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Application of Sequence Stratigraphic Concepts to the
Iola Limestone (Missourian, Upper Pennsylvanian)
in Kansas and Missouri

by

Thomas D. Olszewski

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APPLICATION OF SEQUENCE STRATIGRAPHIC CONCEPTS TO THE IOLA LIMESTONE (MISSOURIAN, UPPER PENNSYLVANIAN) IN KANSAS AND MISSOURI

by

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ABSTRACT

The Iola Limestone (Linn Subgroup, Kansas City Group) is the marine portion of a Missourian (Upper Pennsylvanian) cyclothem. Significant sequence stratigraphic surfaces (lithologically recognizable and laterally continuous) are present within the unit. These provide a framework for understanding how accommodation space changed during the deposition of this portion of the cyclothem. The lowermost surface is an erosional horizon or paleosol at the base of the Chanute Shale; this is a type 1 sequence boundary unconformity. The Chanute Shale, an estuarine valley fill package, is the lowstand systems tract of the Iola cycle. The transgressive systems tract includes both the Paola limestone and the Muncie Creek shale. A transgressive surface, the sharp facies transition between the Chanute Shale and the Paola limestone, represents the passage of effective wave base as it transgressed during sea level rise. The black shale lithology of the Muncie Creek resulted when effective wave base transgressed coastal peat swamps and began flushing detrital organic matter into the distal marine basin. The maximum flooding surface is a submarine erosional surface at the base of the Raytown limestone. In most places the entire Muncie Creek has been removed, leaving nothing but a lag of exhumed phosphatic nodules on a hard/firmground at the top of the Paola. The Raytown itself represents the highstand systems tract. It was during stillstand that carbonate tidal flats could

prograde in Nebraska and northwest Missouri and a phylloid algal limestone mound aggraded in southeastern Kansas. The cycle ends as the Lane Shale fills in any remaining accommodation space, capping the sequence with a type 2 sequence boundary.

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INTRODUCTION

General Statement

The most striking aspect of Mid-Continent, Upper Pennsylvanian stratigraphy for any outside observer is its remarkably repetitive nature. This pattern was first explicitly described by Udden (1912), but cyclic packaging of rock units in Kansas was recognized by Moore in 1931.

However, the cyclic concept of sedimentation in epeiric seaways, such as that found on North America during the late Carboniferous, has been criticized on a number of points (Bayer at al., 1985; Reading, 1978). These are not conceptual, but rather, they deal with the consequences of adopting a stratigraphic model such as a "cyclothem":

1.) cycles often are established on the basis of subjective criteria,

2.) identification of cycles becomes more important than the facies pattern within any one cycle,

3.) recognition of cycles focuses on their causes which, in turn, often terminates investigation of the sedimentological regime,

4.) and, an *a priori* mindset expecting cyclicity often results in neglect of stratigraphic or sedimentological features which are not incorporated into the model.

The point of these criticisms is that recognition of and search for cycles can lead to disregard for details which can test different hypotheses about their driving mechanisms and criteria for their definition.

The cyclic nature of the Pennsylvanian stratigraphy in the Mid-Continent is not generally in dispute, as might be inferred from point number one. However, the definition of a cyclothem and what caused them has been the subject of much debate ever since their first recognition (see Heckel, 1984b for a thorough review). Although based on the studies of previous workers, the current paradigm explaining these cyclothems was first fully developed by Heckel in 1977 (a more recent review is given in Heckel, 1991). This model will be considered in a later section, but basically each individual cyclothem is a transgressive-regressive wedge created by eustatic changes in sea level. Heckel redefined the term "cyclothem" in the following way:

> "The basic vertical cyclic pattern that emerges to characterize particularly the Missourian (Kansas City-Lansing) part of the Upper Pennsylvanian is, in ascending order: sandy (outside) shale formation--middle limestone member--black (core) shale member--upper limestone member--sandy (outside) shale formation. This basic sequence is termed herein simply a cyclothem (Kansas-type)....Moore's (1936, 1949) restricted usage of cyclothem for only a shale-limestone couplet is abandoned." (Heckel, 1977, p. 1046)

Heckel (1977) used this definition to identify a series of cyclothems in the Upper Pennsylvanian and, because he attributed cyclothem development to eustatic changes in sea-level, he went on to develop a qualitative sea-level curve for this time period (Heckel, 1986).

