stop 6, p.56; Heckel, 1978, Stop 6A, p. 34; Heckel, et al., 1979, Stop 6A, p. 30

Collected: May 23, 1980




| Sample | Mite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AI3/s | 1.23 | 9.0 | 39 | 42 | | 5 | 13 | | | | | 1.00 | | 3 | | | 67 | | | | 33 | |
| AI3/0 | 3.81 | 9.8 | 38 | 5 | | | 57 | | | | | .13 | | 389 | 2 | | 91 | | | 1 | 6 | |
| AI3/cc | 1.72 | 9.2 | 37 | 21 | | 9 | 33 | | | | | .59 | | 19 | | | 62 | | | 3 | 35 | |

# 4.Al 3


FT M
.2
.5
.1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Al3/s
Al3/O
Al3/cc
x
x
x
Bigeneria

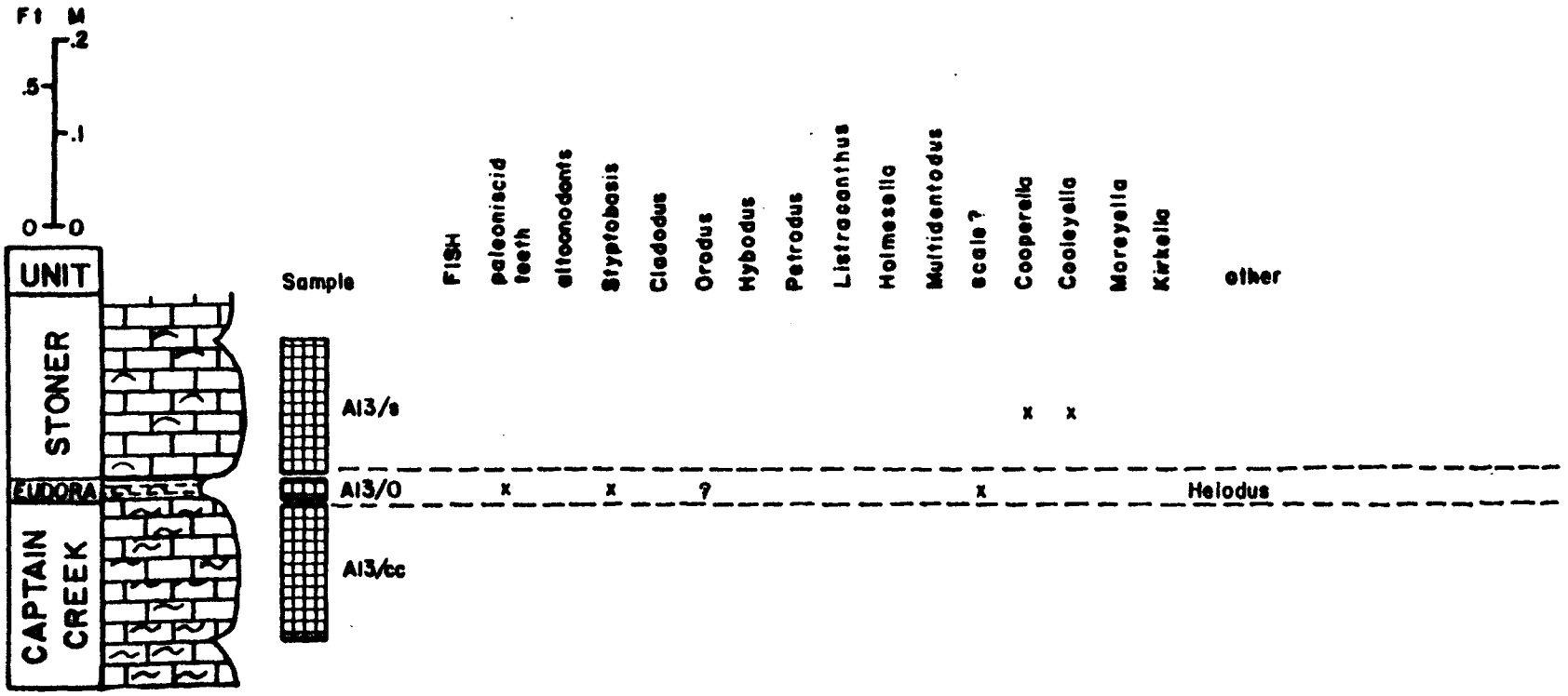
# 4.AI 3


FT M
2
.5
.1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
AI3/s
AI3/O
AI3/cc
x
x
x
terebratulid

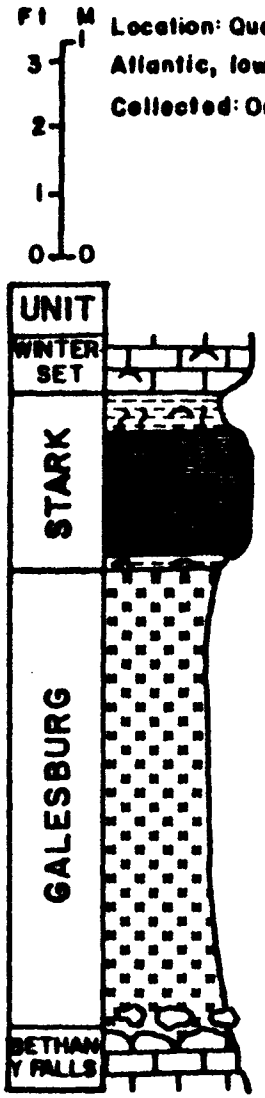
# 4.Al 3


Ft M
2
.5
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Al3/s
Al3/0 x 3 2 x 1 ? ?
Al3/cc 1

# 4.AI 3


Ft M
2
5
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
Sample
FISH
paleoniscid teeth
ctenonodents
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkella
other
AI3/s
AI3/O
AI3/cc
x
x
?
x
x
x
Helodus

# 5. At I

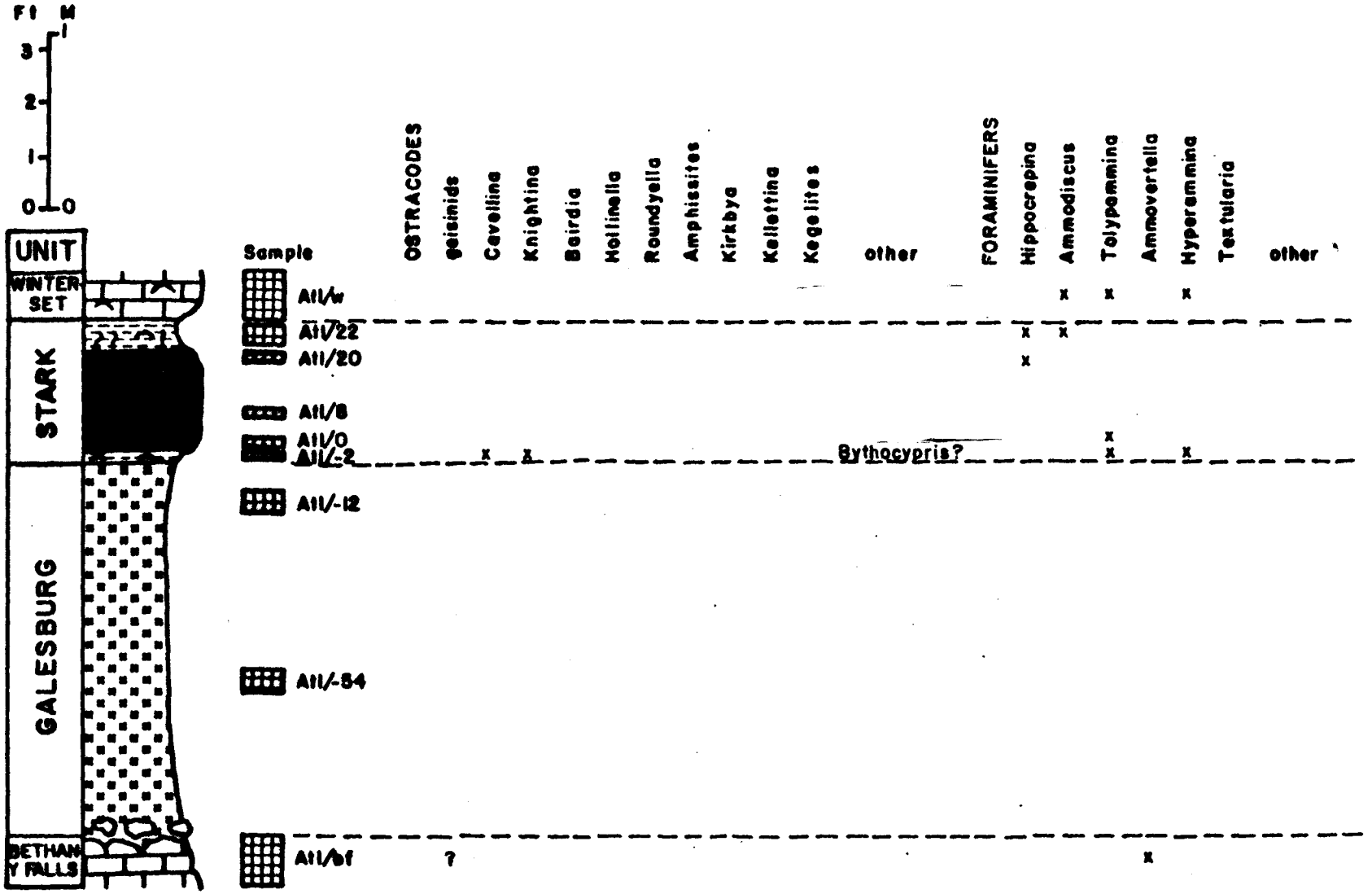


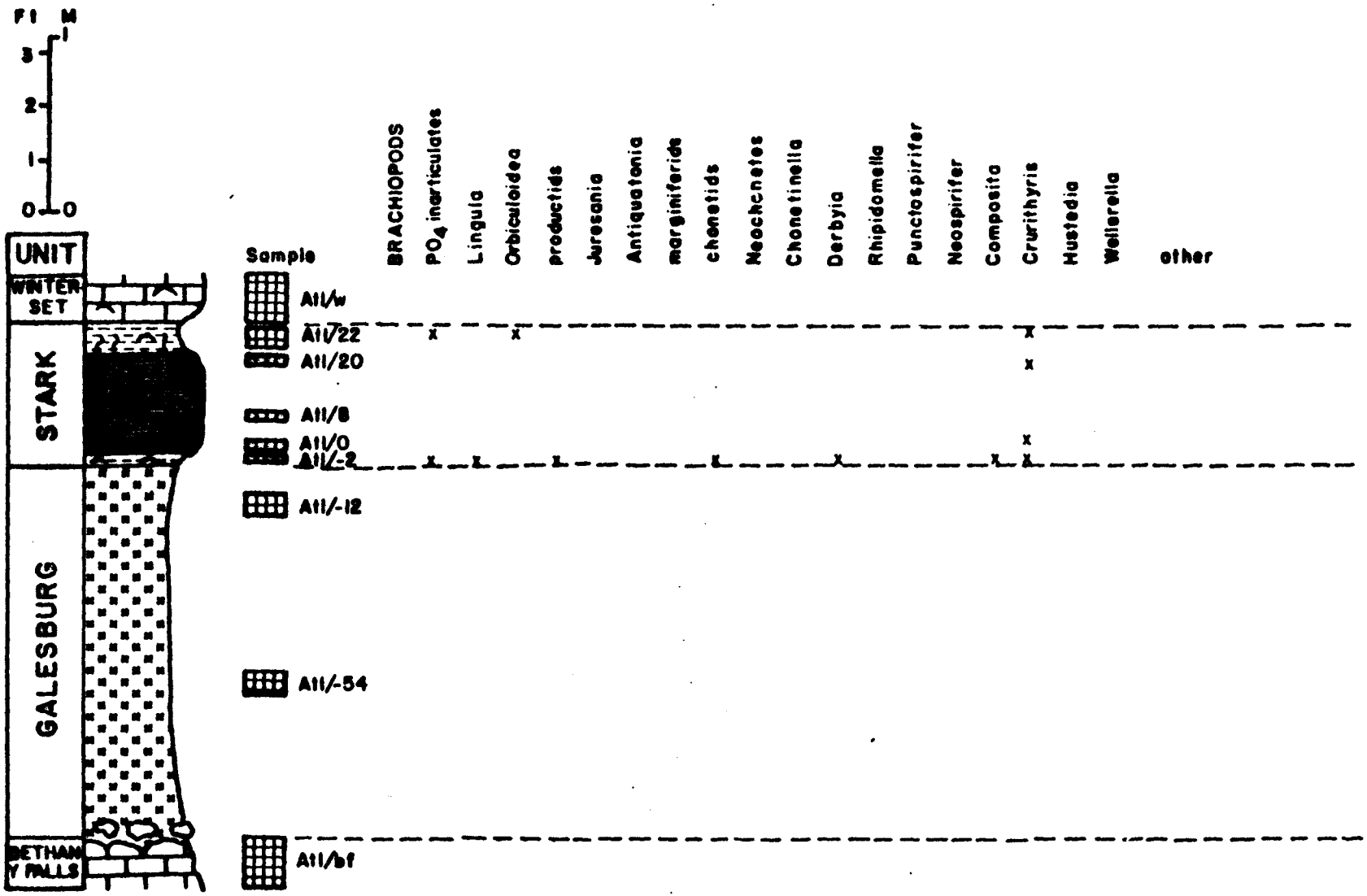

Location: Quarry northwest of Atlantic, Iowa
Atlantic, Iowa, 7 1/2'
Collected: October 10, 1980

T76NR36W5NW1/4SW1/4SW1/4

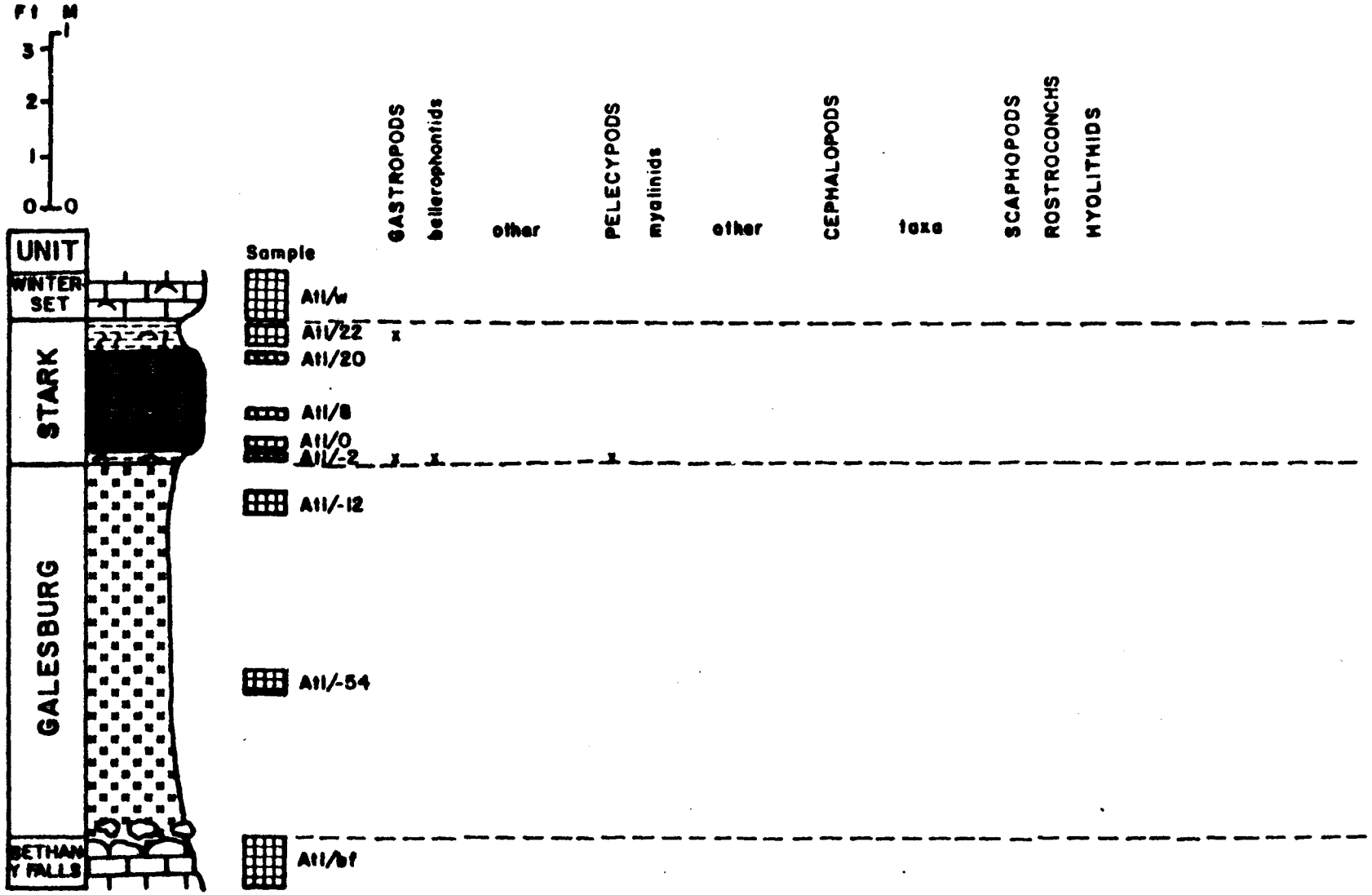
| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AII/w | 1.48 | 9.3 | 61 | 12 | 6 | 21 | | | | | | 1.00 | | 41 | | | 88 | 12 | | | | |
| AII/22 | 2.15 | 9.5 | 65 | 15 | | 20 | | | x | | | .81 | | 218 | | | 68 | 1 | | 3 | 27 | |
| AII/20 | 1.89 | 9.3 | 58 | 19 | | 23 | | | | | | .06 | | 1982 | | | 75 | | | 4 | 21 | |
| AII/8 | 1.30 | 9.2 | 72 | 18 | | 11 | | | | | | .49 | | 451 | | | 88 | | | 11 | 1 | |
| AII/0 | 1.62 | 9.8 | 70 | 7 | | 23 | | | | | | .65 | | 409 | | | 97 | 1 | | 3 | | |
| AII/-2 | 1.14 | 9.4 | 51 | 28 | 14 | 7 | | | x | | | .15 | | 364 | 10 | | 23 | 8 | | 1 | | |
| AII/-12 | 1.13 | 7.6 | 17 | 52 | 28 | 3 | | | | | | | | | | | | | | | | |
| AII/-54 | 1.20 | 8.6 | 42 | 18 | 29 | 13 | | | | | | | | | | | | | | | | |
| AII/bf | 1.43 | 8.8 | 56 | 18 | 9 | 17 | | | | | | | | | | | | | | | | |

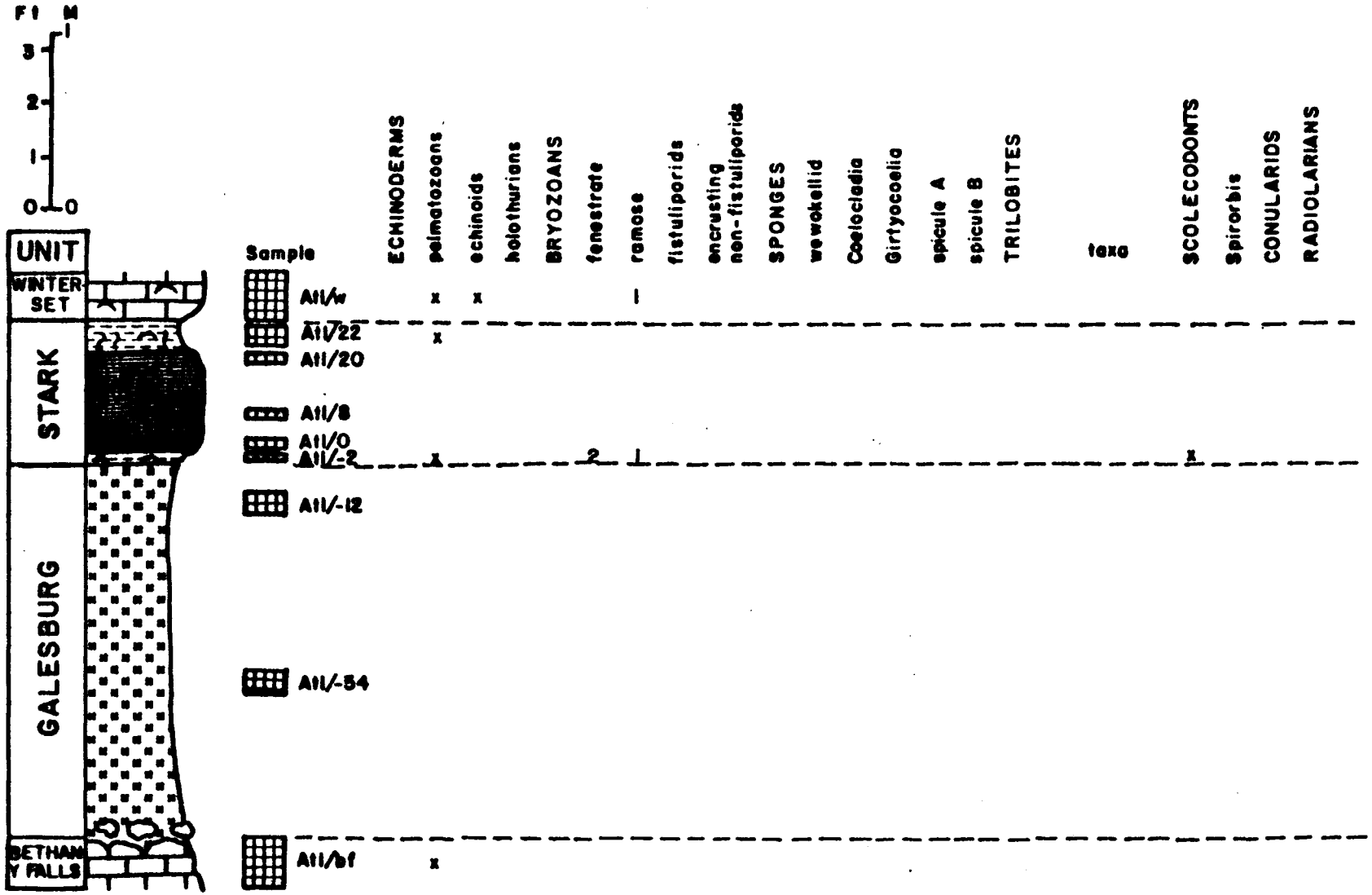
## 5. At I


Ft
M
3
2
1
0
0
UNIT
WINTER SET
STARK
GALESBURG
BETHANY FALLS
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
At1/w
At1/22
At1/20
At1/8
At1/0
At1/-2
At1/-12
At1/-54
At1/bf
Bythocypris?
?

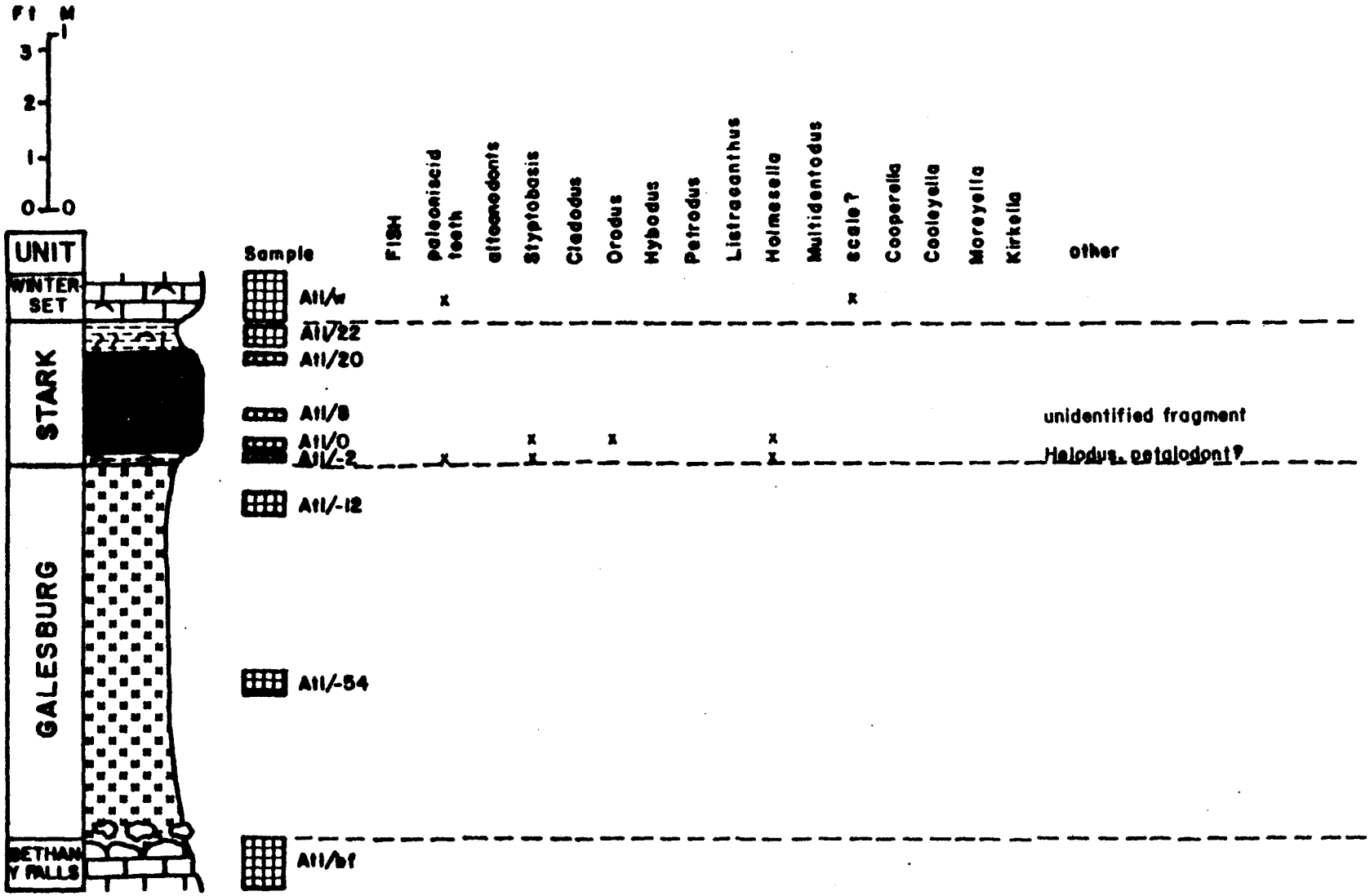

FT
M
3
2
1
0
0
UNIT
WINTER SET
STARK
GALESBURG
BETHANY FALLS
Sample
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
A11/w
A11/22
A11/20
A11/8
A11/0
A11/-2
A11/-12
A11/-54
A11/bf

# 5. At I


FT
M
3
2
1
0
0
UNIT
WINTER SET
STARK
GALESBURG
BETHANY FALLS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
AII/w
AII/22
AII/20
AII/8
AII/0
AII/-2
AII/-12
AII/-54
AII/bf
x
x
x
x

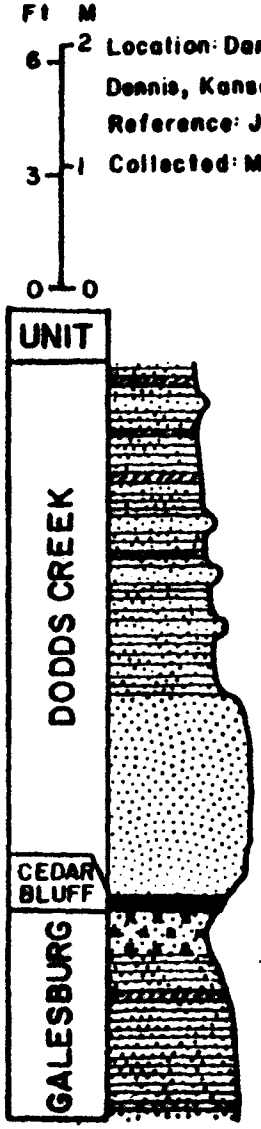

5. At I
FT
M
3
2
1
0
0
UNIT
WINTER SET
STARK
GALESBURG
BETHANY FALLS
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
At1/w
At1/22
At1/20
At1/8
At1/0
At1/-2
At1/-12
At1/-54
At1/bf

# 5. At I


Ft
M
3
2
1
0
0
UNIT
WINTER SET
STARK
GALESBURG
BETHANY FALLS
Sample
FISH
paleoniscid teeth
eltenodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
At1/w
At1/22
At1/20
At1/8
At1/0
At1/-2
At1/-12
At1/-54
At1/bf
unidentified fragment
Helodus, petalodont?

# 6.BC I

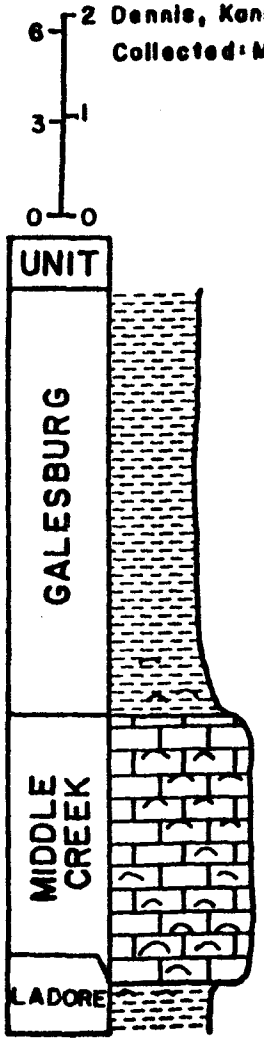
Location: Dam spillway (Big Hill Creek dam) 3 1/2 mi east of Cherryvale, Kansas
Dennis, Kansas, 7 1/2' T32SR18E7SE1/4NW1/4NW1/4
Reference: Jungmann, 1960, Loc. 13, p.85 (section about 1/2 mi north)
Collected: May 24, 1980




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BCI/3 | 3.98 | 9.8 | 43 | 9 | | | 48 | x | | | |
| BCI/2 | 2.08 | 9.8 | 56 | 14 | | 17 | 12 | x | | | |
| BCI/1 | 3.41 | 9.5 | 53 | 15 | | 18 | 14 | x | | | |

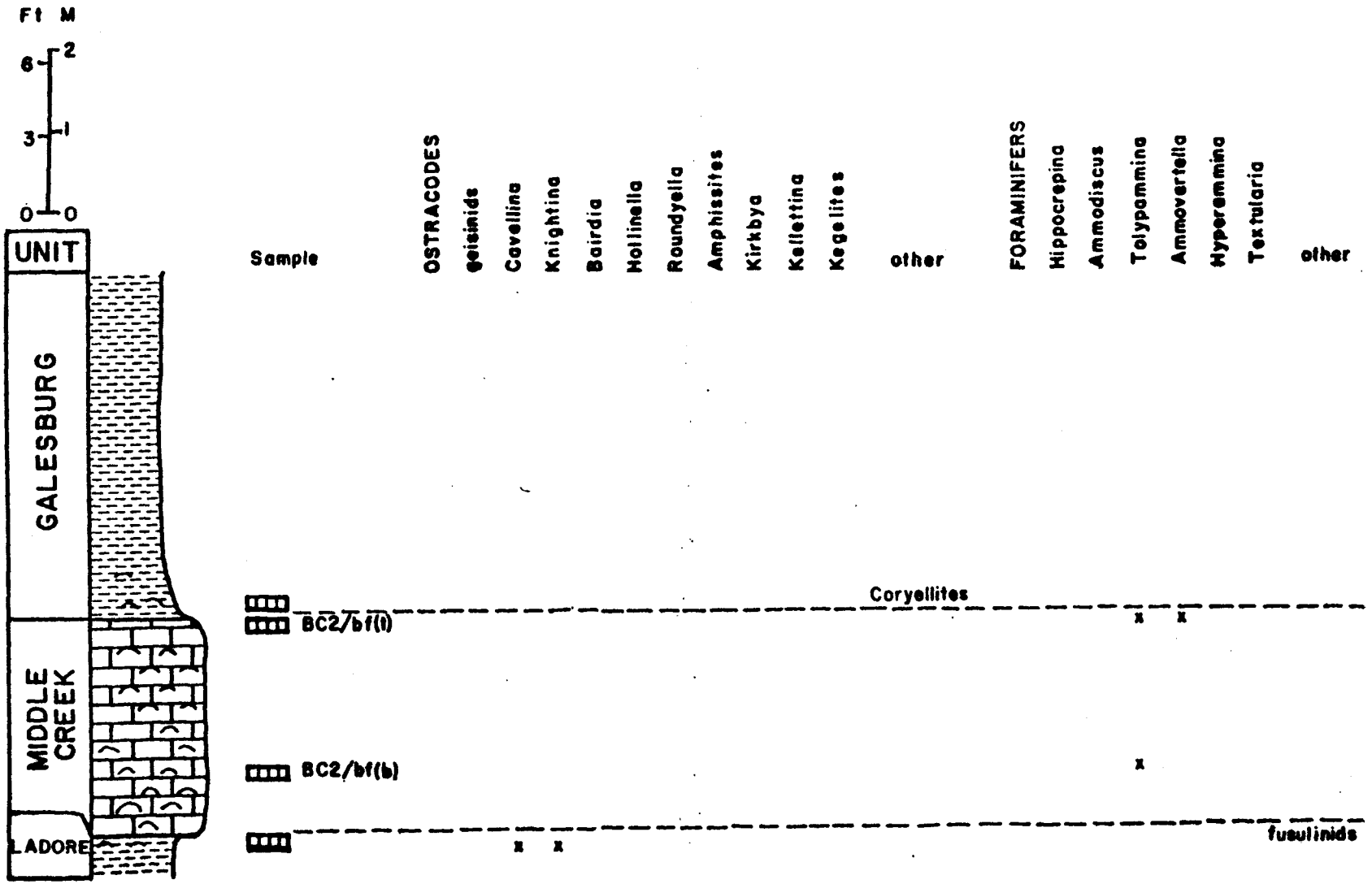
# 7.BC 2

Location: Quarry 5 mi east and 1/4 mi south of Cherryvale, Kansas
Dennis, Kansas, 7 1/2'
T32SR18E18NE1/4SE1/4NE1/4
Collected: May 24, 1980, and October 27, 1980




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Acetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.05 | 9.4 | 72 | 20 | | 5 | 4 | x | | | | .39 | | 31 | 17 | | 75 | 8 | | | | |
| BC2/bf(t) | 1.43 | 9.4 | 49 | 34 | | 17 | | | x | | | .98 | | 35 | 9 | | 74 | 18 | | | | |
| BC2/bf(b) | 2.47 | 9.0 | 73 | 9 | | 15 | 4 | | | | | 1.00 | | 1 | | | | 100 | | | | |
| | 2.39 | 10.2 | 66 | 5 | | 18 | 11 | x | | | | | | | | | | | | | | |

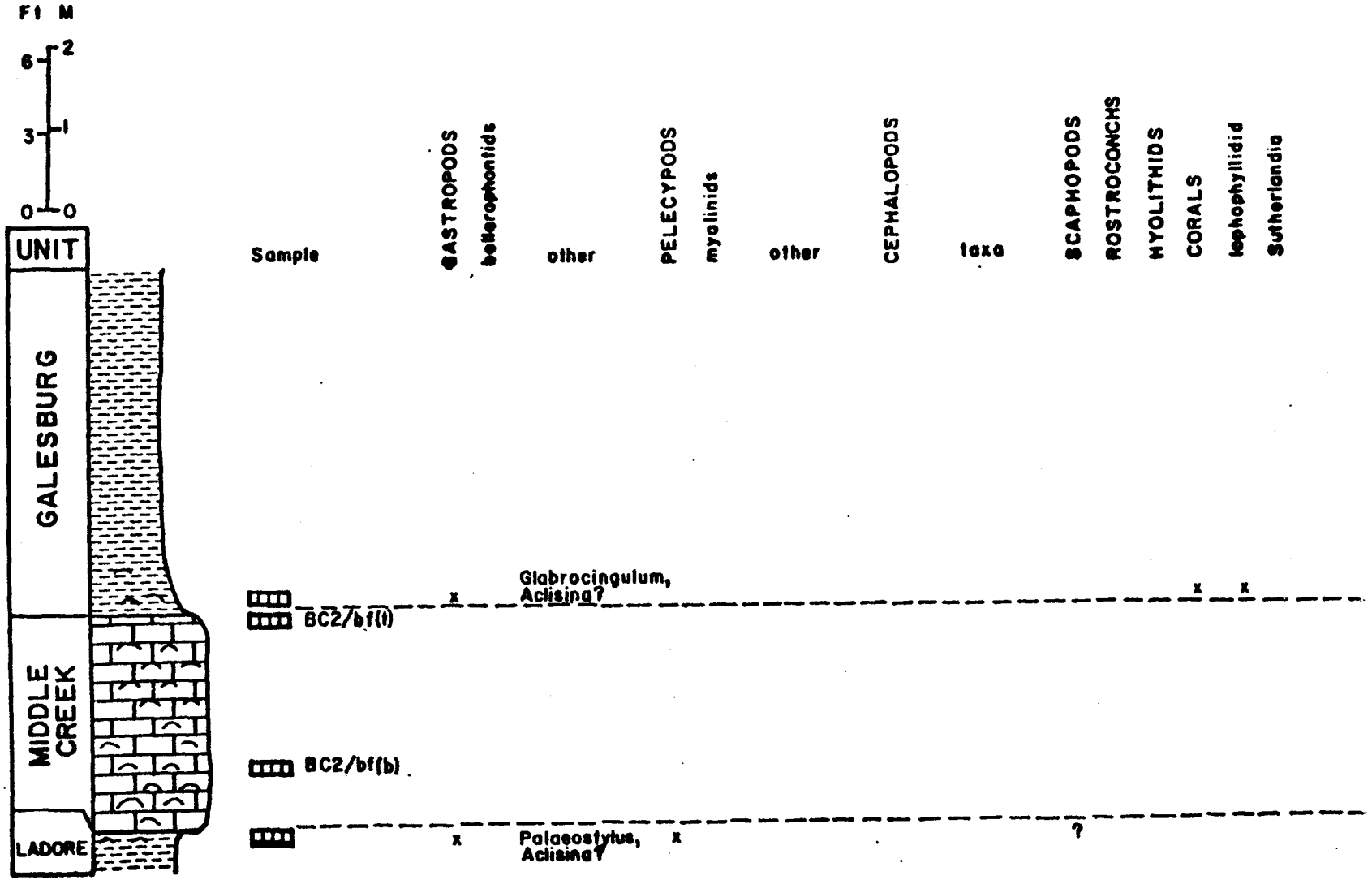
# 7.BC 2


Ft M
6 2
3 1
0 0
UNIT
GALESBURG
MIDDLE CREEK
LADORE
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Coryellites
BC2/bf(t)
BC2/bf(b)
fusulinids

## 7.BC 2


Ft M
6
3
0
2
1
0
UNIT
GALESBURG
MIDDLE CREEK
LADORE
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
BC2/bf(t)
BC2/bf(b)

# 7.BC 2


Ft M
6 2
3 1
0 0
UNIT
GALESBURG
MIDDLE CREEK
LADORE
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Glabrocingulum, Aclisina?
BC2/bf(t)
BC2/bf(b)
Palaeostylus, Aclisina?

7.BC 2

| Sample | BC2/b1(i) | BC2/b1(b) | |
|---|---|---|---|
| **ECHINODERMS** | | | |
| palmatozoans | x | x | |
| echinoids | 2 | 2 | |
| holothurians | 1 | | |
| **BRYOZOANS** | | | |
| fenestrate | x | | |
| ramose | | | |
| fistuliporids | | | |
| encrusting non-fistuliporids | | | |
| **SPONGES** | | | |
| wewokellid | | | |
| Coelocladia | | | |
| Girtyocoelia | | | |
| spicule A | | | |
| spicule B | | | |
| **TRILOBITES** | | | |
| | x | | |
| Sample | BC2/b1(i) | BC2/b1(b) | |
| **SCOLECODONTS** | | | |
| Spirorbis | | | |
| **CONULARIDS** | | | |
| **RADIOLARIANS** | | | |

## 7.BC 2


FT M
6
3
0
2
1
0
UNIT
GALESBURG
MIDDLE CREEK
LADORE
Sample
FISH
paleoniscid teeth
eltenodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
BC2/bf(t)
BC2/bf(b)

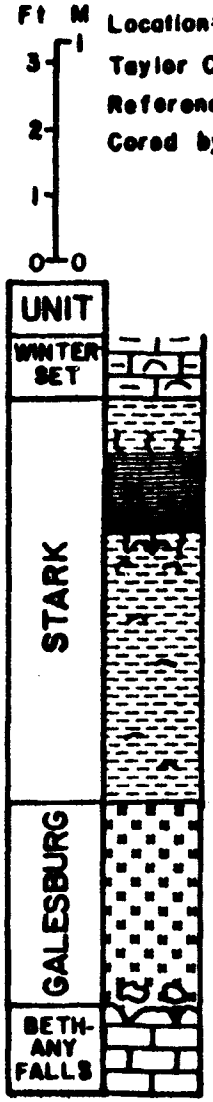
# 8.Be I

Location: About 2 mi west of Bedford, Iowa

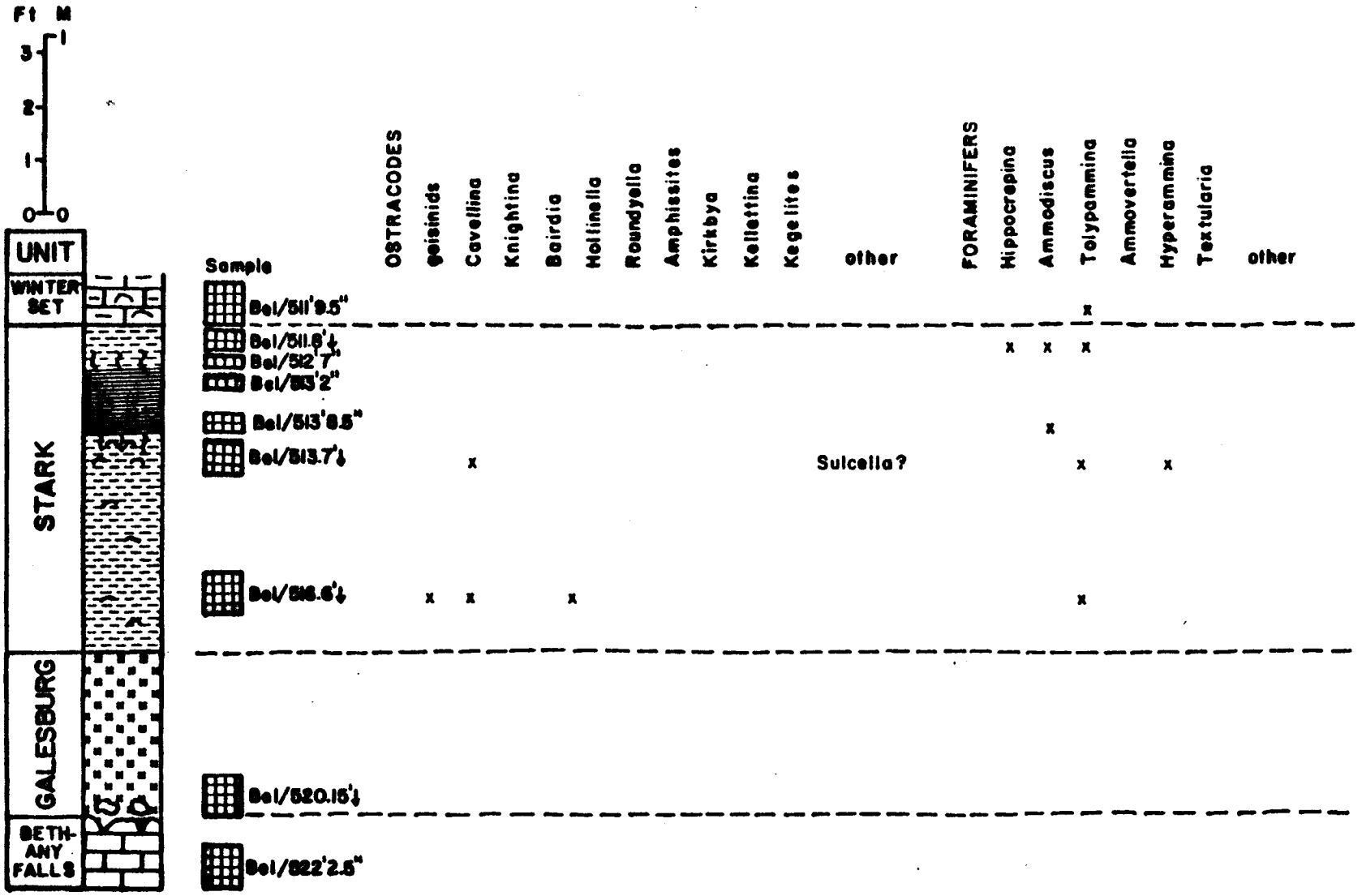
Taylor County, Iowa, map T67NR34W4SE1/4

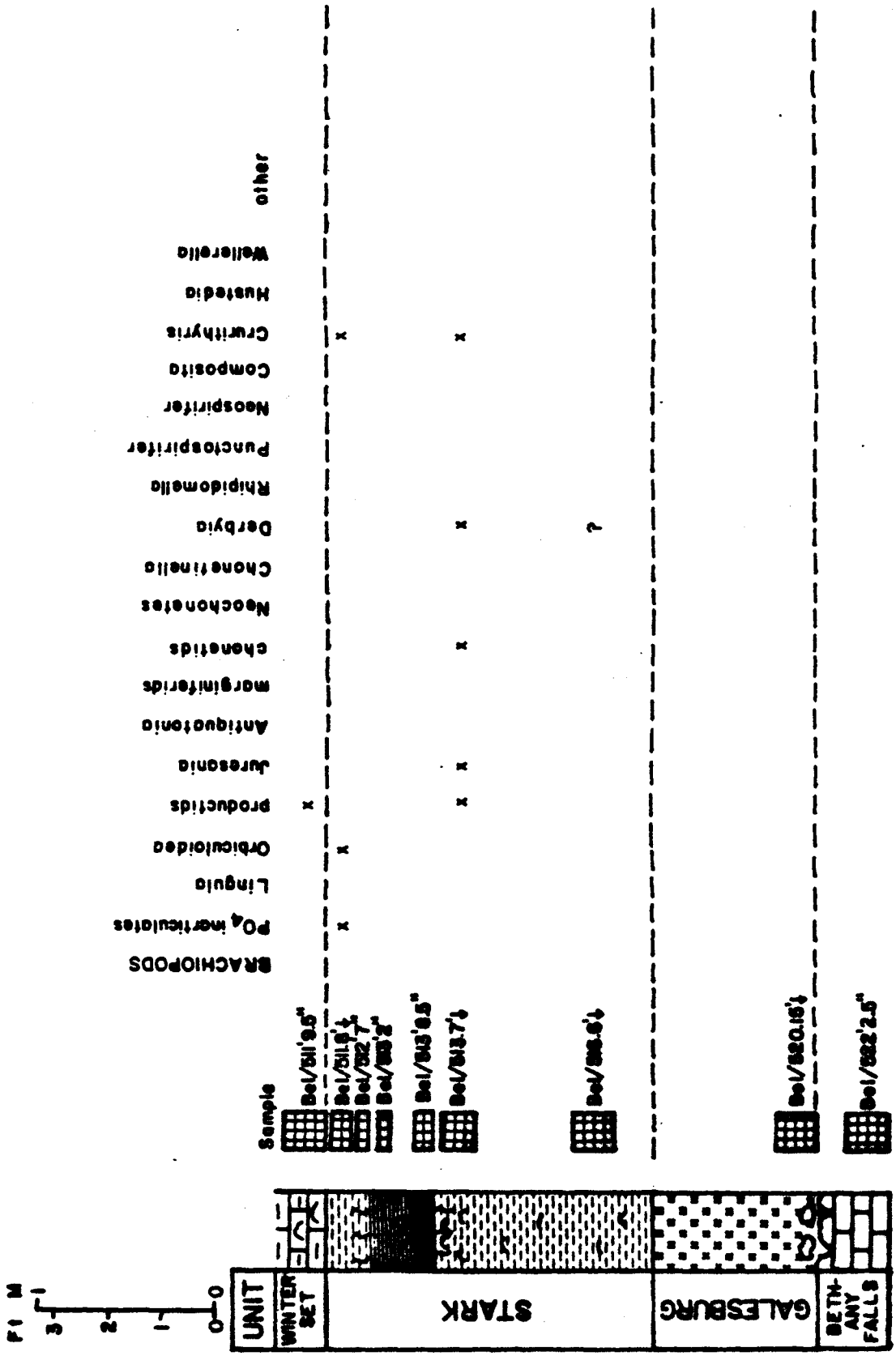
Reference: Heckel, 1980, p.5

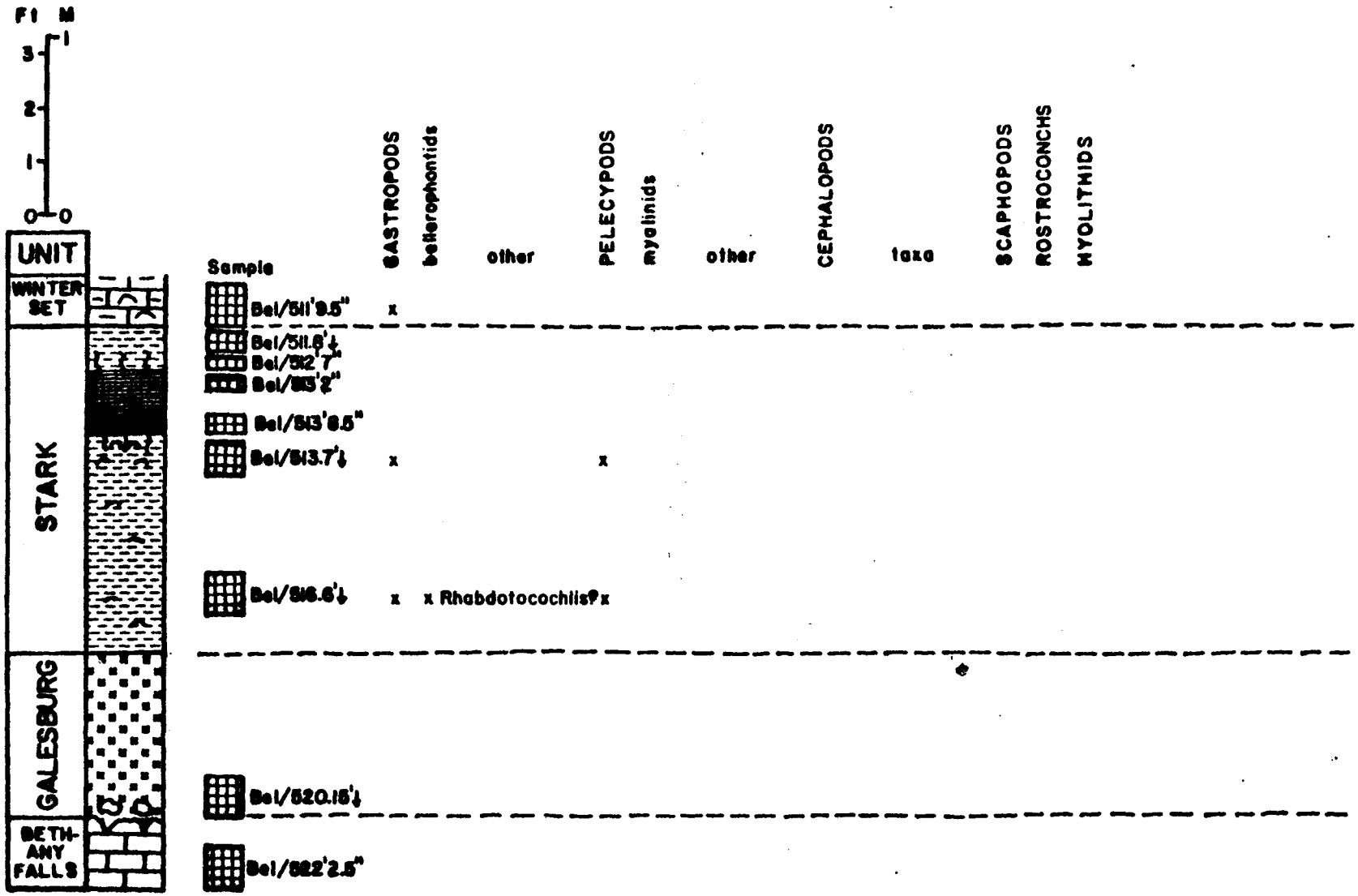
Cored by Iowa Geological Survey

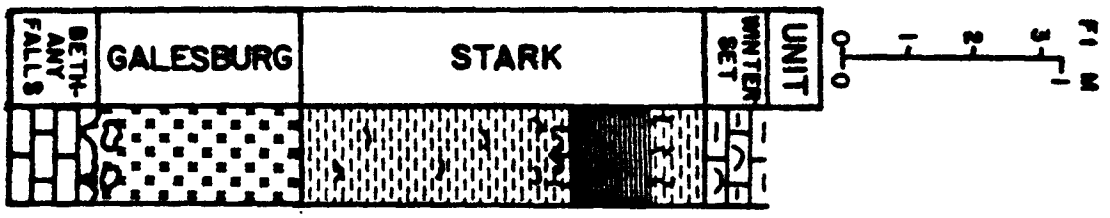


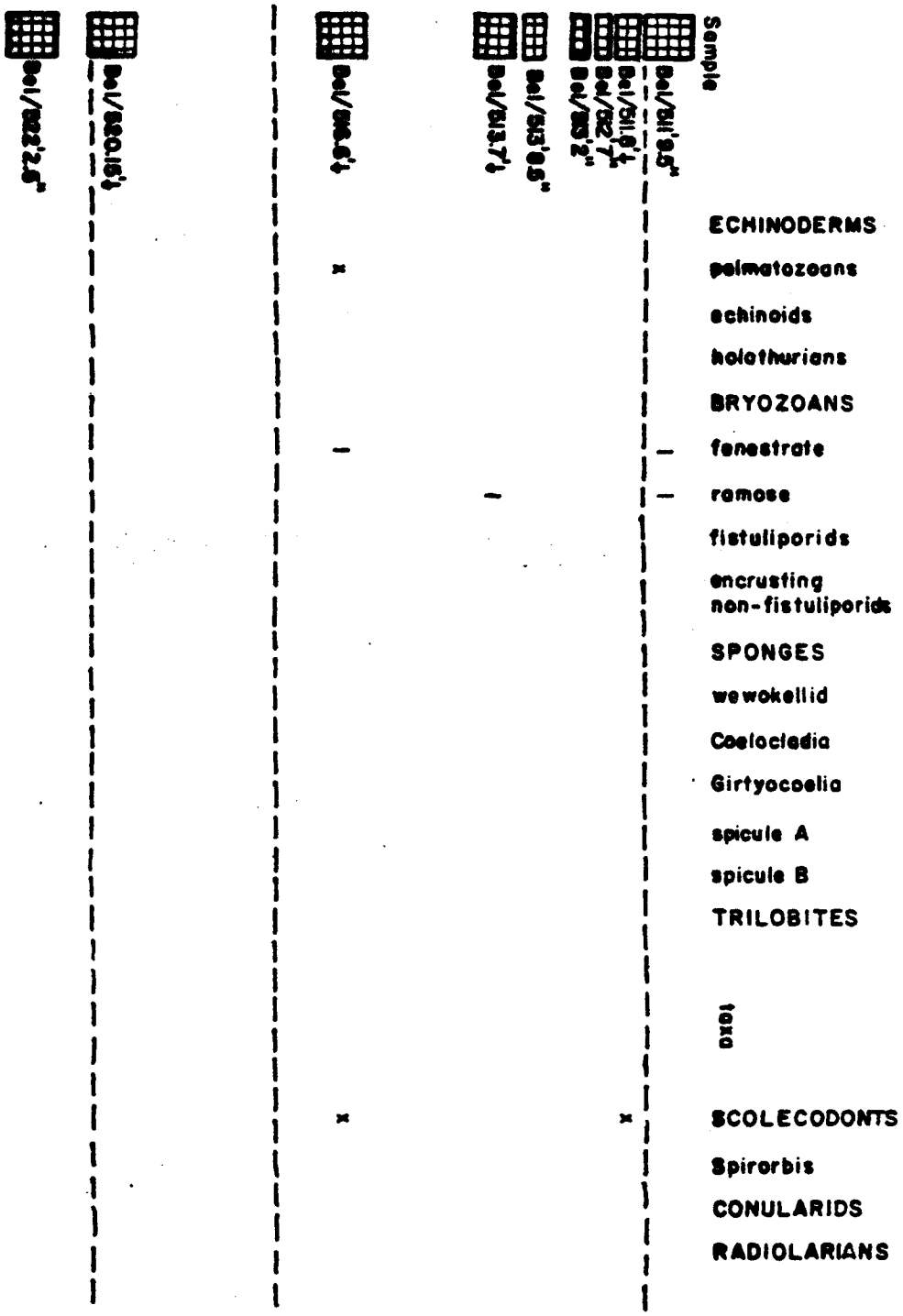

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bel/511'9.5" | 1.70 | 9.5 | 60 | 16 | | 24 | | | x | ? | | .19 | 127 | | | | 95 | 4 | | 1 | | |
| Bel/511.8'↓ | 1.95 | 8.7 | 55 | 25 | | 20 | | | x | | | .22 | 388 | | | | 70 | | | 4 | 27 | |
| Bel/512'7" | 1.57 | 9.2 | 64 | 11 | | 26 | | | | | | .09 | 514 | | | | 61 | | | 6 | 34 | |
| Bel/513'2" | 2.27 | 9.7 | 57 | 28 | | 15 | | | | | | .18 | 499 | | | | 76 | | | 10 | 17 | |
| Bel/513'8.5" | 1.34 | 9.3 | 46 | 39 | | 15 | | | | | | .19 | 440 | | | | 94 | | | 6 | | |
| Bel/513.7'↓ | .94 | 9.3 | 38 | 48 | | 14 | | | x | | | .37 | 74 | 4 | | | 93 | 4 | | | | |
| Bel/516.6'↓ | .83 | 7.6 | 35 | 42 | | 23 | | | | | | | | | | | | | | | | |
| Bel/520.15'↓ | 1.05 | 9.3 | 41 | 34 | | 26 | | | x | | | | | | | | | | | | | |
| Bel/522'2.5" | 1.27 | 9.7 | 46 | 39 | | 15 | | | | | | | | | | | | | | | | |


8.Be I
Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Bel/511'9.5"
Bel/511.6'↓
Bel/512'7"
Bel/513'2"
Bel/513'8.5"
Bel/513.7'↓
Sulcella?
Bel/516.6'↓
Bel/520.15'↓
Bel/522'2.5"


8.Be l
Ft M
3
2
1
0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
Be1/B11'9.6"
Be1/B11.8'4
Be1/B22'7"
Be1/B23'2"
Be1/B43'8.5"
Be1/B43.7'4
Be1/B55.6'4
Be1/B20.15'4
Be1/B22'2.5"
BRACHIOPODS
PO4 ingrticulates
Lingula
Orbiculoidea
productids
juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other

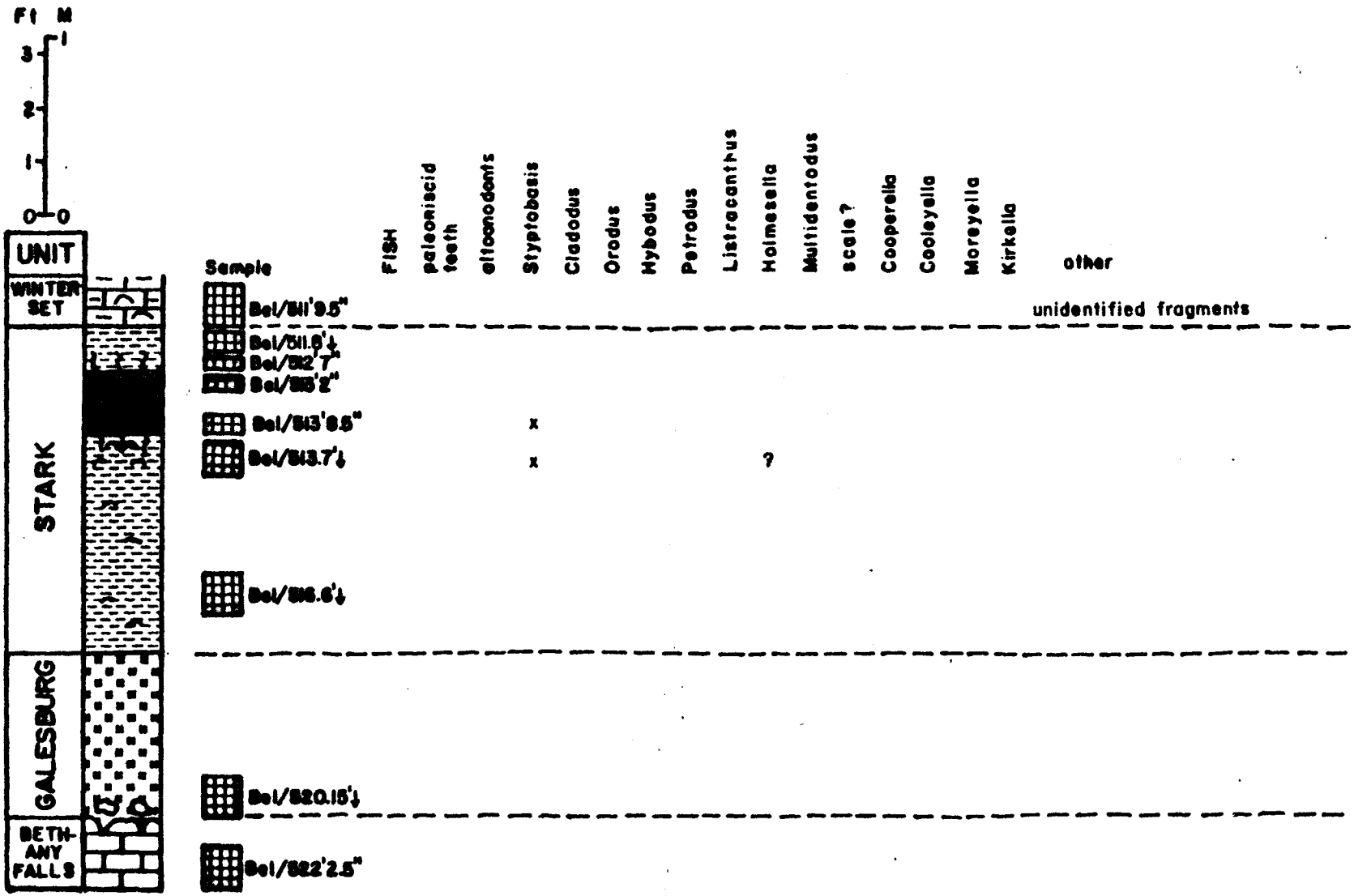

8.Be I
Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
GASTROPODS
heterophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Bel/511'9.5"
Bel/511.8'↓
Bel/512'7"
Bel/515'2"
Bel/513'8.5"
Bel/513.7'↓
Bel/516.6'↓
Bel/520.15'↓
Bel/522'2.5"
x
x
x
x Rhabdotocochilis? x


BETH-ANY FALLS
GALESBURG
STARK
WINTER SET
UNIT
0
1
2
3
FT
M


Sample
Bel/882'2.6"
Bel/880.6'
Bel/883.7'
Bel/883'2"
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
remose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS

8.Bel

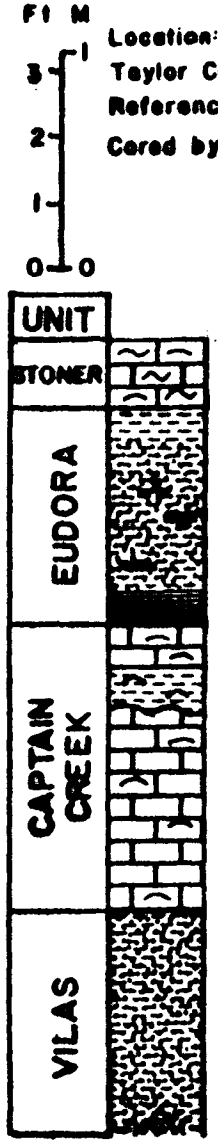
## 8.Bel


FT M
3
2
1
0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
elloanodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Bel/511'9.5"
unidentified fragments
Bel/511.8'↓
Bel/512'1"
Bel/513'2"
Bel/513'8.5"
x
Bel/513.7'↓
x
?
Bel/516.6'↓
Bel/520.15'↓
Bel/522'2.5"

# 8.Bel

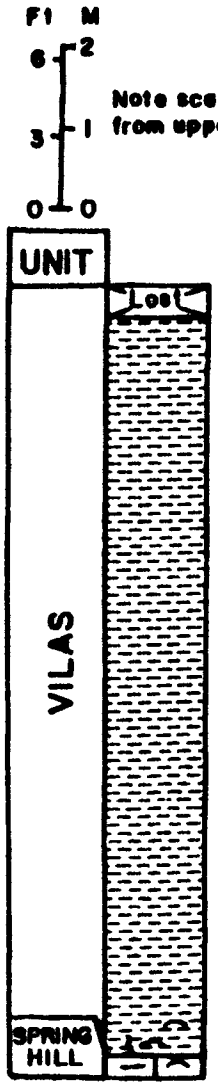
Location: About 2 mi west of Bedford, Iowa
Taylor County, Iowa, map
Reference: Heckel, 1980, p. 5
Cored by Iowa Geological Survey

T67NR34W4SE1/4




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bel/329'10" | 1.51 | 9.2 | 63 | 14 | | 23 | | | x | | | .69 | | 4 | | | 100 | | | | | |
| Bel/330.3' | 1.98 | 9.6 | 62 | 11 | | 27 | | | x | | | .34 | | 80 | | | 96 | 4 | | | | |
| Bel/330.4' | 1.95 | 9.4 | 60 | 15 | | 25 | | | | | | .04 | | 493 | | | 99 | | | 1 | | |
| Bel/332' | 1.93 | 9.5 | 60 | 13 | | 28 | | | | | | .19 | | 73 | | | 100 | | | | | |
| Bel/333'3" | 1.56 | 9.3 | 69 | 10 | | 22 | | | | | | .03 | | 1528 | | | 60 | | | 6 | 34 | |
| Bel/335'11" | 1.89 | 9.1 | 68 | 10 | | 22 | | | x | | | .46 | | 147 | | | 92 | 7 | | 1 | | |
| Bel/336'7" | 1.90 | 9.1 | 50 | 9 | | 24 | 17 | | | | | .87 | | 8 | 57 | | 29 | 14 | | | | |
| Bel/337'7" | 2.03 | 10.0 | 62 | 9 | | 16 | 13 | | | | | | | | | | | | | | | |
| Bel/338'4" | 1.65 | 9.5 | 52 | 16 | | 21 | 11 | x | | | x | .45 | | 34 | 87 | | 13 | | | | | |
| Bel/340'1" | 1.30 | 9.4 | 40 | 28 | | 16 | 15 | x | | | x | .18 | | 386 | 78 | | 21 | 1 | | | | |
| Bel/340.7' | 2.50 | 9.7 | 53 | 2 | | 21 | 24 | x | | | | | | | | | | | | | | |

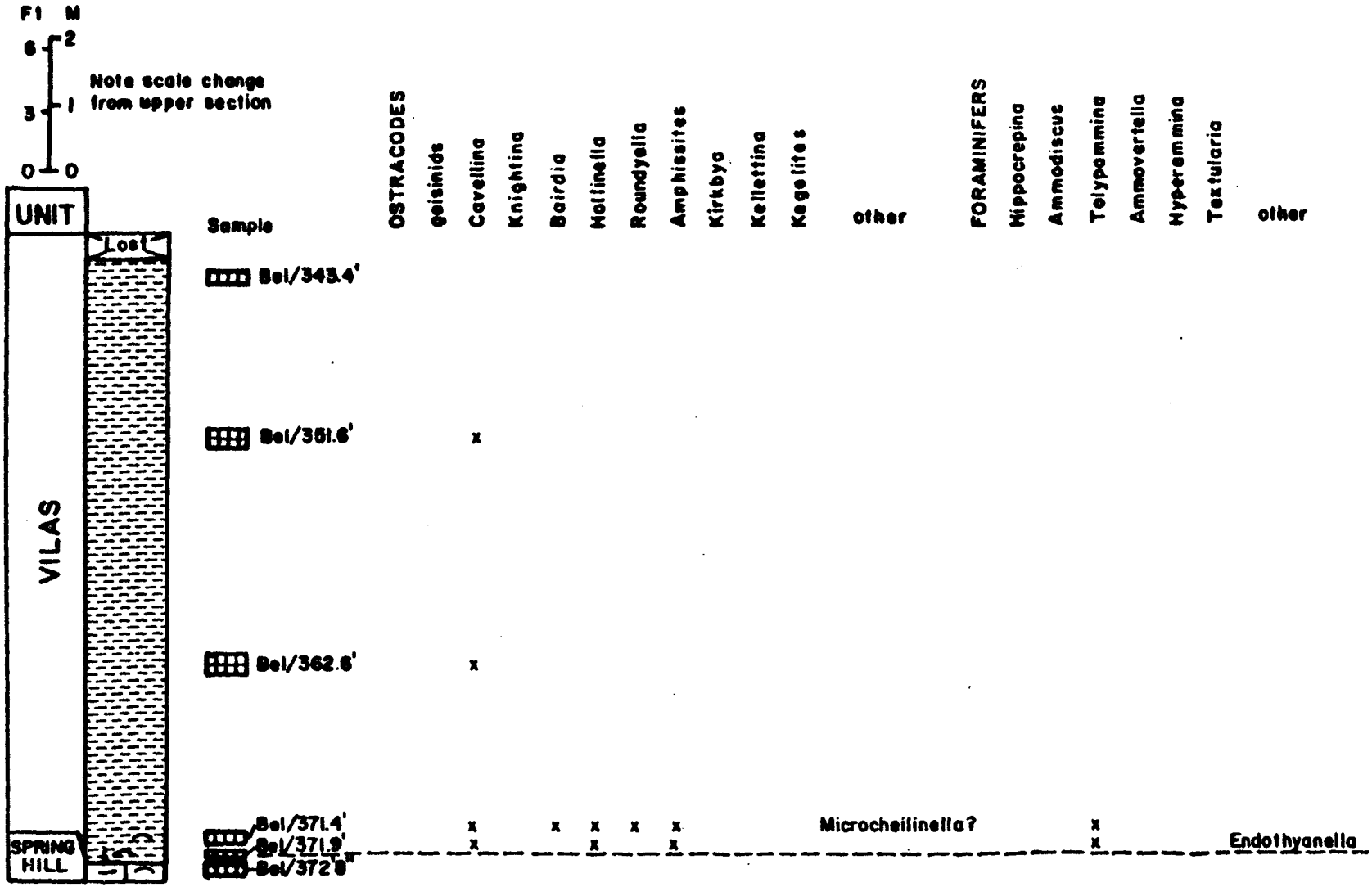
## 8. Bel (cont.)




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bel/343.4' | 2.07 | 9.7 | 51 | 8 | | 27 | 14 | x | | | | .47 | | 11 | 100 | | | | | | | |
| Bel/351.6' | 2.68 | 9.6 | 60 | 8 | | 32 | | x | | | | .65 | | 5 | 100 | | | | | | | |
| Bel/362.6' | 2.84 | 10.0 | 62 | 4 | | 34 | | x | | | | | | | | | | | | | | |
| Bel/371.4' | 2.17 | 9.6 | 55 | 18 | | 27 | | | | | | .15 | 596 | 3 | | 94 | 2 | | | | | |
| Bel/371.9' | 1.79 | 9.7 | 56 | 15 | | 29 | | | | | x | .15 | 877 | 22 | | 76 | 3 | | | | | |
| Bel/372'8" | 2.34 | 10.3 | 71 | 3 | | 26 | | | | | | .64 | 39 | 16 | | 84 | | | | | | |

8.Bel
FI M
3
2
1
0
0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Bel/329'10"
Bel/330.3'
Bel/330.4'
Bel/332'
Bel/333'3"
Bel/333'11"
Bel/335'7"
Bel/337'7"
Bel/338'4"
Bel/340'1"
Bel/340.7'
Bythocypris?
Bairdiacypris
Ammodiscella

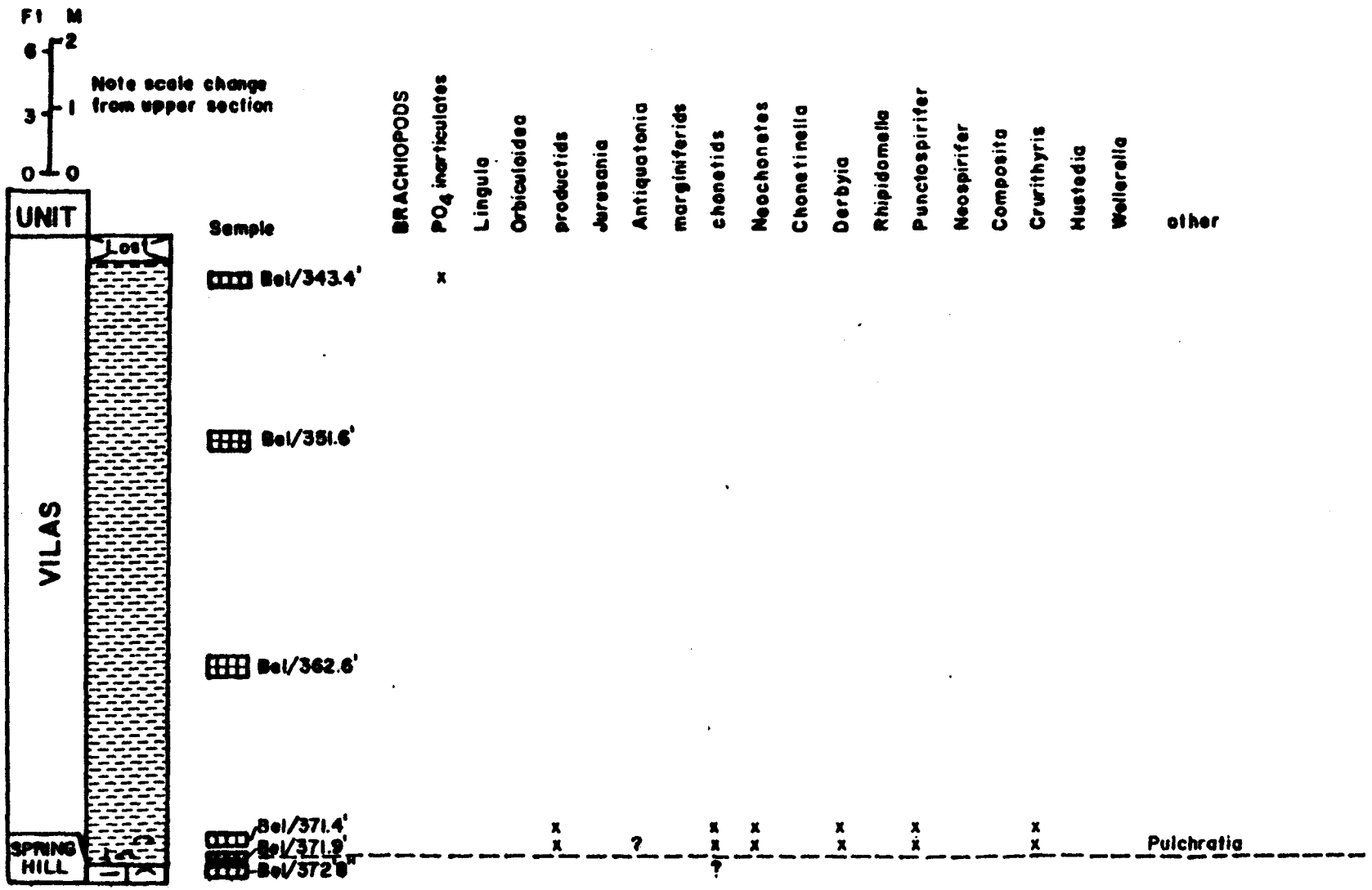
## 8. Bel (cont.)

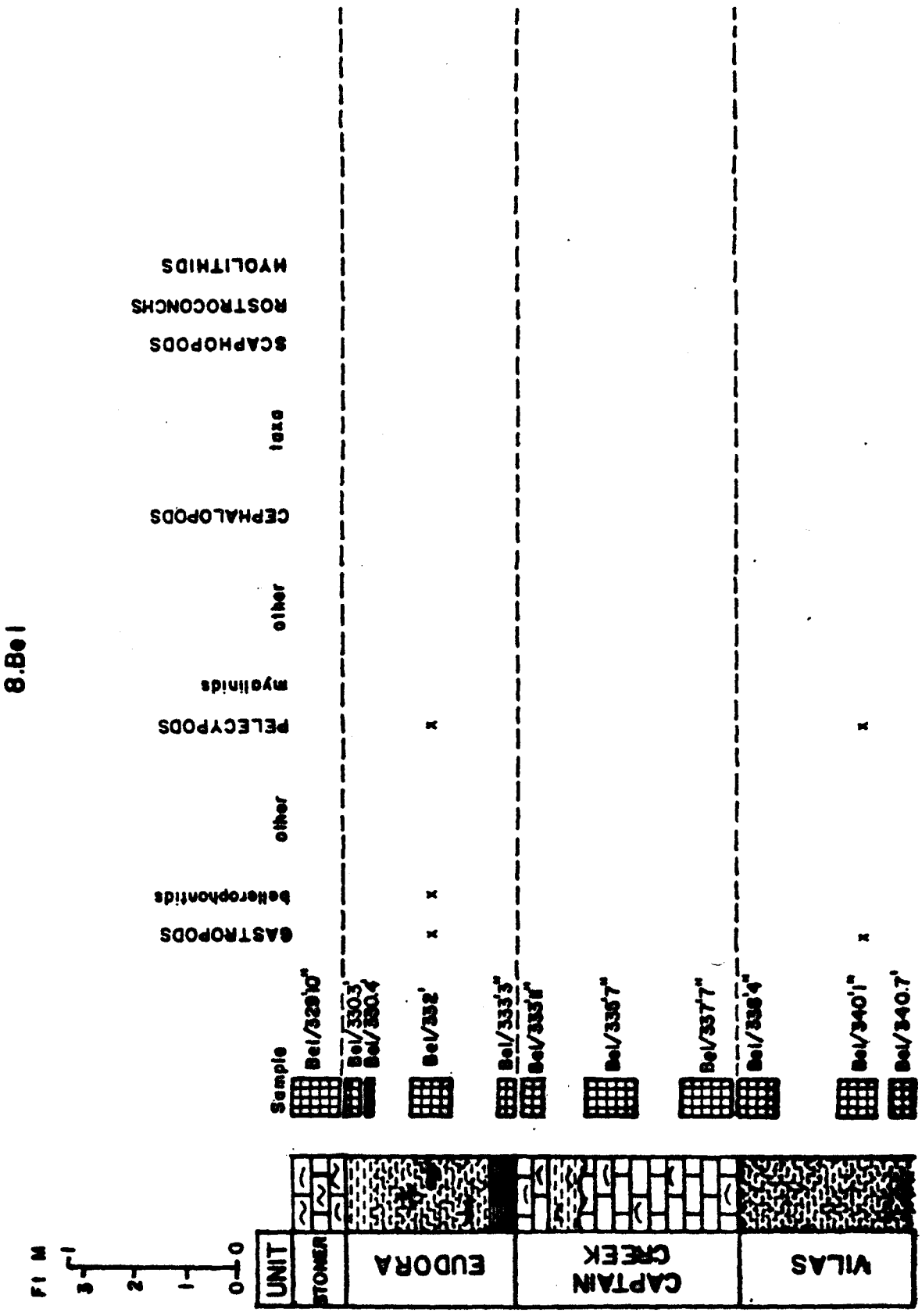

Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
VILAS
SPRING HILL
Loss
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Bel/343.4'
Bel/351.6'
Bel/362.6'
Bel/371.4'
Bel/371.9'
Bel/372.8'
Microcheilinella?
Endothyanella

## 8.Bel

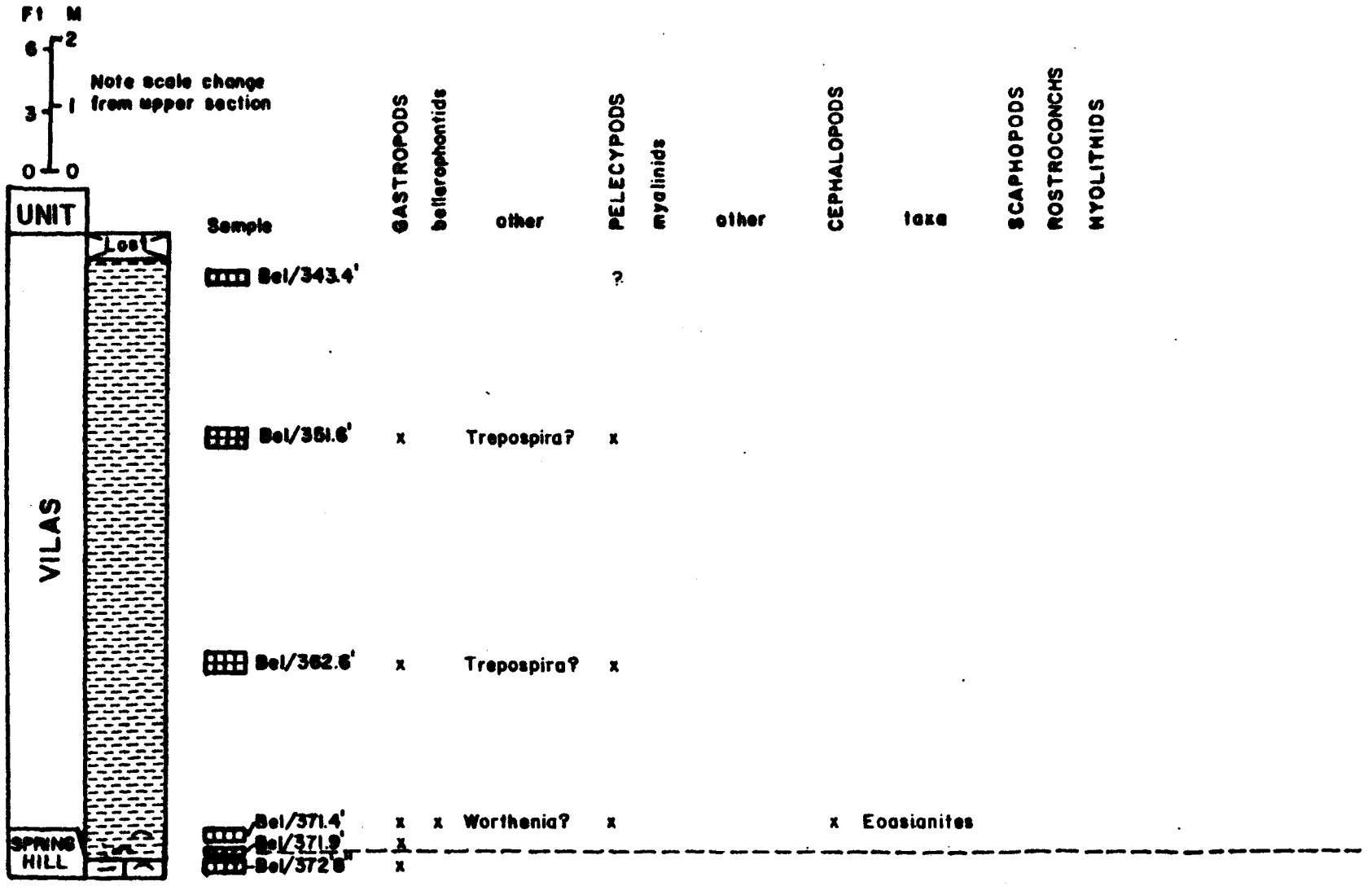

Ft M
5 1
4
3
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Entelates?
Bel/328'10"
Bel/330.3'
Bel/330.4'
Bel/332'
Bel/333'3"
Bel/333'8"
Bel/336'7"
Bel/337'7"
Bel/338'4"
Bel/340'1"
Bel/340.7'

## 8. Bel (cont.)


Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
VILAS
SPRING HILL
Lost
Sample
Bel/343.4'
Bel/351.6'
Bel/362.6'
Bel/371.4'
Bel/371.9'
Bel/372.8'
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Pulchratia


8.Bel
Sample
Bel/329'10"
Bel/330.3'
Bel/330.4'
Bel/332'
Bel/333'3"
Bel/333'11"
Bel/336'7"
Bel/337'7"
Bel/338'4"
Bel/340'1"
Bel/340.7'
GASTROPODS
heterophontids
other
PELECYPODS
myaliniids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
FT M
3 1
2
1
0

## 8. Bel (cont.)

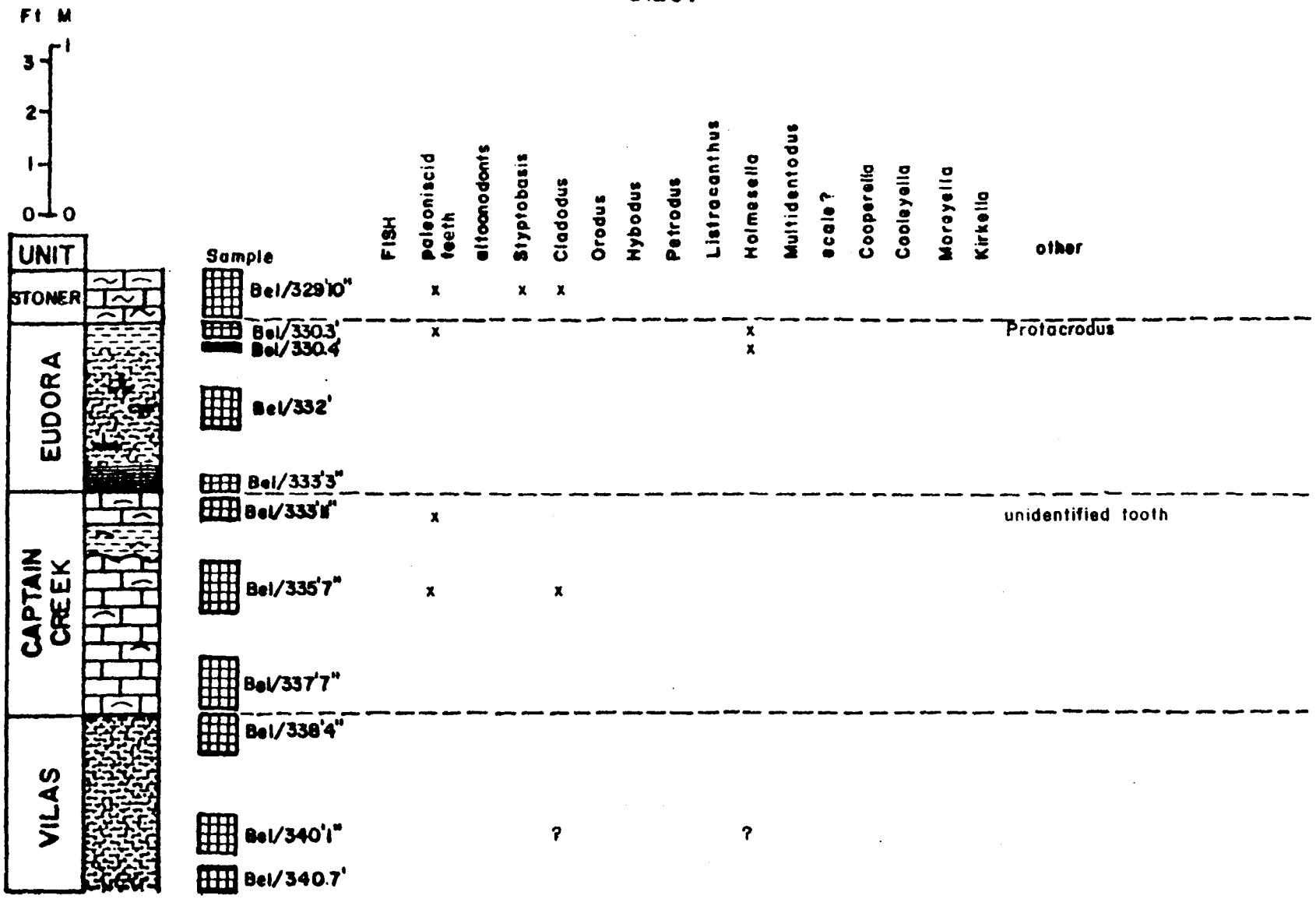

Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
VILAS
SPRING HILL
Loss
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Bel/343.4'
?
Bel/351.6'
x
Trepospira?
x
Bel/362.6'
x
Trepospira?
x
Bel/371.4'
x
x
Worthenia?
x
x
Eoasianites
Bel/371.9'
x
Bel/372.6'
x

## S.Bel

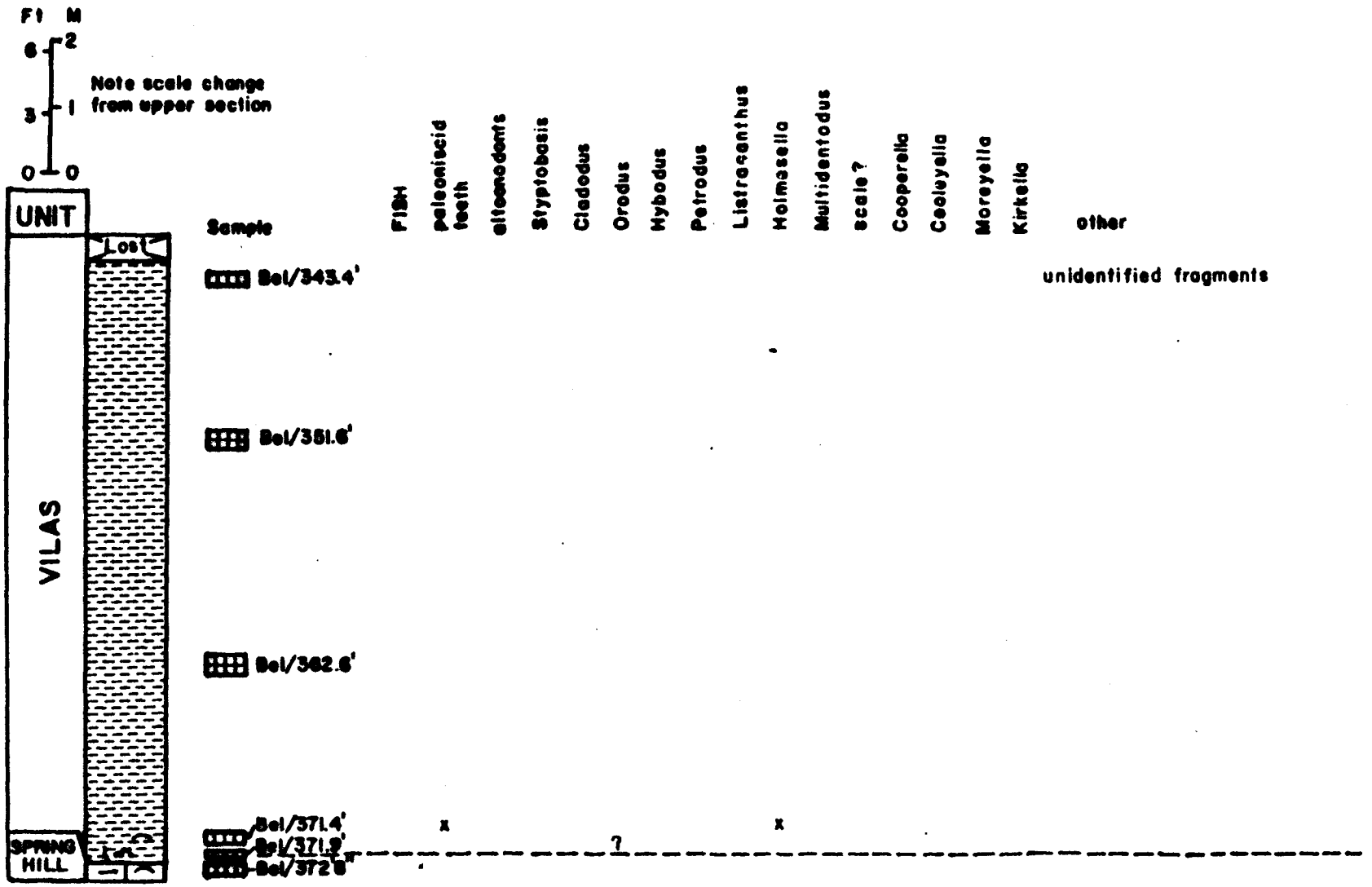

FT M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
Bel/329'10"
Bel/330'3"
Bel/330'4"
Bel/332'
Bel/333'3"
Bel/333'11"
Bel/335'7"
Bel/337'7"
Bel/338'4"
Bel/340'1"
Bel/340'7"
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS

## 8. Bel (cont.)


Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
VILAS
SPRING HILL
Sample
Bel/343.4'
Bel/361.6'
Bel/382.6'
Bel/371.4'
Bel/371.9'
Bel/372.8'
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicula B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS

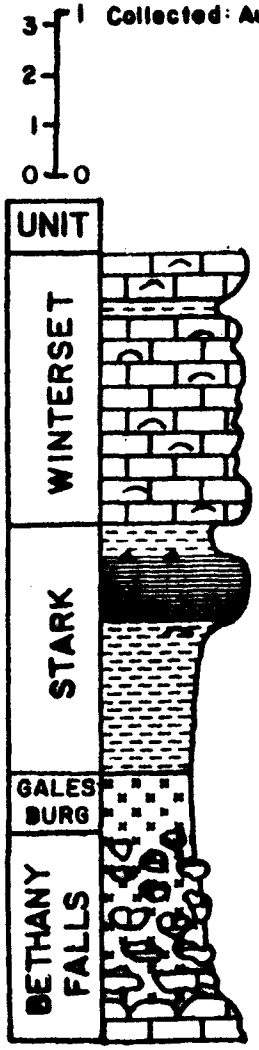

8.Bel
Ft M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
FISH
paleoniscid teeth
allocanodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Morayella
Kirkella
other
Bel/329'10"
Bel/330.3'
Bel/330.4'
Bel/332'
Bel/333'3"
Bel/333'11"
Bel/335'7"
Bel/337'7"
Bel/338'4"
Bel/340'1"
Bel/340.7'
Protacrodus
unidentified tooth

## 8. Bel (cont.)


Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
VILAS
SPRING HILL
Lost
Sample
FISH
paleoniscid teeth
eugnathodonts
Stypobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Coeleyella
Moreyella
Kirkella
other
unidentified fragments
Bel/343.4'
Bel/351.6'
Bel/362.6'
Bel/371.4'
Bel/371.9'
Bel/372.8'
x
x
?

# 9.Br I

Location: Farmer's Stone Products quarry, 3 mi west and 1/2 mi north of Breckenridge, Missouri
Caldwell County, Missouri, map T57NR26W6SWI/4SWI/4SWI/4
Collected: August 11, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Br I/wp | 1.66 | 9.8 | 62 | 16 | | 22 | | | x | | | .16 | 469 | 1 | | 95 | 3 | | 1 | | | |
| Br I/w | 2.06 | 9.2 | 74 | 9 | | 17 | | | | | | .99 | 1 | | | 100 | | | | | | |
| Br I/66 | 1.41 | 9.8 | 63 | 31 | | 7 | | | | | | .10 | 696 | | | 46 | | | | 5 | 50 | |
| Br I/65 | 1.33 | 9.6 | 78 | | | 22 | | | | | | .09 | 353 | | | 60 | | | | 7 | 33 | |
| Br I/86 | 1.83 | 9.2 | 76 | 12 | | 13 | | | | | | .51 | 484 | | | 91 | | | | 9 | | |
| Br I/49 | 1.06 | 9.6 | 45 | 51 | | 4 | | | | | | .46 | 358 | 6 | | 89 | 4 | | | 1 | | |
| Br I/40 | .83 | 8.7 | 54 | 46 | | | | | | | ? | | | | | | | | | | | |
| Br I/5 | .88 | 9.1 | 64 | 36 | | | | | | | | | | | | | | | | | | |
| Br I/0 | 1.49 | 9.7 | 84 | 16 | | | | | | | | | | | | | | | | | | |
| Br I/bf | .99 | 9.1 | 58 | 33 | | 9 | | | | | | | | | | | | | | | | |

# 9.Br I




| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Br I/wp | | | | | | | | | | | | | | | | | | | | |
| Br I/w | | | | | | | | | | | | | | | x | | x | | | |
| Br I/65 | | | | | | | | | | | | | x | x | x | | | | | |
| Br I/49 | | | | | | | | | | | | | | x | x | | x | | | |
| Br I/40 | x | | | | | | | | | | | | | | | | | | | |
| Br I/5 | | | | | | | | | | | | | | | | | | | | |
| Br I/0 | | | | | | | | | | | | | | | | | | | | |
| Br I/bf | | | | | | | | | | | | | | | | | | | | |

## 9.Br I


FI M
3 1
2
1
0 0
UNIT
WINTERSET
STARK
GALESBURG
BETHANY FALLS
Sample
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Br I/wp
Br I/w
Br I/68
Br I/65
Br I/58
Br I/49
Br I/40
Br I/15
Br I/0
Br I/bf
Streptorhynchus

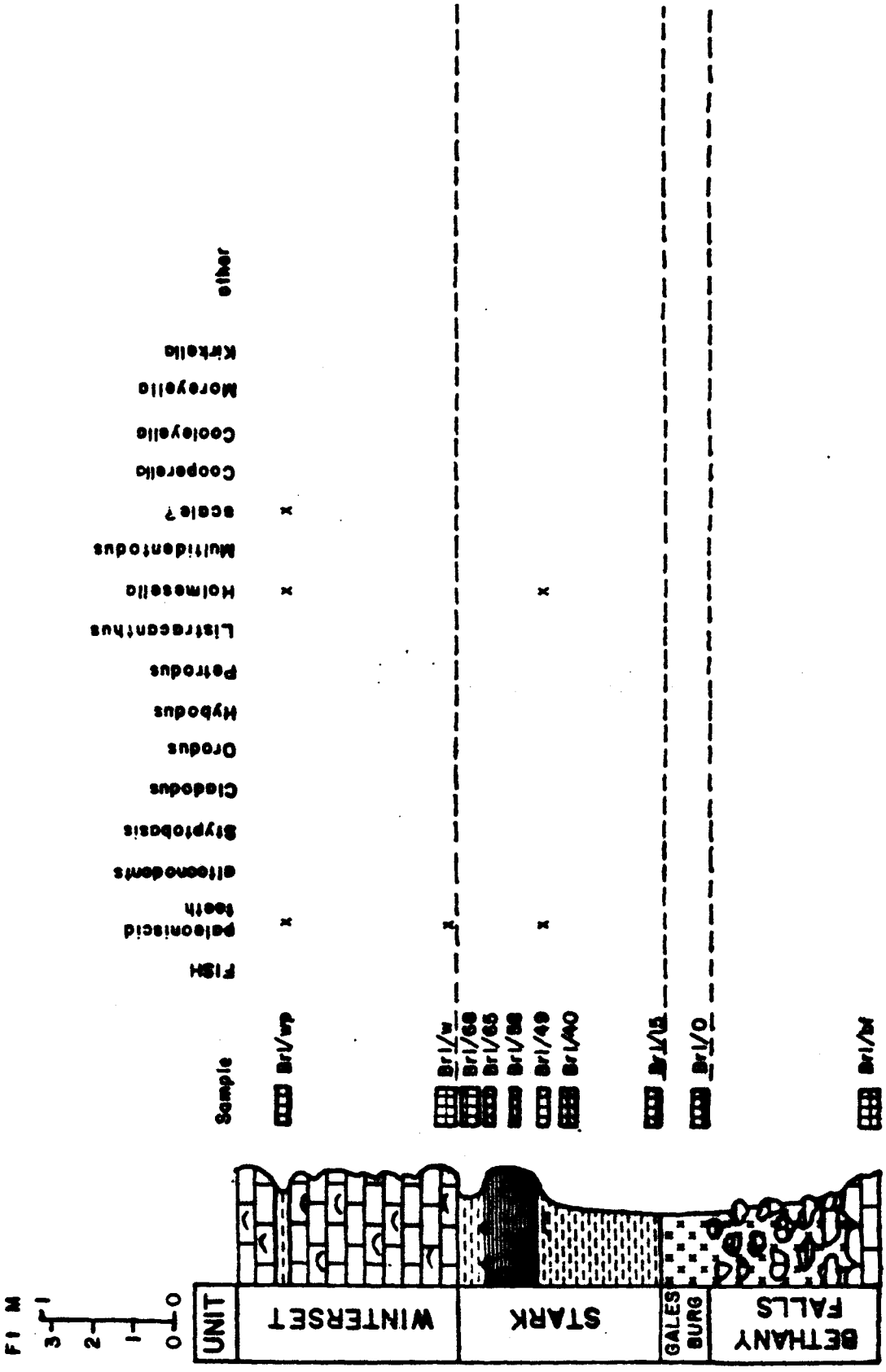
# 9.Br I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | MYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Br I/wp | x | x | | x | | | x | ammonoid | | | |
| Br I/w | | | | | | | | | | | |
| Br I/68 | | | | | | | | | | | |
| Br I/65 | | | | | | | | | | | |
| Br I/56 | | | | | | | | | | | |
| Br I/49 | | | | | | | | | | | |
| Br I/40 | x | | | | | | | | | | |
| Br I/15 | | | | | | | | | | | |
| Br I/0 | x | | | | | | | | | | |
| Br I/bf | | | | | | | | | | | |

## 9.Br I


FI M
3 1
2
1
0 0
UNIT
WINTERSET
STARK
GALESBURG
BETHANY FALLS
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Br1/wp
Br1/w
Br1/68
Br1/65
Br1/56
Br1/49
Br1/40
Br1/15
Br1/0
Br1/bf
x
2
1


9.Br I
Sample
Br1/wp
Br1/w
Br1/68
Br1/65
Br1/58
Br1/49
Br1/40
Br1/15
Br1/0
Br1/bf
FISH
paleoniscid tooth
x
x
x

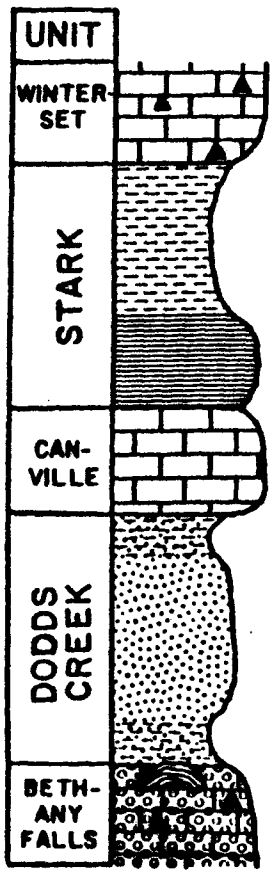
# 10.Bro 1

Location: Quarry 2 mi south and 3/4 mi east of Bronson, Kansas

Moran SE, Kansas, 7 1/2'  T25SR22E24NE1/4NW1/4NW1/4

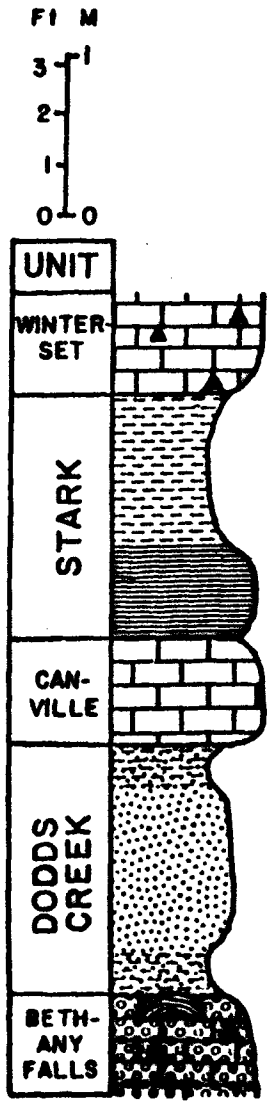
References: Kans. Geol. Soc., 1932, Stop II, p.25-26; Dimitracopoulos, 1979 (Note: Description by Newell for measured section, as everything but the top of the Bethany Falls now covered)

Collected: August 7, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Asthotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brol/bf | | | | | | | | | | | x | 2.00 | | 3 100 | | | | | | | | |

## 10.Bro I

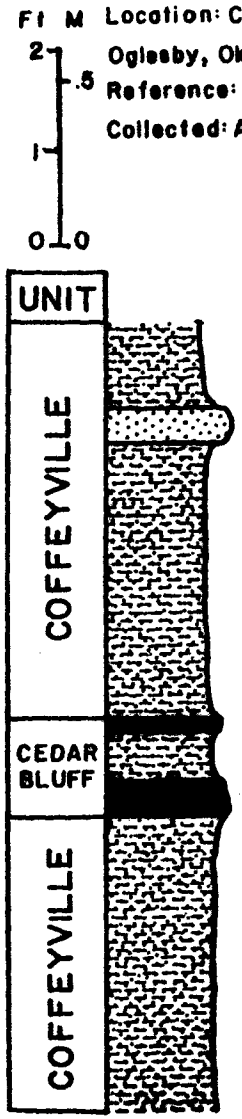



| Sample | FORAMINIFERS | | | | | | | other | CEPHALOPODS | taxa |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | | | |
| Brol/bf | | | | x | | | | | | Grab sample lower in oolite yielded Eoasianites, pseudorthocerid |

## II.Bt I

Location: Creek bank 12 mi east of Bartlesville, Oklahoma
Ogleeby, Oklahoma, 7 1/2'
Reference: Bloesch, 1930, v.3, p.357-358
Collected: August 9, 1979

T26NR14E16NE1/4NE1/4NE1/4



# 12.Bt 2

Ft M

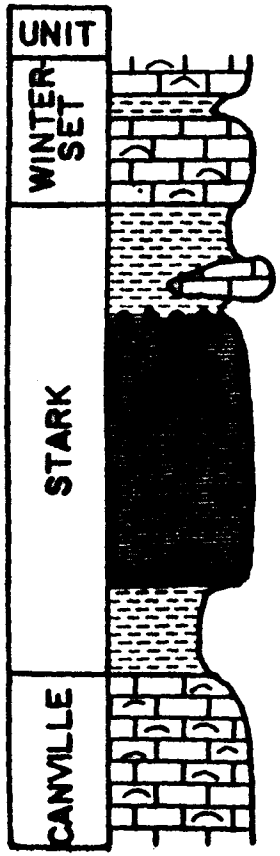
.5 Location: Road cut on county road, 1 mi south and .2 mi east of Hogshooter, Oklahoma
Ogiesby, Oklahoma, 7 1/2' T25NR14EGNE1/4 NW1/4NE1/4

1

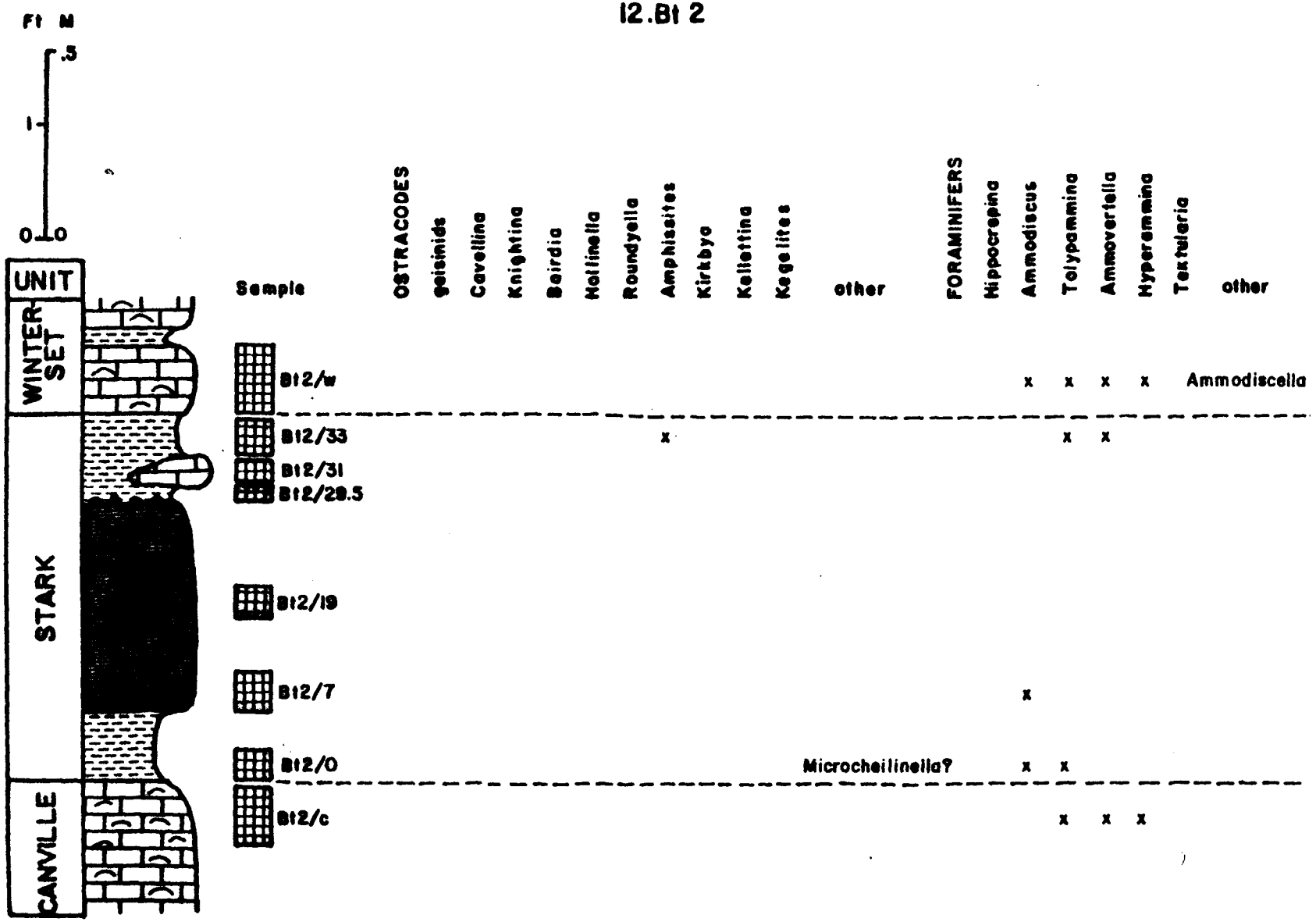
References: Hansen, 1957, sect. 12, p. 160-162; Cronoble and Mankin, 1965, sect. 3, p. 98, 105-106

Collected: August 9, 1979

0



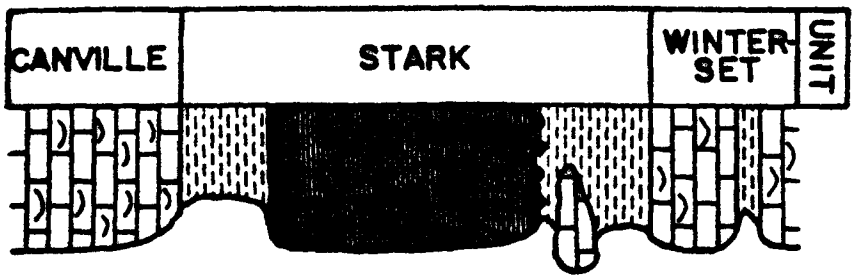

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Bondiella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B12/w | 1.44 | 8.9 | 58 | 31 | | 12 | | x | | | | 1.00 | | 9 | | | 100 | | | | | |
| B12/33 | | 9.2 | 38 | 27 | | | 34 | x | | | | .22 | | 688 | | | 97 | | | 1 | 2 | |
| B12/31 | | | | | | | | | | | | .99 | | 10 | | | 82 | | | 18 | | |
| B12/29.5 | 1.37 | 9.4 | 56 | 44 | | | | x | | | | .04 | | 5330 | | | 97 | | | 2 | 1 | |
| B12/19 | 1.24 | 8.8 | 73 | 27 | | | | | | | | .30 | | 97 | | | 95 | | | 5 | | |
| B12/7 | 1.41 | 9.2 | 68 | 32 | | | | x | | | | .73 | | 184 | | | 97 | | | 2 | 2 | |
| B12/0 | 1.23 | 9.0 | 51 | 41 | | 6 | 2 | x | | | | .30 | | 205 | | | 98 | | | | 2 | |
| B12/c | 1.30 | 9.8 | 54 | 46 | | | | x | | | | .73 | | 15 | | | 64 | 36 | | | | |


12.Bt 2
Ft M
3
1
0 0
UNIT
WINTER SET
STARK
CANVILLE
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphisites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Bt2/w
Bt2/33
Bt2/31
Bt2/29.5
Bt2/19
Bt2/7
Bt2/0
Bt2/c
Microcheilinella?
Ammodiscella

12.Bt 2
Ft M
.5
1
0 0
UNIT
WINTER SET
STARK
CANYILLE
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
B12/w
B12/33
B12/31
B12/29.5
B12/19
B12/7
B12/0
B12/c

12.Bt 2


Ft M
.5
1
0 0
UNIT
WINTER SET
STARK
CANVILLE
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Bt2/w
Bt2/33
Bt2/31
Bt2/29.5
Bt2/19
Bt2/7
Bt2/0
Bt2/c
x
x
?
x
x




| taxa | B12/e | B12/0 | B12/7 | B12/19 | B12/23.5 | B12/31 | B12/33 | B12/w |
|---|---|---|---|---|---|---|---|---|
| ECHINODERMS | | | | | | | | |
| pelmatozoans | | x | | | x | | x | |
| echinoids | | | | | | | | |
| holothurians | | | | | | | | |
| BRYOZOANS | | | | | | | | |
| fenestrate | | – | | | – | | 2 | |
| remose | | – | | | | | – | |
| fistuliporids | | | | | | | x | |
| encrusting non-fistuliporids | | | | | | | – | |
| SPONGES | | x | | | | | x | x |
| wewokellid | | | | | | | x | |
| Coelocladia | | | | | | | | |
| Girtyocoelia | | | | | | | | |
| spicule A | | | | | | | | |
| spicule B | | | | | | | | x |
| TRILOBITES | | | | | | | | |
| SCOLECODONTS | | | | | | | | |
| Spirorbis | | | | | | | | |
| CONULARIDS | | | | | | | | |
| RADIOLARIANS | | | | | | | | |

Sample

12.Bt 2

12.Bt 2
Ft M
.5
1
0
0
UNIT
WINTER-SET
STARK
CANVILLE
Sample
FISH
paleoniscid teeth
ctenomdonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Bt2/w
Bt2/33
Bt2/31
Bt2/29.5
Bt2/19
Bt2/7
Bt2/0
Bt2/c
unidentified fragments

13.By I

Ft M

.5 Location: Quarry I mi north of Bethany, Missouri

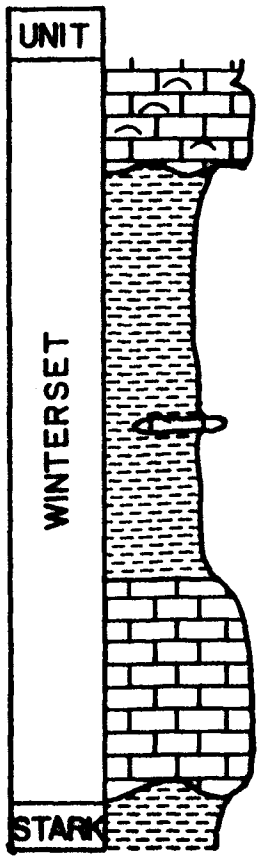
Harrison County, Missouri, map

T63NR28W2NEI/4NEI/4

Reference: Lamerson, 1956, Sect. 31, p. 123

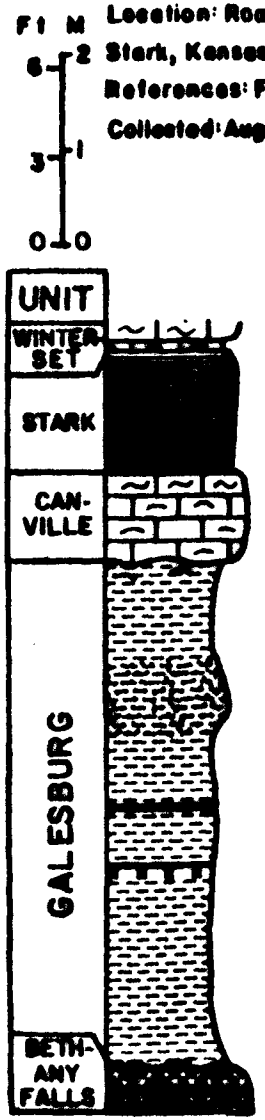
1 Collected: October 26, 1980

0 0

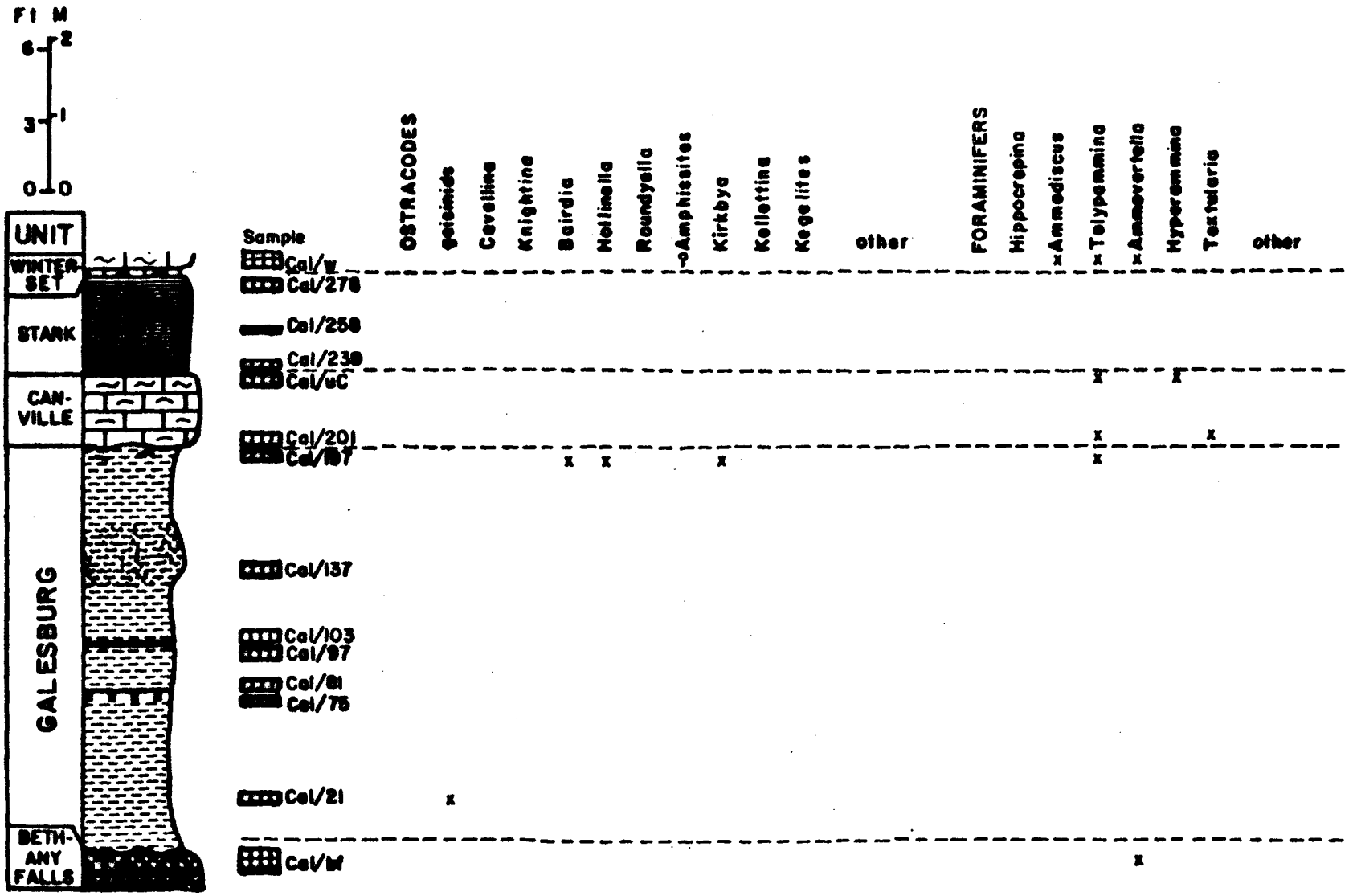


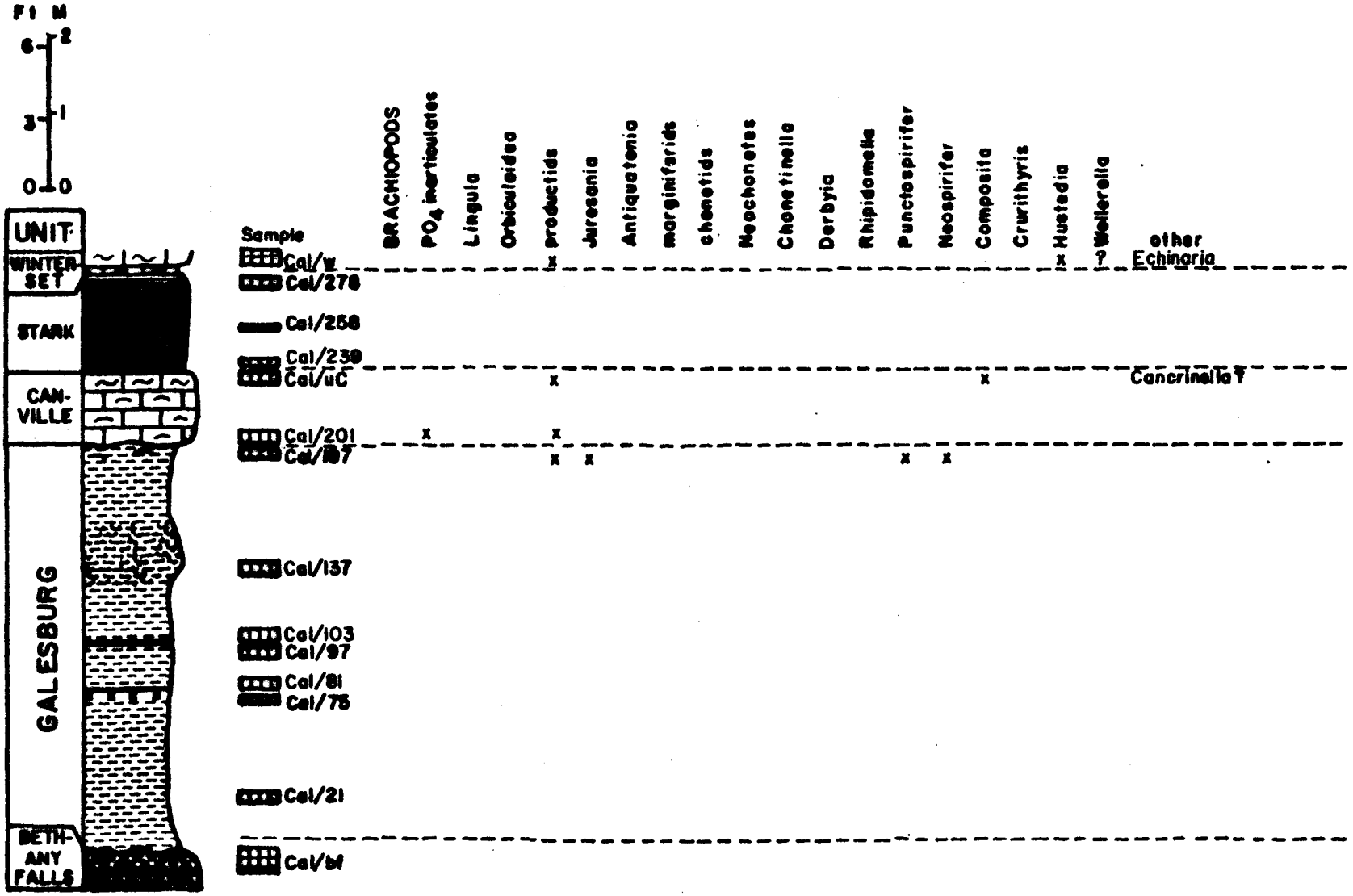
# 14. Ca I

Location: Road cut on US Highway 59 near bridge over Canville Creek
Stark, Kansas, 7 1/2'
T27SR20E23NW1/4NW1/4NW1/4
References: Frest, 1968, Lec. 33, p. 155-157; Heckel, et al., 1979, Stop 4, p.26-27
Collected: August 17, 1978

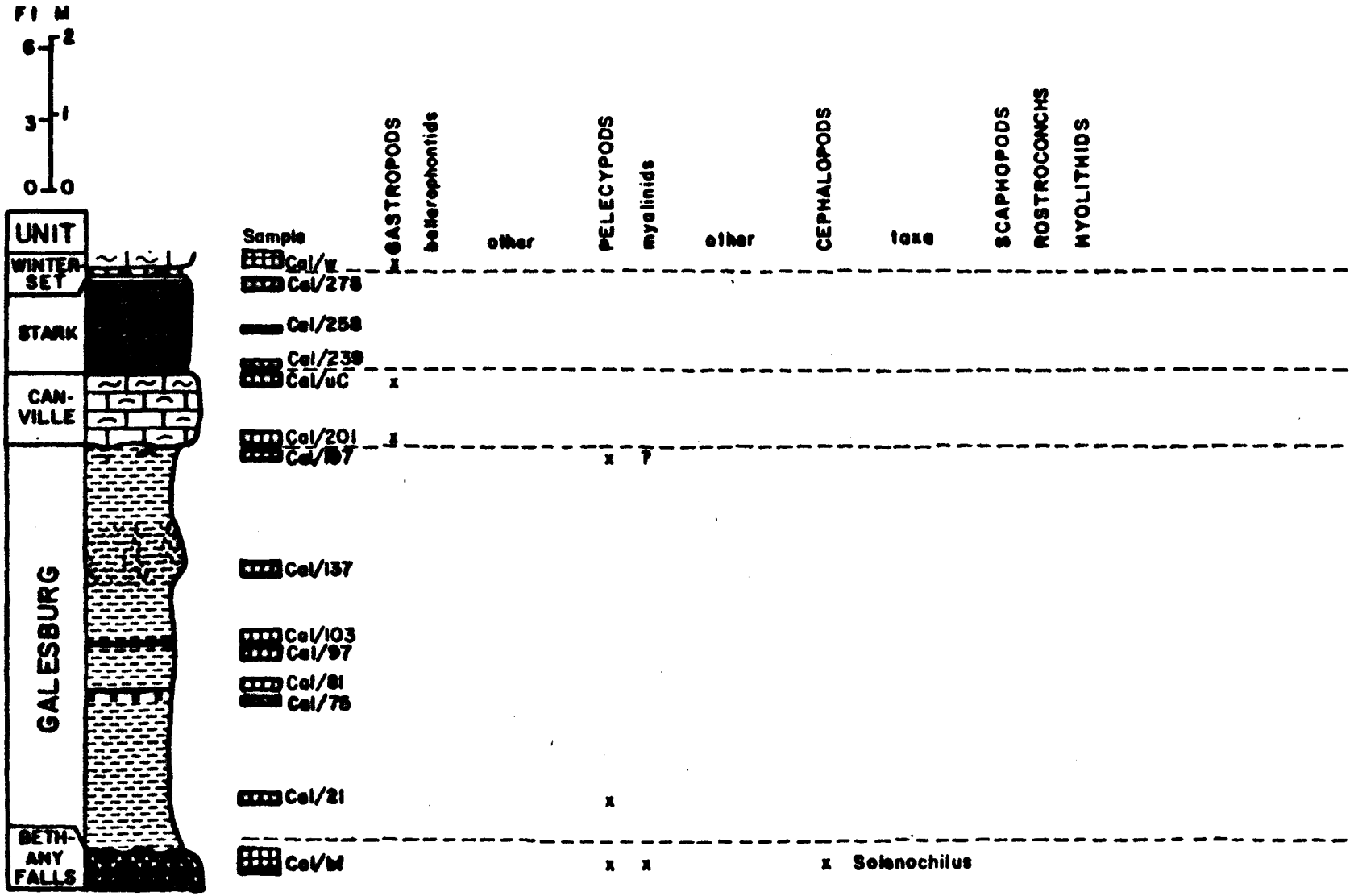


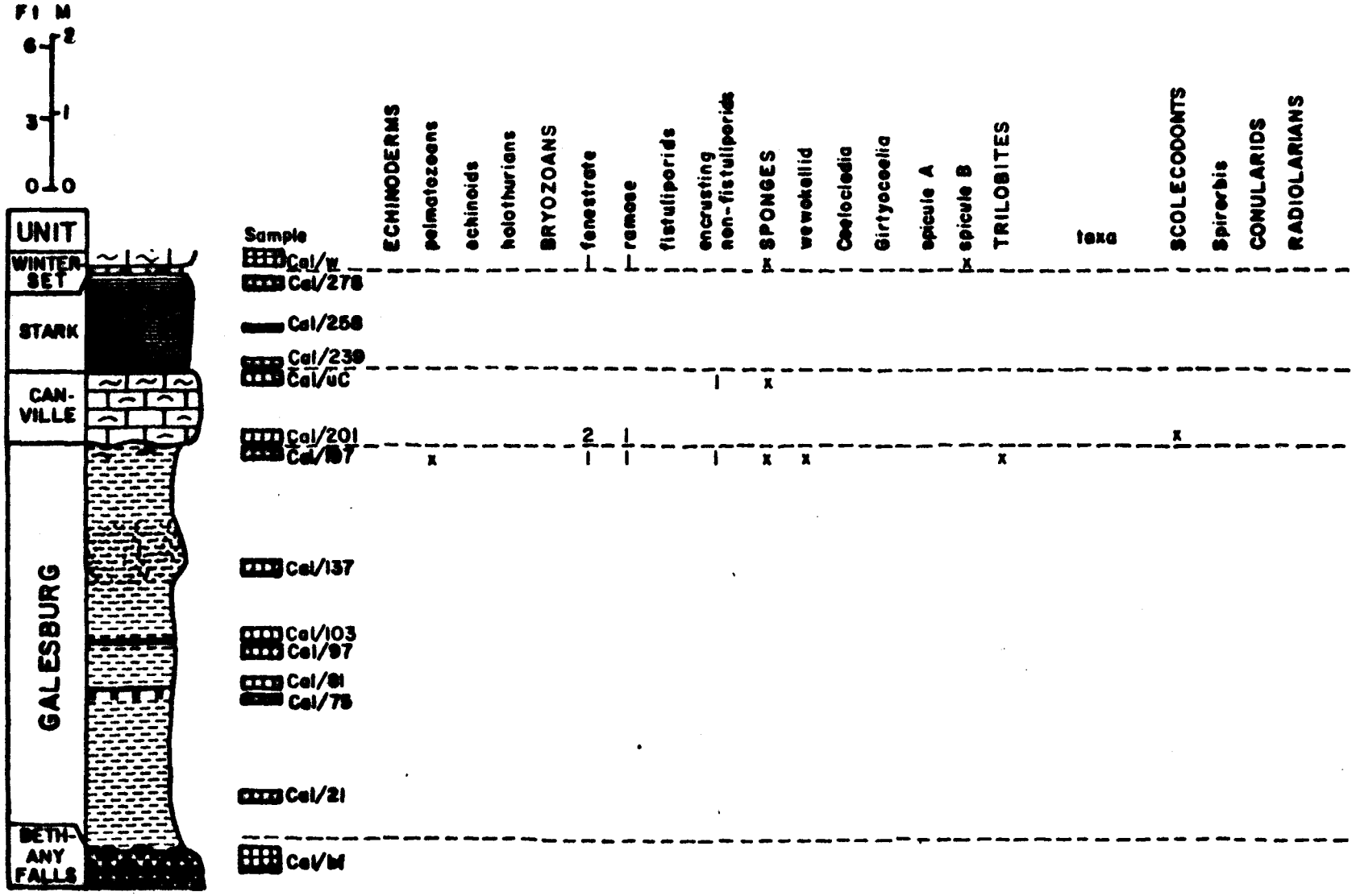

| Sample | White crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | =% Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cal/W | 2.00 | 9.0 | 60 | 41 | | | | | | | | .88 | | 61 | 2 | | 80 | | | 3 | 4 | |
| Cal/278 | 1.21 | 8.3 | 47 | 53 | | | | | | | | .08 | | 254 | | | 71 | | | 4 | 25 | |
| Cal/258 | | | | | | | | | | | | .38 | | 21 | | | 90 | | | 10 | | |
| Cal/239 | 1.29 | 7.0 | 52 | 48 | | | | | | | | .61 | | 574 | | | 96 | t | | 3 | t | |
| Cal/uC | 1.52 | 8.9 | 58 | 28 | | 14 | | | | | | 2.02 | | 18 | 35 | 3 | 54 | 8 | | | | |
| Cal/201 | .84 | 9.2 | 43 | 60 | | 8 | | x | | | | 1.00 | | 46 | 71 | 2 | 17 | 9 | | | | |
| Cal/187 | 1.05 | 8.4 | 43 | 47 | | 7 | 3 | x | x | | | .90 | | 54 | 69 | | 19 | 13 | | | | |
| Cal/137 | 10.9 | 9.3 | 40 | 8 | | 11 | 40 | x | | | | | | | | s | | | | | | |
| Cal/103 | 1.61 | 9.2 | 38 | 23 | | 11 | 28 | x | | | | | | | | | | | | | | |
| Cal/97 | 1.79 | 9.3 | 36 | 18 | | 16 | 30 | x | | | | | | | | | | | | | | |
| Cal/81 | 1.90 | 10.1 | 40 | 21 | | 18 | 21 | x | | | | | | | | | | | | | | |
| Cal/75 | 1.81 | 10.2 | 45 | 13 | | 13 | 29 | x | | | | | | | | | | | | | | |
| Cal/21 | 1.29 | 9.5 | 42 | 37 | | 10 | 12 | x | | | | .76 | | 1 | | | 100 | | | | | |
| Cal/bf | 1.84 | 9.0 | 51 | 16 | | | 33 | | | | | | | | | | | | | | | |

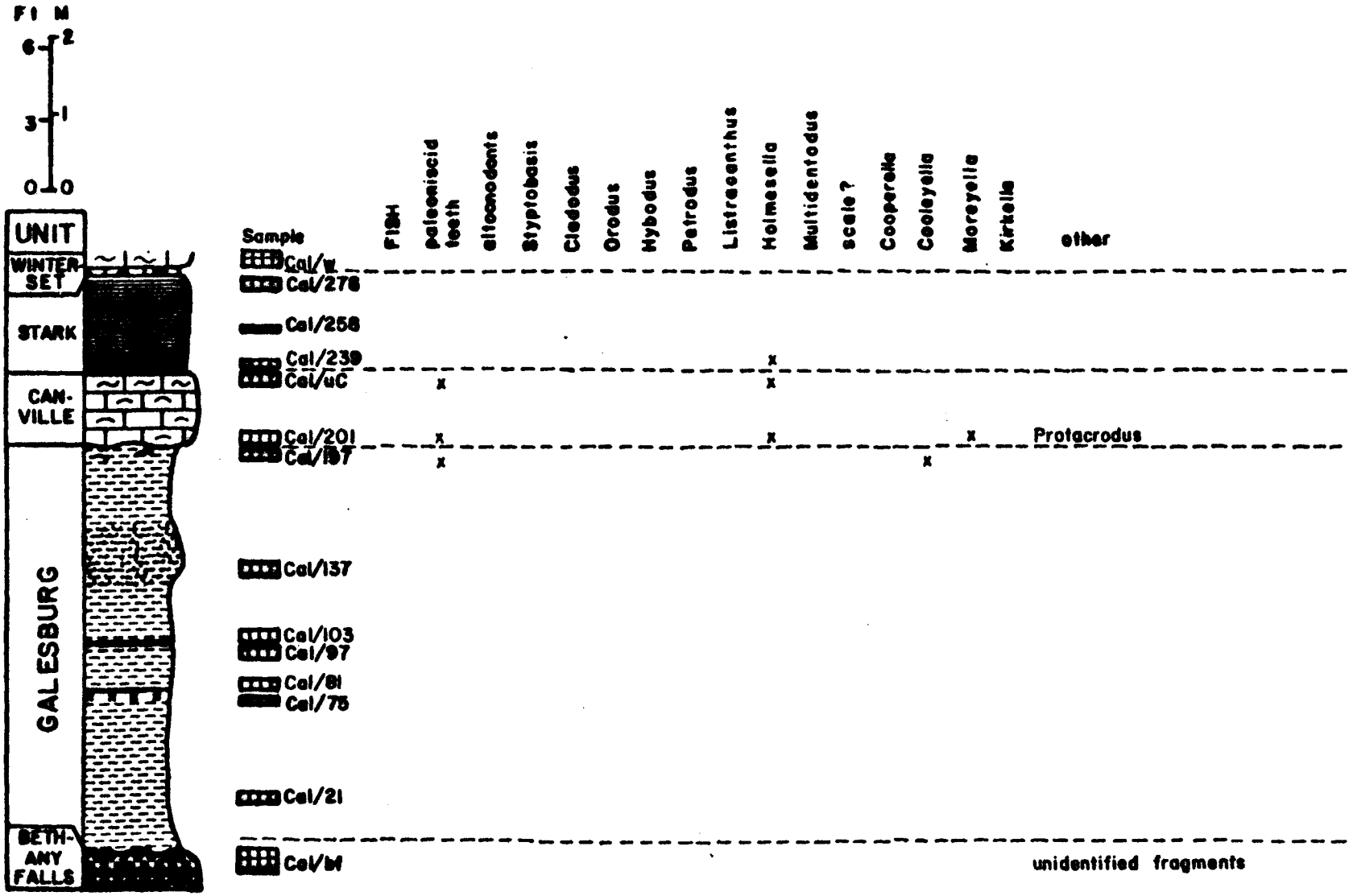

FIM
6 2
3 1
0 0
UNIT
WINTER SET
STARK
CAN-VILLE
GALESBURG
BETH-ANY FALLS
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Cal/W
Cal/278
Cal/258
Cal/238
Cal/uC
Cal/201
Cal/187
Cal/137
Cal/103
Cal/97
Cal/81
Cal/75
Cal/21
Cal/bf


FT M
6 2
3 1
0 0
UNIT
WINTER SET
STARK
CAN-VILLE
GALESBURG
BETH-ANY FALLS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other Echinoria
Cal/W
Cal/278
Cal/258
Cal/230
Cal/uC
Cal/201
Cal/187
Cal/137
Cal/103
Cal/97
Cal/81
Cal/75
Cal/21
Cal/bf
Cancrinella ?

# 14.Ca I


FI M
6 2
3 1
0 0
UNIT
WINTER SET
STARK
CAN-VILLE
GALESBURG
BETH-ANY FALLS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Cal/W
Cal/278
Cal/258
Cal/239
Cal/uC
Cal/201
Cal/187
Cal/137
Cal/103
Cal/97
Cal/81
Cal/75
Cal/21
Cal/M
Solenochilus


FI M
6 2
3 1
0 0
UNIT
WINTER SET
STARK
CAN-VILLE
GALESBURG
BETH-ANY FALLS
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Ceolocladia
Girtycoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Cal/W
Cal/278
Cal/258
Cal/239
Cal/uC
Cal/201
Cal/187
Cal/137
Cal/103
Cal/97
Cal/81
Cal/75
Cal/21
Cal/bl


FI M
6 2
3 1
0 0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALESBURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
elliconodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirtella
other
Cal/W
Cal/278
Cal/258
Cal/239
Cal/uC
Cal/201
Cal/187
Cal/137
Cal/103
Cal/97
Cal/81
Cal/75
Cal/21
Cal/bM
Protacrodus
unidentified fragments

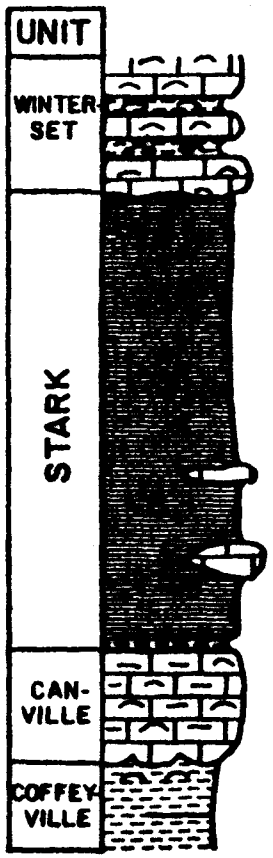
# 15.CB 1

Location: Road cut along Verdigris River 2.2 mi north of Coffeyville, Kansas

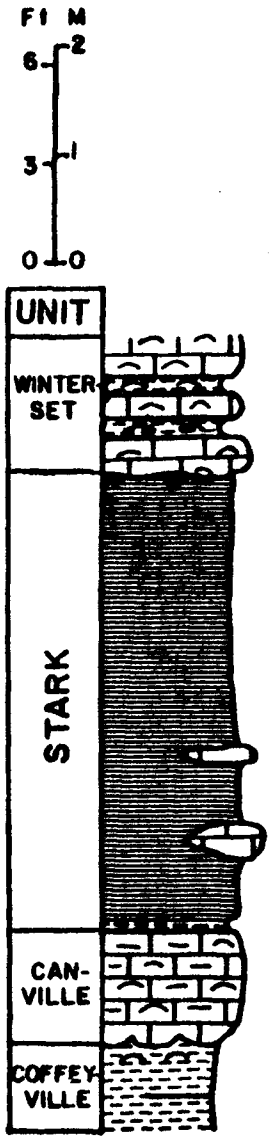
Coffeyville W, Kansas, 7 1/2'  T34SR16E14SW1/4SW1/4SE1/4

References: Moore, 1937, Stop 16, p.52-53; Jewett and Muilenburg, 1957, Stop 6, p.21-22

Collected: June 16, 1979

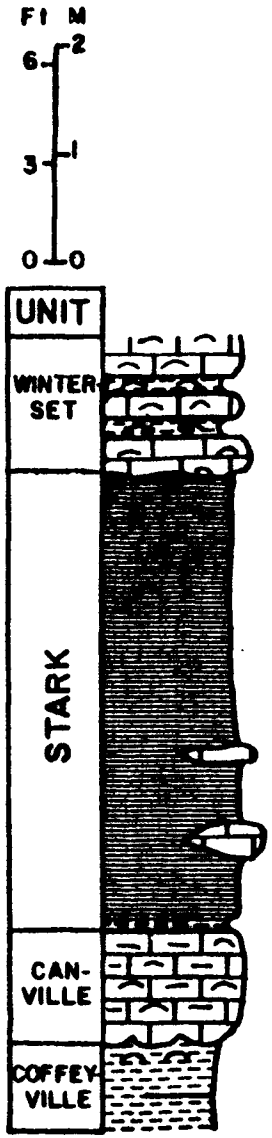



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CBI/w-2 | 1.55 | 8.6 | 50 | 35 | | 10 | 5 | x | | | | .87 | | 18 | | | 100 | | | | | |
| CBI/wU | 1.12 | 9.5 | 63 | 30 | | 7 | | | x | | | 1.00 | | 6 | | | 100 | | | | | |
| CBI/w | 1.69 | 8.8 | 54 | 46 | | | | | | | | .96 | | 29 | | | 90 | | | 6 | 4 | |
| CBI/20I | 1.44 | 9.3 | 81 | 14 | | 5 | | | | | | .59 | | 27 | | | 80 | | | 7 | 12 | |
| CBI/166 | 1.43 | 9.2 | 73 | 27 | | | | | | | | .25 | | 25 | | | 95 | | | 5 | | |
| CBI/142 | 1.80 | 9.4 | 74 | 27 | | | | | | | | .37 | | 162 | | | 85 | | | 12 | 4 | |
| CBI/118 | 2.58 | 8.0 | 87 | 7 | | 6 | | | | | | .44 | | 194 | | | 97 | | | 3 | | |
| CBI/94 | 1.20 | 8.8 | 63 | 31 | | 5 | 1 | | | | | .72 | | 1 | | | | | | 100 | | |
| CBI/70 | 1.54 | 9.2 | 66 | 34 | | | | | | | | .71 | | 3 | | | 100 | | | | | |
| CBI/42 | 1.77 | 9.9 | 79 | 14 | | 3 | 4 | x | | | | .17 | | 238 | | | 98 | 2 | | | | |
| CBI/cU | | | | | | | | | | | | .37 | | 27 | | | 90 | 10 | | | | |
| CBI/cL | 1.62 | 9.1 | 59 | 15 | | 14 | 12 | x | | | | 1.00 | | 6 | | | 83 | 17 | | | | |
| CBI/-4 | 1.84 | 9.0 | 58 | 26 | | 7 | 10 | x | | | | 1.02 | | 14 | | | 100 | | | | | |
| CBI/-22 | 2.02 | 9.5 | 66 | 15 | | 9 | 11 | x | | | | .34 | | 67 | | | 96 | 4 | | | | |



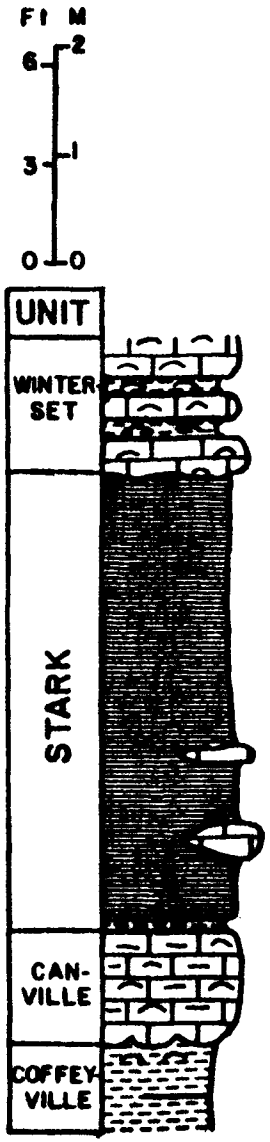

| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammoverfella | Hyperammina | Textularia | |
| CBI/w+2 | | | | x | | | x | | | | | | x | x | x | | x | | |
| CBI/wU | | | | | | | | | | | | | | x | x | x | x | x | Ammodiscella |
| CBI/w | | | | | | | | | | | | | x | x | x | | | | |
| CBI/20I | | | | | | | | | | | | | x | x | x | | | | |
| CBI/166 | | | | | | | | | | | | | | | | | | | |
| CBI/142 | | | | | | | | | | | | | | | x | | | | |
| CBI/118 | | | | | | | | | | | | | | | | | | | |
| CBI/94 | | | | | | | | | | | | | | x | | | | | |
| CBI/70 | | | | | x | | | | | | | | | x | | | | | |
| CBI/42 | | x | | | | | | | | | | Silenites, Microcheilinella? | | x | x | | x | | |
| CBI/cU | x | | | x | | | | | | | | | | x | x | x | | | |
| CBI/cL | x | | | x | | | | | | | | | | | x | x | | | |
| CBI/-4 | x | ? | | x | x | | x | | | | | Bairdiacypris, Silenites | | | x | x | | | |
| CBI/-22 | x | x | | x | x | | x | | | | | Silenites | | | x | | | | Ammodiscella |

# 15.CB 1

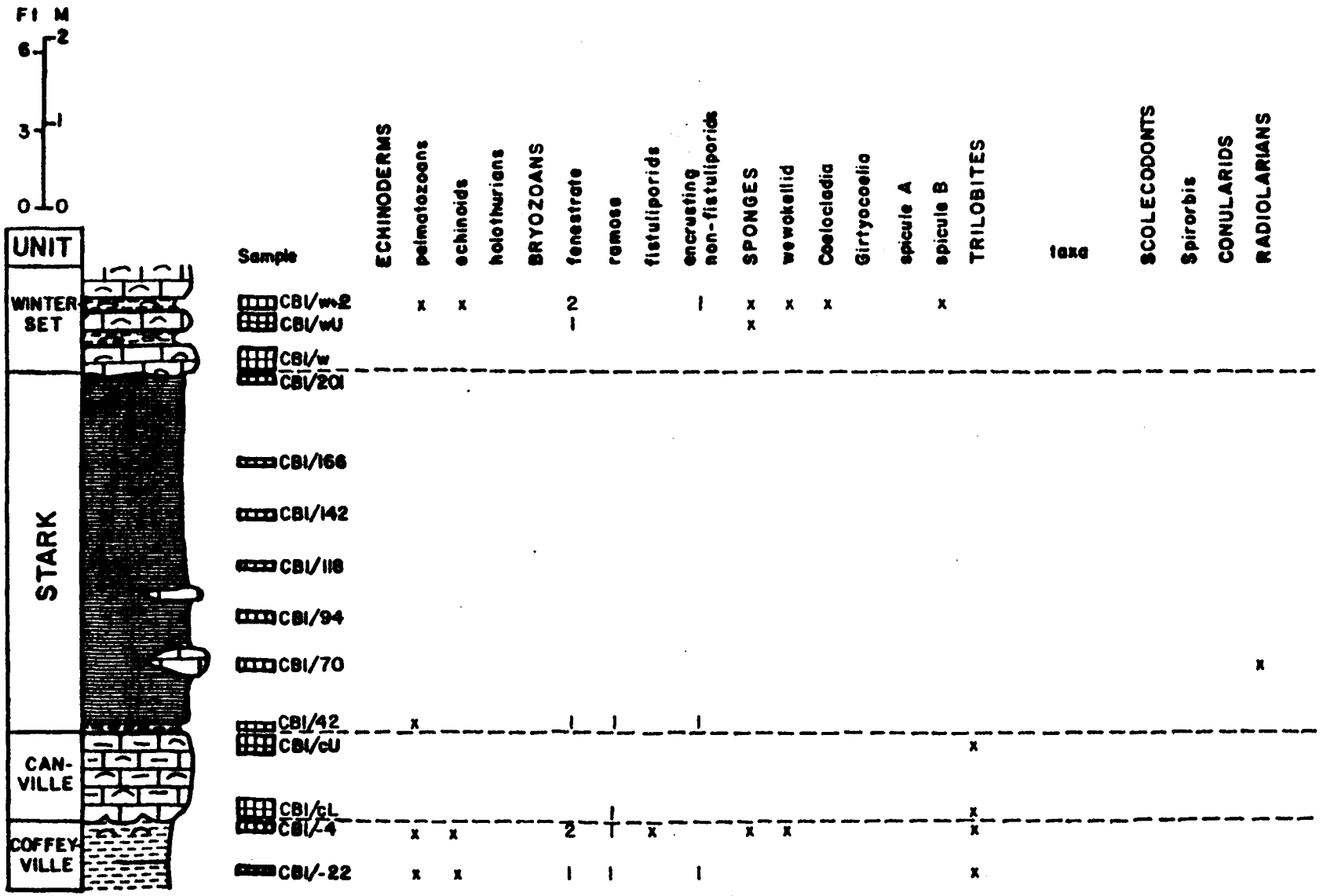



| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CBI/w+2 | | | | | x | | | x | x | | x | | | x | | | x | x | | |
| CBI/wU | | | | | x | | | | | | | | | | | | | | | |
| CBI/w | | | | | | | | | | | | | | | | | | | | |
| CBI/20I | | | | | | | | | | | | | | | | | | | | |
| CBI/166 | | | | | | | | | | | | | | | | | | | | |
| CBI/142 | | | | | | | | | | | | | | | | | | | | |
| CBI/118 | | | | | | | | | | | | | | | | | | | | |
| CBI/94 | | x | | x | | | | | | | | | | | | | | | | |
| CBI/70 | | | | | | | | | | | | | | | | | | | | |
| CBI/42 | | x | | | x | | | | x | | | | | x | | x | | x | | |
| CBI/cU | | x | x | | | | | | ? | | | | | | | | | | | |
| CBI/cL | | x | ? | | | | | | ? | | | | | | | | | | | |
| CBI/-4 | | | | | x | | | x | x | x | | | | x | x | x | x | x | x | Phricodothyris |
| CBI/-22 | | x | x | | x | | | | x | x | | ? | | x | | x | | x | | |

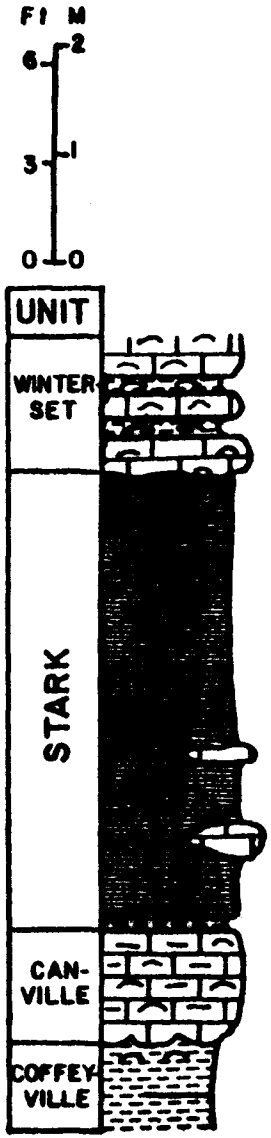
## 15.CB 1




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | CORALS | lophophyllidid | Sutherlandia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CBI/w+2 | x | | Helminthozyga? | | | | | | | | | | | |
| CBI/wU | | | | | | | | | | | | | | |
| CBI/w | | | | | | | | | | | | | | |
| CBI/20I | | | | | | | | | | | | | | |
| CBI/166 | | | | | | | | | | | | | | |
| CBI/142 | | | | | | | | | | | | | | |
| CBI/118 | | | | | | | | | | | | | | |
| CBI/94 | | | | | | | | | | | | | | |
| CBI/70 | | | | | | | | | | | | | | |
| CBI/42 | x | | | | | | | | | | | x | x | |
| CBI/cU | x | | | | | | | | x | | | | | |
| CBI/cL | x | | | | | | | | | | | | | |
| CBI/-4 | x | x | Glabrocingulum?, platycerid? | x | | cf Astartella | | | | | | x | x | x |
| CBI/-22 | x | | | x | | | x | cf Eoasianites | | | | | | |

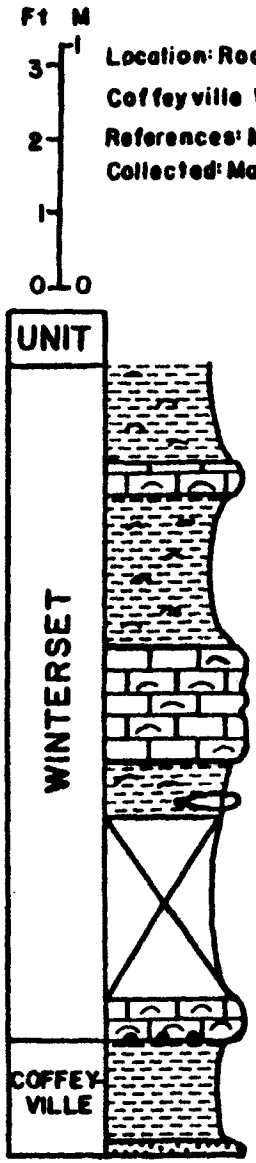

15.CB 1
FI M
6 2
3 1
0 0
UNIT
WINTER SET
STARK
CAN-VILLE
COFFEY-VILLE
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
CBI/w+2
CBI/wU
CBI/w
CBI/20I
CBI/166
CBI/142
CBI/118
CBI/94
CBI/70
CBI/42
CBI/cU
CBI/cL
CBI/-4
CBI/-22

## 15.CB 1




| Sample | FISH | paleoniscid teeth | ellocnodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirtalla | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CBI/w+2 | | x | | | | | | | | | | | | | | | |
| CBI/wU | | x | | x | | | | | | x | | x | | | | | |
| CBI/w | | | | | | | | | | | | | | | | | |
| CBI/2QI | | | | | | | | | | | | | | | | | |
| CBI/166 | | | | | | | | | | | | | | | | | |
| CBI/142 | | | | | | | | | | | | | | | | | unidentified fragments |
| CBI/118 | | | | | | | | | | | | | | | | | unidentified fragments |
| CBI/94 | | | | | | | | | | | | | | | | | |
| CBI/70 | | | | | | | | | | | | | | | | | |
| CBI/42 | | | | | | | | | | x | | x | | | | | |
| CBI/cU | | x | | ? | | | | | | x | | | | | | | |
| CBI/cL | | | | | | | | | | | | | | | | | unidentified fragments |
| CBI/-4 | | x | | | | | | | | | | | | | | | |
| CBI/-22 | | x | | | | x | | | | x | | | | | | | |

# 16.CB 2



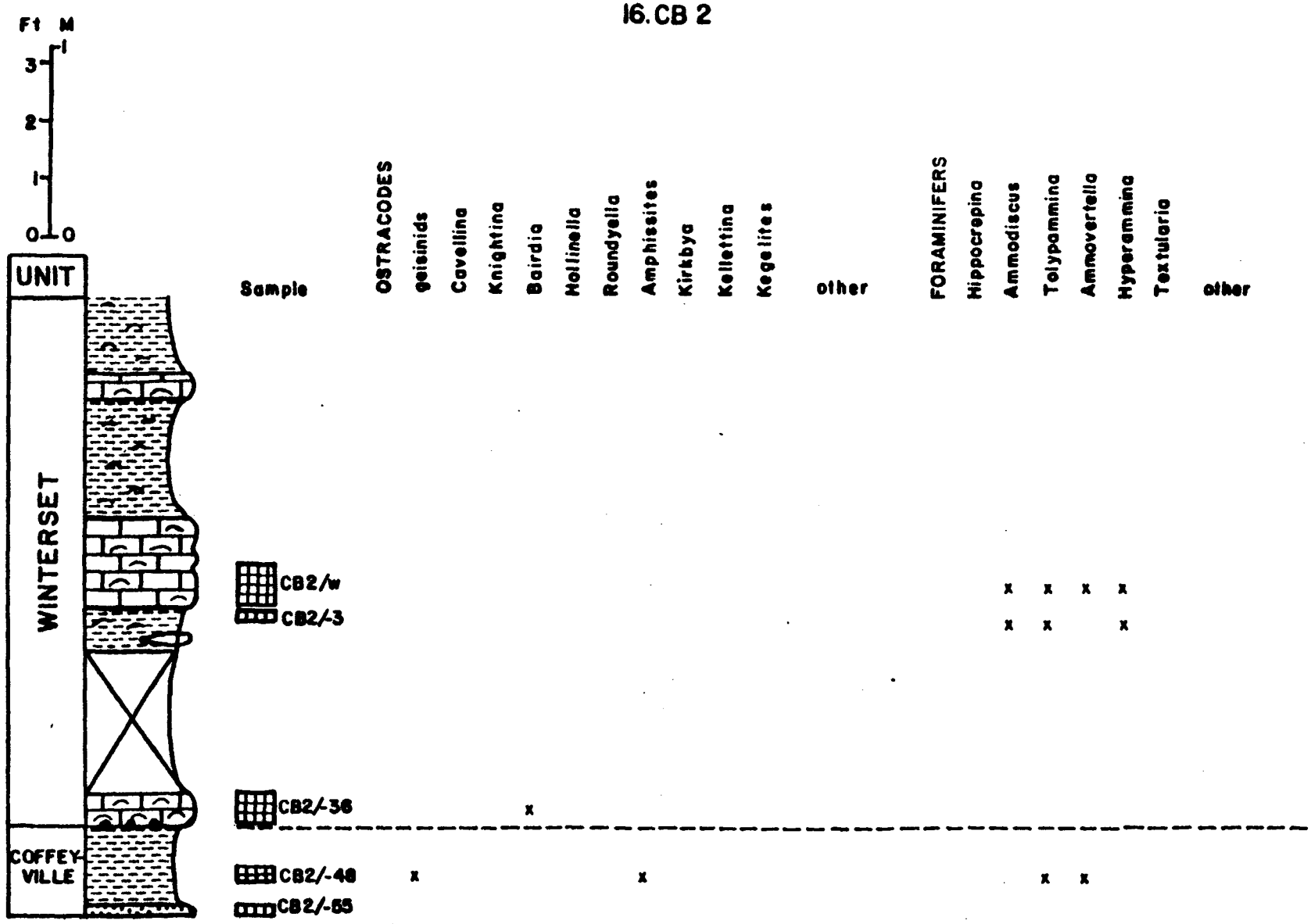

Location: Road cut (Roosevelt Drive) about 1.2 mi north of Coffeyville, Kansas

Coffeyville W, Kansas, 7 1/2'  T34SR16E23SW1/4SW1/4SW1/4

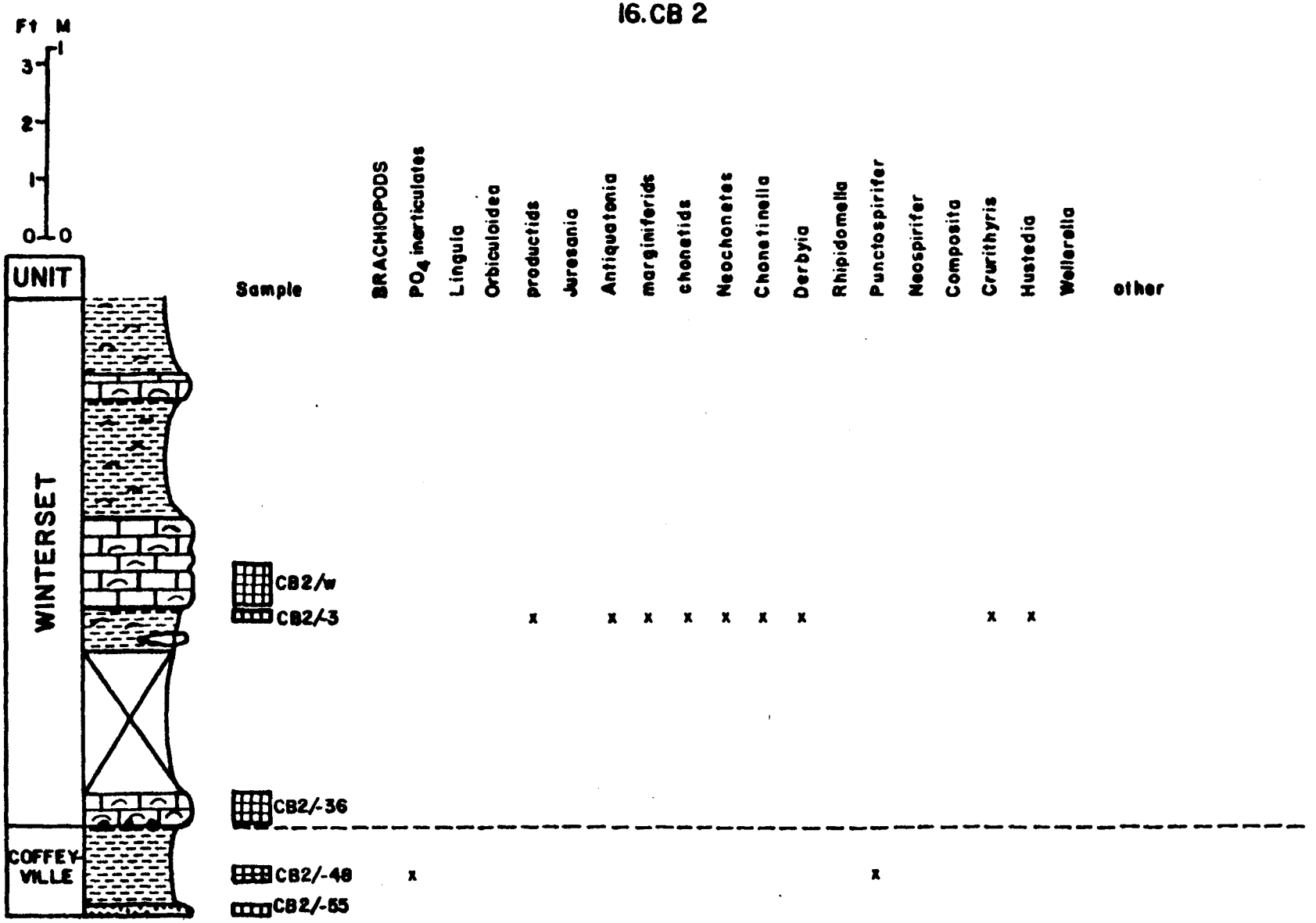
References: Moore, 1937, Stop 16, p. 52-53; Hansen, 1957, Sect. 1, p. 129-131; Jewett and Muilenburg, 1957, Stop 6, p. 21-22

Collected: May 23, 1980

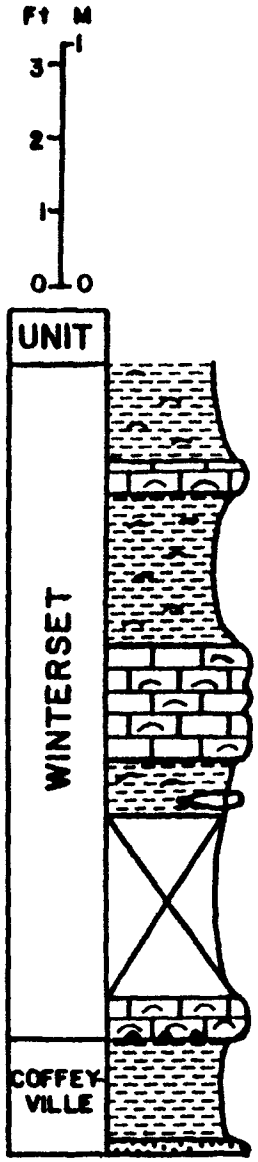
| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CB2/w | 1.57 | 9.4 | 59 | 36 | | 4 | 2 | | | | | 1.00 | | 16 | | | 94 | 6 | | | | |
| CB2/-3 | 1.30 | 9.2 | 45 | 50 | | 4 | 1 | x | | | | .82 | | 13 | | | 91 | 9 | | | | |
| CB2/-36 | 1.65 | 9.6 | 60 | 28 | | 7 | 5 | x | | | | .97 | | 2642 | | | 94 | 1 | | 3 | 3 | |
| CB2/-48 | 2.11 | 9.9 | 51 | 28 | | 5 | 17 | x | | | | .68 | | 24 | 56 | | 44 | | | | | |
| CB2/-55 | 3.46 | 9.0 | 63 | 13 | | 6 | 19 | x | | | | .05 | | | | | | | | | | x |


16. CB 2
Ft M
3
2
1
0 0
UNIT
WINTERSET
COFFEY-VILLE
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
CB2/w
CB2/-3
CB2/-36
CB2/-48
CB2/-55

## 16. CB 2


Ft M
3 1
2
1
0 0
UNIT
WINTERSET
COFFEYVILLE
Sample
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
CB2/w
CB2/-3
CB2/-36
CB2/-48
CB2/-55

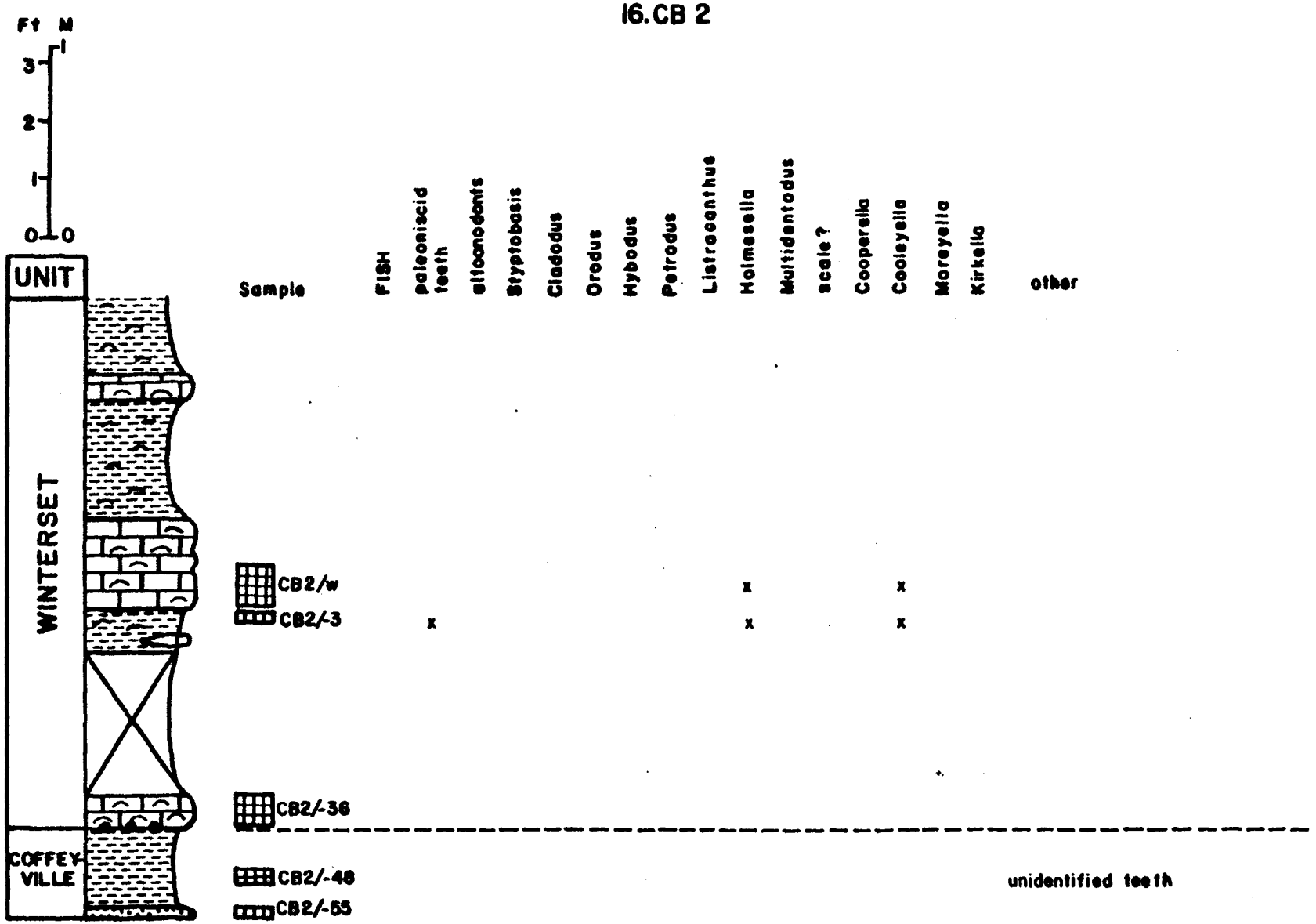
16. CB 2




| Sample | GASTROPODS | heterophrentids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | CORALS | lophophyllidid | Sutherlandia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CB2/w | | | | | | | | | | | | | | |
| CB2/-3 | | | | | | | | | | | | x | | |
| CB2/-36 | x | | | | | | x | pseudorthocerid | | | | | | |
| CB2/-48 | x | Glabrocingulum? | | x | | Euchondria | | | | | | | | |
| CB2/-55 | | | | | | | | | | | | | | |

# 16.CB 2


Ft M
3
2
1
0 0
UNIT
WINTERSET
COFFEY-VILLE
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
CB2/w
CB2/-3
x x 2 2 x 1
CB2/-36
CB2/-46
CB2/-55
x x 3 1 1 x x

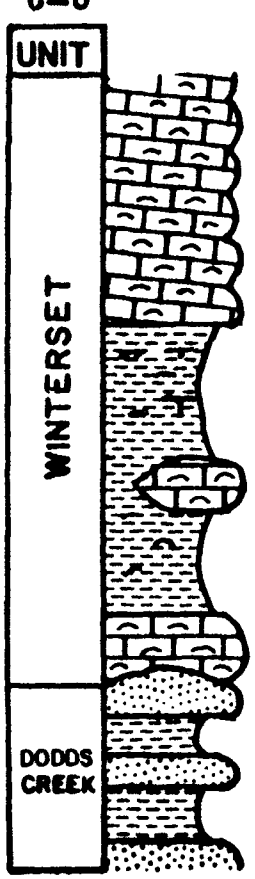

16. CB 2
Ft M
3
2
1
0
0
UNIT
WINTERSET
COFFEY-VILLE
Sample
FISH
paleoniscid teeth
elliconodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
CB2/w
CB2/-3
CB2/-36
CB2/-48
CB2/-55
unidentified teeth

# 17.Cf 1

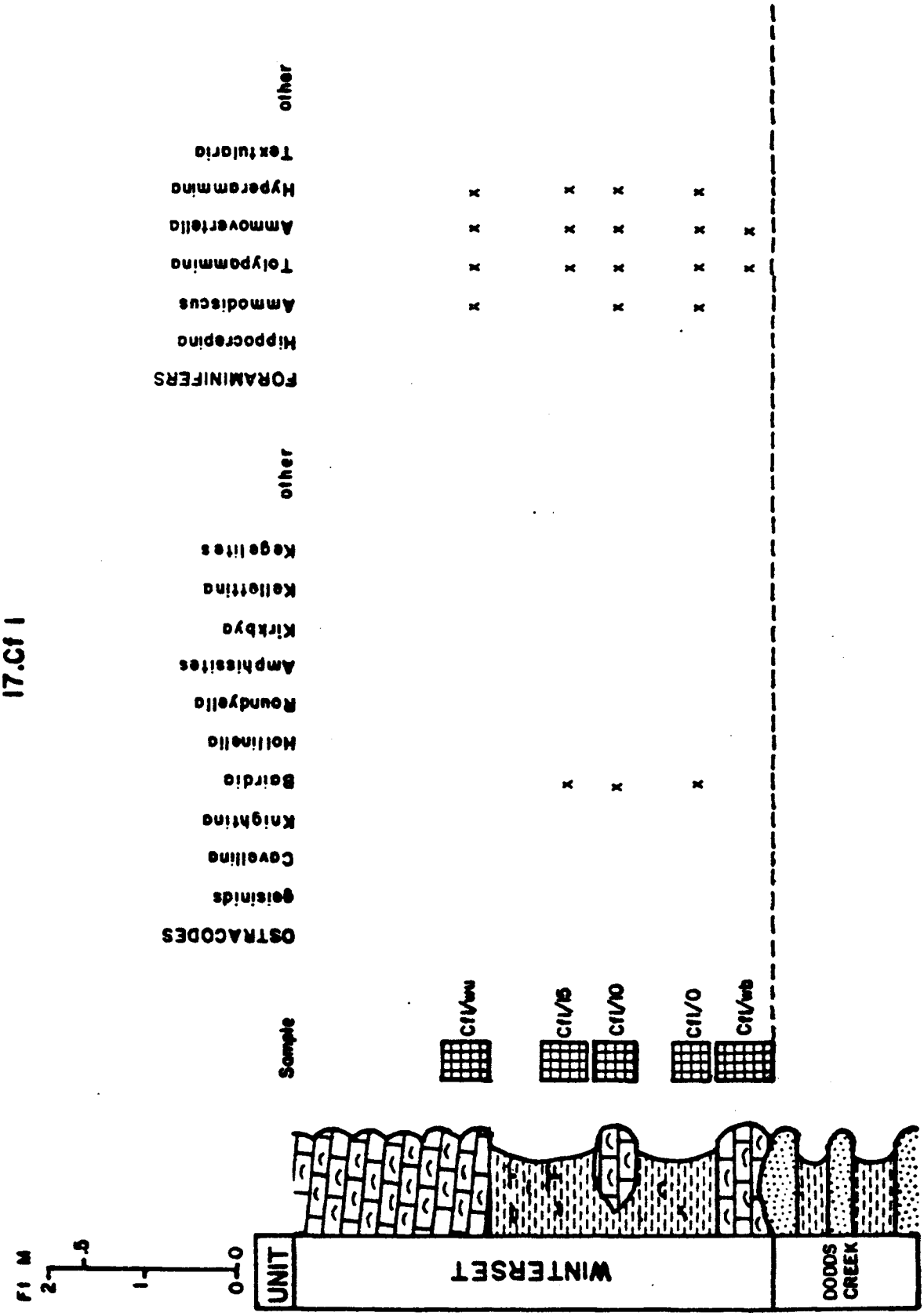
Location: Roadcut on US Highway 166 about 1.1 mi west of Coffeyville, Kansas

Coffeyville W, Kansas, 7 1/2'

T34SR16E31SE1/4SE1/4SW1/4




| Sample | Mite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cf1/wu | 1.08 | 9.2 | 65 | 26 | | 9 | | x | | | | 1.00 | | 49 | 2 | | 96 | 2 | | | | |
| Cf1/15 | 1.63 | 10.0 | 56 | 32 | | 9 | 3 | x | | | | .90 | | 17 | | | 93 | 7 | | | | |
| Cf1/10 | 1.59 | 10.0 | 57 | 17 | | 20 | 6 | | x | x | | .62 | | 23 | | | 93 | 7 | | | | |
| Cf1/0 | 1.85 | 9.7 | 57 | 20 | | 16 | 7 | x | x | x | | .98 | | 14 | | | 100 | | | | | |
| Cf1/wb | 1.22 | 9.4 | 61 | 28 | | | 11 | x | x | x | | .07 | | 2880 | | | 96 | | | 2 | 2 | |


FT M
2
1
0
UNIT
WINTERSET
DODDS CREEK
Sample
C1V/su
C1V/5
C1V/0
C1L/0
C1L/sb
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammoverteilla
Hyperammina
Textularia
other

17.Cf 1

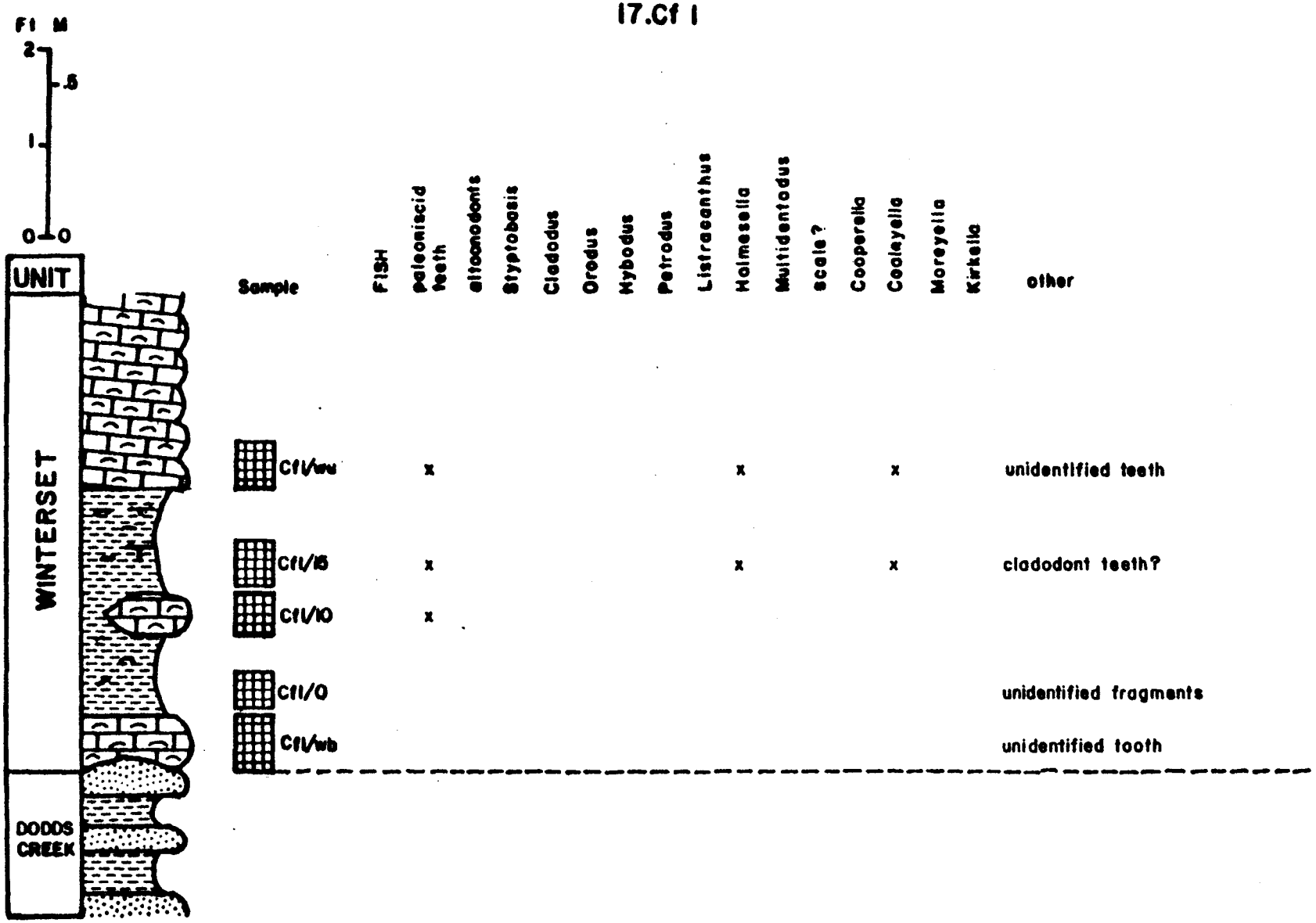
17.Cf 1


Ft M
2
.5
1
0 0
UNIT
WINTERSET
DODDS CREEK
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Cf1/wu
Cf1/15
Cf1/10
Cf1/0
Cf1/wb
x
x
x
x
x
x
x
x
x
x
?
x

17.Cf 1


FI M
2
.5
1
0
0
UNIT
WINTERSET
DODDS CREEK
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Cf1/wu
Cf1/15
Cf1/10
Cf1/0
Cf1/wb
x
x
x
x
Glabrocingulum
x
x
x
x

17.Cf 1
Ft M
2
.5
1
0
0
UNIT
WINTERSET
DODDS CREEK
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Calcicidia
Girtyocoelia
spicule A
spicule B
TRILOBITES
faxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Cf1/wu
Cf1/15
Cf1/10
Cf1/0
Cf1/wb
x
2
2
1
x
x
x
1
2
1
x
x

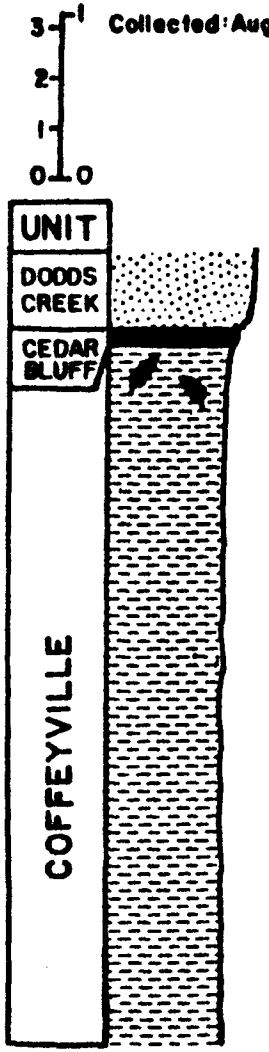

17.Cf 1
FT M
2
.5
1
0
0
UNIT
WINTERSET
DODDS CREEK
Sample
FISH
paleoniscid teeth
eltonodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Coelacella
Moreyella
Kirkella
other
Cf1/ww
Cf1/15
Cf1/10
Cf1/0
Cf1/wb
unidentified teeth
cladodont teeth?
unidentified fragments
unidentified tooth

# 18.Cf 2

Location: Spoil cut along county road about 1 mi south of Coffeyville, Kansas

Coffeyville W, Kansas, 7 1/2'  T35SR16E9NW1/4NW1/4NW1/4

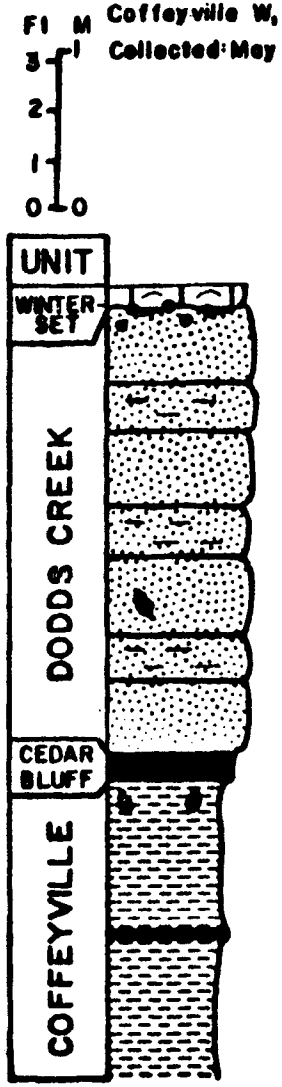
Collected: August 9, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cf2/bc | 1.71 | 9.4 | 44 | 8 | | | 48 | x | | | |

# 19.Cf 3

Location: Spoil cut along county road about 1.4 mi south of Coffeyville, Kansas
Coffeyville W, Kansas, 7 1/2'  T35SR16EIOSWI/4NWI/4NWI/4
Collected: May 23, 1980




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cf3/w | 1.56 | 9.6 | 36 | 18 | | | 46 | x | x | . | | 1.00 | 257 | | 1 | | 95 | 1 | | 2 | 3 | |

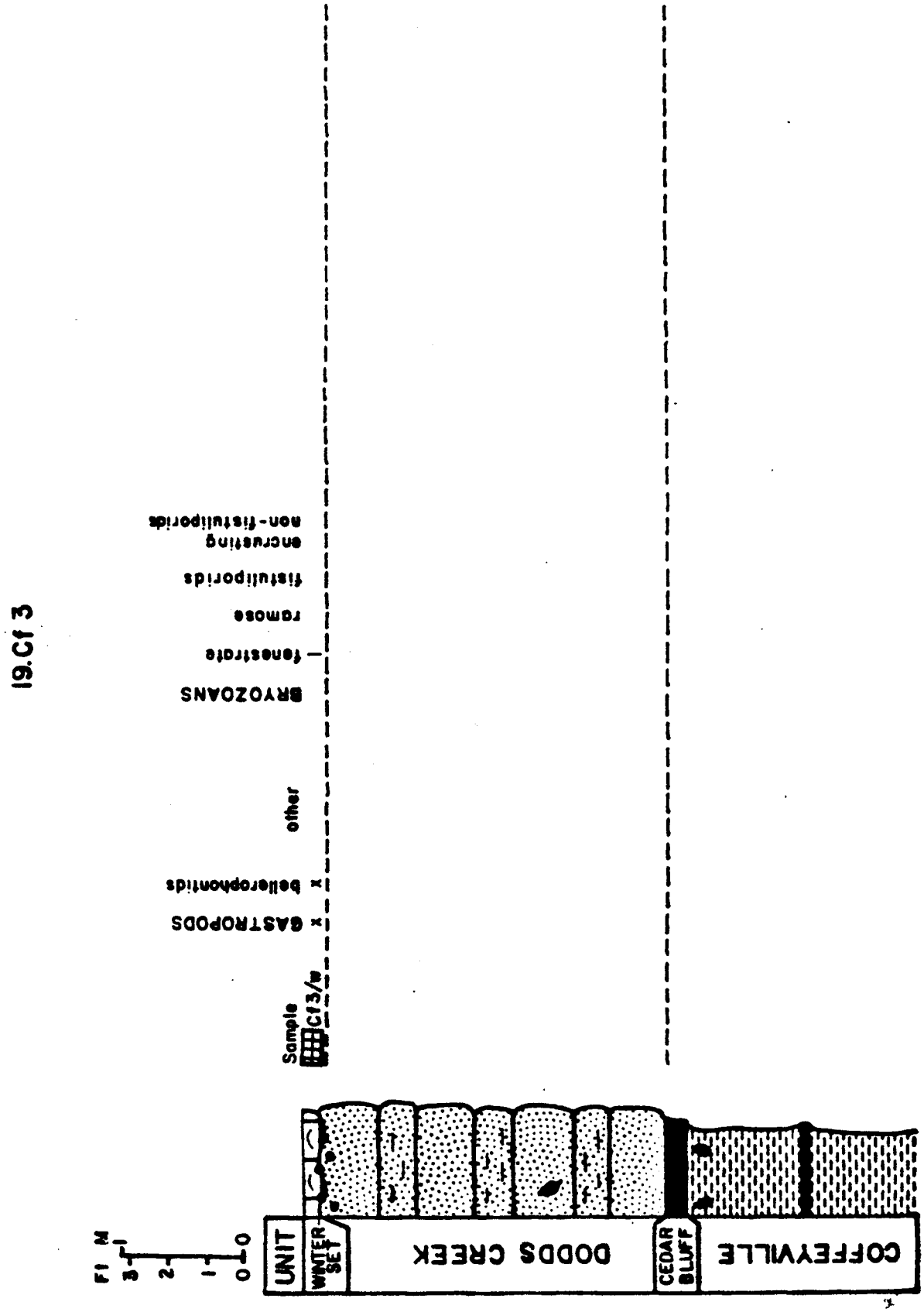
19.Cf 3

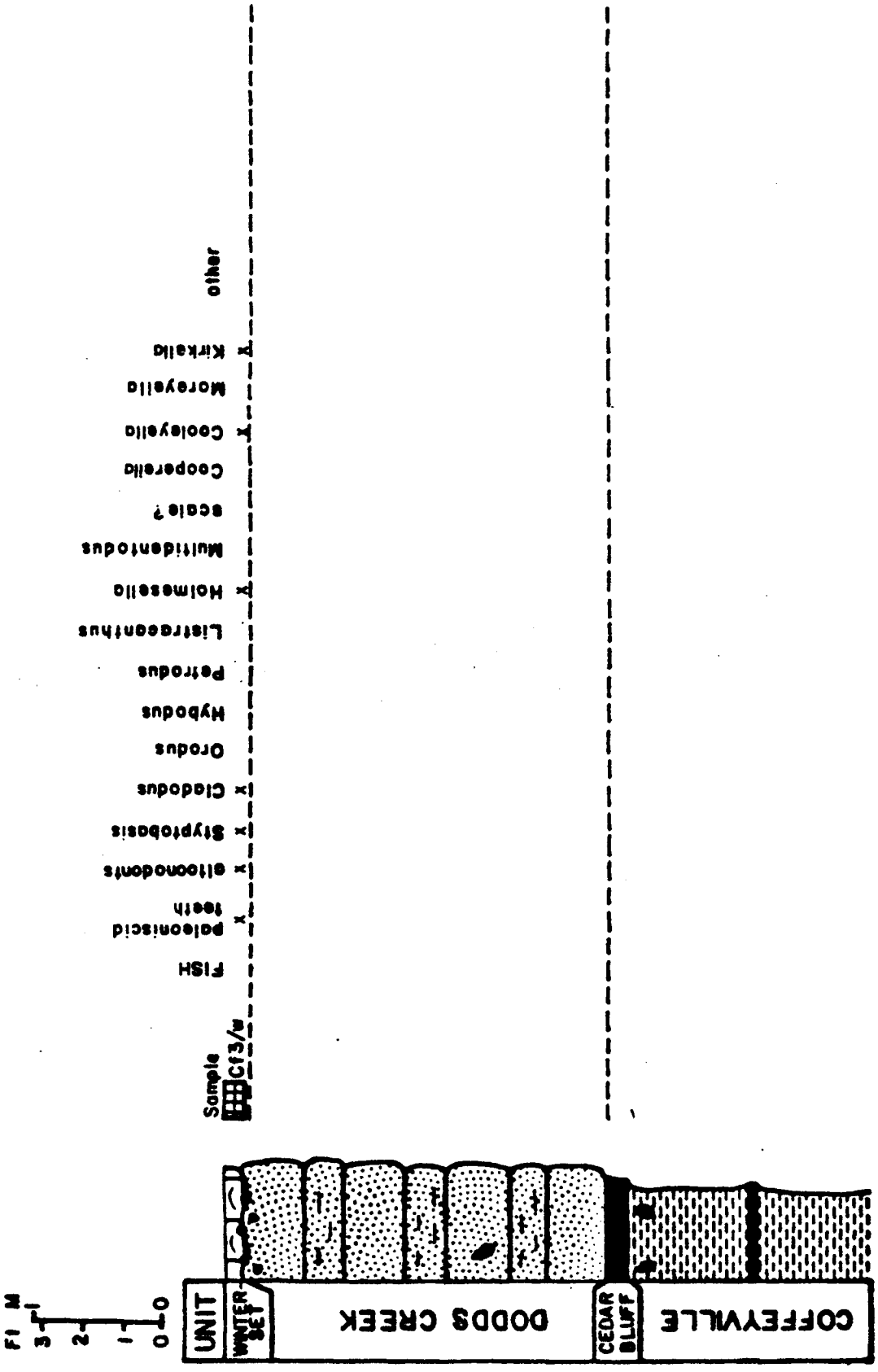



| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other unidentified | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Cf3/w | | | | | | | | | | | | | | | | x | | | | |

19.Cf 3

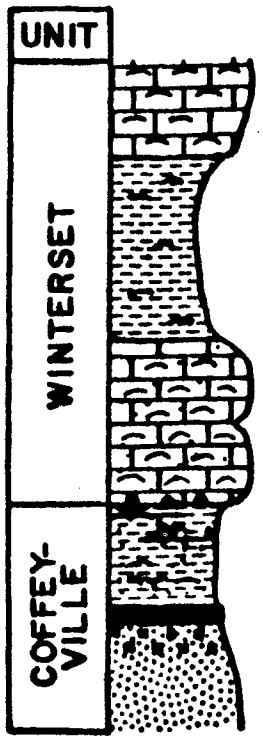

Ft
M
3
2
1
0
0
UNIT
WINTER SET
DODDS CREEK
CEDAR BLUFF
COFFEYVILLE
Sample
Cf3/w
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other


19.Cf 3
Sample
C13/w
GASTROPODS
bellerophontids
other
BRYOZOANS
— fenestrate
ramose
fistuliporids
encrusting
non-fistuliporids
FT M
3
2
1
0
UNIT
WINTER SET
DODDS CREEK
CEDAR BLUFF
COFFEYVILLE


19.Cf 3
Sample
Cf3/w
FISH
paleoniscid teeth
altoconodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkalla
other
UNIT
WINTER SET
DODDS CREEK
CEDAR BLUFF
COFFEYVILLE
FT M
3
2
1
0

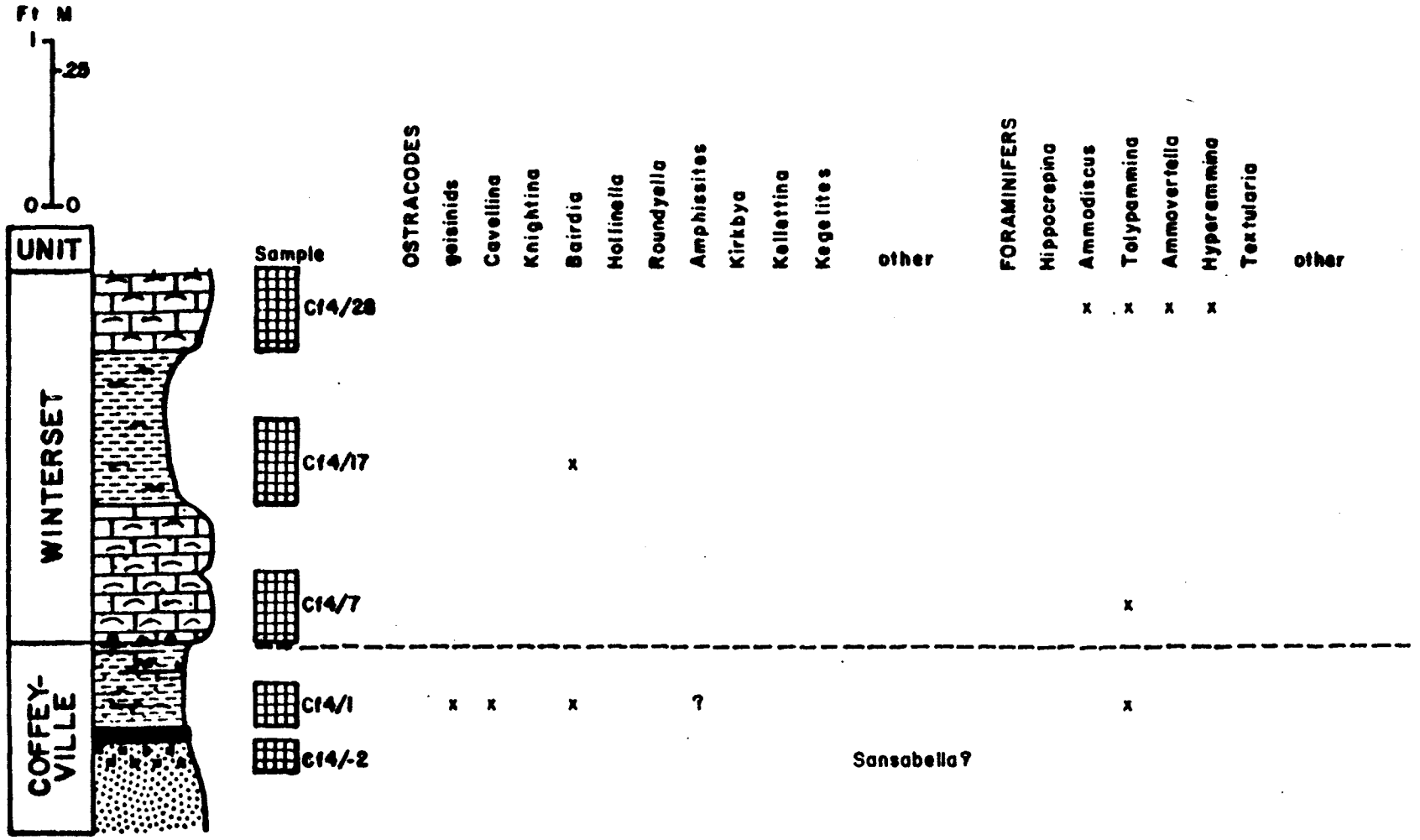
# 20.Cf 4

Ft M Location: Road cut on county road about 2.2 mi west and 4 mi south of Coffeyville, Kansas
Elliott, Oklahoma-Kansas, 7 1/2' T29NR15E20SE1/4SE1/4SE1/4
References: Hansen, 1967, Sect. 6, p. 143-144; Cronoble and Mankin, 1965, Sect. 16, p. 99, 119-120
Collected: May 24, 1960



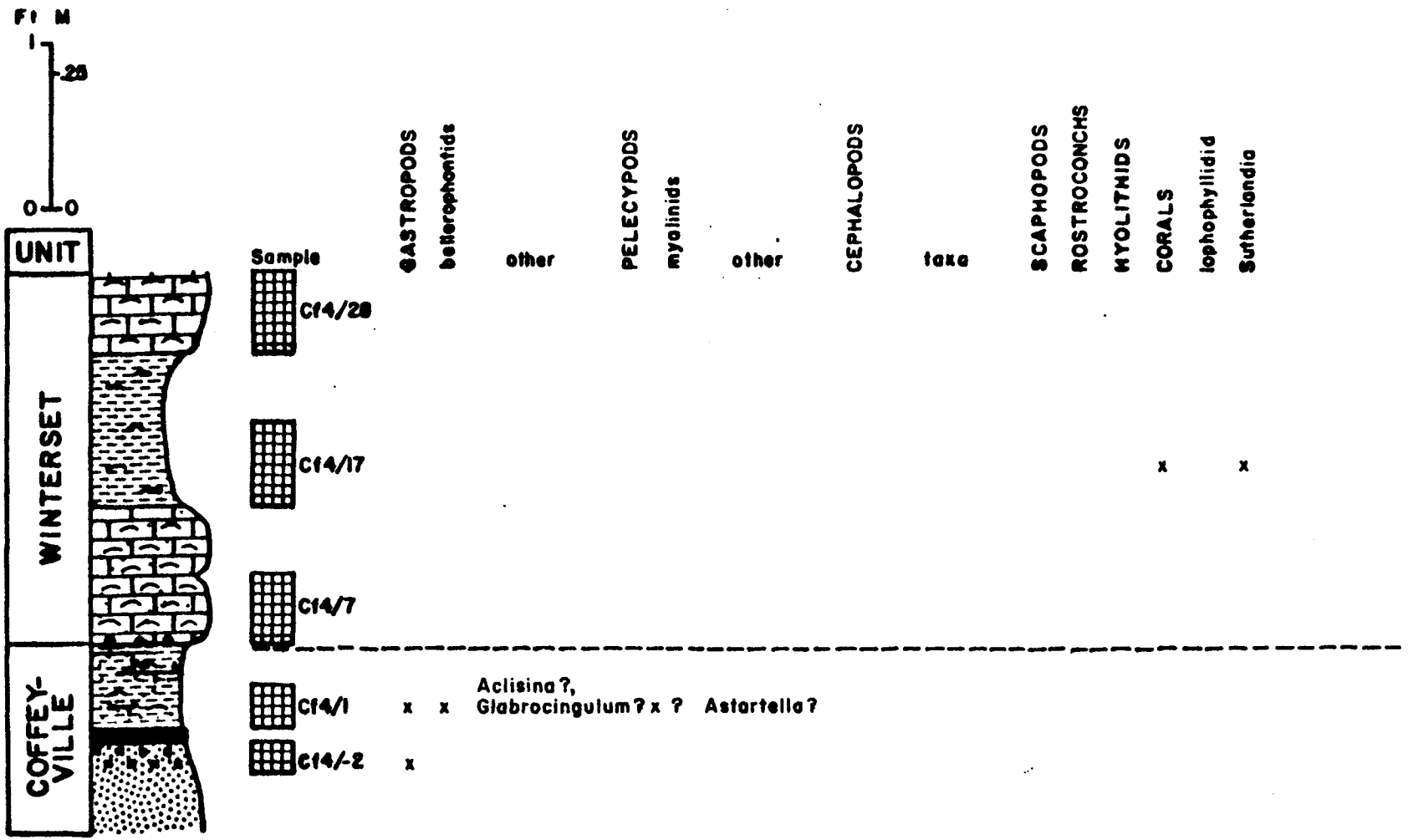

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cf4/28 | 1.28 | 9.1 | 54 | 33 | | 9 | 5 | x | x | | | 1.00 | | 4 | | | 100 | | | | | |
| Cf4/17 | 1.23 | 9.8 | 38 | 38 | | 6 | 8 | x | | | | np | | | | | | | | | | |
| Cf4/7 | 1.49 | 9.5 | 60 | 18 | | 8 | 14 | x | x | x | | .12 | 2415 | | | | 94 | t | | 2 | 4 | |
| Cf4/1 | 3.98 | 10.1 | 38 | 45 | | | 17 | x | | | | .32 | | 31 | 10 | | 90 | | | | | |
| Cf4/-2 | 2.41 | 9.5 | 69 | 5 | | | 26 | x | | | | | | | | | | | | | | |

20.Cf 4


Ft M
1
0
25
0
UNIT
WINTERSET
COFFEY-VILLE
Sample
C14/28
C14/17
C14/7
C14/1
C14/-2
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
?
Sansabella?