However, apart from general predictions based on the transgressive-regressive model (Heckel, 1980, 1983, 1984a), little has been published about the facies distributions and geometries at the scale of the entire Pennsylvanian embayment. In addition, the stratinomic influences on individual beds within a single cyclothem have also generally been neglected. Larger scale, basin-wide studies of individual rock units are needed to fill this gap in understanding so roundly criticized by Bayer at al. (1985) and Reading (1978).

Purpose of Study

The primary purpose of this study is to develop an effective understanding of the origins and inter-relationships of the facies in the open marine part of an individual cyclothem, the Iola Limestone (fig. 1). The point is to produce the most precise description possible of the Pennsylvanian in the Mid-Continent at a series of geologic "moments" in time. Hopefully, a single study covering an area as large as this one (fig. 2) will contribute to a better understanding of how to compare cycles and why they differ from one another in outcrop.

Area and Methods of Study

The Iola Limestone extends from northern Oklahoma, through southeastern Kansas and northwestern Missouri, to

KANSAS ROCK COLUMN
(modified from Zeller, 1969)

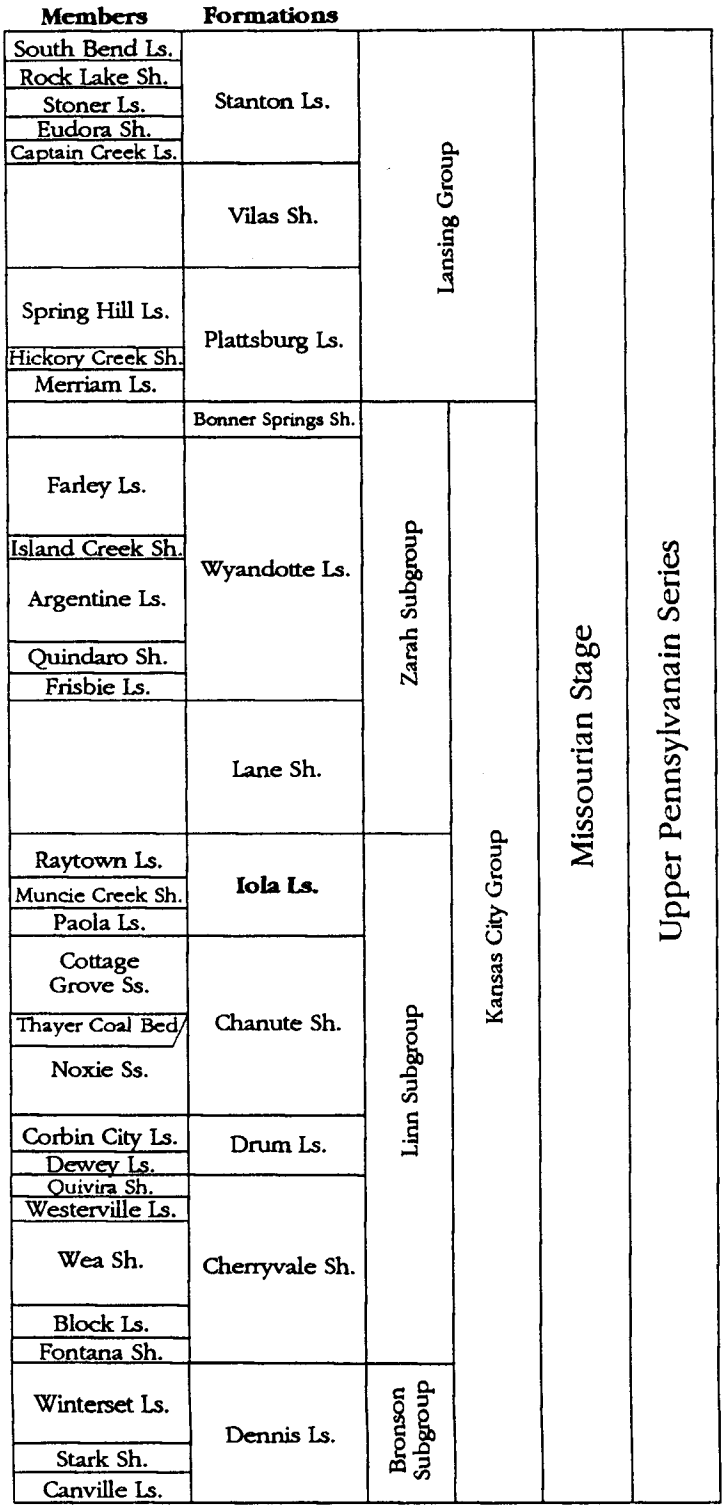

Figure 1. Stratigraphic position of the Iola Limestone (modified from Zeller, 1969).