Ft M
25
0 0
UNIT
WINTERSET
COFFEY-VILLE
Sample
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
C14/28
C14/17
C14/7
C14/1
C14/-2

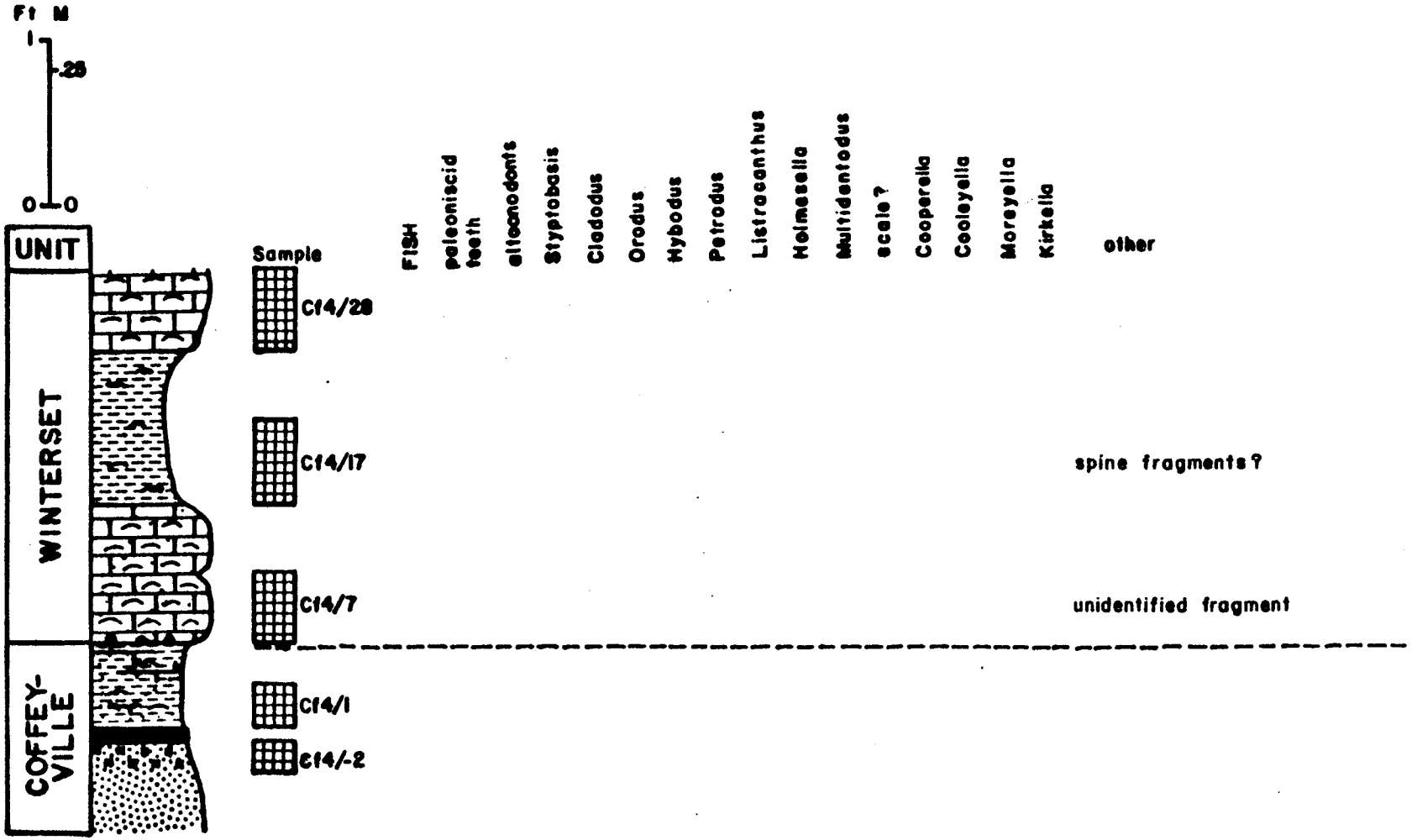
20.Cf 4


Ft M
25
0 0
UNIT
WINTERSET
COFFEY-VILLE
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Cf4/28
Cf4/17
Cf4/7
Cf4/1
Cf4/-2
x x Aclisina?, Glabrocingulum? x ? Astartella?
x
x
x

20.Cf 4


Ft M
1
25
0
0
UNIT
WINTERSET
COFFEY-VILLE
Sample
C14/28
C14/17
C14/7
C14/1
C14/-2
ECHINODERMS
pelmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
x
x
x
3
3
1
x
x
x
x
2
1
1
x

20.Cf 4


Ft M
1
0
28
0
UNIT
WINTERSET
COFFEY-VILLE
Sample
FISH
paleoniscid teeth
allenodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Helmaselle
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
C14/28
C14/17
C14/7
C14/1
C14/-2
spine fragments?
unidentified fragment

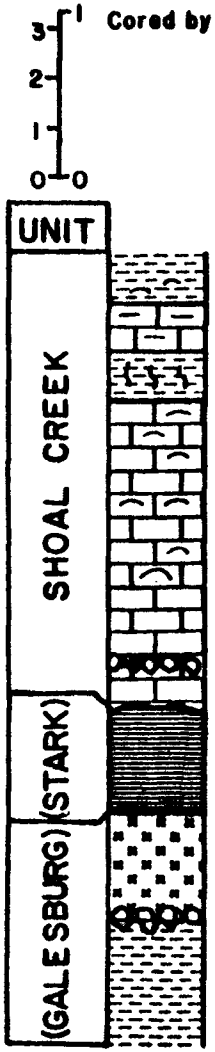
# 21.Ch I

Location: Core from Charleston, Illinois

Ft M Toledo, Illinois, 15'

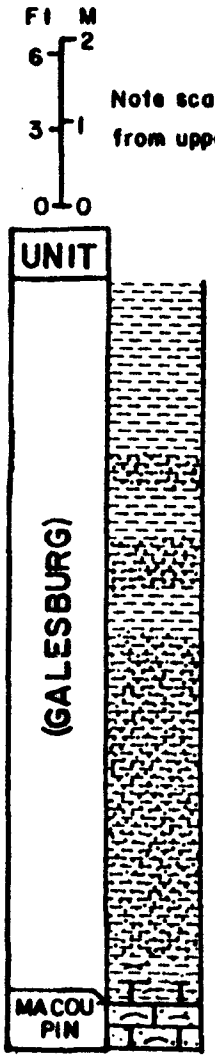
Cored by Illinois State Geological Survey

TI2NR9E9SEI/4SEI/4SWI/4

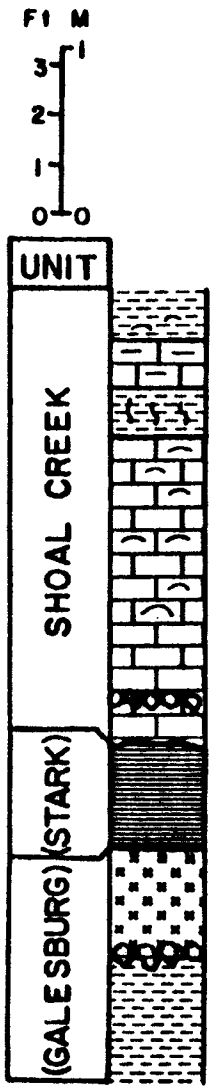



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chl/734.5 | 3.22 | 9.5 | 57 | 9 | 34 | | | | | | | .03 | 179 | | | 100 | | | | | | |
| Chl/735.3 | 4.34 | 9.8 | 53 | 7 | 31 | 9 | | | | | x | .28 | 65 | | | 99 | | | | 1 | | |
| Chl/735.6 | 2.13 | 9.1 | 55 | 17 | 18 | 9 | | | | | | .10 | 52 | | | 100 | | | | | | |
| Chl/736.4 | 1.37 | 9.4 | 63 | | 26 | 11 | | | | | | .19 | 357 | | | 88 | | | | 3 | 9 | |
| Chl/737.1 | 1.64 | 9.4 | 56 | 17 | 21 | 7 | | | | | | .17 | 689 | | | 95 | | | | 3 | 2 | |
| Chl/737.55 | 1.40 | 9.5 | 55 | 23 | 17 | 5 | | | | | | .11 | 342 | | | 98 | | | | 2 | | |
| Chl/737.8 | .99 | 8.8 | 37 | 42 | 13 | 9 | | | | | | .07 | 659 | | | 98 | | | | 2 | | |
| Chl/737.84 | .60 | 7.2 | 17 | 48 | 18 | 18 | | | | | | | | | | | | | | | | |
| Chl/740.3 | 1.45 | 9.5 | 50 | 35 | 8 | 7 | | | x | | | | | | | | | | | | | |
| Chl/740.34 | 2.23 | 9.6 | 49 | 18 | 21 | 13 | | | | | | | | | | | | | | | | |

## 21.Ch I (cont.)

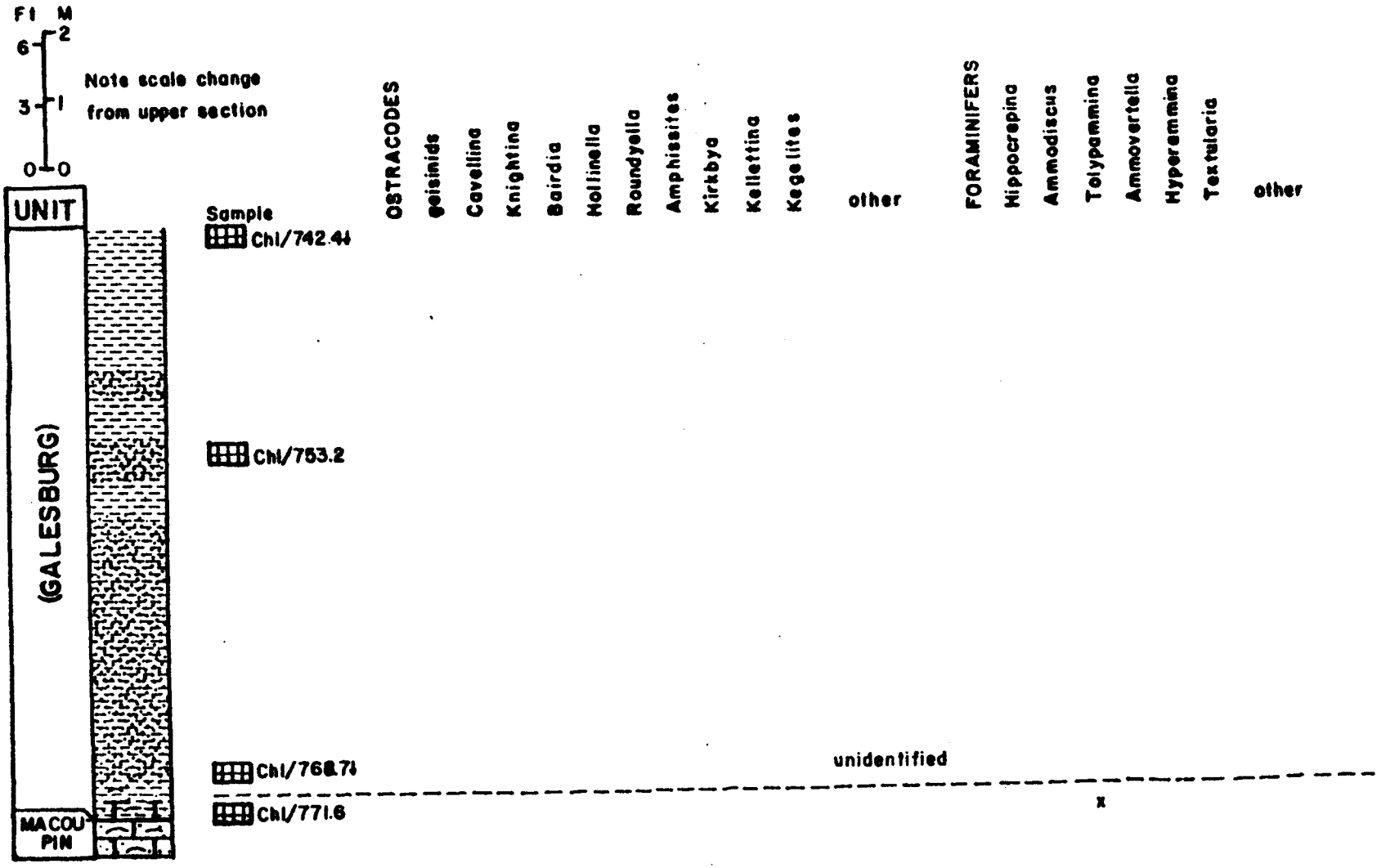



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chl/742.4‡ | 3.02 | 9.6 | 55 | 13 | | 21 | 11 | | | | |
| Chl/753.2 | 2.64 | 9.4 | 51 | 14 | | 24 | 11 | | | | |
| Chl/768.7‡ | 2.60 | 9.5 | 48 | 19 | | 20 | 13 | x | | | |
| Chl/771.6 | 2.21 | 9.8 | 45 | 20 | | 9 | 26 | x | | | |



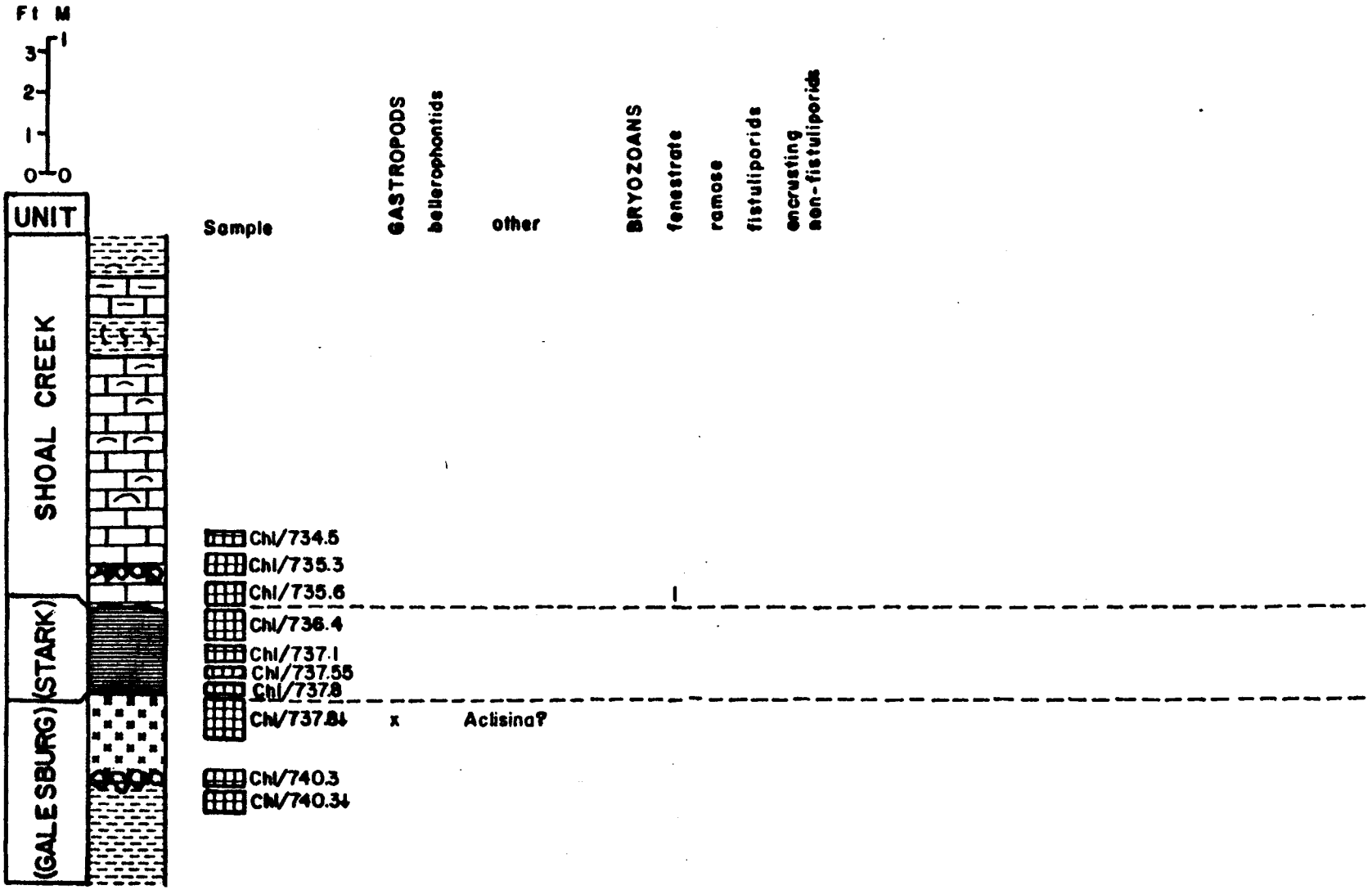

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chl/734.5 | | | | | | | | | | | | unidentified | | | | x | | | | |
| Chl/735.3 | | | | | | | | | | | | | | | | x | | x | | |
| Chl/735.6 | | | | | | | | | | | | | | | | x | | x | | |
| Chl/736.4 | | | | | | | | | | | | | | | x | x | | | | |
| Chl/737.1 | | | | | | | | | | | | | | | | | | | | |
| Chl/737.55 | | | | | | | | | | | | | | | | | | | | |
| Chl/737.8 | | | x | | x | | x | | | | | | | | x | | | | | |
| Chl/737.84 | | | | | | | | | | | | Healdia | | | | | | | | |
| Chl/740.3 | | | | | | | | | | | | | | | | | | | | |
| Chl/740.34 | | | | | | | | | | | | | | | | | | | | |

## 21.Ch I (cont.)

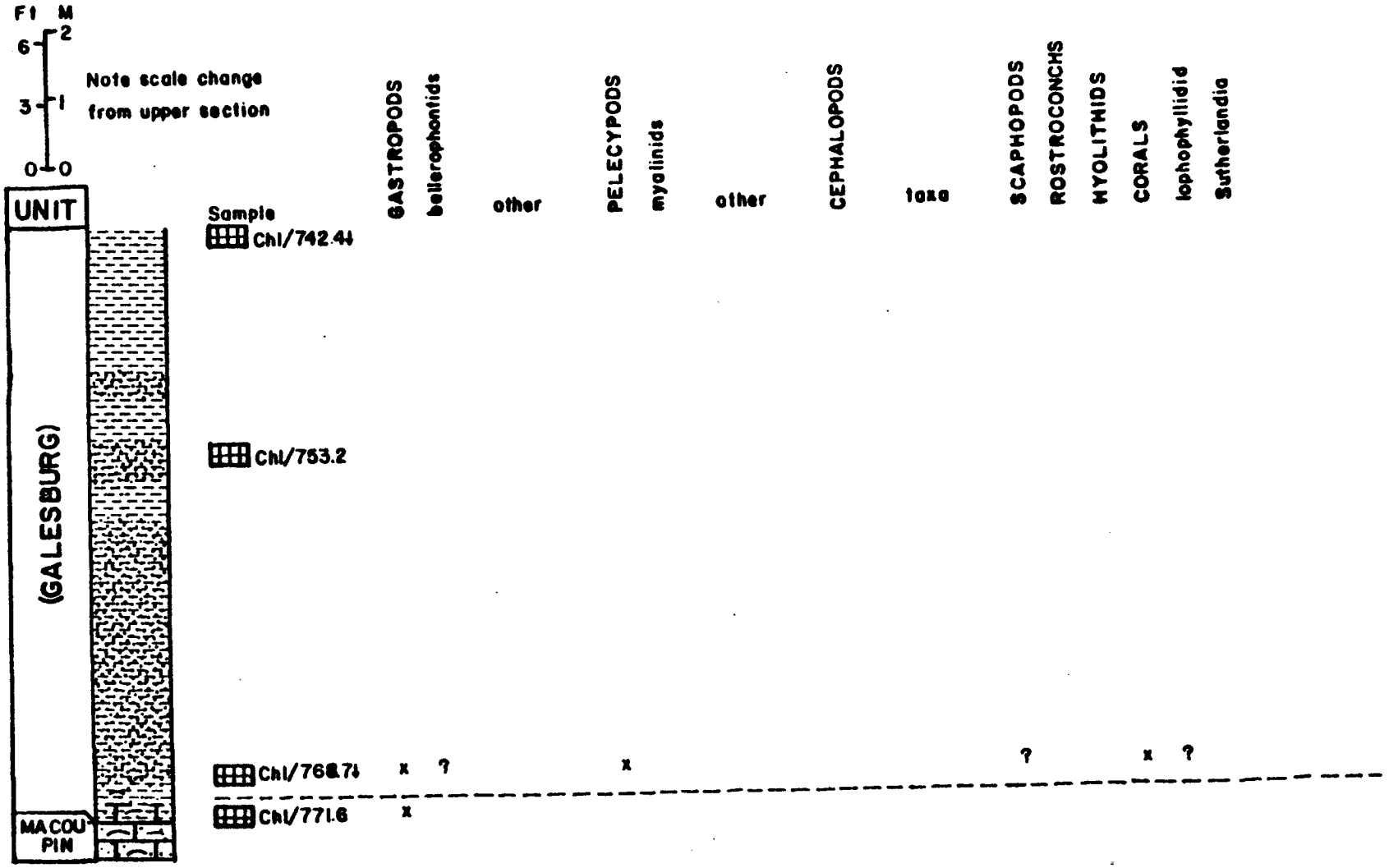

Ft M
6 2
3 1
0 0
Note scale change from upper section
UNIT
(GALESBURG)
MACOUPIN
Sample
Chl/742.4
Chl/753.2
Chl/768.7
Chl/771.6
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
unidentified

# 21.Ch I


Ft M
3
2
1
0
0
UNIT
SHOAL CREEK
(STARK)
(GALESBURG)
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Chl/734.5
Chl/735.3
Chl/735.6
Chl/736.4
Chl/737.1
Chl/737.55
Chl/737.8
Chl/737.84
Chl/740.3
Chl/740.34
x


Ft M
3 1
2
1
0 0
UNIT
SHOAL CREEK
(STARK)
(GALESBURG)
Sample
GASTROPODS
bellerophontids
other
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting
non-fistuliporids
Chl/734.5
Chl/735.3
Chl/735.6
Chl/736.4
Chl/737.1
Chl/737.55
Chl/737.8
Chl/737.84
x
Actisina?
Chl/740.3
Chl/740.34

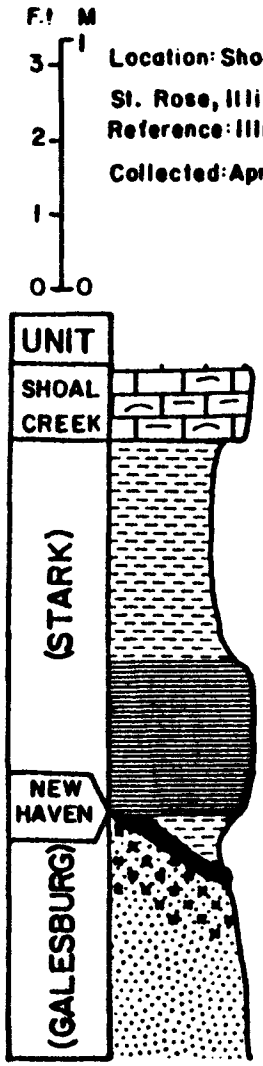
## 21.Ch I (cont.)


Ft M
6 2
3 1
0 0
Note scale change
from upper section
UNIT
(GALESBURG)
MA COU
PIN
Sample
Chl/742.4
Chl/753.2
Chl/768.7
Chl/771.6
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
MYOLITHIDS
CORALS
lophophyllidid
Sutherlandia

## 21.Ch I


FT M
3 1
2
1
0 0
UNIT
SHOAL CREEK
(STARK)
(GALESBURG)
Sample
FISH
paleoniscid teeth
actinodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirtella
other
Chl/734.5
Chl/735.3
Chl/735.6
Chl/736.4
Chl/737.1
Chl/737.55
Chl/737.8
Chl/737.84
Chl/740.3
Chl/740.34
x
?
x
x
x

# 22.C11



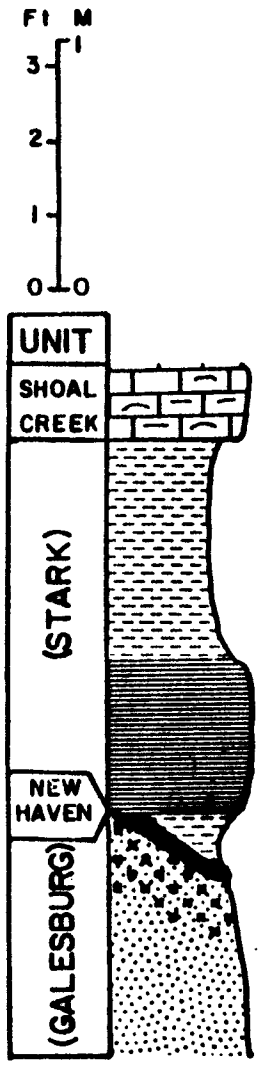

Location: Shoal Creek type locality, 1/4 mi south of Jamestown, Illinois

St. Rose, Illinois, 7 1/2'  T3NR4W25SW1/4SE1/4NE1/2

Reference: Illinois State Geological Survey unpublished report

Collected: April 1 and 2, 1980, by R.B. Jacobson and C.B. Trask

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C11/scbs | 2.20 | 8.4 | 59 | 17 | | 18 | 6 | x | | | | .24 | 1054 | | | | 97 | | | 3 | 1 | |




## 22.C11

| Sample | FISH | paleoniscid teeth | altaconodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C11/scbs | | | | | | | | | | | | | | | | | unidentified tooth |

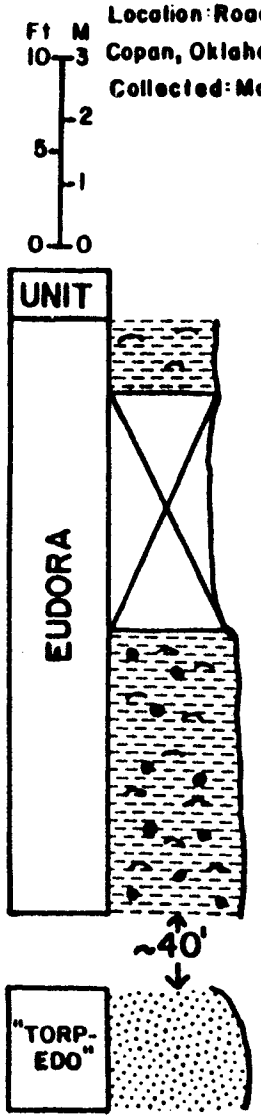
# 23.Cp I

Location: Road cut on US Highway 75 1 3/4 mi north of Copan, Oklahoma

Copan, Oklahoma - Kansas, 7 1/2'

T28NR13E1ONW1/4SW1/4W1/4

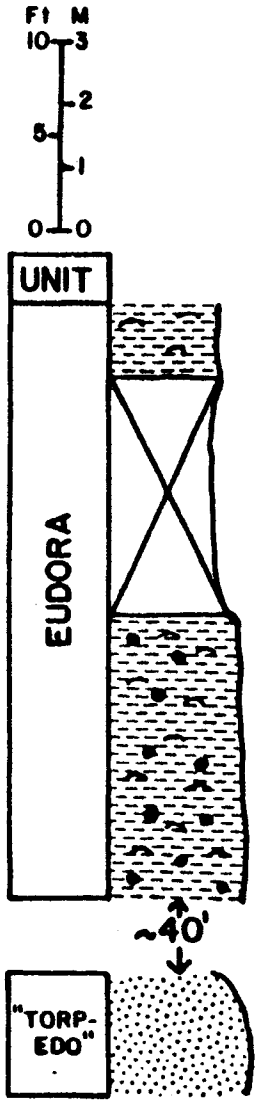
Collected: May 24, 1980




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cpl/30.5' | 1.48 | 9.4 | 54 | 7 | | 24 | 15 | x | | | | | | | | | | | | | | |
| Cpl/13.5' | 1.70 | 9.6 | 59 | 18 | | 15 | 8 | x | x | | x | | | | | | | | | | | |
| Cpl/0' | 1.91 | 9.8 | 63 | 13 | | 17 | 7 | x | | | | .94 | | 1 | | | 100 | | | | | |

Sandstone exposed along Pooler Creek north of road cut; see frontispiece, Oakes, 1940

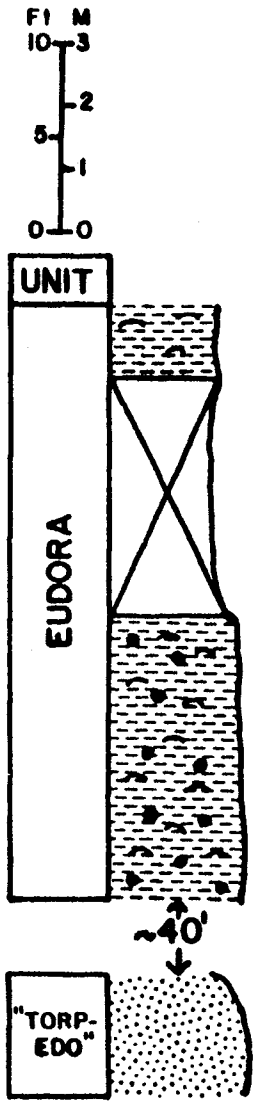
# 23.Cp 1




| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Cpl/30.5' | | | | | | | | | | | | | | | | | | | | |
| Cpl/13.5' | | | | | | | | | | | | | | | | | | | | |
| Cpl/0' | | x | | | x | | x | | | | | | | x | | | | | | Ammobaculites, Endothyranella? |

Sandstone exposed along Pooler Creek north of road cut; see frontispiece, Oakes, 1940

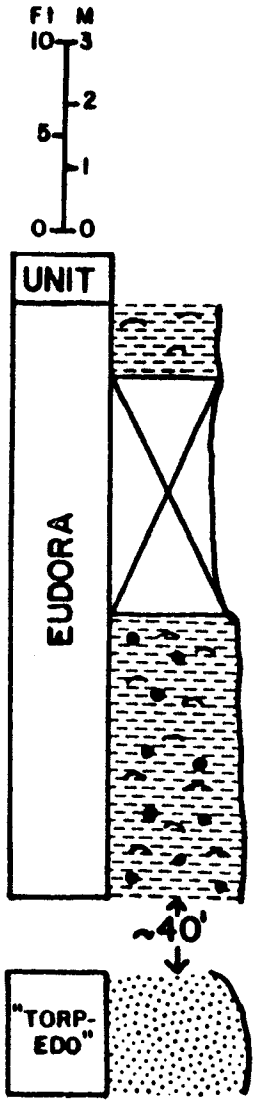
## 23.Cp 1




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cpl/30.5' | | x | | x | x | | | | | | | | | x | | x | | x | | |
| Cpl/13.5' | | | | | x | | | | x | | x | | | x | | | x | x | | |
| Cpl/0' | | | | | | | | | | | | | | | | | x | | | |

Sandstone exposed along Pooler Creek north of road cut; see frontispiece, Oakes, 1940

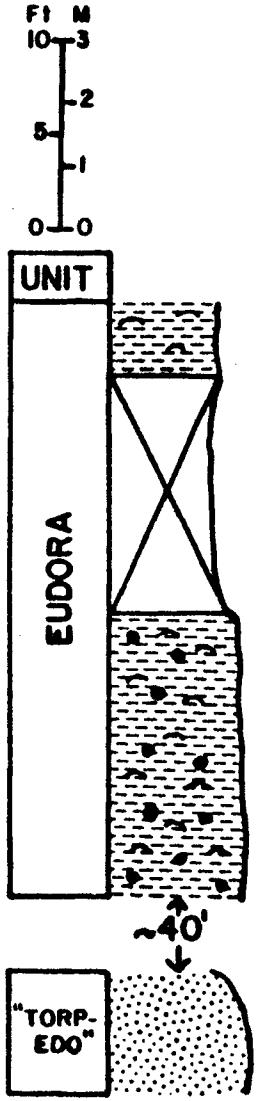
## 23.Cp 1




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cpl/30.5' | x | | Glabrocingulum | | | | | | | | |
| Cpl/13.5' | x | | Glabrocingulum, Palaeostylus?, Ananias? | x | ? | | | | | | |
| Cpl/0' | x | | Glabrocingulum, cf Bulimorpha, Plocezyga, Aclisina? | x | | Astartella | | | x | | x |

Sandstone exposed along Pooler Creek north of road cut; see frontispiece, Oakes, 1940

## 23.Cp 1




| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coeloclodia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cpl/305' | | x | x | | | 3 | 3 | x | 1 | x | | x | | | | x | | | | | |
| Cpl/13.5' | | x | | | | 3 | 4 | | 1 | | | | | | | x | | | | | |
| Cpl/0' | | x | | | | 1 | 1 | | 1 | | | | | | | | | | | x | |

Sandstone exposed along Pooler Creek north of road cut; see frontispiece, Oakes, 1940

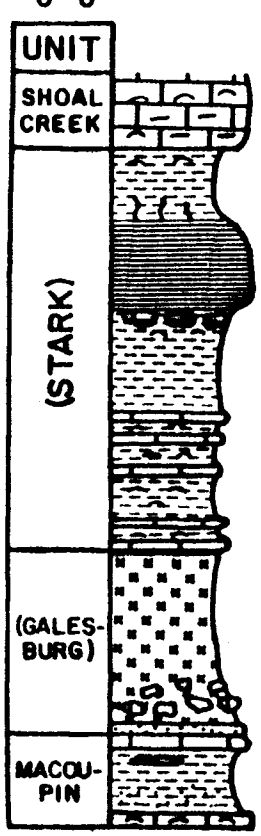
# 24.Cr I

Ft M Location: Creek bank about 1 1/2 mi southeast of Carlinville, Illinois

Carlinville E, Illinois, 7 1/2' T9NR7W2NW1/4NE1/4NE1/4

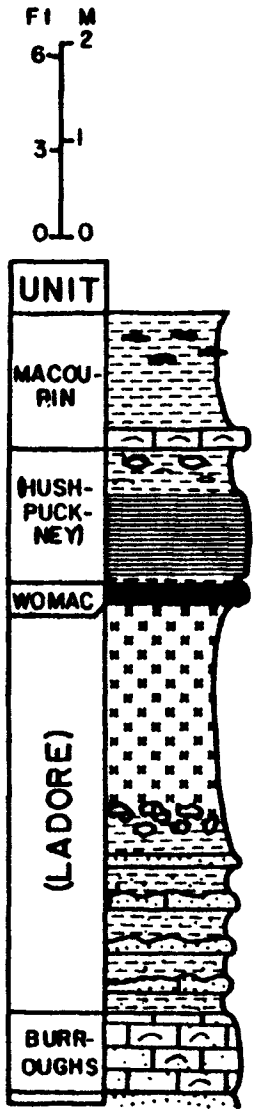
Reference: Ball, 1952, Geologic section 19

Collected: November 11, 1979 (Note: The section is drawn largely from Ball's description; when collected, much of the section was covered)



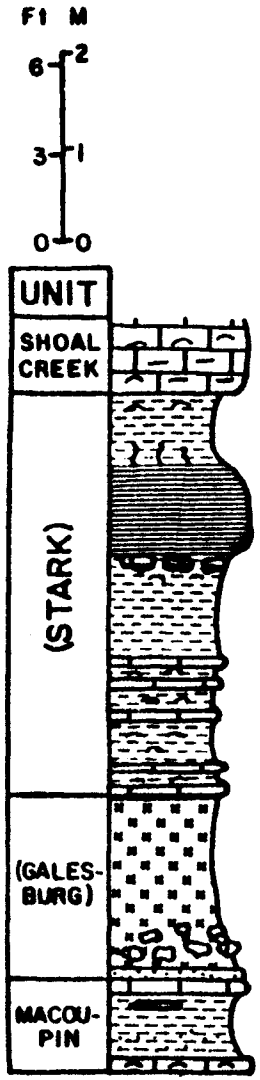

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr1/scf | 1.81 | 9.4 | 52 | 32 | | 8 | 9 | x | | | | .99 | | 25 | 25 | | 50 | 8 | | 5 | 12 | |
| grab Cr1/sc+m | 2.50 | 9.2 | 48 | 25 | | 16 | 11 | x | | | | .71 | | 17 | 16 | | 57 | | | 2 | 24 | |

## 24. Cr I (cont.)



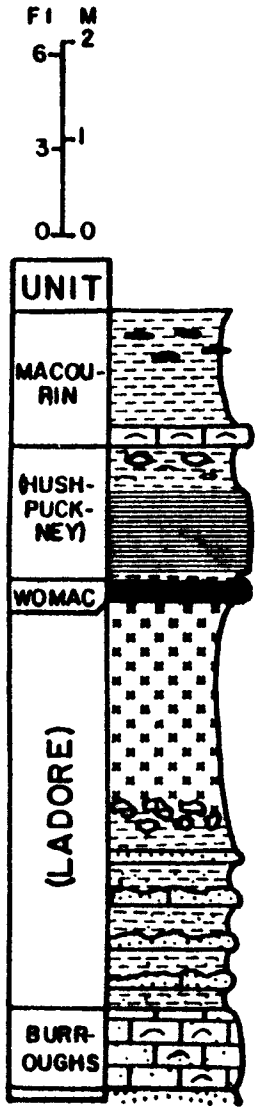

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/mt | 1.87 | 9.8 | 53 | 21 | | 14 | 12 | x | | | | .91 | | 5 | | | 100 | | | | | |
| Cr I/m | 2.34 | 9.2 | 52 | | | 10 | 39 | x | | | | 1.00 | | 174 | 7 | | 78 | 4 | | 2 | 9 | |
| Cr I/mabs | 2.29 | 9.6 | 46 | 35 | | 15 | 5 | | | | | .47 | | 504 | | | 92 | 1 | | 4 | 4 | |

# 24.Cr I



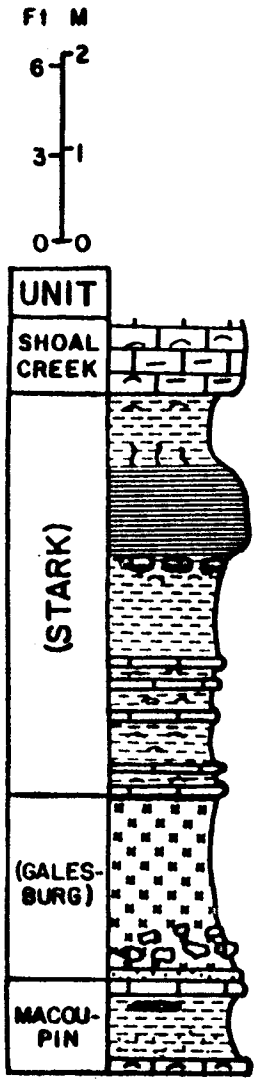

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr/scf | | | | | | | | | | | | | | | | x | x | | | |
| grab Cr/sc+m | | | | | | | | x | | | | | | | | | | | | |

## 24. Cr I (cont.)



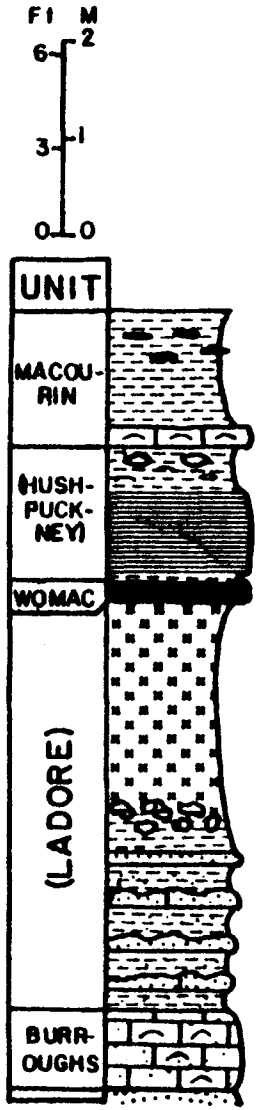

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/m+ | | | x | | x | | | | | | | | | | | x | | | | |
| Cr I/m | | | | | | | | | | | | | | | | x | | | | |
| Cr I/mabs | | | | | | | | | | | | | | | | | | | | |

# 24.Cr 1



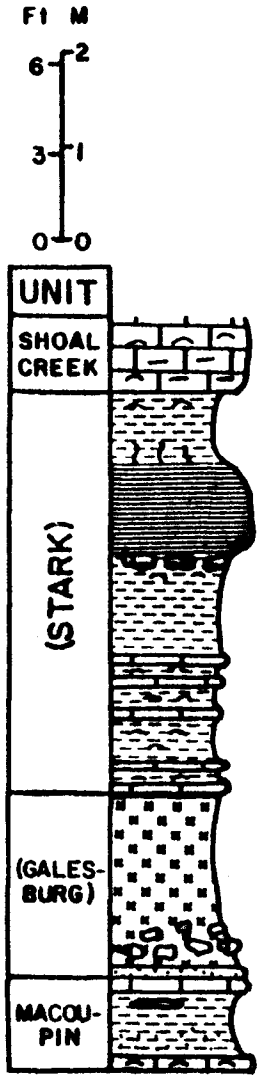

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr1/scf | | x | x | | | | | | | | | | | | | | | | | |
| grab Cr1/sec+m | | | | | x | | | | | | | | | | | | x | | | |

## 24. Cr I (cont.)



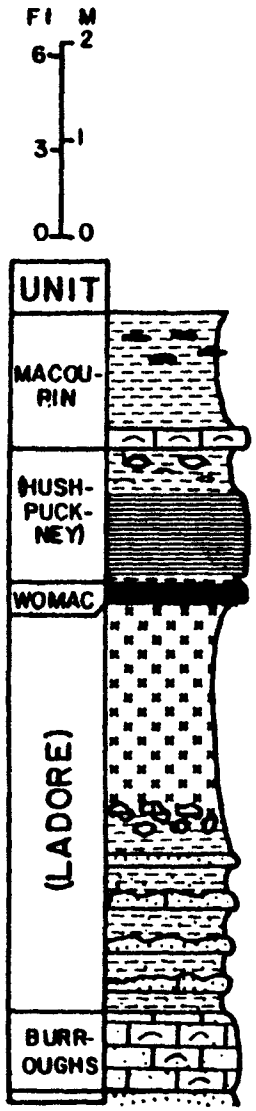

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/m+ | | | | | | | | | x | x | | ? | | x | | | x | | x | |
| Cr I/m | | | | | | | | | | | | | | | | | ? | | | |
| Cr I/mabs | | | | | | | | | | | | | | | | | | | | |

# 24.Cr I



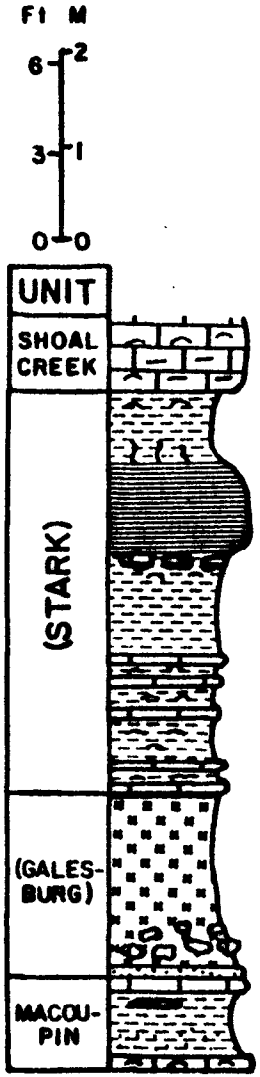

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr/scf | x | x | | x | | | | | | | |
| grab Cr/sc•m | x | | | | | | | | | | |

## 24. Cr I (cont.)



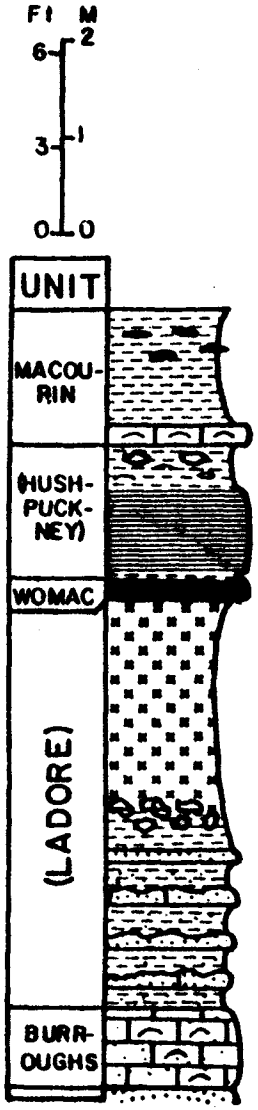

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/ms | x | | Palaeostylus?, Anematina?, Straparollus?, Rhabdotocochis? | | | | | | | | |
| Cr I/m | x | | | x | | | | | | | |
| Cr I/mabs | | | | | | | | | | | |

# 24.Cr I



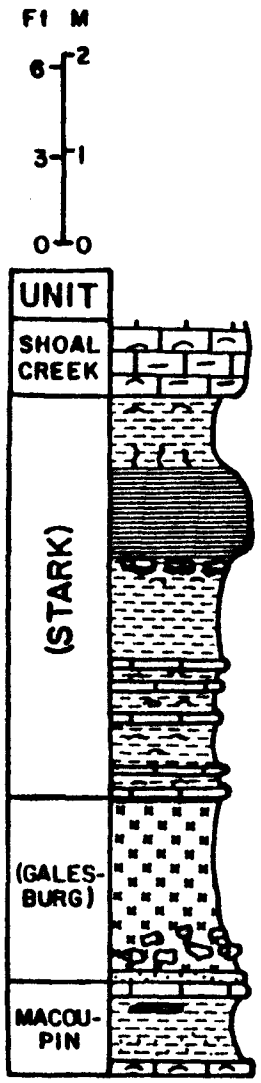

| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtycoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr I/scf | | | | | | | | | | | | | | | | | | | | | |
| grab Cr I/sc+m | | x | | | | | | | | | | | | | | x | Ditomopyge | | | | |

## 24. Cr I (cont.)



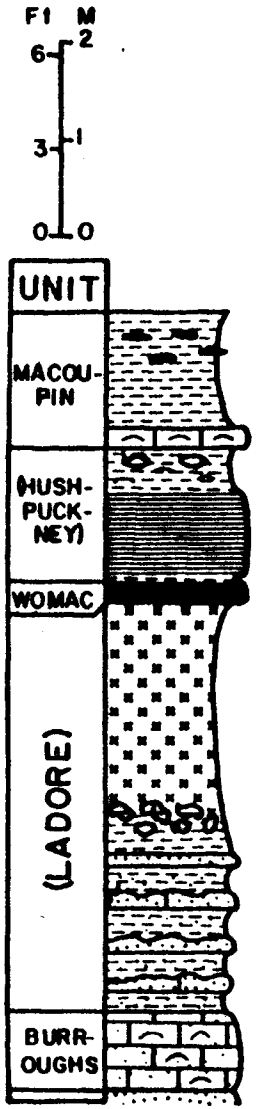

| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/m+ | | x | | | | I | I | | | | | | | | | x | Ameura, Ditomopyge | | | | |
| Cr I/m | | | | | | | | | | | | | | | | | | | | | |
| Cr I/mabs | | | | | | | | | | | | | | | | | | | | | |

# 24.Cr I




| Sample | FISH | paleoniscid teeth | altoamodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| float Cr I/scf | | x | | | | | | | | x | | | | | | | unidentified tooth |
| grab Cr I/sc•m | | | | | | | | | | x | | | | | | | |

## 24. Cr I (cont.)




| Sample | FISH | paleoniscid teeth | elasmodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr I/m+ Cr I/m | | x | | x | x | x | | | | | | x | | | | x | Protacrodus |
| Cr I/mabs | | | | x | | | | | x | | | | | | | | |

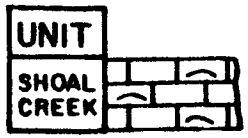
# 25.Cr 2

Location: Quarry 6 mi east of Carlinville, Illinois

Atwater, Illinois, 7 1/2'  T10NR6W27SE1/4NW1/4NW1/4

Reference: Berggren, 1979, p. 23

Note: Section unmeasured due to lack of reference horizon, but sample from near top of exposure




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr 2/sc | 1.72 | 9.2 | 52 | 17 | | 12 | 19 | | | | | 1.00 | | 4 | | | 75 | 25 | | | | |

## 25.Cr 2




Sample

Cr 2/sc

FORAMINIFERS

Hippocrepina

Ammodiscus

x Tolypammina

Ammovertella

Hyperammina

Textularia

other

x GASTROPODS

bellerophontids

other

## 25.Cr 2




Sample

Cr 2/ec

FISH

paleoniscid teeth

allomodonts

Stypobasis

Cladodus

Orodus

Hybodus

Petrodus

Listracanthus

Holmesella

Multidentodus

scale ?

Cooperella

Coelacyella

Moreyella

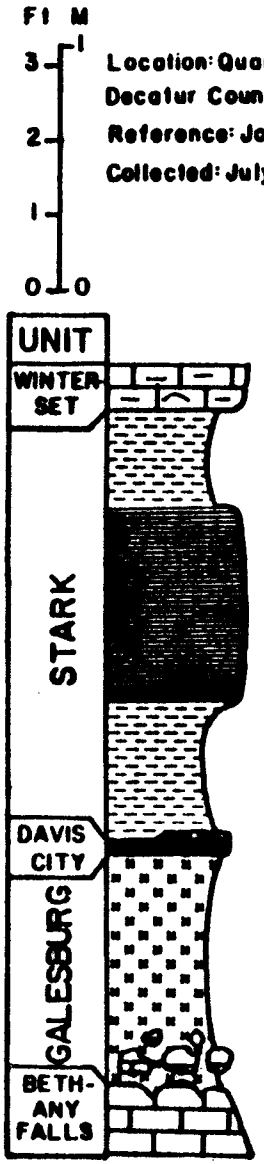
Kirkella

other unidentified fragments

# 26.DC I

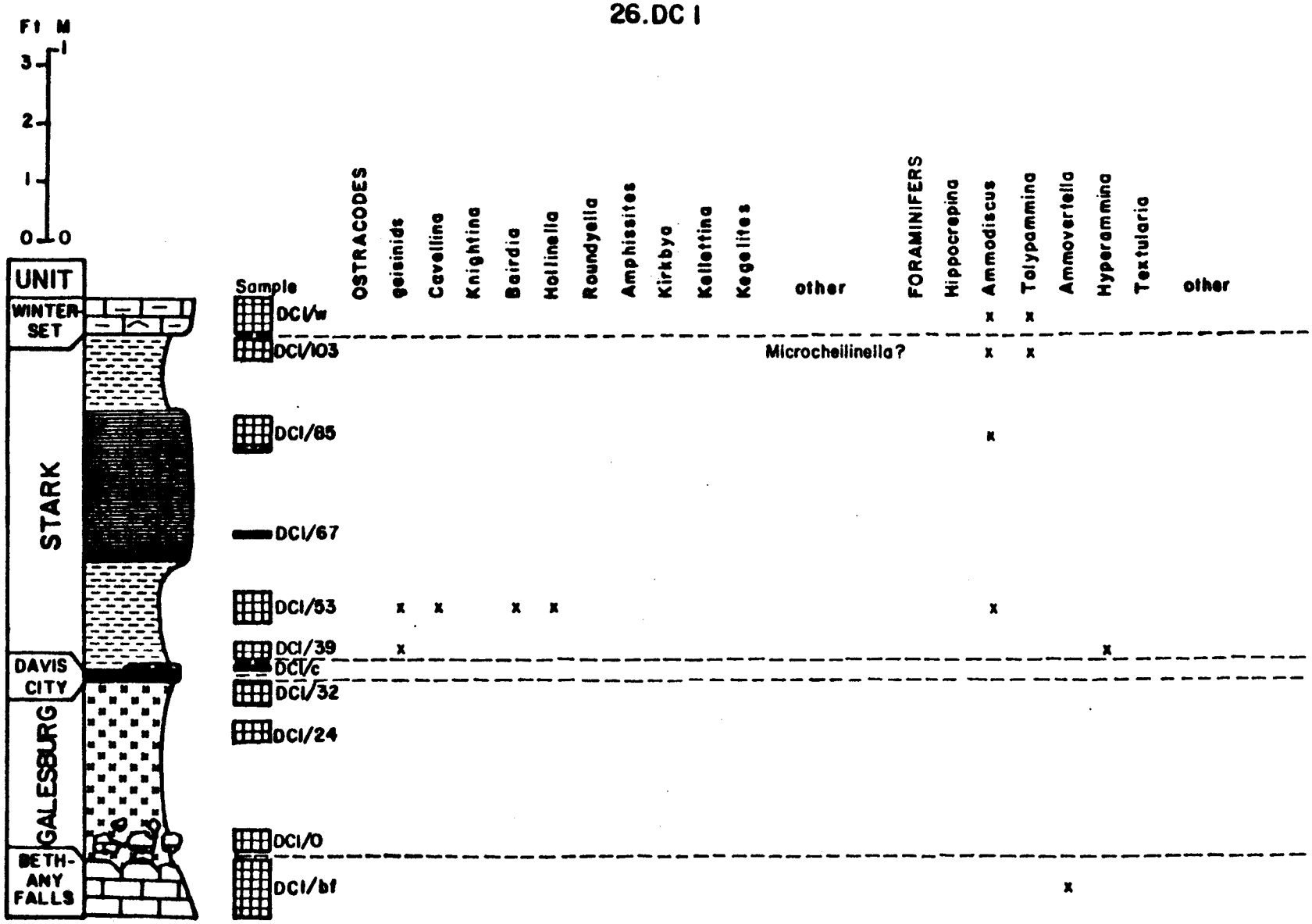
Location: Quarry 2 mi west of Davis City, Iowa
Decatur County, Iowa, map
Reference: Johnson, 1971, Loc. 53, p. 85
Collected: July 21, 1979

T67NR26W4NE1/4SE1/4

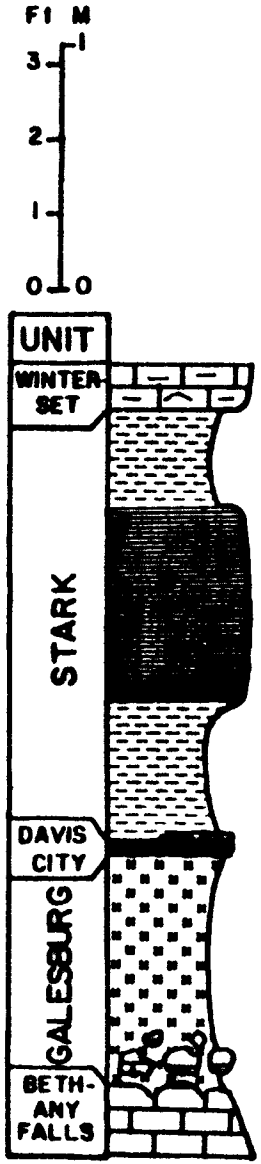



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DCI/w | 1.80 | 10.6 | 82 | | | 18 | | | x | | | 1.00 | | 119 | | | 88 | 11 | | 1 | | |
| DCI/103 | 2.30 | 9.9 | 63 | 14 | | 22 | | | | | | 1.02 | | 60 | | | 87 | 10 | t | 2 | | |
| DCI/85 | 4.21 | 10.8 | 66 | | | 34 | | | | | | .78 | | 68 | | | 74 | | | 2 | 25 | |
| DCI/67 | 1.83 | 9.5 | 59 | 14 | | 27 | | | | | | .76 | | 560 | | | 93 | | | 7 | 1 | |
| DCI/53 | 1.41 | 9.8 | 39 | 48 | | 14 | | | | | | .94 | | 111 | 58 | | 40 | 2 | | 1 | | |
| DCI/39 | 1.09 | 10.2 | 50 | 38 | | 12 | | | | | | | | | | | | | | | | |
| DCI/c | 1.04 | 6.4 | 42 | 53 | | 6 | | | x | | | | | | | | | | | | | |
| DCI/32 | .95 | 9.9 | 78 | 11 | | 11 | | | | | | | | | | | | | | | | |
| DCI/24 | 1.02 | 9.8 | 35 | 46 | | 19 | | | | | | | | | | | | | | | | |
| DCI/0 | 1.24 | 10.1 | 50 | 31 | | 19 | | | | | | | | | | | | | | | | |
| DCI/bf | 1.26 | 8.7 | 43 | 37 | | 20 | | | | | | | | | | | | | | | | |

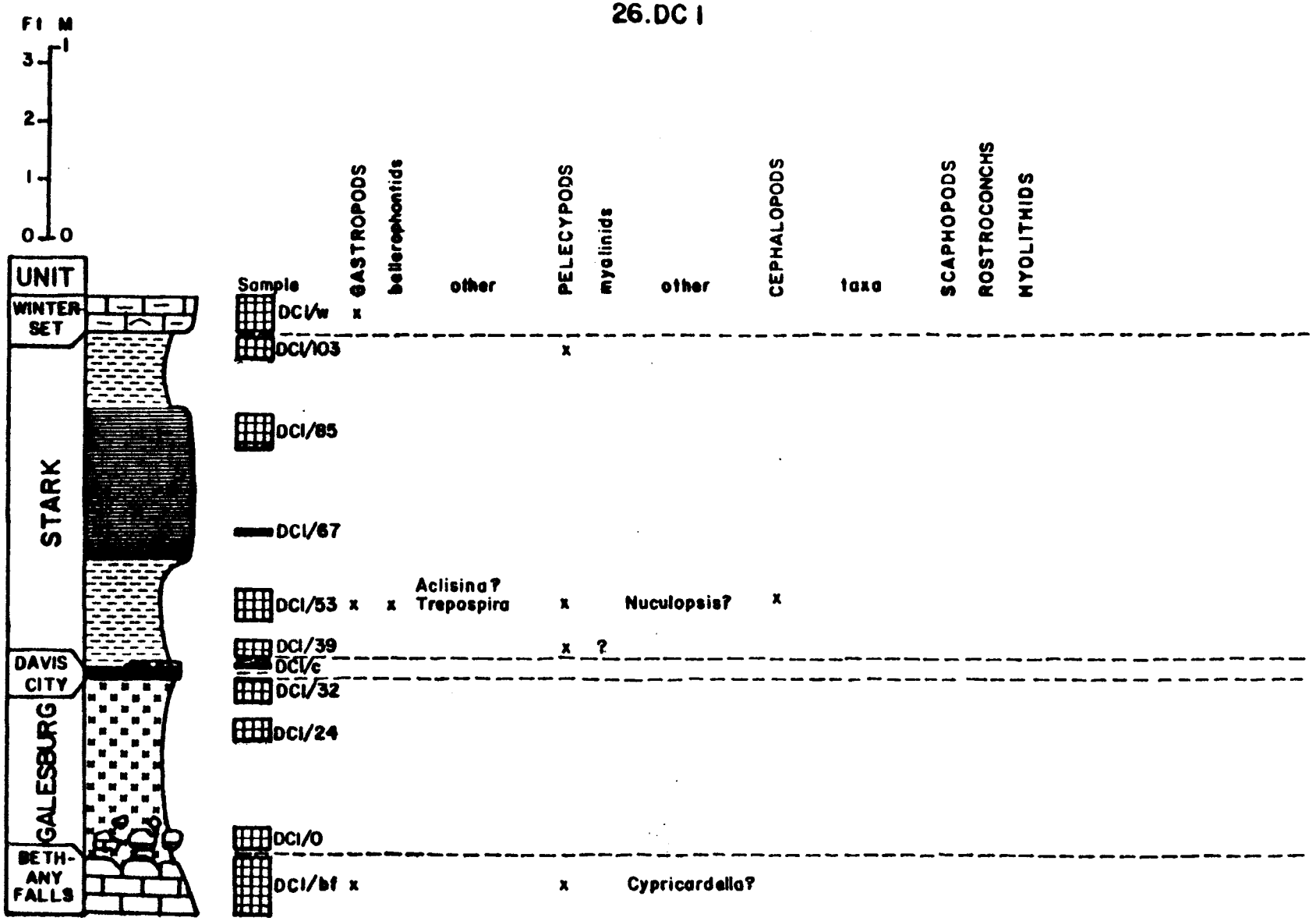
# 26.DC I


FT M
3
2
1
0
UNIT
WINTER-SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
OSTRACODES
geisinids
Cavelline
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
DCI/w
DCI/103
Microcheilinella?
DCI/85
DCI/67
DCI/53
DCI/39
DCI/c
DCI/32
DCI/24
DCI/0
DCI/bf

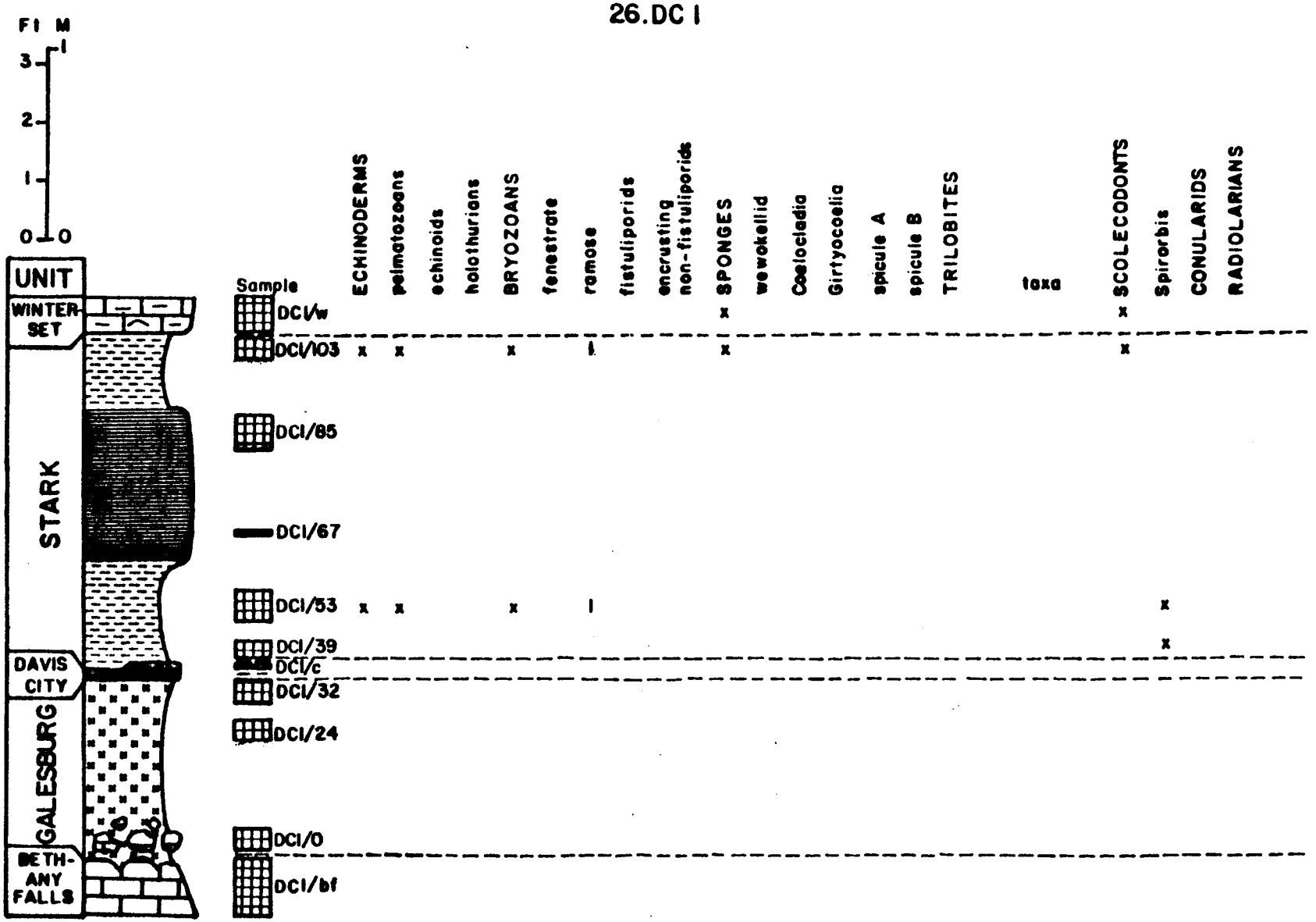
# 26.DC I



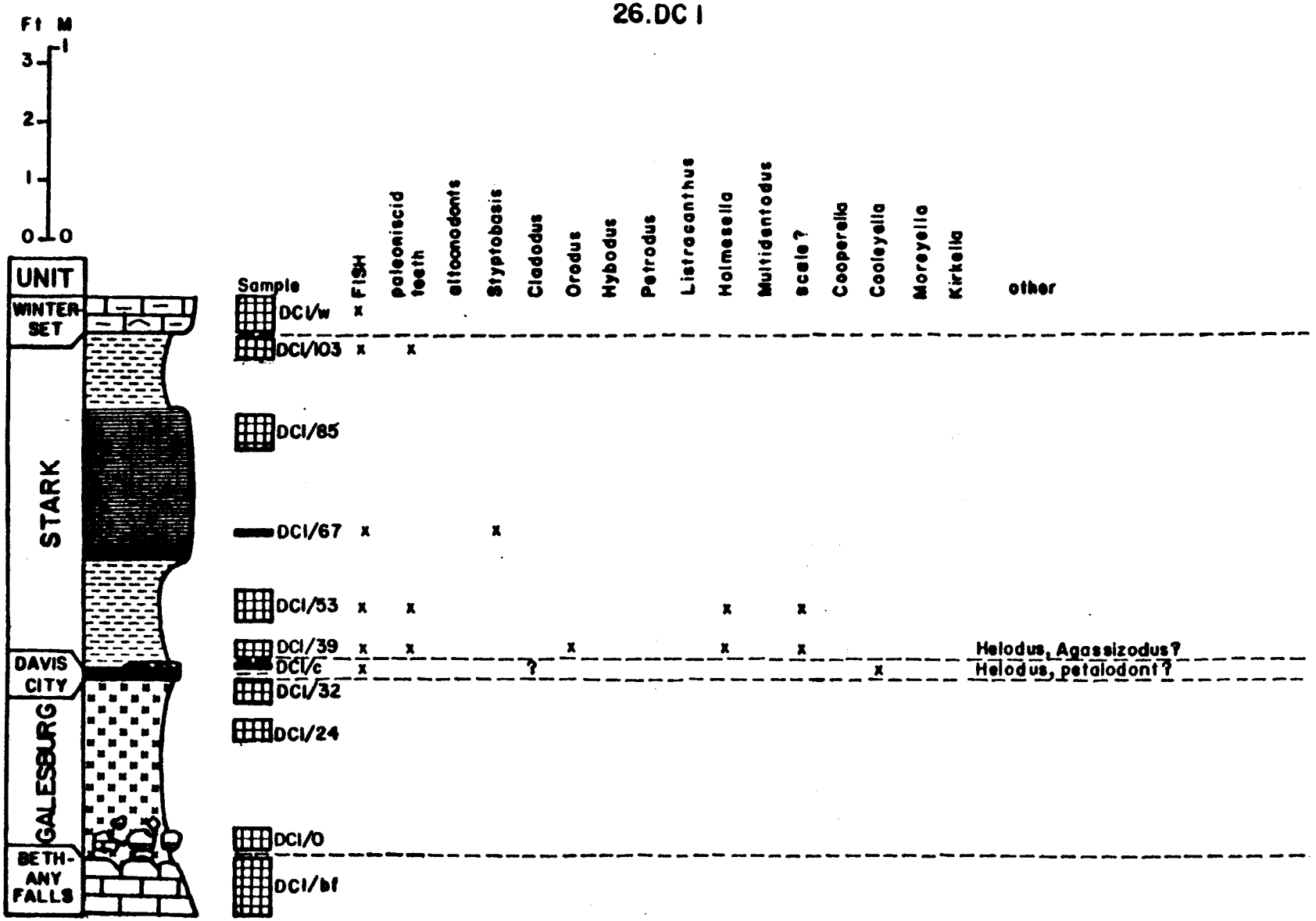

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | ? productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DCI/w | | x | | | | | | | | | | | | | | | | | | |
| DCI/103 | | x | | | | | | | x | | | | | x | | ? | x | x | | |
| DCI/85 | | x | | x | | | | | | | | | | | | | x | | | |
| DCI/67 | | | | | | | | | | | | | | | | | | | | |
| DCI/53 | | x | | | x | | | | x | x | | x | | | | | x | | | |
| DCI/39 | | x | | | | | | | | | | | | | | | x | | | |
| DCI/c | | x | | | | | | | | | | | | | | | | | | |
| DCI/32 | | | | | | | | | | | | | | | | | | | | |
| DCI/24 | | | | | | | | | | | | | | | | | | | | |
| DCI/0 | | | | | | | | | | | | | | | | | | | | |
| DCI/bf | | | | | | | | | | | | | | | | | | | | |


26.DC I
FT M
3
2
1
0
UNIT
WINTER-SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
DCI/w x
DCI/103 x
DCI/85
DCI/67
DCI/53 x x Aclisina? Trepospira x Nuculopsis? x
DCI/39 x ?
DCI/c
DCI/32
DCI/24
DCI/0
DCI/bf x x Cypricardella?

# 26.DC I


FT M
3 1
2
1
0 0
UNIT
WINTER-SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
DCI/w
DCI/103
DCI/85
DCI/67
DCI/53
DCI/39
DCI/c
DCI/32
DCI/24
DCI/0
DCI/bf

# 26.DC I


Ft M
3 1
2
1
0 0
UNIT
WINTER-SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
elteonodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
DCI/w
DCI/103
DCI/85
DCI/67
DCI/53
DCI/39
DCI/c
DCI/32
DCI/24
DCI/0
DCI/bf
Helodus, Agassizodus?
Helodus, petalodont?

# 27.Del

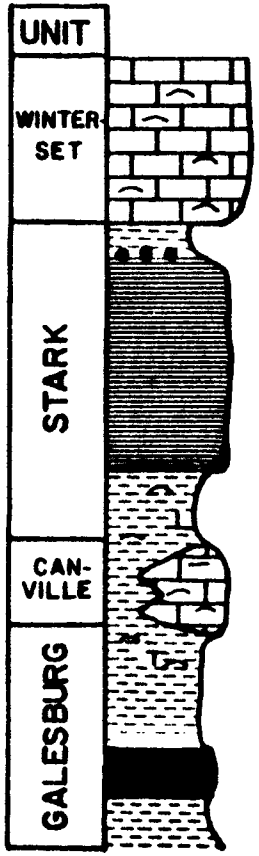
Ft M Location: Road cut on county road 1 mi west and 1/2 mi south of Dennis, Kansas

1 .3 Dennis, Kansas, 7 1/2' T3IS R18E 2INE1/4NE1/4SE1/4

References: Frost, 1968, Loc. 9, p.135; Heckel et al., 1979, Stop 7, p.34

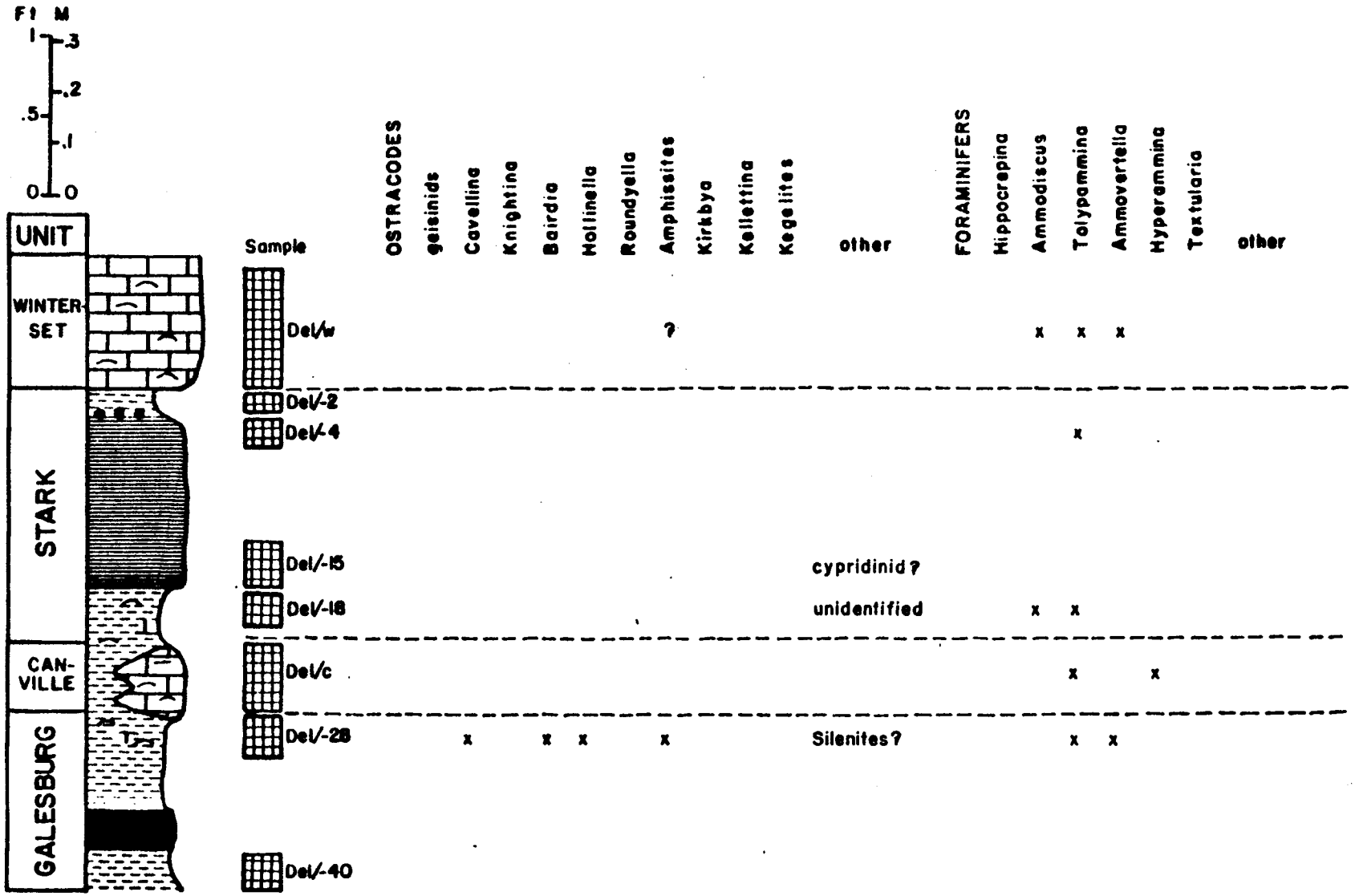
.5 .2 Collected: August 16, 1978

0 .1 0




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Del/w | 1.53 | 9.3 | 66 | 27 | | 6 | 1 | | x | | | .91 | | 285 | | | 96 | 4 | | | | |
| Del/-2 | 1.48 | 9.3 | 50 | 43 | | 2 | 4 | x | | | | .52 | | 959 | | | 94 | t | | 2 | 3 | |
| Del/-4 | 1.35 | 8.8 | 69 | 29 | | 2 | | | | | | .08 | | 2759 | | | 94 | | | 3 | 3 | |
| | Carbonate nodule from same level as Del/-15 processed for conodonts only → | | | | | | | | | | | 1.99 | | 70 | | | 92 | 6 | | 3 | | |
| Del/-15 | 1.46 | 9.5 | 55 | 17 | | 28 | | | | | | .07 | | 533 | | | 95 | | | 5 | | |
| Del/-18 | 1.29 | 10.0 | 63 | 27 | | 4 | 6 | x | | | | .10 | | 263 | | | 100 | | | | | |
| Del/c | 1.83 | 9.2 | 66 | 7 | | 16 | 11 | x | x | | | 2.00 | | 40 | 13 | | 74 | 14 | t | | | |
| Del/-28 | 1.71 | 9.4 | 62 | 33 | | 3 | 3 | x | | | | .12 | | 347 | | | 98 | 2 | | | | |
| Del/-40 | 1.45 | 9.3 | 51 | 22 | | 8 | 20 | x | | | | | | | | | | | | | | |

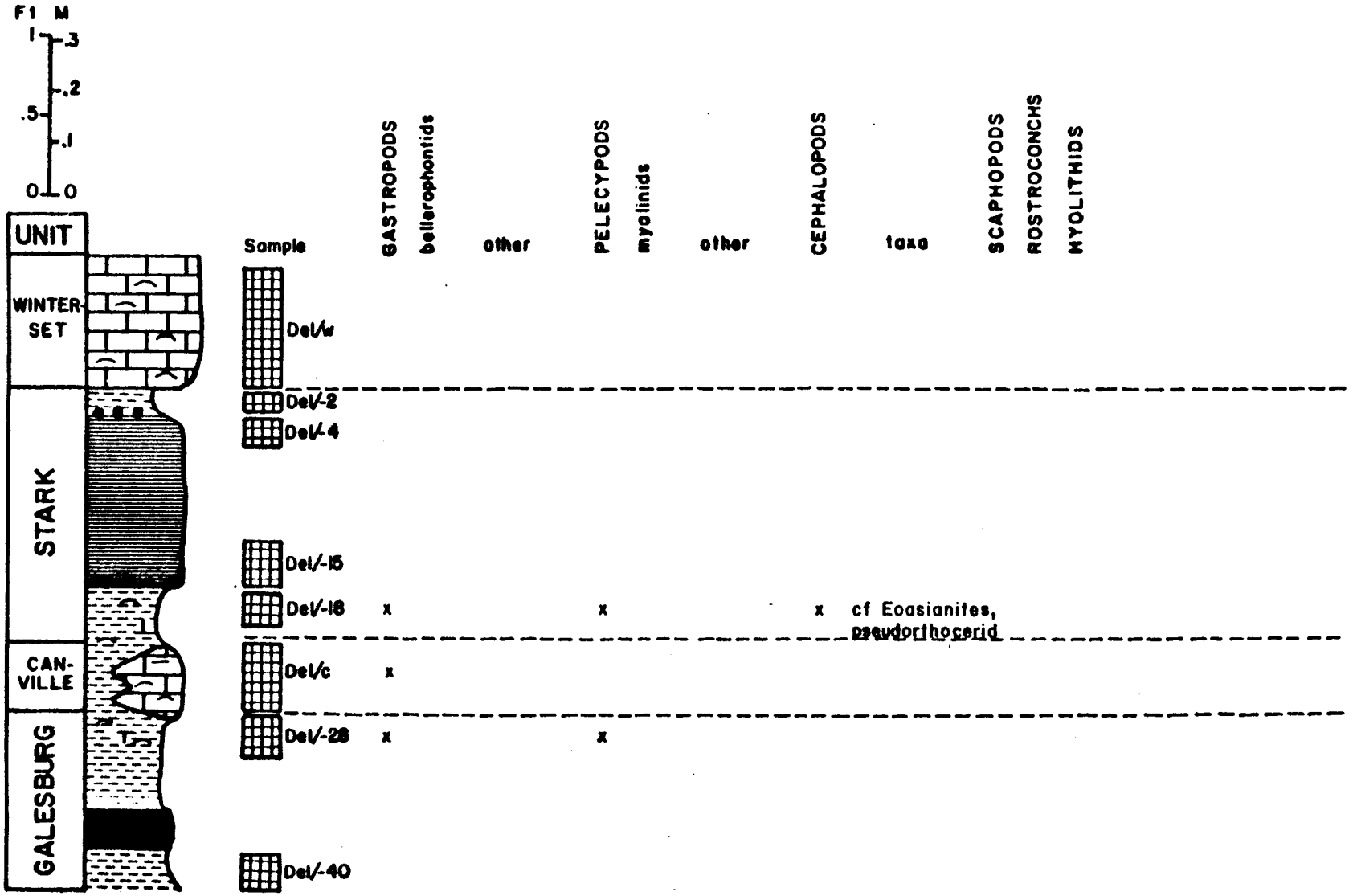
# 27.De I

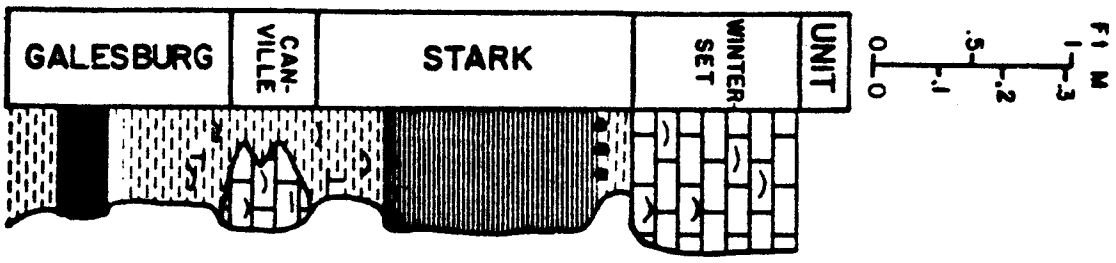

FT M
1 .3
.2
.5 .1
0 0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALESBURG
Sample
OSTRACODES
geisinids
Cavelina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Talypammina
Ammovertella
Hyperammina
Textularia
other
DeI/w
DeI/-2
DeI/-4
DeI/-15
DeI/-18
DeI/c
DeI/-28
DeI/-40
cypridinid?
unidentified
Silenites?

# 27.De I


Ft M
1 3
.2
.5
.1
0 0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALESBURG
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Jurassania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
DeI/w
DeI/-2
DeI/-4
DeI/-15
DeI/-18
DeI/c
DeI/-28
DeI/-40

# 27.Del


F1 M
1 .3
.2
.5 .1
0 0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALESBURG
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Del/w
Del/-2
Del/-4
Del/-15
Del/-18
x
x
x
cf Eoasianites, pseudorthoceríd
Del/c
x
Del/-28
x
x
Del/-40

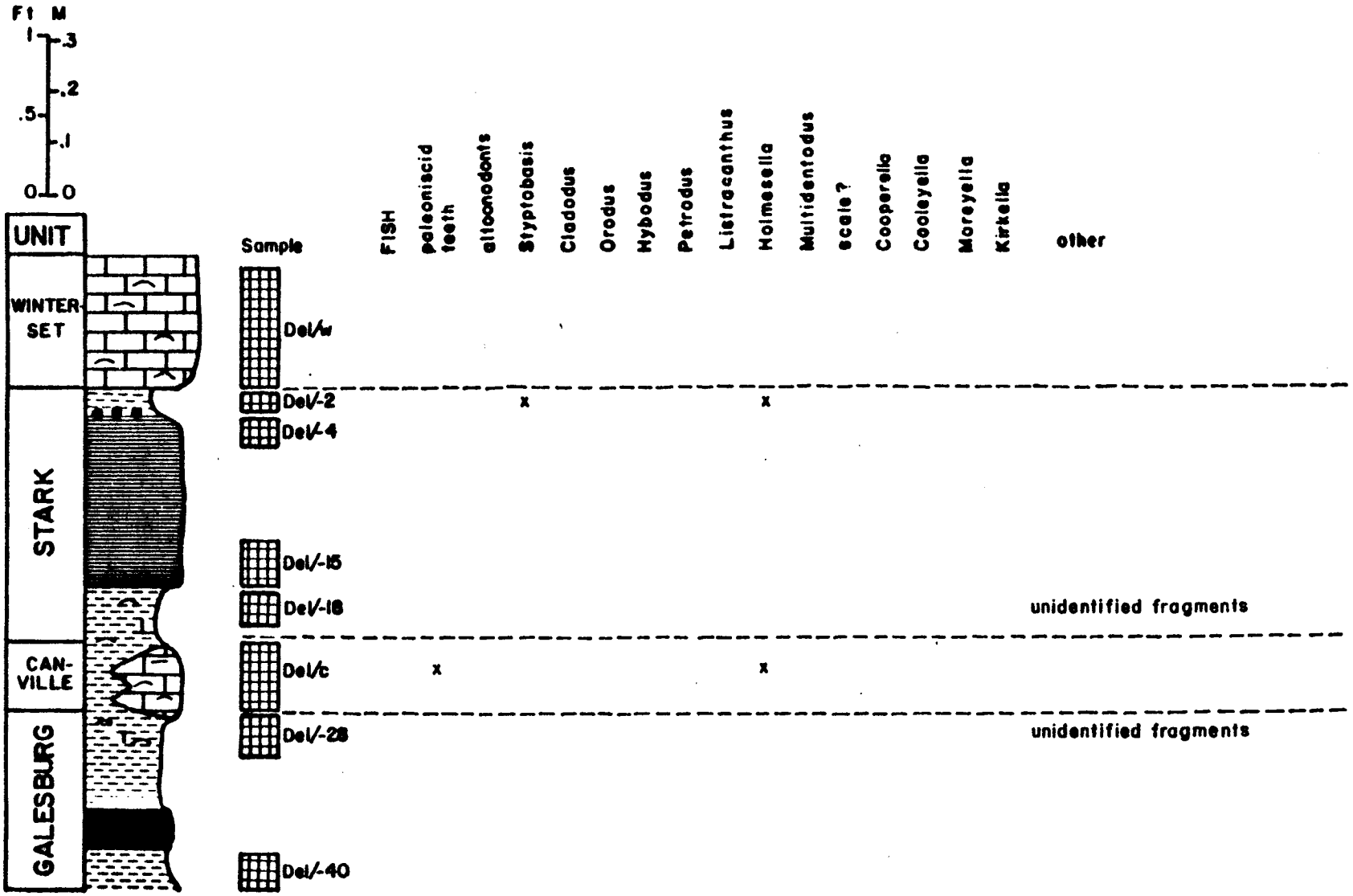



| Sample | Del/w | Del/-2 | Del/-4 | Del/-15 | Del/-18 | Del/c | Del/-28 | Del/-40 |
|---|---|---|---|---|---|---|---|---|
| ECHINODERMS | | | | | | | | |
| pelmatozoans | | | | | x | | x | |
| echinoids | | | | | | | x | |
| holothurians | | | | | | | | |
| BRYOZOANS | | | | | | | | |
| fenestrate | | | 1 | | 2 | | 1 | ? |
| ramose | | | 1 | | 1 | 1 | 1 | |
| fistuliporids | | | | | | | | |
| encrusting non-fistuliporids | | | | | | | 1 | |
| SPONGES | | | | | | | | |
| wewokellid | | | | | | | | |
| Coelocladia | | | | | | | | |
| Girtyocoelia | | | | | | | | |
| spicule A | | | | | | | | |
| spicule B | | | | | | | | |
| TRILOBITES | | | | | x | | x | |
| SCOLECODONTS | | | | | | | | |
| Spirorbis | | | | | | | | |
| CONULARIDS | | | | | | | | |
| RADIOLARIANS | | | x | | | | | |

text

27.Del

# 27.Del

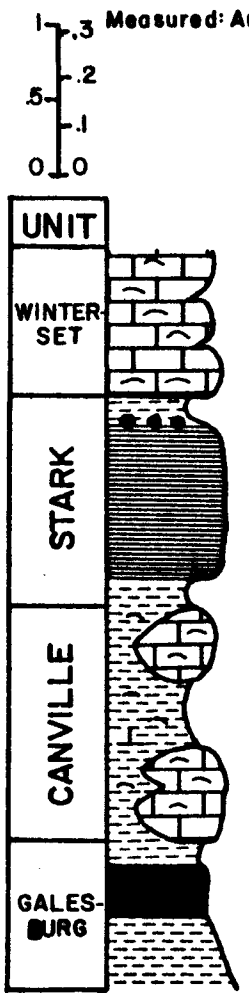

Ft M
1 .3
.2
.5 .1
0 0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALESBURG
Sample
FISH
paleoniscid teeth
allocnodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Del/w
Del/-2
Del/-4
Del/-15
Del/-18
Del/c
Del/-28
Del/-40
x
x
x
x
unidentified fragments
unidentified fragments

# 28.De 2

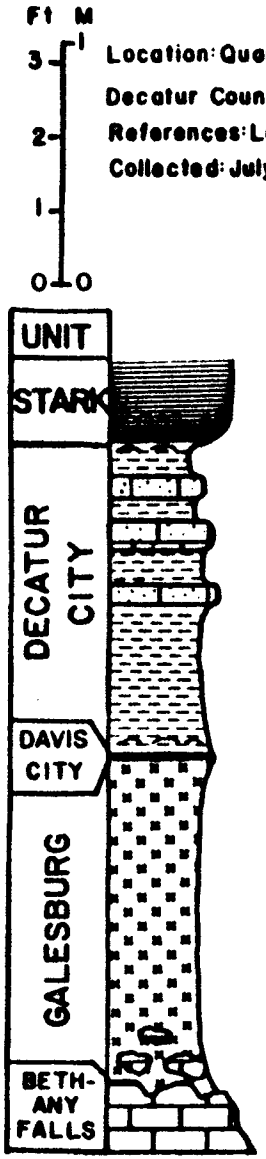
Location: Road ditch on county road, 2 mi and 1/3 mi south of Dennis, Kansas

Dennis, Kansas, 7 1/2'  T31SR18E20NE1/4NE1/4NE1/4

Measured: August 16, 1978



# 29.DeC I




Location: Quarry about 2 mi southwest of Decatur (City), Iowa

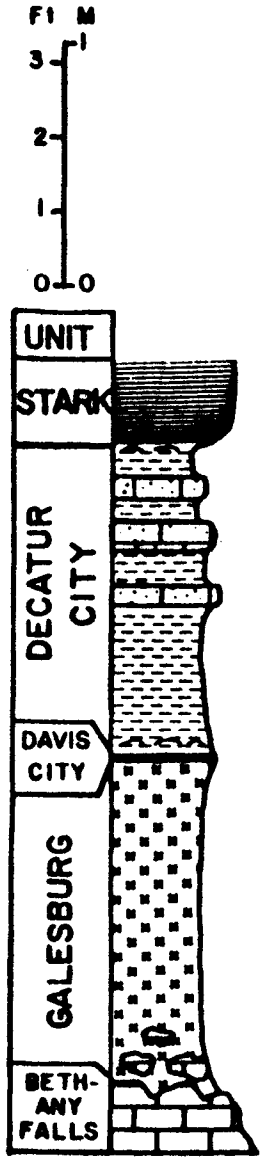
Decatur County, Iowa, map T69NR26W32SW1/4SE1/4

References: Lamerson, 1956, Sect. 33, p.125; Johnson, 1971, Loc. 50, p.84

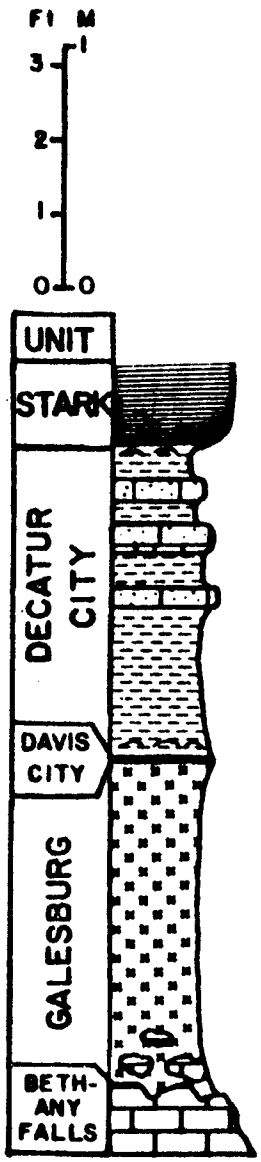
Collected: July 21, 1979

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Asthotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DeCI/102 | 1.85 | 8.6 | 51 | 29 | | 21 | | | | | | .55 | 577 | t | | 96 | t | | 4 | | |
| DeCI/97 | 1.40 | 9.9 | 51 | 30 | | 19 | | | x | | | .19 | 623 | 25 | | 70 | 4 | | t | | |
| DeCI/85 | 1.09 | 8.8 | 59 | 31 | | 10 | | | | | | | | | | | | | | | | |
| DeCI/63 | 1.09 | 9.5 | 44 | 38 | | 19 | | | | | | .74 | 1 | | | 100 | | | | | | |
| DeCI/53 | 1.25 | 10.6 | 39 | 47 | | 15 | | | | | | | | | | | | | | | | |
| DeCI/45 | 1.14 | 9.0 | 37 | 43 | | 20 | | | | | | | | | | | | | | | | |

## 29.DeC I



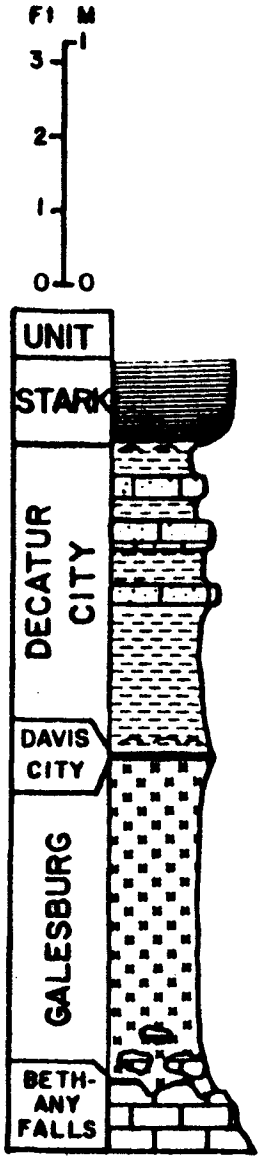

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DeCI/102 | | | | | | | | | | | | | | | | x | | | | |
| DeCI/97 | | x | x | | x | | | | | | | Sulcella | | | | x | | | | |
| DeCI/85 | | | | | | | | | | | | | | | | | | | | |
| DeCI/63 | | x | | | | | | | | | | | | | | x | | x | | |
| DeCI/53 | | x | | | | | | | | | | | | | | x | | x | | |
| DeCI/45 | | | | | | | | | | | | | | | | | | | | |



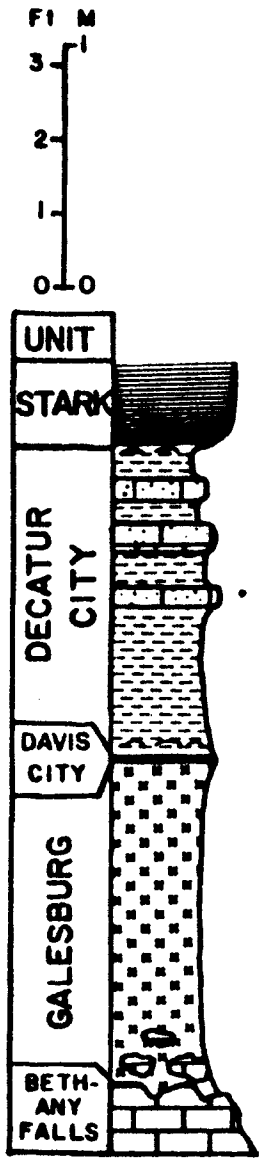

## 29.DeCl

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DeCl/102 | | | | | | | | | | | | | | | | | x | | | |
| DeCl/97 | | x | | | x | | | | x | | x | x | | | | | x | | | |
| DeCl/85 | | | | | | | | | | | | | | | | | | | | |
| DeCl/63 | | | | | | | | | | | | x | | | | | x | | | |
| DeCl/53 | | x | | | | | | | | | | | | | | | | | | |
| DeCl/46 | | | | | | | | | | | | | | | | | | | | |

## 29.DeC I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | MYOLITHIDS | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DeCI/102 | | | | | | | | | | | | | | | | |
| DeCI/97 | x | x | Trepospira? | x | | | | | x | | | | I | I | | |
| DeCI/85 | | | | | | | | | | | | | | | | |
| DeCI/63 | x | | Hypselentoma?, ? Aclisina? | | ? | | | | | | | | | | | |
| DeCI/53 | x | | Aclisina? | x | x | | | | | | | | | | | |
| DeCI/46 | | | | | | | | | | | | | | | | |

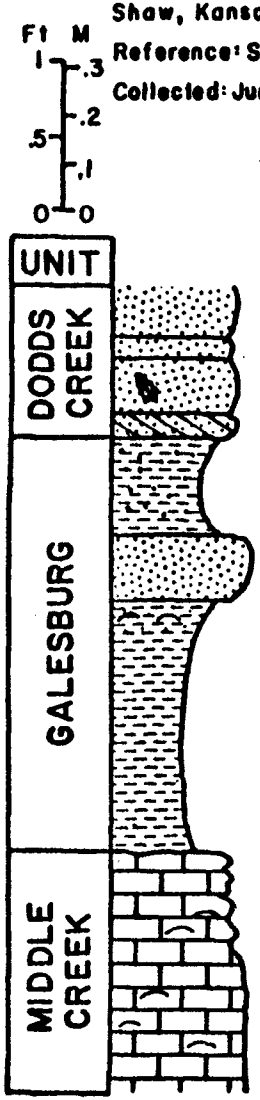



## 29.DeC I

| Sample | Fish | paleoniscid teeth | elliconodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Coelacella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DeCI/102 | | | | | | | | | | | | | | | | | unidentified fragments |
| DeCI/97 | | x | | | | | | | | | | | | | | | |
| DeCI/85 | | | | | | | | | | | | | | | | | |
| DeCI/63 | | | | | | | | | | | | | | | | | |
| DeCI/53 | | x | | | | | | | | | | | | | | | Helodus |
| DeCI/45 | | | | | | | | | | | | | | | | | |

# 30.Er 1

Location: Road cut on US Highway 59 at intersection with Kansas Highway 146 1 3/4 mi north of Erie, Kansas
Shaw, Kansas, 7 1/2'  T28SR20E19NE1/4NE1/4NE1/4
Reference: Stobbe, 1971, Outcrop No. 3, p. 2
Collected: June 10, 1979

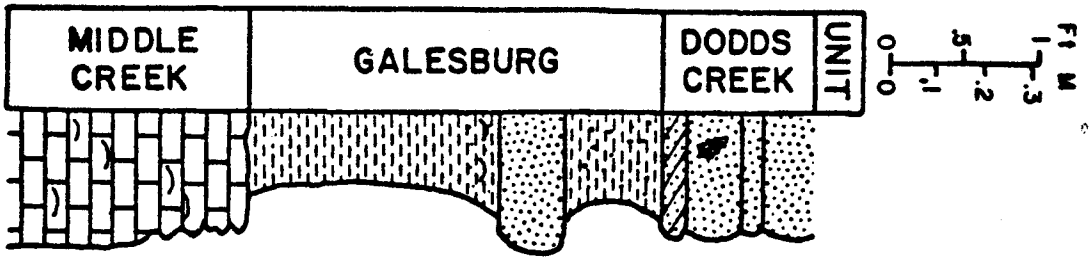



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Er1/26 | 4.41 | 9.9 | 60 | 8 | | 7 | 26 | x | | | | .94 | | | | | | | | | | x |
| Er1/17 | 1.92 | 9.0 | 46 | 24 | | | 31 | x | | | | .24 | | 8 | | | 100 | | | | | |
| Er1/0 | 1.76 | 9.3 | 47 | 24 | | 6 | 23 | x | | | | .98 | | 3 | 33 | | 33 | | | | 33 | |
| Er1/bf | | | | | | | | | | | | 1.00 | | 26 | 65 | 8 | 4 | 23 | | | | |

# 30. Er 1




| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Er1/25 | | | | | | | | | | | | | | | | | | | | |
| Er1/17 | | | | | | | | | | | | | | | | | | | | |
| Er1/0 | | | | | | | | | | | | | | | | | | | | |
| Er1/bf | x | | | | | | | | | | | | | | x | | | | | |




| Sample | Er1/26 | Er1/17 | Er1/0 | Er1/bf |
|---|---|---|---|---|
| **ECHINODERMS** | | | | |
| pelmatozoans | x | x | | |
| echinoids | | | | |
| holothurians | | | | |
| **BRYOZOANS** | | | | |
| fenestrate | | | | |
| ramose | | | | – |
| fistuliporids | | | | – |
| encrusting non-fistuliporids | | | | – |
| **SPONGES** | | | | |
| wewokellid | | | | |
| Coelocladia | | | | |
| Girtyocoelia | | | | |
| spicule A | | | | |
| spicule B | | | | |
| **TRILOBITES** | | | | |

| taxa | |
|---|---|
| **SCOLECODONTS** | |
| Spirorbis | |
| **CONULARIDS** | |
| **RADIOLARIANS** | |

30.Er 1

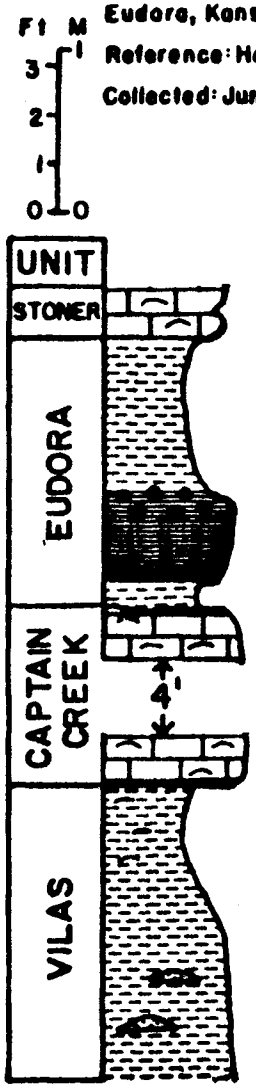
# 30. Er 1



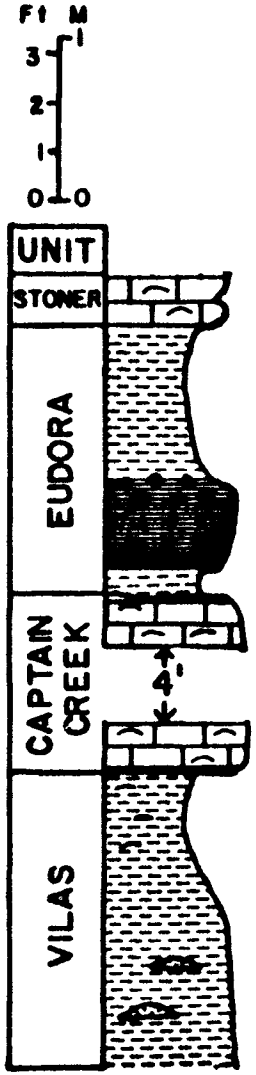

| Sample | FISH | paleoniscid teeth | elliocnodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Er1/25 | | | | | | | | | | | | | | | | | |
| Er1/17 | | ? | | | | | | | | | | | | | | | |
| Er1/0 | | | | | | | | | | | | | | | | | |
| Er1/bf | | x | | | | | | | | x | | | | x | | | |

# 31. Eu I

Location: Road cut at Kansas Highway 10 interchange 4 mi ENE of Eudora, Kansas
Eudora, Kansas, 7 1/2' T12SR21E36SE1/4SE1/4
Reference: Heckel et al., 1979, Stop 13, p. 43
Collected: June 7, 1979




| Sample | Mite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eul'/5 | 1.90 | 9.7 | 58 | 18 | | 23 | | | x | | | 1.00 | | 19 | | | 70 | 27 | | 3 | | |
| Eul'/59 | 2.02 | 10.2 | 58 | 28 | | 14 | | | x | | | .30 | | 41 | | | 96 | | | 4 | | |
| Eul'/49 | 2.16 | 9.8 | 55 | 26 | | 19 | | | x | | | .17 | | 206 | 3 | | 94 | | | 3 | | |
| Eul'/31 | 1.91 | 9.8 | 52 | 29 | | 19 | | | x | | | .34 | | 40 | | | 22 | | | 4 | 74 | |
| Eul'/16 | 1.38 | 9.8 | 49 | 37 | | 14 | | | | | | .11 | | 552 | | | 63 | | | 3 | 34 | |
| Eul'/5 | 1.62 | 10.1 | 51 | 33 | | 16 | | | | | | .27 | | 166 | | | 99 | | | 1 | | |
| Eul'/0 | | | x | x | | x | | | x | | | .18 | | 893 | | | 99 | 1 | | | | |
| Eul/cc | 1.95 | 10.4 | 46 | 44 | | 7 | 3 | | | | | 1.00 | | 5 | 60 | | | 40 | | | | |
| Eul/-4 | 1.78 | 10.2 | 40 | 57 | | | 3 | x | | | | .65 | | 11 | 57 | | | 43 | | | | |
| Eul/-36 | 2.04 | 10.1 | 59 | 37 | | 2 | 2 | x | | | | | | | | | | | | | | |
| Eul/-66 | 2.32 | 10.7 | 47 | 38 | | 10 | 5 | x | | | | | | | | | | | | | | |

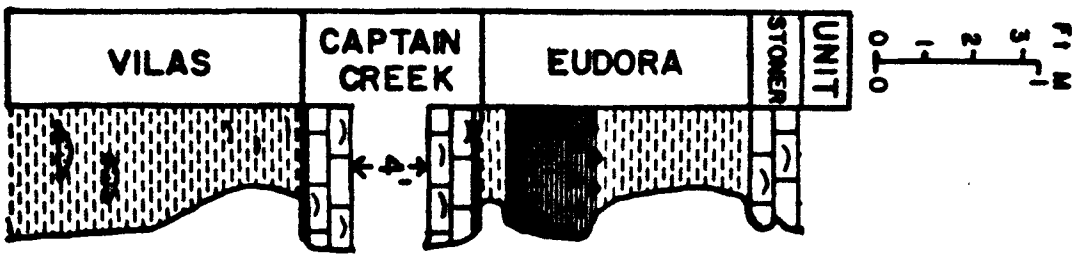



| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eul'/5 | | | | | | | | | | | | | | | | x | | x | | |
| Eul'/59 | | | x | | | | | | | | | | | | x | x | | | | |
| Eul'/49 | | | x | | | | | | | | | | | | x | | | x | x | |
| Eul'/31 | | | | | | | | | | | | | | | x | | | | | |
| Eul'/16 | | | | | | | | | | | | | | | | | | | | |
| Eul'/5 | | | | | | | | | | | | | | | | | | | | |
| Eul'/0 | | | x | | x | | | x | | | | | | | | x | | x | | |
| Eul/cc | | | | | | | | | | | | | | | | x | | | | |
| Eul/-4 | | | x | x | x | | | | | | | Bairdiacypris | | | | | | x | x | Endothyra? |
| Eul/-36 | | | | | | | | | | | | | | | | | | | | |
| Eul/-65 | | | | | | | | | | | | | | | | | | | | |

31.Eu I
Ft M
3
2
1
0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
4'
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Eul/3
Eul/59
Eul/49
Eul/31
Eul/16
Eul/5
Eul/0
Eul/cc
Eul/-4
Eul/-36
Eul/-65
?

## 31.Eu I

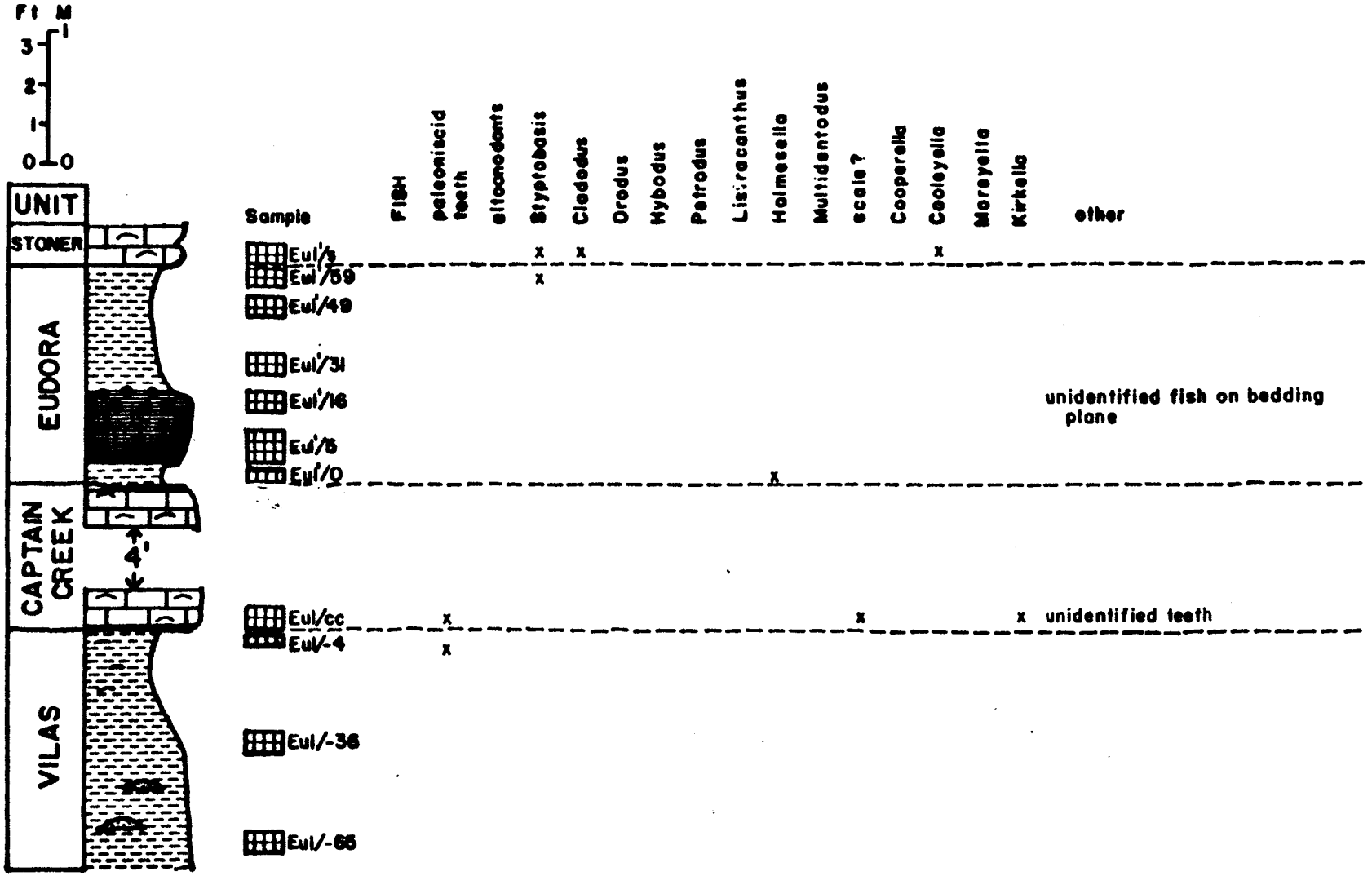

Ft
M
3
2
1
0
0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Eul/5
Eul/59
Eul/49
Eul/31
Eul/16
Eul/5
Eul/0
Eul/cc
Eul/-4
Eul/-36
Eul/-65
x
x
x
x




| Sample | Eul/-86 | Eul/-36 | Eul/GC Eul/-4 | Eul/2 Eul/69 | Eul/49 | Eul/31 | Eul/18 | Eul/5 | Eul/2 |
|---|---|---|---|---|---|---|---|---|---|
| ECHINODERMS | | | | | | | | | |
| pelmatozoans | x | x | x | | | | | | x |
| echinoids | | | x | | | | | | |
| holothurians | | | | | | | | | |
| BRYOZOANS | | | | | | | | | |
| fenestrate | 1 | 1 | 2 | | | | | | 1 |
| ramose | 1 | | 1 | | | | | | 1 |
| fistuliporids | | | | | | | | | |
| encrusting non-fistuliporids | | | | | | | | | |
| SPONGES | | | | x | | | | | |
| wewokellid | | | | | | | | | |
| Coelocladia | | | | | | | | | |
| Girtyocoelia | | | | | | | | | |
| spicule A | | | | x | | | | | |
| spicule B | | | | | | | | | |
| TRILOBITES | | x | | | | | | | |
| taxa | | | | | | | | | |
| SCOLECODONTS | | | | | | | | | x |
| Spirorbis | | | | | | | | | |
| CONULARIDS | | | | | | | | | |
| RADIOLARIANS | | | | | | | | | |

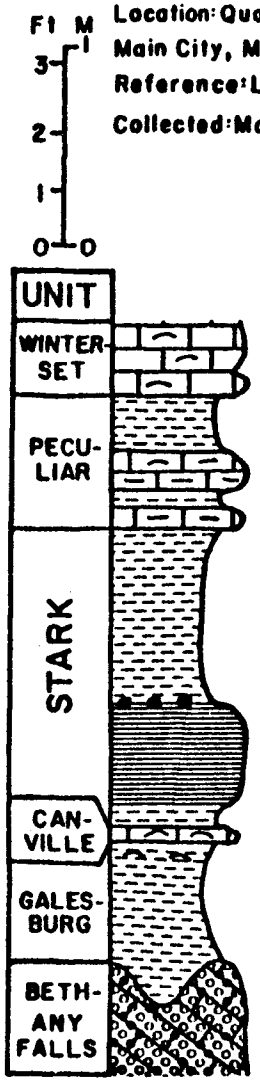
31.Eu 1

# 31.Eu 1


Ft M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
4'
VILAS
Sample
FISH
paleomicrid teeth
elloconodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Coelacylia
Moreyella
Kirkella
other
Eul/5
Eul/59
Eul/49
Eul/31
Eul/16
Eul/6
Eul/0
Eul/cc
Eul/-4
Eul/-36
Eul/-66
unidentified fish on bedding plane
unidentified teeth

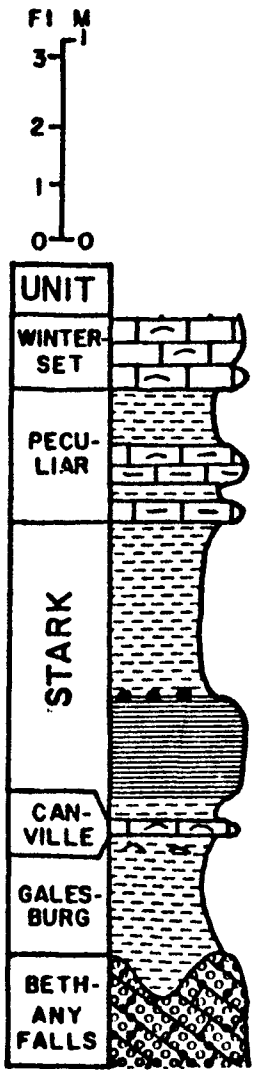
# 32.Evl

Location: Quarry 3 1/4 mi west and .4 mi south of Everett, Missouri
Main City, Missouri, 7 1/2'
T43NR32W29NW1/4SE1/4NW1/4
Reference: Lamerson, 1956, Section 5, p.97
Collected: May 25, 1980



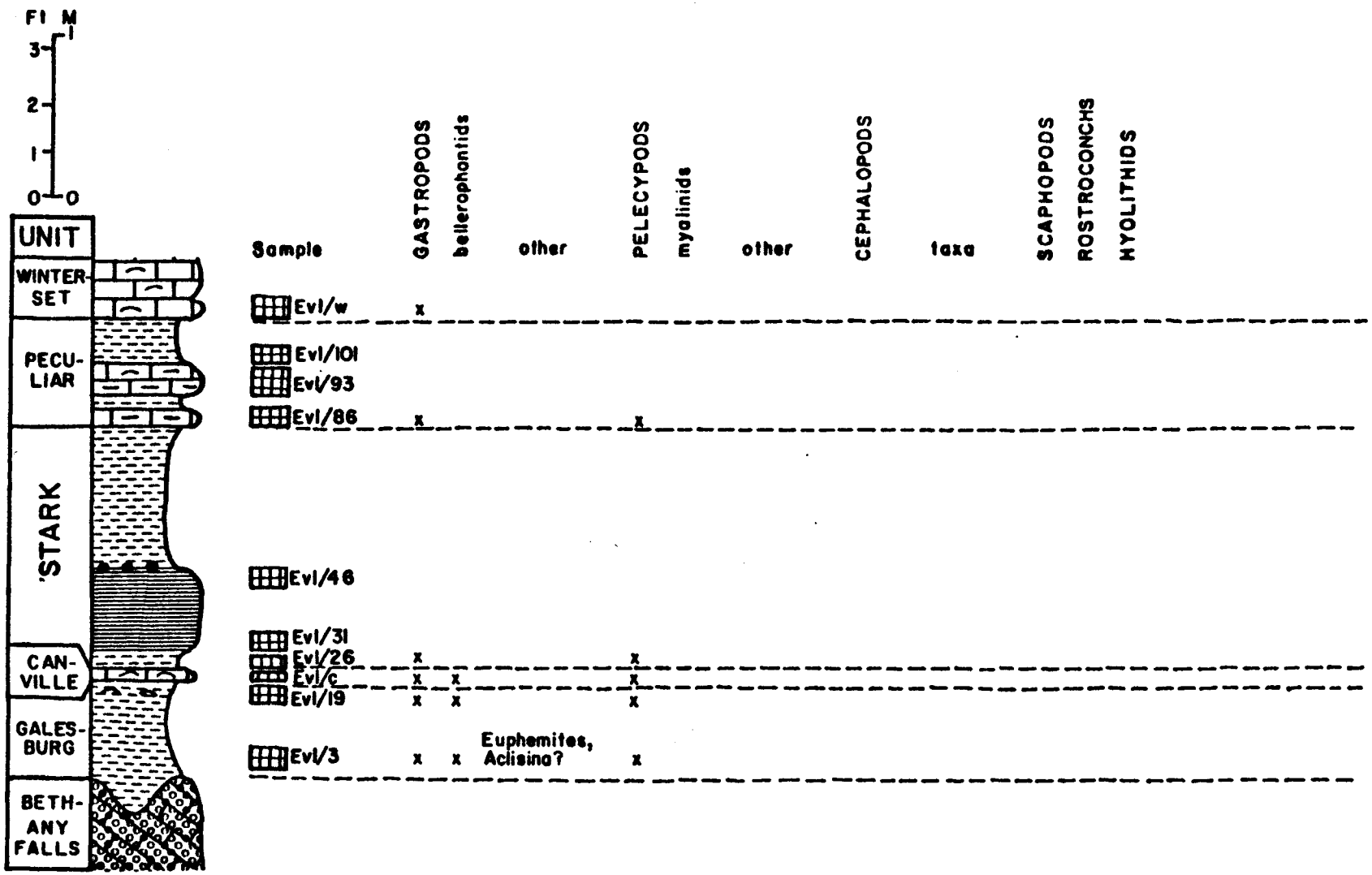

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | | | |
| Evl/w | | | | | | | | | | | | | | | x | | x | | | | | |
| Evl/101 | | x | | x | x | x | x | | | | | | | | | | | | | | | |
| Evl/93 | | | | | | | | | | | | | | x | x | | | | | | | |
| Evl/86 | | x | | ? | | | | | | | | | | x | | | | | | | | |
| Evl/46 | | | | | | | | | | | | | | | | | | | | | | |
| Evl/31 | | | | | | | | | | | | | | | | | | | | | | |
| Evl/26 | | x | | | | | | | | | | | | | | | | | | | | |
| Evl/c | | | | | | | | | | | | | | | x | | | | | | | |
| Evl/19 | | | ? | x | | | | | | | | | | | | | | | | | | |
| Evl/3 | | x | | | | | | | | | Microcheilinella? | | | | x | | | | | | | |

# 32.Ev I

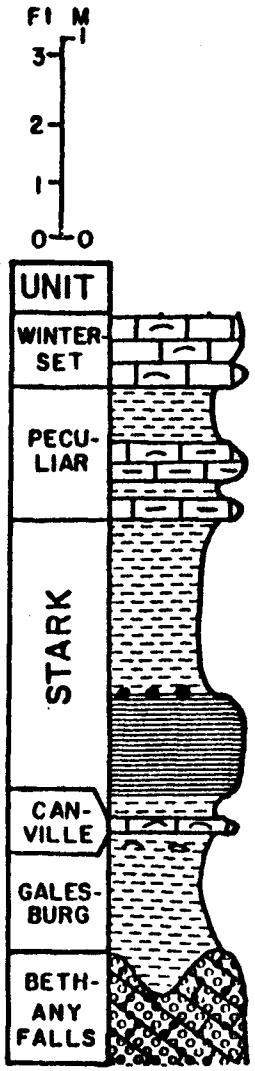



| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ev1/w | | x | | | | | | | | | | | | | | | | | | Teguliferina? |
| Ev1/101 | | | | | x | | | x | x | x | x | x | | x | | x | x | x | | |
| Ev1/93 | | | | | | | | | | | | | | | | | | | | |
| Ev1/86 | | | | | | | | | | | | | | | | | x | | | |
| Ev1/46 | | | | | | | | | | | | | | | | | | | | |
| Ev1/31 | | | | | | | | | | | | | | | | | | | | |
| Ev1/26 | | | | | | | | | | | | | | | | | | | | |
| Ev1/c | | x | | | x | | | | | | | | | | | | | | | |
| Ev1/19 | | | | | x | x | | | | | | x | | | | x | x | | | |
| Ev1/3 | | | | | x | | | | | | | | | | | | | | | |

# 32.Ev I

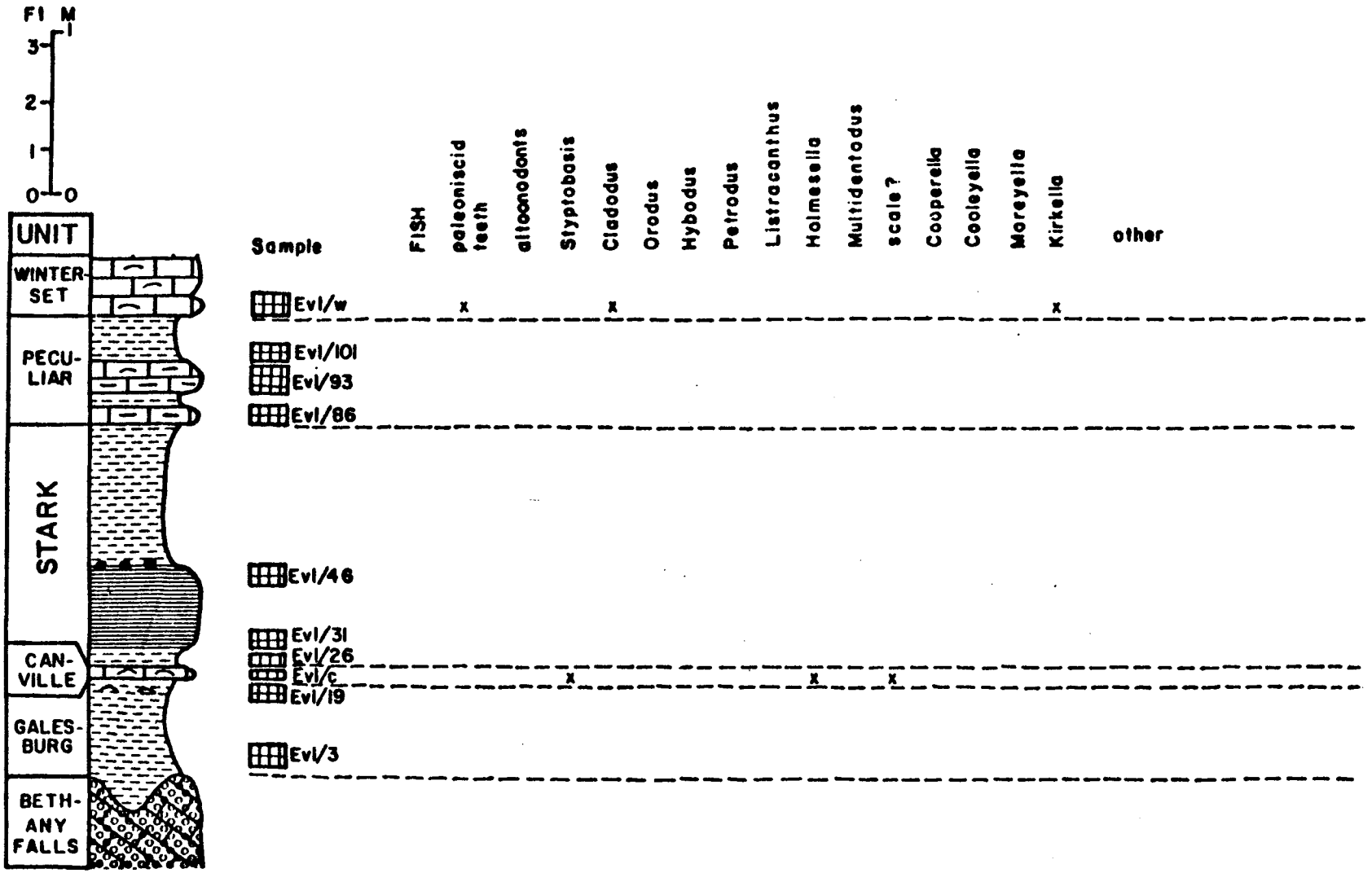

FT M
3
2
1
0 0
UNIT
WINTER-SET
PECU-LIAR
'STARK
CAN-VILLE
GALES-BURG
BETH-ANY FALLS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Evl/w
Evl/101
Evl/93
Evl/86
Evl/46
Evl/31
Evl/26
Evl/c
Evl/19
Evl/3
Euphemites, Aclisina?

# 32.Ev I




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ev I/w | | | | | | | | | | | | | | | | | | | | | |
| Ev I/101 | | | | | | I | I | | I | | | | | | | x | | | | | |
| Ev I/93 | | | | | | | | | | x | | | | | | | | x | | | |
| Ev I/86 | | | | | | I | | | | | | | | | | | | | | | |
| Ev I/46 | | | | | | | | | | | | | | | | | | | | | |
| Ev I/31 | | | | | | | | | | | | | | | | | | | | | |
| Ev I/26 | | x | | | | | | | | | | | | | | | | | | | |
| Ev I/c | | x | | | | | I | | | | | | | | | | | | | | |
| Ev I/19 | | x | | | | 2 | I | x | | | | | | | | | | | | | |
| Ev I/3 | | x | | | | | I | | | | | | | | | | | | | | |

# 32.Evl


FI M
3
2
1
0 0
UNIT
WINTER-SET
PECU-LIAR
STARK
CAN-VILLE
GALES-BURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
allocanodonts
Stypobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Evl/w
Evl/101
Evl/93
Evl/86
Evl/46
Evl/31
Evl/26
Evl/c
Evl/19
Evl/3

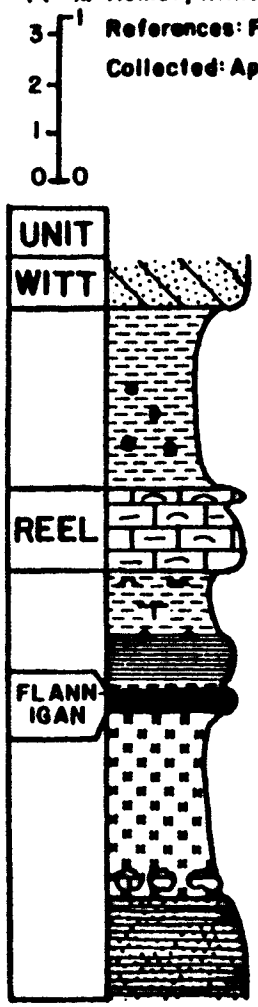
# 33.Ft I

Location: Stream bank along Salt Fork, 3 1/2 mi south of Fithian, Illinois

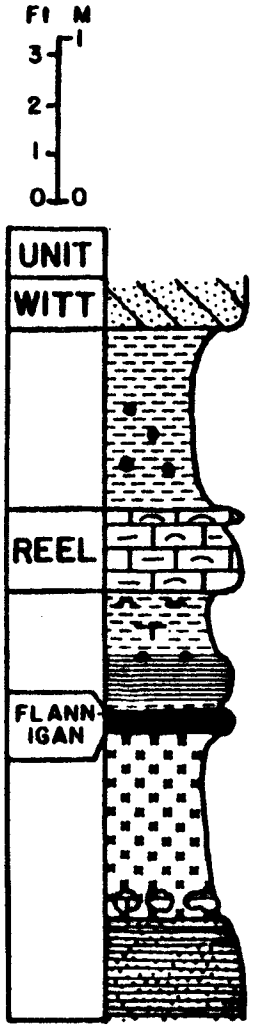
Homer, Illinois, 7 1/2'  T19NR13W31SW1/4NW1/4NW1/4

References: Filewicz, 1973; Filewicz, 1980; Heckel et al., 1980; Langenheim et al., 1980, Stop II, p. 66-70

Collected: April 26 and September 28, 1980

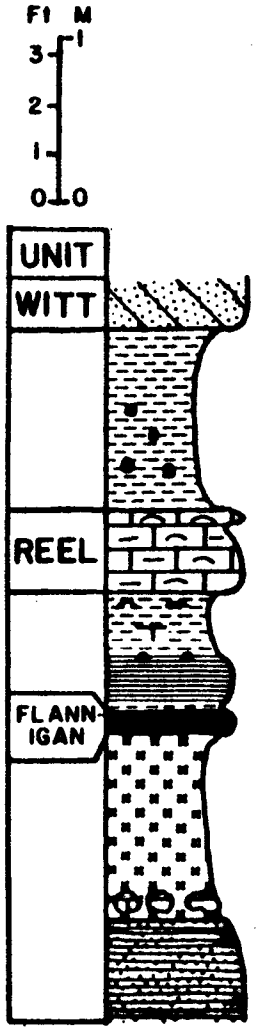



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ft1/w | 4.08 | 9.2 | 23 | 6 | | 11 | 60 | x | | | | | | | | | | | | | | |
| Ft1/u | 1.99 | 9.4 | 46 | 13 | | 27 | 14 | x | | | | .69 | | 3 | 50 | | 50 | | | | | |
| Ft1/47 | 2.73 | 9.7 | 57 | | | 28 | 15 | x | | | | .74 | | 1 | | | 100 | | | | | |
| Ft1/44 | 2.45 | 9.3 | 65 | | | 17 | 18 | | | | | .60 | | 17 | 10 | | 90 | | | | | |
| Ft1/26 | 2.26 | 9.7 | 55 | 22 | | 16 | 7 | | x | | | .57 | | 21 | | | 75 | 25 | | | | |
| Ft1/19 | 1.92 | 9.7 | 52 | 13 | | 26 | 10 | | x | | | 1.06 | | 13 | | | 100 | | | | | |
| Ft1/12 | 2.57 | 9.8 | 55 | | | 32 | 13 | | | | | .90 | | 202 | | | 97 | 1 | | 2 | 1 | |
| Ft1/4 | 1.94 | 9.2 | 60 | 4 | | 23 | 13 | | | | | .58 | | 1262 | | | 84 | t | | 1 | 16 | |
| Limestone lens between coal and black shale unsampled, omitted from diagram | | | | | | | | | | | | | | | | | | | | | | |
| Ft1/-12 | 1.19 | 9.5 | 68 | 29 | | 2 | 1 | | | | | | | | | | | | | | | |
| Ft1/-42 | 1.24 | 9.6 | 55 | 30 | | 9 | 7 | x | | | | | | | | | | | | | | |
| Ft1/b | 3.08 | 9.8 | 54 | 7 | | 21 | 18 | | | | | | | | | | | | | | | |



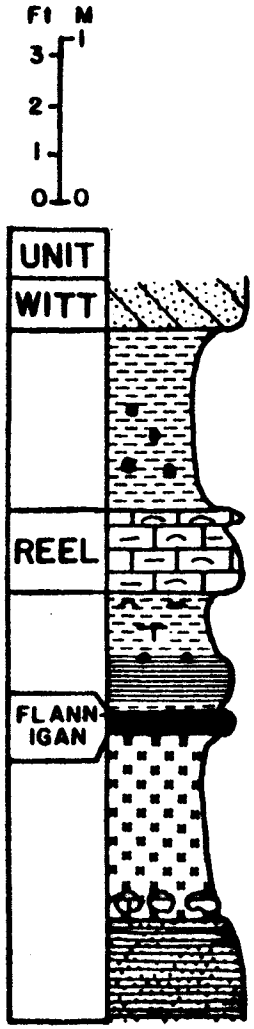

| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F11/w | | | | | | | | | | | | | | | | | | | | | |
| F11/u | | | | | | | | | | | | | | | | | | | | | |
| F11/47 | | x | | | | 2 | 1 | | | | | | | | | | | x | | | |
| F11/44 | | | | | | | | | | | | | | | | | | | | | |
| F11/26 | | | | | | | 1 | | | x | | | | | | | | x | | | |
| F11/19 | | x | x | | | 2 | 1 | | | | | | | | | x | Ditomopyge | | | | |
| F11/12 | | x | | | | 1 | 1 | | | x | | | | | | x | | | | | |
| F11/4 | | | | | | | | | | | | | | | | | | | | | |
| Limestone lens between coal and black shale unsampled, omitted from diagram | | | | | | | | | | | | | | | | | | | | | |
| F11/-12 | | | | | | | | | | | | | | | | | | | | | |
| F11/-42 | | | | | | | | | | | | | | | | | | | | | |
| F11/b | | | | | | | | | | | | | | | | | | | | | |

# 33.Ft I



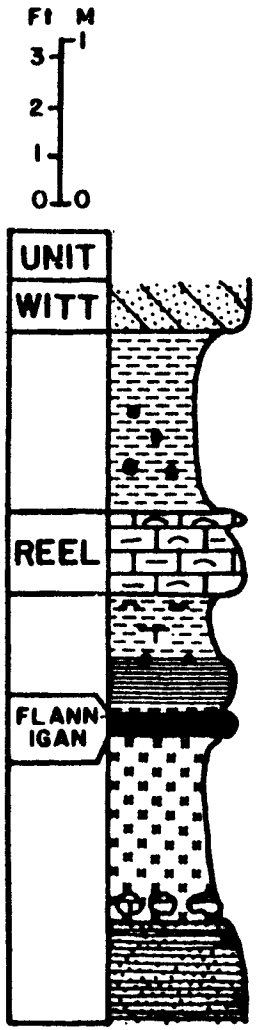

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | CORALS | lophophyllidid | Sutherlandia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1I/w | | | | | | | | | | | | | | |
| F1I/u | | | | | | | | | | | | | | |
| F1I/47 | x | | Aclisina? | | | | | | | | | | | |
| F1I/44 | x | | | | | | | | | | | | | |
| F1I/26 | ? | | | | | | | | | | | | | |
| F1I/19 | | | | x | | | | | | | | x | x | |
| F1I/12 | | | | | | | | | | | | | | |
| F1I/4 | | | | | | | | | | | | | | |
| Limestone lens between coal and black shale unsampled, omitted from diagram | | | | | | | | | | | | | | |
| F1I/-12 | | | | | | | | | | | | | | |
| F1I/-42 | | | | | | | | | | | | | | |
| F1I/s | | | | | | | | | | | | | | |

# 33.Ft 1




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F11/w | | | | | | | | | | | | | | | | | | | | |
| F11/u | | | | | | | | | | | | | | | | | | | | |
| F11/47 | | | | | x | | | | | | | ? | | | | | x | | | |
| F11/44 | | x | | x | | | | | | | | | | | | | | | | |
| F11/26 | | | | | | | | | | | | | | | | | | | | |
| F11/19 | | x | | | x | x | | x | x | | x | x | | x | | | x | x | | |
| F11/12 | | x | | | x | | | x | x | | x | | | | | x | x | x | | |
| F11/4 | | | | | | | | | | | | | | | | | | | | |
| Limestone lens between coal and black shale unsampled, omitted from diagram | | | | | | | | | | | | | | | | | | | | |
| F11/-12 | | | | | | | | | | | | | | | | | | | | |
| F11/-42 | | | | | | | | | | | | | | | | | | | | |
| F11/6 | | | | | | | | | | | | | | | | | | | | |

# 33.Ft I



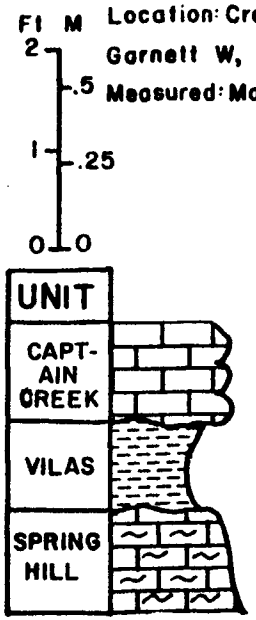

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | | |
| FtI/w | | | | | | | | | | | | | | | | | | | | | |
| FtI/u | | | | | | | | | | | | | | x | x | | | | | | |
| FtI/47 | | | | x | x | | x | | | | | | | | x | | | | | | |
| FtI/44 | | | | | | | | | | | | | | x | | | | | | | |
| FtI/26 | | | | | | | | | | | | | | | x | x | | | | | |
| FtI/19 | | | | | | | | | | | | | | | | | | | | | |
| FtI/12 | | | | x | | | x | x | | | | | | x | | | | | | | |
| FtI/4 | | | | | | | | | | | | | | | | | | | | | |
| Limestone lens between coal and black shale unsampled, omitted from diagram | | | | | | | | | | | | | | | | | | | | | |
| FtV-12 | | | | | | | | | | | | | | | | | | | | | |
| FtV-42 | | | | | | | | | | | | | | | | | | | | | |
| FtI/s | | | | | | | | | | | | | | | | | | | | | |

# 34.Ga l

Location: Creek bank along Pottawatomie Creek, 3 1/2 mi west and 3 3/4 mi north of Garnett, Kansas

Garnett W, Kansas, 7 1/2'  T20SR19E5NE1/4NE1/4

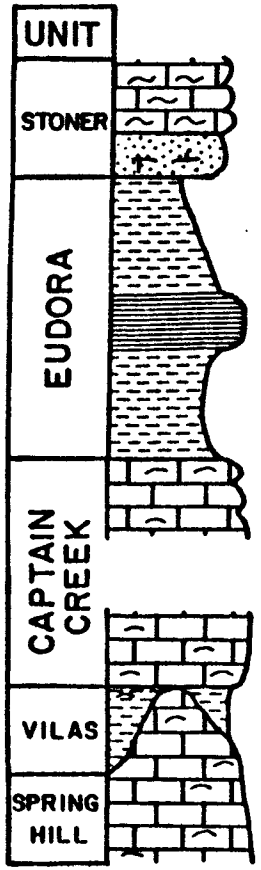
Measured: May 17, 1978



# 35. Ga 2

Location: McAdams Quarry, 3 mi north of Garnett, Kansas
Garnett W, Kansas, 7 1/2'
Collected: June 8, 1979

T20SR19EINEI/4NWI/4SEI/4




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ga2/48 | 1.53 | 8.6 | 58 | 30 | | 13 | | | | | |
| Ga2/22 | 1.48 | 9.6 | 61 | 18 | | 23 | | | | | |
| Ga2/10 | 1.60 | 9.4 | 55 | 20 | | 19 | 6 | | | | |
| Ga2/cc | | | 10 | 8 | | | 82 | | | | |
| Ga2/-2 | 1.90 | 9.4 | 40 | 28 | | 18 | 15 | | | | |
| Ga2/-9 | 1.47 | 9.7 | 47 | 47 | | 6 | | | | | |
| Ga2/p | 3.58 | 8.5 | 67 | 3 | | 30 | | | | | |

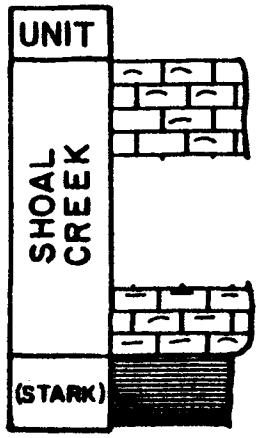
# 36.Gi l

Location: Quarry 2 mi north of Gillespie, Illinois

Gillespie N, Illinois, 7 1/2'  T8NR7WINWI/4SEI/4NWI/4

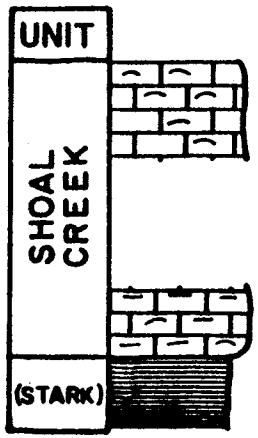
Reference: Berggren, 1979, Stop 6, p.23

Note: Section unmeasured, but Shoal Creek locally up to 12' thick; lower two samples actually float

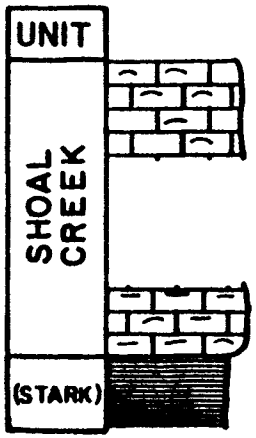



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gil/sc | 1.42 | 8.9 | 34 | 15 | | | 51 | | | | | 1.00 | | 12 | | | 92 | 8 | | | | |
| Gil/scf | 1.90 | 9.2 | 45 | 29 | | 4 | 22 | | | | | .12 | | 148 | 17 | | 83 | | | | | |
| Gil/bs | 4.67 | 11.0 | 40 | 32 | | 19 | 10 | | | | | .49 | | 1437 | | | 95 | | | 3 | 1 | |

# 36.Gi l

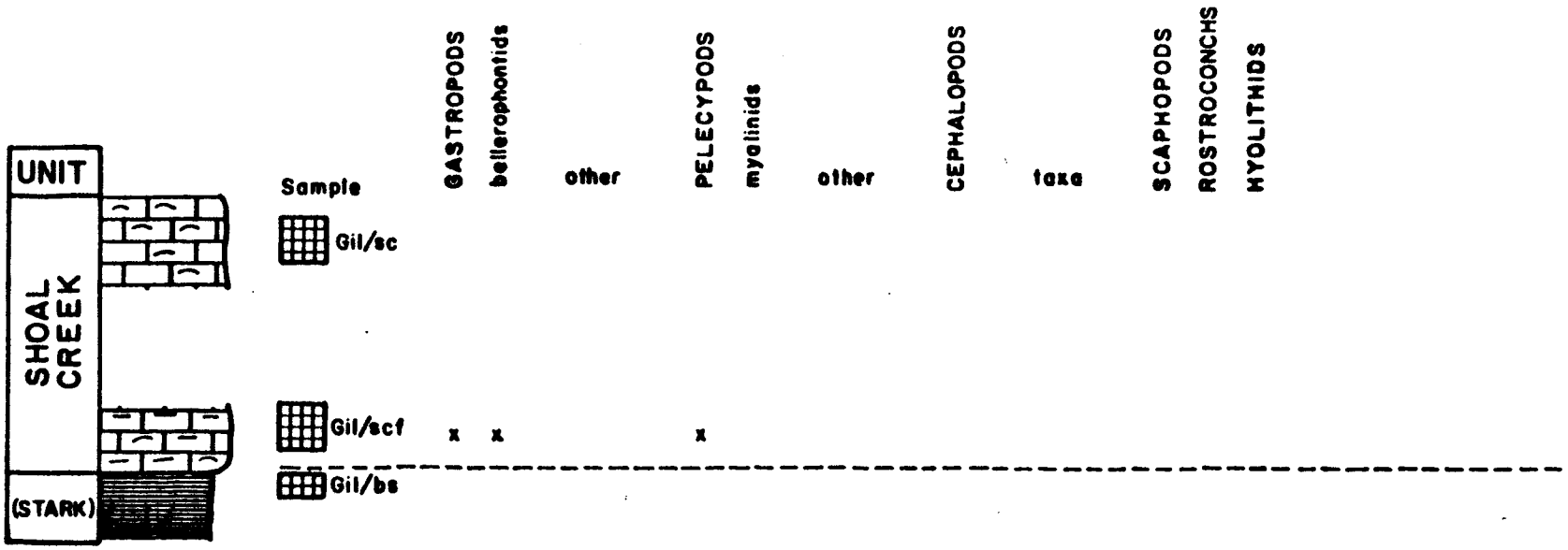


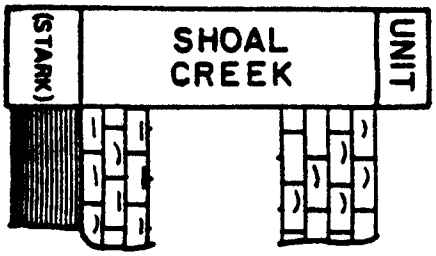

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Gil/sc | | | | | | | | | | | | | | | x | | x | | | |
| Gil/scf | | x | | x | x | | | | | | Sulcella | | | | x | x | | | | |
| Gil/bs | | | | | | | | | | | | | x | | x | | | | | |




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gil/sc | | | | | | | | | | | | | | | | | | | | |
| Gil/scf | | x | | | | | | | x | | | x | | | | | | | | |
| Gil/bs | | | | | | | | | | | | | | | | | | | | |

## 36.Gi l


UNIT
SHOAL CREEK
(STARK)
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Gil/sc
Gil/scf
x
x
x
Gil/bs

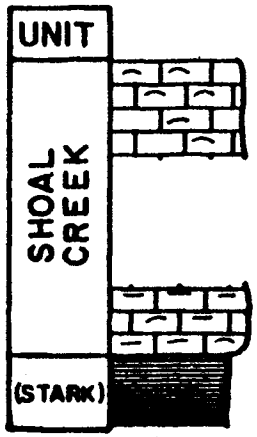



| Gil/bs | Gil/scf | Gil/sc | Sample | |
|---|---|---|---|---|
| | | | | ECHINODERMS |
| | x | | | pelmatozoans |
| | | | | echinoids |
| | | | | holothurians |
| | | | | BRYOZOANS |
| | | | | fenestrate |
| | – | | | ramose |
| | | | | fistuliporids |
| | | | | encrusting non-fistuliporids |
| | | | | SPONGES |
| | | | | wewokellid |
| | | | | Coelocladia |
| | | | | Girtyocoelia |
| | | | | spicule A |
| | | | | spicule B |
| | x | | | TRILOBITES |
| | | | | SCOLECODONTS |
| | | | | Spirorbis |
| | | | | CONULARIDS |
| | | | | RADIOLARIANS |

taxa

36.Gi 1

# 36.Gi l




| Sample | FISH | paleoniscid teeth | alteanodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gil/sc | | | | | | | | | | | | x | | x | | | |
| Gil/scf | | x | | x | | | | | | x | | | | | x | | |
| Gil/bs | | | | x | | | | | | | | | | | | | |

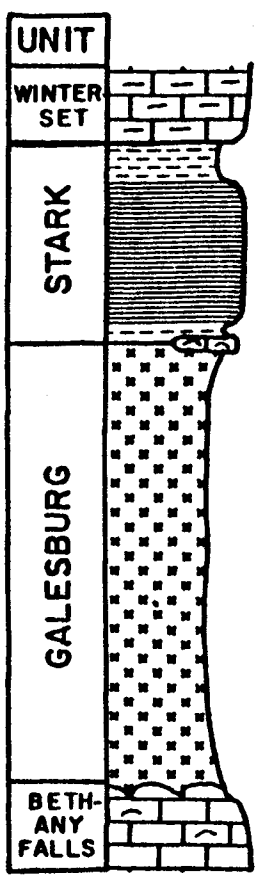
# 37. Je I

Location: Quarry 12 mi north of Greenfield, Iowa; in Jefferson Township

Greenfield, Iowa, 15' T77NR31W17NW1/4NW1/4

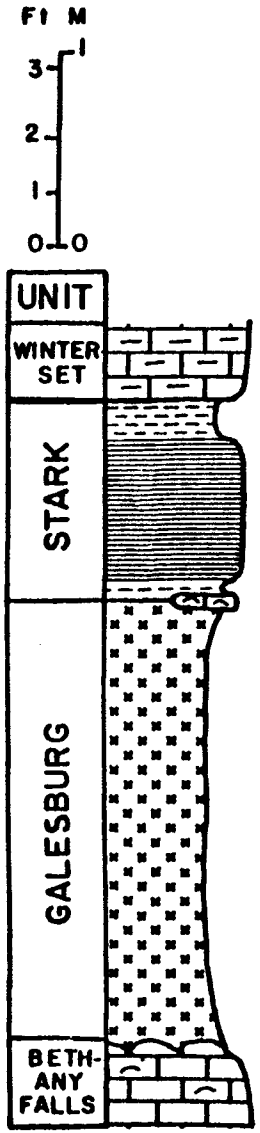
References: Welp et al., 1968, Stop 9; Johnson, 1971, Loc. I, p. 80

Collected: July 20, 1979



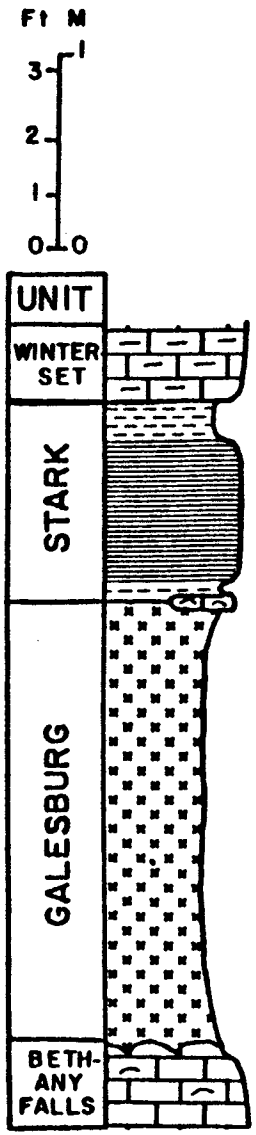

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Je I/118 | | | | | | | | | | | |
| Je I/c | 1.05 | 9.0 | 65 | 8 | | 27 | | | | | |
| Je I/bf | 1.91 | 9.5 | 83 | 12 | | 5 | | | | | |

# 37.Jo 1




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jo1/118 | | | | | | | | | | | | | | | | x | ? | | | |
| Jo1/c | | | | | | | | | | | | | | | | | | | | |
| Jo1/bf | | | | | | | | | | | | | | | | | | | | |

# 37.Je l




| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jel/118 | | x | | | | | 1 | | | | | | | | | | | | | | |
| Jel/c | | | | | | | | | | | | | | | | | | | | | |
| Jel/bf | | | | | | | | | | | | | | | | | | | | | |

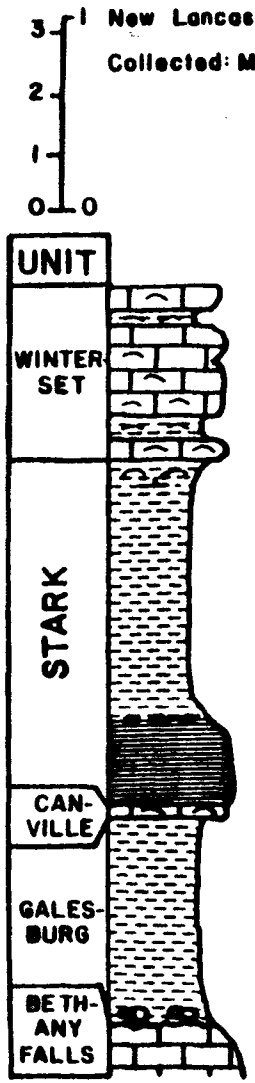
# 38. Ji l

Location: County road cut 2 mi north and 1/2 mi east of Jingo, Kansas

New Lancaster, Kansas, 7 1/2'

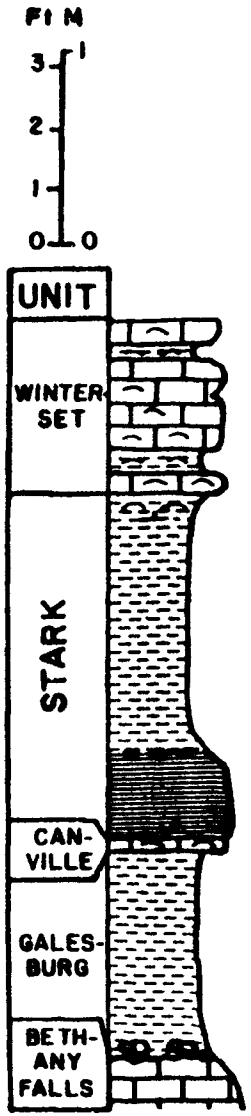
T18SR25E30SE1/4SW1/4SW1/4

Collected: May 20, 1978



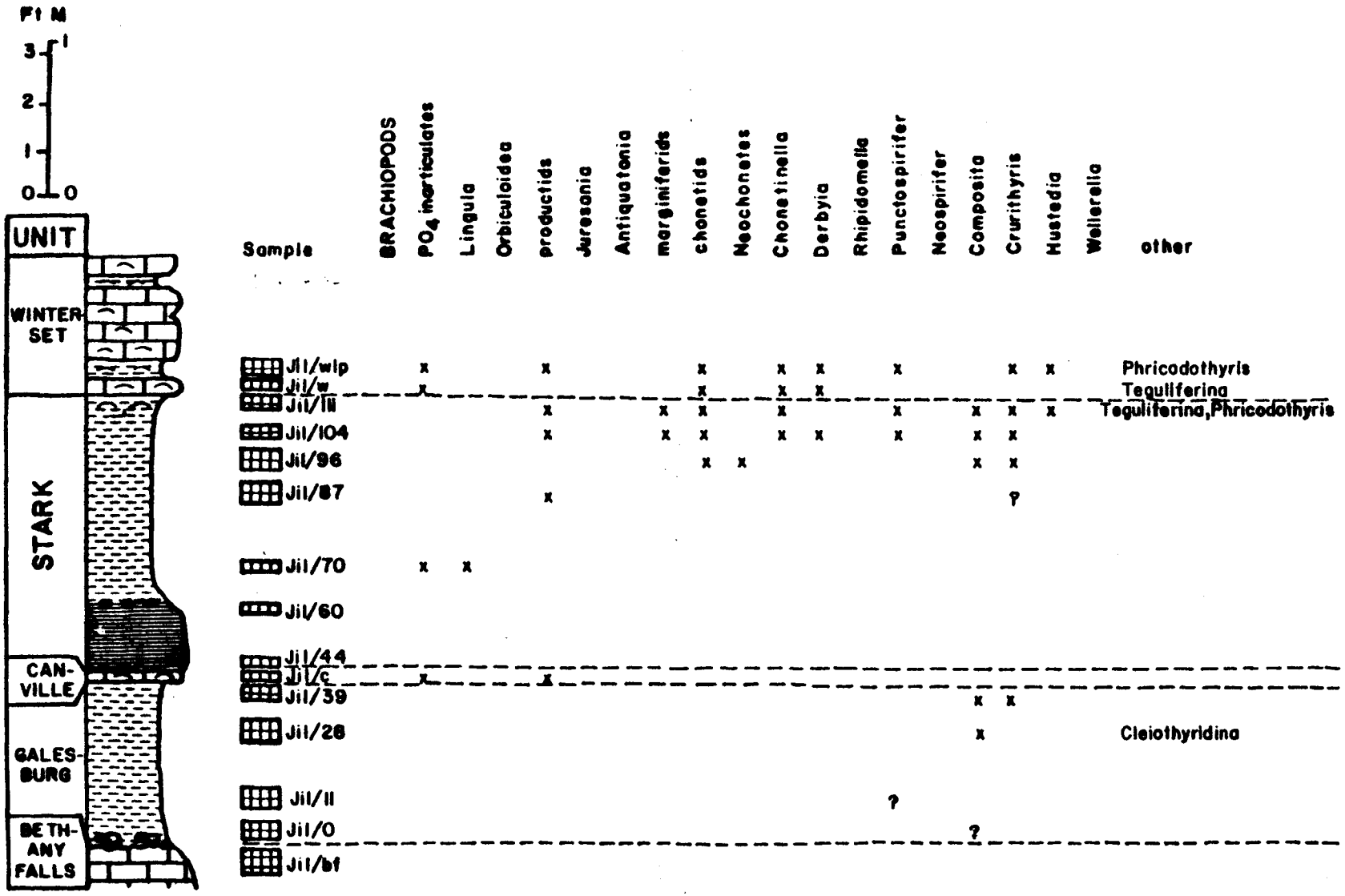

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jil/w2p | 1.61 | 9.5 | 68 | 18 | | 14 | | | | | | | | np | | | | | | | | |
| Jil/wlp | 1.54 | 9.3 | 57 | 35 | | 8 | | | | | | .82 | | 42 | | | 91 | 9 | | | | |
| Jil/w | 1.24 | 9.4 | 56 | 33 | | 11 | | | x | | | 3.02 | | 13 | | | 79 | 21 | 1 | | | |
| Jil/lll | 1.27 | 9.9 | 56 | 27 | | 17 | | | | | | .53 | | 216 | | | 95 | 4 | 1 | 1 | | |
| Jil/104 | 1.38 | 9.4 | 60 | 27 | | 13 | | | | | | .21 | | 1156 | | | 92 | 2 | | 6 | | |
| Jil/96 | 1.80 | 9.5 | 50 | 34 | | 16 | | | | | | .63 | | 70 | | | 93 | 5 | | 3 | | |
| Jil/87 | 1.50 | 9.4 | 64 | 25 | | 11 | | | | | | .28 | | 81 | | | 99 | | | 1 | | |
| Jil/70 | 1.77 | 9.1 | 53 | 33 | | 14 | | | | | | .84 | | 120 | | | 88 | | | 2 | 10 | |
| Jil/60 | 1.79 | 9.3 | 62 | 30 | | 9 | | | | | | | | | | | 71 | | | 9 | 21 | |
| Jil/44 | 1.27 | 9.5 | 51 | 30 | | 19 | | | | | | .87 | | 579 | 1 | | 98 | 1 | | 1 | | |
| Jil/c | | | | | | | | | x | | | 3 | | 11 | 35 | | 56 | 9 | | 1 | | |
| Jil/39 | .85 | 9.4 | 35 | 41 | | 16 | 8 | | | | | .76 | | 68 | 77 | | 17 | 6 | | | | |
| Jil/28 | 1.03 | 9.2 | 48 | 32 | | 13 | 8 | | | | | .96 | | 14 | 62 | 15 | 23 | | | | | |
| Jil/11 | 1.21 | 9.4 | 56 | 24 | | 10 | 10 | | | | | 1.06 | | 2 | | | 91 | | | 9 | | |
| Jil/0 | 1.36 | 9.4 | 51 | 34 | | 15 | | | | | | 1.13 | | 9 | | | 87 | | | 3 | 10 | |
| Jil/bf | 1.24 | 10.3 | 74 | 16 | | 10 | | | | | | .92 | | 3 | | 33 | 67 | | | | | |

# 38. Ji l

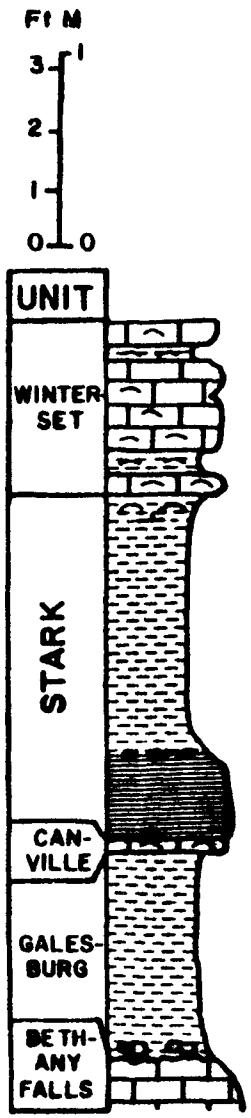



| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Jil/wlp | | | | x | x | | x | | x | | | | | x | x | | | | Polytaxis | |
| Jil/w | | | | | | | | | | | | | | x | x | x | | | Thurammina,Ammodiscella | |
| Jil/lll | | | | x | x | | | x | x | | | | | x | x | x | x | | | |
| Jil/104 | | x | | x | | | x | x | | | | | | x | x | | | | | |
| Jil/96 | | x | | x | x | x | x | x | | | | | | x | x | | | | | |
| Jil/87 | | x | | | | | | | | | | | x | x | x | | | | | |
| Jil/70 | | | | | | | | | | | | | | | | | | | | |
| Jil/60 | | | | | | | | | | | | | | | | | | | | |
| Jil/44 | | | | x | | | | | | x | Healdia | | | | x | | | | | |
| Jil/c | | | | | | | | | | | | | | | x | | | | | |
| Jil/39 | | | | x | | | | | | | | | | | x | x | | | | |
| Jil/28 | | | | x | x | | | | | | | | | | x | | | | | |
| Jil/ll | | | | | | | x | | | | | | | | | | | | | |
| Jil/0 | | | | | | | | | | | | | | x | | | | | | |
| Jil/bf | | | | | | | | | | | | | | | x | x | | | | |

# 38. Ji l

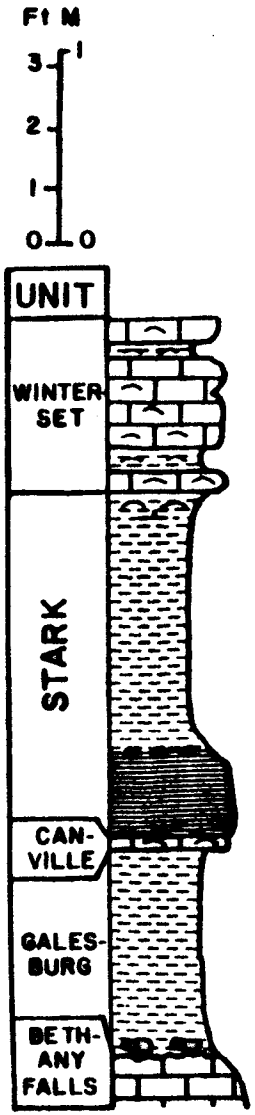

Ft M
3
2
1
0
UNIT
WINTER SET
STARK
CAN-VILLE
GALES-BURG
BETH-ANY FALLS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Ji l/wlp
Ji l/w
Ji l/li
Ji l/104
Ji l/96
Ji l/87
Ji l/70
Ji l/60
Ji l/44
Ji l/c
Ji l/39
Ji l/28
Ji l/11
Ji l/0
Ji l/bf
Phricodothyris
Teguliferina
Teguliferina,Phricodothyris
Cleiothyridina

# 38. Ji l



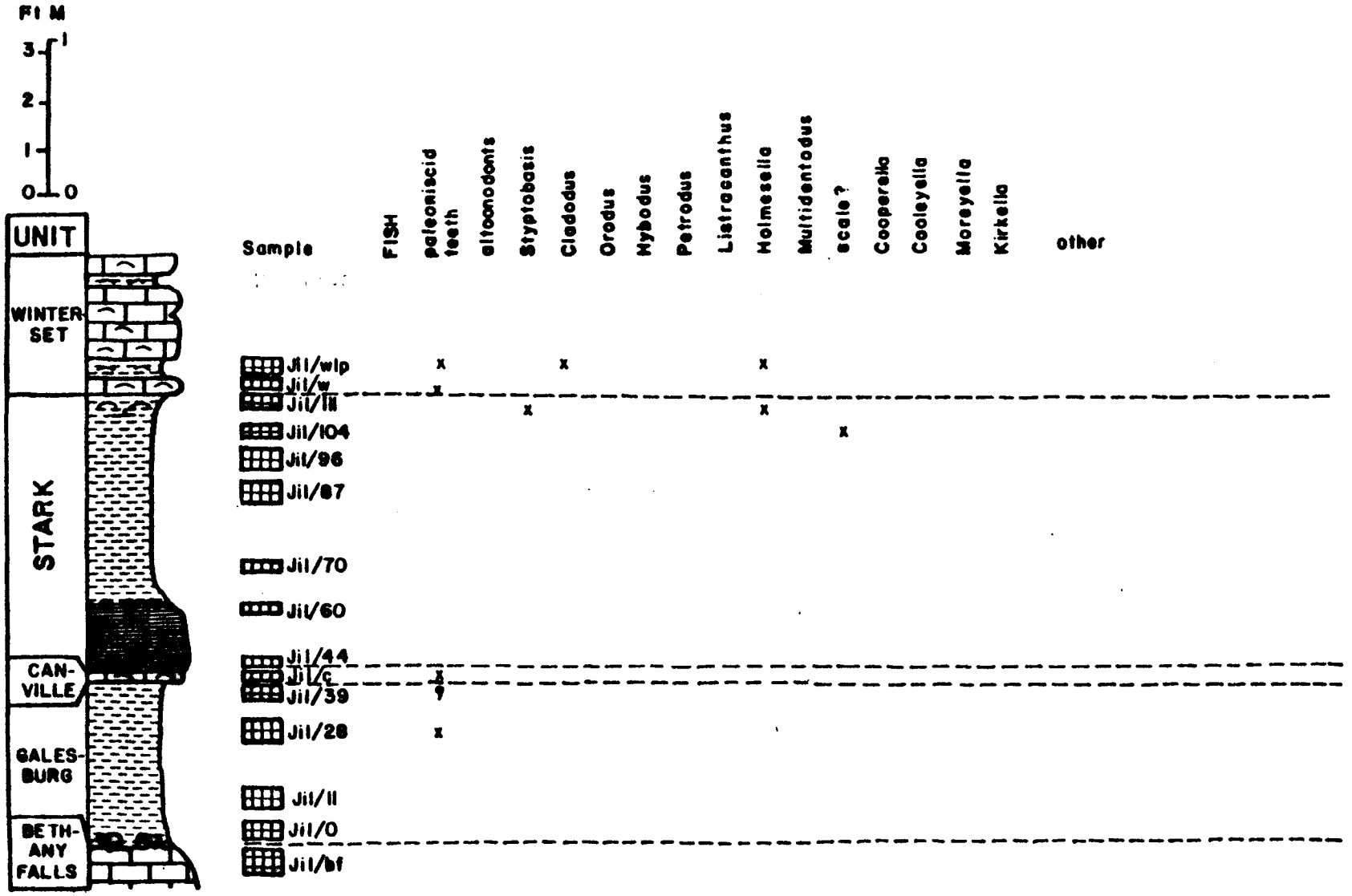

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | CORALS | lophophyllidid | Sutherlandia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jil/wlp | x | | | | | | | | | | | | x | |
| Jil/w | x | | | | | | | | | | | | | |
| Jil/lll | x | x | Euphemites? | x | | | | | | | | | | |
| Jil/104 | | | | | | | | | | | | | x | |
| Jil/96 | x | | | | | | | | | | | | | |
| Jil/87 | x | | | | | | x | | | | | | | |
| Jil/70 | | | | | | | | | | | | | | |
| Jil/60 | | | | | | | | | | | | | | |
| Jil/44 | x | x | | | | | | | | | | | | |
| Jil/c | x | x | | x | | | | | | | | | | |
| Jil/39 | x | x | Glabrocingulum, Palaeostylus, Euphemites?, Aclisina? | x | | | | | | | | | | |
| Jil/28 | x | | | x | | | | | | | | | | |
| Jil/ll | x | | | | | | | | | | | | | |
| Jil/0 | x | | Anematina? | x | | Cypricardella? | | | | | | | | |
| Jil/bf | x | | Anematina? | x | | Cypricardella? | | | | | | | | |

## 38. Ji l




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jil/wlp | | x | x | | | 3 | 1 | x | 1 | | | | | | | x | Ditomopyge | | | | |
| Jil/w | | | | | | | | | | | | | | | | | | | | | |
| Jil/lll | | x | x | | | 3 | 1 | x | 1 | | | | | | | x | Ditomopyge | | | | |
| Jil/104 | | x | | | | 1 | 2 | | | | | | | | | x | | | | | |
| Jil/96 | | x | | | | | 1 | | | | | | | | | | | | | | |
| Jil/87 | | x | | | | 1 | 1 | | | | | | | | | | | | | | |
| Jil/70 | | | | | | | | | | | | | | | | | | | | | |
| Jil/60 | | | | | | | | | | | | | | | | | | | | | |
| Jil/44 | | x | | | | | | | | | | | | | | | | | | | |
| Jil/c | | | | | | | | | | | | | | | | | | | | | |
| Jil/39 | | x | | | | 3 | 1 | | | | | | | | | | | | | | |
| Jil/28 | | x | | | | 1 | | | | | | | | | | | | x | | | |
| Jil/ll | | x | | | | 1 | 2 | | | | | | | | | | | | | | |
| Jil/0 | | x | | | | 1 | | | | | | | | | | | | | | | |
| Jil/bf | | | | | | | | | | | | | | | | | | | | | |

# 38. Ji l


FI M
3
2
1
0
1
0
UNIT
WINTER-SET
STARK
CAN-VILLE
GALES-BURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
eltoonodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Coelacella
Moreyella
Kirkella
other
Jil/wlp
Jil/w
Jil/lll
Jil/104
Jil/96
Jil/87
Jil/70
Jil/60
Jil/44
Jil/c
Jil/39
Jil/28
Jil/ll
Jil/0
Jil/bf

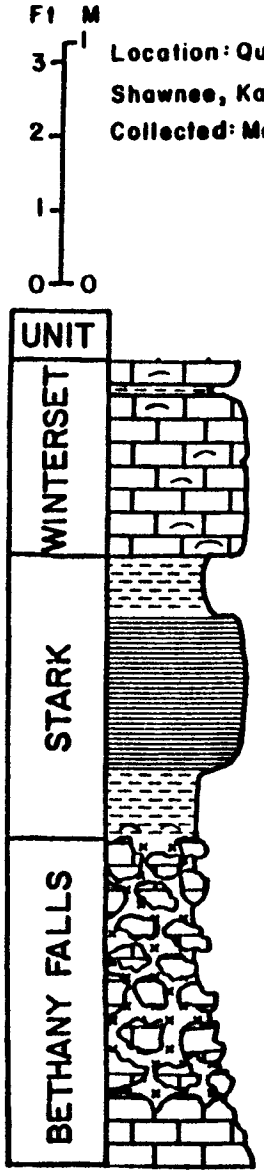
# 39. KC I

Location: Quarry along Inland Drive, Kansas City, Kansas

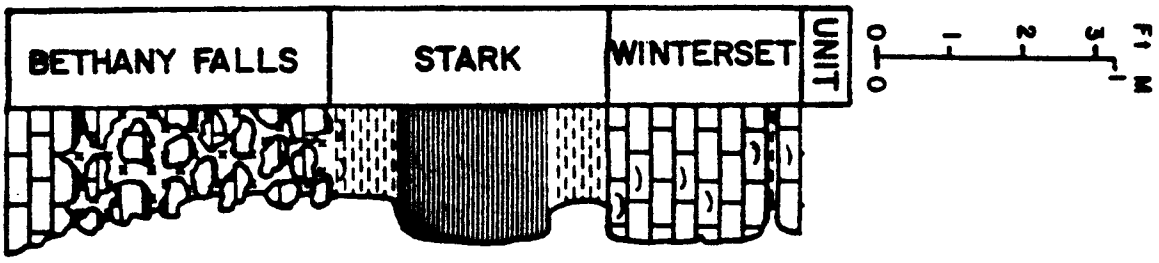
Shawnee, Kansas, 7 1/2'

Collected: May 20, 1978

T11SR24E27NE1/4NW1/4NW1/4

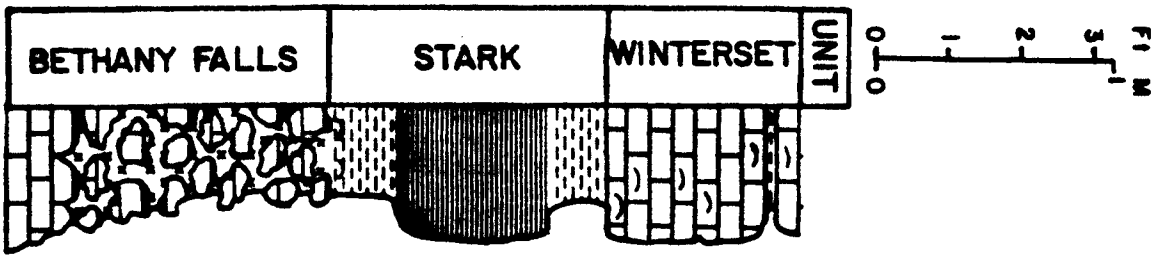



| Sample | Net processed sample (kg) | CONODONTS Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frog |
|---|---|---|---|---|---|---|---|---|---|---|
| KCI/wp | .34 | 804 | | | 94 | 5 | 1 | 2 | | |
| KCI/4I | | | | | np | | | | | |
| KCI/3I | | | | | np | | | | | |
| KCI/II | | | | | np | | | | | |
| KCI/8 | | | | | np | | | | | |
| KCI/3 | | | | | np | | | | | |




39.KC 1

| Sample | KCI/wp | KCI/4I | KCI/3I | KCI/2I | KCI/1I | KCI/3 |
|---|---|---|---|---|---|---|
| OSTRACODES | | | | | | |
| geisinids | | | | | | |
| Cavellina | | | | | x | |
| Knightina | | | | | | |
| Bairdia | | | | | x | x |
| Hollinella | | | | | | |
| Roundyella | | | | | | |
| Amphissites | | | | | | |
| Kirkbya | | | | | | |
| Kellettina | | | | | | |
| Kegelites | | | | | | |
| other | | | | | | |
| FORAMINIFERS | | | | | | |
| Hippocrepina | | | | | | |
| Ammodiscus | | | | | | |
| Tolypammina | x | | | | | |
| Ammovertella | | | | | | |
| Hyperammina | | | | | | |
| Textularia | | | | | | |
| other | | | | | Microcheilinella? | x |



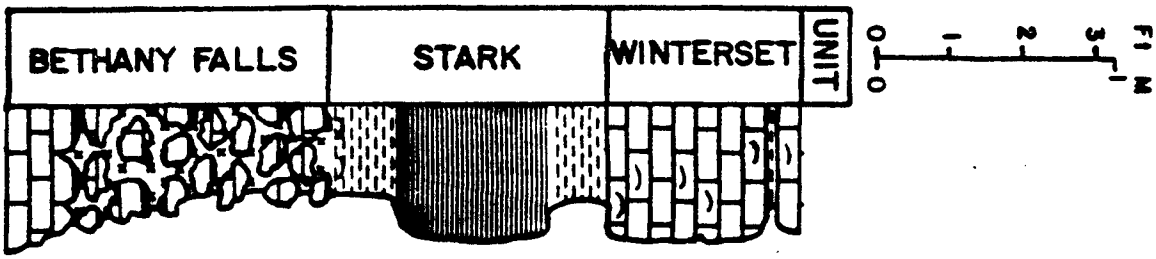

39. KC I

| Sample | KC1/wp | KC1/4I | KC1/3I | KC1/II | KC1/8 | KC1/3 |
|---|---|---|---|---|---|---|
| BRACHIOPODS | | | | | | |
| $PO_4$ inarticulates | | | | | | |
| Lingula | | | | | | |
| Orbiculoidea | | | | | | |
| productids | x | | | | | |
| Juresania | | | | | | |
| Antiquatonia | | | | | | |
| marginiferids | | | | | | |
| chonetids | x | x | | | | |
| Neochonetes | | | | | | |
| Chonetinella | | | | | | |
| Derbyia | | | | | | x x |
| Rhipidomella | | | | | | |
| Punctospirifer | | | | | | |
| Neospirifer | ? | | | | | ? x |
| Composita | | | | | | |
| Crurithyris | | x | | | x | |
| Hustedia | | | | | | |
| Wellerella | | | | | | |
| other | | | | | | |

## 39. KC I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KCI/wp | x | | | | | | x | cf Eoasianites | | | |
| KCI/4I | | | | | | | | | | | |
| KCI/3I | | | | | | | | | | | |
| KCI/II | | | | | | | | | | | |
| KCI/8 | x | | Aclisina? | x | x | | | | | | |
| KCI/3 | x | | Helminthozyga? | x | x | | | | | | |




39.KC I

| Sample | KCI/wp | KCI/4I | KCI/3I | KCI/2I | KCI/3 |
|---|---|---|---|---|---|
| ECHINODERMS | | | | | |
| pelmatozoans | | x | | | |
| echinoids | | | | | |
| holothurians | | | | | |
| BRYOZOANS | | | | | |
| fenestrate | | | | | |
| ramose | — | | | 2 | |
| fistuliporids | | | | | |
| encrusting non-fistuliporids | | | | | — — |
| SPONGES | | | | | |
| wewokellid | | | | | |
| Coelocladia | | | | | |
| Girtyocoelia | | | | | |
| spicule A | | | | | |
| spicule B | | | | | |
| TRILOBITES | | | | | |
| taxa | | | | | |
| SCOLECODONTS | | | | | x |
| Spirorbis | | | | | |
| CONULARIDS | | | | | |
| RADIOLARIANS | | | | | |

# 39. KC I




| Sample | FISH | paleoniscid teeth | actinodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KCI/wp | | x | | x | x | | | | | x | | x | | | | | Protacrodus? |
| KCI/4I | | | | | | | | | | | | | | | | | |
| KCI/3I | | | | | | | | | | | | | | | | | |
| KCI/II | | | | | | | | | | | | | | | | | |
| KCI/8 | | | | | | | | | | | | | | | | | |
| KCI/3 | | | | | | | | | | | | | | | | | |

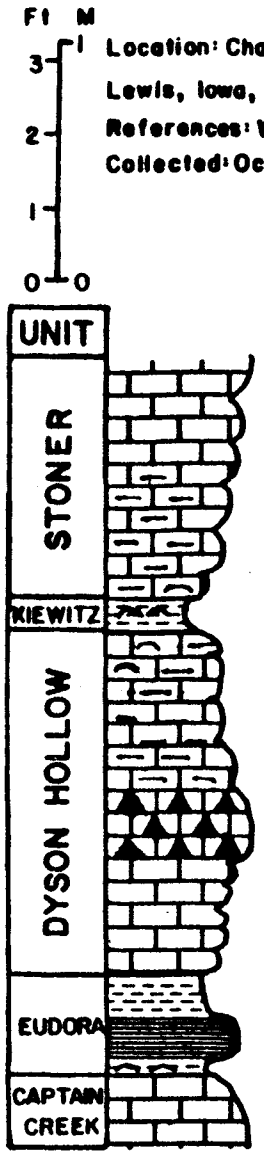
# 40.Le l

Location: Channelization cut on East Nishnabotna River, 1/2 mi south of Lewis, Iowa

Lewis, Iowa, 7 1/2'  T75NR37WI5NWI/4SWI/4SEI/4

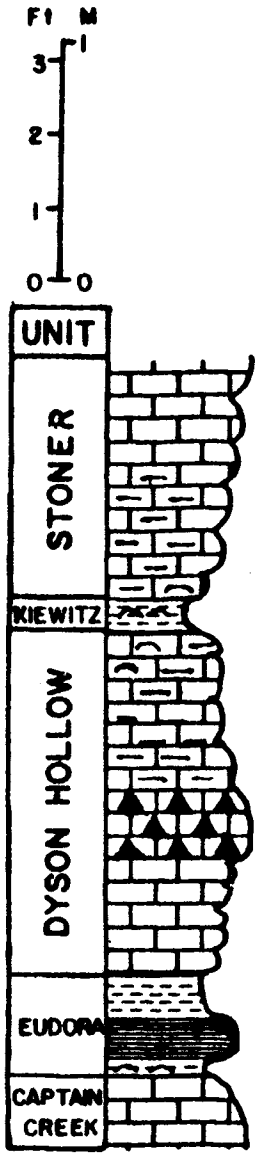
References: Wenberg, 1941, Sect. 21, p. 144-148; Toomey, 1964, Loc. 27, p. 181; Evans, 1966, Loc. 2, p. 132

Collected: October 10, 1980




| Sample | Mite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Le l/k | 1.32 | 10.2 | 40 | 33 | | 7 | 19 | | | | | .96 | | 17 | 19 | | 75 | 6 | | | | |
| Le l/s | 1.90 | 8.7 | 63 | 23 | | 15 | | | | | | .97 | | 18 | | | 88 | 12 | | | | |
| Le l/12 | 1.86 | 9.2 | 49 | 34 | | 17 | | | x | | | .31 | | 70 | | | 23 | | | 2 | 74 | |
| Le l/4 | 1.47 | 9.5 | 60 | 23 | | 18 | | | | | | .10 | | 2455 | | | 39 | 2 | | 5 | 54 | |
| Le l/2.5 | 1.76 | 9.3 | 62 | 16 | | 22 | | | | | | .07 | | 208 | | | 89 | | | 11 | | |
| Le l/0 | 1.94 | 9.5 | 57 | 25 | | 14 | 5 | | x | | | .75 | | 1066 | | | 96 | 2 | | 2 | 1 | |
| Le l/cc | 1.79 | 9.7 | 54 | 27 | | 19 | | | x | | | .99 | | 10 | | | 100 | | | | | |

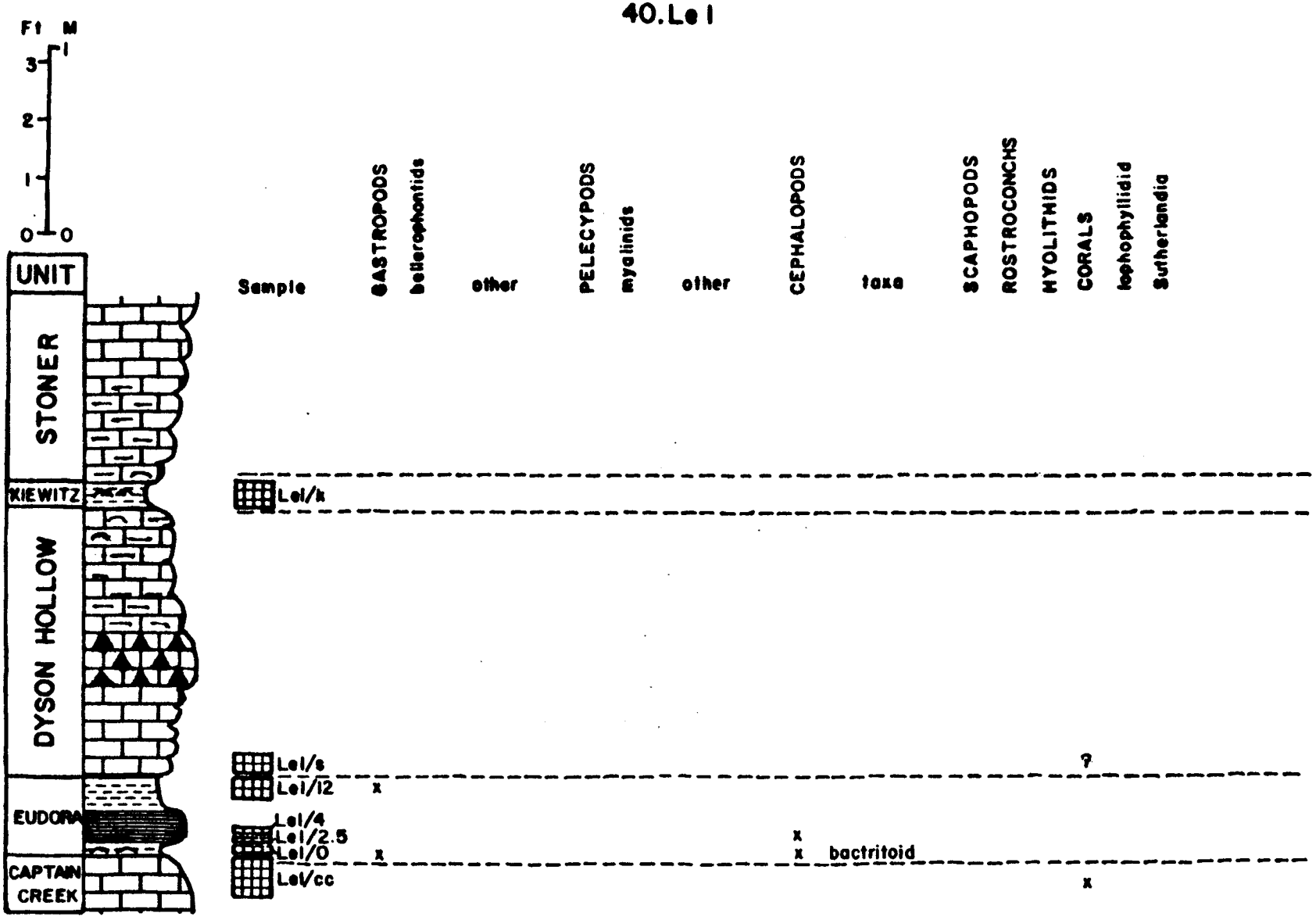
# 40.Le l




| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tetrataxis | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Le l/k | | | ? | | | | | | | | | | | | | x | | | | fusulinids |
| Le l/s | | | | | | | | | | | | | | | | x | x | | | |
| Le l/12 | | | | | | | | | | | | | | x | x | | | | | |
| Le l/4 | | | | | | | | | | | | | | | | | | | | |
| Le l/2.5 | | | | | | | | | | | | | | | | | | | | |
| Le l/0 | | | | | | | | | | | | | | | | x | x | x | | |
| Le l/cc | | | | | | | | | | | | | | | | x | x | | | |

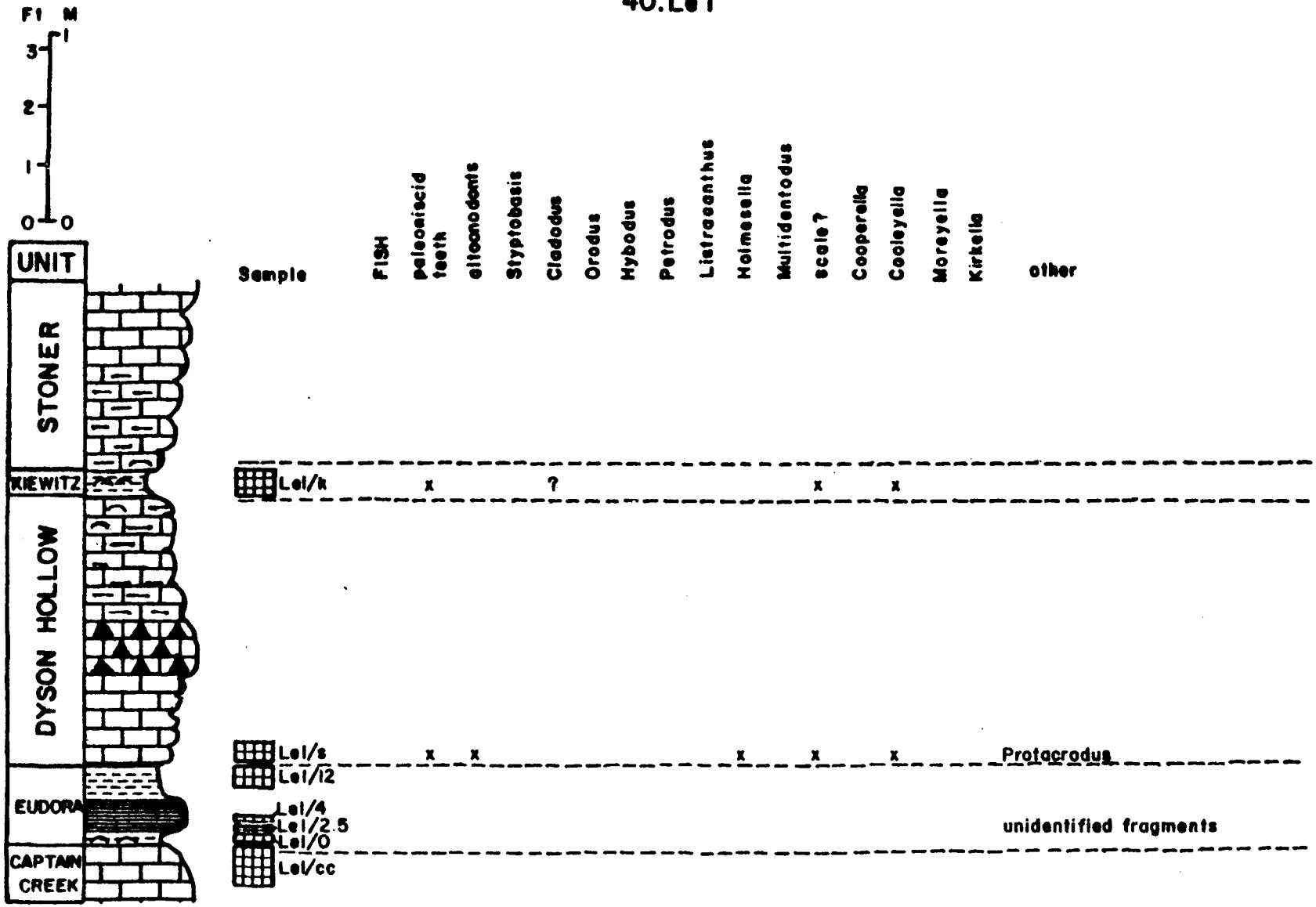
40.Le I
Ft M
3 1
2
1
0 0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Le I/k
Le I/s
Le I/12
Le I/4
Le I/2.5
Le I/0
Le I/cc

# 40.Le I


Ft M
3 1
2
1
0 0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
tophophyllidid
Sutherlandia
Le I/k
Le I/s
Le I/12
Le I/4
Le I/2.5
Le I/0
Le I/cc
bactritoid
?

40.Le I
Ft M
3 1
2
1
0 0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Le/k
Le/s
Le/12
Le/4
Le/2.5
Le/0
Le/cc

# 40.Le l


FT M
3 1
2
1
0 0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
Sample
FISH
paleoniscid teeth
elteanodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Le l/k
Le l/s
Le l/12
Le l/4
Le l/2.5
Le l/0
Le l/cc
Protacrodus
unidentified fragments

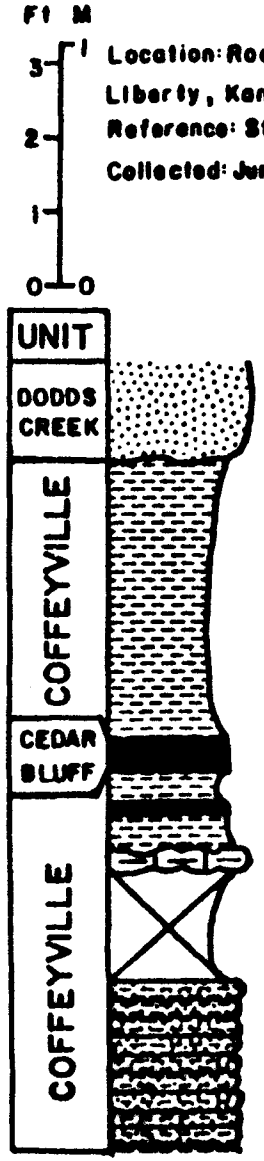
# 41.Li 1

Location: Road cut on county road about 1 mi north and 3 mi east of Liberty, Kansas

Liberty, Kansas, 7 1/2'  T33SR17E16SE1/4NE1/4NE1/4

Reference: Stobbe, 1971, Outcrop No. 5, p.3

Collected: June 9, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Li1/61 | 2.07 | 9.9 | 67 | 17 | | 8 | 9 | x | | | |
| Li1/30 | 2.57 | 9.6 | 70 | 18 | | 5 | 8 | x | | | |
| Li1/21 | 2.11 | 9.0 | 64 | 26 | | 4 | 6 | x | | | |
| Li1/11 | 3.84 | 9.8 | 71 | 14 | | 9 | 7 | x | | | |
| Li1/9 | 1.75 | 9.6 | 53 | 29 | | 10 | 7 | x | | | |
| Li1/3 | 4.38 | 9.6 | 67 | 8 | | 14 | 12 | x | | | |
| Li1/1a | 1.66 | 9.4 | 61 | 8 | | 16 | 15 | x | | | |

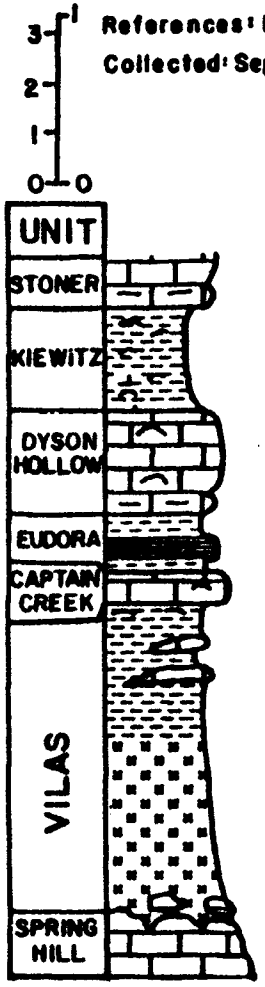
# 42. Lo I

Location: Derby Stone Products Quarry, about 1/2 mi north and 1 mi west of Louisville, Nebraska

Springfield, Nebraska, 7 1/2' T12NR11E16NE1/4NW1/4SE1/4

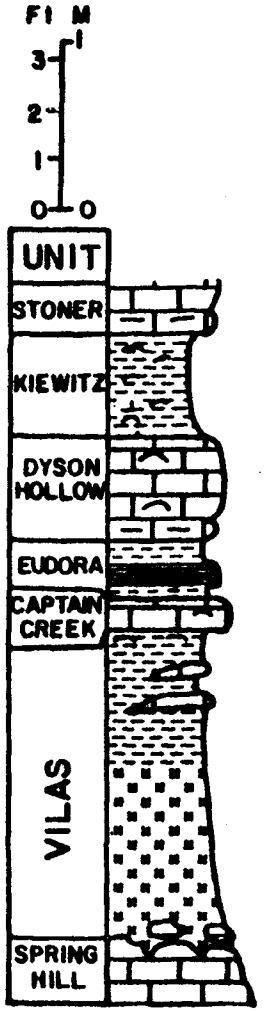
References: Pabian and Fagerstrom, 1972, Loc. 2, p. 815; Heckel et al., 1979, Stop 20, p. 54-55

Collected: September 30, 1979



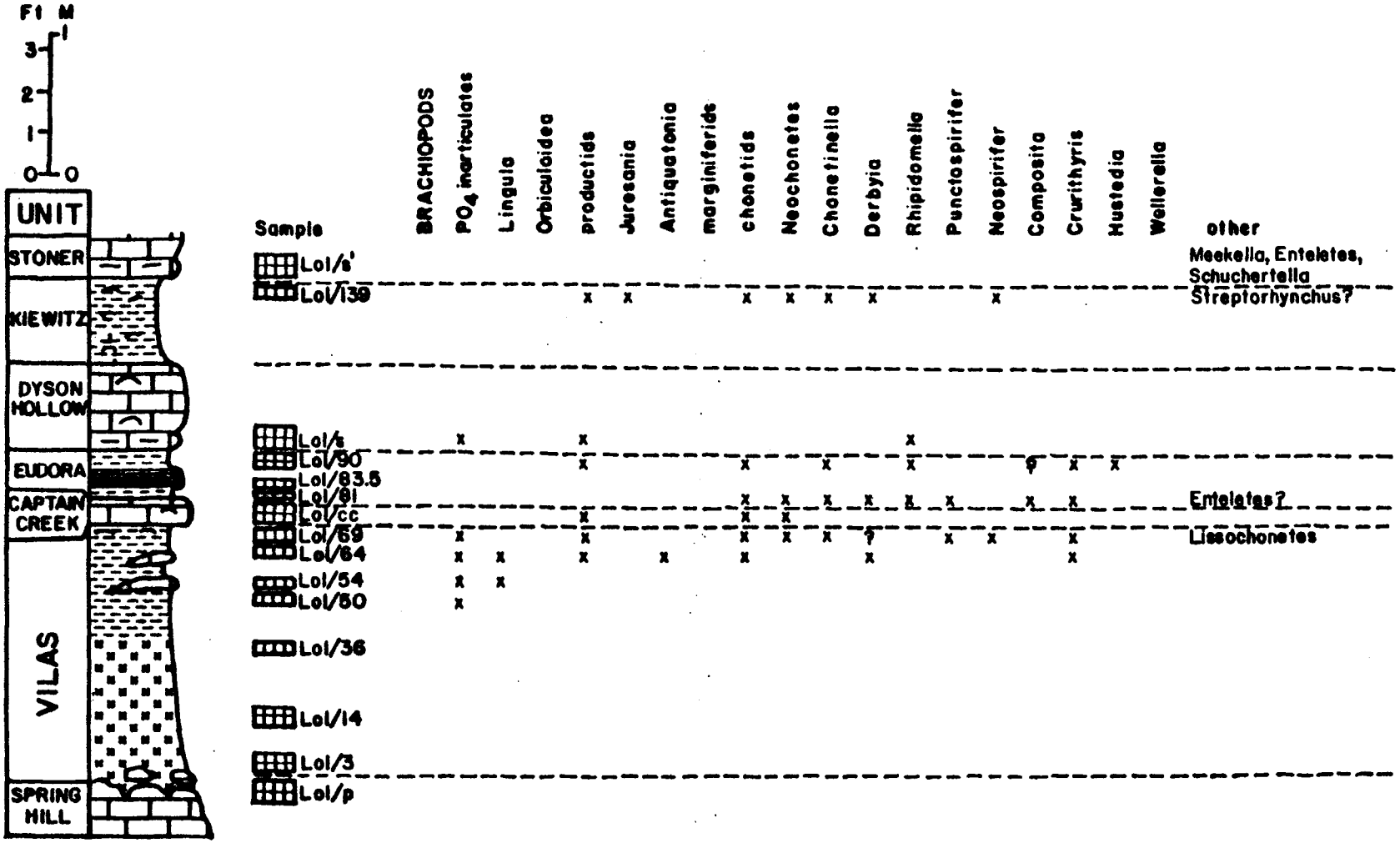

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lol/s' | 1.84 | 9.8 | 61 | 25 | | 15 | | | | | | .99 | | 21 | 5 | | 81 | 14 | | | | |
| Lol/130 | 2.9 | 10.5 | 71 | | | 29 | | | | | | .88 | | 50 | 2 | | 91 | 7 | | | | |
| Lol/s | 1.76 | 9.0 | 61 | 27 | | 12 | | | | | | 1.00 | | 43 | | | 85 | 14 | | 1 | | |
| Lol/90 | 1.64 | 9.1 | 53 | 29 | | 18 | | | | | | .22 | | 234 | | | 39 | | | 5 | 56 | |
| Lol/83.5 | 1.37 | 8.9 | 45 | 43 | | 13 | | | | | | .04 | | 608 | | | 91 | | | 4 | 5 | |
| Lol/81 | 1.79 | 9.2 | 60 | 24 | | 16 | | | | | | .30 | | 1285 | | | 93 | 4 | | 2 | 1 | |
| Lol/cc | 1.31 | 9.8 | 45 | 42 | | 13 | | | t | | | 1.00 | | 47 | | | 93 | 6 | | 1 | | |
| Lol/69 | 1.37 | 9.9 | 53 | 32 | | 15 | | | | | | .99 | | 164 | 4 | | 91 | 4 | | | | |
| Lol/64 | 1.41 | 9.8 | 57 | 37 | | 6 | | | | | | .16 | | 79 | 77 | | 15 | 8 | | | | |
| Lol/54 | 2.85 | 10.9 | 60 | 29 | | 11 | | x | | | | | | | | | | | | | | |
| Lol/50 | 1.49 | 9.6 | 62 | 29 | | 9 | | x | | | | .74 | | 1 | 100 | | | | | | | |
| Lol/36 | 3.00 | 10.4 | 67 | 21 | | 12 | | | | | | | | | | | | | | | | |
| Lol/14 | 1.58 | 8.7 | 54 | 30 | | 17 | | | | | | | | | | | | | | | | |
| Lol/3 | 1.59 | 8.8 | 52 | 29 | | 19 | | | | | | | | | | | | | | | | |
| Lol/p | 2.42 | 9.0 | 69 | 16 | | 16 | | x | | | | 1.00 | | 1 | 100 | | | | | | | |

# 42. Lo I

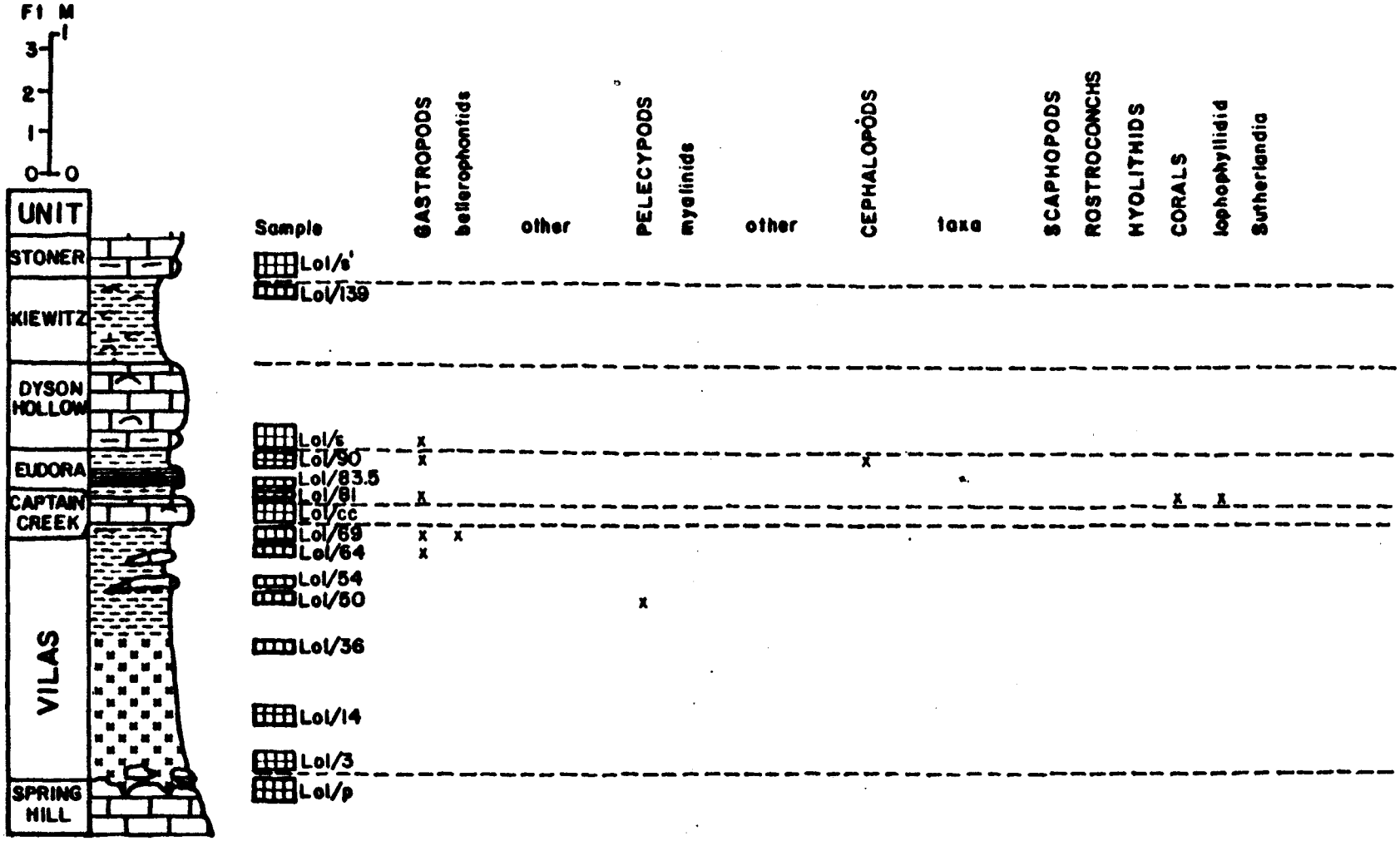



| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | |
| Lol/s' | | | | | | | | | | | | | | | | | | | | |
| Lol/139 | | x | | x | x | | x | | | | | | | | x | | x | | | fusulinids |
| Lol/s | | | | | | | | | | | | unidentified | | | | | | | | |
| Lol/90 | | ? | x | x | x | x | x | | x | | | | | | x | | | | | Ammodiscella |
| Lol/83.5 | | | | | | | | | | | | | | | | | | | | |
| Lol/81 | | x | | x | x | | x | | | | | Bairdiacypris | | | x | | | | | |
| Lol/cc | | | | | | | | | | | | | | | x | | | | | |
| Lol/69 | | x | x | x | x | | | | | | | | | | x | | | | | |
| Lol/64 | x | x | x | x | x | | | | | | | | | | x | | | | | |
| Lol/54 | x | | | | | | | | | | | | | | | | | | | |
| Lol/50 | x | | | | x | | | | | | | | | | x | x | | | | |
| Lol/36 | x | | | | | | | | | | | | | | | | | | | |
| Lol/14 | | | | | | | | | | | | | | | | | | | | |
| Lol/3 | | | | | | | | | | | | | | | | | | | | |
| Lol/p | | | | | | | | | | | | | | | | x | | | | |

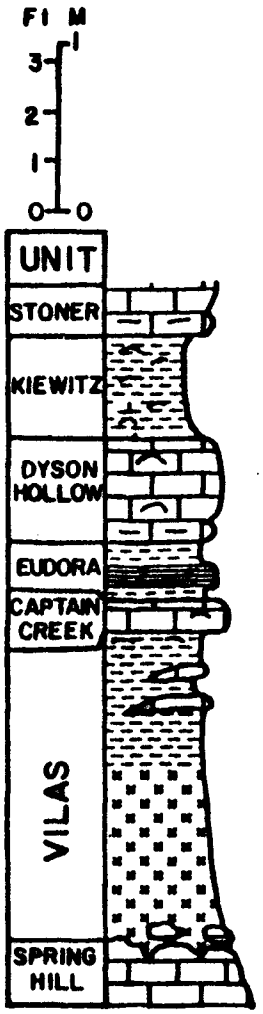
# 42.Lo1


Ft M
3
2
1
0
0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Lol/s'
Lol/139
Meekella, Enteletes, Schuchertella
Streptorhynchus?
Lol/s
Lol/90
Lol/83.5
Lol/81
Lol/cc
Lol/69
Lol/64
Lol/54
Lol/50
Lol/36
Lol/14
Lol/3
Lol/p
Enteletes?
Lissochonetes

# 42.Lo1

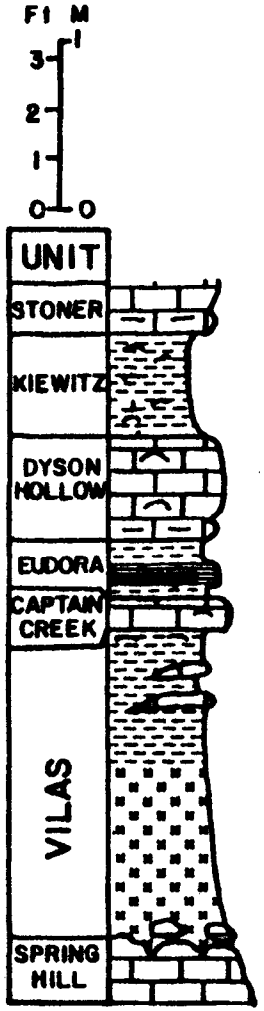

FT M
3
2
1
0
UNIT
STONER
KIEWITZ
DYSON HOLLOW
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Lo1/s'
Lo1/139
Lo1/s
Lo1/90
Lo1/83.5
Lo1/81
Lo1/cc
Lo1/69
Lo1/64
Lo1/54
Lo1/50
Lo1/36
Lo1/14
Lo1/3
Lo1/p

# 42. Lo I




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lol/s' | | x | | | | | | | | | | | | | | | | | | | |
| Lol/139 | | x | x | | | 1 | 2 | x | | | | | | | | x | | | | | |
| Lol/s | | x | | | | | | | | | | | | | | | | | | | |
| Lol/90 | | x | | | | 2 | 1 | | | | | | | | | x | | | | | |
| Lol/83.5 | | | | | | | | | | | | | | | | | | | | | |
| Lol/81 | | x | x | | | 1 | 1 | | | | | | | | | | | | | | |
| Lol/cc | | x | | | | | | | | | | | | | | | | | | | |
| Lol/69 | | x | | | | 3 | 1 | | | | | | | | | x | | | | | |
| Lol/64 | | x | | | | 2 | 2 | | 1 | | | | | | | | | | | | |
| Lol/54 | | | | | | | | | | | | | | | | | | | | | |
| Lol/50 | | | | | | | | | | | | | | | | | | x | | | |
| Lol/36 | | | | | | | | | | | | | | | | | | x | | | |
| Lol/14 | | | | | | | | | | | | | | | | | | | | | |
| Lol/3 | | | | | | | | | | | | | | | | | | | | | |
| Lol/p | | | | | | | | | | | | | | | | | | | | | |

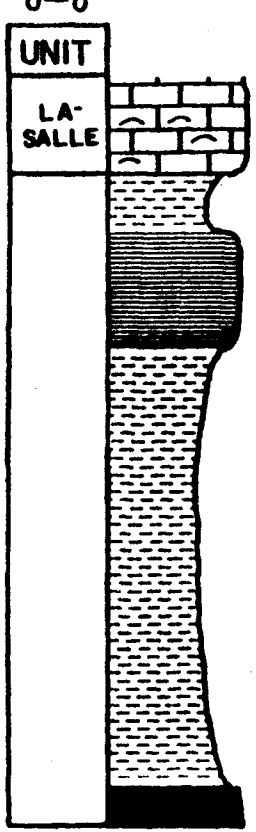
# 42. Lol




| Sample | FISH | paleoniscid teeth | ctenodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lol/s' | | x | | | | | | | | | | x | | | | | |
| Lol/139 | | x | | x | | | | | | x | x | | | | | | Protacrodus |
| Lol/s | | x | | x | | | | | | x | | | | x | | | |
| Lol/90 | | ? | | | | | | | | | | | | | | | |
| Lol/83.5 | | | | | | | | | | | | | | | | | |
| Lol/81 | | | | | | | | | | | | | | | | | |
| Lol/cc | | x | | | | | | | | | | | | | | | |
| Lol/69 | | x | x | | | | | | | x | | x | | | | | |
| Lol/64 | | x | | | | | | | | x | | | | | | | |
| Lol/54 | | | | | | | | | | | | | | x | | | |
| Lol/50 | | x | | | | | | | | | | | | x | | | |
| Lol/36 | | | | | | | | | | | | | | | | | unidentified fragments |
| Lol/14 | | | | | | | | | | | | | | | | | |
| Lol/3 | | | | | | | | | | | | | | | | | |
| Lol/p | | x | | | | | | | | | | | | | | | |

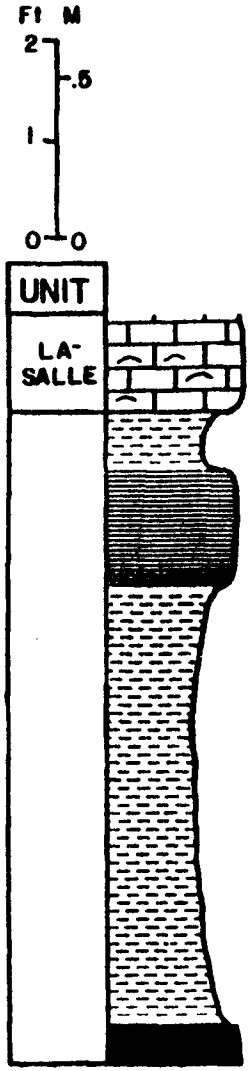
# 43. LS I

Location: Bridge over Bailey Creek, Marquette Cement Co. quarry, Oglesby, Illinois
LaSalle, Illinois, 7 1/2'  T32NR2E6SWI/4NEI/4NEI/4
References: Collinson et al., 1972, p. 15-18; Merrill and Martin, 1976
Collected: July 24, 1979



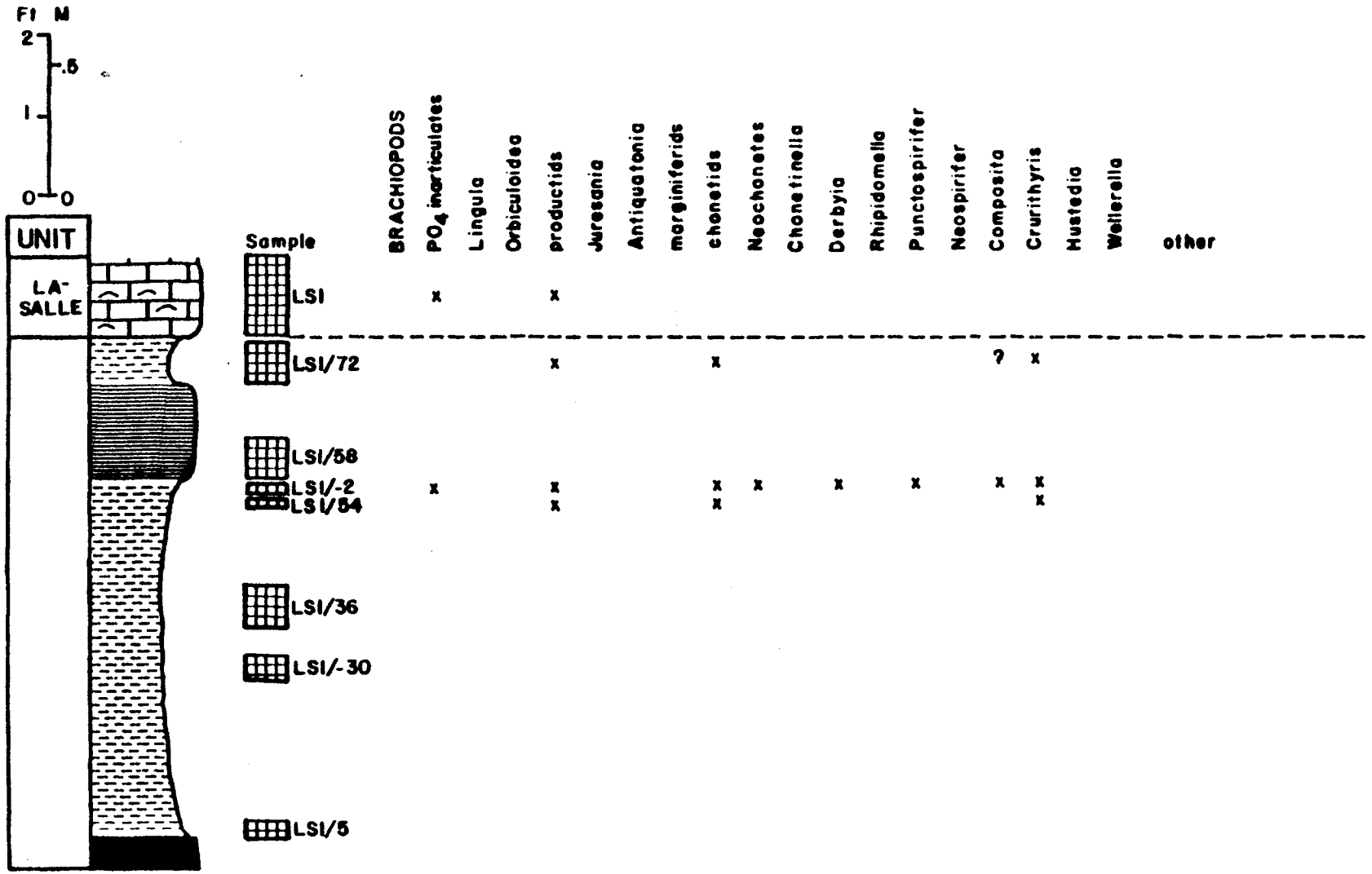

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSI | 1.64 | 9.3 | 48 | 15 | 26 | 10 | | | x | | x | .48 | 529 | | | | 95 | 5 | | 1 | | |
| LSI/72 | 1.94 | 9.5 | 53 | 9 | 27 | 12 | | | x | | | .88 | 661 | | | | 91 | 2 | | 4 | 3 | |
| LSI/58 | 2.12 | 9.5 | 54 | 6 | 29 | 11 | | | | | | .58 | 876 | | | | 96 | | | 3 | 1 | |
| LSI/-2 | 1.76 | 9.6 | 43 | 23 | 21 | 13 | | x | x | | | .03 | 1244 | | 19 | | 73 | 7 | | 1 | | |
| LSI/54 | 1.13 | 10.7 | 50 | 30 | 9 | 11 | | | x | | | .22 | 254 | | 16 | | 77 | 7 | | | | |
| LSI/36 | 1.50 | 9.8 | 40 | 22 | 23 | 15 | | | | | | | | | | | | | | | | |
| LSI/-30 | 1.14 | 8.0 | 34 | 31 | 13 | 22 | | | | | | | | | | | | | | | | |
| LSI/5 | 1.63 | 9.5 | 49 | 28 | 14 | 9 | | | | | | | | | | | | | | | | |

# 43. LS I

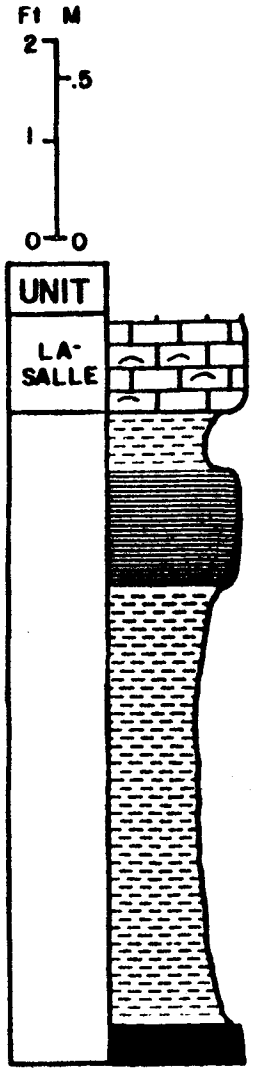



| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | |
| LSI | | | | | | | | | | | | | | | x | | | | | |
| LSI/72 | | | | x | | | x | | | | | | x | x | x | | | | | |
| LSI/58 | | | | | | | | | | | | | x | | x | | | | | |
| LSI/-2 | | x | | x | | | | | | | | | | | x | | | | | |
| LSI/54 | | x | | x | x | | | | | | | | | | x | | | | | |
| LSI/36 | x | x | | | | | | | | | | | | | x | | | | | |
| LSI/-30 | | | | | | | | | | | | | | | | | | | | |
| LSI/5 | | | | x | | | | | | | | Sulcella | | | x | | | | | |

# 43. LS I

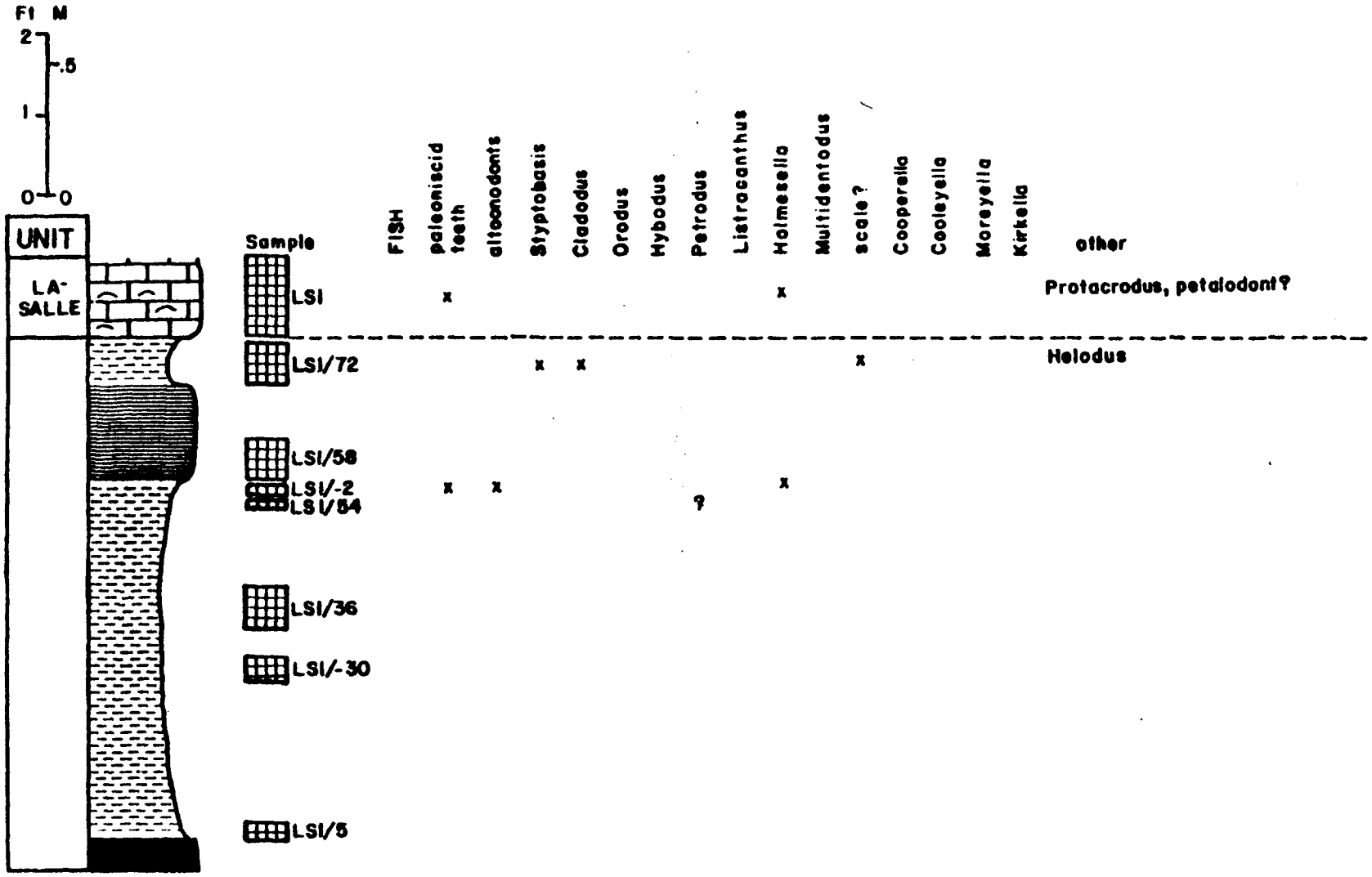

Ft M
2
.5
1
0
0
UNIT
LA-SALLE
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
LSI
LSI/72
LSI/58
LSI/-2
LSI/54
LSI/36
LSI/-30
LSI/5

## 43. LS I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SCOLECODONTS | Spirorbis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSI | | | | | | | | | | | | | | | |
| LSI/72 | | | | | | | | | | | | | | | |
| LSI/58 | | | | | | | | | | | | | | | |
| LSI/-2 | x | x | | x | ? | | | | | | | | | | |
| LSI/54 | | | | | | | | | | | | | | | |
| LSI/36 | x | | | | | | | | | | | | | | x |
| LSI/-30 | | | | | | | | | | | | | | | |
| LSI/5 | x | | | x | | | | | | | | | | | x |

# 43. LS I


Ft M
2
.5
1
0
0
UNIT
LA-SALLE
Sample
FISH
paleoniscid teeth
allocnodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
LSI
Protacrodus, petalodont?
LSI/72
Helodus
LSI/58
LSI/-2
LSI/54
LSI/36
LSI/-30
LSI/5

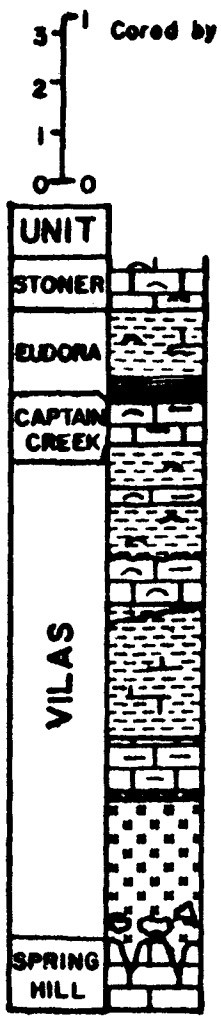
# 44. Mal

Location: 1 mi south and 1/2 mi east of Malvern, Iowa

Ft M Tabor NE, Iowa, 7 1/2'

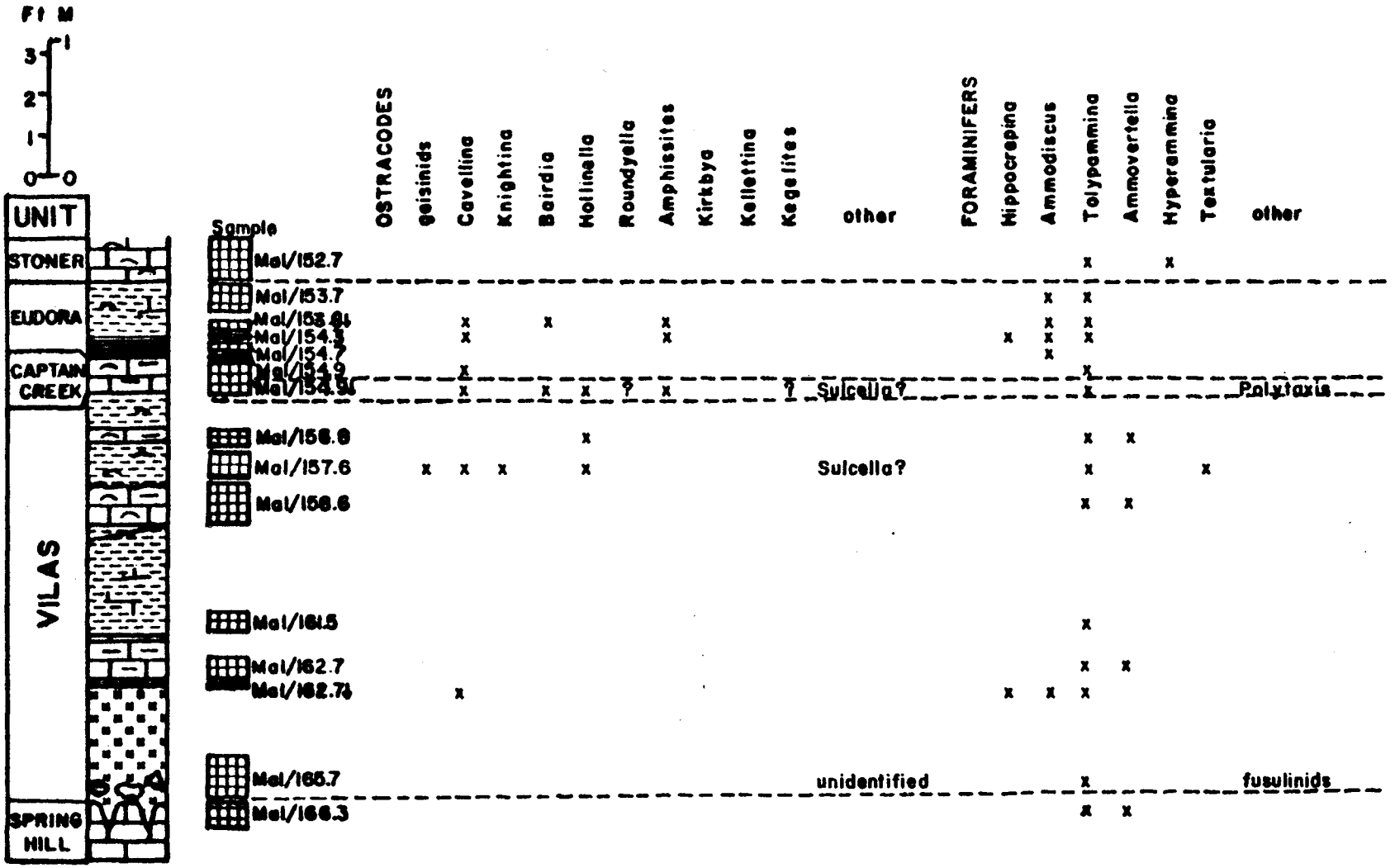
T7INR41W5NW1/4SW1/4

Cored by the Iowa Geological Survey

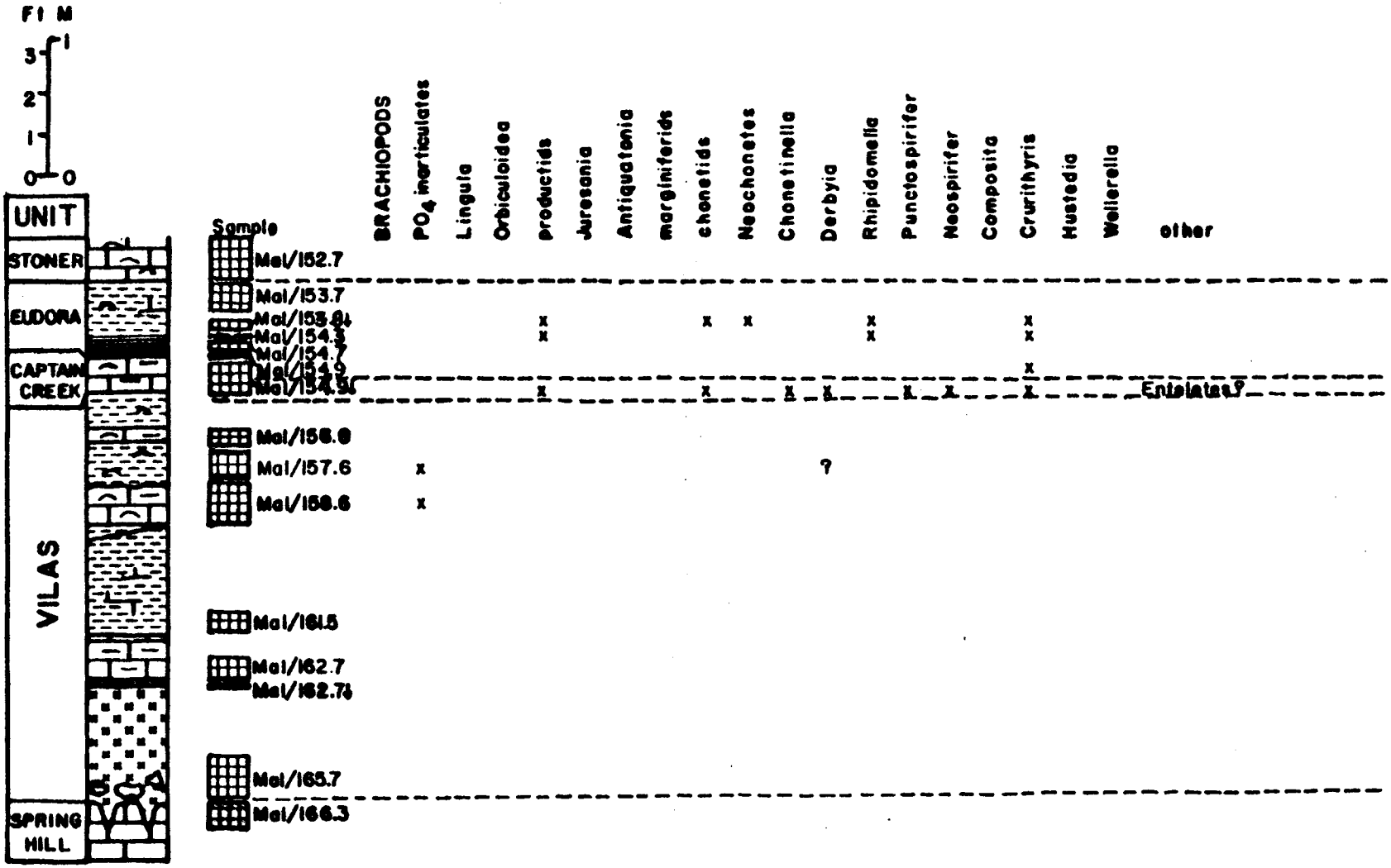



| Sample | Wite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Asthetaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mal/152.7 | 1.75 | 9.5 | 66 | 15 | | 19 | | | | | | .73 | | 61 | 5 | | 89 | 7 | | | | |
| Mal/153.7 | 1.80 | 9.1 | 60 | 21 | | 19 | | | | | | .34 | | 90 | | | 89 | | | 4 | 7 | |
| Mal/153.8↓ | 1.63 | 9.3 | 42 | 45 | | 13 | | | | | | .10 | | 1126 | | | 62 | | | 2 | 36 | |
| Mal/154.3 | 1.74 | 9.2 | 53 | 24 | | 24 | | | | | | .14 | | 296 | | | 49 | | | 2 | 49 | |
| Mal/154.7 | 1.75 | 9.6 | 75 | 14 | | 11 | | | | | | .04 | | 1878 | | | 49 | 1 | | 4 | 46 | |
| Mal/154.9 | 1.70 | 9.1 | 50 | 31 | | 19 | | | | | | .08 | | 263 | | | 91 | | | 9 | | |
| Mal/154.9↓ | 1.56 | 9.9 | 34 | 31 | | 35 | | | | | | .35 | | 211 | 1 | | 92 | 2 | | 1 | | |
| Mal/156.0 | 1.43 | 9.1 | 56 | 43 | | 2 | | | | | | .20 | | 35 | 86 | | 14 | | | | | |
| Mal/157.6 | 1.24 | 9.2 | 55 | 31 | | 14 | | | | | | .70 | | 4 | 100 | | | | | | | |
| Mal/158.6 | 1.74 | 8.9 | 57 | 37 | | 7 | | | | | | .54 | | 55 | 93 | 3 | | 3 | | | | |
| Mal/161.5 | 1.61 | 8.9 | 55 | 32 | | 13 | | x | | | | .42 | | | | | | | | | | x |
| Mal/162.7 | 1.74 | 8.8 | 58 | 29 | | 13 | | | | | | | | | | | | | | | | |
| Mal/162.7↓ | 1.75 | 9.2 | 74 | 19 | | 7 | | | | | | | | | | | | | | | | |
| Mal/165.7 | 1.96 | 9.3 | 87 | 10 | | 3 | | | | | | | | | | | | | | | | |
| Mal/166.3 | | 11.0 | x | | | x | | | | | | .39 | | 20 | 75 | | 25 | | | | | |

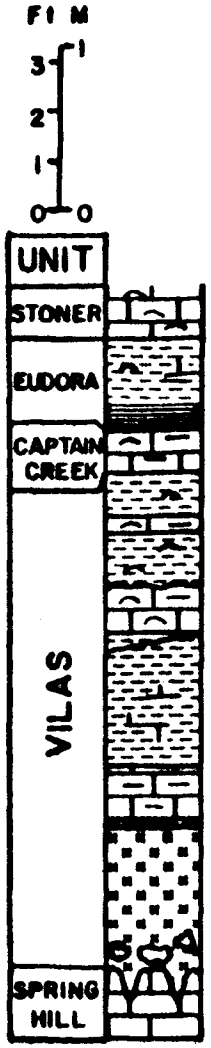
# 44. Mal


FT M
3
2
1
0
UNIT
STONER
ELDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Mal/152.7
Mal/153.7
Mal/158.8
Mal/154.3
Mal/154.7
Mal/154.9
Mal/154.9
Sulcella?
Polytaxis
Mal/156.9
Mal/157.6
Sulcella?
Mal/158.6
Mal/161.5
Mal/162.7
Mal/162.7
Mal/165.7
unidentified
fusulinids
Mal/166.3

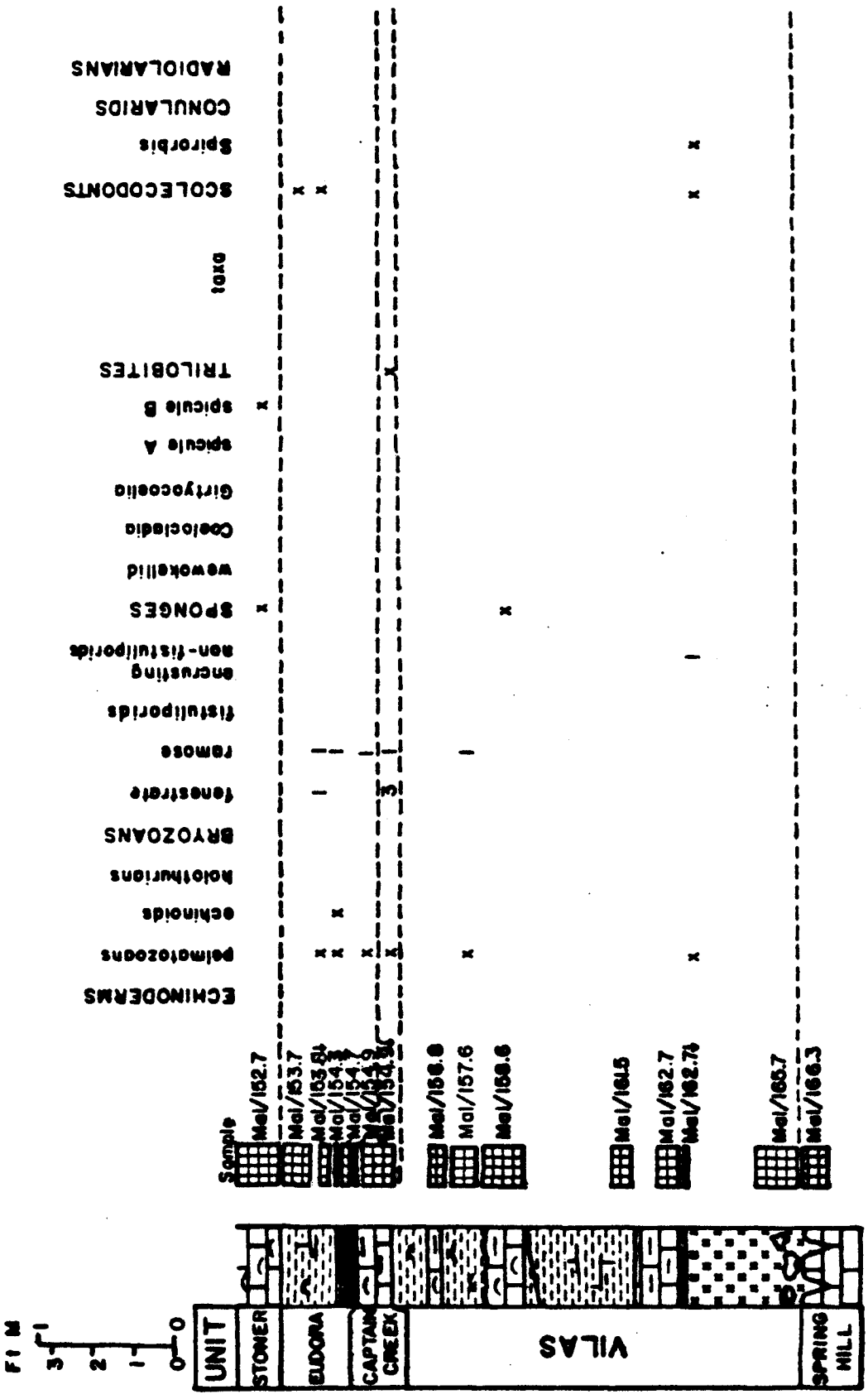
# 44. Mal


FT M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Mal/152.7
Mal/153.7
Mal/155.8
Mal/154.3
Mal/154.7
Mal/154.9
Mal/154.5
Enteletes?
Mal/156.8
Mal/157.6
Mal/158.6
Mal/161.5
Mal/162.7
Mal/162.7½
Mal/165.7
Mal/166.3

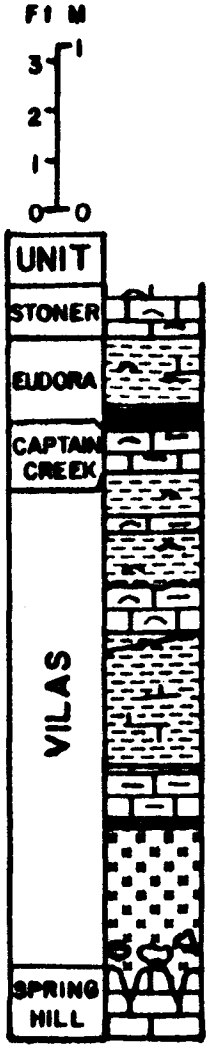
# 44. Mal




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | CORALS | lophophyllidid | Sutherlandia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mal/152.7 | | | | | | | x | Eoasianites | | | | x | | |
| Mal/153.7 | | | | | | | x | Eoasianites | | | | | | |
| Mal/153.8↓ | | | | | | | | | | | | | | |
| Mal/154.5 | x | | | x | | | | | | | | | | |
| Mal/154.7 | | | | | | | | | | | | | | |
| Mal/154.9 | x | | | ? | | | | | | | | | | |
| Mal/154.9↓ | x | x | | x | | | | | | | | x | ? | |
| Mal/156.8 | | | | | | | | | | | | | | |
| Mal/157.6 | x | | Aclisina? | x | ? | | | | | | | | | |
| Mal/158.6 | | | | | | | | | | | | | | |
| Mal/161.5 | | | | | | | | | | | | | | |
| Mal/162.7 | | | | | | | | | | | | | | |
| Mal/162.7↓ | x | | | x | | | | | | | | | | |
| Mal/165.7 | x | | | x | | | | | | | | | | |
| Mal/166.3 | x | | | | | | | | | | | | | |


44.Mal
ECHINODERMS
pelmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistulliporids
encrusting
ean-fistulliporids
SPONGES
wewokellid
Coelocladia
Girtycoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Sample
Mal/152.7
Mal/153.7
Mal/153.8
Mal/154.3
Mal/154.7
Mal/154.9
Mal/154.95
Mal/156.8
Mal/157.6
Mal/158.6
Mal/161.5
Mal/162.7
Mal/162.74
Mal/165.7
Mal/166.3
UNIT
STONER
EUDORA
CAPTAN CREEK
VILAS
SPRING HILL
FEET
3
2
1
0

# 44. Mal




| Sample | FISH | paleoniscid teeth | elliocnodont | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mal/152.7 | | x | | ? | | | | | | | | | | | | | |
| Mal/153.7 | | | | | x | | | | | | | | | | | | |
| Mal/155.84 | | x | | | | | | | | | | x | | | | | |
| Mal/154.3 | | | | | | | | | | | | | | | | | |
| Mal/154.7 | | | | x | | | | | | | | | | | | | Petalodont? |
| Mal/154.9 | | | | | | | | | | | | | | | | | |
| Mal/154.95 | | x | | | x | | | | | x | | x | | | | | |
| Mal/155.6 | | | | | | | | | | | | | | | | | |
| Mal/157.6 | | | | | | | | | | | | | | | | | unidentified fragment |
| Mal/158.6 | | x | | x | ? | | | | | | | | | x | | | |
| Mal/161.5 | | | | | | | | | | | | | | | | | |
| Mal/162.7 | | x | | | | | | | | | | | | | | | |
| Mal/162.74 | | | | | | | | | | | | | | | | | |
| Mal/166.7 | | | | | | | | | | | | | | | | | unidentified fragments |
| Mal/166.3 | | x | | | | | | | | | | | | | | | |

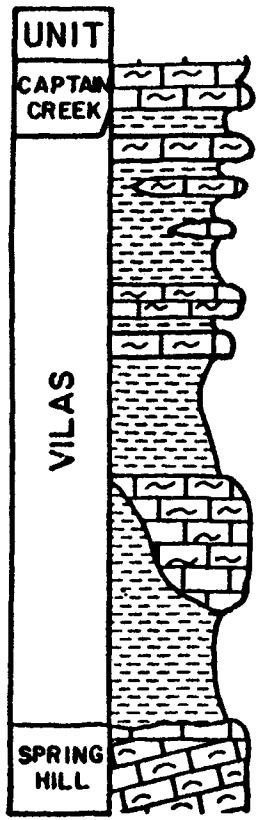
# 45. Ne I

Location: Road cut on Kansas Highway 96, 2 mi west of Neodesha, Kansas

Neodesha, Kansas, 7 1/2' T30SR15E23SW1/4SE1/4SE1/4

References: Davis, 1959, p. 330-331; Kans. Geol. Soc., 1962, Stop I, p. 26-31; Heckel, 1978, p. 36-37

Collected: June 10, 1979




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ne1/p | 1.43 | 9.6 | 64 | 23 | | 14 | 10 | | | | |

# 46.Oal

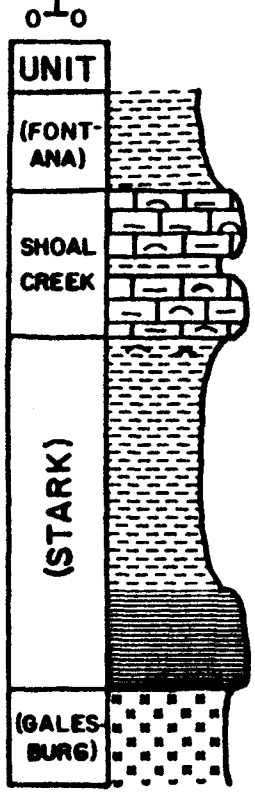
Location: Ravine 1 1/2 mi west and 1 mi south of Oakwood, Illinois

Oakwood, Illinois, 7 1/2' T19NR13W22SE1/4SW1/4NE1/4

Reference: Langenheim et al., 1980, Stop 10, p. 62-65

Collected: September 28, 1980

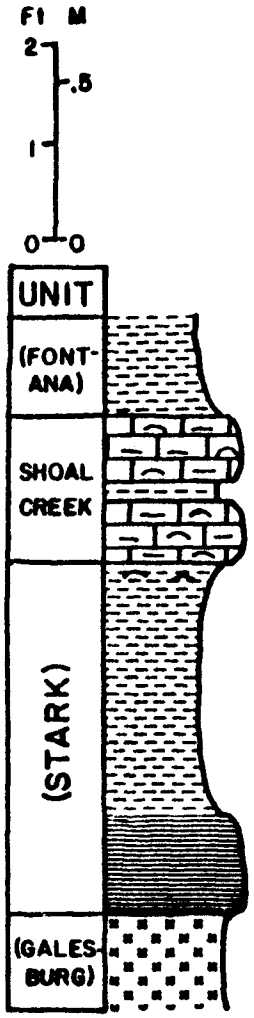
Note: Only sampled interval exposed, remainder from published description. *Gondolella denuda* suggests this may be the Macoupin cyclothem, rather than the Shoal Creek




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oal/sc | 1.71 | 9.5 | 65 | 21 | | 13 | | x | | | | 1.53* | | 276 | 9 | 1 | 69 | 15 | 1 | t | 4 | |
| Oal/-11 | 1.32 | 8.9 | 52 | 22 | | 26 | | | | | | .90 | | 270 | | | 88 | | | 3 | 9 | |

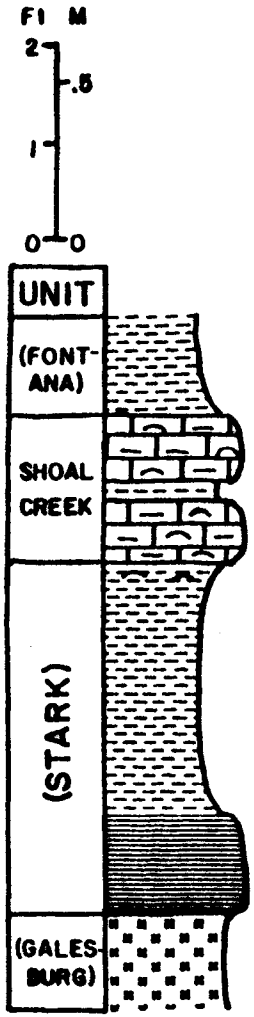
*Conodont data for Oal/sc from Merrill (1980)

# 46.Oal



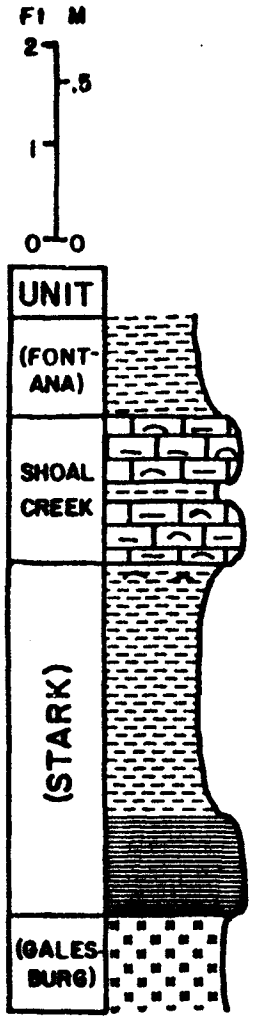

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oal/sc | | | | | | | | ? | | | | | | | | x | x | | | |
| Oal/-11 | | | | | | | | | | | | | | | | | | | | |

# 46.0al



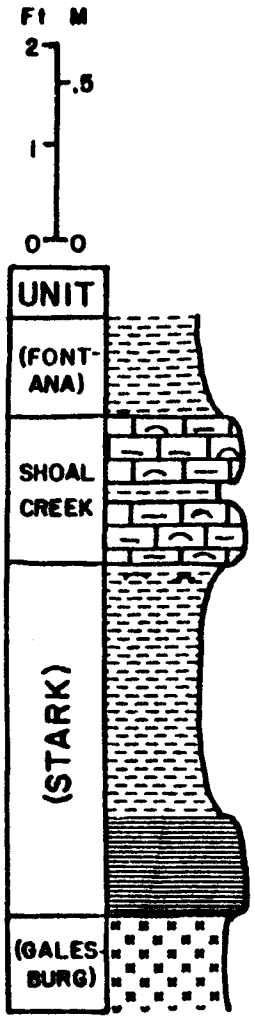

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0al/sc | | | | | | | | | | | | | | | | | | | | |
| 0al/-11 | | | | | x | | | | | | | | | | | | x | | | |

# 46.Oal




| Sample | ECHINODERMS | | | | BRYOZOANS | | | | | GASTROPODS | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pelmatozoans | echinoids | holothurians | | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | | | bellerophontids | |
| Oal/sc | | | | | | | | | | x | | |
| Oal/-11 | x | | | | 1 | 1 | | | | x | | |

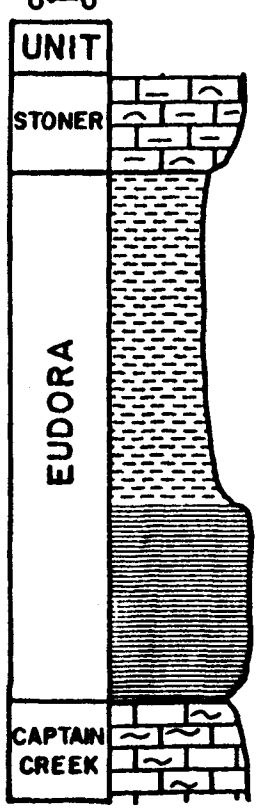
# 46.Oal




| Sample | FISH | paleoniscid teeth | altoamodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Morayella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oal/sc | | | | | | | | | | | | | | | | | unidentified fragment |
| Oal/-II | | | | | | | | | | | | | | | | | unidentified tooth |

# 47.01 I

Ft M Location: Quarry 3/4 mi east of Ottawa, Kansas
2 Peoria, Kansas, 7 1/2'
.5 Collected: August 11, 1979
T17SR20E6SE1/4SW1/4NE1/4
1
0 0



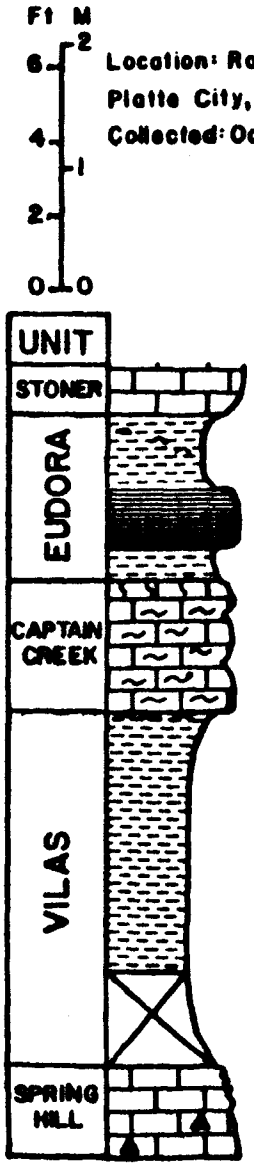

| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | |
| 011/48 | | x | | | | | | | | | | | | x | | | x | x | | |

# 48. PC I

Location: Road cut on Interstate 29 east of Platte City, Missouri

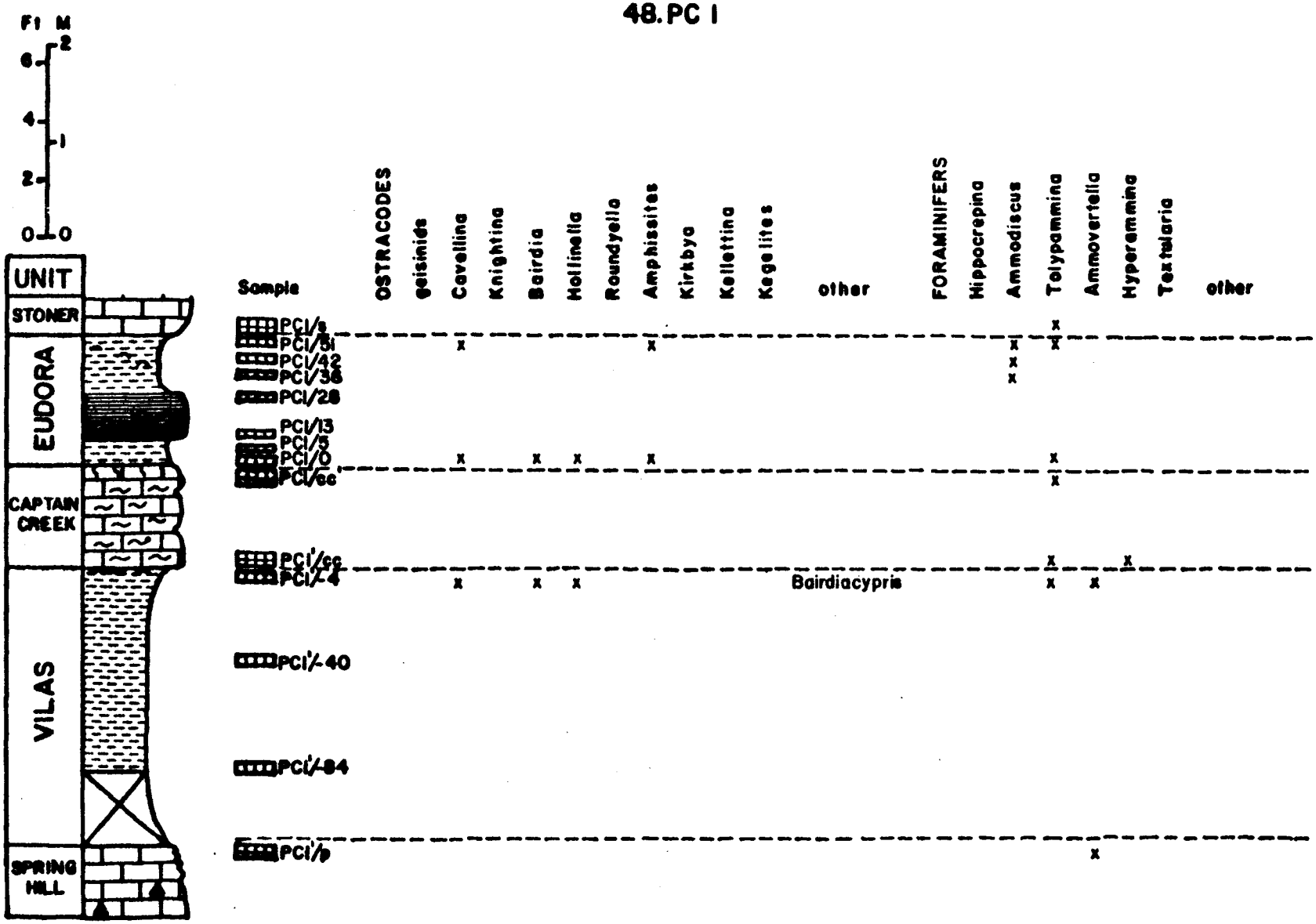
Platte City, Missouri-Kansas, 7 1/2'  T53NR35W25SE1/4SE1/4NW1/4

Collected: October 21, 1979

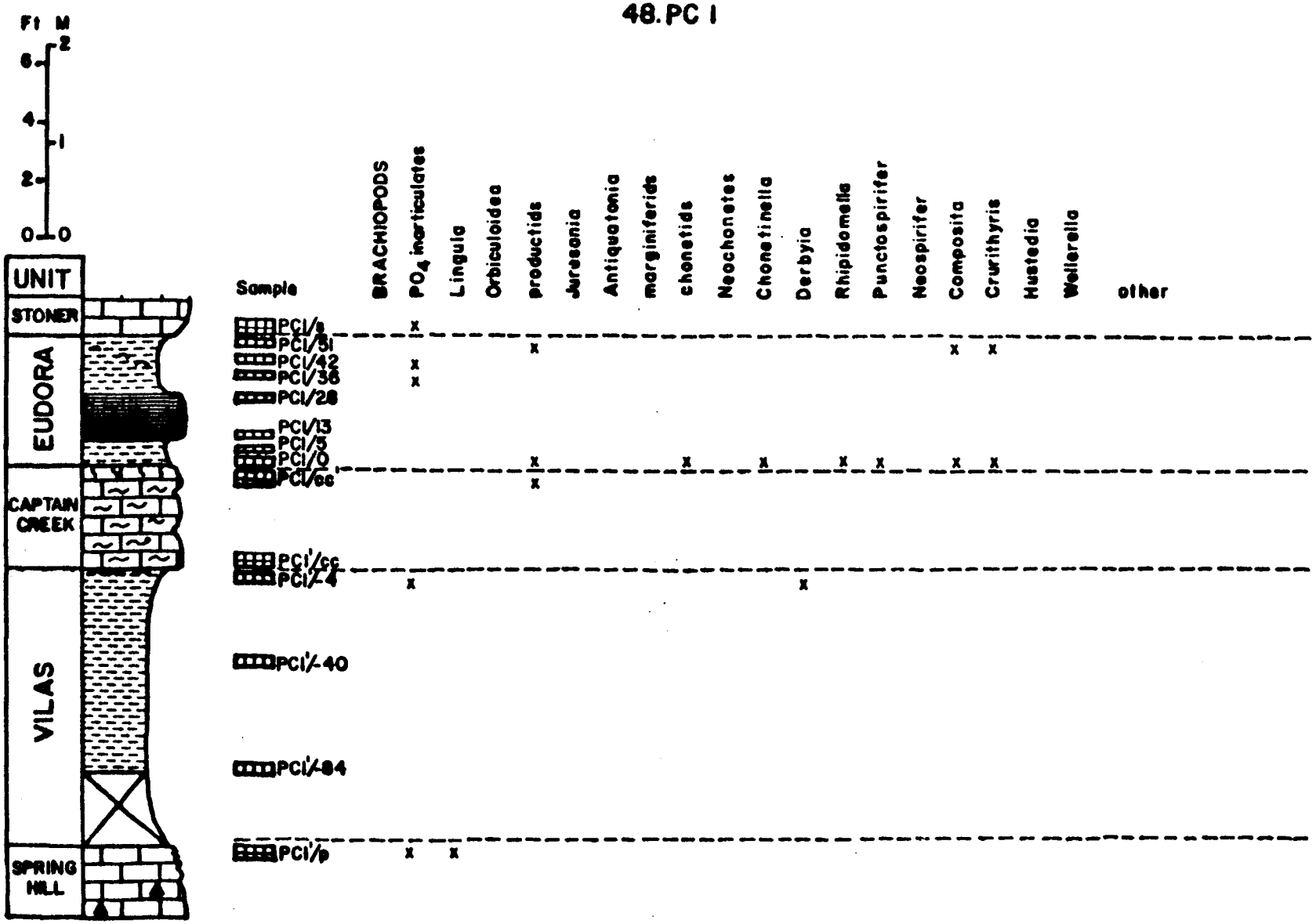



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Archignathodus | % Asthenotaxis | % Idioprioniodus | % Bondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCI/s | 2.01 | 9.3 | 44 | 43 | | 13 | | | x | | | .99 | | 7 | | | 97 | | | 3 | | |
| PCI/5I | 1.75 | 9.4 | 45 | 24 | | 23 | 8 | | | | | .37 | | 61 | | | 97 | | | 3 | | |
| PCI/42 | 1.20 | 9.1 | 43 | 36 | | 21 | | | | | | .35 | | 207 | | | 98 | | | 2 | | |
| PCI/36 | 1.28 | 9.9 | 52 | 40 | | 8 | | | | | | .28 | | 229 | | | 71 | | | 1 | 28 | |
| PCI/28 | 1.75 | 9.4 | 46 | 34 | | 21 | | | | | | .66 | | 286 | | | 45 | | | 2 | 54 | |
| PCI/13 | 1.25 | 9.7 | 40 | 42 | | 18 | | | | | | .60 | | 258 | | | 98 | | | 2 | | |
| PCI/5 | 1.74 | 9.5 | 48 | 28 | | 25 | | | | | | | | | | np | | | | | | |
| PCI/0 | 1.51 | 9.7 | 54 | 25 | | 21 | | | x | | | .13 | | 802 | 2 | | 98 | | | 1 | | |
| PCI/6c | 1.70 | 9.5 | 55 | 26 | | 19 | | | x | | | .99 | | 7 | 71 | | 14 | 14 | | | | |
| PCI'/cc | 1.77 | 9.7 | 42 | 35 | | 12 | 12 | | | | | 1.00 | | 15 | 93 | | | 7 | | | | |
| PCI'/-4 | 1.79 | 9.3 | 42 | 30 | | | 28 | x | | | | .60 | | 43 | 92 | | | 8 | | | | |
| PCI'/-40 | 2.25 | 9.8 | 33 | 30 | | | 37 | x | | | | | | | | | | | | | | |
| PCI'/-84 | 2.66 | 9.3 | 40 | 23 | | | 37 | x | | | | | | | | | | | | | | |
| PCI'/p | 1.35 | 9.5 | 58 | 34 | | 8 | | | | | | | | | | | | | | | | |

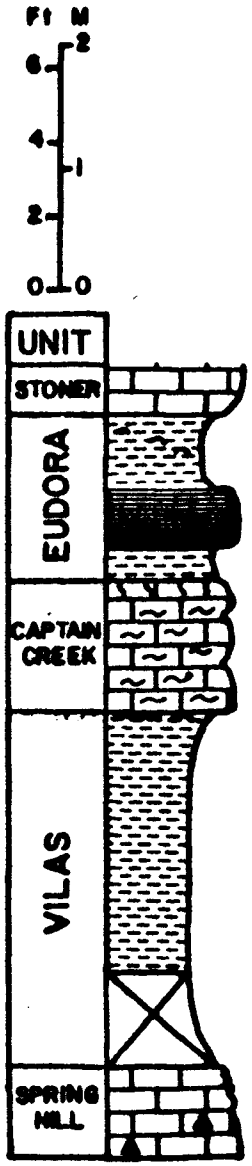
# 48. PC I


Ft M
2
6
4
1
2
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
PCI/3
PCI/51
PCI/42
PCI/36
PCI/28
PCI/13
PCI/5
PCI/0
PCI/cc
PCI'/cc
PCI'/-4
Bairdiacypris
PCI'/-40
PCI'/-84
PCI/b

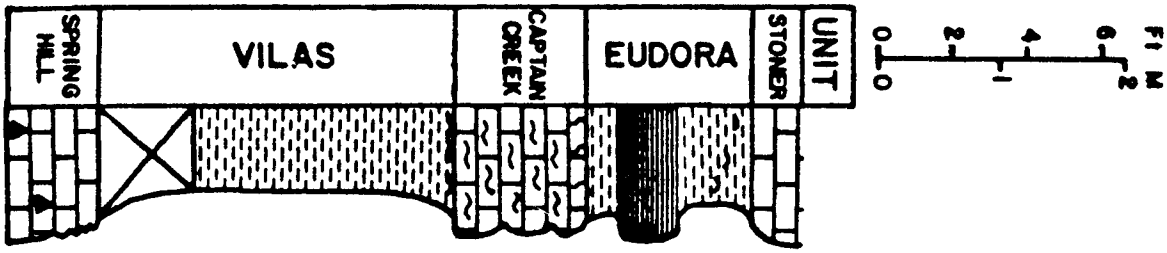
# 48. PC I


Ft M
6 2
4 1
2
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
PCI/a
PCI/5i
PCI/42
PCI/36
PCI/28
PCI/13
PCI/5
PCI/0
PCI/cc
PCI'/cc
PCI'/-4
PCI'/-40
PCI'/-84
PCI'/b

## 48. PC I



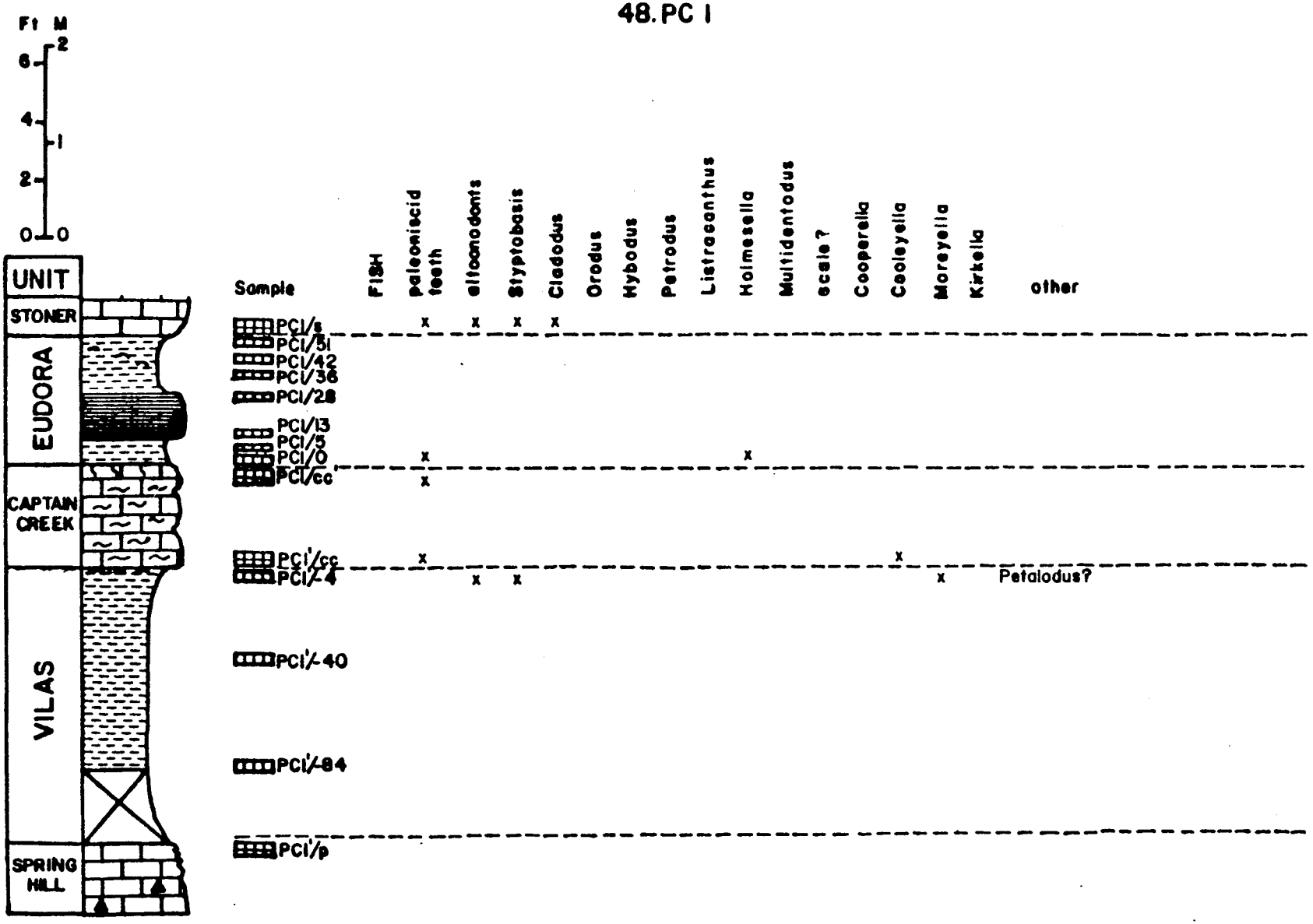

| Sample | GASTROPODS | heterophrentids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PCI/s | | | | | | | | | | | |
| PCI/51 | | | | | | | | | | | |
| PCI/42 | | | | | | | x | | | | |
| PCI/36 | | | | | | | | | | | |
| PCI/28 | | | | | | | | | | | |
| PCI/13 | | | | | | | | | | | |
| PCI/5 | | | | | | | | | | | |
| PCI/0 | x | | | | | | | | | | |
| PCI/cc | | | | | | | | | | | |
| PCI'/cc | | | | | | | | | | | |
| PCI'/4 | x | | Aclisina? | x | | | | | | | |
| PCI'/40 | | | | x | | | | | | | |
| PCI'/84 | | | | ? | | | | | | | |
| PCI'/b | | | | | | | | | | | |




48.PC I

| Sample | taxa |
|---|---|
| PCi/6 PCi/31 PCi/42 PCi/36 PCi/28 PCi/13 PCi/5 PCi/0 PCi/66 PCi/24 PCi/55 PCi/-40 PCi/-84 PCi/9 | ECHINODERMS |
| | pelmatozoans |
| | echinoids |
| | holothurians |
| | BRYOZOANS |
| | fenestrate |
| | ramose |
| | fistuliporids |
| | encrusting non-fistuliporids |
| | SPONGES |
| | wewokellid |
| | Coelocladia |
| | Girtyocoelia |
| | spicule A |
| | spicule B |
| | TRILOBITES |
| | SCOLECODONTS |
| | Spirorbis |
| | CONULARIDS |
| | RADIOLARIANS |

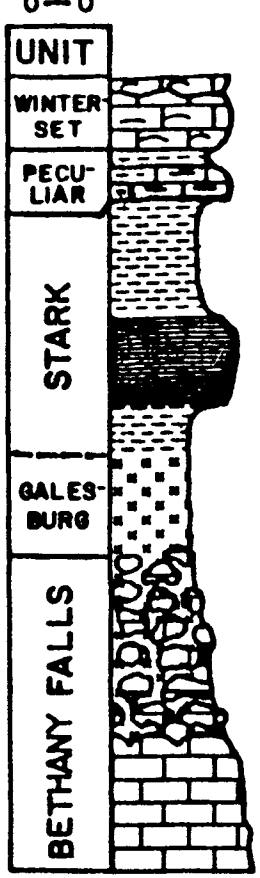
# 48. PC I


Ft M
6 2
4 1
2
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
SPRING HILL
Sample
FISH
paleoniscid teeth
allacanodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
PCI/s
PCI/51
PCI/42
PCI/36
PCI/28
PCI/13
PCI/5
PCI/0
PCI/cc
PCI'/cc
PCI'/4
Petalodus?
PCI'/-40
PCI'/-84
PCI'/p

# 49. Pq l

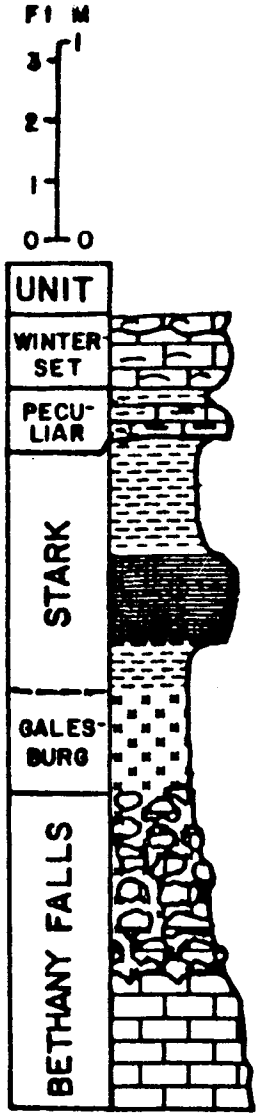
Location: Quarry on SE edge of Peculiar, Missouri
Peculiar, Missouri, 7 1/2'
Reference: Lamerson, 1956, Section 6, p. 98
Collected: May 25, 1980

T45NR32W23NW1/4NW1/4NE1/4



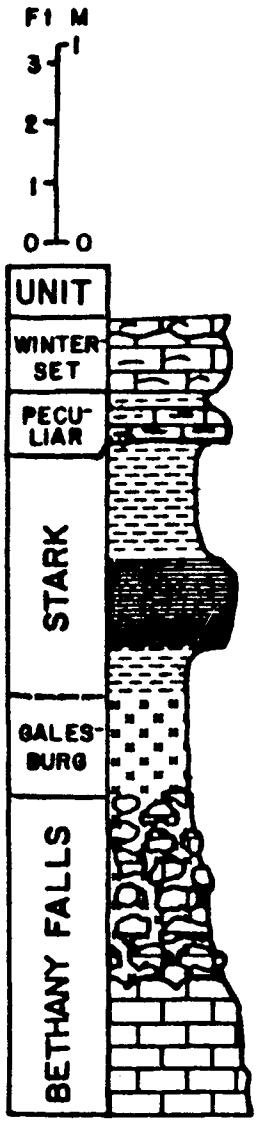

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pql/w | .93 | 9.5 | 43 | 57 | | | | | | | | 1.00 | | 5 | | | 100 | | | | | |
| Pql/79 | 1.44 | 9.6 | 64 | 36 | | | | | | | | .52 | 1020 | | | | 95 | 2 | | 4 | | |
| Pql/72 | 1.52 | 8.6 | 72 | 28 | | | | | x | | x | .52 | 26 | | | | 91 | | | 9 | | |
| Pql/66 | 1.80 | 9.5 | 80 | 17 | | 3 | | | | | | .26 | 107 | | | | 97 | | | 3 | | |
| Pql/46 | 1.52 | 9.5 | 64 | 23 | | 13 | | | | | | .05 | 800 | | | | 84 | | | 2 | 13 | |
| Pql/30 | 2.83 | 9.8 | 70 | 15 | | 15 | | | | | | .05 | 929 | | | | 96 | | | 4 | | |
| Pql/24 | .83 | 9.5 | 41 | 52 | | 7 | | x | | | | .63 | 80 | | 30 | | 62 | 6 | | 3 | | |
| Pql/bf | 1.65 | 9.5 | 61 | 17 | | 13 | 9 | | | | | 1.00 | | | | | | | | | | x |

# 49. Pq l



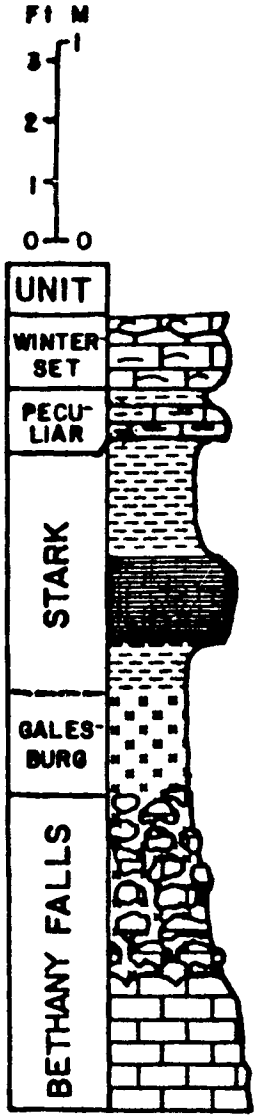

| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Talypammina | Ammovertella | Hyperammina | Textularia | | |
| Pql/w | | | | | | | | | | | | | | x | x | x | x | | | Ammodiscella |
| Pql/79 | | x | | x | x | x | x | x | x | | | | | x | x | | | | | |
| Pql/72 | | | | | | | | | | | | | | x | | | | | | |
| Pql/66 | | x | | | | x | x | | | | | | x | x | | | | | | |
| Pql/46 | | | | | | | | | | | | | | | x | | | | | |
| Pql/30 | | | | | | | | | | | | | | | | | | | | |
| Pql/24 | x | x | | | | x | x | | | | | | | x | x | | x | | | |
| Pql/bf | | | | | | | | | | | | | | | x | x | | | | |

## 49. Pq I



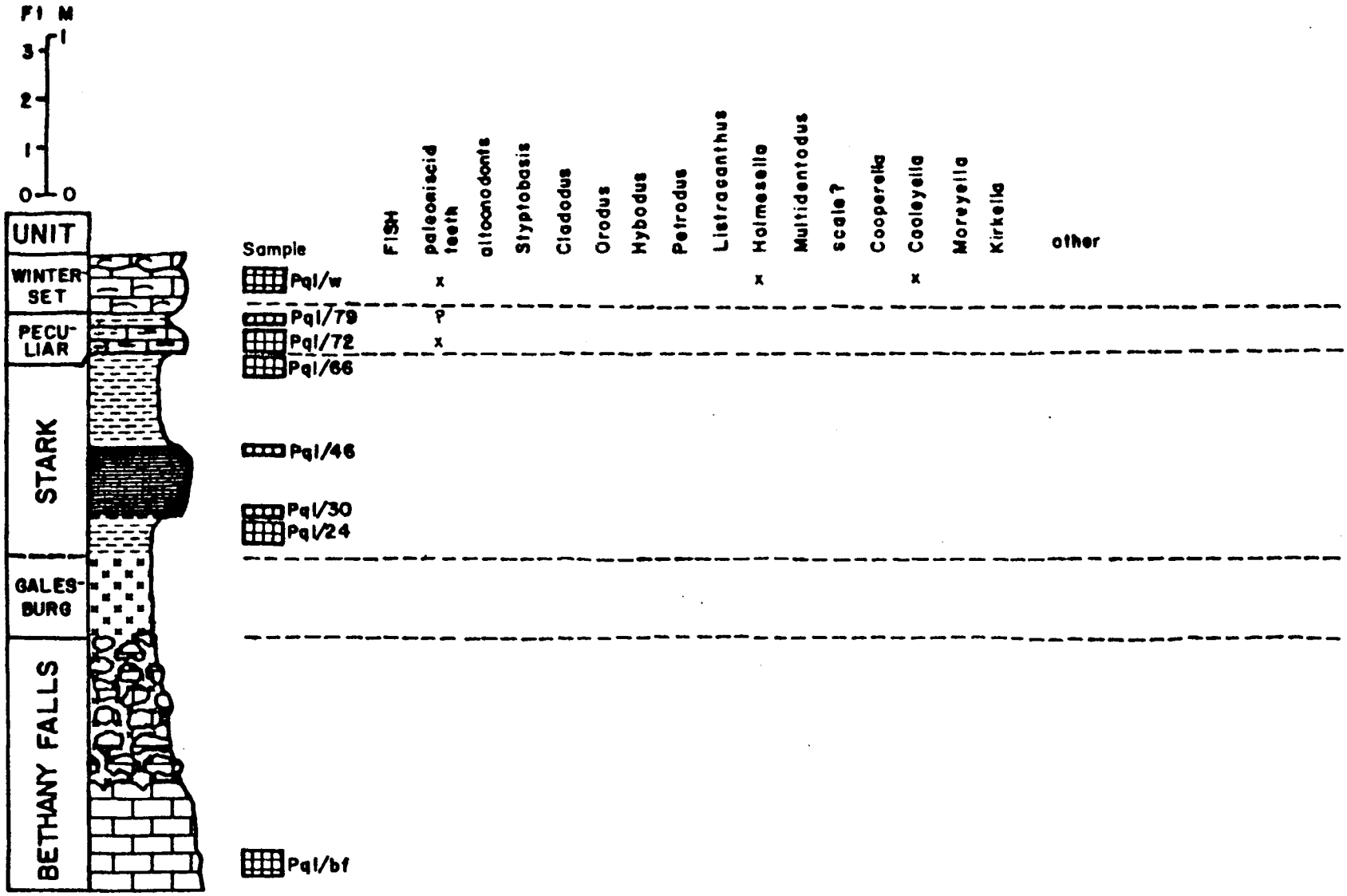

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pql/w | | | | | x | | | | | | | | | | | | | | | Teguliferina? |
| Pql/79 | | | | | x | | | x | x | | x | x | | x | | x | x | x | | |
| Pql/72 | | x | | | | | | | | | | | | | | | | | | |
| Pql/66 | | x | | | | | | | | | | | | | | | x | | | |
| Pql/46 | | | | | | | | | | | | | | | | | | | | |
| Pql/30 | | | | | | | | | | | | | | | | | | | | |
| Pql/24 | | x | | | x | | | | | | | x | | | | | x | x | | |
| Pql/bf | | | | | ? | | | | | | | | | | | | | | | |

## 49. Pq I



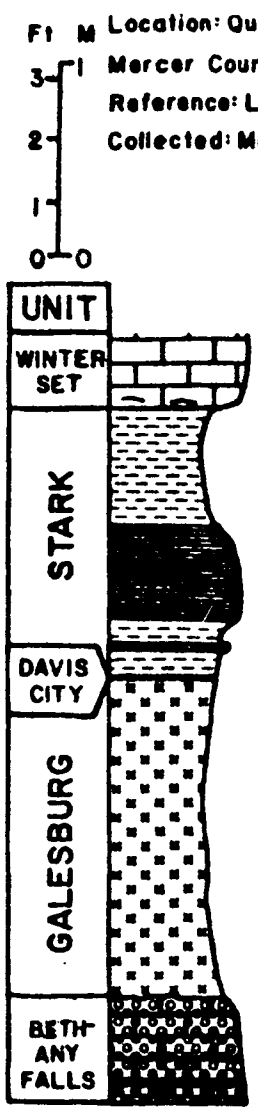

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pq I/w | | | | | | | | | | | | | | | |
| Pq I/79 | | | | | | | | x | | | | 2 | 1 | | |
| Pq I/72 | | | | | | | | | | | | | | | |
| Pq I/66 | x | | | | | | | | | | | | 1 | | |
| Pq I/46 | | | | | | | | | | | | | | | |
| Pq I/30 | | | | | | | | | | | | | | | |
| Pq I/24 | x | x | Aclisina? | ? | ? | | | x | | | | 1 | 1 | | |
| Pq I/bf | | | | | | | | | | | | | ? | | |

## 49. Pq l


FI M
3
2
1
0
UNIT
WINTER SET
PECU-LIAR
STARK
GALES-BURG
BETHANY FALLS
Sample
FISH
paleoniscid teeth
allocnodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Pql/w
Pql/79
Pql/72
Pql/66
Pql/46
Pql/30
Pql/24
Pql/bf

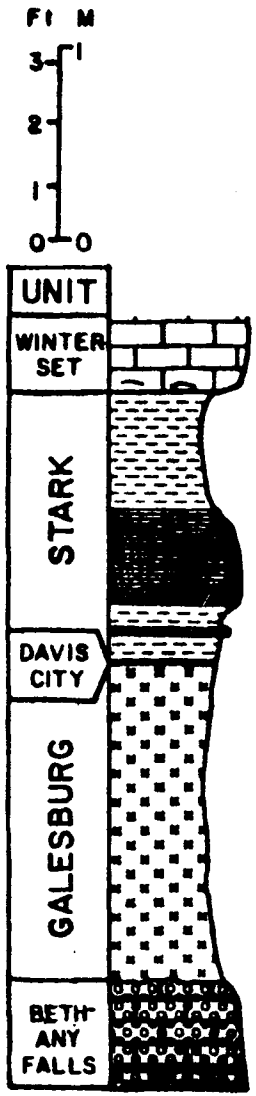
# 50. Pr I

Location: Quarry 2 mi south of Princeton, Missouri
Mercer County, Missouri, map
T64NR24WIINWI/4SWI/4NEI/4
Reference: Lamerson, 1956, Sect. 32, p. 124
Collected: May 21, 1980



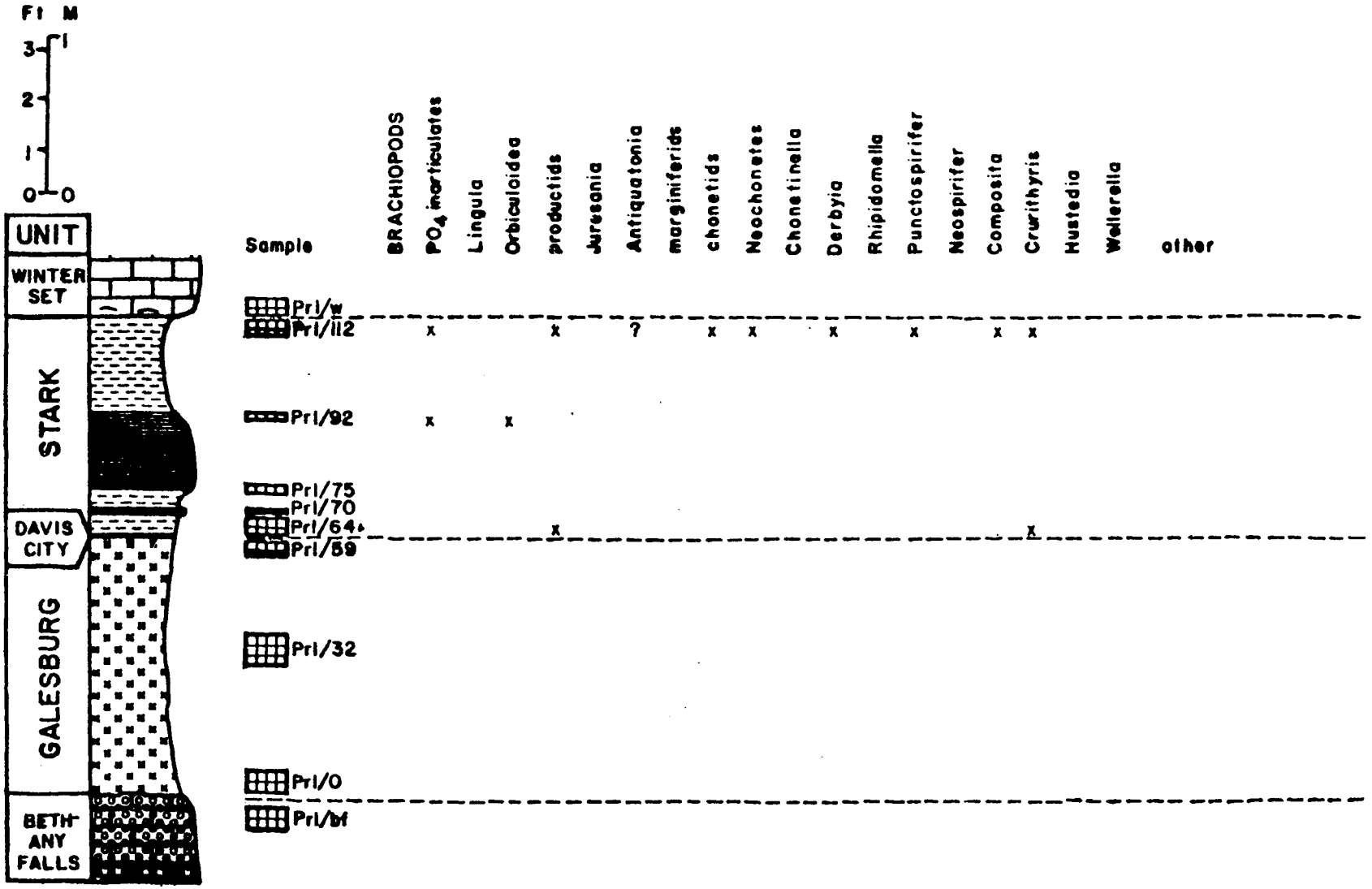

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pr I/w | 1.71 | 8.4 | 54 | 28 | | 18 | | | | | | 1.00 | | 380 | | | 83 | 17 | 1 | 1 | | |
| Pr I/112 | 1.86 | 8.9 | 60 | 19 | | 21 | | | | | | 46 | | 77 | | | 88 | 9 | | 3 | | |
| Pr I/92 | 1.50 | 9.2 | 51 | 30 | | 20 | | | | | | .43 | | 369 | | | 53 | | | 4 | 43 | |
| Pr I/75 | 1.45 | 9.2 | 60 | 27 | | 14 | | | | | | .22 | | 570 | | | 85 | | | 11 | 4 | |
| Pr I/70 | .93 | 8.1 | 38 | 55 | | 7 | | | | | | .20 | | 20 | 50 | | 50 | | | | | |
| Pr I/64 | .94 | 8.5 | 25 | 50 | | 11 | 14 | | | | | .91 | | 7 | 83 | | 17 | | | | | |
| Pr I/59 | .71 | 6.4 | 36 | 13 | 41 | 7 | 3 | | | | | | | | | | | | | | | |
| Pr I/32 | .80 | 7.8 | 16 | 53 | 17 | 7 | 7 | | | | | | | | | | | | | | | |
| Pr I/0 | .78 | 8.5 | 25 | 55 | | 10 | 10 | | | | | | | | | | | | | | | |
| Pr I/bf | 1.75 | 10.9 | 33 | 18 | | 20 | 29 | | | | x | 2.00 | | 25 | 14 | 2 | 73 | 10 | | | | |

## 50. Pr I

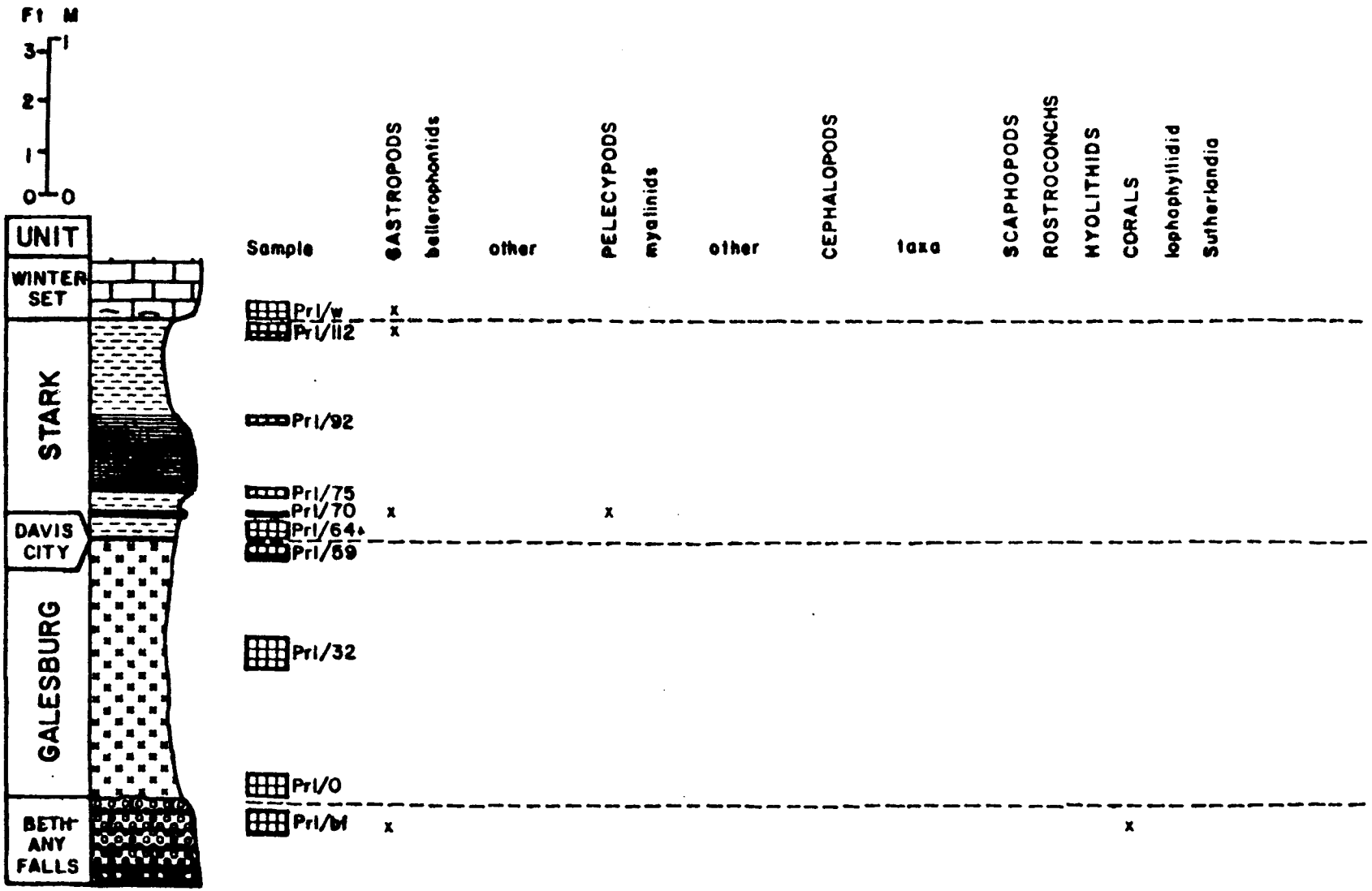



| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prl/w | | | | | ? | | | | | | | | | | x | x | | x | | |
| Prl/112 | | | x | | | | | | | | | Bythocypris ? | | | x | x | | | | |
| Prl/92 | | | | | | | | | | | | | | x | x | x | | | | |
| Prl/75 | | | | | | | | | | | | | | | | | | | | unidentified encrusting |
| Prl/70 | | x | | | | | | | | | | | | | | | | | | |
| Prl/64+ | | x | | | | | | | | | | | | | | | | | | |
| Prl/59 | | x | | | | | | | | | | | | | | | | | | |
| Prl/32 | | | | | | | | | | | | | | | | | | | | |
| Prl/0 | | | | | | | | | | | | | | | | | | | | |
| Prl/bf | | | | | | | | | | | | | | | | | x | | | Ammodiscella, fusulinids |

# 50. Pr I


Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
Prl/w
Prl/112
Prl/92
Prl/75
Prl/70
Prl/64
Prl/59
Prl/32
Prl/0
Prl/bf

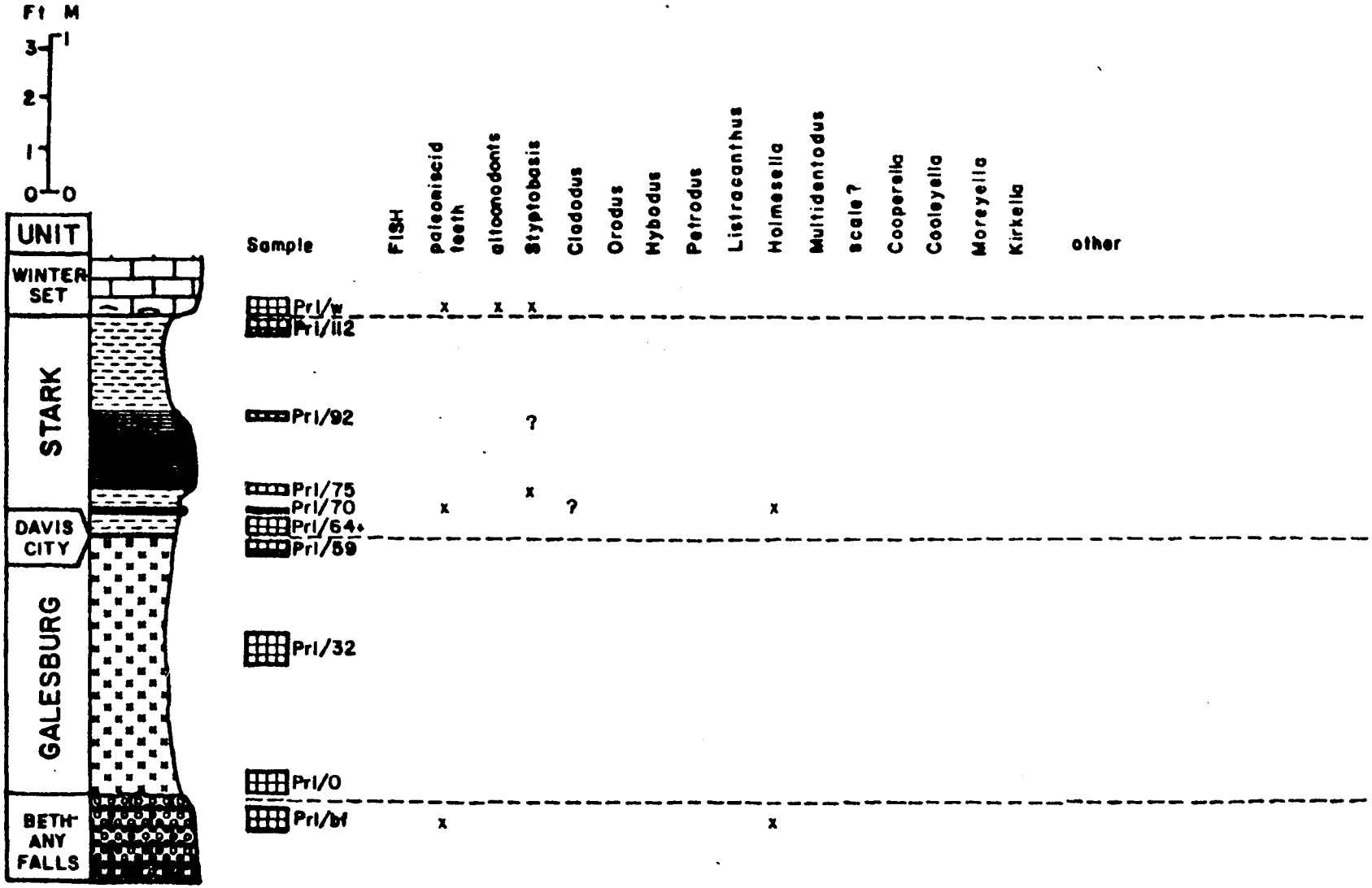
## 50. Pr I


Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia
Pr I/W
Pr I/112
Pr I/92
Pr I/75
Pr I/70
Pr I/64+
Pr I/59
Pr I/32
Pr I/0
Pr I/bf

## 50. Pr I


Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
ECHINODERMS
pelmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Pr I/w
Pr I/112
Pr I/92
Pr I/75
Pr I/70
Pr I/64+
Pr I/59
Pr I/32
Pr I/0
Pr I/bf

# 50. Pr I


Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
DAVIS CITY
GALESBURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
allocanodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Pr I/w
Pr I/12
Pr I/92
Pr I/75
Pr I/70
Pr I/64+
Pr I/59
Pr I/32
Pr I/0
Pr I/bf

# 51. Ra I

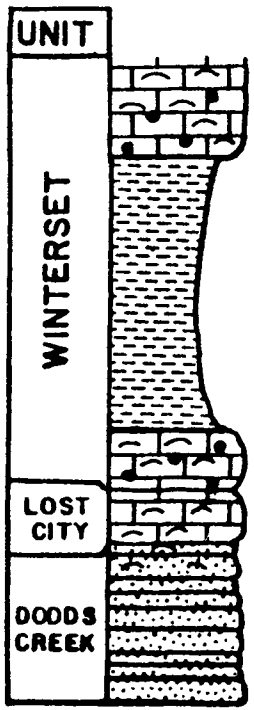
Location: Santa Fe railroad cut 1/4 mi southeast of Ramona, Oklahoma

Ramona, Oklahoma, 7 1/2' T24NR13E34NW1/4NE1/4NW1/4

References: Moore and Dott, 1937, Stop 26, p. 61; Cronoble and Mankin, 1965, Section 9, p.113-114

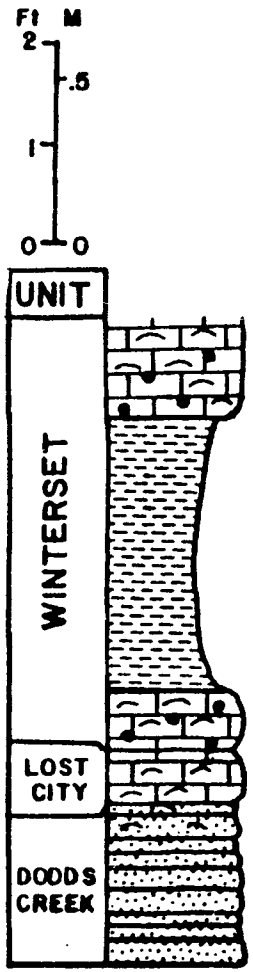
Collected: June 9, 1979

Note: When collected, only upper limestone ledge exposed (sample actually float from bed); sandstone from float; description from Cronoble and Mankin



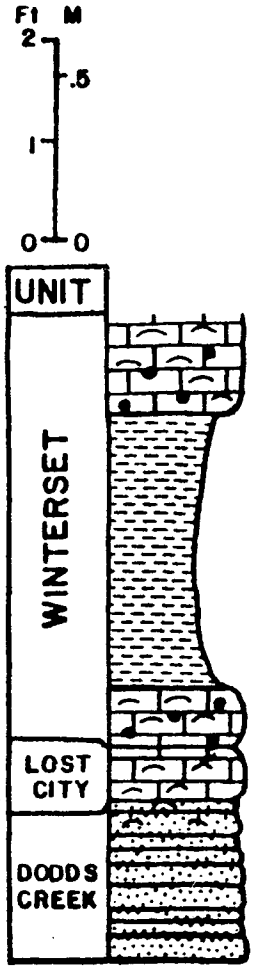

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ral/f | 1.07 | 9.8 | 32 | 28 | | 16 | 24 | | | | | .02 | 2100 | | | | 97 | | | t | 2 | |

## 51. Ra I



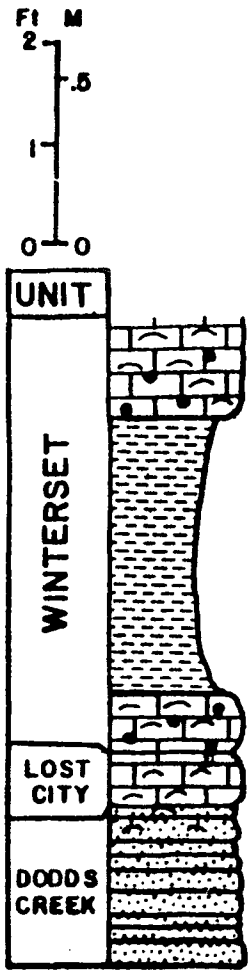

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ral/f | | | x | | x | | | | | | | |

# 51. Ra I




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra I/f | | | | | x | | | | | | | | | | | | | | | |

## 5l. Ra l




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ral/f | x | x | | x | | | | l | l | | |

Sandstone float with Aviculopecten and Modiolus

# 52.Ra 2

Location: Creek bank on South Fork of Double Creek, below Santa Fe railroad bridge on northwest edge of Ramona, Oklahoma

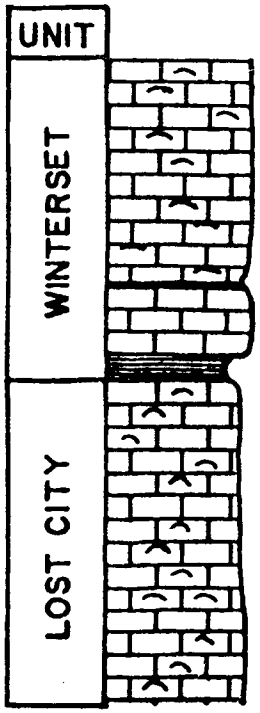
Ft M Ramona, Oklahoma, 7 1/2' T24NR13E28NE1/4SW1/4NE1/4

1 .3 Reference: Cronoble and Mankin, 1965, Section 20, p. 124-126

.2 Collected: June 9, 1979

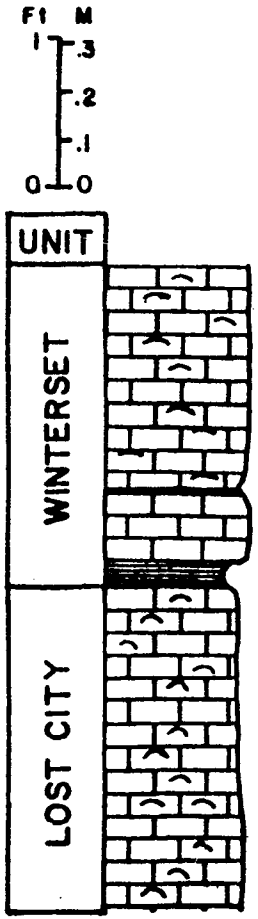
.1 Note: Cronoble and Mankin reported black shale at the base of Winterset, but inaccessible when collected

0 0



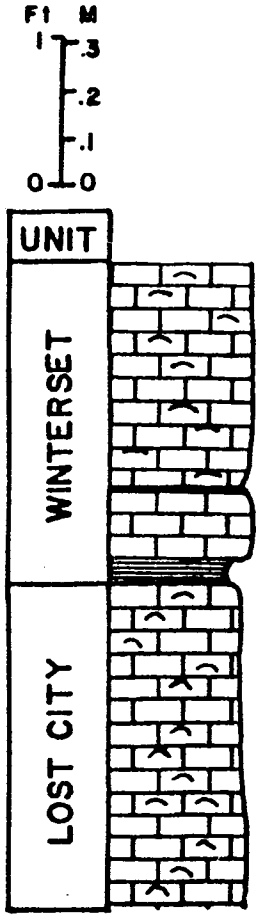

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra2/r | 2.66 | 9.3 | 41 | 32 | | 10 | 17 | | | | | .97 | | 50 | | | 100 | | | | | |
| Ra2/lc | 2.13 | 9.2 | 61 | 22 | | 7 | 10 | x | | | | 1.96 | | 10 | 16 | | 84 | | | | | |

# 52.Ra 2

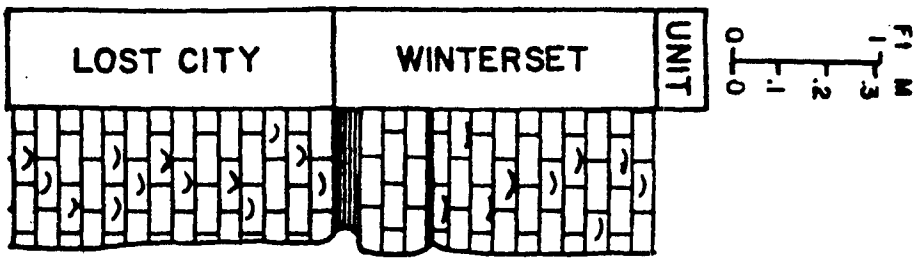



| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegulites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ra2/r | | | ? | | | | | | | | | | | | | | | | | |
| Ra2/lc | | | | | x | | | | | | | Sulcella? | | | | | | | | fusulinids |

## 52.Ra 2

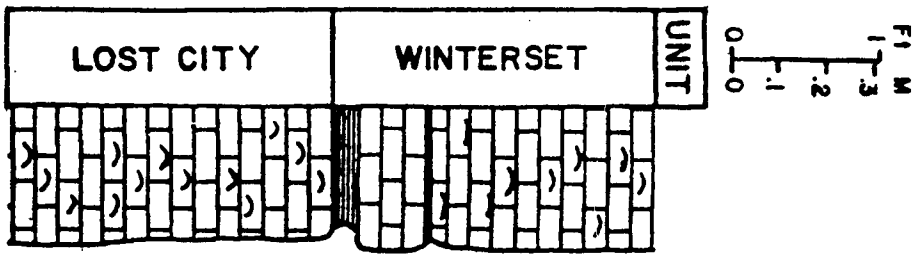



| Sample | GASTROPODS bellerophontids | other | PELECYPODS myalinids | other | CEPHALOPODS taxa | SCAPHOPODS ROSTROCONCHS HYOLITHIDS |
|---|---|---|---|---|---|---|
| Ra2/r | x x | | x | Acanthopecten | | |
| Ra2/lc | x x | Palaeostylus | x | | ? | ? |




52.Ra 2

| Sample | Ra2/1c | Ra2/1 |
|---|---|---|
| ECHINODERMS | | |
| palmatozoans | | |
| echinoids | | |
| holothurians | | |
| BRYOZOANS | | |
| fenestrate | | |
| ramose | 1 | |
| fistuliporids | | |
| encrusting non-fistuliporids | | |
| SPONGES | x | |
| wewokellid | | |
| Coelocladia | | |
| Girtyocoelia | | |
| spicule A | | |
| spicule B | | |
| TRILOBITES | | |
| taxa | | |
| SCOLECODONTS | | |
| Spirorbis | | |
| CONULARIDS | | |
| RADIOLARIANS | | |







Ra2/1c

Ra2/1r

Sample

FISH

paleoniscid teeth

x

elfoonodonts

Styptobasis

Cladodus

Orodus

Hybodus

Petrodus

Listracanthus

Holmesella

Multidentodus

scale?

Cooperella

Cooleyella

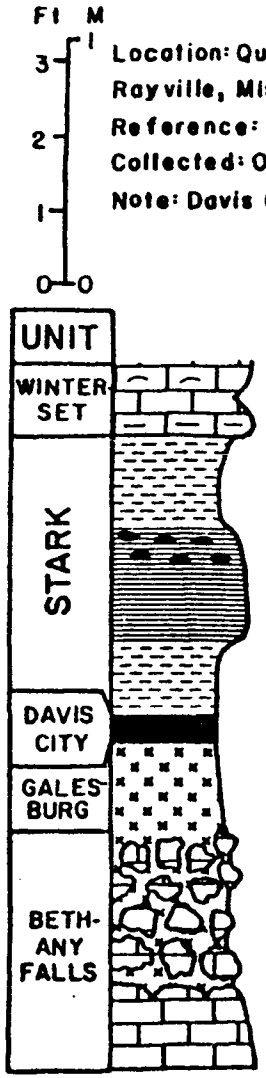
Moreyella

Kirkella

other

52.Ra 2

# 53. Rd 1




Location: Quarry 4 mi west of Richmond, Missouri

Rayville, Missouri, 7 1/2'  T53NR28W32SE1/4SE1/4SE1/4

Reference: 2 1/2 mi southeast of Lamerson, 1956, Sect. 15, p. 107

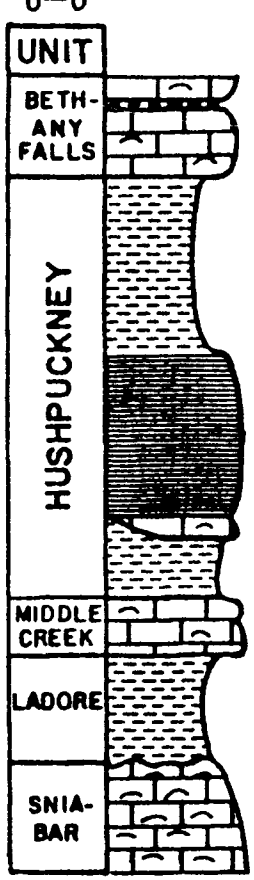
Collected: October 29, 1980

Note: Davis City is bone coal or cooly shale

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rd1/50 | 1.59 | 9.3 | 60 | 18 | | | 22 | | | | |

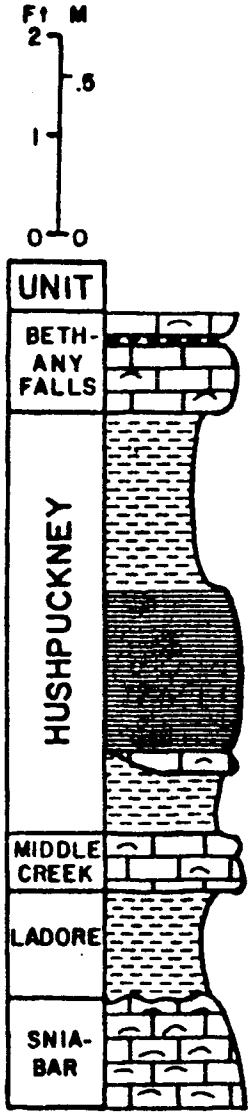
# 54. Ri l

Location: Richfield PWA Quarry, about 2 1/2 mi south of Richfield, Nebraska
Cedar Creek, Nebraska, 7 1/2'  T13NR12E28NE1/4SE1/4
Reference: Heckel et al., 1979, Stop 19A, p. 52-53
Collected: September 30, 1979



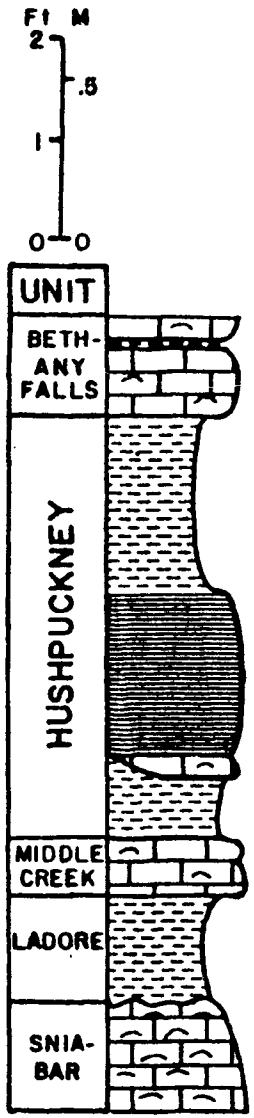

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ril/bf | 1.69 | 9.1 | 53 | 33 | | 15 | | | | | | 1.00 | | 150 | | | 72 | 9 | 1 | 3 | 15 | |
| Ril/60 | 1.95 | 9.3 | 52 | 34 | | 14 | | | | | | .16 | | 76 | | | 23 | 8 | | 2 | 68 | |
| Ril/48 | 1.52 | 9.0 | 62 | 40 | | 10 | | | | | | .45 | | 1239 | | | 62 | | | 3 | 35 | |
| Ril/34 | 1.54 | 9.3 | 42 | 44 | | 14 | | | | | | .72 | | 468 | | | 90 | 1 | | 7 | 2 | |
| Ril/29 | 1.14 | 9.6 | 51 | 34 | | 14 | | | x | | | 1.00 | | 4 | | | 100 | | | | | |
| Ril/20 | 1.55 | 9.9 | 42 | 45 | | 13 | | | | | | np | | | | | | | | | | |
| Ril/mc | 1.22 | 9.4 | 49 | 48 | | 3 | | | | | | 1.00 | | 26 | 42 | | 53 | 4 | | 1 | | |
| Ril/8 | 1.44 | 9.3 | 45 | 37 | | 17 | | | | | | .75 | | 4 | | | 67 | | | | 33 | |
| Ril/0 | .99 | 8.9 | 47 | 42 | | 11 | | | | | | .99 | | 2 | 100 | | | | | | | |
| Ril/h | 1.01 | 8.8 | 48 | 45 | | 7 | | | | | | 1.00 | | 5 | 100 | | | | | | | |

# 54.RI I



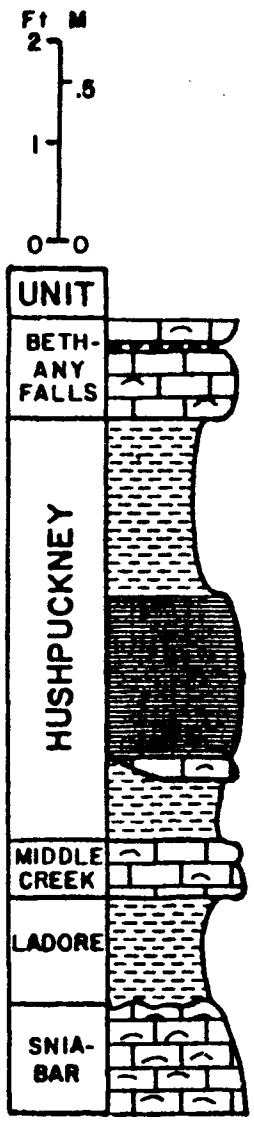

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RiI/bf | | | x | x | x | | | x | | x | | | | | | | | | | |
| RiI/60 | | | x | | x | | | x | | | | Bairdiacypris | | | x | x | | | | fusulinids |
| RII/48 | | | | | | | | | | | | | | | | | | | | |
| RII/34 | | | | | | | | | | | | Sansabella | | | | | | | | |
| RII/29 | | | | | | | | | | | | | | | | x | | x | | |
| RiI/20 | | | x | | | | | | | | | | | | | x | | | | |
| RiI/mc | | | | | | | | | | | | | | | | x | | | | Glomospira |
| RiI/8 | | | x | | x | | | x | | | | | | | | x | x | | | fusulinids |
| RII/0 | | | x | | x | | | | | | | | | | x | x | x | | | fusulinids |
| RiI/h | | | ? | | | | | | | | | | | | | | x | | | |

# 54.Ril



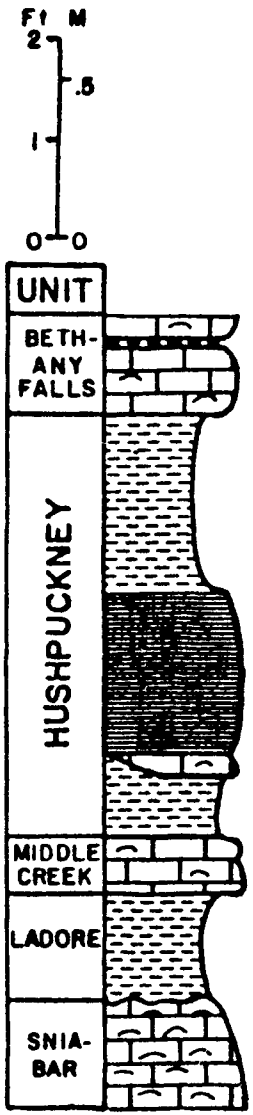

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ril/bf | | | | | | | | | | | | | | ? | | | ? | | | |
| Ril/60 | | x | | | x | | | ? | | | | | | | | x | x | x | | |
| Ril/48 | | | | | | | | | | | | | | | | | | | | |
| Ril/34 | | | | | | | | | | | | | | | | | | | | |
| Ril/29 | | | | | | | | | | | | | | | | | | | | |
| Ril/20 | | | | | x | | | | | | | | | | | | | | | |
| Ril/mc | | | | | | | | | | | | | | | | | | | | |
| Ril/8 | | | | | x | x | | | x | x | | | | | | x | x | | | Pulchratia |
| Ril/0 | | | | | x | | | | | | | | | | | x | | | | Pulchratia? |
| Ril/h | | | | | | | | | | | | | | | | | | | | |

# 54.Ri I



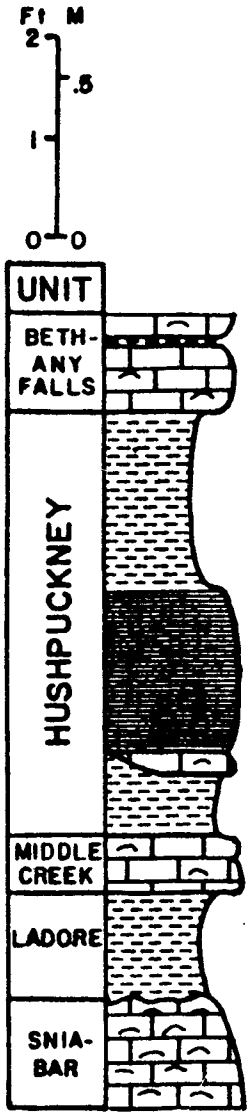

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ril/bf | x | x | | x | | | | | | | |
| Ril/60 | | | | | | | | | | | |
| RII/48 | | | | | | | | | | | |
| RII/34 | | | | | | | | | | | |
| Ril/29 | x | | | x | | | | | | | |
| Ril/20 | x | | | | | | | | | | |
| Ril/mc | | | | | | | | | | | |
| Ril/8 | x | | | | | | | | | | |
| RII/0 | x | | | | | | | | | | |
| Ril/h | | | | | | | | | | | |

## 54.Ri I




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ril/bf | | x | | | | | \| | | | | | | | | | | | x | | | |
| Ril/60 | | x | | | | \| | \| | | | | | | | | | x | | | | | |
| Ril/48 | | | | | | | | | | | | | | | | | | | | | |
| Ril/34 | | | | | | | | | | | | | | | | | | | | | |
| Ril/29 | | | | | | | | | | | | | | | | | | | | | |
| Ril/20 | | x | | | | | \| | | | | | | | | | | | | | | |
| Ril/mc | | x | | | | | | | | | | | | | | | | x | | | |
| Ril/8 | | x | x | | | \| | \| | | \| | | | | | | | | | | | |
| Ril/0 | | x | x | | | | \| | | | | | | | | | | | x | | | |
| Ril/h | | | | | | | | | | | | | | | | | | | | | |

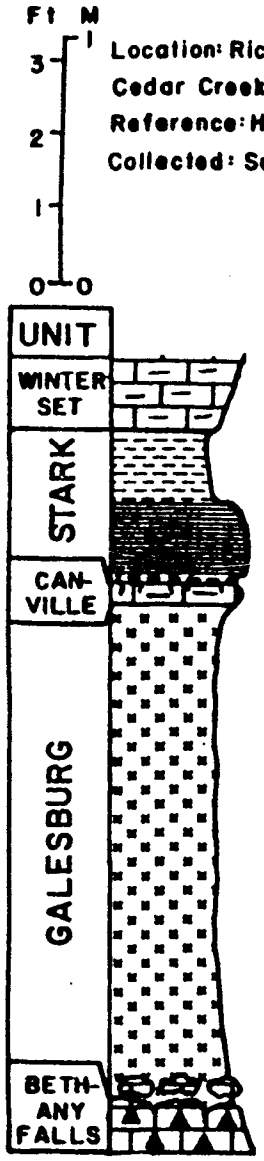
# 54. Ril




| Sample | FISH | paleoniscid teeth | altaonodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ril/bf | | x | | | | | | | | x | | | | | | | |
| Ril/60 | | | | | | | | | | | | | | | | | |
| Ril/48 | | x | | x | | | | | | | | | | | | | |
| Ril/34 | | | | | | | | | | | | | | | | | |
| Ril/29 | | | | | | | | | | | | | | | | | |
| Ril/20 | | | | | | | | | | | | | | | | | |
| Ril/mc | | | | | | | | | | x | x | | | | | | |
| Ril/8 | | | | | | | | | | | | | | | | | |
| Ril/0 | | | | | | | | | | | | | | | | | |
| Ril/h | | x | | | | | | | | | | | | | | | |

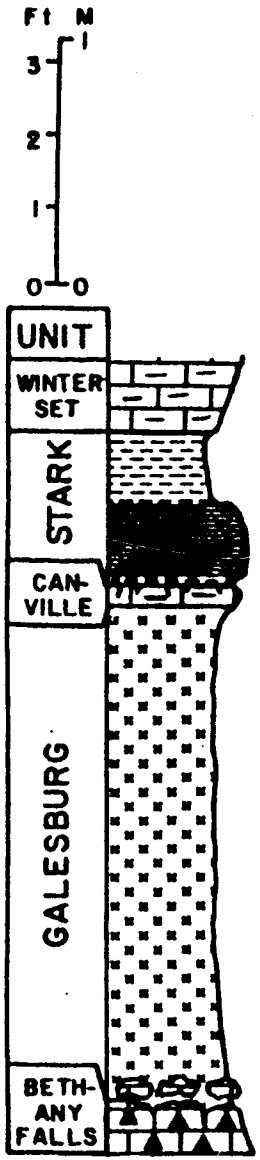
# 54. Rila

Location: Richfield PWA Quarry, about 2 1/2 mi of Richfield, Nebraska
Cedar Creek, Nebraska, 7 1/2'  T13NR12E28NE1/4SW1/4
Reference: Heckel et al., 1979, Stop 19B, p. 53
Collected: September 30, 1979



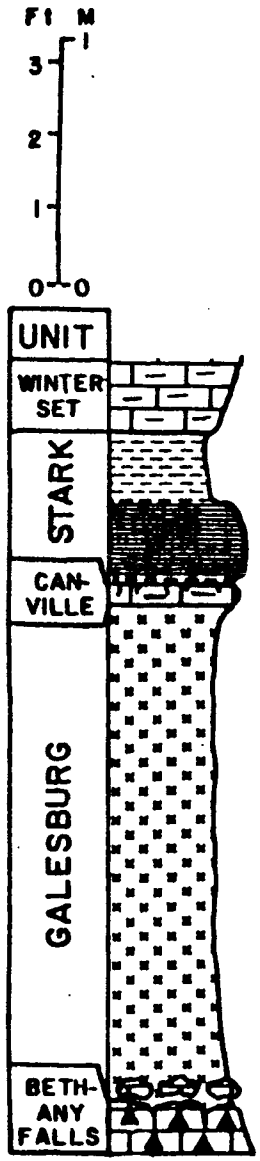

| | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rila/w | 1.45 | 9.1 | 65 | 22 | | 13 | | | | | | .66 | | 420 | | | 87 | 6 | | 3 | 4 | |
| Rila/103 | 1.45 | 9.2 | 48 | 45 | | 7 | | | | | | .41 | | 375 | | | 70 | 7 | | 3 | 19 | |
| Rila/94 | 1.75 | 9.2 | 72 | 15 | | 13 | | | | | | .44 | | 649 | | | 88 | | | 9 | 4 | |
| Rila/84 | 1.73 | 9.9 | 49 | 39 | | 12 | | | | | | .44 | | 660 | | | 96 | | | 4 | | |
| Rila/c | 1.09 | 9.1 | 55 | 33 | | 12 | | | | | | .98 | | 13 | 85 | 8 | 8 | | | | | |
| Rila/74 | .83 | 7.1 | 30 | 64 | | 6 | | | | | | .72 | | 50 | 92 | | 8 | | | | | |
| Rila/48 | .94 | 8.3 | 31 | 65 | | 4 | | | | | | | | | | | | | | | | |
| Rila/24 | .98 | 8.4 | 29 | 65 | | 6 | | | | | | .81 | | | | | | | | | | x |
| Rila/0 | .97 | 8.8 | 30 | 65 | | 5 | | | | | | | | | | | | | | | | |
| Rila/bf | 1.75 | 9.1 | 59 | 34 | | 8 | | | | | | | | | | | | | | | | |

# 54. Rila



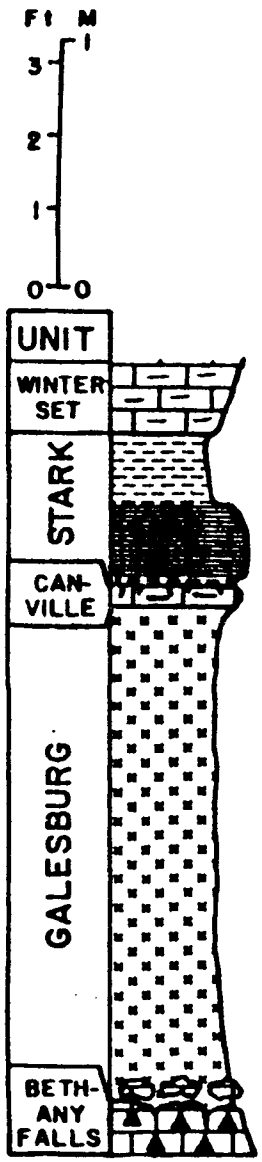

| | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | |
| Rila/w | | | | | | | | | | | | | | x | x | | | | | |
| Rila/103 | | | | | | | | | | | | | | x | x | | x | | | |
| Rila/94 | | | | | | | | | | | | | | | | | | | | |
| Rila/84 | | | | | | | | | | | | | | | | | | | | |
| Rila/c | | | | | | | | | | | | | | | x | x | | x | | |
| Rila/74 | | x | | x | | | | | | | | | | | x | | | | | |
| Rila/48 | | | | | | | | | | | | | | | | | | | | fusulinids |
| Rila/24 | | | | x | | | | | | | | | | | | | | | | fusulinids |
| Rila/0 | | | | | | | | | | | | unidentified | | | | | | | | fusulinids |
| Rila/bf | | | | | | | | | | | | Sansabella ? | | | | x | | | | |

# 54.Rila



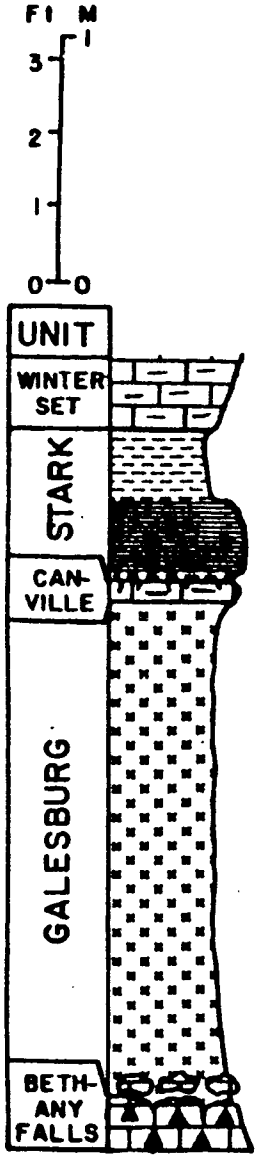

| | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rila/w | | x | | | | | | | | | | | | | | | | | | |
| Rila/103 | | | | | | | | | | | | | | | | | x | | | |
| Rila/94 | | | | | | | | | | | | | | | | | | | | |
| Rila/84 | | | | | | | | | | | | | | | | | x | | | |
| Rila/c | | | | | | | | | | | | | | | | | | | | |
| Rila/74 | | x | | | x | | ? | | | | | | | | | x | | | | Pulchratia? |
| Rila/48 | | | | | x | | | | | | | ? | | | | | | | | |
| Rila/24 | | x | | | x | | | | | | | | | | | | | | | |
| Rila/0 | | | | | | | | | | | | | | | | | | | | |
| Rila/bf | | x | | | | | | | | | | | | | | | x | | | |

## 54.Rila



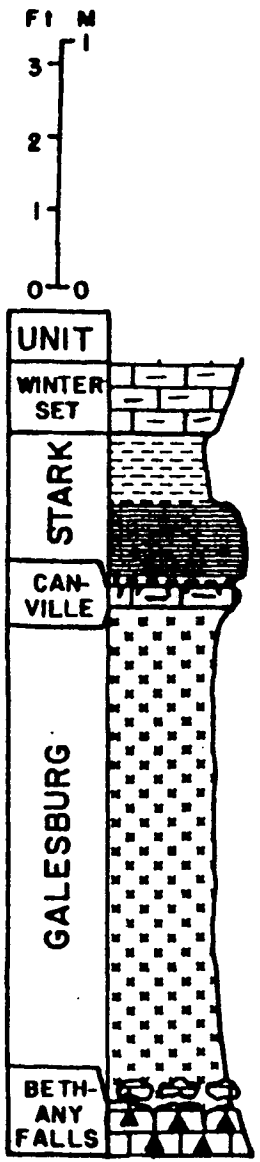

| | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rila/w | x | | | x | | | | | | | |
| Rila/103 | x | | | | | | | | | | |
| Rila/94 | | | | | | | | | | | |
| Rila/84 | | | | | | | | | | | |
| Rila/c | x | x | | x | | | | | | | |
| Rila/74 | x | | | x | ? | | | | | | |
| Rila/48 | x | | | | | | | | | | |
| Rila/24 | | | | | | | | | | | |
| Rila/0 | | | | | | | | | | | |
| Rila/bf | x | | Murchisonia? | | | | | | | | |

# 54. Rila




| | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rila/w | | | | | | | \| | | | | | | | | | | | | | | |
| Rila/103 | | x | | | | | | | | | | | | | | | | | | | |
| Rila/94 | | | | | | | | | | | | | | | | | | | | | |
| Rila/84 | | | | | | | | | | | | | | | | | | | | | |
| Rila/c | | | | | | | | | | | | | | | | | | x | | | |
| Rila/74 | | x | x | | | \| | \| | | \| | | | | | | | x | | | | | |
| Rila/48 | | x | | | | \| | \| | | | | | | | | | | | | | | |
| Rila/24 | | x | | | | | | | | | | | | | | | | | | | |
| Rila/0 | | x | | | | | \| | | | | | | | | | | | | | | |
| Rila/bf | | x | | | | | | | | x | | | | | | | | | | | |

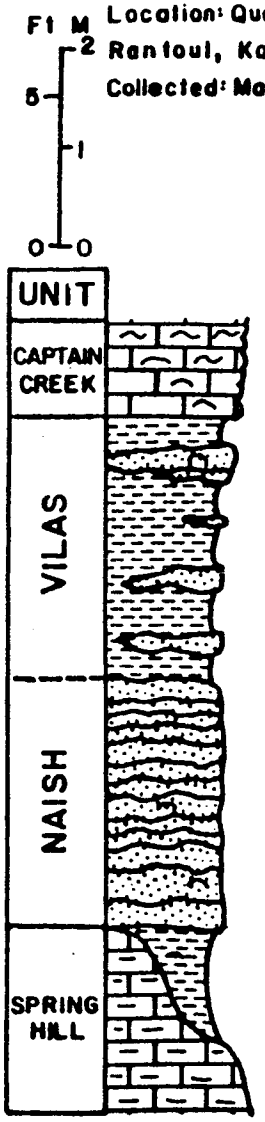
# 54. Rila




| | FISH | paleoniscid teeth | allocanodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rila/w | | x | | | | | | | | | | | | | | | |
| Rila/103 | | | | | | | | | | | | | | | | | |
| Rila/94 | | ? | | | | | | | | | | | | | | | |
| Rila/84 | | | | x | | | | | | x | | | | | | | |
| Rila/c | | ? | | x | | | | | | x | | | | | | | |
| Rila/74 | | x | | x | | | | | | x | | | | | | | |
| Rila/48 | | | | | | | | | | | | | | | | | |
| Rila/24 | | | | | | | | | | | | | | | | | |
| Rila/0 | | | | | | | | | | | | | | | | | |
| Rila/bf | | ? | | | | | | | | | | | | | | | |

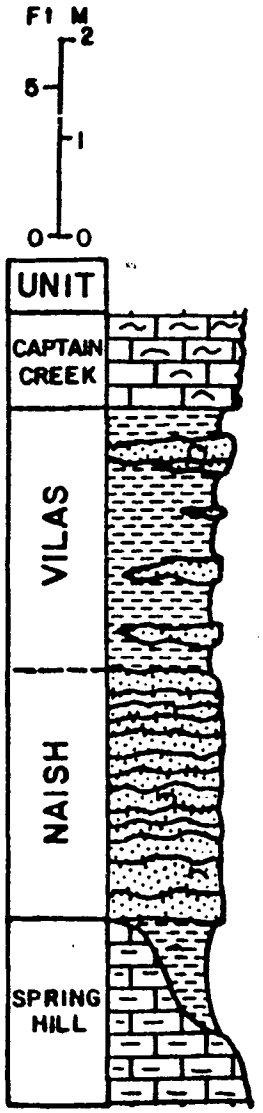
# 55. Sn l

Location: Quarry 3 mi north and 1 1/2 mi east of Stanton, Kansas
Rantoul, Kansas, 7 1/2'
T17SR22E7NWl/4SEl/4SWl/4
Collected: May 22, 1980



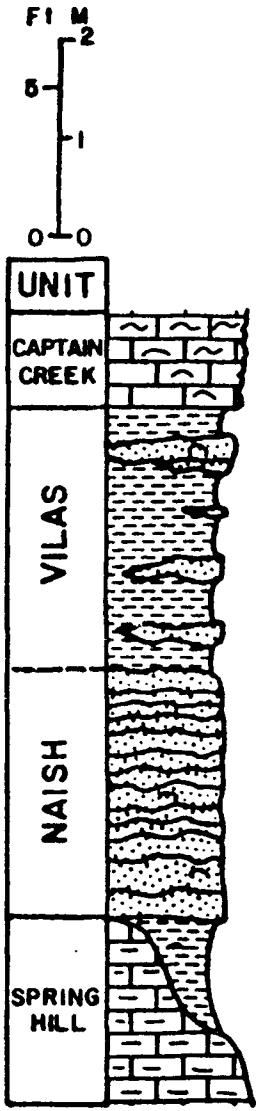

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | x Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Snl/cc | 1.93 | 9.5 | 68 | 29 | | 3 | | | x | | | 1,00 | | 1 | | | 100 | | | | | |
| Snl/n | 1.43 | 9.1 | 54 | 25 | | 7 | 15 | | | | | .91 | | 3 | 67 | | 33 | | | | | |
| Snl/17 | 1.83 | 10.2 | 85 | | | 10 | 6 | | | | | | | | | | | | | | | |
| Snl/p | 1.44 | 9.4 | 53 | 35 | | 7 | 5 | | x | | | | | | | | | | | | | |

# 55. Sn I



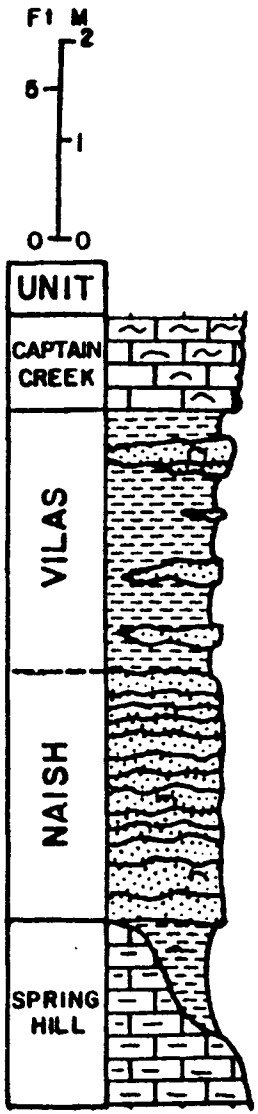

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Talypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sn I/cc | | | | | | | | | | | | | | | | | | | | |
| Sn I/n | | | | | | | | | | | | | | | | | | | | |
| Sn I/17 | | | | | | | | | | | | unidentified | | | | | | | | |
| Sn I/p | | | ? | | | | | | | | | | | | | | x | | | |

## 55. Sn I



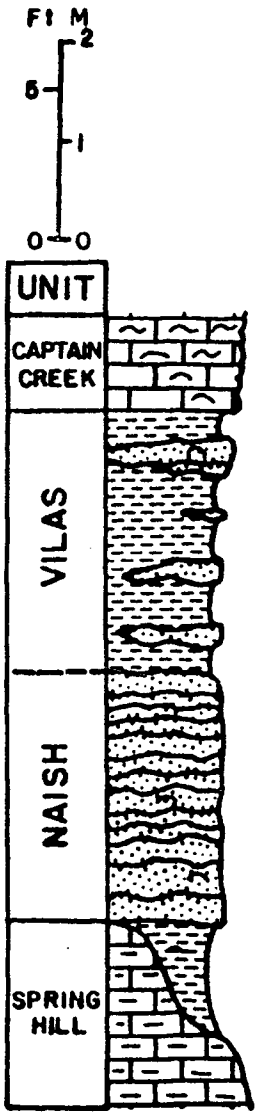

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other Entelates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Snl/cc | | | | | x | | | | | | | | | | | | | | | |
| Snl/n | | | | | | | | | | | | | | | | | | | | |
| Snl/17 | | | | | x | | x | | | | | | | | | | | | | |
| Snl/p | | | | | x | | | | | | | | | | | | | | | |

## 55. Sn I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS | SCOLECODONTS | Spirorbis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sn I/cc | | | | | | | | | | | | | |
| Sn I/n | | | | | | | | | | | | | |
| Sn I/17 | x | | | x | | | | | | | | | |
| Sn I/p | | | | | | | | | | | | x | |

## 55. Sn I




| Sample | FISH | paleoniscid teeth | allocnodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sn I/cc | | | | | | | | | | | | | | | | | |
| Sn I/n | | | | | | | | | | | | | | | | | |
| Sn I/17 | | | | | | | | | | | | | | | | | |
| Sn I/p | | x | | | | | | | | | | | | x | | | |

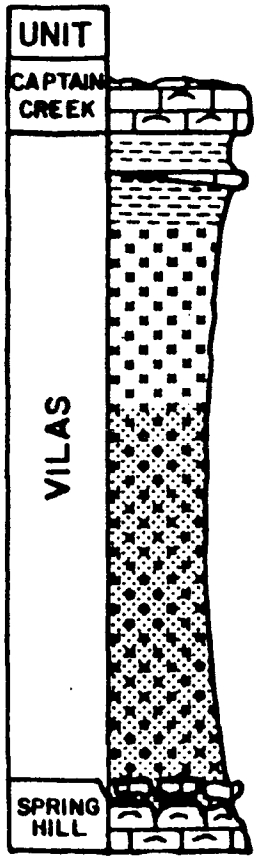
# 56. St I

Location: Quarry about 10 mi west, 1 mi south of Winterset; near Stanzel, Iowa

Winterset, Iowa, 15' T75NR29W5SE1/4SW1/4

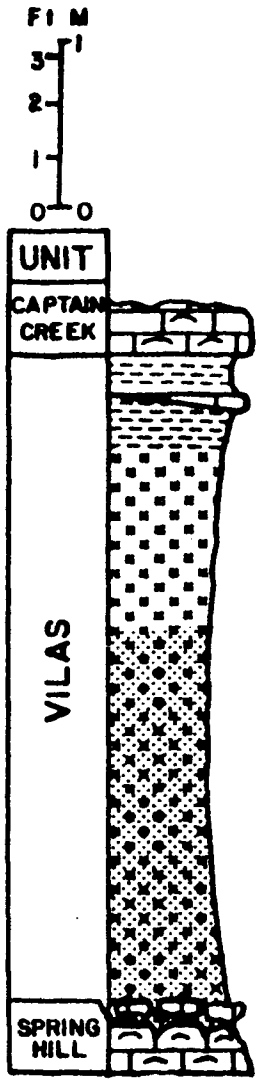
References: Wenberg, 1941, Sect. 27, p. 158-160; Welp et al., 1968, Stop 5; Heckel, 1980, Stop 5, p. 22-23

Collected: July 20, 1979



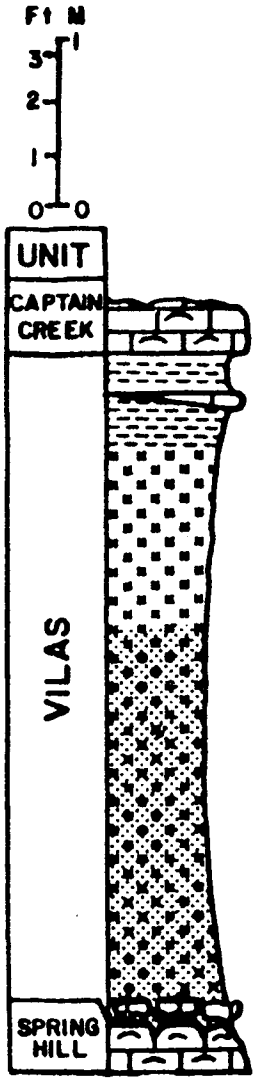

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St1/s | 1.28 | 8.9 | 60 | 26 | | 14 | | | | | | 1.00 | | 33 | 85 | 3 | 3 | 9 | | | | |
| St1/155 | 1.52 | 9.6 | 51 | 34 | 10 | 6 | | x | | | | | | | | | | | | | | |
| St1/cc | 1.20 | 9.0 | 51 | 29 | | 19 | | | | | | | | | | | | | | | | |
| St1/140 | 1.39 | 9.5 | 43 | 33 | 9 | 15 | | x | | | | | | | | | | | | | | |
| St1/128 | 1.49 | 9.6 | 38 | 39 | 11 | 12 | | | | | | | | | | | | | | | | |
| St1/96 | 1.28 | 9.3 | 49 | 25 | 10 | 16 | | | | | | | | | | | | | | | | |
| St1/48 | 1.49 | 9.6 | 67 | 28 | | 4 | | | | | | | | | | | | | | | | |
| St1/15 | 1.53 | 9.5 | 69 | 18 | | 12 | | | | | | | | | | | | | | | | |
| St1/5 | 1.32 | 8.5 | 51 | 31 | | 19 | | x | | | | 1.00 | | 1 | 100 | | | | | | | |
| St1/p | 1.39 | 8.4 | 58 | 35 | | 7 | | | | | | 1.77 | | 40 | 93 | 1 | 1 | 4 | | | | |

## 56. St 1



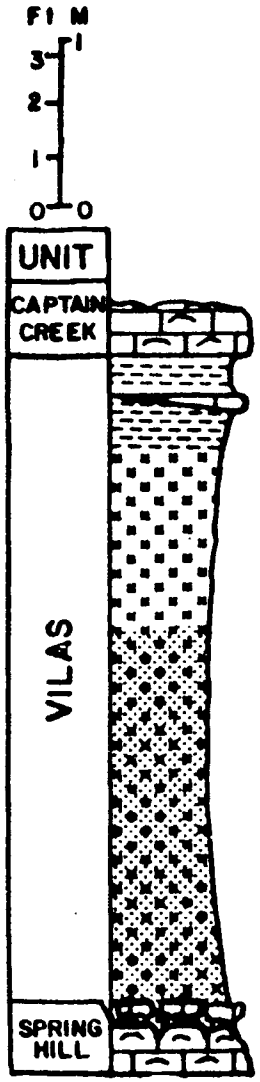

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Talypammina | Ammovertella | Hyperammina | Textularia | other | |
| St1/s | | | | | | | | | | | | | | x | x | x | | | | |
| St1/155 | | x | | | | | | | | | | | | x | x | | | | | |
| St1/cc | | | | | | | | | | | | | | | | | | | | |
| St1/140 | x | x | | | | | | | | | | | | | | | | | | |
| St1/128 | x | x | | | | | | | | | | | | | x | | | | | |
| St1/96 | | | | | | | | | | | | | | | | | | | | |
| St1/48 | | | | | | | | | | | | | | | | | | | | |
| St1/15 | | | | | | | | | | | | | | | | | | | | |
| St1/5 | x | x | | | x | | | | | | | | | | x | x | | | | |
| St1/p | | x | | | | | | | | | | | | | x | x | | | | |

# 56. St I



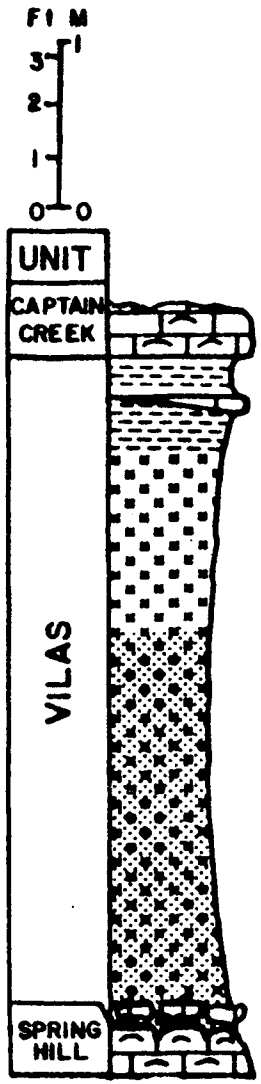

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SII/s | | | | | | | | | ? | | | | | | | | | | | |
| SII/155 | | x | | | | | | | | | | | | | | | | | | |
| SII/cc | | | | | | | | | | | | | | | | | | | | |
| SII/140 | | x | | | | | | | | | | | | | | | | | | |
| SII/128 | | x | | | | | | | | | | | | | | | | | | |
| SII/96 | | | | | | | | | | | | | | | | | | | | |
| SII/48 | | | | | | | | | | | | | | | | | | | | |
| SII/15 | | | | | | | | | | | | | | | | | | | | |
| SII/5 | | x | x | | x | | | | | | | | | | | x | ? | | | |
| SII/p | | x | | | | | | | | | | | | | | | | | | |

## 56. St I




| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | TRILOBITES | taxa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St1/6 | x | | | | | | | | | | | | | | | | |
| St1/155 | x | | | x | | | | | | | | | | | | | |
| St1/cc | | | | | | | | | | | | | | | | | |
| St1/140 | | | | x | | | | | | | | | | | | | |
| St1/128 | | | | | | | | | | | | | | | | | |
| St1/96 | | | | | | | | | | | | | | | | | |
| St1/48 | | | | | | | | | | | | | | | | | |
| St1/15 | | | | | | | | | | | | | | | | | |
| St1/5 | x | | | x | | | | x | | | | | | | | x | |
| St1/p | x | x | | x | | | | x | | | | | | | | | |

# 56. St I

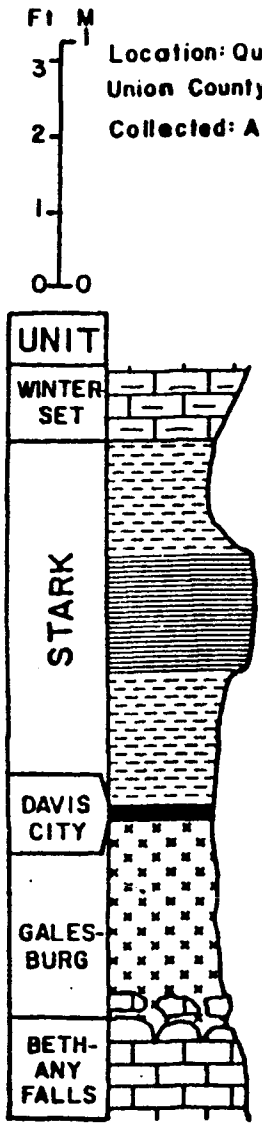



| Sample | FISH | paleoniscid teeth | allocanodonts | Stypobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St I/s | | x | | | | | | | | | | | | x | | | Protacrodus, unidentified teeth |
| St I/155 | | | | | | | | | | | | | | | | | |
| St I/cc | | | | | | | | | | | | | | | | | |
| St I/140 | | | | | | | | | | | | | | | | | |
| St I/128 | | | | | | | | | | | | | | | | | |
| St I/96 | | | | | | | | | | | | | | | | | |
| St I/48 | | | | | | | | | | | | | | | | | |
| St I/15 | | | | | | | | | | | | | | | | | |
| St I/5 | | | | | | | | | | | | | | | | | |
| St I/p | | x | | | | | | | | x | | | | x | | | |

1000

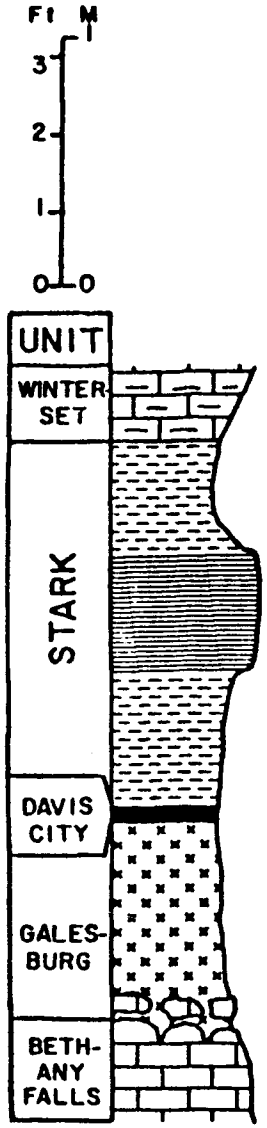
# 57. Th I

Location: Quarry 2 mi south of Thayer, Iowa
Union County, Iowa, map
T72NR28W35NE1/4NW1/4
Collected: August 21 and September 29, 1979



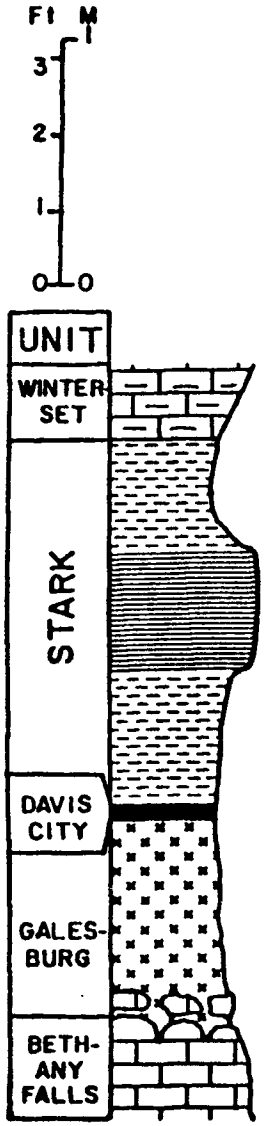

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thl/w | 1.53 | 9.4 | 60 | 20 | | 20 | | | x | | | .98 | | 146 | | | 88 | 11 | | 1 | | |
| Thl/79 | 2.09 | 9.8 | 55 | 24 | | 21 | | | x | | | .21 | | 103 | | | 88 | 9 | | 2 | | |
| Thl/55 | 1.54 | 9.4 | 46 | 29 | | 25 | | | | | | .53 | | 320 | | | 95 | | | 4 | 1 | |
| Thl/47 | 1.03 | 9.3 | 32 | 53 | | 15 | | | | | | .67 | | 57 | 50 | | 34 | 16 | | 1 | | |
| Thl/34 | .97 | 8.4 | 36 | 53 | | 11 | | | | | | .56 | | 2 | 100 | | | | | | | |
| Thl/23 | .82 | 7.7 | 19 | 62 | | 20 | | | | | | | | | | | | | | | | |
| Thl/0 | 1.32 | 9.5 | 36 | 33 | | 31 | | | | | | | | | | | | | | | | |
| Thl/bf | 1.57 | 9.0 | 44 | 33 | | 23 | | | | | | | | | | | | | | | | |

# 57. Th I



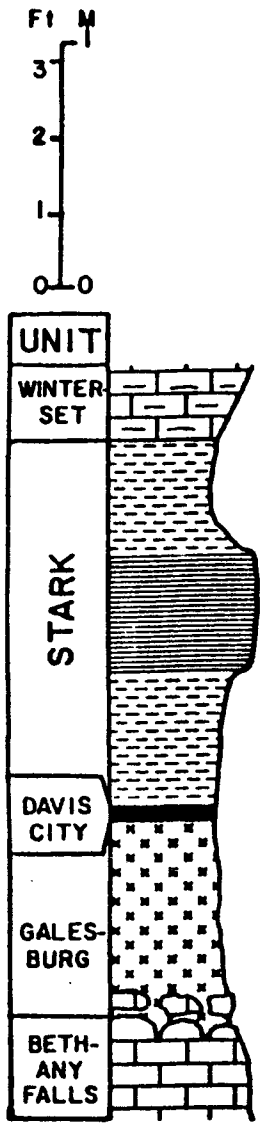

| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | |
| Thl/w | | | | x | | | | | | | | | | x | x | x | | | | |
| Thl/79 | | | | | | | | | | | | Microcheilinella? | | x | x | | | | | |
| Thl/55 | | | | | | | | | | | | | | | | | | | | |
| Thl/47 | x | x | | x | x | | x | | | | | | | x | x | | | | | |
| Thl/34 | x | | | | | | | | | | | | | | x | | | | | |
| Thl/23 | | | | | | | | | | | | | | | | | | | | |
| Thl/0 | | | | | | | | | | | | | | | | | | | | |
| Thl/bf | | | | | | | | | | | | | | | | x | | | | |

# 57. Th I



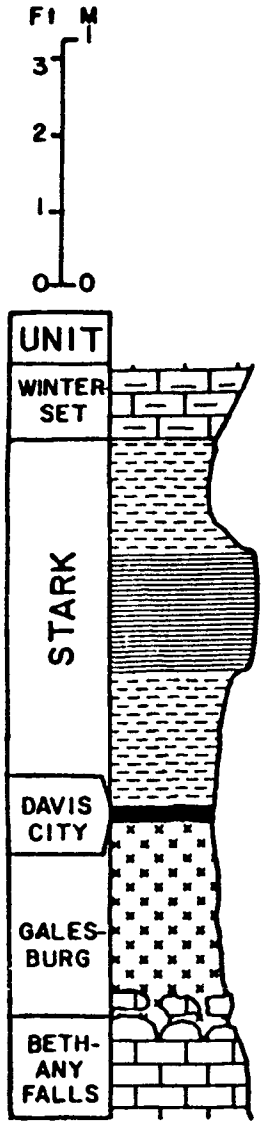

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thl/w | | | | | x | | | | | | | | | | | | | | | |
| Thl/79 | | | | | x | | | | x | | | x | | x | | x | x | | | |
| Thl/55 | | | | | | | | | | | | | | | | | x | | | |
| Thl/47 | | | | | x | | | | | | | | | | | | x | | | |
| Thl/34 | | x | x | | | | | | | | | | | | | | | | | |
| Thl/23 | | | | | | | | | | | | | | | | | | | | |
| Thl/0 | | | | | | | | | | | | | | | | | | | | |
| Thl/bf | | | | | | | | | | | | | | | | | | | | |

# 57. Th I



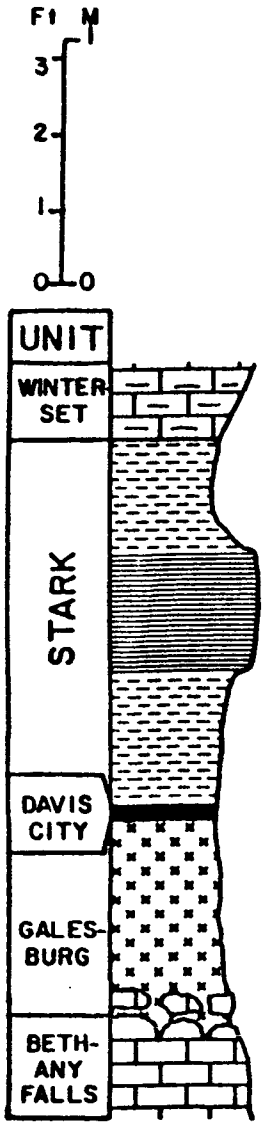

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Thl/w | x | | | x | | | | | | | |
| Thl/79 | x | | | | | | | | | | |
| Thl/55 | | | | | | | | | | | |
| Thl/47 | x | x | | | | | | | | | |
| Thl/34 | | | | | | | | | | | |
| Thl/23 | | | | | | | | | | | |
| Thl/0 | | | | | | | | | | | |
| Thl/bf | | | | | | | | | | | |

# 57. Th l




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thl/w | | | | | | | 1 | | | | | | | | | | | x | | | |
| Thl/79 | | | | | | | 1 | | | x | | | | | | | | x | | | |
| Thl/55 | | | | | | | | | | | | | | | | | | | | | |
| Thl/47 | | | | | | 1 | 2 | | | | | | | | | | | | | | |
| Thl/34 | | | | | | | | | | | | | | | | | | | x | | |
| Thl/23 | | | | | | | 1 | | | | | | | | | | | | | | |
| Thl/0 | | | | | | | | | | | | | | | | | | | | | |
| Thl/bf | | | | | | | | | | | | | | | | | | | | | |

# 57. Th I



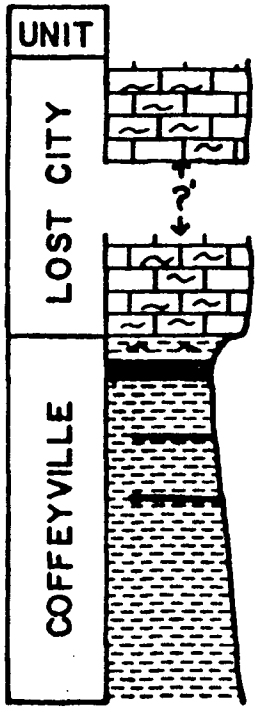

| Sample | FISH | paleoniscid teeth | ctenodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirtella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thl/w | | x | x | x | | | | | | | | x | | | | | unidentified teeth |
| Thl/79 | | | | | | x | | | | | | | | | | | |
| Thl/55 | | | | | | | | | | | | | | | | | unidentified fragments |
| Thl/47 | | x | | | | | | | | | | | | | | | |
| Thl/34 | | | | | | | | | | | | | | | | | unidentified fragments |
| Thl/23 | | | | | | | | | | | | | | | | | |
| Thl/0 | | | | | | | | | | | | | | | | | |
| Thl/bf | | | | | | | | | | | | | | | | | |

# 58. Tu I

Location: River bluff along Arkansas River 2 mi east of interchange of Oklahoma highways 51 and 97 in Prattville, Oklahoma (Sample Tul/Ic from middle of the Lost City at the interchange)

Ft M
2
.5 Sand Springs, Oklahoma, 7 1/2'
1
Reference: Hansen, 1957, sect. 24, p. 185-187
0 0
Collected: August 9, 1979

T19NR11E13NE1/4SW1/4 (Sample Tul/Ic from T19NR11E14SW1/4SW1/4)




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tul/Ic | 2.22 | 9.7 | 64 | 8 | | 10 | 18 | | | | | .94 | | 2 | | | 100 | | | | | |
| Tul/Icf | 1.37 | 6.8 | 22 | 9 | | | 69 | | | | | 1.00 | | 1 | | | 100 | | | | | |
| Tul/-3 | | | 22 | 18 | | | 60 | x | | | | | | | | | | | | | | |
| Tul/-27 | 1.15 | 9.9 | 34 | 15 | | | 51 | | | | | | | | | | | | | | | |

# 58. Tu I


Ft M
2
1
0 0
UNIT
LOST CITY
COFFEYVILLE
Sample
Tul/lc
Tul/lcf
Tul/-3
Tul/-27
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
x
x
?
x
x

# 58. Tu I


Ft
M
2
1
0
3
0
UNIT
LOST CITY
COFFEYVILLE
Sample
Tul/lc
Tul/lcf
Tul/-3
Tul/-27
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
x
unidentified fragment

## 58. Tu I


Ft M
2
3
1
0 0
UNIT
LOST CITY
COFFEYVILLE
Sample
GASTROPODS
bellerophontids
other
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
SCOLECODONTS
Spirorbis
Tul/Ic
Tul/Icf
Tul/-3
Tul/-27
x
x
x
1
1

# 59. Ty I

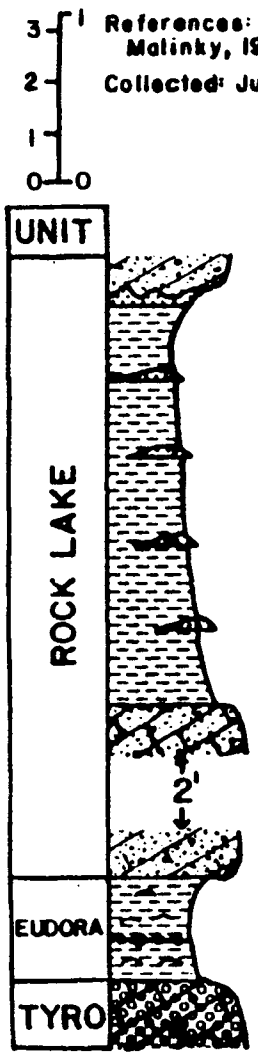
Location: Quarry 3/4 mi north and 1/2 mi east of Tyro, Kansas

Tyro, Kansas, 7 1/2'

T34SR15E30SE1/4SW1/4NW1/4

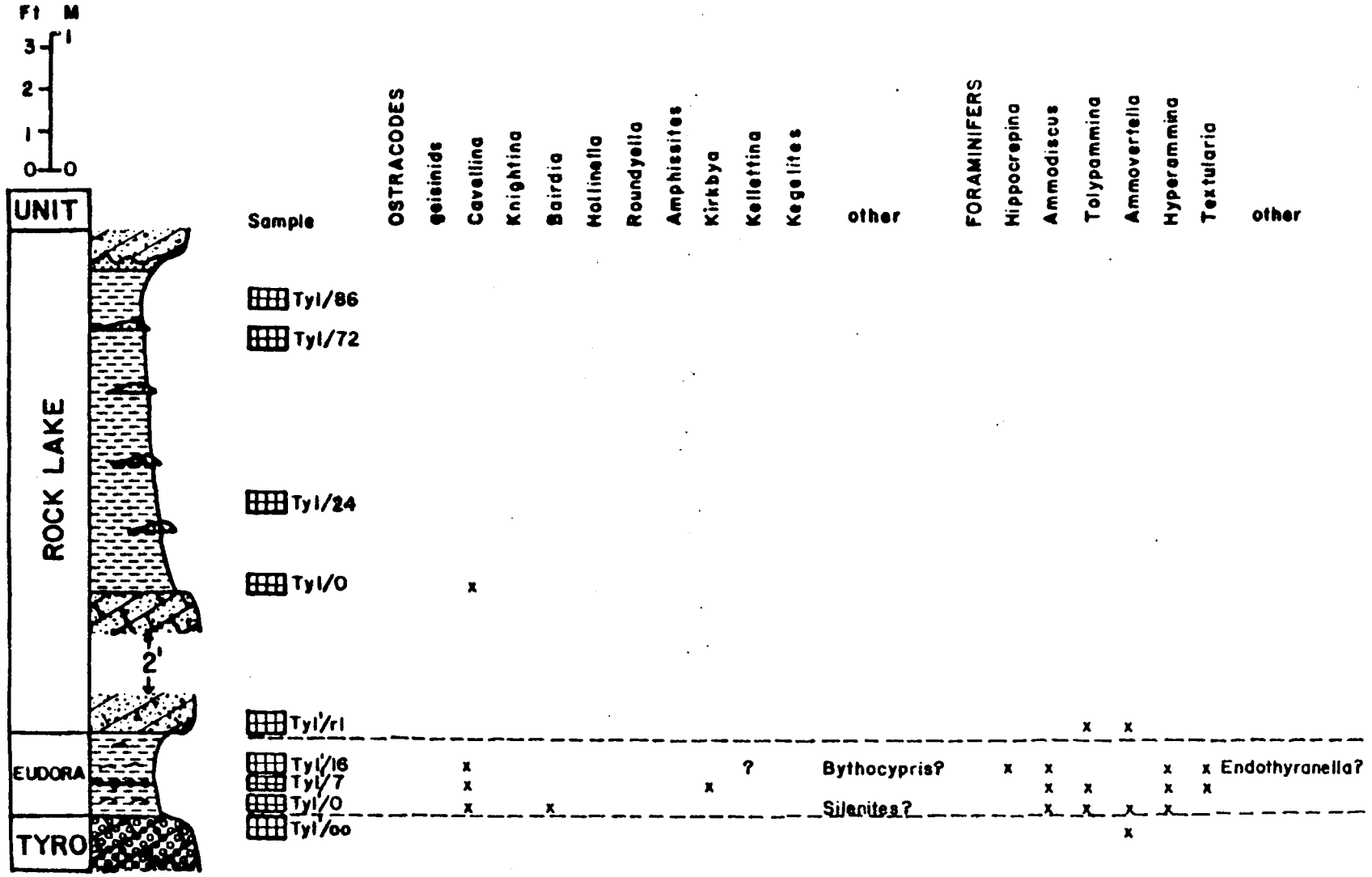
References: Kansas Geol. Soc., 1962, Stop 12, p. 56, 58; Mapes, 1977, Sect. P15, p. 367-370; Heckel, 1978, Stop 10, p. 43; Malinky, 1980

Collected: June 15 and October 20, 1979

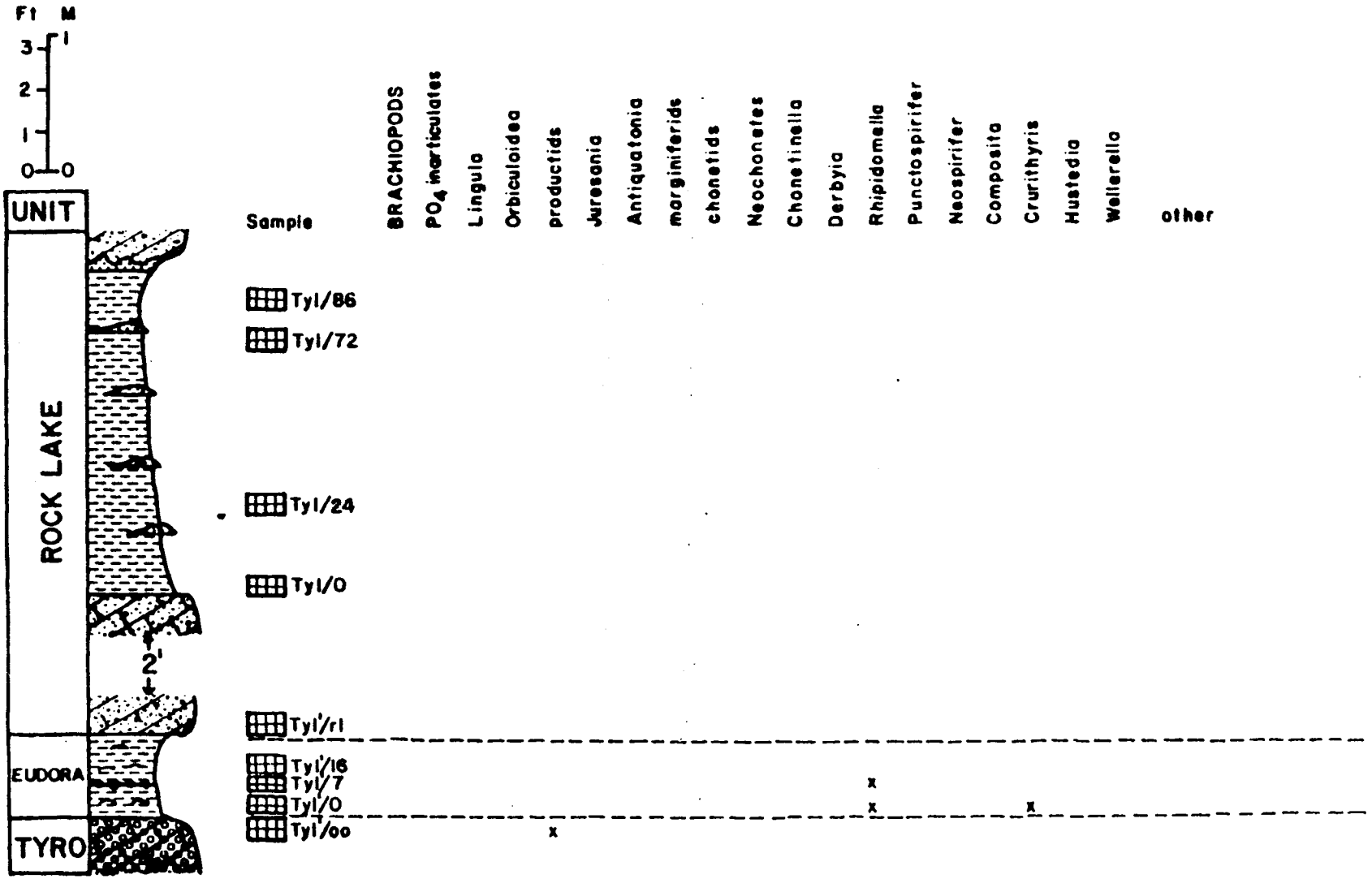



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ty1/86 | 1.68 | 9.7 | 57 | 27 | | 4 | 11 | x | | | | | | | | | | | | | | |
| Ty1/72 | 1.89 | 10.8 | 65 | | | 18 | 17 | x | | | | | | | | | | | | | | |
| Ty1/24 | 1.67 | 9.6 | 50 | 27 | | 13 | 11 | x | | | | | | | | | | | | | | |
| Ty1/0 | 1.48 | 9.9 | 56 | 34 | | 4 | 6 | x | | | | | | | | | | | | | | |
| Ty1'/r1 | 1.62 | 9.7 | 66 | 14 | | 6 | 14 | | x | | | .86 | 5 | | | 100 | | | | | | |
| Ty1'/16 | 1.59 | 10.0 | 47 | 41 | | 6 | 6 | | | | | .89 | 4 | | | 100 | | | | | | |
| Ty1'/7 | 1.82 | 10.2 | 66 | 14 | | 10 | 10 | x | x | | | .39 | 666 | | | 88 | | | | 4 | 9 | |
| Ty1'/0 | 2.60 | 10.6 | 63 | 17 | | 10 | 11 | x | x | | | .92 | 21 | | | 100 | | | | | | |
| Ty1'/oo | 1.93 | 10.0 | 60 | 17 | | 9 | 13 | x | x | | | 2.00 | 6 | 16 | | 74 | 8 | 2 | | | | |

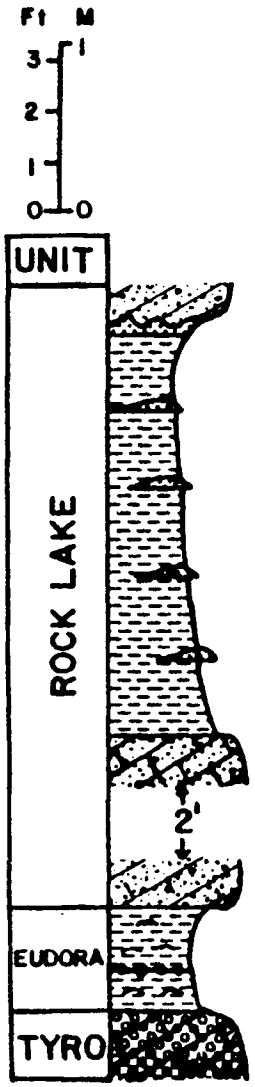
# 59. Ty I


Ft M
3 1
2
1
0 0
UNIT
ROCK LAKE
EUDORA
TYRO
2'
Sample
OSTRACODES
geisinids
Cavellina
Knightina
Bairdia
Hollinella
Roundyella
Amphissites
Kirkbya
Kellettina
Kegelites
other
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammovertella
Hyperammina
Textularia
other
Ty I/86
Ty I/72
Ty I/24
Ty I/0
Ty I'/rl
Ty I'/16
Ty I/7
Ty I'/0
Ty I/oo
?
Bythocypris?
Silenites?
Endothyranella?

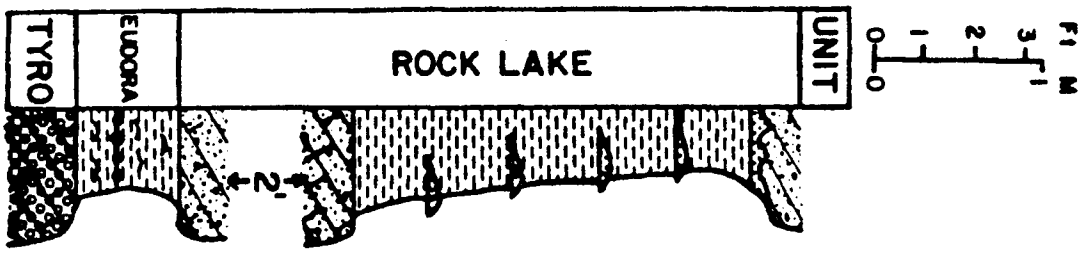
# 59. Ty I


Ft M
3 1
2
1
0 0
UNIT
ROCK LAKE
EUDORA
TYRO
2'
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
TyI/86
TyI/72
TyI/24
TyI/0
TyI'/rI
TyI'/16
TyI/7
TyI/0
TyI/oo

# 59. Ty I



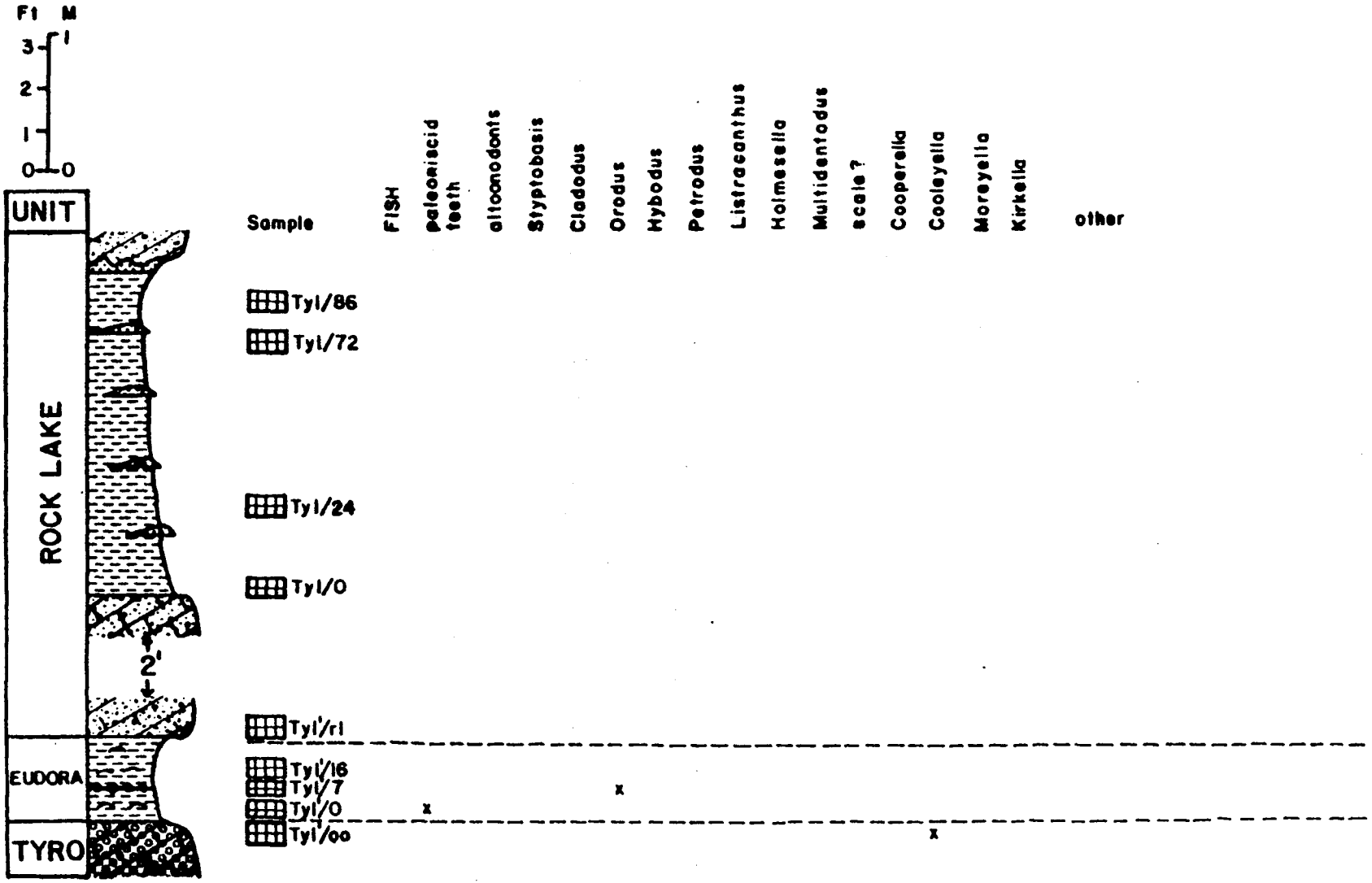

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tyl/86 | | | | | | | | | | | |
| Tyl/72 | | | | | | | | | | | |
| Tyl/24 | | | | | | | | | | | |
| Tyl/0 | | | | | | | | | | | |
| Tyl'/rl | x | | | x | | | x | Eoasianites, bactritoid? | | | |
| Tyl'/16 | x | x | | x | | | x | Eoasianites, bactritoids | | | |
| Tyl/7 | x | | | | | | | | | | |
| Tyl/0 | | | | | | | x | | | | |
| Tyl/oo | | | | | | | | | | | |




| Sample | Tyl/86 | Tyl/72 | Tyl/24 | Tyl/0 | Tyl/r1 | Tyl/7 | Tyl/16 | Tyl/10 | Tyl/00 |
|---|---|---|---|---|---|---|---|---|---|
| ECHINODERMS | | | | | | | | | |
| pelmatozoans | | | | | | x | | | x |
| echinoids | | | | | | | | | |
| holothurians | | | | | | | | | |
| BRYOZOANS | | | | | | | | | |
| fenestrate | | | | – | ? – | | ? – | | – |
| ramose | | | | | | | | | |
| fistuliporids | | | | | | | | | |
| encrusting non-fistuliporids | | | | | | | | | |
| SPONGES | | | | | | x | | | |
| wewokellid | | | | | | | | | |
| Coelocladia | | | | | | | | | |
| Girtyocoelia | | | | | | x | | | |
| spicule A | | | | | | | | | |
| spicule B | | | | | | | | | |
| TRILOBITES | | | | | | | | | |
| taxa | | | | | | | | | |
| SCOLECODONTS | | | | | | | | | x |
| Spirorbis | | | | | | | | | |
| CONULARIDS | | | | | | | | | |
| RADIOLARIANS | | | | | | | | | |

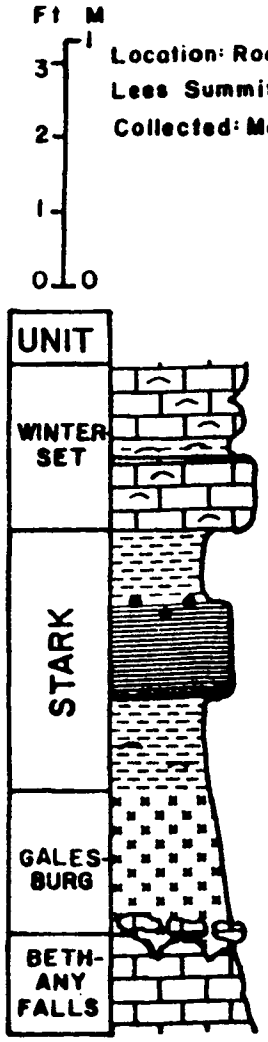
59.Ty1

# 59. Ty I


Ft M
3
2
1
0
0
UNIT
ROCK LAKE
EUDORA
TYRO
2'
Sample
FISH
paleoniscid teeth
allocmodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Tyl/86
Tyl/72
Tyl/24
Tyl/0
Tyl'/rl
Tyl'/16
Tyl/7
Tyl'/0
Tyl'/oo
x
x
x

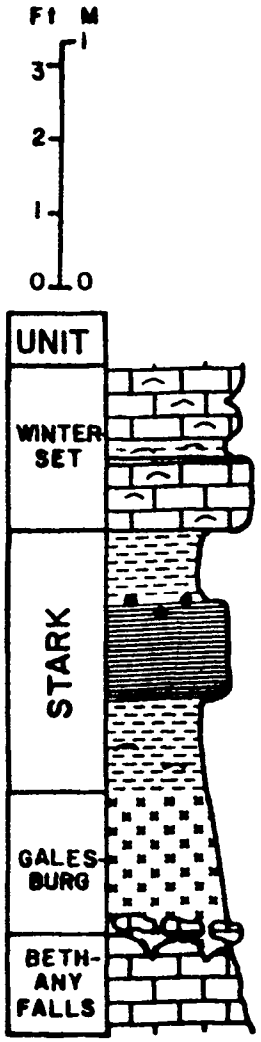
# 60. UV I

Location: Road cut on U.S. Highway 150, just west of Unity Village, Missouri
Lees Summit, Missouri, 7 1/2'  T48NR32W26NE1/4NW1/4NW1/4
Collected: May 22, 1980



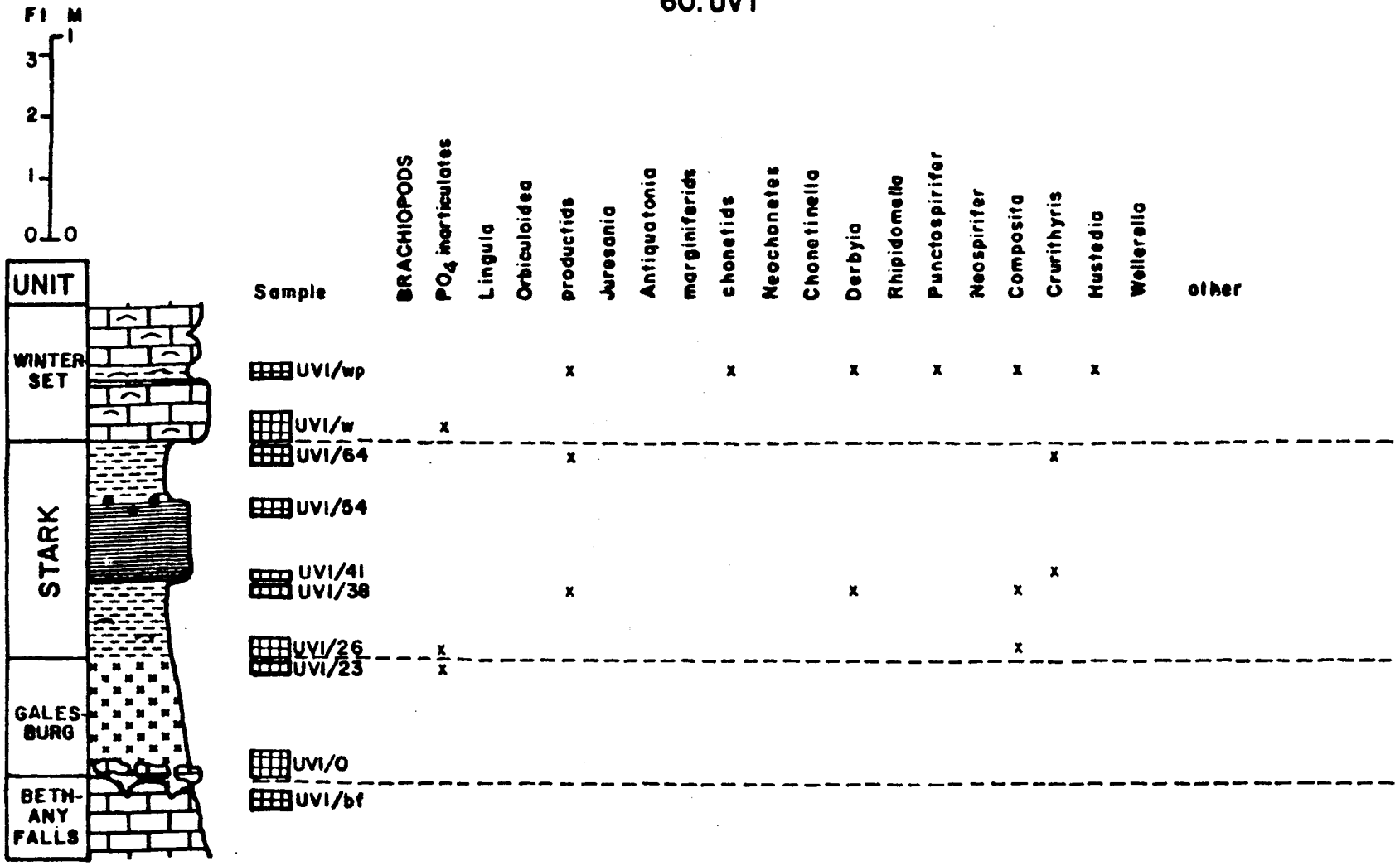

| Sample | Mite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Asthotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UVI/wp | 1.59 | 9.9 | 55 | 39 | | 6 | | | | | | .34 | | 1195 | | | 96 | 3 | | 2 | | |
| UVI/w | 1.41 | 8.9 | 56 | 21 | | 23 | | | x | | | 1.00 | | 338 | | | 93 | 5 | 1 | 2 | | |
| UVI/64 | 2.33 | 9.2 | 58 | 25 | | 17 | | | | | | | | | | | 97 | 2 | | 2 | | |
| UVI/54 | 1.45 | 9.5 | 60 | 26 | | 14 | | | | | | .06 | | 721 | | | 82 | | | 5 | 14 | |
| UVI/41 | 1.79 | 10.7 | 75 | | | 25 | | | | | | .15 | | 1427 | | | 95 | | | 4 | 1 | |
| UVI/38 | .89 | 9.4 | 48 | 43 | | 7 | 3 | | | | | .97 | | 6 | 100 | | | | | | | |
| UVI/26 | 1.03 | 8.6 | 39 | 45 | | 11 | 5 | x | | | | | | | | | | | | | | |
| UVI/23 | .91 | 9.3 | 43 | 40 | | 12 | 6 | | | | | .89 | | 1 | | | 100 | | | | | |
| UVI/0 | 1.04 | 8.8 | 37 | 43 | | 13 | 7 | | | | | | | | | | | | | | | |
| UVI/bf | 1.16 | 8.7 | 41 | 41 | | 13 | 5 | | | | | | | | | | | | | | | |

# 60. UV I

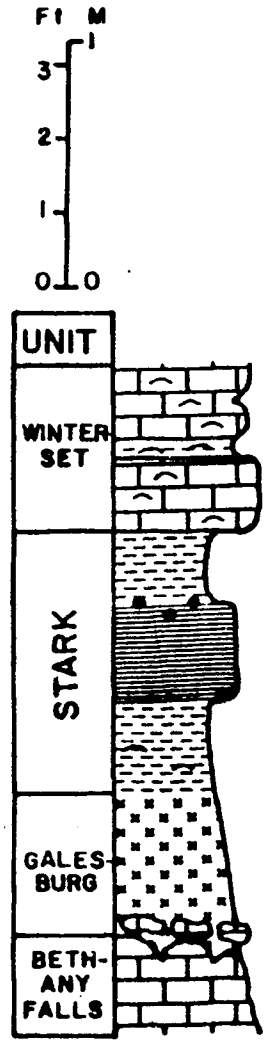



| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | | |
| UVI/wp | | | | x | | | x | | | | | | | | x | | | | | | |
| UVI/w | | | | | | | | | | | | | x | x | x | | | | | | |
| UVI/64 | | x | | x | | | | | | | | | x | x | x | | | | | | |
| UVI/54 | | | | | | | | | | | | | | | x | | | | | | |
| UVI/41 | | | | x | | | | | | | | | | | | | | | | | |
| UVI/38 | | x | | x | | | | | | | | | | | x | | x | | | | |
| UVI/26 | x | x | | | | | | | | | | | | | x | | x | | | | |
| UVI/23 | | | | | | | | | | | | | | | | | x | | | | |
| UVI/0 | | | | | | | | | | | | | | | | | | | | | |
| UVI/bf | | | | | | | | | | | | | | | | | | | | | |

# 60. UVI

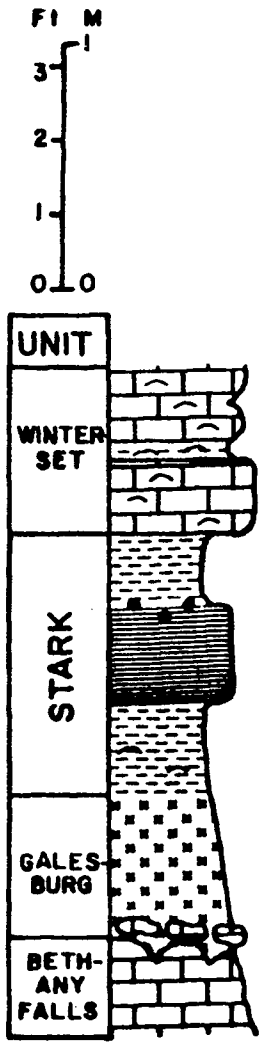

Ft M
3 1
2
1
0 0
UNIT
WINTER SET
STARK
GALES-BURG
BETH-ANY FALLS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
UVI/wp
UVI/w
UVI/64
UVI/54
UVI/41
UVI/38
UVI/26
UVI/23
UVI/0
UVI/bf

# 60. UV1



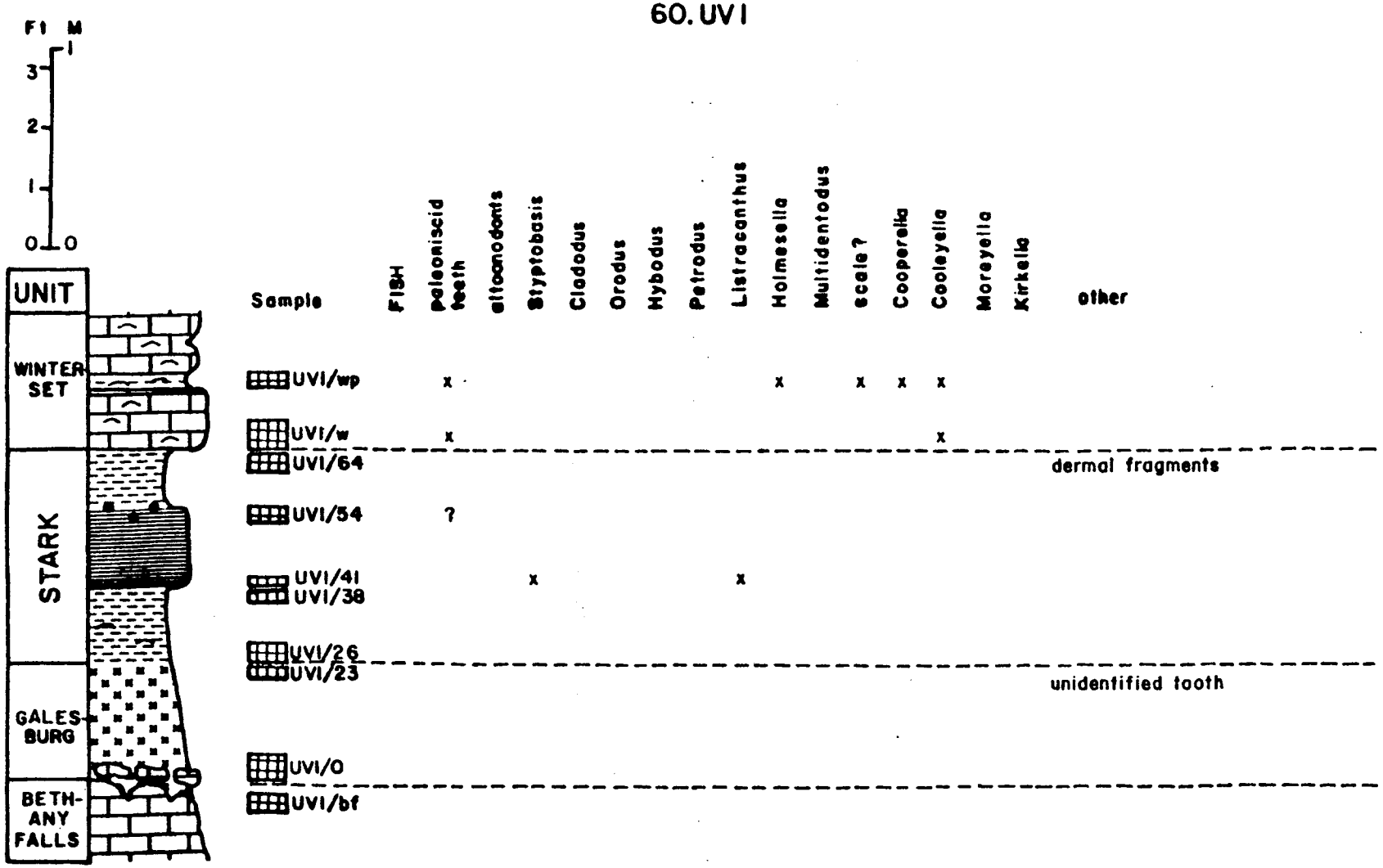

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UV1/wp | | | | | | | | | | | |
| UV1/w | | | | | | | | | | | |
| UV1/64 | x | | | | | | x | | | | |
| UV1/54 | | | | | | | | | | | |
| UV1/41 | | | | | | | | | | | |
| UV1/38 | x | | Palaeostylus, Aclisina? | | | | | | | | |
| UV1/26 | x | | Aclisina? | x | | | | | | | |
| UV1/23 | x | | | x | | | | | | | |
| UV1/0 | | | | | | | | | | | |
| UV1/bf | | | | | | | | | | | |

# 60. UVI



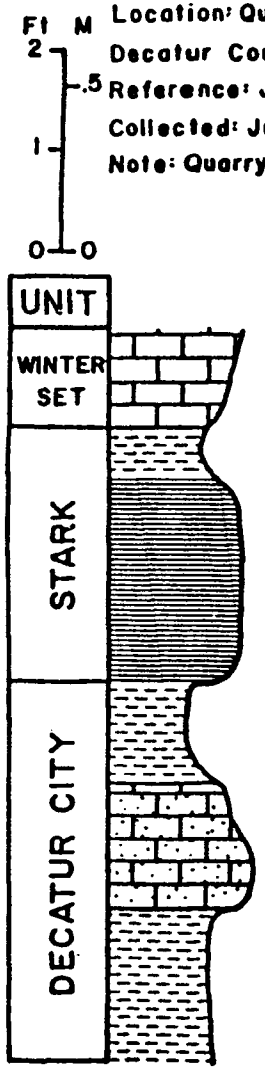

| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UVI/wp | | x | | | | 1 | 2 | | | x | x | | | | | | | | | | |
| UVI/w | | | | | | | | | | | | | | | | | | x | | | |
| UVI/64 | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| UVI/54 | | | | | | | | | | | | | | | | | | | | | |
| UVI/41 | | | | | | | 1 | | | x | | | | | x | | | | | | |
| UVI/38 | | | | | | | 1 | | | | | | | | | | | | | | |
| UVI/26 | | | | | | | | | | | | | | | | | | | | | |
| UVI/23 | | | | | | | | | | | | | | | | | | | | | |
| UVI/0 | | | | | | | | | | | | | | | | | | | | | |
| UVI/bf | | | | | | | | | | | | | | | | | | | | | |

# 60. UVI


FT M
3
2
1
0 0
UNIT
WINTER SET
STARK
GALES-BURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
ctenacanthodont
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkella
other
UVI/wp
UVI/w
UVI/64
UVI/54
UVI/41
UVI/38
UVI/26
UVI/23
UVI/0
UVI/bf
dermal fragments
unidentified tooth

# 61. VW I

Location: Quarry 2 mi south and 3 mi west of Van Wert, Iowa
Decatur County, Iowa, map T70NR26W21SE1/4SW1/4
Reference: Johnson, 1971, Loc. 49, p. 84
Collected: July 21, 1979
Note: Quarry was flooded when collected, so measurement and lithology approximate



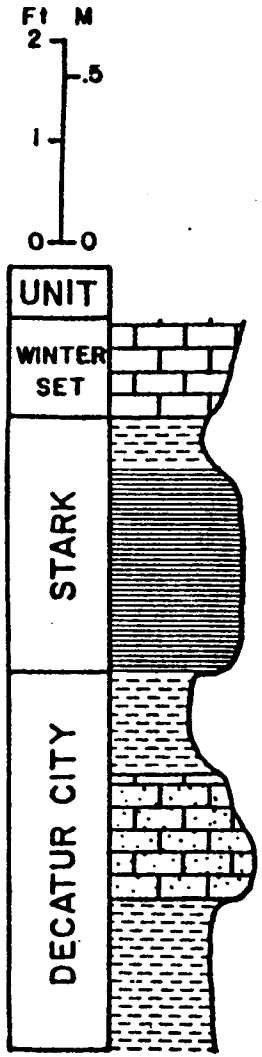

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VWI | 1.01 | 8.1 | 33 | 32 | 12 | 23 | | | | | | x | | | | | | | | | | | |

# 61. VW I




| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VWI | | x | x | | | | | | | | | | | | | | | | | |

# 61. VW I




| Sample | FISH | paleoniscid teeth | allocanodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VWI | | x | | | | | x | | | | | x | | x | | | Helodus, Agassizodus?, petalodont, unidentified teeth |

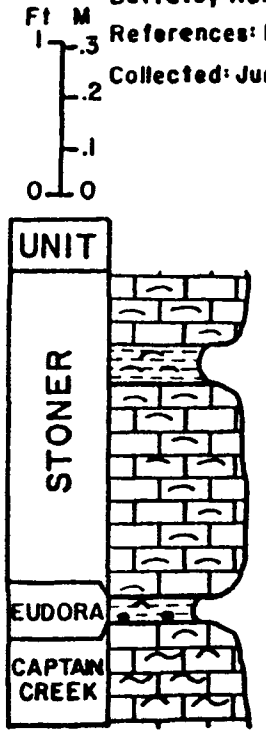
# 62. WCL 1

Location (upper section): Quarry at Wilson County State Lake, 1 mi south and .6 mi east of Buffalo, Kansas

Buffalo, Kansas, 7 1/2' T27SR16E17SE1/4SE1/4SW1/4

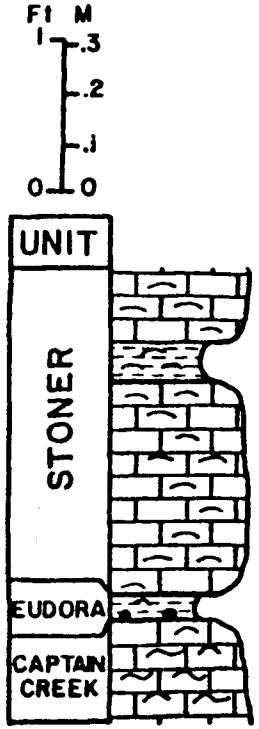
References: Heckel, 1978, Stop 4, p. 30-31; Heckel et al., 1979, Stop 5, p. 28-29

Collected: June 18, 1979



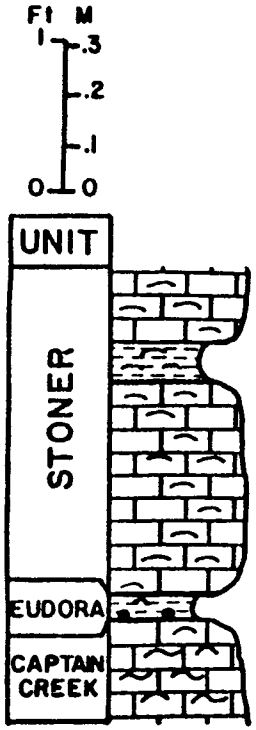

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Bendodella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCL1'/19 | 1.35 | 9.2 | 46 | 22 | | 14 | 18 | | x | | | 1.00 | | 21 | | | 95 | | | | 5 | |
| WCL1'/18 | 1.09 | 9.0 | 37 | 25 | | 13 | 26 | | | | | np | | | | | | | | | | |
| WCL1'/3 | 1.20 | 8.9 | 53 | 22 | | 11 | 14 | | | | | 1.00 | | 48 | | | 74 | 23 | | 1 | 2 | |
| WCL1/0 | 1.56 | 9.4 | 56 | 22 | | 9 | 13 | | | | | .09 | | 2697 | | | 94 | | | 2 | 5 | |

# 62. WCL 1



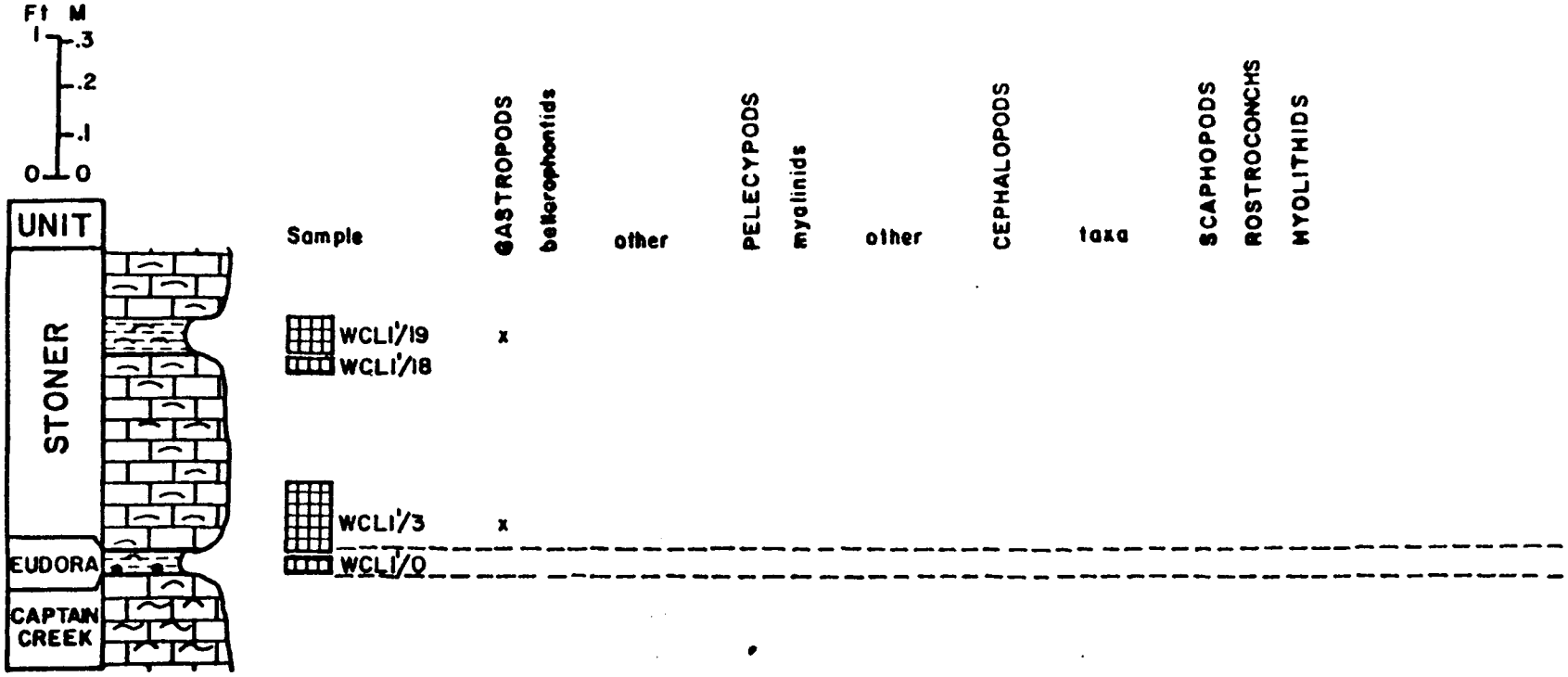

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | | |
| WCL1'/19 | | | | x | | | | | | | | | | x | x | x | | | | | |
| WCL1'/18 | | | | | | | | | | | | | x | | x | x | | | | | |
| WCL1'/3 | | | | | | | | | | | | | | x | x | x | | | | | |
| WCL1'/0 | | | | | | | | | | | | | | x | x | | x | | | | |

# 62. WCL 1

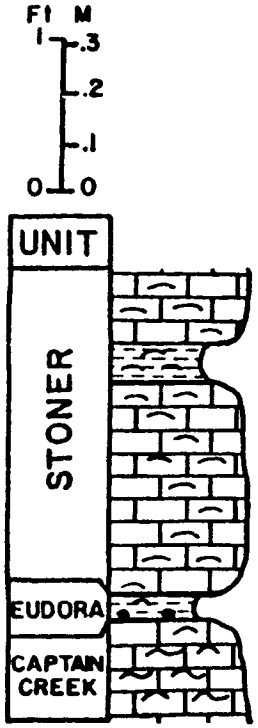



| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCL1'/19 | | x | | | x | | | | | | | | | | | x | | x | | |
| WCL1'/18 | | | | | | | | | | | | | | | | | | | | |
| WCL1'/3 | | | | | | | | | | | | | | | | | | | | |
| WCL1/0 | | | | | x | | | | x | | x | | x | x | | | x | | | |

# 62. WCL 1

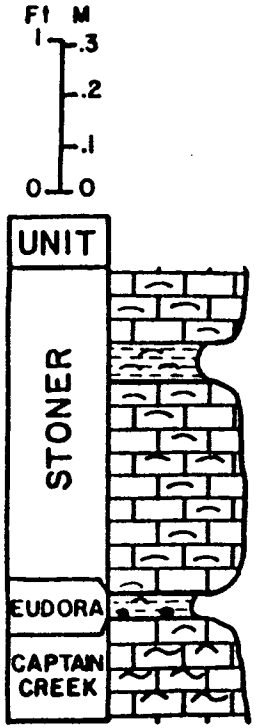

Ft M
1 .3
.2
.1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
WCL1'/19
WCL1'/18
x
WCL1'/3
WCL1'/0
x

# 62. WCL I




| Sample | ECHINODERMS | palmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtycoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI'/19 | | x | x | | | 1 | 1 | x | | x | x | x | | | | | | | | | |
| WCLI'/18 | | | | | | | | | | | | | | | | | | | | | |
| WCLI'/3 | | | | | | | | | | | | | | | | | | | | | |
| WCLI'/0 | | x | | | | 1 | 2 | x | | | | | | | | | | | | | |

# 62. WCL I




| Sample | FISH | paleoniscid teeth | actinodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI'/19 | | x | x | | | | | | | | | x | | | | | |
| WCLI'/18 | | | | | | | | | | | | | | | | | |
| WCLI'/3 | | x | x | x | | | | | | | | | | x | | x | Protacrodus |
| WCLI'/0 | | x | x | x | | x | | | | x | | | | | | | unidentified teeth |

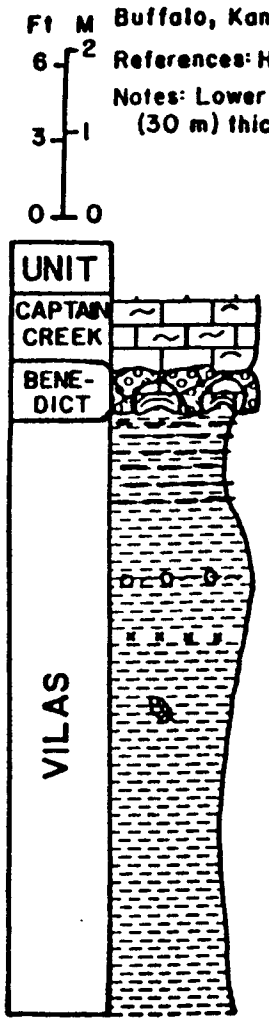
# 62.WCLI (cont.)

Location (lower section): Plunge pool at Wilson County State Lake, 1 mi south and .4 mi east of Buffalo, Kansas

Buffalo, Kansas, 7 1/2' T27SR16E17SE1/4SW1/4SW1/4

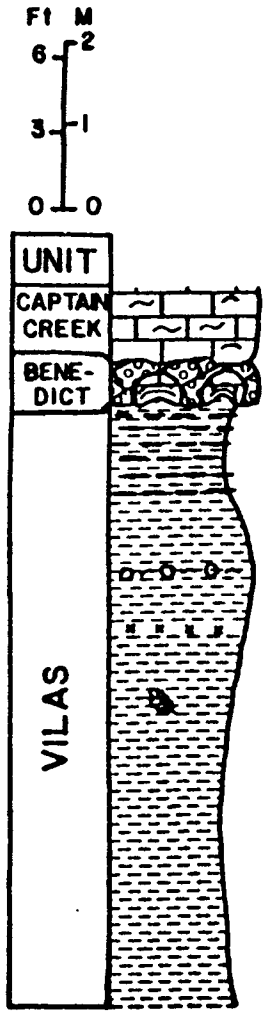
References: Heckel, 1978, Stop 4, p. 30-31; Heckel et al., 1979, Stop 5, p. 28-29

Notes: Lower section .2 mi west of upper section; Heckel reported the Captain Creek is 21' (6.5 m) thick, while the Vilas is 100' (30 m) thick



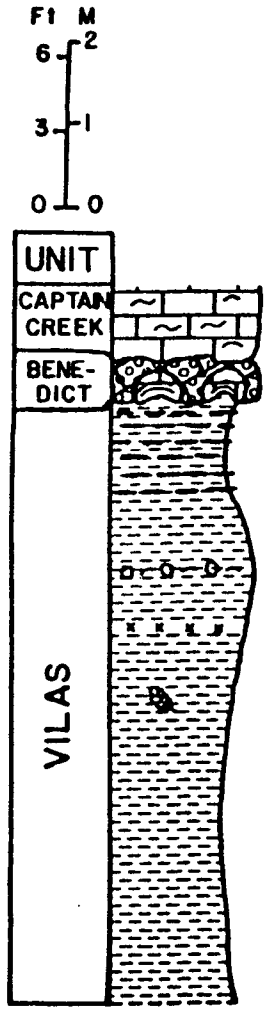

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI/b | 1.35 | 9.7 | 44 | 36 | | 6 | 15 | x | | | | 2.00 | | 161 | 72 | 1 | 26 | 1 | | | | |
| WCLI/24' | 1.55 | 9.6 | 45 | 39 | | 6 | 11 | x | | | | 1.07 | | | | | | | | | | x |
| WCLI/17' | 1.92 | 9.8 | 48 | 24 | | 20 | 8 | x | | | | | | | | | | | | | | |
| WCLI/15' | 3.15 | 9.9 | 57 | 19 | | 17 | 7 | | | | | | | | | | | | | | | |
| WCLI/10' | 2.60 | 9.8 | 50 | 27 | | 17 | 7 | x | | | | | | | | | | | | | | |
| WCLI/5' | 2.60 | 9.6 | 56 | 22 | | 15 | 7 | x | | | | | | | | | | | | | | |
| WCLI/0' | 2.15 | 10.1 | 55 | 21 | | 17 | 8 | x | | | | | | | | | | | | | | |

## 62.WCLI (cont.)



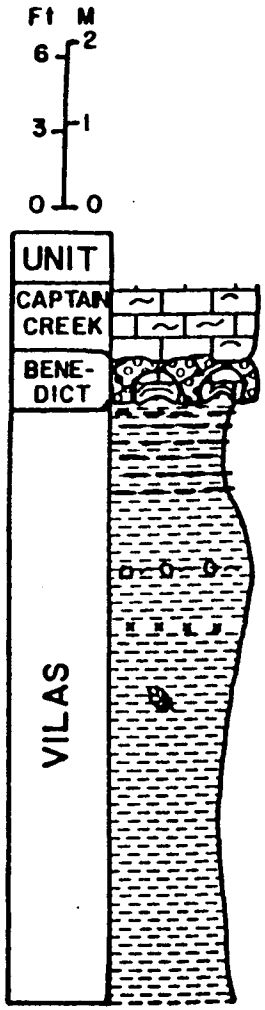

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geismids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| WCLI/b | | | | | | | | | | | | | | | x | x | | | | |
| WCLI/24' | x | | | | | | | | | | | | | | | | | | | |
| WCLI/17' | x | | | | | | | | | | | | | | | | | | | |
| WCLI/15' | | | | | | | | | | | | | | | | | | | | |
| WCLI/10' | x | | | | | | | | | | | | | | | | | | | |
| WCLI/5' | x | x | | | | | | | | | | | | | | | | | | |
| WCLI/0' | | | | | | | | | | | | | | | | | | | | |

# 62.WCLI (cont.)



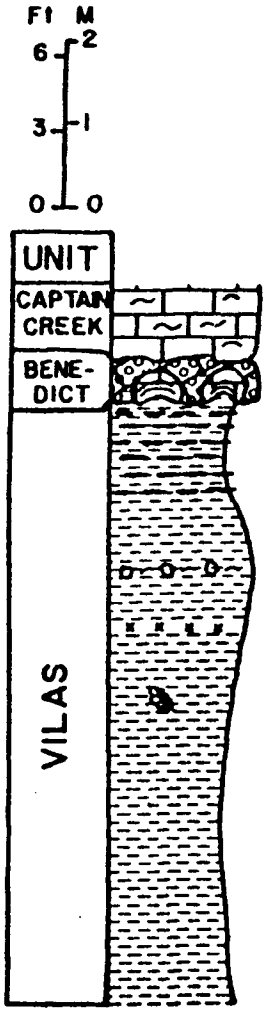

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI/b | | x | | ? | | | | | | | | | | x | | | | | | |
| WCLI/24' | | | | | | | | | | | | | | | | | | | | |
| WCLI/17' | | | | | | | | | | | | | | | | | | | | |
| WCLI/15' | | | | | | | | | | | | | | | | | | | | |
| WCLI/10' | | | | | | | | | | | | | | | | | | | | |
| WCLI/5' | | | | | | | | | | | | | | | | | | | | |
| WCLI/0' | | | | | | | | | | | | | | | | | | | | |

# 62.WCLI (cont.)




| Sample | GASTROPODS | heterophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | MYOLITHIDS | ECHINODERMS | pelmatozoans | echinoids | holothurians |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI/b | x | | | | | | | | | | | | | | |
| WCLI/24' | x | | | | | | | | | | | | x | | |
| WCLI/17' | x | | Hypselentoma | x | | | | | | | | | | | |
| WCLI/15' | x | | Hypselentoma? | | | | | | | | | | | | |
| WCLI/10' | | | | | | | | | | | | | | | |
| WCLI/5' | | | | | | | | | | | | | | | |
| WCLI/0' | x | | Hypselentoma? | | | | | | | | | | | | |

# 62.WCLI (cont.)




| Sample | FISH | paleoniscid teeth | actinodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WCLI/b | | | x | | | | | | | | | | | x | | | |
| WCLI/24' | | | | | | | | | | | | | | | | | |
| WCLI/17' | | | | | | | | | | | | | | | | | |
| WCLI/15' | | | | | | | | | | | | | | | | | |
| WCLI/10' | | | | | | | | | | | | | | | | | |
| WCLI/5' | | | | | | | | | | | | | | | | | |
| WCLI/0' | | | | | | | | | | | | | | | | | |

# 63. Wi l

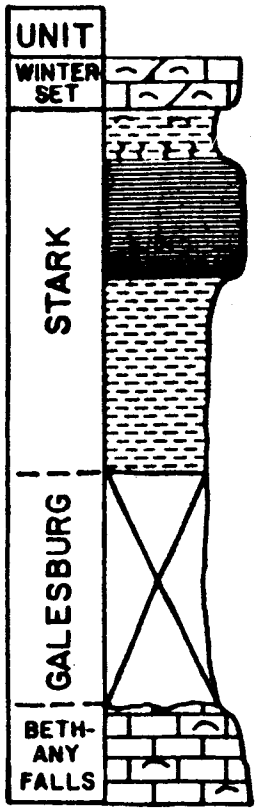
Location: Road cut on U.S. Highway 169 1/2 mi west and 1/2 mi south of Winterset, Iowa

Winterset, Iowa, 15'  T75NR28WIINE1/4SE1/4

References: Price, 1977, p.5; Heckel, 1980, Stop 1, p. 14-15

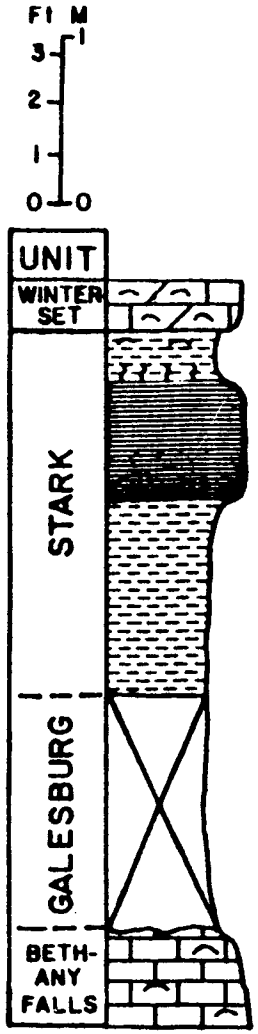
Collected: June 9, 1978

Note: Price reported lenses of "Canville", but none were apparent when collected



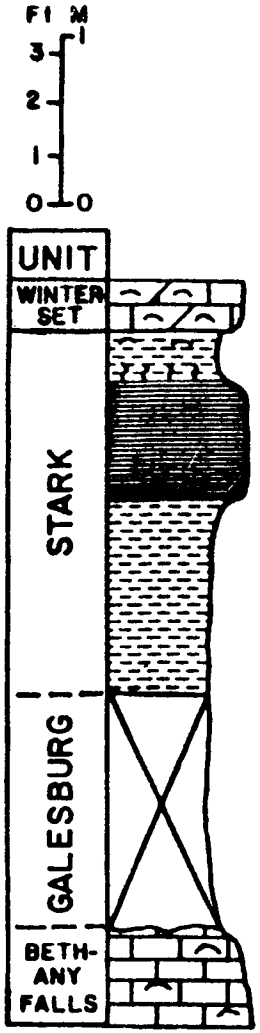

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wil/w | 1.30 | 9.6 | 54 | 43 | | 3 | | | x | | | 1.00 | | 291 | | | 95 | 4 | t | t | | |
| Wil/-4 | 1.91 | 9.3 | 59 | 35 | | 6 | | | | | | .75 | | 174 | | | 88 | 11 | | 1 | | |
| Wil/-13 | 1.75 | 9.6 | 62 | 25 | | 13 | | | x | | | .20 | | 472 | | | 70 | 3 | | 5 | 22 | |
| Wil/-20 | 1.62 | 9.1 | 48 | 26 | | 27 | | | | | | .62 | | 300 | | | 58 | | | 9 | 34 | |
| Wil/-32 | | | | | | | | | | | | .59 | | 724 | | | 91 | | | 8 | t | |
| Wil/-42 | 1.27 | 8,9 | 41 | 42 | | 17 | | | | | | .30 | | 180 | 6 | | 92 | 2 | | 1 | | |
| Wil/-50 | 1.27 | 9.0 | 40 | 55 | | 6 | | | | | | | | | | | | | | | | |
| Wil/-61 | 1.39 | 8.2 | 31 | 62 | | 7 | | | | | | | | | | | | | | | | |
| Wil/-88 | 1.33 | 9.1 | 31 | 60 | | 9 | | | | | | | | | | | | | | | | |
| Wil/bf | 2.80 | 8.6 | 52 | 48 | | | | | | | | 1,98 | | 14 | 30 | 4 | 48 | 19 | | | | |

# 63. Wil



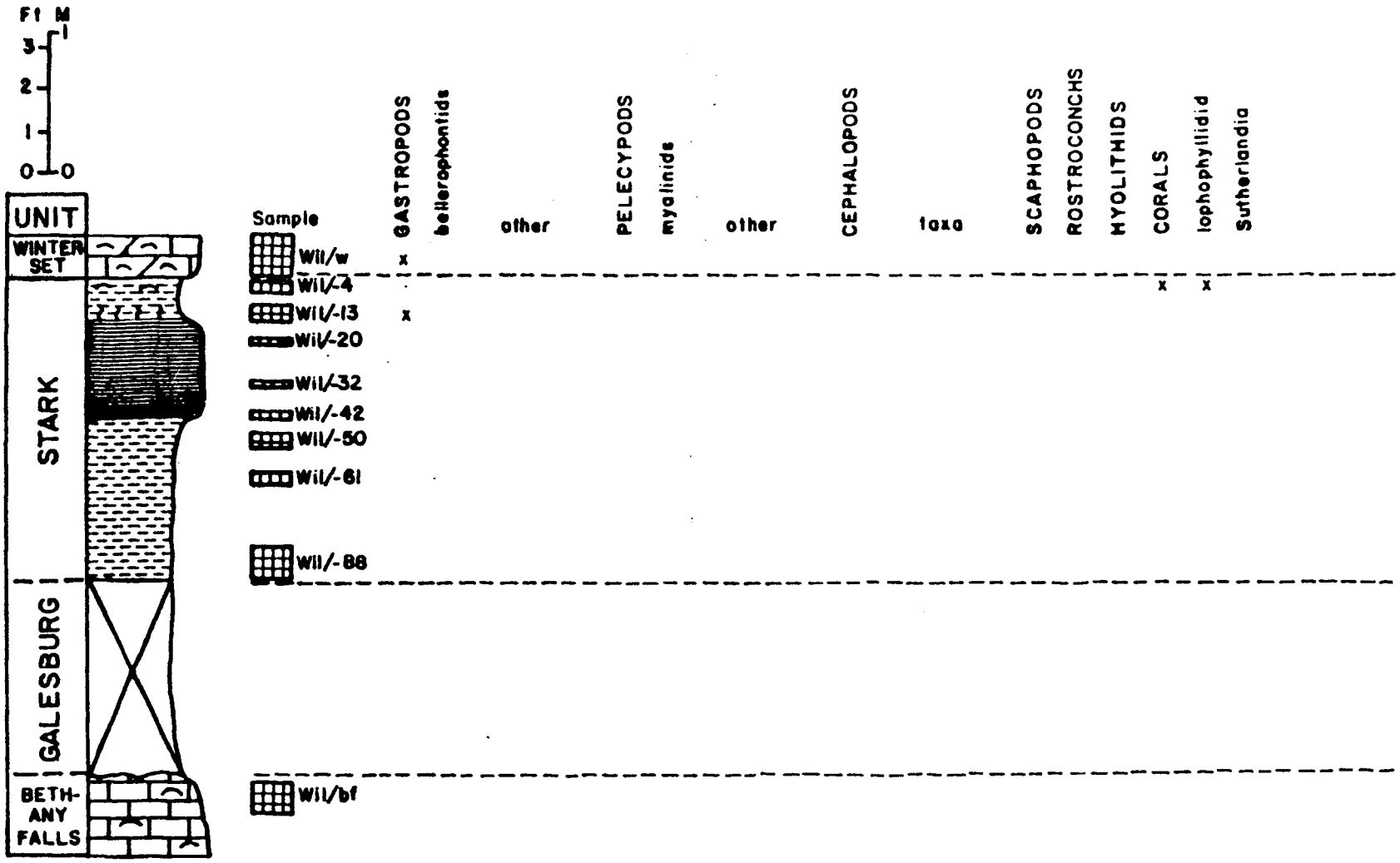

| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | | |
| Wil/w | | | | | | | | | | | | | | | x | | | | | |
| Wil/-4 | | x | | x | x | | | | x | x | | | | x | x | | | | | |
| Wil/-13 | | x | | | | | | | | | | | x | x | x | | | | | |
| Wil/-20 | | | | | | | | | | | | | | | | | | | | |
| Wil/-32 | | | | | | | | | | | | | | | | | | | | |
| Wil/-42 | | x | | x | | | | | | | | | | | x | | | | | |
| Wil/-50 | x | | | x | | | | | | | | | | | | | | | | |
| Wil/-61 | | | | | | | | | | | | | | | | | | | | |
| Wil/-88 | | | | | | | | | | | | | | | | | | | | |
| Wil/bf | | | | | | | | | | | | | | | x | x | | | | |

# 63. Wi l

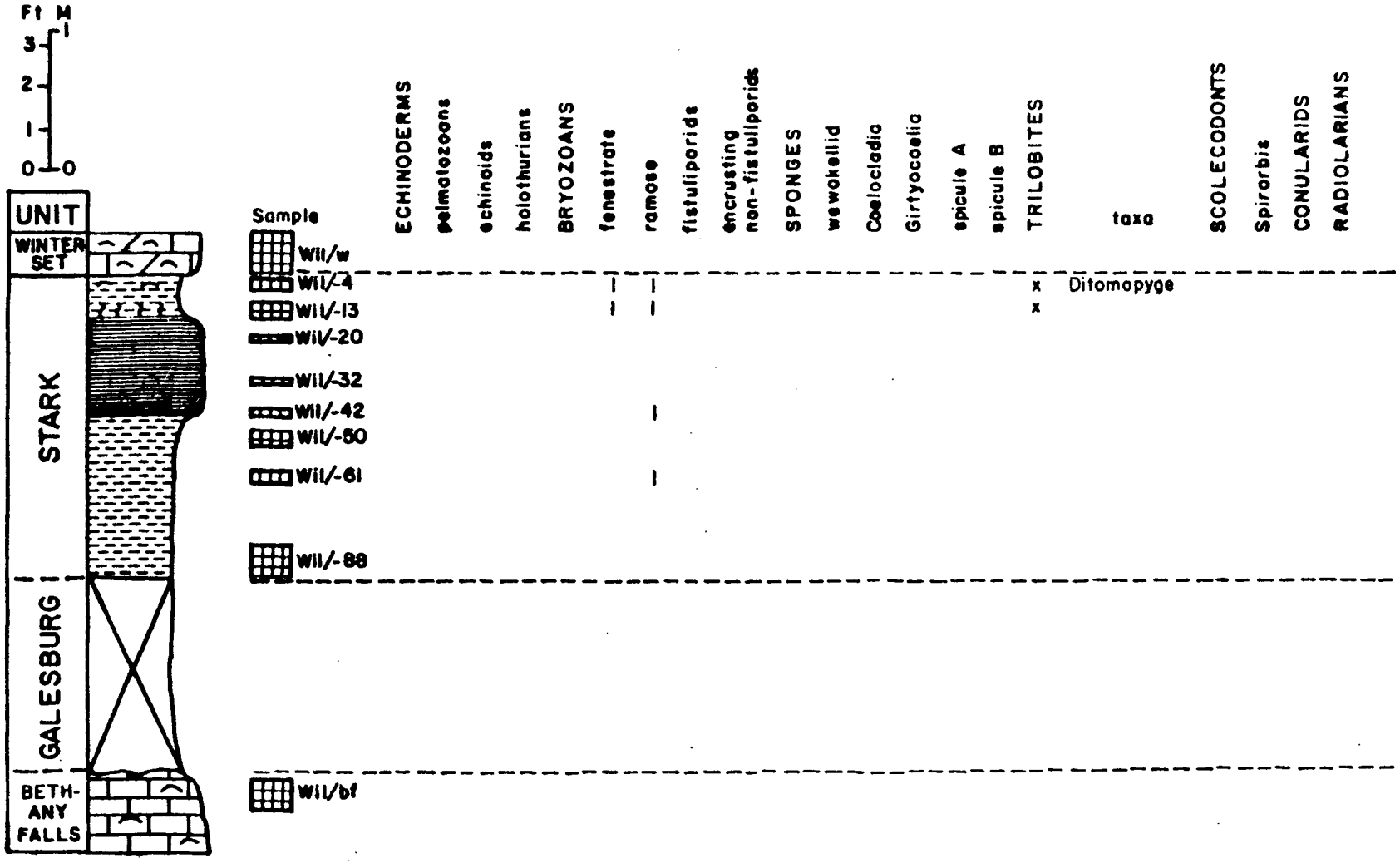



| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wil/w | | | | | | | | | | | | | | | | | | | | |
| Wil/-4 | | x | | | x | | | x | x | | x | x | | x | x | x | x | | | Crania, Reticulatia |
| Wil/-13 | | | | | x | | | | x | | x | x | | x | | x | x | | | |
| Wil/-20 | | | | | | | | | | | | | | | | | | | | |
| Wil/-32 | | | | | | | | | | | | | | | | | | | | |
| Wil/-42 | | x | | | x | | | | x | | | ? | | | | | | | | |
| Wil/-50 | | | | | x | | | | | | | ? | | | | | | | | |
| Wil/-61 | | | | | | | | | | | | | | | | | | | | |
| Wil/-88 | | | | | | | | | | | | | | | | | | | | |
| Wil/bf | | | | | | | | | | | | | | | | | | | | |

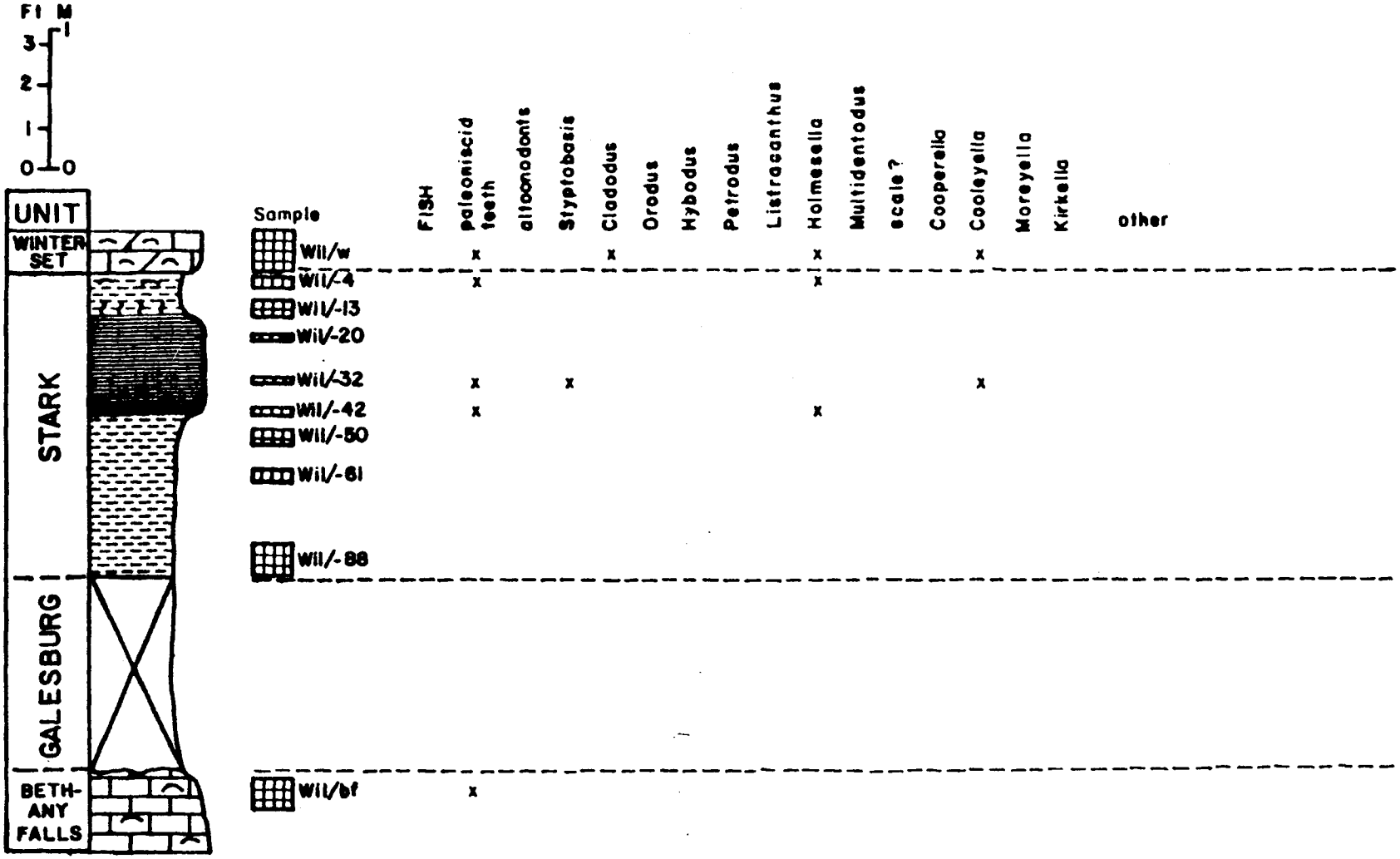
# 63.Wil


Ft M
3
2
1
0 0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
Wil/w
Wil/-4
Wil/-13
Wil/-20
Wil/-32
Wil/-42
Wil/-50
Wil/-61
Wil/-88
Wil/bf
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
CORALS
lophophyllidid
Sutherlandia

# 63.Wil


Ft M
3
2
1
0 0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
Wil/w
Wil/-4
Wil/-13
Wil/-20
Wil/-32
Wil/-42
Wil/-50
Wil/-61
Wil/-88
Wil/bf
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coeloclodia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
Ditomopyge
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS

# 63.Wil


FT M
3
2
1
0 0
UNIT
WINTER SET
STARK
GALESBURG
BETH-ANY FALLS
Sample
FISH
paleoniscid teeth
allocnodonts
Stypiobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Wil/w
Wil/-4
Wil/-13
Wil/-20
Wil/-32
Wil/-42
Wil/-50
Wil/-61
Wil/-88
Wil/bf

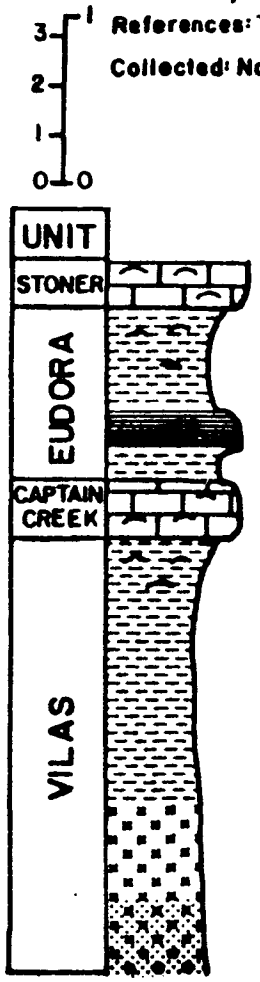
# 64. Wi 2

Location: On small creek bank east of county road about 11 mi west and 1 mi south of Winterset, Iowa

Winterset, Iowa, 15' T75NR29W7NW1/4SW1/4NW1/4

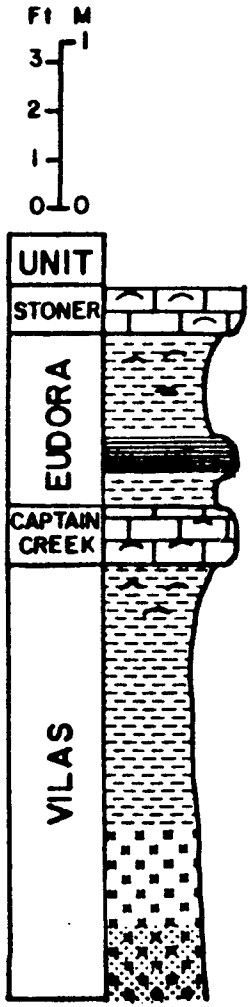
References: Toomey, 1964, Loc. 29, p. 181; Evans, 1966, Loc. 1, p. 132; Welp et al., 1968, Stop 6; Heckel, 1980, Stop 6, p. 24-25

Collected: November 4, 1978



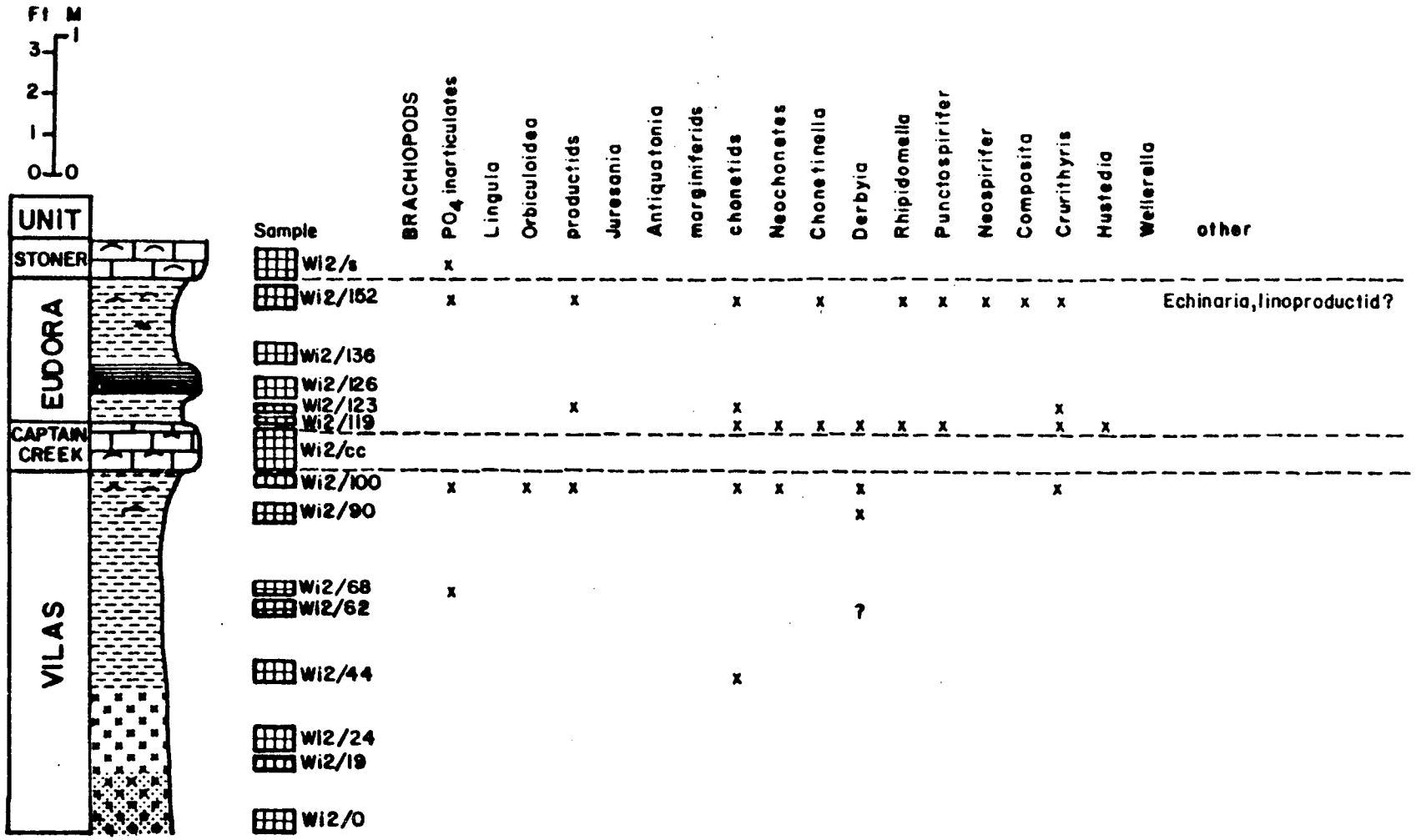

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wi2/s | | | | | | | | | | | | .99 | | 18 | | | 74 | 22 | | 3 | | |
| Wi2/152 | 1.92 | 9.5 | 62 | 28 | | 8 | 3 | | | | | .85 | | 431 | | | 81 | | | 1 | 18 | |
| Wi2/136 | 1.72 | 9.3 | 65 | 25 | | 8 | 2 | | | | | .70 | | 29 | | | 59 | | | 1 | 40 | |
| Wi2/126 | 1.55 | 9.1 | 45 | 33 | | 22 | | | | | | .47 | | 469 | | | 46 | | | 7 | 47 | |
| Wi2/123 | 1.92 | 9.5 | 57 | 20 | | 17 | 6 | | | | | .60 | | 563 | | | 97 | 1 | | 1 | | |
| Wi2/119 | 1.81 | 10.1 | 51 | 38 | | 11 | | | x | | | .49 | | 107 | | | 94 | 6 | | | | |
| Wi2/cc | 1.42 | 9.7 | 40 | 46 | | 15 | | | | | | .79 | | 64 | 4 | | 94 | 2 | | | | |
| Wi2/100 | 1.78 | 9.6 | 62 | 26 | | 12 | | | x | | | .56 | | 186 | 32 | | 66 | 2 | | | | |
| Wi2/90 | 1.38 | 9.1 | 46 | 37 | | 10 | 8 | | | | | .65 | | 14 | 78 | 11 | 11 | | | | | |
| Wi2/68 | 1.69 | 10.0 | 59 | 23 | | 18 | | x | | | | | | | | | | | | | | |
| Wi2/62 | 1.31 | 9.2 | 42 | 44 | | 14 | | | | | | | | | | | | | | | | |
| Wi2/44 | 1.27 | 9.1 | 44 | 37 | | 19 | | | | | | .79 | | 2 | | | | | | 17 | 83 | |
| Wi2/24 | 1.57 | 9.1 | 49 | 29 | | 22 | | | | | | | | | | | | | | | | |
| Wi2/19 | 1.36 | 9.0 | 41 | 36 | | 24 | | | | | | | | | | | | | | | | |
| Wi2/0 | 1.88 | 10.4 | 42 | 29 | | 29 | | | | | | | | | | | | | | | | |

# 64. Wi 2

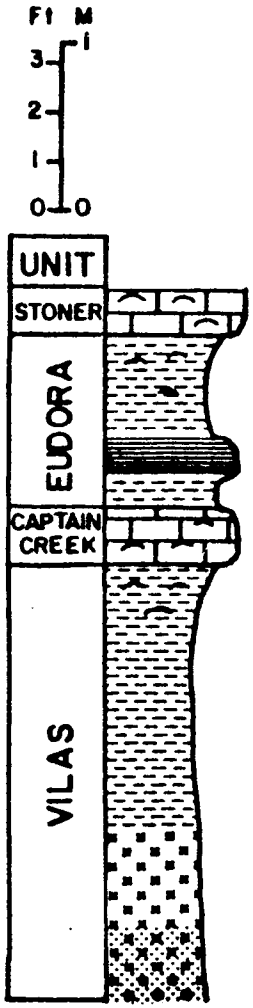



| Sample | OSTRACODES | | | | | | | | | | | other | FORAMINIFERS | | | | | | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | |
| Wi2/s | | | | | | | | | | | | | | | x | | | | |
| Wi2/152 | | x | | | | | | | | | | | x | x | x | | | | Endothyranella?, fusulinids |
| Wi2/136 | | x | | | | | | | | | | | x | x | | | | | |
| Wi2/126 | | | | | | | | | | | | | | | | | | | |
| Wi2/123 | | | | | | | | | | | | | | | x | | | | |
| Wi2/119 | | | | x | x | | x | x | | | | | | | x | | x | | fusulinids |
| Wi2/cc | | | | | | | | | | | | | | | x | x | x | | |
| Wi2/100 | | x | | | | | | | | | | | | | x | | x | | fusulinids |
| Wi2/90 | | x | | | x | | | | | | | | | | x | | | | |
| Wi2/68 | x | x | | | x | | | | | | | | | | x | | | | |
| Wi2/62 | x | | | | | | | | | | | | | | | | | | |
| Wi2/44 | x | | | | | | | | | | | | | | | | | | |
| Wi2/24 | | | | | | | | | | | | | | | | | | | |
| Wi2/19 | | | | | | | | | | | | | | | | | | | |
| Wi2/0 | | | | | | | | | | | | | | | | | | | |

# 64. WI 2

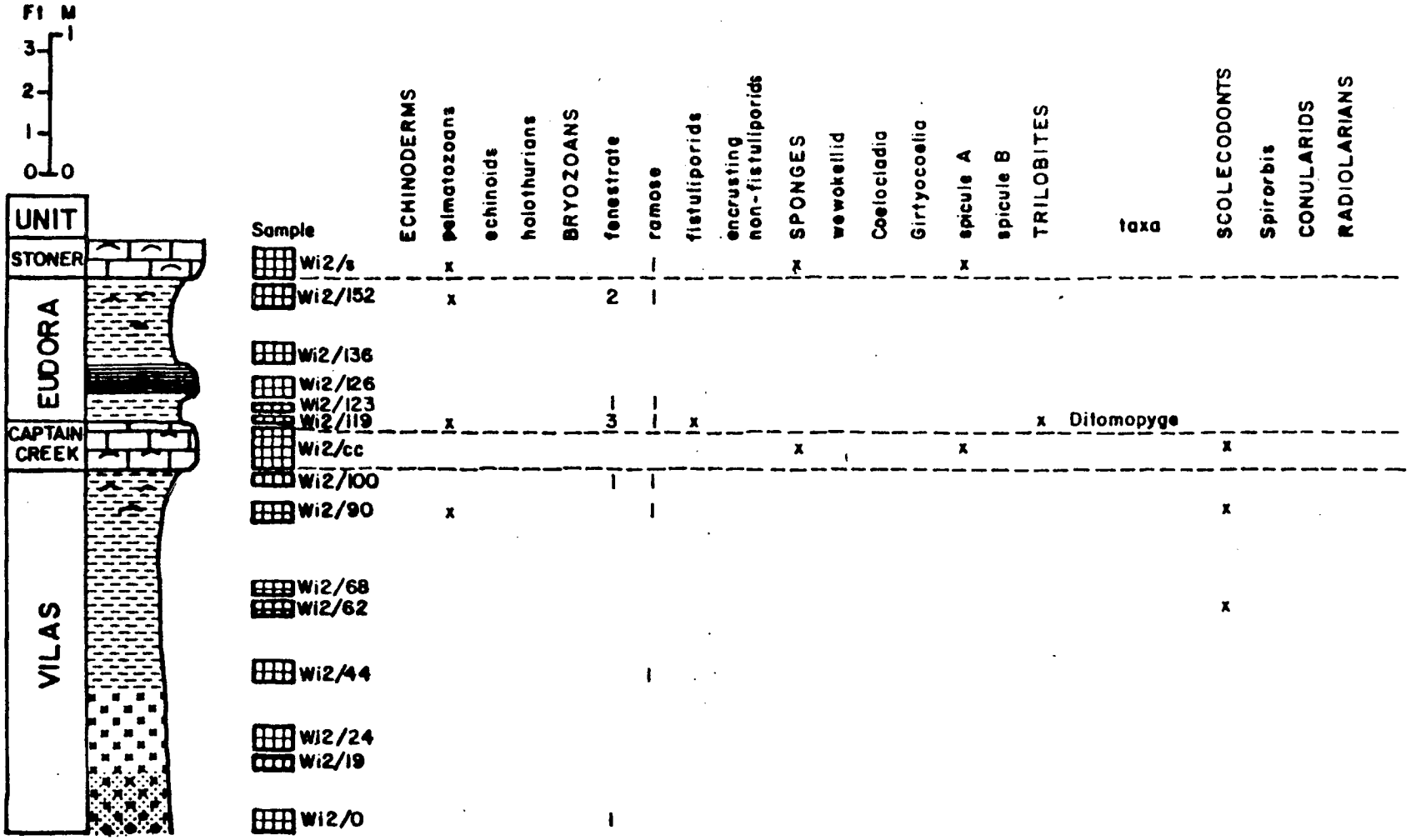

Ft M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
WI2/s
WI2/152
WI2/136
WI2/126
WI2/123
WI2/119
WI2/cc
WI2/100
WI2/90
WI2/68
WI2/62
WI2/44
WI2/24
WI2/19
WI2/0
Echinaria, linoproductid?
?

# 64. WI 2

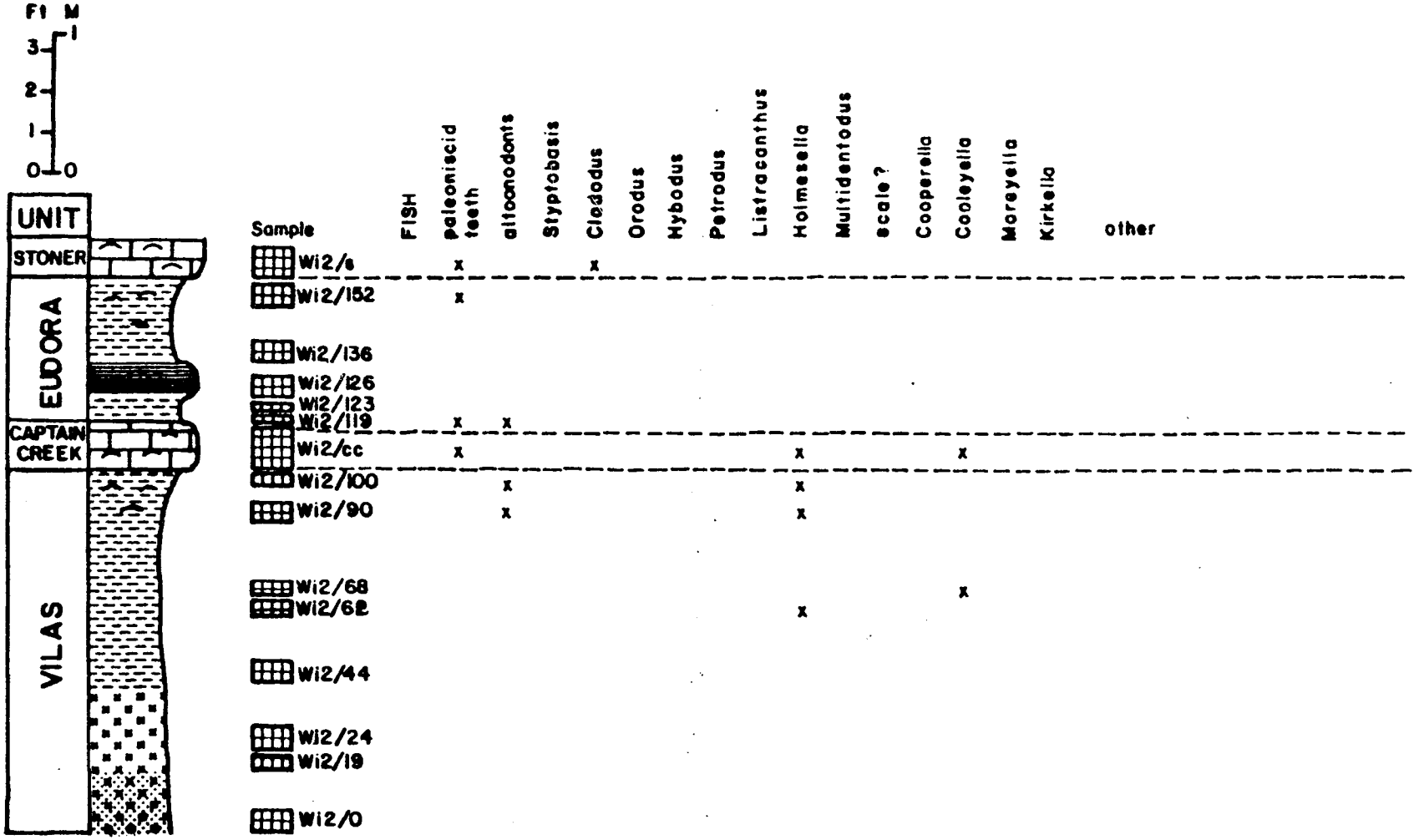



| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wi2/s | | | | | | | | | | | |
| Wi2/152 | x | | | x | | | | | | | |
| Wi2/136 | x | | | | | | | | | | |
| Wi2/126 | | | | | | | | | | | |
| Wi2/123 | x | | | | | | | | | | |
| Wi2/119 | | | | | | | | | | | |
| Wi2/cc | | | | | | | | | | | |
| Wi2/100 | x | | | | | | | | | | |
| Wi2/90 | x | | | | | | | | | | |
| Wi2/68 | x | ? | | x | | | | | | | |
| Wi2/62 | x | | | | | | | | | | |
| Wi2/44 | | | | | | | | | | | |
| Wi2/24 | | | | | | | | | | | |
| Wi2/19 | | | | | | | | | | | |
| Wi2/0 | | | | | | | | | | | |

# 64. Wi 2


Ft M
3
2
1
0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
ECHINODERMS
palmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Wi2/s
Wi2/152
Wi2/136
Wi2/126
Wi2/123
Wi2/119
Wi2/cc
Wi2/100
Wi2/90
Wi2/68
Wi2/62
Wi2/44
Wi2/24
Wi2/19
Wi2/0
Dilomopyge

# 64. WI 2


Ft M
3 1
2
1
0 0
UNIT
STONER
EUDORA
CAPTAIN CREEK
VILAS
Sample
FISH
paleoniscid teeth
allaeodonts
Styptobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale?
Cooperella
Cooleyella
Moreyella
Kirkella
other
WI2/s
WI2/152
WI2/136
WI2/126
WI2/123
WI2/119
WI2/cc
WI2/100
WI2/90
WI2/68
WI2/62
WI2/44
WI2/24
WI2/19
WI2/0

# 65. WM I

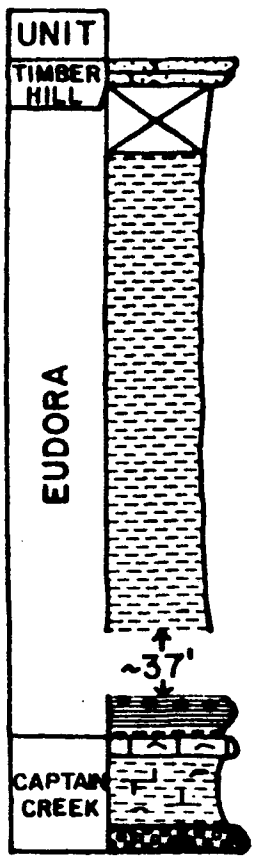
Location: West slope of Walker Mound, about 5 mi west and 1 mi south of Independence, Kansas

Bolton, Kansas, 7 1/2' T33SR15E5NE1/4NE1/4NW1/4

Reference: Moore, 1937, p. 49 (measured by N.D. Newell)

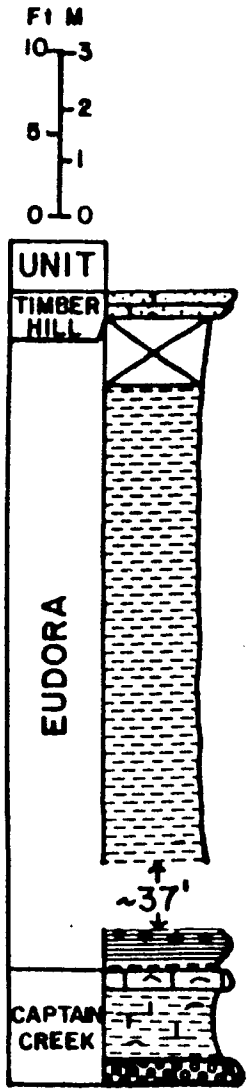
Collected: August 10, 1979

Note: Only sampled portion now exposed; the remainder is from Newell's description. He also reported 90' of Lane-Vilas shale below the Captain Creek.



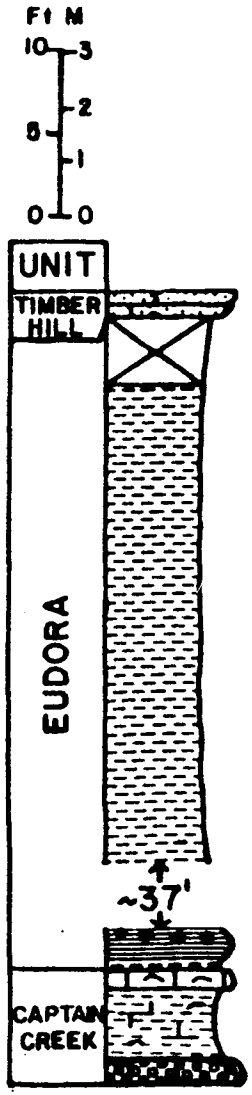

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | 1.06 | 9.8 | 50 | 32 | | 8 | 10 | x | | | | | | | | | | | | | | |
| WMI/-10' | 1.16 | 9.7 | 44 | 44 | | 6 | 7 | | | | | | | | | | | | | | | |
| WMI/-15' | 1.24 | 9.9 | 56 | 28 | | 10 | 6 | x | | | | | | | | | | | | | | |
| WMI/20' | 1.37 | 9.7 | 64 | 26 | | 7 | 3 | x | | | | .79 | | 1 | | | 100 | | | | | |
| WMI/-27' | 1.26 | 9.5 | 62 | 33 | | 3 | 3 | x | | | | .82 | | - | | | | | | | | x |
| WMI/-33' | 1.33 | 9.8 | 42 | 45 | | 6 | 7 | | | | | | | | | | | | | | | |

# 65. WM I



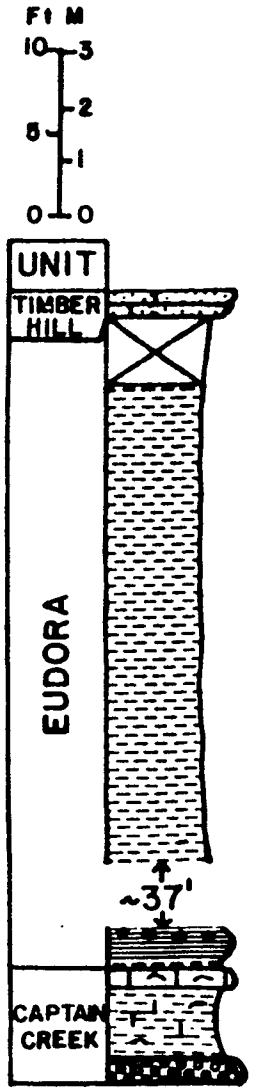

| Sample | OSTRACODES | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | FORAMINIFERS | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | | | x | | | | | | | | | | | | x | | | x | | Endothyranella |
| WMI/-10' | | | x | | x | | | x | | | | | | | x | x | | x | | Endothyranella |
| WMI/-15' | | | | | x | x | | | | | | | | | x | x | | x | | Endothyranella |
| WMI/20' | | | x | | x | x | | | | | | | | | x | x | | x | | |
| WMI/-27' | | | x | | x | x | | x | | | | Silenites | | | x | x | x | x | | |
| WMI/-33' | | | x | | x | | | ? | | | | Silenites | | | x | x | x | x | x | |

# 65. WM I



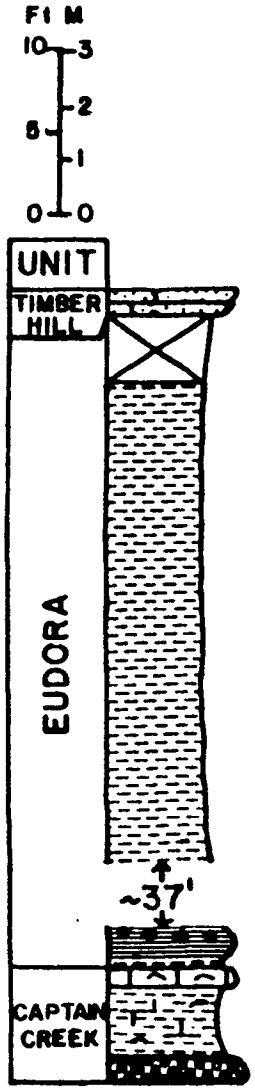

| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | | | | | | | | | | | | | | | | | | | | |
| WMI/-10' | | | | | | | | | | | | | | | | | | | | |
| WMI/-15' | | | | | x | | ? | | | | | | ? | | | | | x | | |
| WMI/20' | | | | | | | | | | | | | ? | | | | | | | |
| WMI/-27' | | | | | | | | | | | | | | | | | | | | |
| WMI/-33' | | | | | | | | | | | | | | | | | | | | |

# 65. WM I



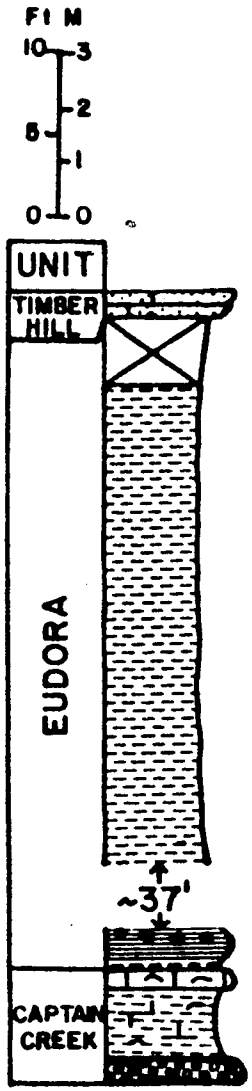

| Sample | GASTROPODS | bellerophontids | other | PELECYPODS | myalinids | other | CEPHALOPODS | taxa | SCAPHOPODS | ROSTROCONCHS | HYOLITHIDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | x | x | | x | | | | | | | |
| WMI/-10' | x | x | Glabrocingulum? Euphemites? | x | | | | | | | |
| WMI/-15' | x | | | x | | | | | | | |
| WMI/20' | x | x | | x | | | | | | | |
| WMI/-27' | x | | Glabrocingulum? Aclisina? psuedozygopleurid | x | | | | | | | |
| WMI/-33' | x | x | Glabrocingulum? | x | | | | | | | |

# 65. WM I




| Sample | ECHINODERMS | pelmatozoans | echinoids | holothurians | BRYOZOANS | fenestrate | ramose | fistuliporids | encrusting non-fistuliporids | SPONGES | wewokellid | Coelocladia | Girtyocoelia | spicule A | spicule B | TRILOBITES | taxa | SCOLECODONTS | Spirorbis | CONULARIDS | RADIOLARIANS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | | | x | x | | | | | | | | | | | | | | | | | |
| WMI/-10' | | x | x | | | | | | | | | | | | | | | | | | |
| WMI/-15' | | x | | | | | | | | | | | | | | | | | | | |
| WMI/20' | | x | | | | I | | | | x | | | | | | | | | | | |
| WMI/-27' | | x | x | | | I | I | | | x | x | | | | | x | | | | | |
| WMI/-33' | | x | x | x | | | 3 | | | x | x | | | | | x | | | | | |

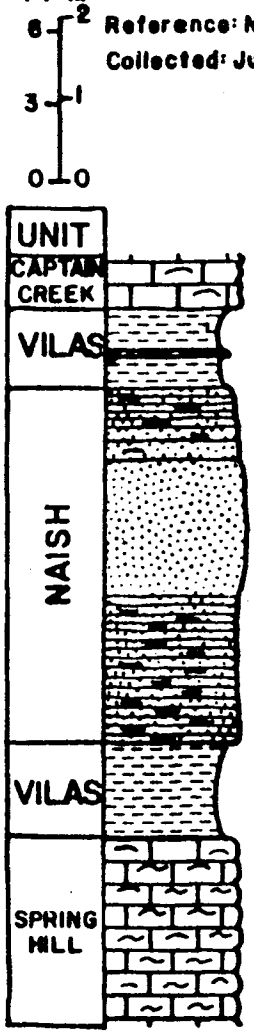
# 65. WM I




| Sample | FISH | paleoniscid teeth | altoconodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMI/-5' | | | | | | | | | | | | | | | | | |
| WMI/-10' | | | | | | | | | | | | | | | | | |
| WMI/-15' | | | | | | | | | | | | | | | | | |
| WMI/20' | | | | | | | | | | | | | | | | | |
| WMI/-27' | x | | | | | | | | | | | | | | | | |
| WMI/-33' | | | | | | | | | | | | | | | | | |

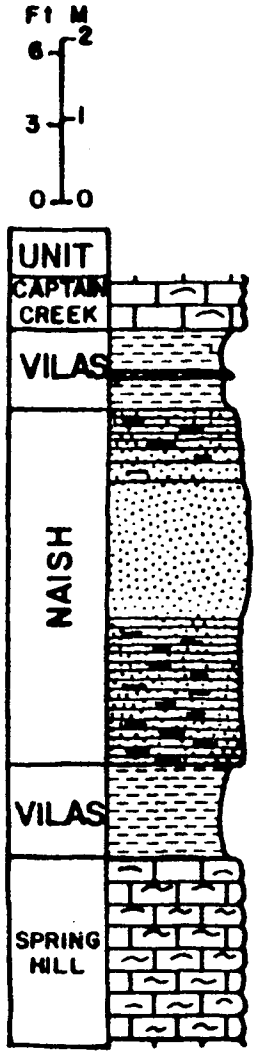
# 66. Zal

Location: Road cut on county road about 1.2 mi south and .5 mi east of Holliday, Kansas
Edwardsville, Kansas, 7 1/2'  T12SR23E10SE1/4NE1/4NE1/4
Reference: Newell, 1935, Sect. 2, p. 86-87
Collected: June 7, 1979



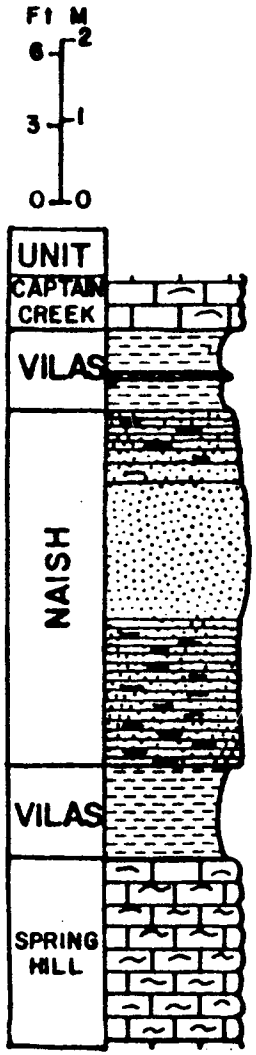

| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Archignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zal/cc | 1.27 | 9.3 | 39 | 37 | | | 24 | | | | | 1.00 | | 7 | 43 | | | 57 | | | | |
| Zal/V4 | 1.15 | 9.2 | 30 | 36 | | | 34 | r | | | | .60 | | 2 | | | | | | 17 | 83 | |
| Zal/V3 | 1.29 | 9.0 | 16 | 45 | | | 39 | x | | | | .82 | | 1 | 100 | | | | | | | |
| Zal/V2 | 1.00 | 9.0 | 26 | 36 | | 5 | 33 | x | | | | | | | | | | | | | | |
| Zal/V1 | 1.03 | 9.6 | 28 | 21 | | | 51 | x | | | | .69 | | 1 | 100 | | | | | | | |
| Zal/V6 | 1.22 | 9.5 | 37 | 24 | | | 39 | x | | | | | | | | | | | | | | |
| Zal/V5 | .94 | 7.7 | 20 | 38 | | | 42 | | | | | | | | | | | | | | | |
| Zal/p | | | | | | | | | | | | 1.00 | | 1 | 100 | | | | | | | |
| Zal/p | 1.79 | 9.2 | 65 | 27 | | 9 | | | | | | 1.00 | | 4 | 48 | 24 | | 24 | 5 | | | |

# 66. Za I



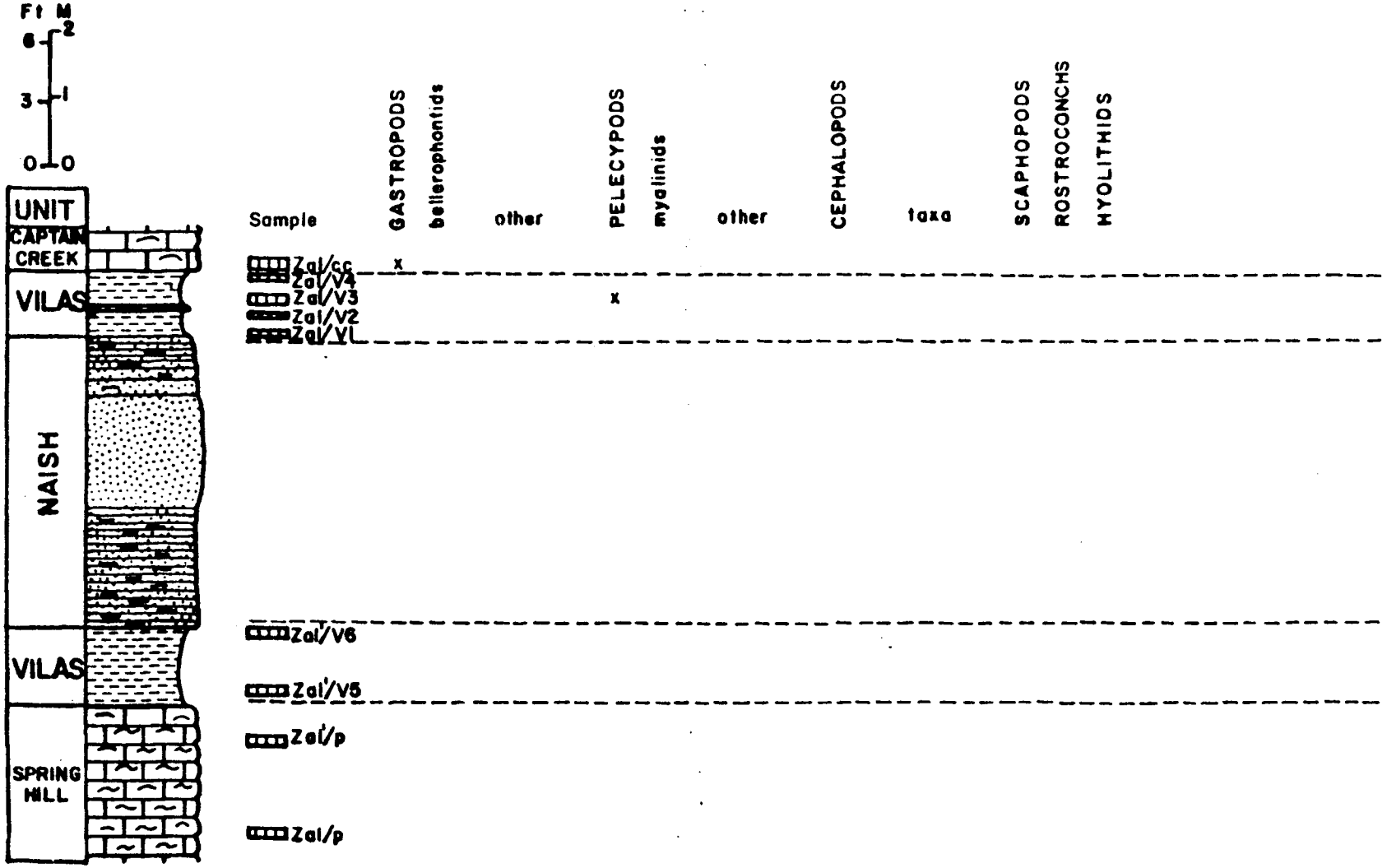

| Sample | OSTRACODES | | | | | | | | | | | | FORAMINIFERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | other | | Hippocrepina | Ammodiscus | Tolypammina | Ammovertella | Hyperammina | Textularia | other | |
| Za I/sc | x | | | x | | | | | | | | | | | x | | | | | |
| Za I/V4 | | | | | | | | | | | | | | | x | | | | | |
| Za I/V3 | | | | | | | | | | | | | | | x | | | | | |
| Za I/V2 | | | | | | | | | | | unidentified | | | | | | | | | |
| Za I/V1 | | | | | x | | | | | | | | | | | | | | | |
| Za I/V6 | | | | | | | | | | | | | | | x | | | | | |
| Za I/V5 | | | | | | | | | | | unidentified | | | | | | | | | |
| Za I/p | | | | | | | | | | | | | | | | | | | | |
| Za I/p | | | | | | | | | | | | | | | x | | | | | |

# 66. Za I

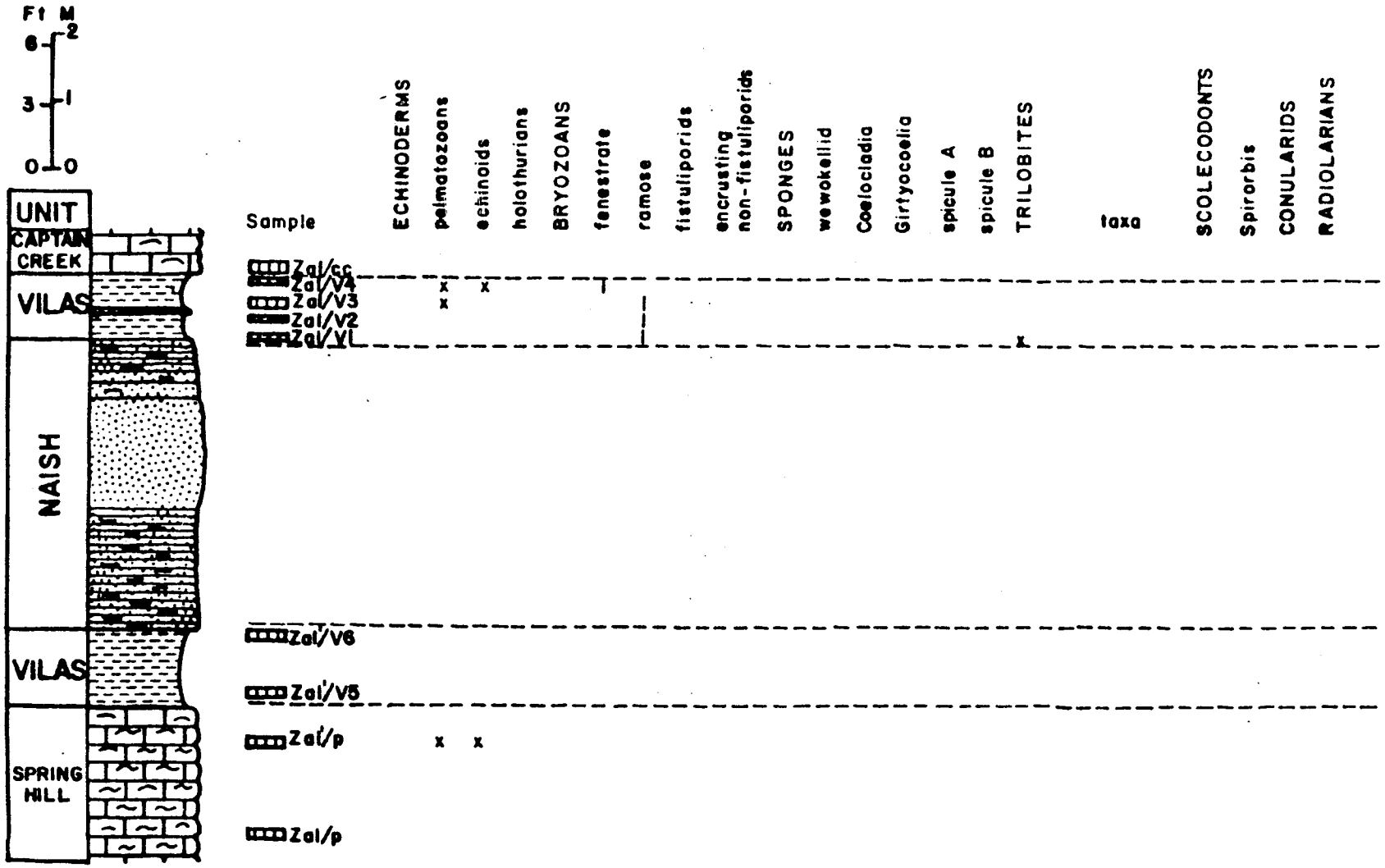



| Sample | BRACHIOPODS | $PO_4$ inarticulates | Lingula | Orbiculoidea | productids | Juresania | Antiquatonia | marginiferids | chonetids | Neochonetes | Chonetinella | Derbyia | Rhipidomella | Punctospirifer | Neospirifer | Composita | Crurithyris | Hustedia | Wellerella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Za I/cc | | | | | | | | | | | | | | | | | | | | |
| Za I/V4 | | | | | | | | | | | | | | x | | | | | | |
| Za I/V3 | | | | | x | | | | | | | ? | | | | | | | | |
| Za I/V2 | | | | | | | | | | | | | | | | | | | | |
| Za I/V1 | | | | | x | | | | | | | | | | | | | | | |
| Za I/V6 | | | | | | | | | | | | | | | | | | | | |
| Za I/V5 | | | | | | | | | | | | | | | | | | | | |
| Za I/p | | x | | | | | | | | | | | | | | | | | | |
| Za I/p | | | | | | | | | | | | | | | | | | | | |

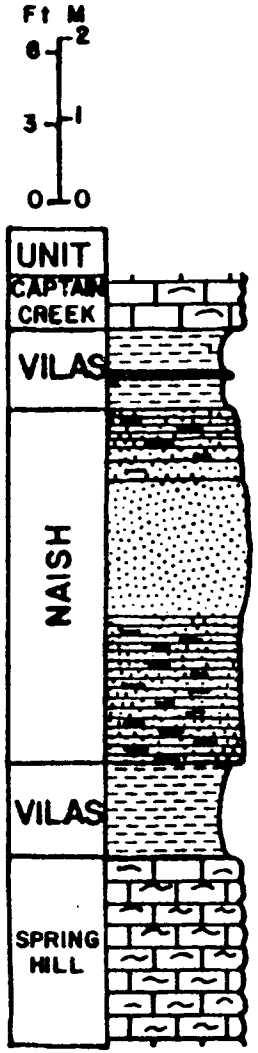
# 66. Za I


Ft M
6 2
3 1
0 0
UNIT
CAPTAIN CREEK
VILAS
NAISH
VILAS
SPRING HILL
Sample
GASTROPODS
bellerophontids
other
PELECYPODS
myalinids
other
CEPHALOPODS
taxa
SCAPHOPODS
ROSTROCONCHS
HYOLITHIDS
Za I/cc
Za I/V4
Za I/V3
Za I/V2
Za I/V1
Za I/V6
Za I'/V5
Za I'/p
Za I/p
x
x

# 66. Za I


Ft M
6 2
3 1
0 0
UNIT
CAPTAIN CREEK
VILAS
NAISH
VILAS
SPRING HILL
Sample
ECHINODERMS
pelmatozoans
echinoids
holothurians
BRYOZOANS
fenestrate
ramose
fistuliporids
encrusting non-fistuliporids
SPONGES
wewokellid
Coelocladia
Girtyocoelia
spicule A
spicule B
TRILOBITES
taxa
SCOLECODONTS
Spirorbis
CONULARIDS
RADIOLARIANS
Za I/cc
Za I/V4
Za I/V3
Za I/V2
Za I/V1
Za I/V6
Za I/V5
Za I/p
Za I/p

# 66. Zal



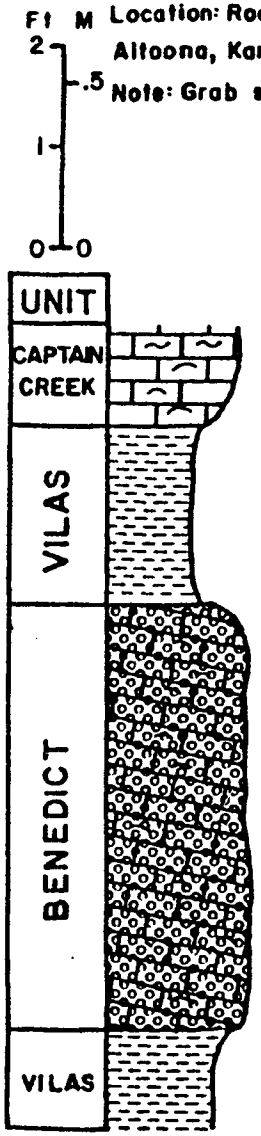

| Sample | FISH | paleoniscid teeth | allognodonts | Styptobasis | Cladodus | Orodus | Hybodus | Petrodus | Listracanthus | Holmesella | Multidentodus | scale? | Cooperella | Cooleyella | Moreyella | Kirkella | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zal/cc | | x | | | | | | | | | | | | x | | | |
| Zal/V4 | | | | | | | | | | | | | | | | | |
| Zal/V3 | | | | | | | | | | | | | | | | | |
| Zal/V2 | | | | | | | | | | | | | | | | | |
| Zal/V1 | | | | | | | | | | | | | | | | | |
| Zal'/V6 | | | | | | | | | | | | | | | | | |
| Zal'/V5 | | | | | | | | | | | | | | | | | |
| Zal'/p | | x | | | | | | | | | | | | x | | | |
| Zal/p | | x | | | | | | | | | | | | x | | | |

# Benedict

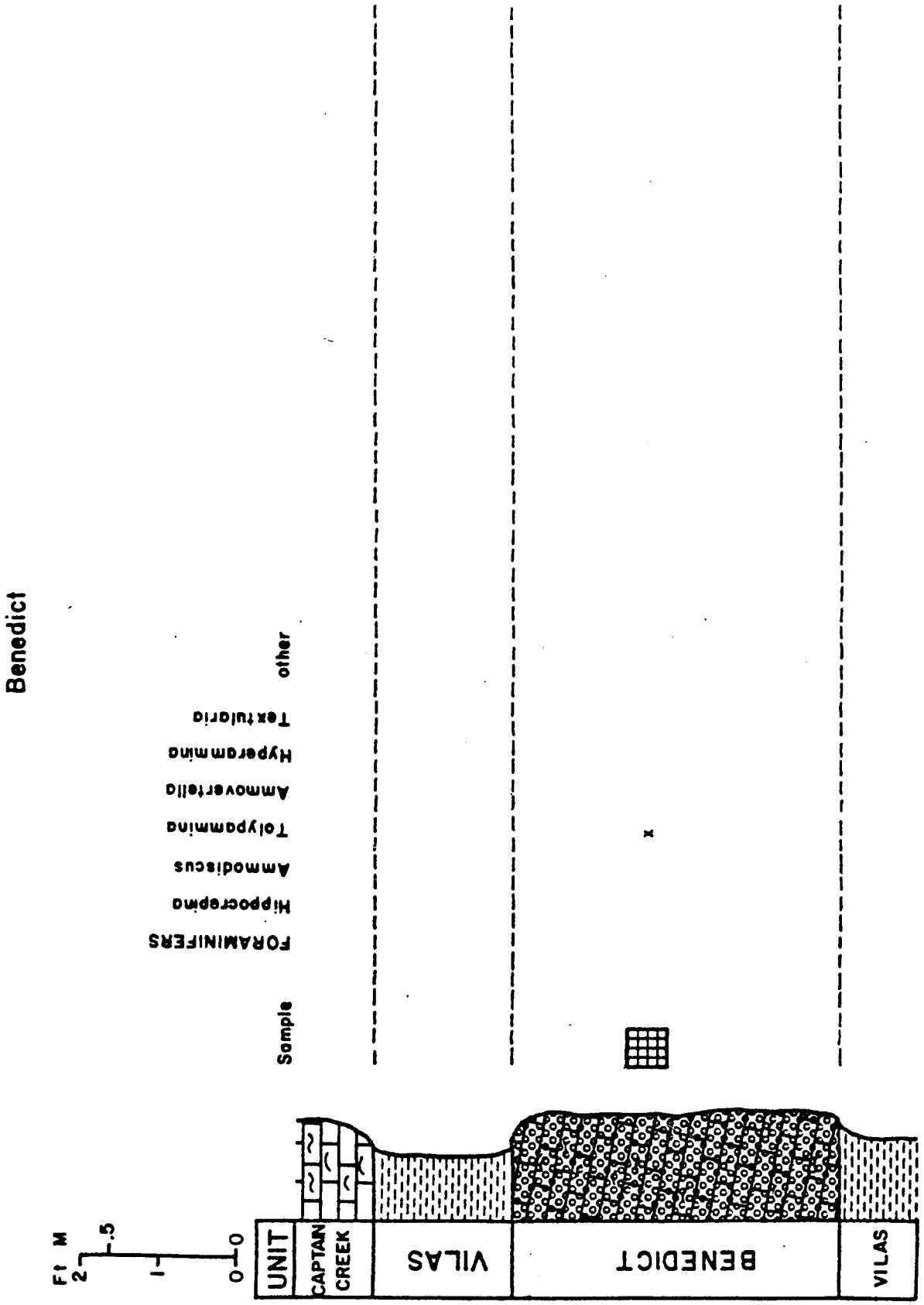
Location: Road cut on county blacktop on west side of Benedict, Kansas

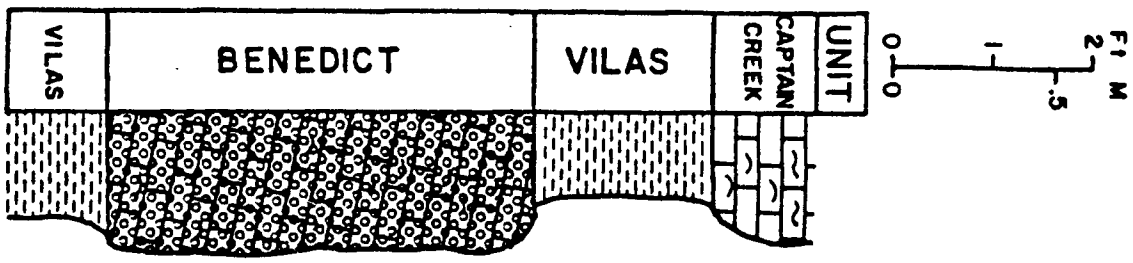
Altoona, Kansas, 7 1/2'  T28SR15E10NE1/4NW1/4

Note: Grab sample from middle of Benedict bed




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.48 | 9.6 | 38 | 17 | | | 45 | | | | | 1.00 | | 10 | | 97 | | | | 3 | | |


Benedict
Sample
FORAMINIFERS
Hippocrepina
Ammodiscus
Tolypammina
Ammoversella
Hyperammina
Textularia
other
x
FT M
2
1
0
.5
0
UNIT
CAPTAN
CREEK
VILAS
BENEDICT
VILAS




Benedict

Sample

BRACHIOPODS

$PO_4$ inarticulates

Lingula

Orbiculoidea

productids

Juresania

Antiquatonia

marginiferids

chonetids

Neochonetes

Chonetinella

Derbyia

Rhipidomella

Punctospirifer

Neospirifer

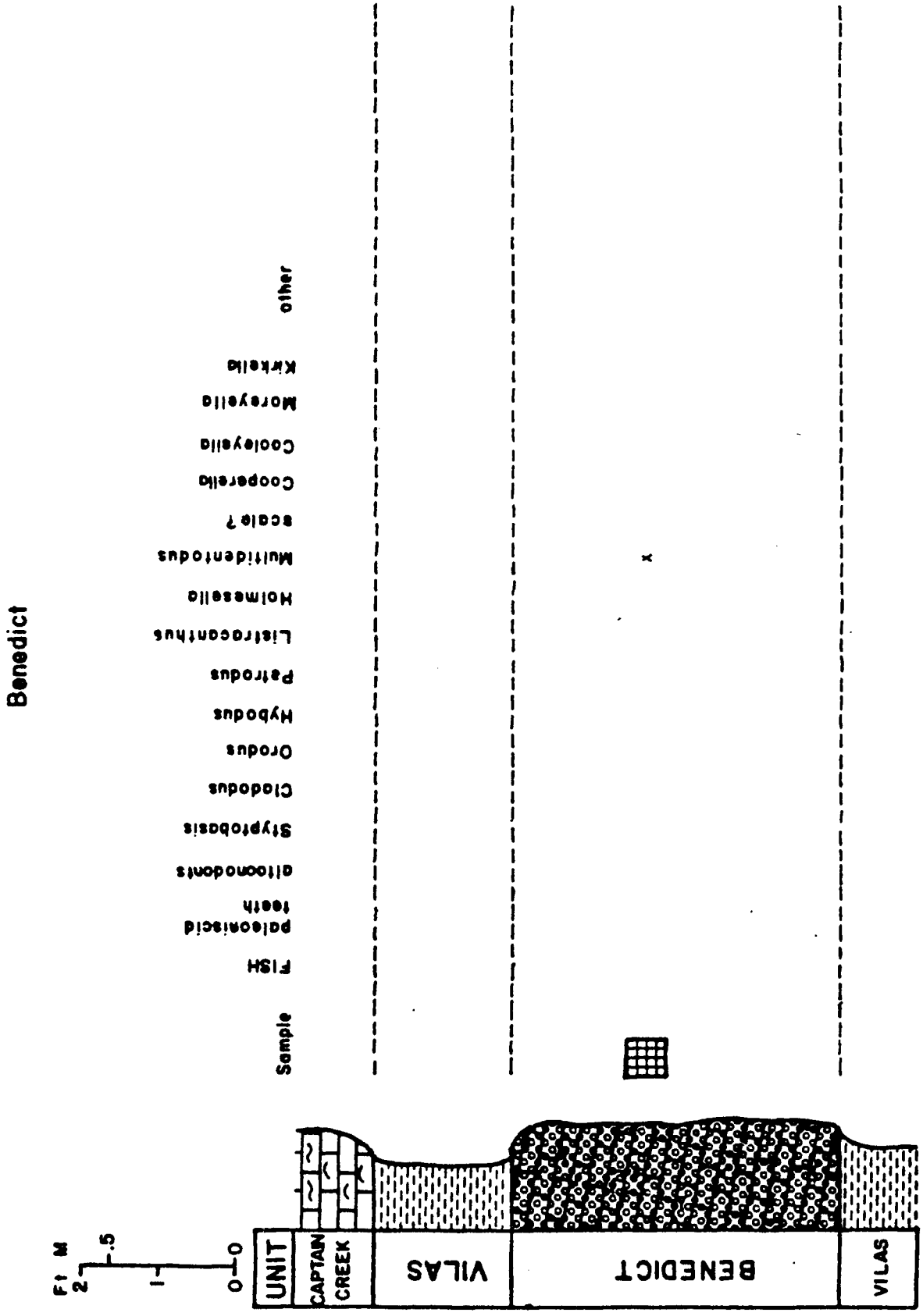
Composita

Crurithyris

Hustedia

Wellerella

other


Benedict
Sample
FISH
paleoniscid teeth
allocnodonts
Styptobasis
Cladodus
Orodus
Hybodus
Patrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkella
other
Ft M
2
1
0
.5
UNIT
CAPTAIN CREEK
VILAS
BENEDICT
VILAS

# BGV I

Location: Ravine 200' north of east-west road, southern end of Big Gypsum Valley, Colorado

Gypsum Gap, Colorado, 7 1/2' T43NR16W8NE1/4 NW1/4NW1/4

Reference: Stone, 1968, Locality 14, p. 28

Collected: May 30, 1982

Note: Paradox Formation; allochthonous block of black shale surrounded by contorted gypsum

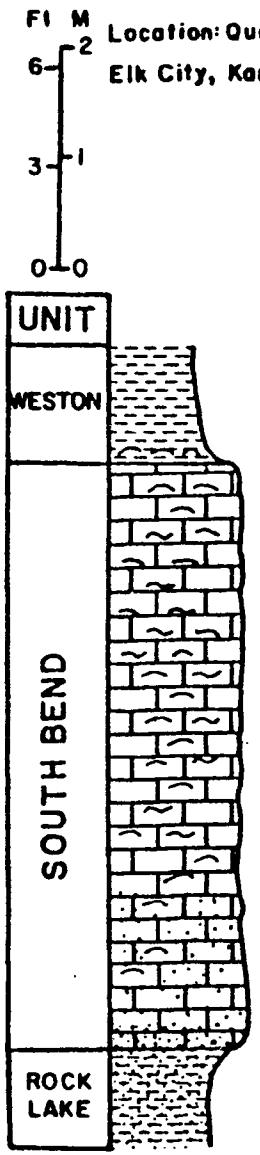
| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | % Neognathodus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Top | 2.38 | 9.6 | 54 | 18 | | 28 | | | | | | .85 | | 31 | | | 92 | | | 1 | | 8 |
| -5' | 2.18 | 9.9 | 49 | 27 | | 25 | | | | | | .69 | | 15 | | | 99 | | | 1 | | |

# ECQ

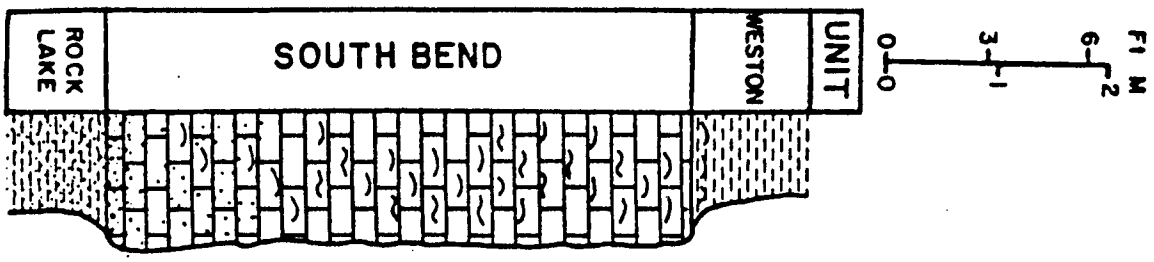
Location: Quarry south of Elk River bridge on U.S. Highway 160

Elk City, Kansas, 7 1/2'

T32SR14E17SW1/4NE1/4N1/2




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ECQ | 1.26 | 9.8 | 58 | 36 | | 4 | 2 | | | | | .31 | | 42 | | | 100 | | | | | |




ECO

Sample

OSTRACODES

geisinids

Cavellina

Knightina

Bairdia x

Hollinella

Roundyella

Amphissites x

Kirkbya

Kellettina

Kegelites

other

Bairdiacypris

FORAMINIFERS

Hippocrepina

Ammodiscus

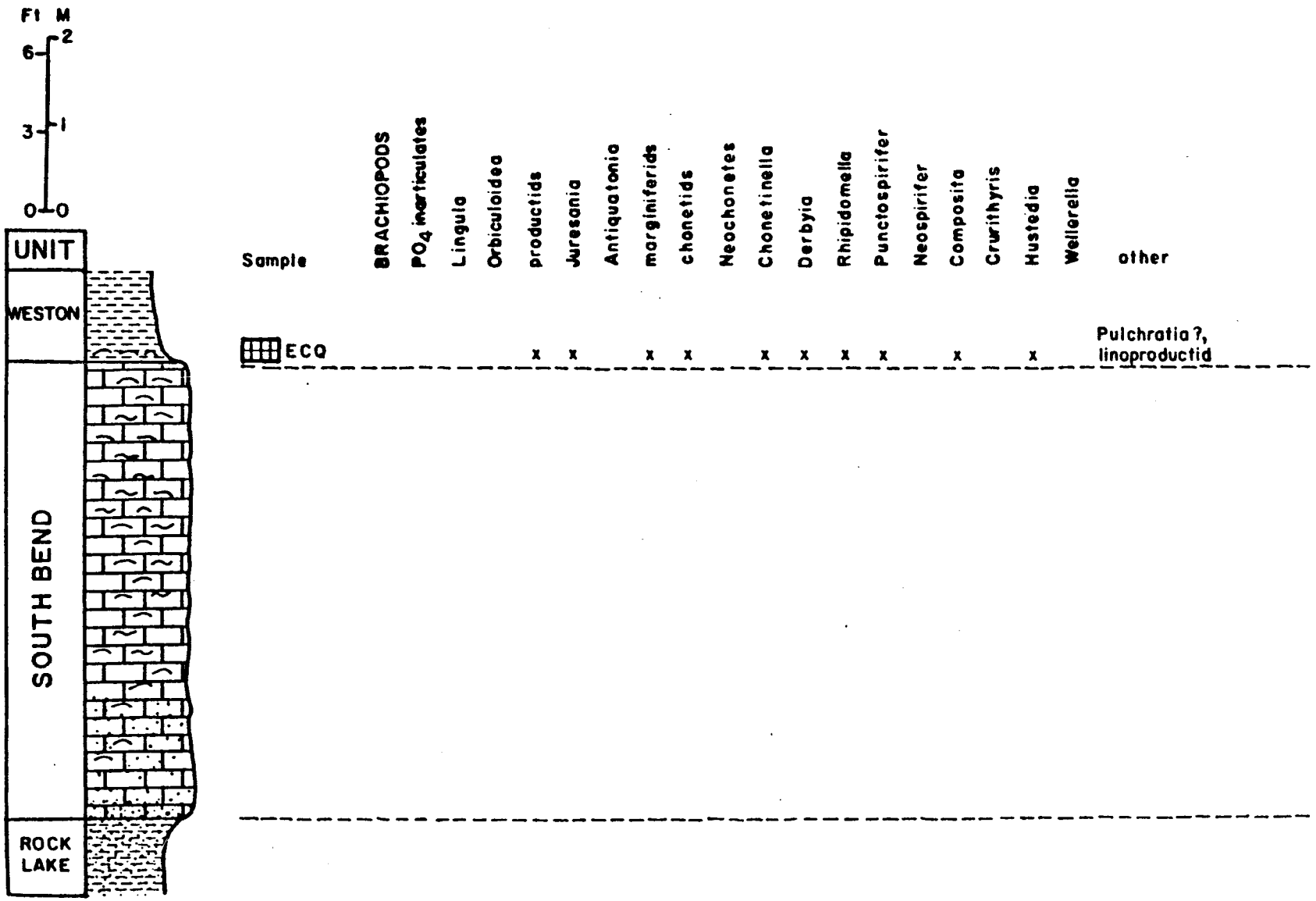
Tolypammina x

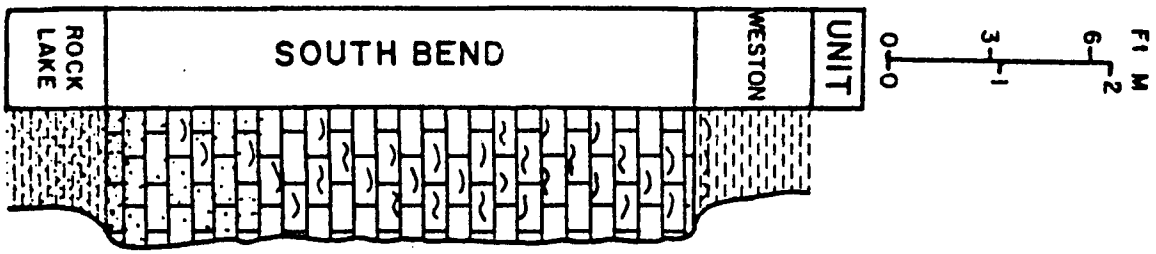
Ammovertella

Hyperammina

Textularia

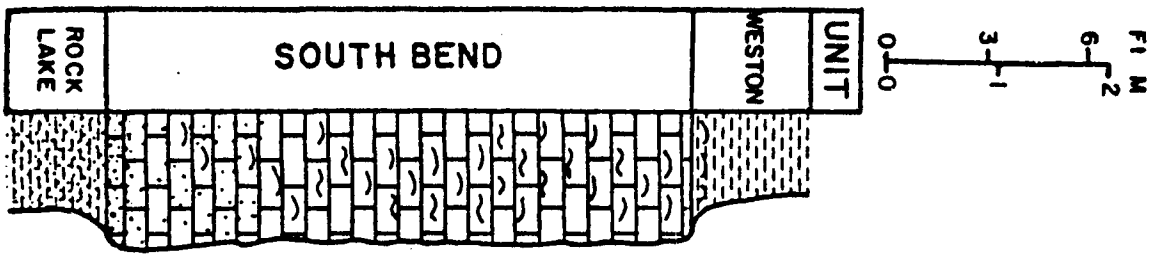
other


ECQ
Ft M
6 2
3 1
0 0
UNIT
WESTON
SOUTH BEND
ROCK LAKE
Sample
BRACHIOPODS
PO4 inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
margiiniferids
chonetids
Neochonetes
Chonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
ECQ
x x x x x x x x x x
Pulchratia ?, linoproductid




| Sample | ECO | taxa |
|---|---|---|
| | | ECHINODERMS |
| | x | pelmatozoans |
| | x | echinoids |
| | | holothurians |
| | | BRYOZOANS |
| | 2 | fenestrate |
| | 3 | ramose |
| | x | fistuliporids |
| | | encrusting non-fistuliporids |
| | | SPONGES |
| | | wewokellid |
| | | Coelocladia |
| | | Girtyocoelia |
| | | spicule A |
| | | spicule B |
| | x | TRILOBITES |
| | | SCOLECODONTS |
| | | Spirorbis |
| | | CONULARIDS |
| | | RADIOLARIANS |

ECO




ECO

| Sample | ECO |
|---|---|
| FISH | |
| paleoniscid teeth | x |
| eltoonodonts | |
| Styptobasis | |
| Cladodus | |
| Orodus | |
| Hybodus | |
| Petrodus | |
| Listracanthus | |
| Holmesella | |
| Multidentodus | |
| scale? | x |
| Cooperella | |
| Cooleyella | |
| Moreyella | |
| Kirkella | |
| other | |

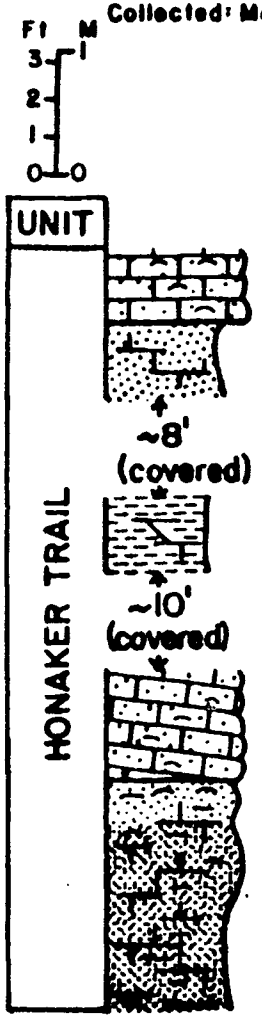
# Go I

Location: Overlook at the Goosenecks of the San Juan, and up access road about 200 yd to the northeast

Mexican Hat, Utah, 15'

T41SR18E33SE1/4SE1/4NW1/4 and T41SR18E34SW1/4NW1/4NW1/4

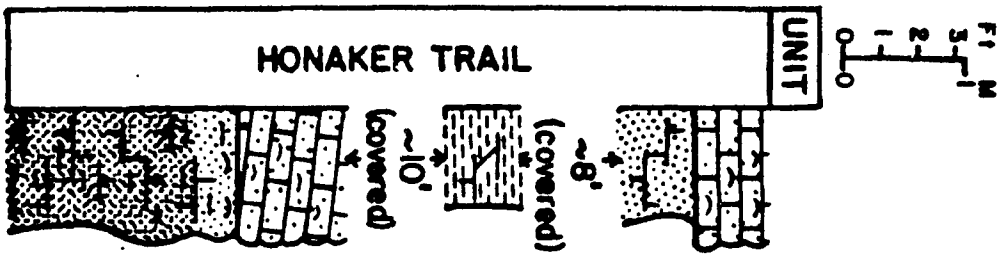
Collected: May 31, 1982




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clays in samples not treated semiquantitatively due to presence of regular mixed layer expandable/chlorite (corrensite?); illite and chlorite also present | | | | | | | | | | | 1.00 | | 53 | 17 | | 83 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 1.00 | | 51 | 92 | | 8 | | | t | | |
| | | | | | | | | | | | | .95 | | 3 | 67 | | 33 | | | | | |
| | | | | | | | | x | | | | 1.00 | | 26 | 77 | | 23 | | | | | |

Go I


Ft
M
3
2
1
0
0
UNIT
HONAKER TRAIL
~8'
(covered)
~10'
(covered)
Sample
BRACHIOPODS
$PO_4$ inarticulates
Lingula
Orbiculoidea
productids
Juresania
Antiquatonia
marginiferids
chonetids
Neochonetes
Cnonetinella
Derbyia
Rhipidomella
Punctospirifer
Neospirifer
Composita
Crurithyris
Hustedia
Wellerella
other
x




| Sample | |
|---|---|
| × | FISH |
| | paleoniscid teeth |
| | elloconodonts |
| | Styptobasis |
| × | Cladodus |
| | Orodus |
| | Hybodus |
| ? | Petrodus |
| × | Listracanthus |
| | Holmesella |
| | Multidentodus |
| × | scale? |
| | Cooperella |
| | Cooleyella |
| | Moreyella |
| | Kirkella |
| | other |

Go 1

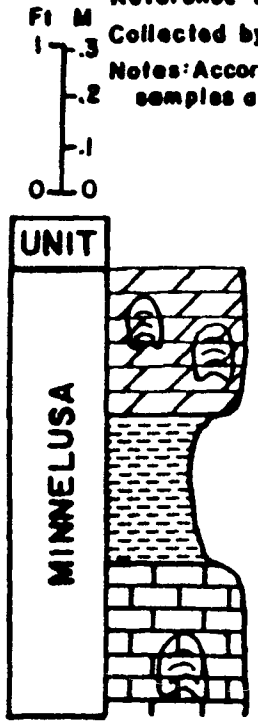
# Minnelusa

Location: Creek valley southwest of Rapid City, South Dakota

Reference: Ward, 1979

Collected by B.A. amEnde

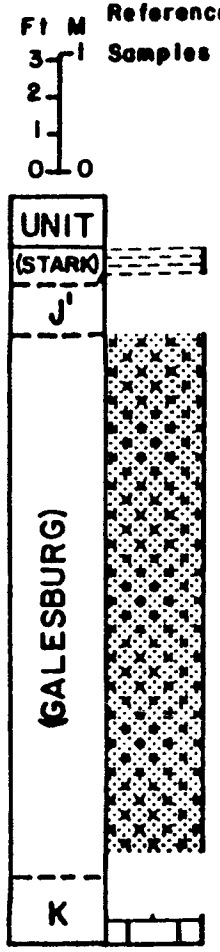
Notes: According to J.W. Swade (pers. comm., 1981) conodonts suggest correlation with Stark or Muncie Creek shales. Other samples are grab samples: "tan" is a buff stromatolitic limestone; "red" is a red mudstone.




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DC-59 | 2.11 | | 79 | 6 | | | 15 | | | | | .62 | 1499 | | | | 94 | | | 1 | 4 | |
| Tan | 1.87 | | 74 | 13 | | | 13 | | | | | .40 | | 3 | | | 100 | | | | | |
| Red | 2.36 | | 68 | 6 | | | 25 | | | | | | | | | | | | | | | |

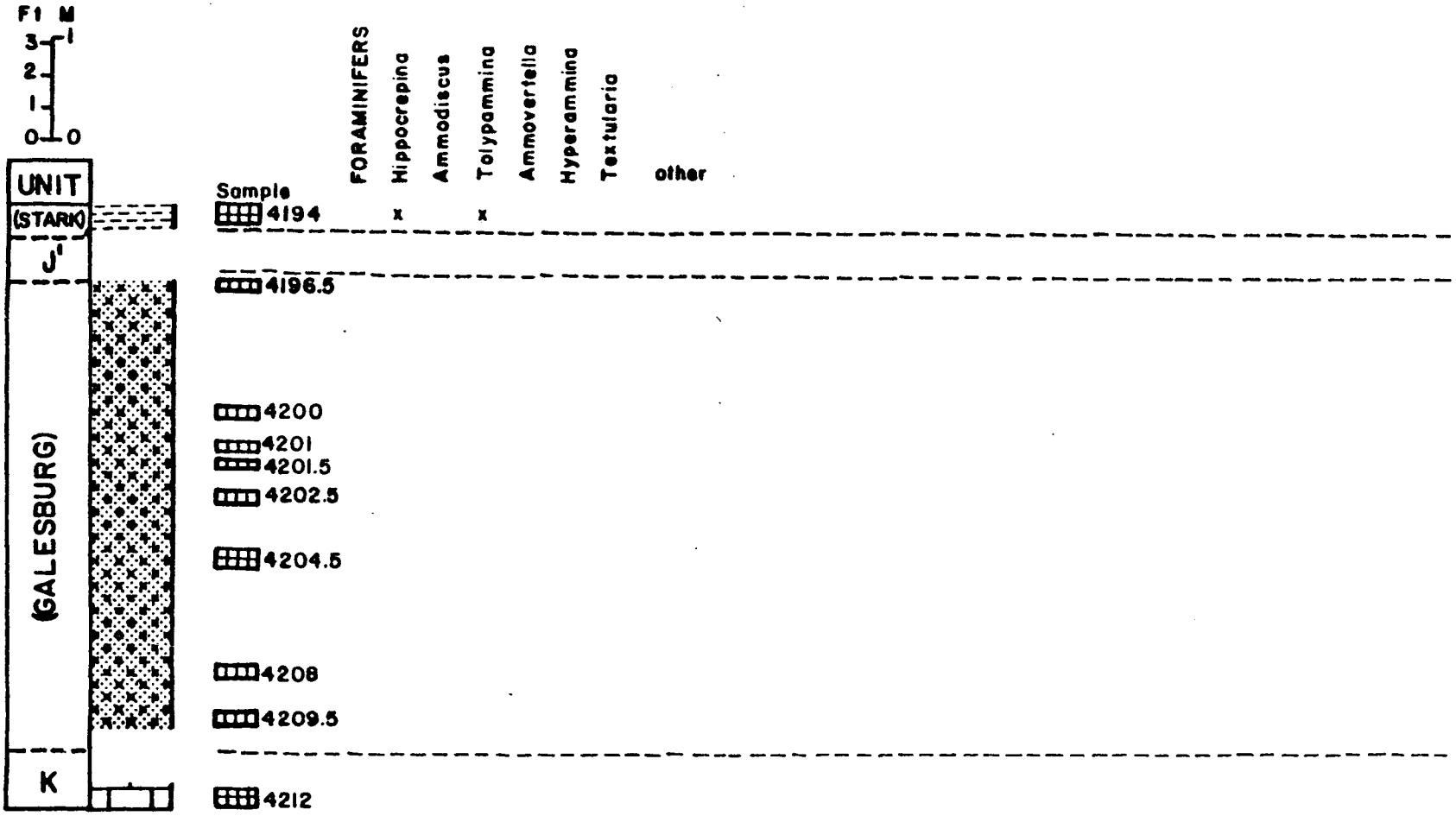
# Shell Bartosovsky No.1

Location: Cahoj Field, Rawlins County, Kansas
Atwood, Kansas, 15'
TISR34W9SW1/4SW1/4SE1/4
Reference: Watney, 1980, p. 10, 13
Samples provided by W.L. Watney, Kansas Geological Survey

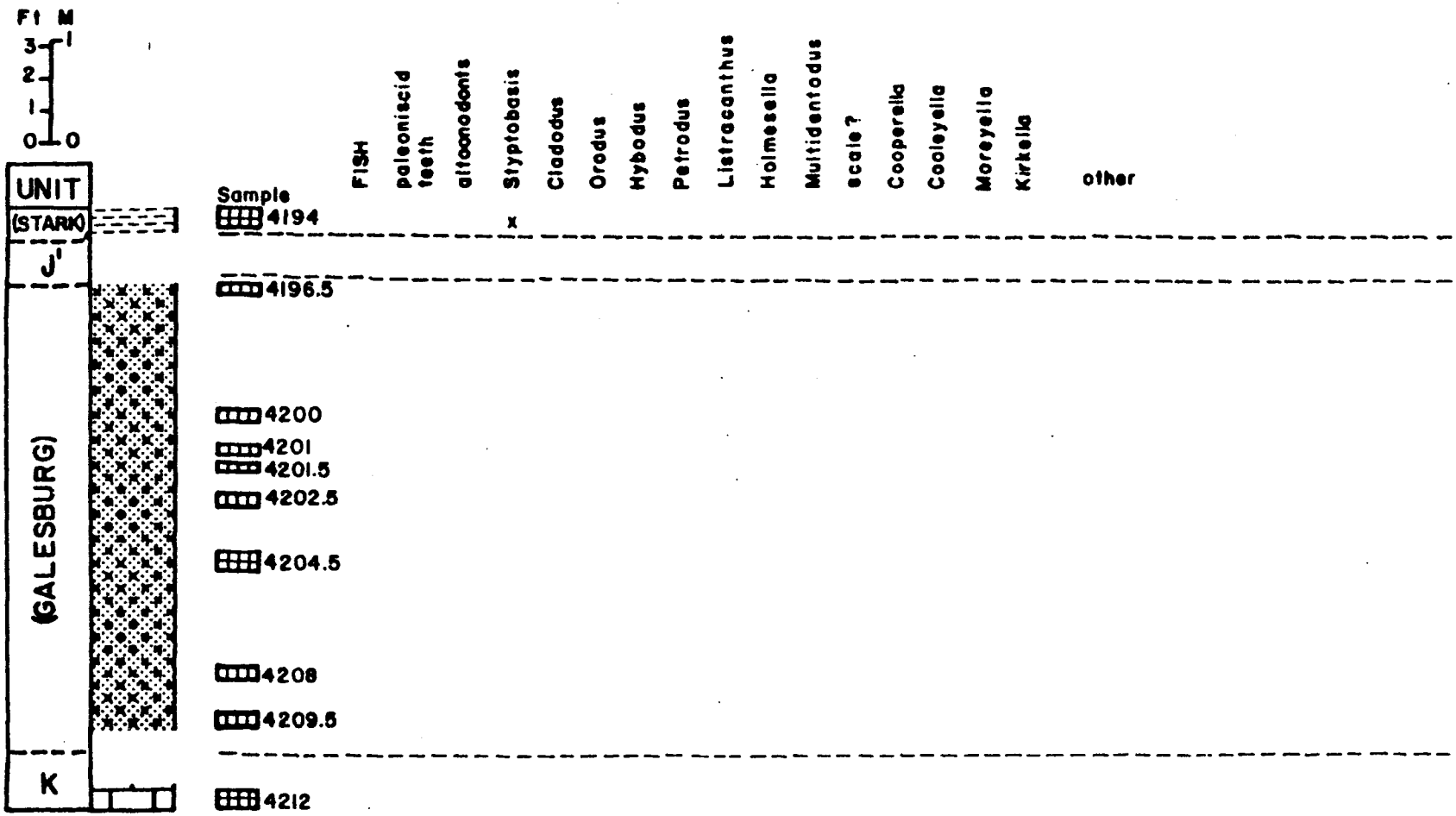



| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4194 | 1.38 | 9.6 | 57 | 9 | | 35 | | | | | | .15 | 224 | 3 | | 97 | | | | 1 | | |
| 4196.5 | 1.15 | 9.3 | 54 | 26 | | 20 | | | | | | | | | | | | | | | | |
| 4200 | 1.34 | 9.7 | 43 | 21 | | 36 | | | | | | | | | | | | | | | | |
| 4201 | 1.41 | 9.9 | 41 | 21 | | 38 | | | | | | | | | | | | | | | | |
| 4201.5 | 1.38 | 10.1 | 33 | 34 | | 33 | | | | | | | | | | | | | | | | |
| 4202.5 | 1.52 | 9.9 | 50 | 24 | | 26 | | | | | | | | | | | | | | | | |
| 4204.5 | 1.65 | 9.5 | 50 | 17 | | 33 | | | | | | | | | | | | | | | | |
| 4208 | 1.00 | 10.5 | 22 | 13 | | 65 | | | | | | | | | | | | | | | | |
| 4209.5 | 1.37 | 10.2 | 54 | 14 | | 32 | | | | | | | | | | | | | | | | |
| 4212 | 10.00 | 11.0 | 39 | 34 | | 27 | | | | | | | | | | | | | | | | |

# Shell Bartosovsky No.1



## Shell Bartosovsky No.1



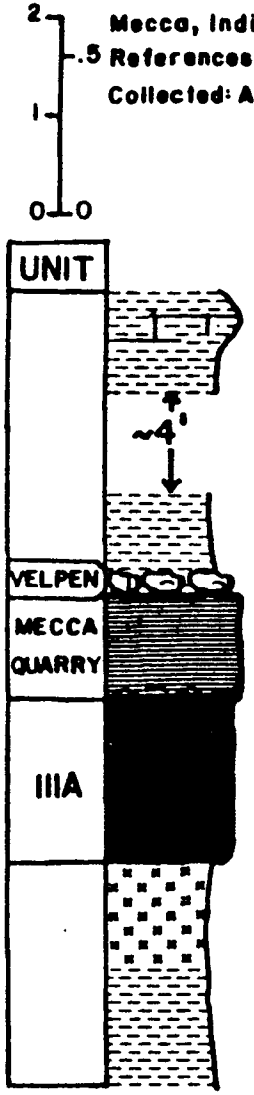
# BARREN CREEK

Location: Valley of Barren Creek about 5 mi southwest of Rockville, Indiana

Mecca, Indiana, 7 1/2' T15NR8W33NLine

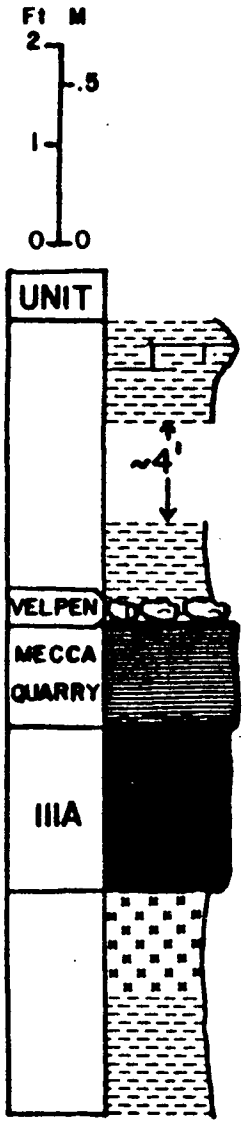
References: Zangerl and Richardson, 1963, p. 37-39; Langenheim, Mann, and Beresky, 1980, Stop 3, p. 23-32

Collected: April 27, 1980




| | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | Net processed sample (kg) | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | % Neognathodus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.18 | 9.7 | 48 | 6 | | 19 | 27 | | | | | | | | | | | | | | | |
| | 1.62 | 9.4 | 60 | 16 | | 12 | 13 | | | | | .54 | | 131 | | 84 | | | | 9 | | 7 |

# BARREN CREEK




| OSTRACODES | | | | | | | | | | | other | GASTROPODS | | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| geisinids | Cavellina | Knightina | Bairdia | Hollinella | Roundyella | Amphissites | Kirkbya | Kellettina | Kegelites | | | bellerophontids | | |
| | | | | | | | | | | | Bythocypris? | x | | |

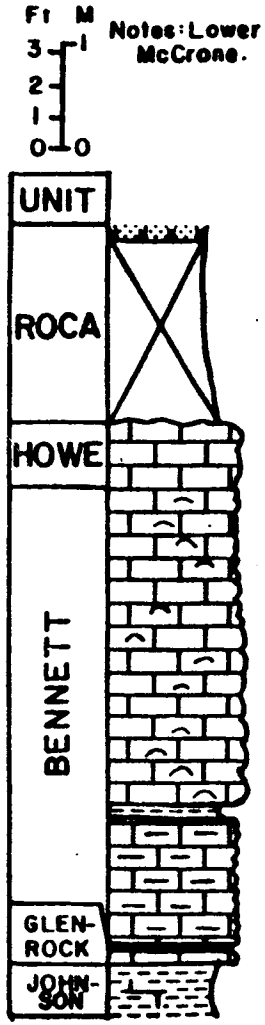
# Grand Summit

Location: Santa Fe railroad cut 4 mi west and 2 mi north of Grenola, Kansas

Cambridge NE, Kansas, 7 1/2' T31SR8E3SE1/4

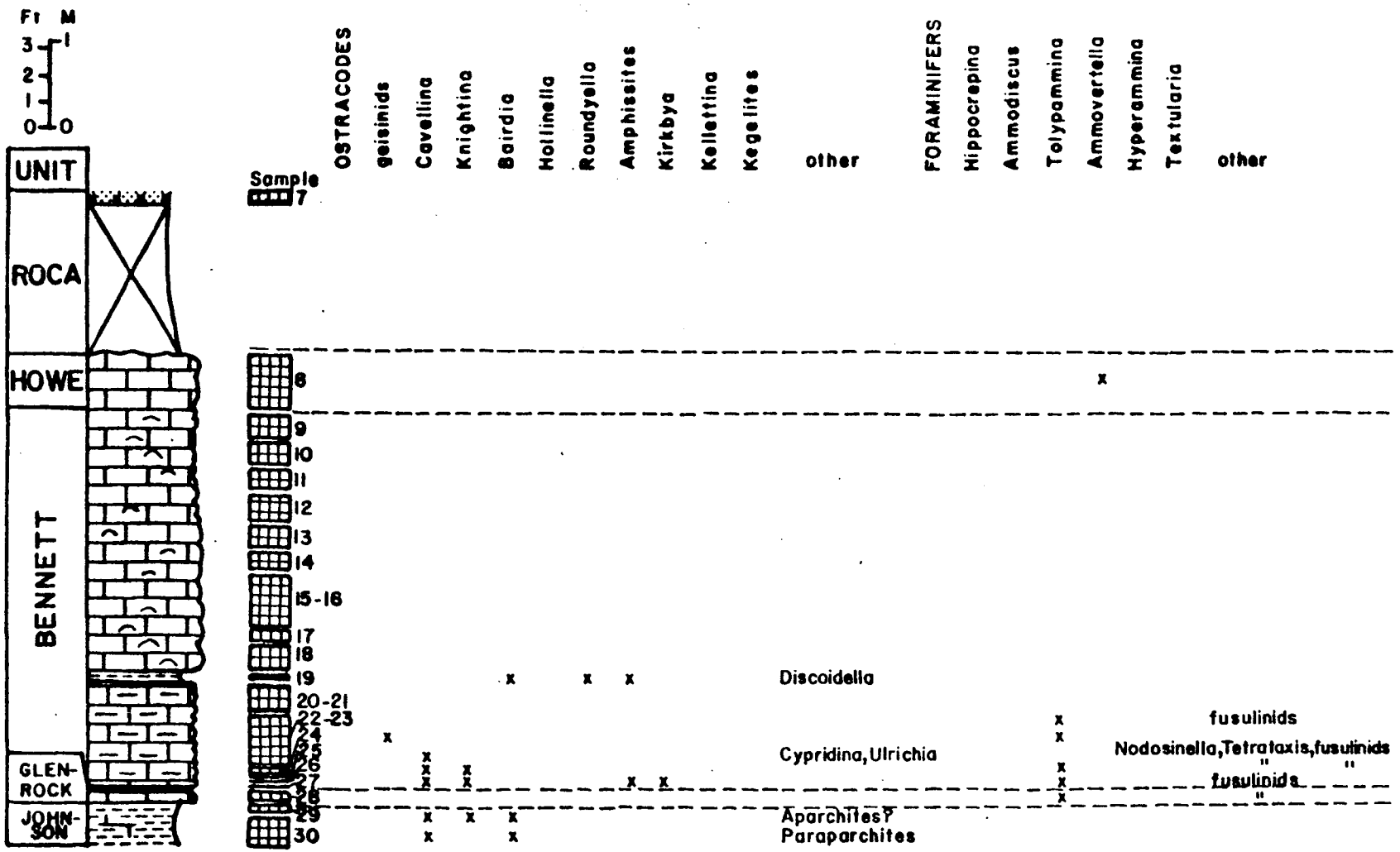
References: McCrone, 1964, Grand Summit section, p. 105-108; Perlmutter, 1975, Sect. 10, p. 97, 107

Notes: Lower Permian Red Eagle cyclothem for comparison of faunal pattern. Conodont data from Perlmutter, rest from McCrone.

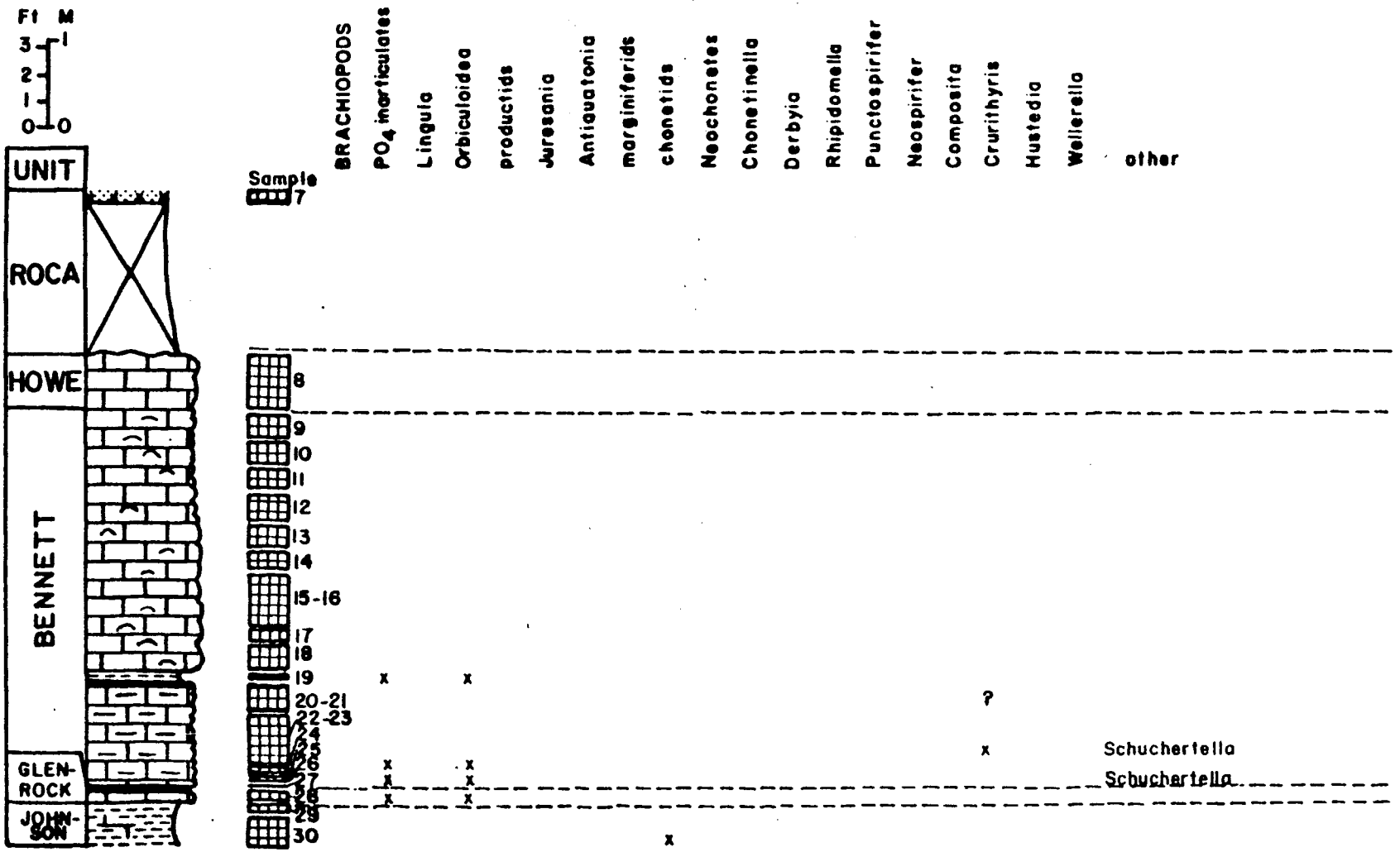



| Sample | CONODONTS | Platforms/kg | % Adetognathus | % Stepanovites | % Idiognathodids | % Anchignathodus | % Aethotaxis | % Idioprioniodus | % Gondolella | unidentified frag |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | 2 | 80 | | | 20 | | | | |
| 3 | | 1 | 33 | | | 67 | | | | |
| 4 | | | | | | | | | | x |
| 5 | | 1 | | | | 100 | | | | |
| 6 | | | | | | | | | | |
| 7 | | 1 | | | 100 | | | | | |
| 9 | | 1 | 100 | | | | | | | |
| 10 | | 1 | 100 | | | | | | | |
| 11 | | 6 | 92 | | | 8 | | | | |
| 12 | | 2 | 25 | | | 75 | | | | |
| 13 | | 1 | | | | 100 | | | | |
| 14 | | 4 | | | 100 | | | | | |
| 15 | | 1 | 33 | | 67 | | | | | |
| 16 | | 39 | | | 100 | | | | | |
| 17 | | 258 | | | 100 | | | | | |
| [illegible] | | 55 | | | 99 | | | | | |

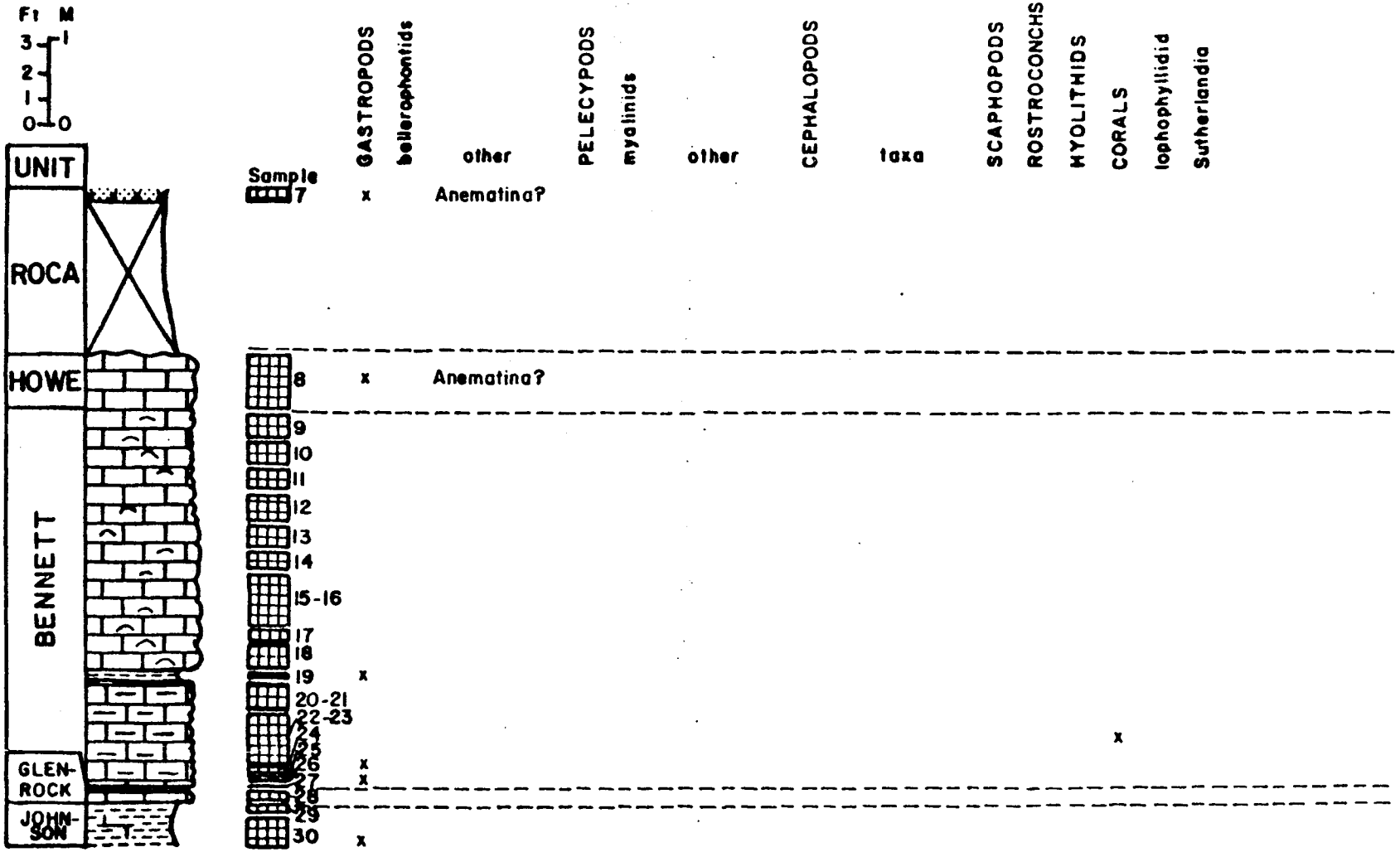
## Grand Summit



## Grand Summit

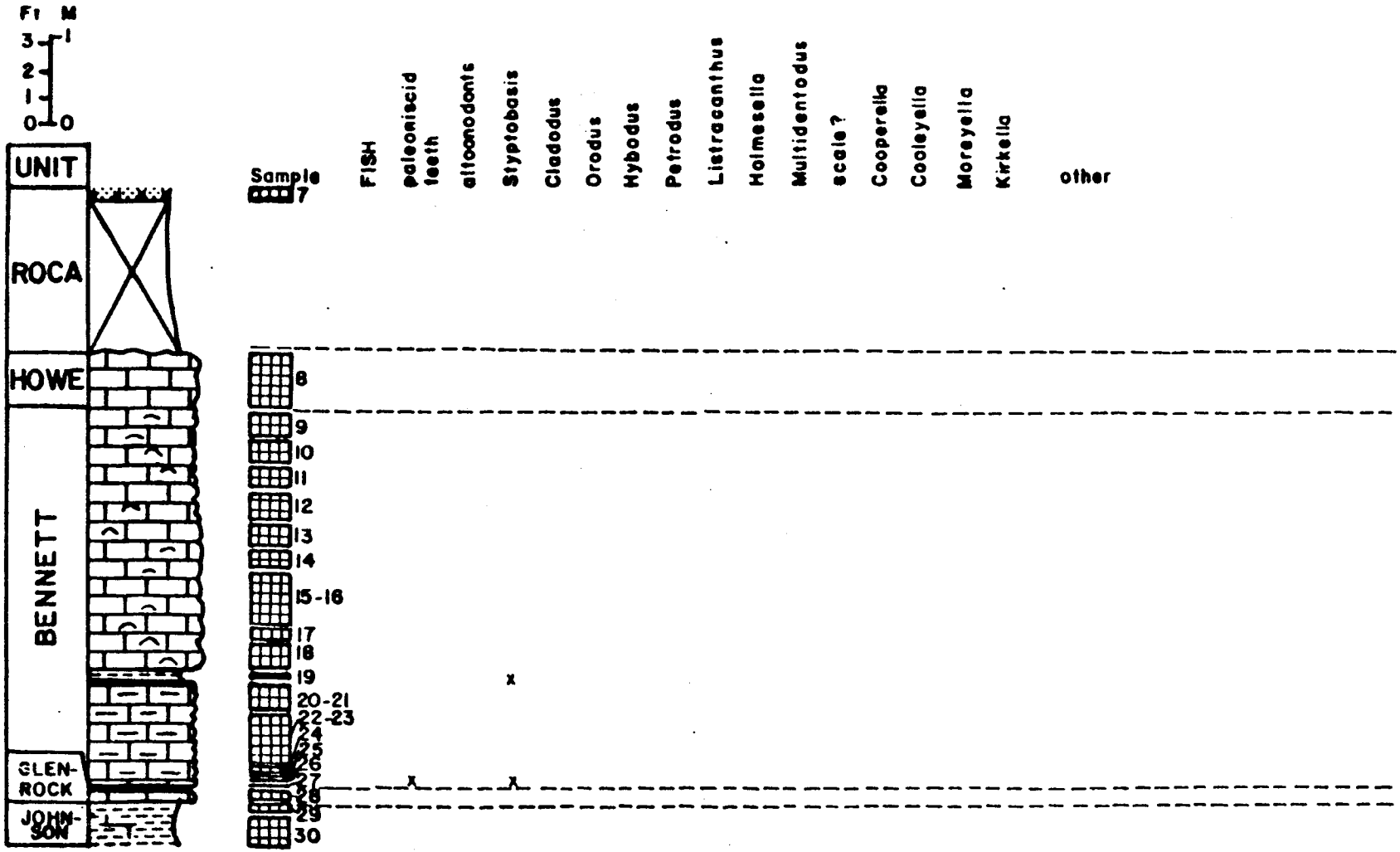


## Grand Summit



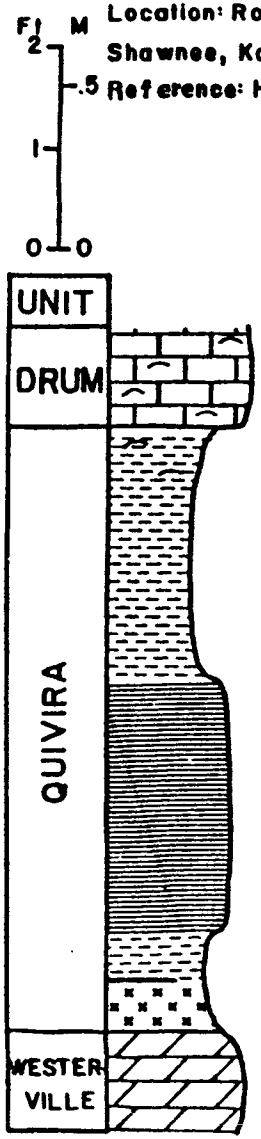
## Grand Summit

## Grand Summit



# K-32 ROADCUT

Location: Road cut at interchange of Interstate 635 and Kansas Highway 32 in Kansas City, Kansas
Shawnee, Kansas, 7 1/2'  T11SR25E7SW1/4SW1/4SW1/4
Reference: Heckel, 1978, p.22-23




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.26 | 9.5 | 50 | 32 | | 13 | 5 | | | | |
| | 1.57 | 9.2 | 42 | 46 | | 8 | 3 | | | | |

# LVP

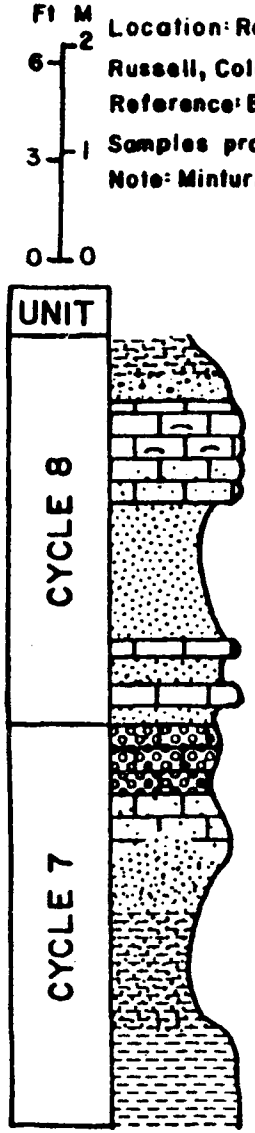
Location: Road cut along U.S. Highway 160 northeast of Russell, Colorado; western approach to La Veta Pass

Russell, Colorado, 7 1/2'  No township and range

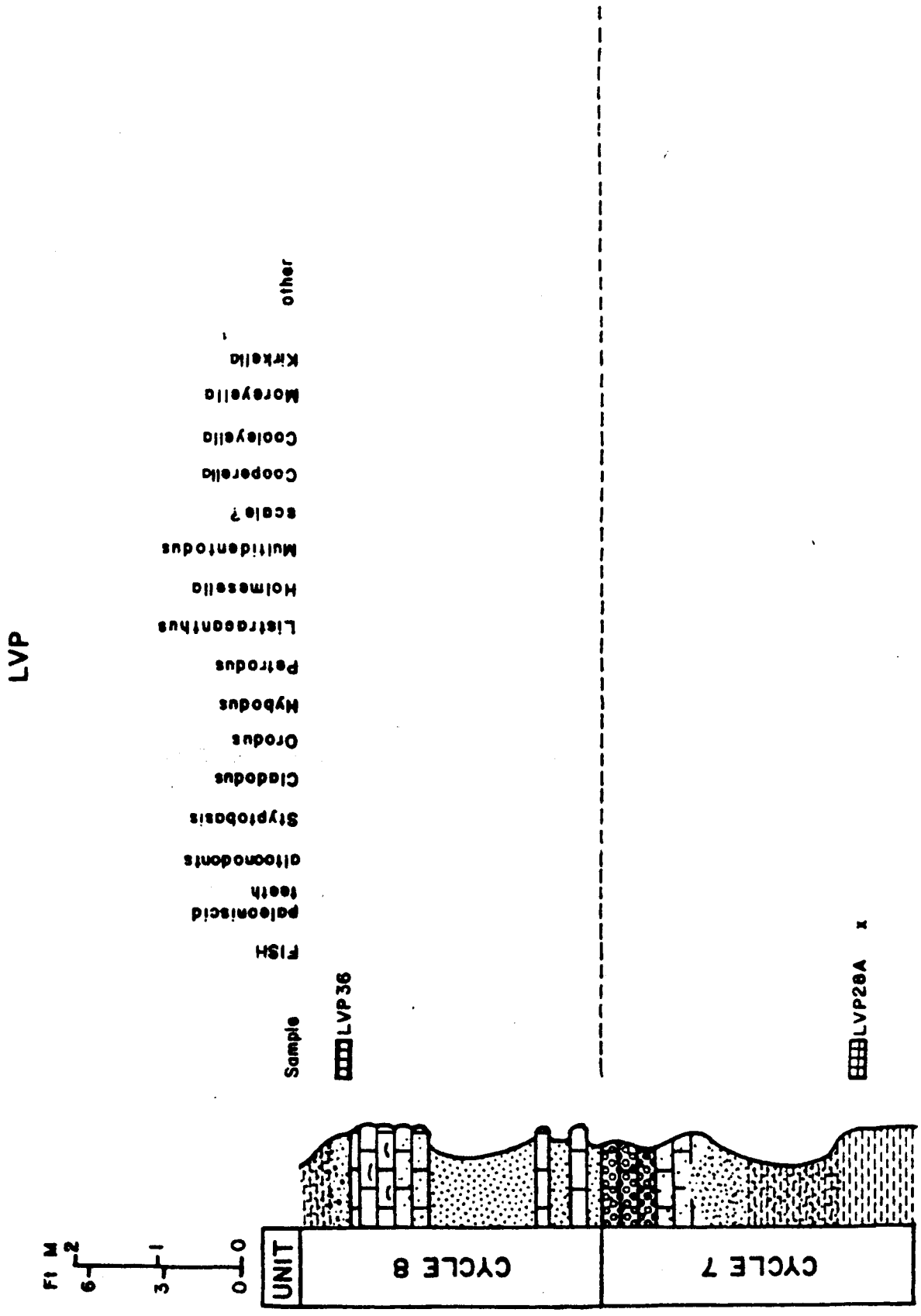
Reference: Becker, 1978, p. 78

Samples provided by P.J. Becker

Note: Minturn Formation




| Sample | Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % | Muscovite | Sphalerite | Galena | Barite | GASTROPODS | bellerophontids | other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LVP36 | 1.42 | 7.5 | 46 | 8 | | 46 | | | | | | x | | |
| LVP28A | 1.71 | 9.7 | 45 | 4 | | 52 | | | | | | | | |


LVP
Sample
LVP36
LVP28A
FISH
paleoniscid teeth
ctenacanthus
Stypticobasis
Cladodus
Orodus
Hybodus
Petrodus
Listracanthus
Holmesella
Multidentodus
scale ?
Cooperella
Cooleyella
Moreyella
Kirkalla
other
UNIT
CYCLE 8
CYCLE 7
Ft M
6 2
3 1
0 0

## Fountain

Location: Northwest tributary to Black Canyon, west of Colorado Springs, Colorado
Manitou Springs, Colorado, 7 1/2' T13SR67W32SE1/4NW1/4
Note: Red siltstone from Fountain Formation

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 1.23 | 9.5 | 7 | 7 | | | 86 |

## Independence

Location: Clay pit on south edge of Independence, Kansas
Independence, Kansas, 7 1/2' T33SR16E6NW1/4SE1/4SE1/4
Reference: Schoewe, 1944, loc. 254, p. 131
Note: Seat earth below Thayer Coal

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 1.60 | 9.4 | 43 | 22 | | | 35 |

## Kalo

Location: Old road cut on county road 2 mi north of Kalo, Iowa
Fort Dodge S, Iowa, 7 1/2' T88NR28W8NW1/4SE1/4SE1/4
Reference: Burggraf et al., 1981, Stop 4, p.72-73
Note: Seat earth, Kalo Formation

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 2.73 | | 11 | 4 | | | 85 |

## Lehigh

Location: Road cut on Iowa Highway 50, north edge of Lehigh, Iowa
Lehigh, Iowa, 7 1/2' T87NR28W12NE1/4SW1/4SE1/4
Note: Kalo Formation grey shale

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 3.67 | | 41 | | | | 59 |

## Mayflower

Location: Paleochannel at 1110 N. Dubuque Street, Iowa City, Iowa
Iowa City W, Iowa, 7 1/2' T79NR6W3SW1/4NE1/4SE1/4
Note: Siltstone

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 1.63 | 9.2 | 54 | 30 | | 5 | 12 |

## Onion Creek

Location: Road cut on county road south of Onion Creek and 3 mi west of Bolton, Kansas
Bolton, Kansas, 7 1/2' T33SR14E22NE1/4 E Line
Reference: Moussavi-Harami, 1980
Note: White, plant-rich shale interbedded with Onion Creek sandstone

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| .98 | 8.0 | 9 | 12 | | 1 | 77 |

## Pottsville 1

Location: 18 mi east of Hamilton, Alabama, at intersection of Alabama Highway 278 and Alabama Highway 233

Gold Mine, Alabama, 7 1/2' T11SR11W16NE1/4SE1/4NW1/4

Note: Upper Pottsville Group. Sample provided by R.C. Price.

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 2.23 | 9.4 | 55 | 22 | | 12 | 11 |

## Pottsville 2

Location: 6 mi east of Double Springs, Alabama, on Alabama Highway 278

Houston, Alabama, 7 1/2' T10SR7W29NW1/4NW1/4SE1/4

Note: Upper Pottsville Group. Sample provided by R.C. Price.

| Illite crystallinity | $K_2O$% | Illite % | Mixed layer % | Smectite % | Chlorite % | Kaolinite % |
|---|---|---|---|---|---|---|
| 2.29 | 9.5 | 55 | 23 | | 12 | 10 |

## Hajji Hollow - Logan Quarry

Location: Creek bank on Rocky Run 2 1/2 mi of Montezuma, Indiana
Montezuma, Indiana, 7 1/2' T15NR8W5SE1/4NE1/4SW1/4
Reference: Zangerl and Richardson, 1963, p.56-57
Note: Fossil locality, Logan Quarry black shale

## Independence - Drum

Location: Road cut on U.S. Highway 160 2 mi east of Independence, Kansas
Independence, Kansas, 7 1/2' T32SR16E33NE1/4NLine
Reference: Heckel, 1978, Stop 9, p. 42
Note: Fossil locality, Drum oolite

## Lawrence - Beil

Location: Road cut on Interstate 70 west of Lawrence, Kansas
T12SR18E24NW1/4NE1/4
Reference: Heckel et al., 1979, Stop 15, p. 46
Note: Fossil locality, Beil Limestone

## LP 1

Location: Ditch along county road 3 mi west and 3 1/2 mi north of Parsons, Kansas
Galesburg, Kansas, 7 1/2' T30SR19E33NW1/4SW1/4NW1/4
Note: Plant-rich exposure of Dodds Creek Sandstone

## Mound City - Ladore

Location: Road cut on Kansas Highway 52 2 1/2 mi southwest of Mound City, Kansas
Mantey, Kansas, 7 1/2' T22SR23E23SW1/2NE1/4
Note: Fossil locality, Ladore Shale

Plate 3. Conodonts

All specimens except 11 coated with ammonium chloride. All x 40.

1. Stepanovites sp, Hi element, Captain Creek Limestone, Stanzel, Iowa (St1/s), lateral view SUI 49115

2. Bird's-foot (Stepanovites element ?), Vilas Shale, Malvern, Iowa (Ma1/158.6') SUI 49116

   a. Aboral view
   b. Lateral view
   c. Oral view

3. Aethotaxis sp, Sa (?) element, Stark Shale, Jingo, Kansas (Ji1/111), lateral view SUI 49120

4. Anchignathodus sp, Pa element, Bethany Falls Limestone, Richfield, Nebraska (Ri1/bf) SUI 49118

   a. Lateral view
   b. Oral view

5. Adetognathus sp, Pa element, Honaker Trail Formation, Mexican Hat, Utah (Go1/1st Ls) SUI 49121

   a. Lateral view
   b. Oral view

6. Aethotaxis sp, Sc element, Bethany Falls Limestone, Richfield, Nebraska (Ri1/bf), lateral view SUI 49119

7. Streptognathodus sp, Pa element, Eudora Shale, Lewis, Iowa (Le1/0), oral view SUI 49127

8. Idiognathodus sp, Pa element, Bethany Falls Limestone, Richfield, Nebraska (Ri1/bf) SUI 49123

   a. Oral view
   b. Aboral view
   c. Lateral view

Plate 3. Conodonts (cont'd.).

9. Idioprioniodus sp, Sc element, Bethany Falls Limestone, Richfield, Nebraska (Ri1/bf) SUI 49117

   a. Outside lateral view
   b. Inside lateral view

10. Streptognathodus sp, Pa element, Honaker Trail Formation, Mexican Hat, Utah (Go1/1st Ls), oral view SUI 49126

11. Fused idiognathodid cluster, with two Pa elements, two O elements, and a fragment of an A element, Stark Shale, Atlantic, Iowa (At1/O) SUI 49124

# PLATE 3

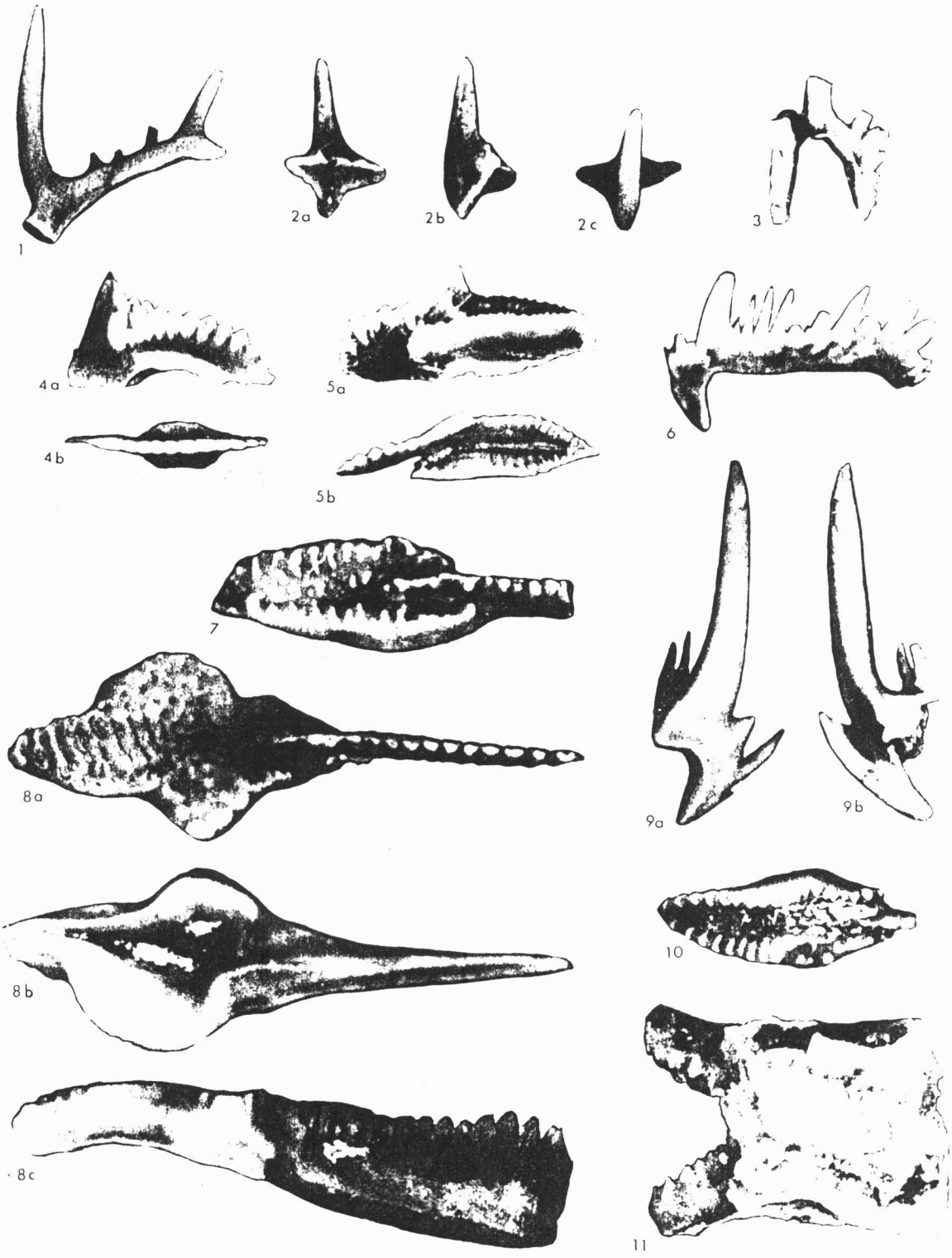


Plate 4. Conodonts and ostracodes

All specimens coated with ammonium chloride. Conodonts x 40.

1. Gondolella sp, Pa element, Bethany Falls Limestone, Richfield, Nebraska (Ril/bf) SUI 49128

   a. Lateral view
   b. Oral view
   c. Oblique aboral view

2. Gondolella denuda, Pa element, Shale below Shoal Creek Limestone, Oakwood, Illinois (Oa1/-11) SUI 49131

   a. Lateral view
   b. Oral view

3. Gondolella denuda, Pa element, Shale below Macoupin Limestone, Carlinville, Illinois (Cr1/mabs) SUI 49132

   a. Lateral view
   b. Oral view

4. Gondolella denuda, Pa element, Hushpuckney Shale, Richfield, Nebraska (Ril/34) SUI 49133

   a. Lateral view
   b. Oral view

5. Gondolella sp, Pa element, Minnelusa Formation (DC-59), Rapid City, South Dakota, oral view SUI 49130

6. Gondolella sp, Pa element, Eudora Shale, Eudora, Kansas (Eu1'/16), oral view SUI 49129

7. Geisinid, Stark Shale, Davis City, Iowa (DC1/39), x 50 SUI 49043

8. Cavellina sp, Vilas Shale, Winterset, Iowa (Wi2/68), x 30 SUI 49052

9. Bairdia sp, Vilas Shale, Platte City, Missouri (PC1'/1-4), x 35 SUI 49050

Plate 4. Conodonts and ostracodes (cont'd.).

10. Kirkbya sp, Winterset Limestone, Peculiar, Missouri (Pq1/79), x 30 SUI 49055

11. Hollinella sp, Vilas Shale, Winterset, Iowa (Wi2/68), x 30 SUI 49048

12. Bairdia sp, Winterset Limestone, Peculiar, Missouri (Pq1/79), x 30, interior view SUI 49049

13. Roundyella sp, Stark Shale, Jingo, Kansas (Ji1/96), x 60 SUI 49053

14. Amphissites sp, Stark Shale, Jingo, Kansas (Ji1/96), x 40 SUI 49044

15. Kellettina sp, Winterset Limestone, Jingo, Kansas (Ji1/wlp), x 30 SUI 49054

16. Kegelites sp, Stark Shale, Winterset, Iowa (Wi1/-4), x 45 SUI 49047

17. Unidentified pelagic ostracode, Stark Shale, Dennis, Kansas De1/-15), x 30 SUI 49057

    a. Hinge view
    b. Lateral view

18. Knightina sp, Vilas Shale, Louisville, Nebraska (Lo1/69), x 30 SUI 49051

# PLATE 4

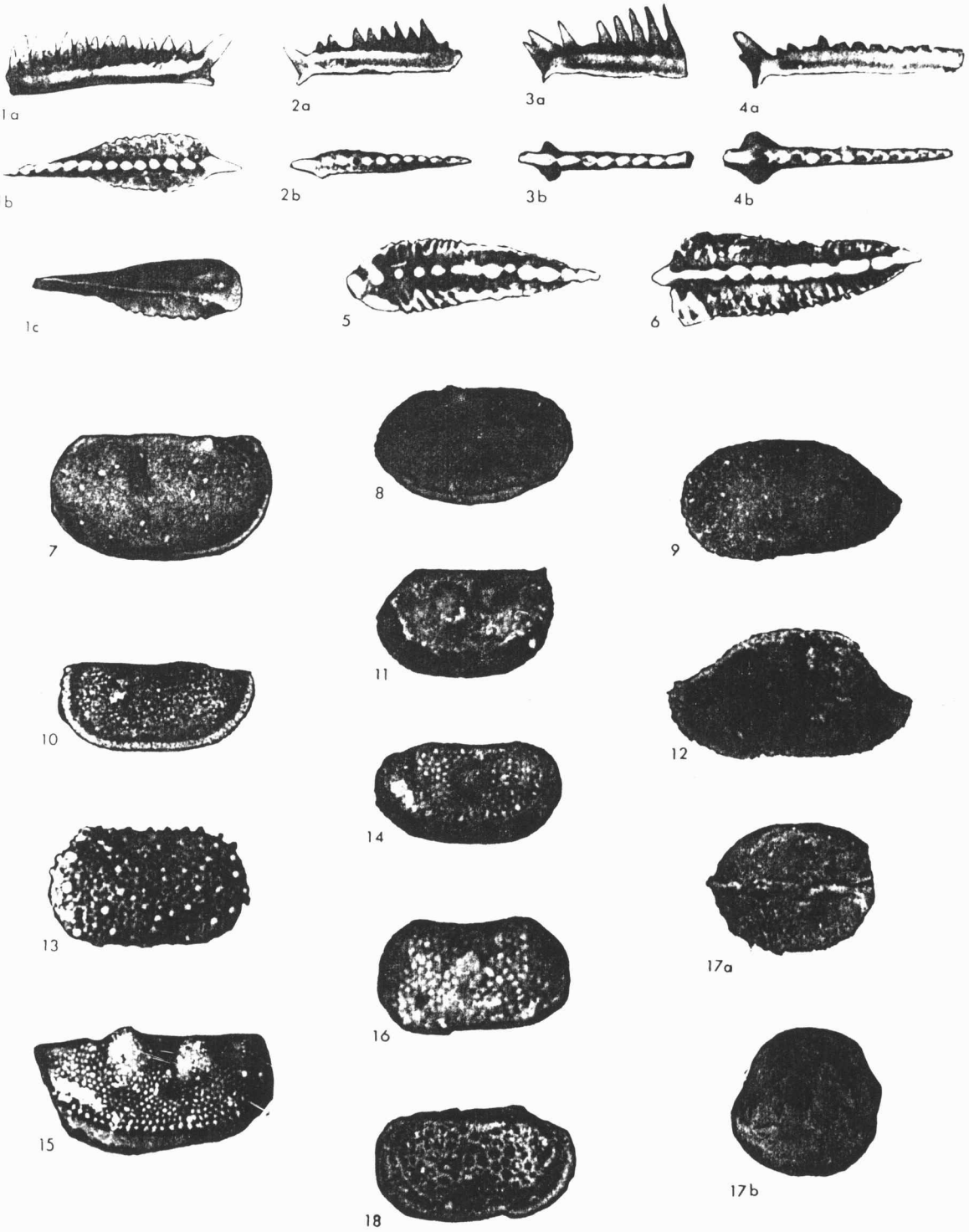


Plate 5. Foraminifers and radiolarians

1-16 coated with ammonium chloride.

1. Polytaxis sp, Winterset Limestone, Jingo, Kansas (Ji1/w1p), x 20 SUI 48993

2. Cyclogyra sp, Vilas Shale, Altoona, Kansas (A11/-14½'), x 60 SUI 48999

3. Glomospira sp, Middle Creek Limestone, Richfield, Nebraska (Ri1/mc), x 100 SUI 49002

4. Nodosinella sp, Vilas Shale, Altoona, Kansas (A11/-26½'), x 50 SUI 48995

5. Tetrataxis sp, Vilas Shale, Altoona, Kansas (A11/-26½'), x 50 SUI 48998A

   a. Lateral view
   b. Apical view
   c. Basal view

6. Endothyranella sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 40 SUI 48986

7. Ammodiscella sp, Winterset Limestone, Jingo, Kansas (Ji1/w), x 40 SUI 49000

8. Thurammina sp, Winterset Limestone, Jingo, Kansas (Ji1/w), x 30 SUI 48990

9. Textularia sp, Eudora Shale, Tyro, Kansas (Ty1/16) SUI 49169

10. Ammobaculites sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 50 SUI 48994

11. Bigeneria sp, Captain Creek Limestone, Altoona, Kansas (A13/cc), x 35 SUI 48985

12. Hyperammina sp, Vilas Shale, Eudora, Kansas (Eu1/-4), x 40 SUI 48991

Plate 5. Foraminifers and radiolarians (cont'd.).

13. Ammovertella sp, Ladore Shale, Richfield, Nebraska (Ri1/8), x 50 SUI 48988

14. Tolypammina sp, Eudora Shale, Altoona, Kansas (Al1'/6), x 30 SUI 48989

15. Ammodiscus sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 60 SUI 49001

16. Hippocrepina sp, Eudora Shale, Winterset, Iowa (Wi2/136), x 30 SUI 48996

17. Unidentified radiolarian, Stark Shale, Dennis, Kansas (De1/-4), thin section of apatite nodule, x 85

18. Unidentified radiolarian, Stark Shale, Dennis, Kansas (De1/-4), thin section of apatite nodule, x 85

# PLATE 5

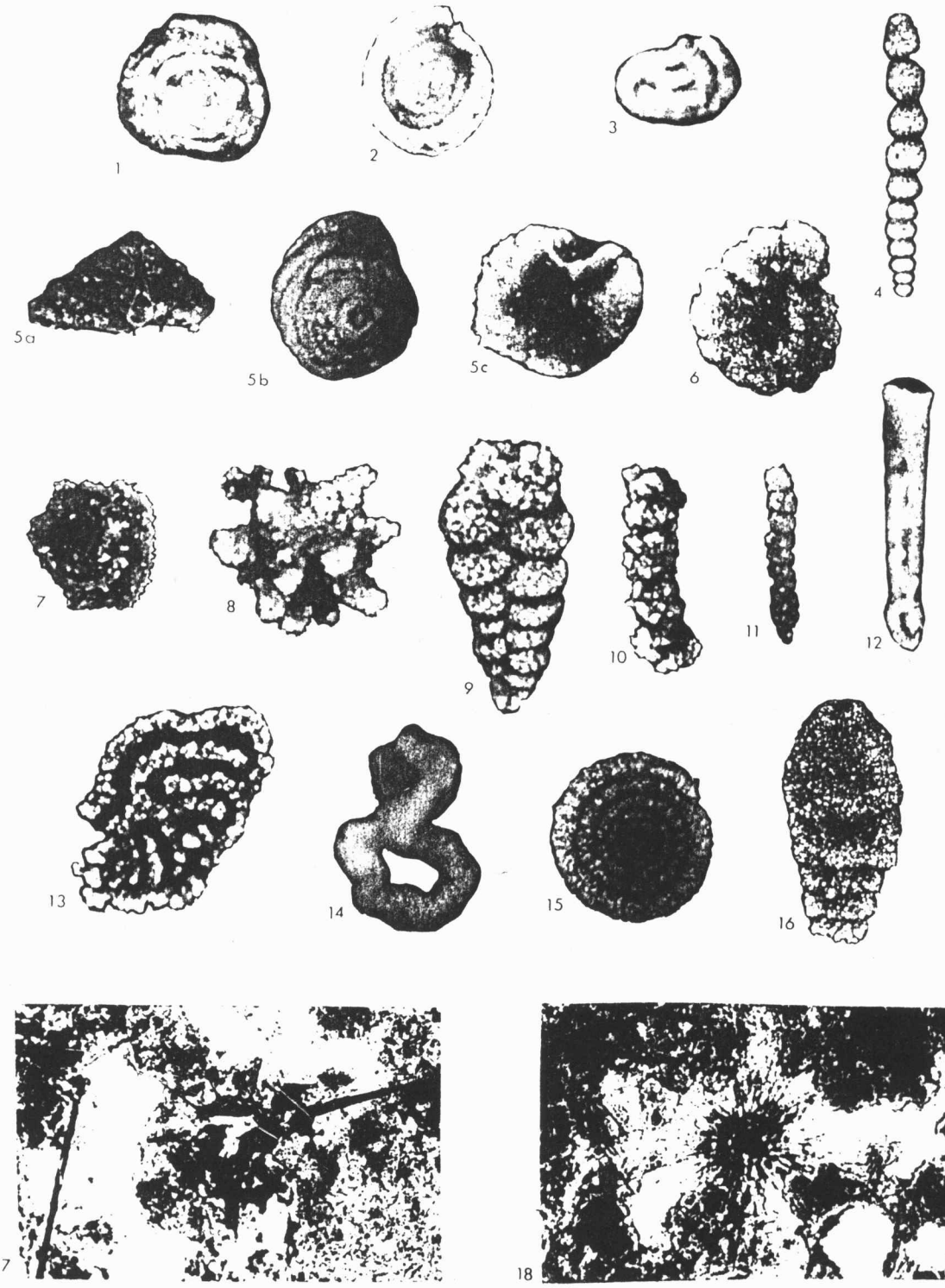


Plate 6. Brachiopods

All specimens coated with ammonium chloride.

1. Antiquatonia sp, Vilas Shale, Stanton, Kansas (Sn1), x 1
   SUI 49017

   a. Lateral view
   b. Posterior view

2. Antiquatonia sp, Kiewitz Shale, Louisville, Nebraska (Lo1), x 1.3, interior of pedicle valve SUI 49016

3. Antiquatonia sp, Kiewitz Shale, Louisville, Nebraska (Lo1), x 1
   SUI 49016

   a. Lateral view
   b. Pedicle view
   c. Brachia view

4. Pulchratia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.5
   SUI 49015

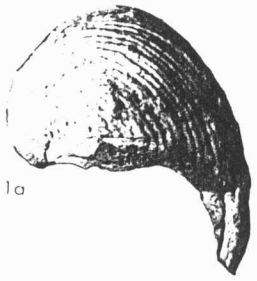
   a. Lateral view
   b. Pedicle view
   c. Brachial view

5. Pulchratia sp, Eudora Shale, Winterset, Iowa (Wi2) SUI 49014

   a. Detail of cardinal process and brachial valve, x 1
      (Pulchratia can be distinguished from Juresania by the single fused cardinal process; Juresania has two separate prongs in its cardinal process)

   b. Exterior of brachial valve, x .75
   c. Interior of brachial valve, x .75

# PLATE 6



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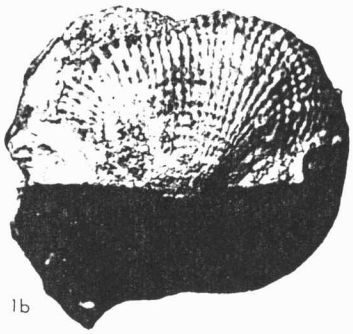

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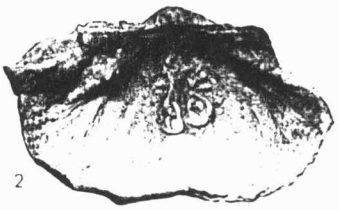

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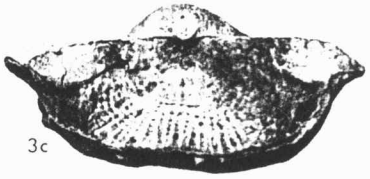

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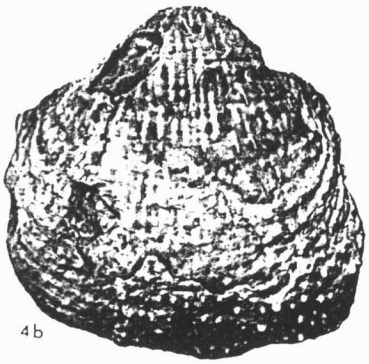

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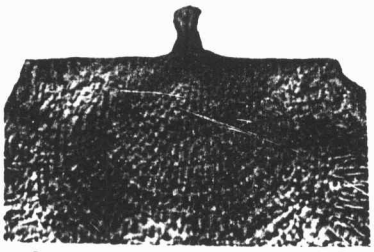

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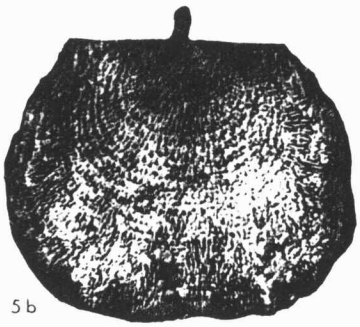

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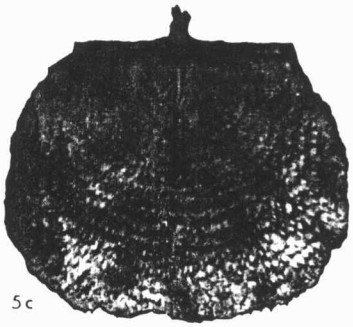


5c

## Plate 7. Brachiopods

All specimens coated with ammonium chloride.

1. Reticulatia sp, Stark Shale, Winterset, Iowa (Wil/-4), x 1.3
   SUI 49167

   a. Interior of brachial valve
   b. Exterior of brachial valve

2. Lino productus sp, Eudora Shale, Copan, Oklahoma (Cpl), x 1.8
   SUI 49018

   a. Pedicle valve
   b. Posterior view
   c. Lateral view

3. Kozlowskia (?) sp, Stark Shale, Winterset, Iowa (Wil/-4), x 3.5
   SUI 49022

   a. Exterior of brachial valve
   b. Interior of brachial valve

4. Kozlowskia (?) sp, Stark Shale, Winterset, Iowa (Wil/-4), x 3.5
   SUI 49022

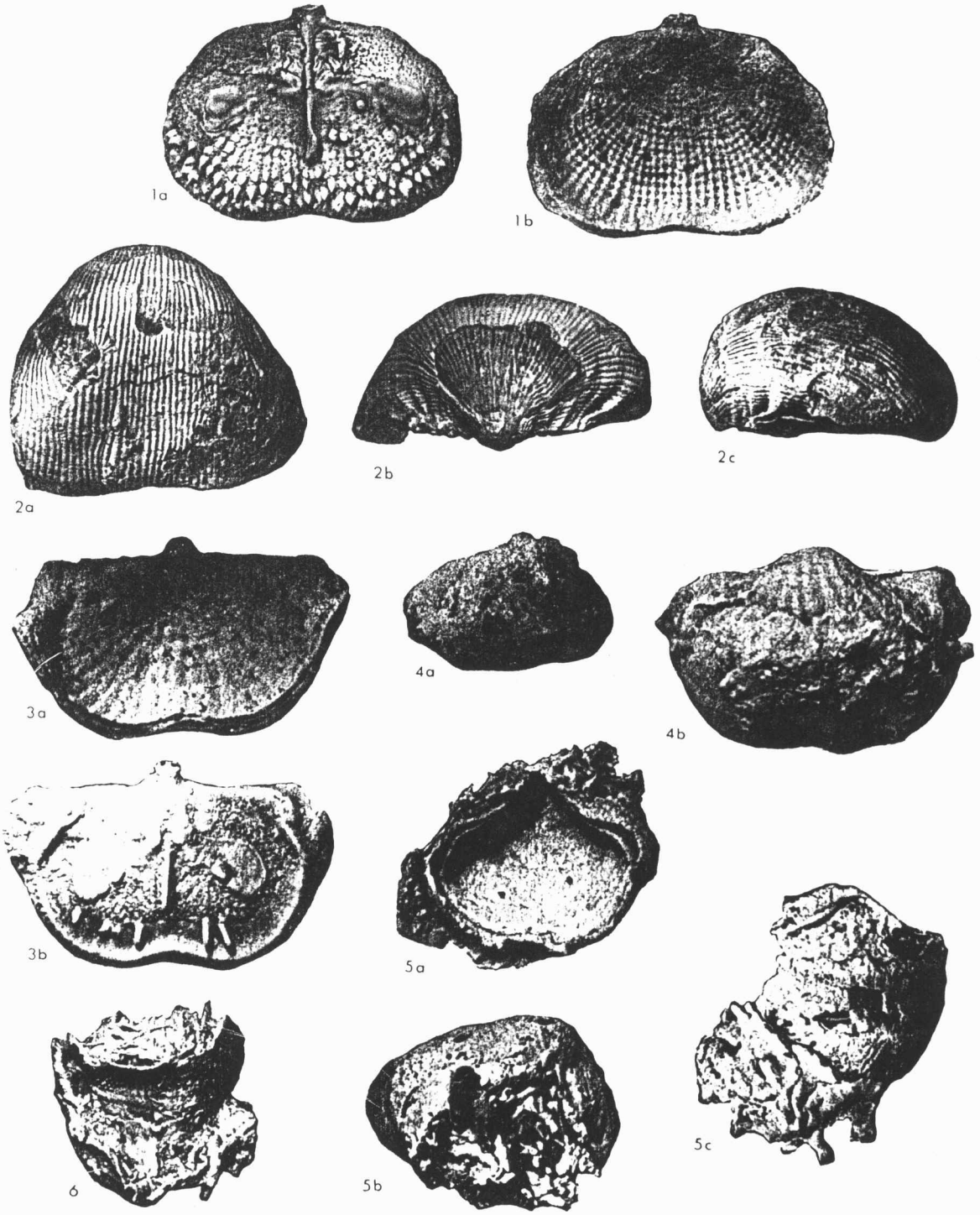
   a. Lateral view
   b. Pedicle view

5. Teguliferina sp, Winterset Limestone, Jingo, Kansas (Jil/w), x 3
   SUI 49030

   a. Interior of pedicle valve
   b. Exterior of pedicle valve
   c. Lateral view of pedicle valve

6. Teguliferina sp, Stark Shale, Jingo, Kansas (Jil/lll), x 2.2,
   exterior of pedicle valve SUI 49031

# PLATE 7



# Plate 8. Brachiopods

All specimens coated with ammonium chloride.

1. Neochonetes sp, Vilas Shale, Louisville, Nebraska (Lol/69) SUI 49029

   a. Interior of brachial valve, x 4
   b. Exterior of pedicle valve, x 3

2. Chonetinella sp, Stark Shale, Winterset, Iowa (Wil/-4) SUI 49023

   a. Interior of brachial valve, x 6
   b. Interior of pedicle valve, x 4.2

3. Chonetinella sp, Winterset Limestone, Jingo, Kansas (Jil/wlp), x 4.5 SUI 49024

   a. Anterior view
   b. Exterior of pedicle valve

4. Neochonetes sp, Vilas Shale, Louisville, Nebraska (Lol/69), x 2.3, interior of pedicle valve SUI 49029

5. Crurithyris sp, Eudora Shale, Copan, Oklahoma (Cpl), x 3 SUI 49028

   a. Lateral view
   b. Posterior view
   c. Brachial view

6. Crurithyris sp, Eudora Shale, Louisville, Nebraska (Lol/81), x 4.5, interior of brachial valve SUI 49027

7. Phricodothyris sp, Beil Limestone, Lawrence, Kansas, x 2 SUI 49033

   a. Posterior view
   b. Pedicle view

Plate 8. Brachiopods (cont'd.).

8. Composita sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 1.7
SUI 49037

a. Posterior view
b. Brachial view
c. Anterior view
d. Lateral view

# PLATE 8

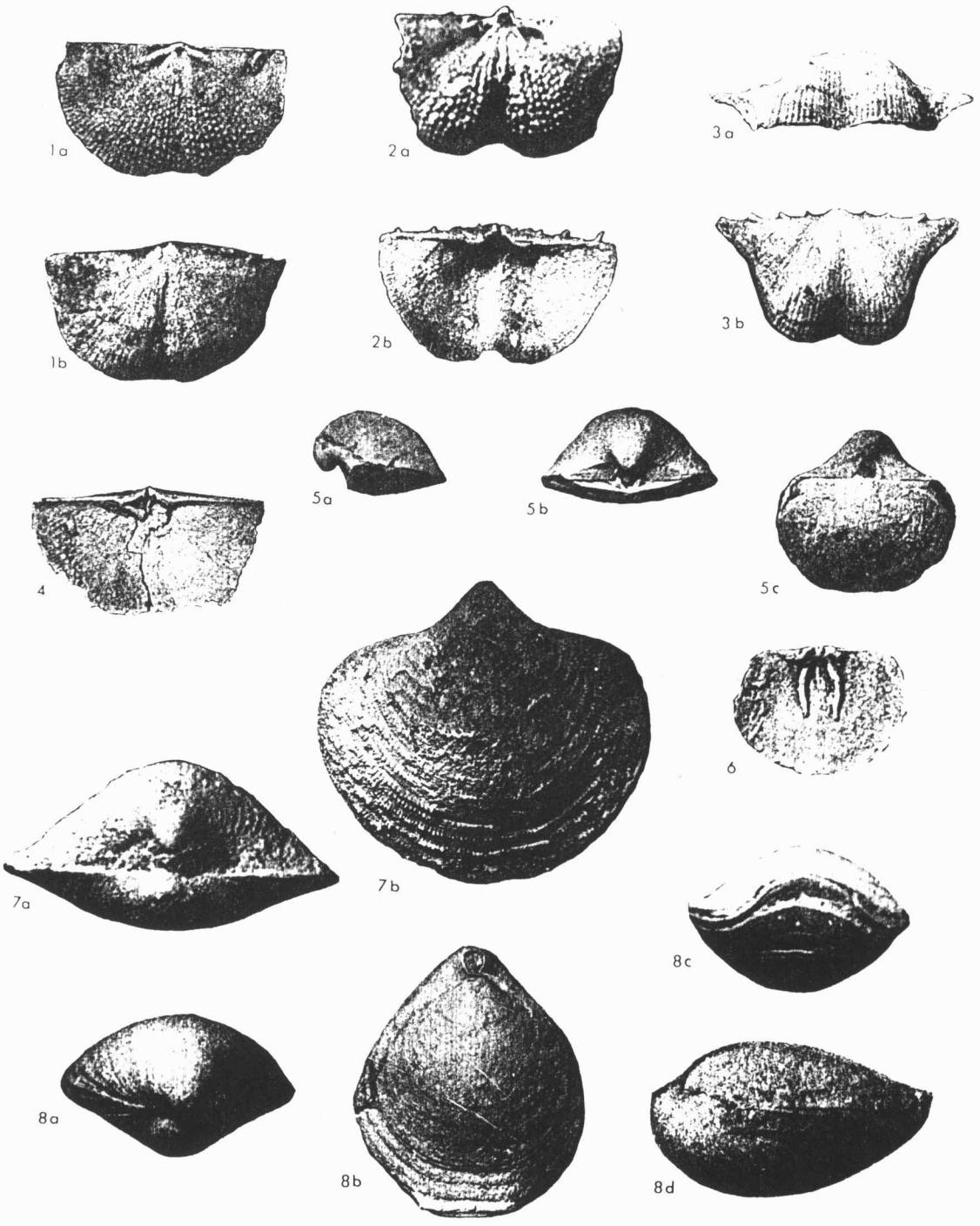


Plate 9. Brachiopods

All specimens coated with ammonium chloride.

1. Neospirifer sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 1 SUI 49019

   a. Pedicle view
   b. Lateral view
   c. Anterior view
   d. Posterior view

2. Punctospirifer sp, Stark Shale, Winterset, Iowa (Wil/-4), x 6 SUI 49166

   a. Exterior of pedicle valve
   b. Interior of pedicle valve
   c. Lateral view of pedicle valve
   c. Posterior view of pedicle valve
   e. Anterior view of pedicle valve

3. Punctospirifer sp, Stark Shale, Winterset, Iowa (Wil/-4), x 5 SUI 49166

   a. Interior of brachial valve
   b. Posterior of brachial valve
   c. Anterior of brachial valve

4. Hustedia sp, Beil Limestone, Lawrence, Kansas, x 4 SUI 49038

   a. Brachial view
   b. Anterior view
   c. Posterior view
   d. Lateral view

5. Rhipidomella sp, Eudora Shale, Winterset, Iowa (Wi2/119), x 5, pedicle view SUI 49032

6. Schizophoria sp, Stoner Limestone, Altoona, Kansas (All), x 1.5 SUI 49020

Plate 9. Brachiopods (cont'd.).

7. Marginiferid (?) spat attached to unidentified substrate, Stark Shale, Winterset, Iowa (Wil/-4), x 13 SUI 49025

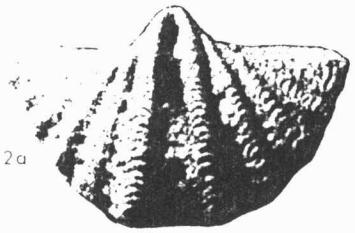
   a. Exterior view
   b. Interior view

# PLATE 9

1a

1b

1c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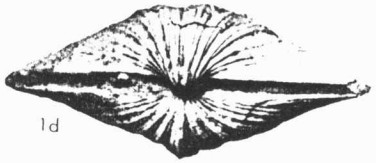
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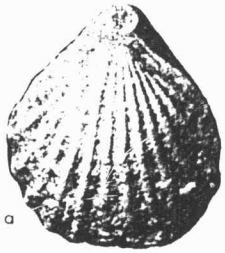
2b

3a

2d

3b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4c

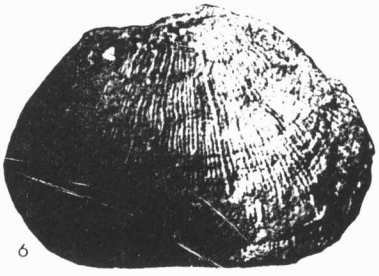
2e

3c

4b

4d

7a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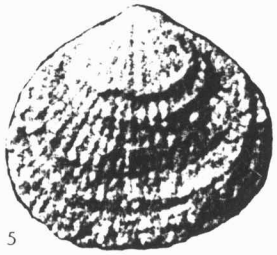
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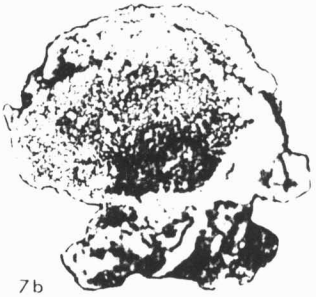

7b

## Plate 10. Brachiopods

All specimens coated with ammonium chloride.

1. Enteletes sp, Captain Creek Limestone, Eudora, Kansas (Eu1), x 2 SUI 49034

   a. Anterior view
   b. Lateral view
   c. Posterior view
   d. Brachial view

2. Wellerella sp, Kiewitz Shale, Louisville, Nebraska (Lo1), x 3.5 SUI 49035

   a. Lateral view
   b. Anterior view
   c. Brachial view
   d. Posterior view

3. Derbyia sp, Ladore Shale, Mound City, Kansas, x 2.7, interior of brachial valve; note borings in shell SUI 49039

4. Derbyia sp, Ladore Shale, Mound City, Kansas, x 1.8 SUI 49039

   a. Interior of pedicle valve
   b. Exterior of pedicle valve

5. Terebratulid, Beil Limestone, Lawrence, Kansas, x 2.2 SUI 49036

   a. Lateral view
   b. Anterior view
   c. Brachial view
   d. Posterior view

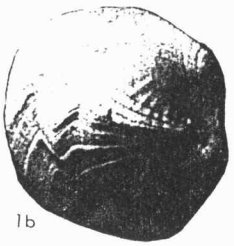
6. Orbiculoidea sp, Eudora Shale, Copan, Oklahoma (Cp1/30), x 3 SUI 49040

   a. Pedicle view
   b. Brachial view

7. Crania sp on Neospirifer sp, Stark Shale, Winterset, Iowa (Wi1/-4), x 3.5 SUI 49021

# PLATE 10

1a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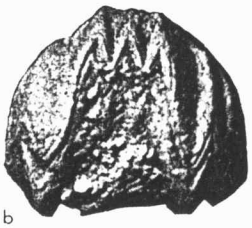
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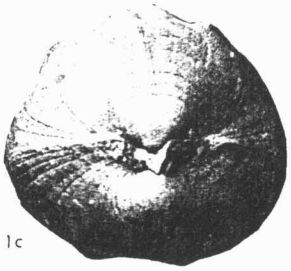
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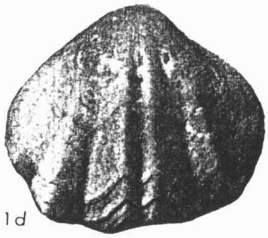
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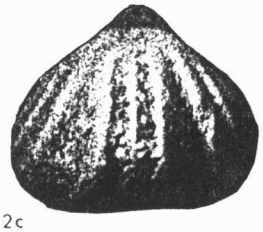
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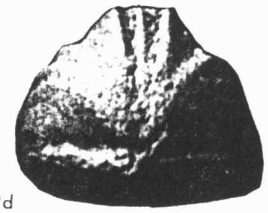
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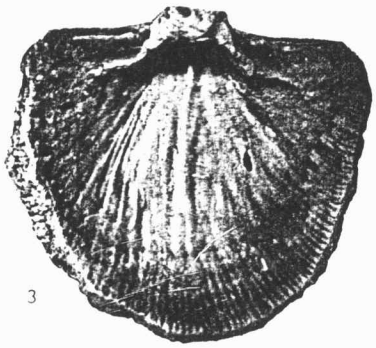
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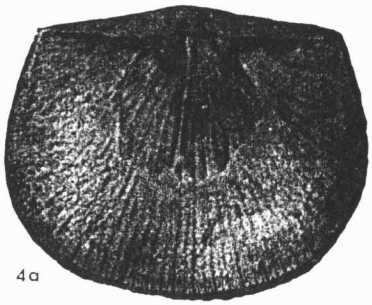
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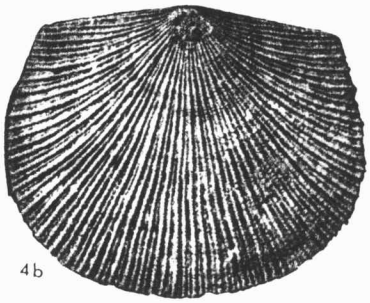
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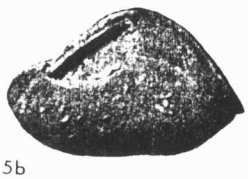
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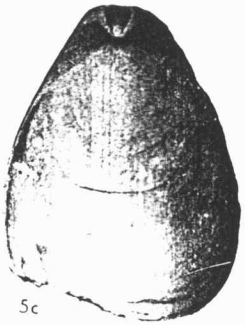
6a

6b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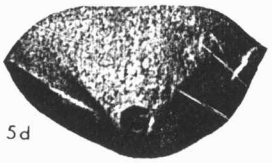

5d

7

Plate 11. Echinoderms

All specimens coated with ammonium chloride.

1. Erisocrinus sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 2.5 SUI 49099

   a. Basal view of cup
   b. Lateral view of cup
   c. Oral view of cup

2. Apographiocrinus sp, Captain Creek Limestone, Independence, Kansas, x 2.5 SUI 49095

   a. Oblique basal view of cup and arms
   b. Lateral view of cup and arms

3. Apographiocrinus sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 1.8 SUI 49096

   a. Basal view of cup
   b. Lateral view of cup, anal side
   c. Oral view of cup

4. Cibolocrinus sp, Captain Creek Limestone, Independence, Kansas, x 2 SUI 49100

   a. Basal view of cup
   b. Lateral view of cup, lateral side
   c. Oral view of cup

5. Stellerocrinus sp, Plattsburg Limestone, Altoona, Kansas (All), x 2, basal view of cup SUI 49101

6. Delocrinus sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 2.5 SUI 49098

   a. Basal view of cup
   b. Lateral view of cup

Plate 11. Echinoderms (cont'd.).

7. Triceracrinus sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 3 SUI 49102

   a. Basal view of cup
   b. Lateral view of cup, anal side
   c. Oral view of cup

8. Delocrinus sp, Captain Creek Limestone, Independence, Kansas, x 3.2, oral view of cup SUI 49097

9. Kallimorphocrinus sp, Eudora Shale, Copan, Oklahoma (Cp1/13½'), x 4, lateral view of calyx SUI 49103

# PLATE 11

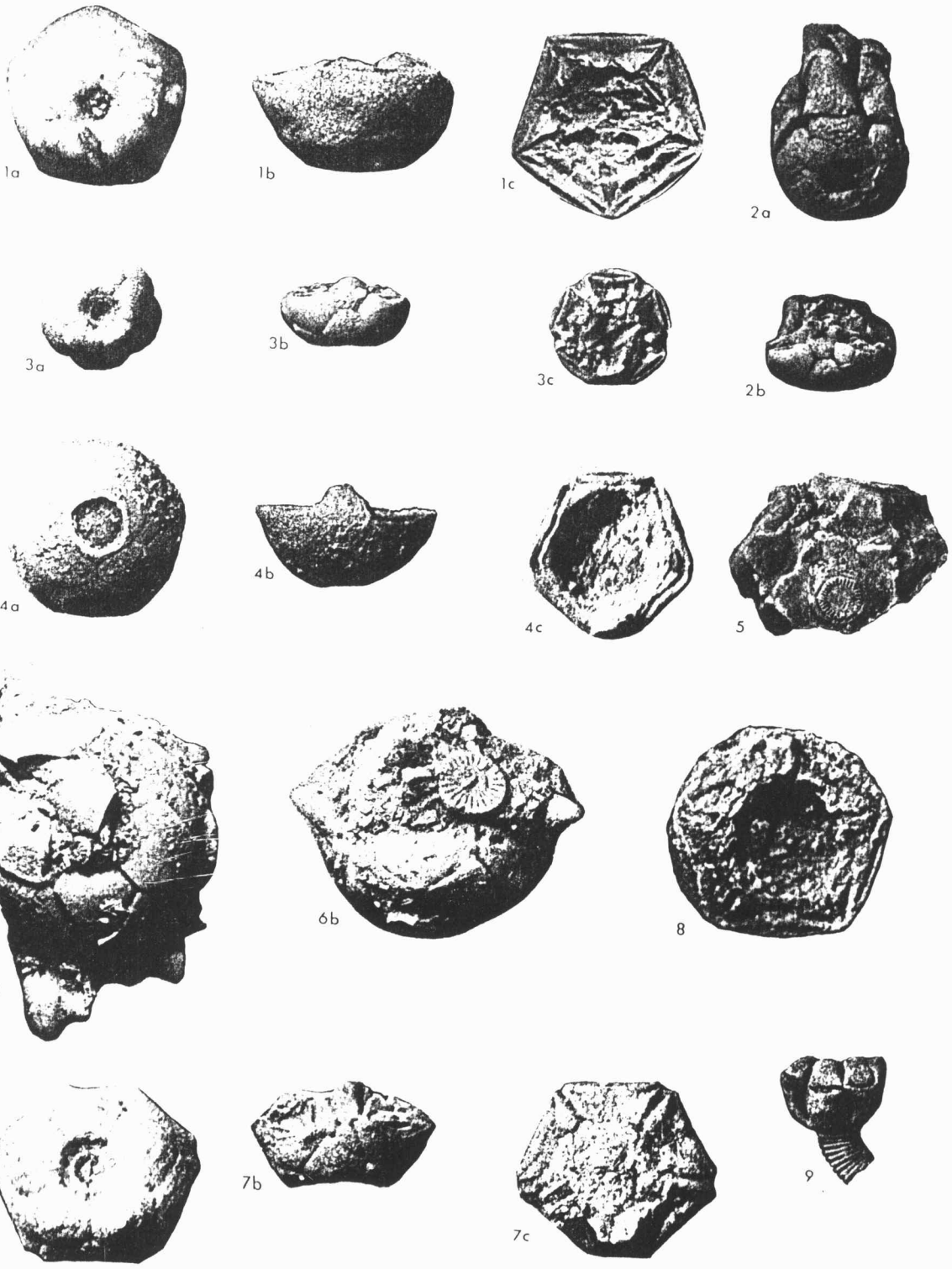


Plate 12. Echinoderms and gastropods

All specimens except 2, 3, and 7 coated with ammonium chloride.

1. Echinoid plate, Eudora Shale, Independence, Kansas (WM1), x 3 SUI 49106

2. Holothurian sclerite, Winterset Limestone, Breckenridge, Missouri (Br1/w), x 30 SUI 49108

3. Holothurian sclerite, Eudora Shale, Independence, Kansas (WM1/-5), x 100 SUI 49109

4. Parasitism of crinoid, Winterset Limestone, Coffeyville, Kansas (Cf1/0), x 3 SUI 49104

5. Echinoid plate, Kiewitz Shale, Louisville, Nebraska (Lo1), x 2.8 SUI 49106

6. Echinoid spine, Galesburg Shale, Richfield, Nebraska (Rila/74), x 12 SUI 49105

7. Echinoid (?) ambulacral plate, Ladore Shale, Richfield, Nebraska (Ri1/8), x 16 SUI 49110

8. Glabrocingulum sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3, apical view SUI 49082

9. Hypselentoma sp, Vilas Shale, Buffalo, Kansas (WCL1/17'), x 1.7, lateral view SUI 49084

10. Hypselentoma sp, Vilas Shale, Buffalo, Kansas (WCL1/17'), x 1.8, lateral view SUI 49084

11. Worthenia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3 SUI 49080

    a. Lateral view
    b. Basal view
    c. Apical view

Plate 12. Echinoderms and gastropods (cont'd.).

12. Glabrocingulum sp, Eudora Shale, Copan, Oklahoma (Cp1), x 4 SUI 49082

    a. Lateral view
    b. Apical view

13. Glabrocingulum sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3.2, basal view SUI 49082

14. Euconospira sp, Stoner Limestone, Buffalo, Kansas (WCL1), x 2, lateral view SUI 49085

# PLATE 12

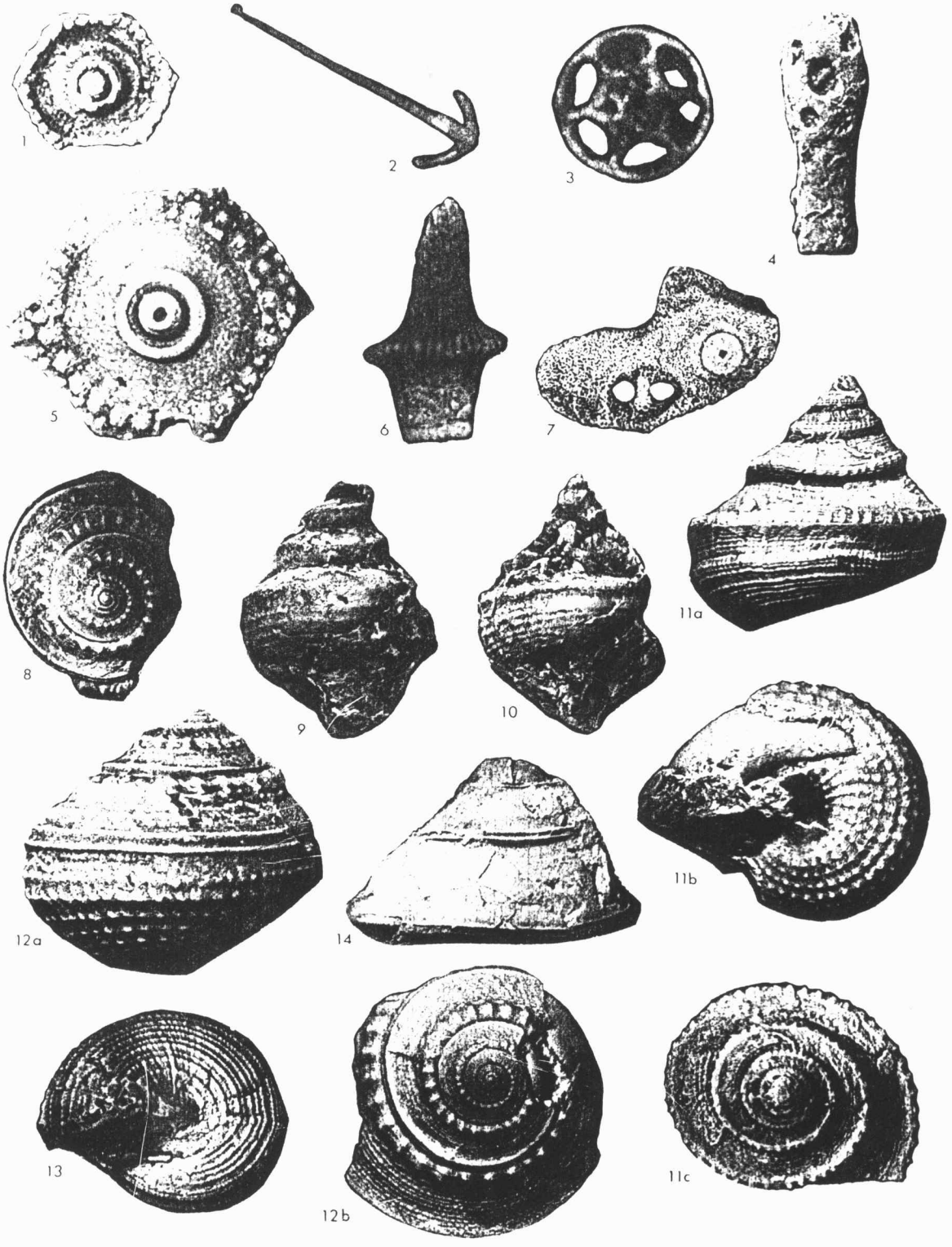


Plate 13. Gastropods and pelecypod

All specimens coated with ammonium chloride.

1. Trepospira sp, Eudora Shale, Copan, Oklahoma (Cp1), x 2 SUI 49083

   a. Apical view
   b. Lateral view

2. Anematina (?) sp, Bethany Falls Limestone, Jingo, Kansas (Ji1/0), x 4.5 SUI 49086

3. Anematina (?) sp, Bethany Falls Limestone, Jingo, Kansas (Ji1/0), x 4.5 SUI 49086

4. cf Aclisina sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 20 SUI 49089

5. cf Soleniscus sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 20 SUI 49088

6. Euphemites sp, Eudora Shale, Copan, Oklahoma (Cp1) SUI 49079

   a. Anterior view, x 1.8
   b. Posterior view, x 1.8
   c. Lateral view, x 2.5

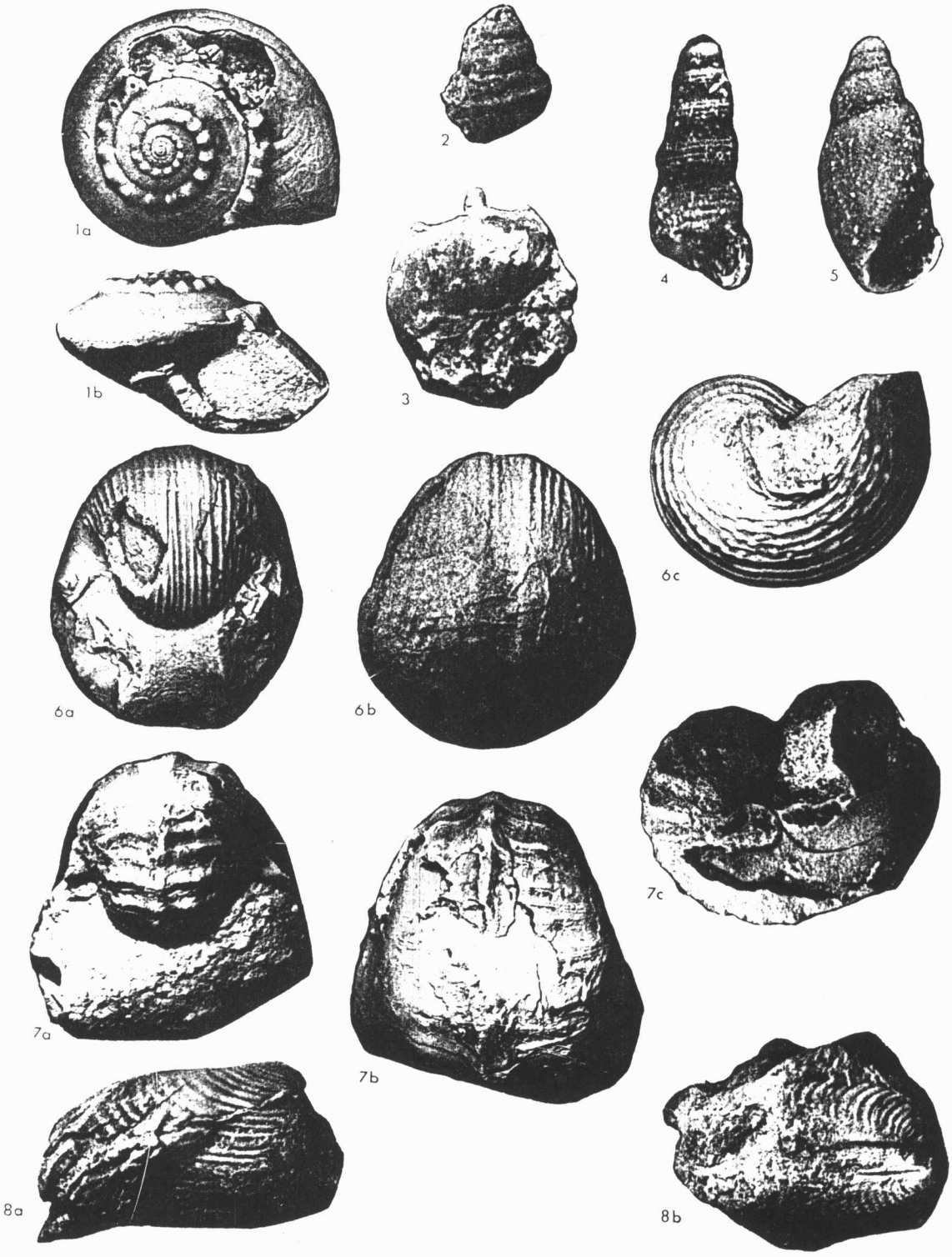
7. Bellerophon (Pharkidonotus) sp, Eudora Shale, Copan, Oklahoma (Cp1), x 2 SUI 49081

   a. Anterior view
   b. Posterior view
   c. Lateral view

8. Wilkingia sp, Beil Limestone, Lawrence, Kansas, x .85 SUI 49072

   a. Lateral view
   b. Hinge view

# PLATE 13



## Plate 14. Pelecypods

All specimens except 9 coated with ammonium chloride.

1. Myalina sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1 SUI 49065

   a. Interior view
   b. Exterior view

2. Leptodesma sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3 SUI 49064

3. Modiolus sp, upper Coffeyville Formation, Ramona, Oklahoma (Ra1), x 1.5, external mold SUI 49067A

4. Modiolus sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3 SUI 49066

5. Leptodesma sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.2 SUI 49064

6. Pteria sp, Mecca Quarry Shale, Montezuma, Indiana, x 4.5, external mold SUI 49069

7. Aviculopecten sp, upper Coffeyville Formation, Ramona, Oklahoma (Ra1), x 2, external mold SUI 49067B

8. Aviculopecten sp, upper Coffeyville Formation, Ramona, Oklahoma (Ra1), x 1.5, external mold SUI 49067B

9. Acanthopecten sp, Winterset Limestone, Ramona, Oklahoma (Ra2), x 1.2 SUI 49070

10. Dunbarella sp, Mecca Quarry Shale, Montezuma, Indiana, x 1.3, external mold SUI 49068

11. Dunbarella sp, Mecca Quarry Shale, Montezuma, Indiana, x 1.6, external mold SUI 49068

# PLATE 14

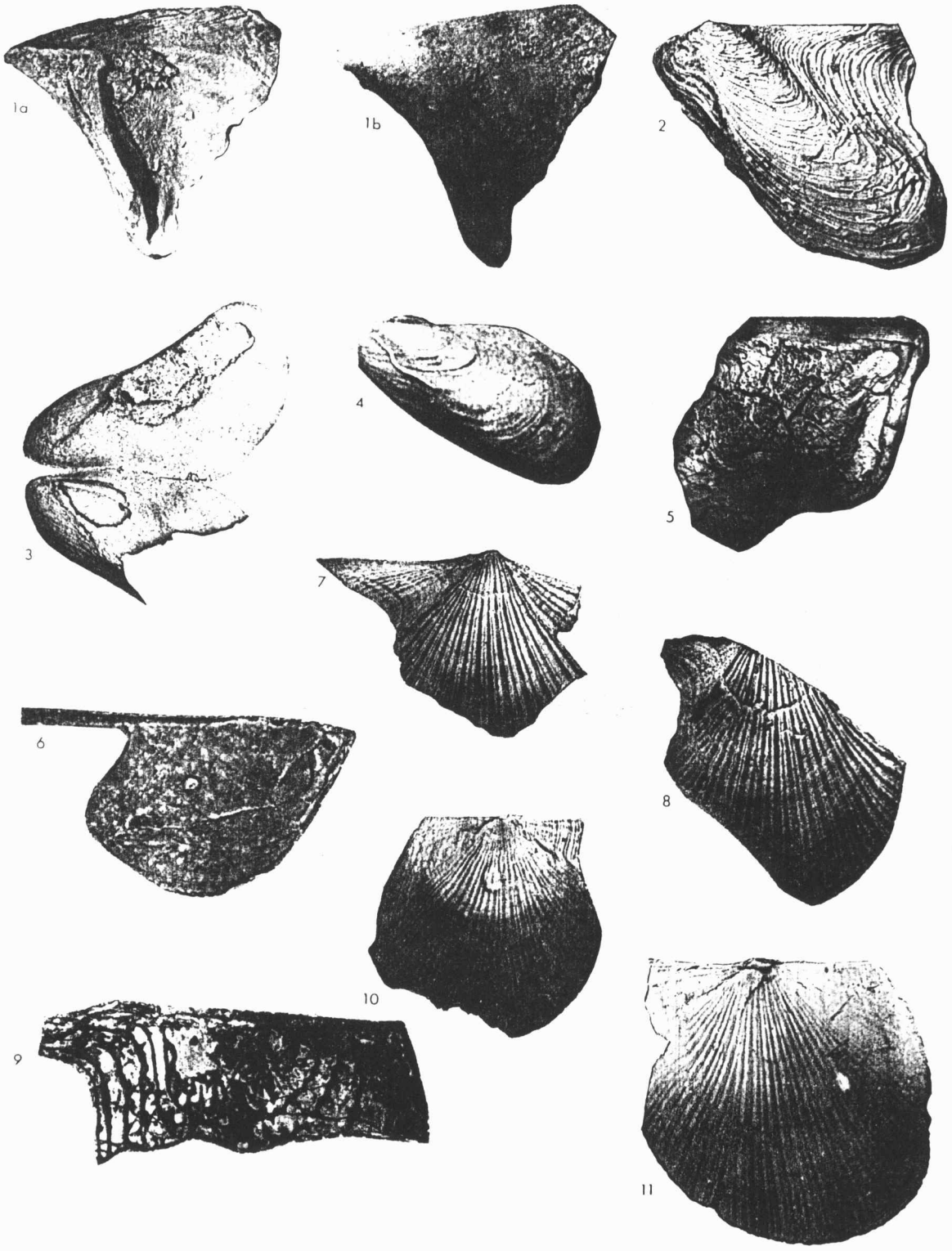


Plate 15. Pelecypods and rostroconch

All specimens coated with ammonium chloride.

1. Nuculid hinge, Vilas Shale, Altoona, Kansas (A11/-26½'), x 16
   SUI 49074
   Note taxodont dentition

2. Nuculopsis (?) sp, Canville Limestone, Everett, Missouri (Ev1/c), x 16 SUI 49075 Internal mold; note taxodont dentition

3. Cypricardella (?) sp, Bethany Falls Limestone, Jingo, Kansas (Ji1/0), x 27 SUI 49076

   a. Exterior view
   b. Interior view

4. Astartella sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 12
   SUI 490 Close-up of cardinal teeth

5. Astartella sp, Eudora Shale, Copan, Oklahoma (Cp1), x 2.5
   SUI 49061

6. Astartella sp, Eudora Shale, Copan, Oklahoma (Cp1), x 3
   SUI 49061

7. Edmondia sp, Stoner Limestone, Altoona, Kansas (A11), x 1.8
   SUI 49071 Internal mold

8. Paleyoldia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.5
   SUI 49063

   a. Hinge view
   b. Lateral view

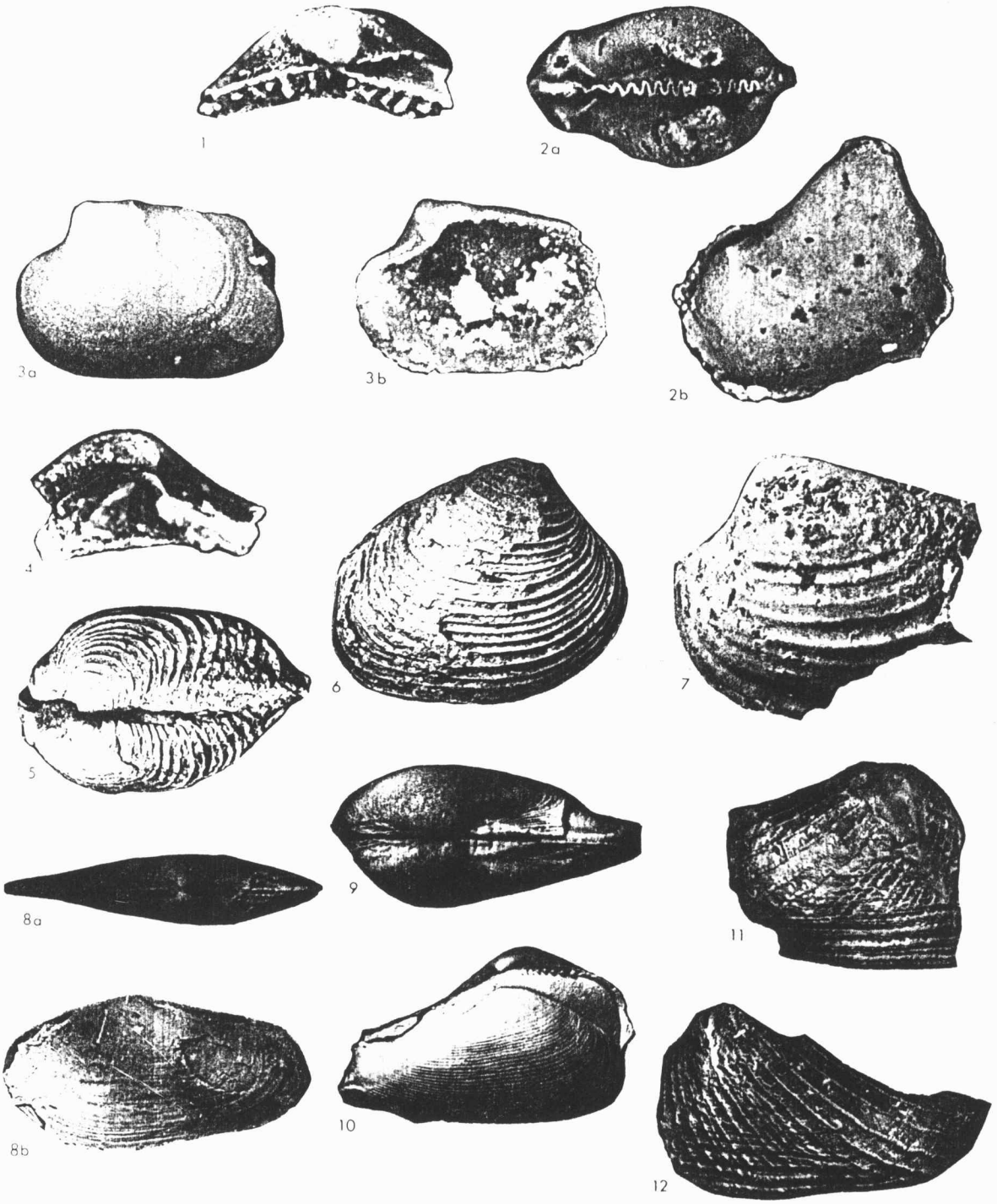
9. Phestia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.7 SUI 49062

10. Phestia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.8 SUI 49062

11. Pseudoconocardium sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.7
    SUI 49077

12. Pseudoconocardium sp, Eudora Shale, Copan, Oklahoma (Cp1), x 1.7
    SUI 49077

# PLATE 15



## Plate 16. Cephalopods, scaphopod, and bryozoan

All specimens coated with ammonium chloride.

1. Pseudorthocerid, Bethany Falls Limestone, Bronson, Kansas (Brol), x 2.5 SUI 49093

   a. Lateral view
   b. View of siphuncle and septum

2. Pseudorthoceras sp, Eudora Shale, Copan, Oklahoma (Cp1), x 2.5 SUI 49092

3. Metacoceras sp, Drum Limestone, Independence, Kansas, x 2.2 SUI 49094

   a. View of interior of coil fragment
   b. View of exterior of coil fragment
   c. Lateral view

4. Eoasianites sp, Bethany Falls Limestone, Bronson, Kansas (Brol), x 2 SUI 49091

   a. Lateral view
   b. Longitudinal view

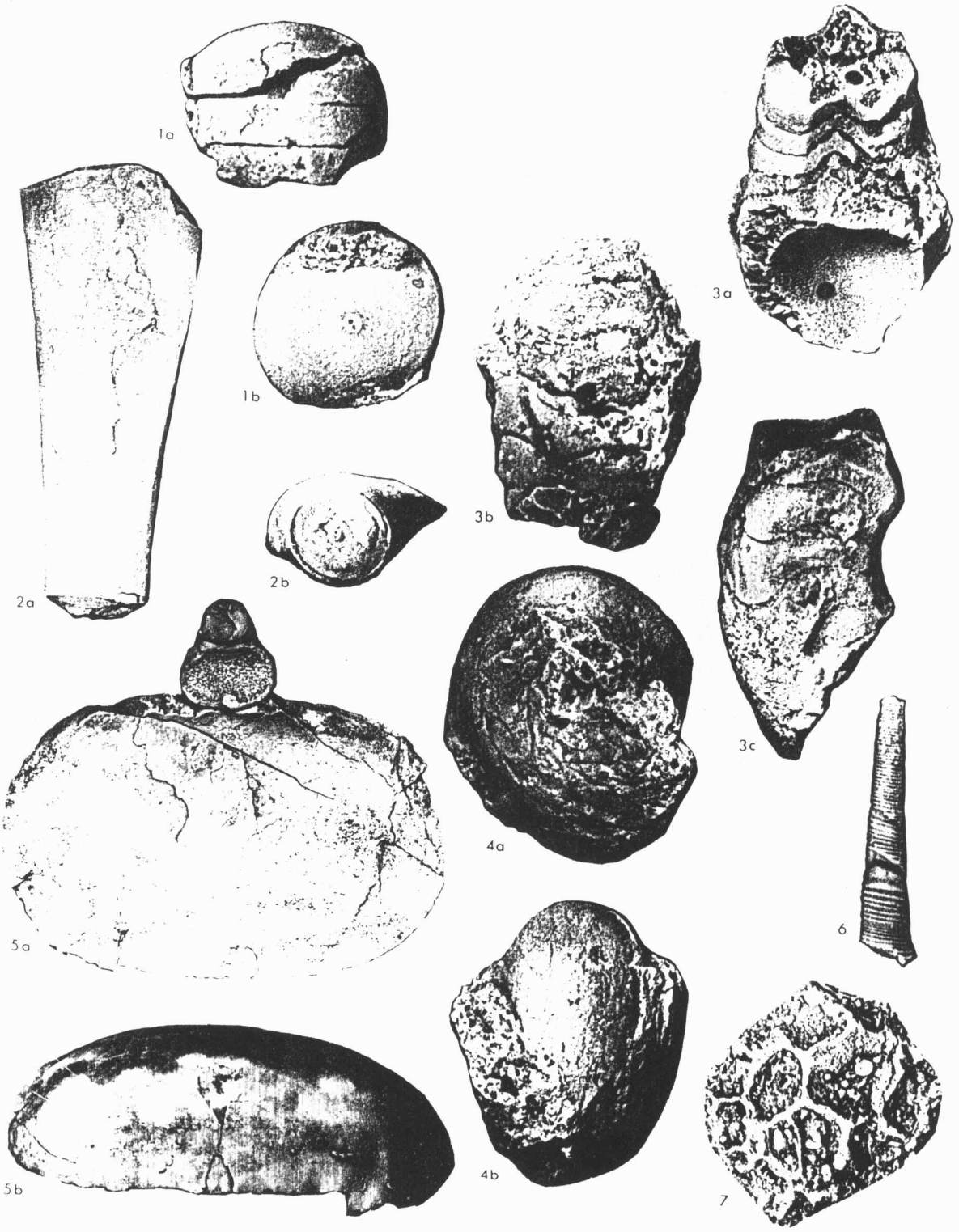
5. Solenochilus sp, Bethany Falls Limestone, Stark, Kansas (Cal/bf), x .56 SUI 49090

   a. View of interior of coil fragment
   b. View of exterior of chamber mold showing siphuncle

6. Plagioglypta sp, Eudora Shale, Copan, Oklahoma (Cp1/0), x 12 SUI 49078

7. Meekoporella sp, Stoner Limestone, Altoona, Kansas (A11), x 1.8 SUI 49009

# PLATE 16



## Plate 17. Sponges, arthropods, corals, and miscellaneous

All specimens coated with ammonium chloride.

1. Amblysiphonella (?) sp, Merriam Limestone, Altoona, Kansas (A11), x 1 SUI 49004

2. Girtyocoelia sp, Merriam Limestone, Altoona, Kansas (A11), x 2 SUI 49003

3. Wewokellid spicule, Vilas Shale, Altoona, Kansas (A12/31½'), x 30 SUI 49008

4. Spicule B, Winterset Limestone, Stark, Kansas (Ca1/w), x 30 SUI 49007

5. Spicule A, Stoner Limestone, Lewis, Iowa (Le1/s), x 30 SUI 49006

6. Coelocladia sp, Eudora Shale, Copan, Oklahoma (Cp1), x 2 SUI 49005

7. Acrothoracic barnacle borings on Euphemites sp, Merriam Limestone, Altoona, Kansas (A11), x 1.5 SUI 49111

8. Trilobite free cheek, Winterset Limestone, Jingo, Kansas (Ji1/w1p), x 3.5

   a. Bottom view
   b. Top view

9. Ditomopyge sp, Winterset Limestone, Jingo, Kansas (Ji1/w1p), x 7 SUI 49041

10. Sutherlandia sp, Winterset Limestone, Coffeyville, Kansas (Cf4/17), x 5 SUI 49013

11. Sutherlandia sp, Coffeyville Formation, Coffeyville, Kansas (CB1/-4), x 3 SUI 49012

12. Ameura sp, Spring Hill Limestone, Altoona, Kansas (A11/p), x 3.8 SUI 49042

Plate 17. Sponges, arthropods, corals, and miscellaneous (cont'd.).

13. Stereostylus sp, Stark Shale, Winterset, Iowa (Wil/-4), x 3
SUI 49011

    a. Oral view; note columnella
    b. Lateral view

15. Stereostylus sp, Kiewitz Shale, Louisville, Nebraska (Lol), x 2
SUI 49010

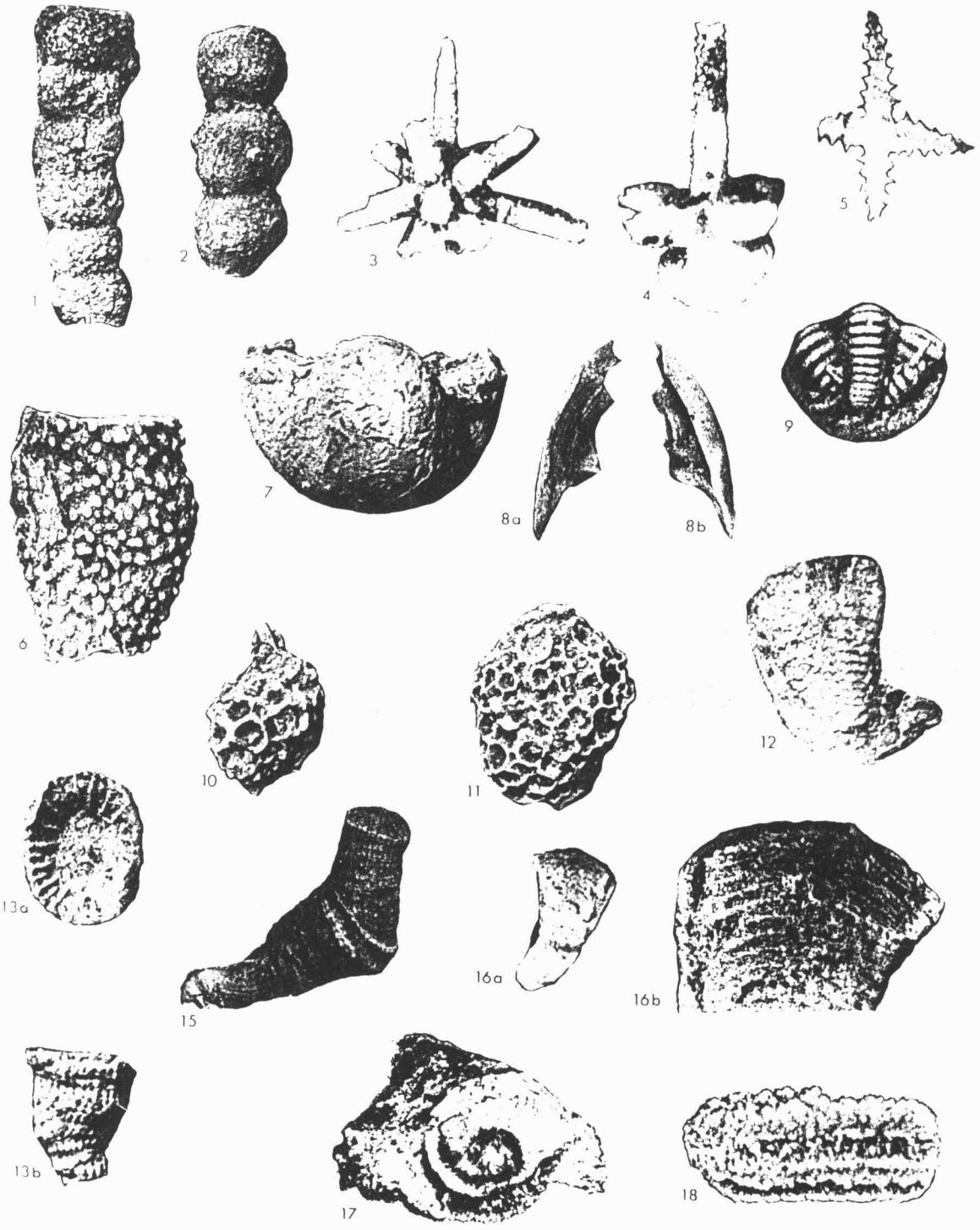
16. Conularid, Eudora Shale, Copan, Oklahoma (Cpl/13½') SUI 49112

    a. Side view, x 4
    b. Close-up of side, x 13

17. Spirorbis sp, shale below LaSalle Limestone, Oglesby, Illinois (LSl/36), x 20 SUI 49113

18. Fecal pellet, Vilas Shale, Bedford, Iowa (Bel/351.6'), x 26
SUI 49114

# PLATE 17



# Plate 18. Fishes

All specimens except 1, 2, and 11 coated with ammonium chloride.

1. Paleoniscid tooth, Vilas Shale, Louisville, Nebraska (Lo1/69) x 20 SUI 49152

2. Paleoniscid tooth, Winterset Limestone, Atlantic, Iowa (At1/w), x 30 SUI 49151

3. Hybodus sp, Decatur City Beds, Van Wert, Iowa (VW1), x 22.5 SUI 49134

4. Cladodus sp, Eudora Shale, Malvern, Iowa (Ma1/153.7'), x 30 SUI 49136

5. Protacrodus sp, Kiewitz Shale, Louisville, Nebraska (Lo1/139), x 25 SUI 49145

6. Orodus sp, Coffeyville Formation, Coffeyville, Kansas (CB1/-22), x 18 SUI 49146

7. Styptobasis sp, Stark Shale, Atlantic, Iowa (At1/0), x 22.5 SUI 49142

8. Petalodont tooth, Vilas Shale, Platte City, Missouri (PC1'/-4), x 14 SUI 49154

9. Petalodont tooth, LaSalle Limestone, Oglesby, Illinois (LS1), x 25 SUI 49155

10. Multidentodus sp, Kiewitz Shale, Louisville, Nebraska (Lo1/139), x 25 SUI 49135

    a. Side view
    b. Frontal view

11. Kirkella sp, Winterset Limestone, Coffeyville, Kansas (Cf3/w), x 50 SUI 49144

12a. Altoonodont, Captain Creek Limestone, Altoona, Kansas (A11'/cc), x 36, side view SUI 49148

Plate 18. Fishes (cont'd.).

12b. Altoonodont, Stoner Limestone, Lewis, Iowa (Le1/s), x 30, basal view SUI 49149

12c. Altoonodont, Stoner Limestone, Platte City, Missouri (PC1/s), x 30, top view SUI 49150

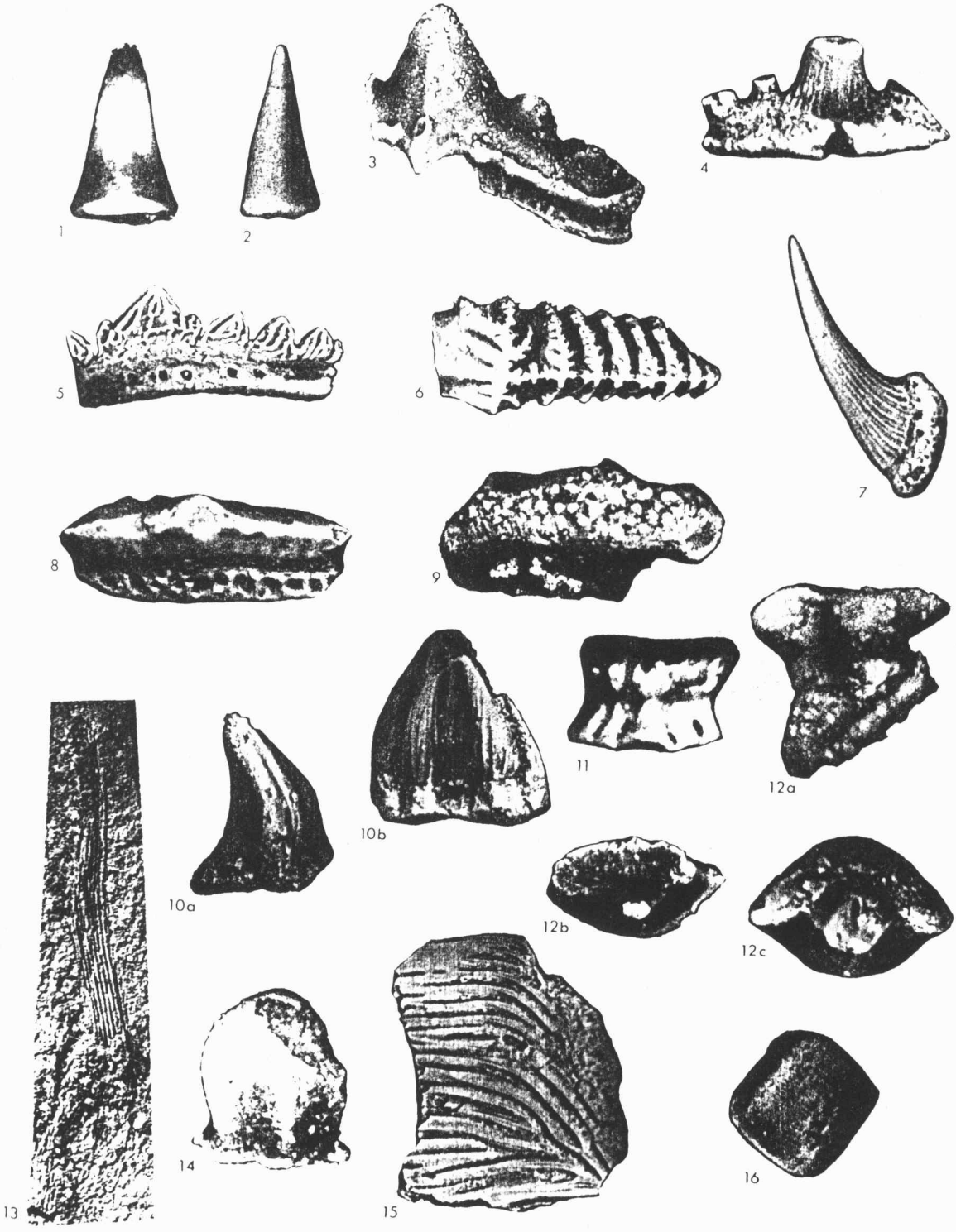
13. Listracanthus sp, Stark Shale, Unity Village, Missouri (UV1/41), x 2.5 SUI 49156

14. Cooleyella sp, Stoner Limestone, Lewis, Iowa (Le1/s), x 60 SUI 49141

15. Scale?, Stoner Limestone, Lewis, Iowa (Le1/s), x SUI 49139

16. Holmesella sp, Winterset Limestone, Kansas City, Kansas (KC1/wp), x 20 SUI 49147

# PLATE 18



# Plate 19. Ferns

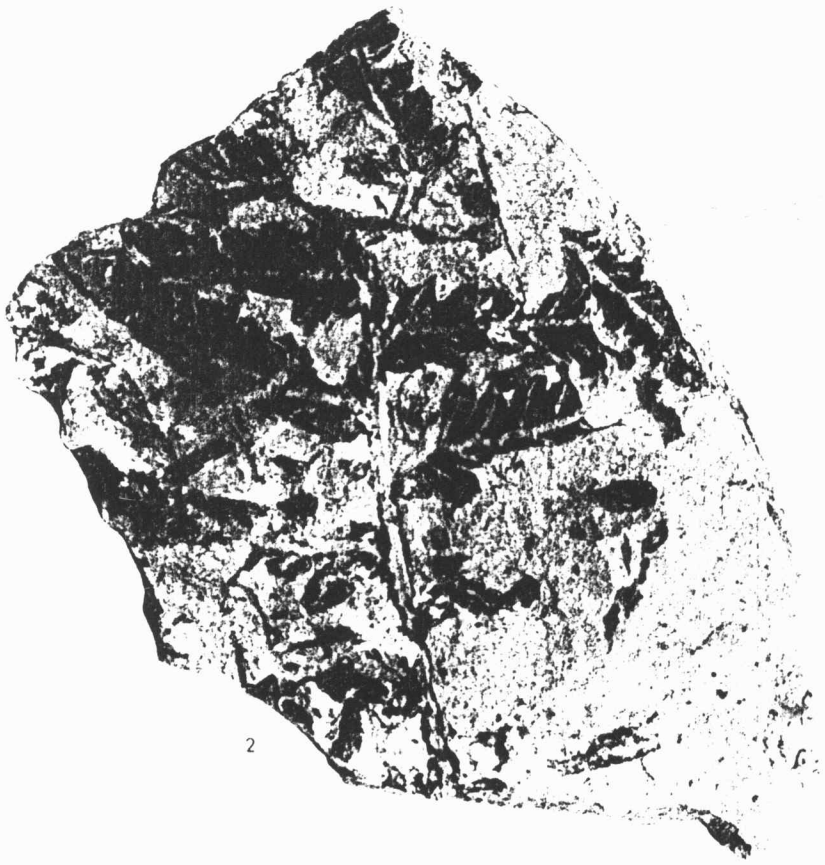
Specimens from upper Coffeyville Formation, Coffeyville, Kansas (Cf2)

1. Alloiopteris sp, x 2.8 SUI 49157A

2. Alloiopteris sp, x 3.2 SUI 49157B

# PLATE 19

1



2

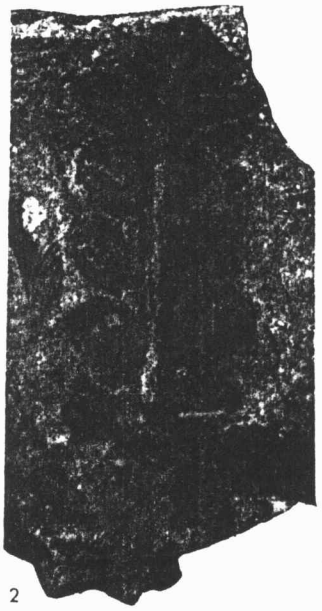
# Plate 20. Ferns

Specimens from upper Coffeyville Formation, Coffeyville, Kansas (Cf2)

1. Neuropteris sp, x 2.8 SUI 49159B
2. Pecopteris (?) sp, x 4 SUI 49163A
3. Neuropteris sp (large pinnules at both left and right ends), x 1.3 SUI 49159A

# PLATE 20

1



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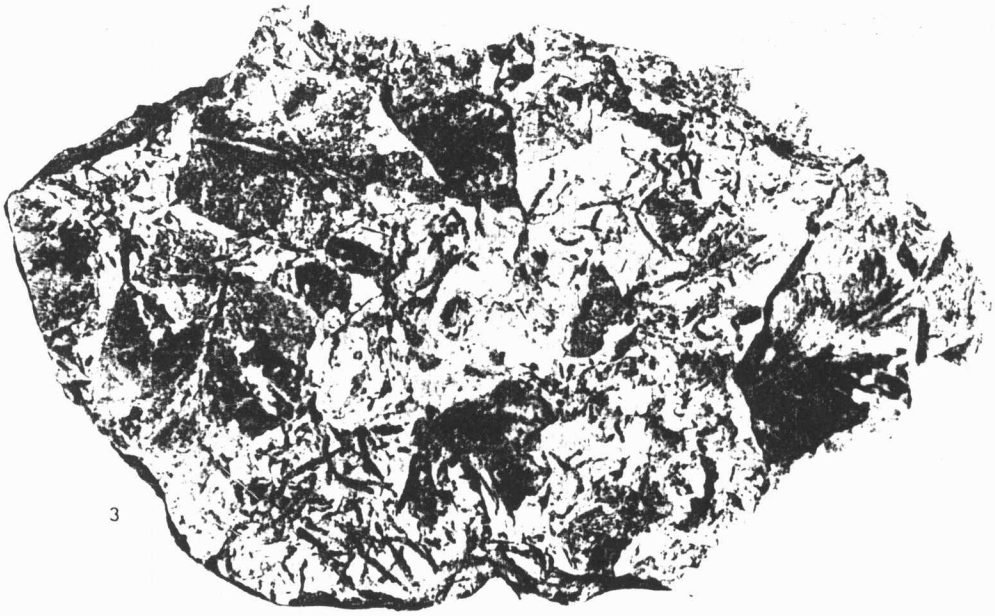


3

Plate 21. Ferns and sphenopsid

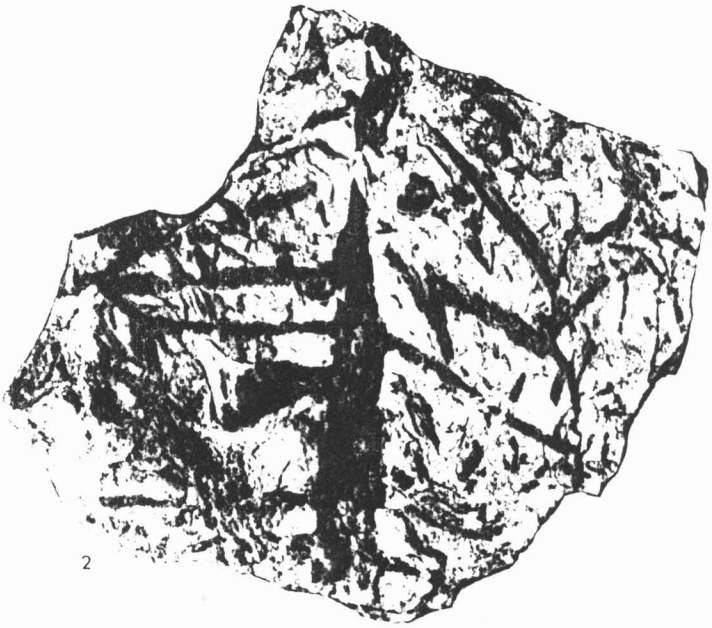
1. Unidentified fern, upper Coffeyville Formation, Coffeyville, Kansas (Cf2), x 3.5 SUI 49163B

2. Pinnularia sp, upper Coffeyville Formation, Coffeyville, Kansas (Cf2), x 2.4 SUI 49161A

3. Thin section of Psaronius stem, Galesburg Formation, Dennis, Kansas (De1), x 17.

# PLATE 21

1



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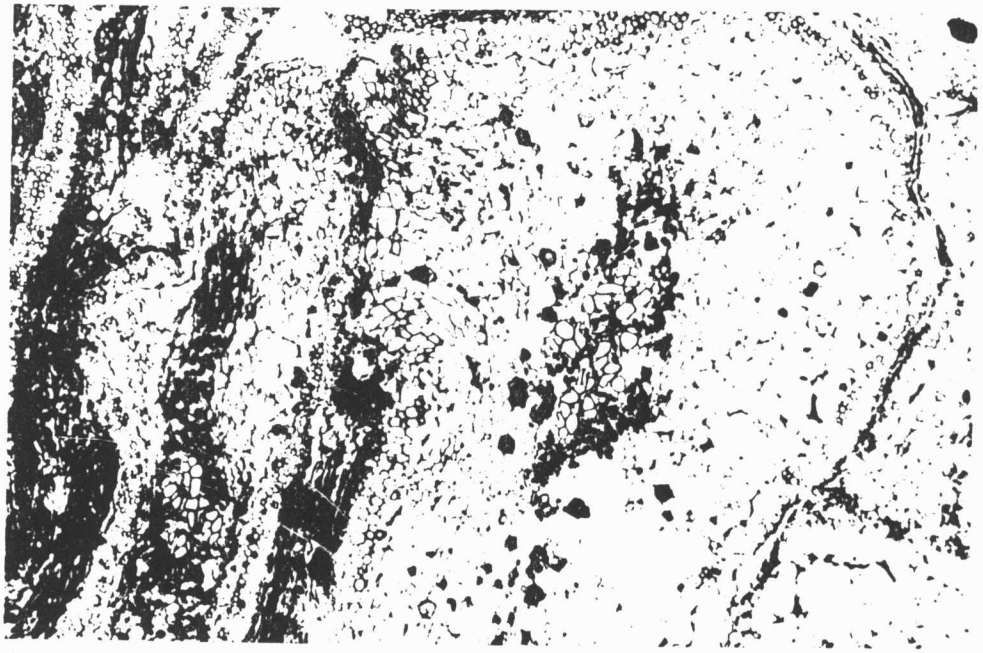


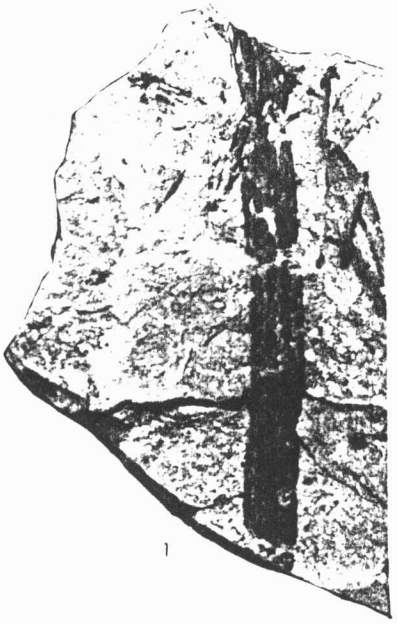
3

Plate 22. Lycopods and ferns

Specimens from upper Coffeyville Formation, Coffeyville, Kansas (Cf2)

1. Lepidophylloides sp, x 2 SUI 49162A
2. Lepidostrobophyllum sp, x 3.3 SUI 49160A
3. Miscellaneous unidentified ferns, x 1.8 SUI 49163C

# PLATE 22



1

2

3

Plate 23. Sphenopsids

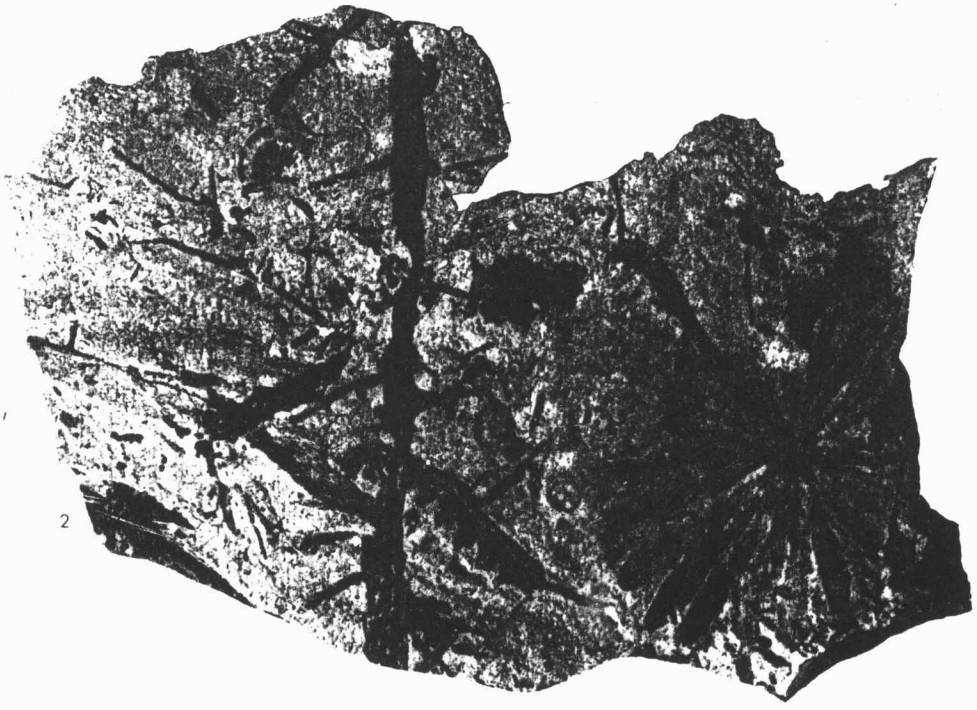
Specimens from upper Coffeyville Formation, Coffeyville, Kansas (Cf2)

1. Annularia mucronata Schenck, x 1.3 SUI 49158A

2. Annularia mucronata Schenck with Pinnularia sp and ferns, x 1.9 SUI 49158B

# PLATE 23

1



2

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