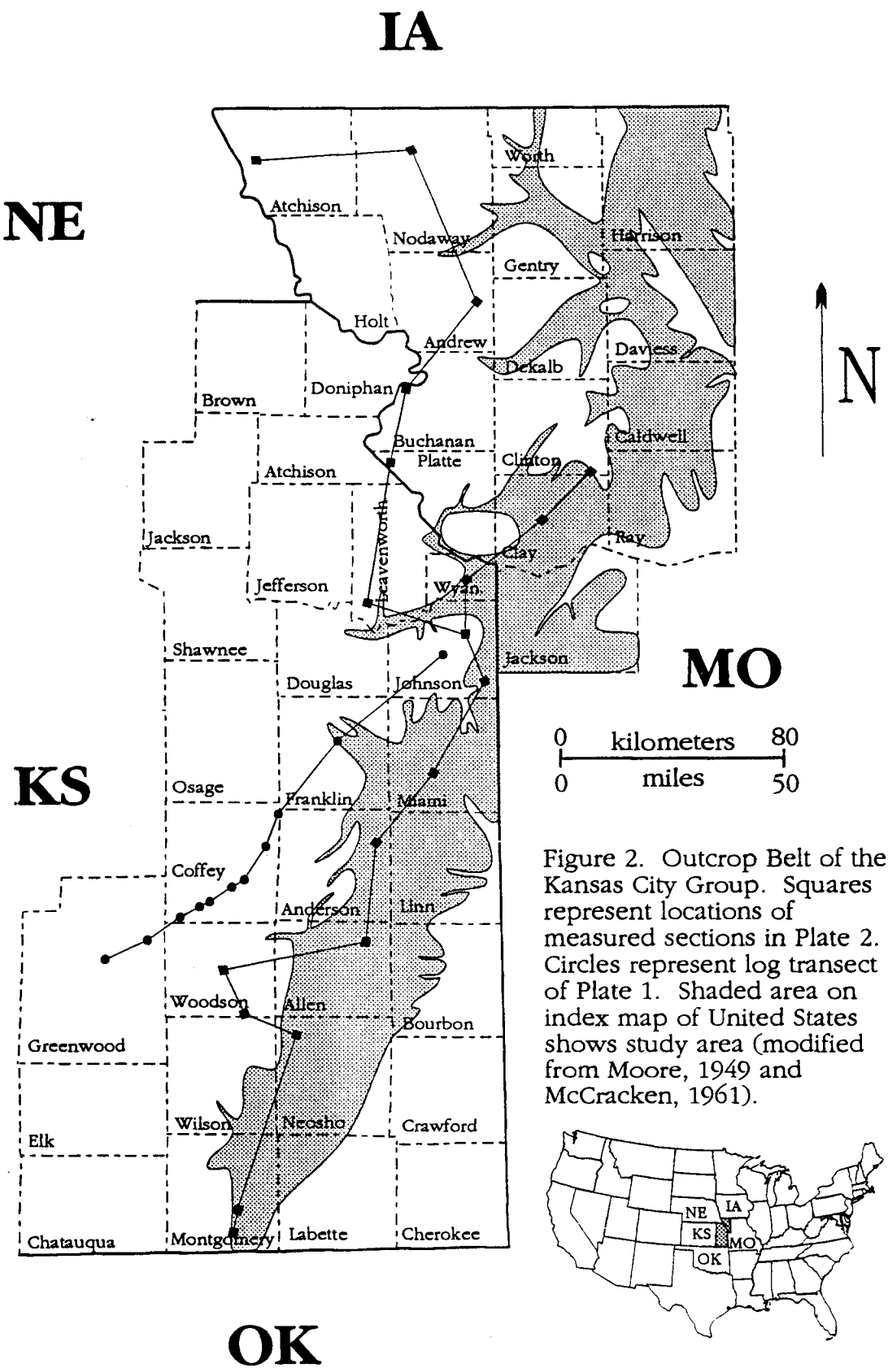

Figure 2. Outcrop Belt of the Kansas City Group. Squares represent locations of measured sections in Plate 2. Circles represent log transect of Plate 1. Shaded area on index map of United States shows study area (modified from Moore, 1949 and McCracken, 1961).

southern Iowa and southeastern Nebraska (fig. 2), but fieldwork was limited to Kansas and Missouri.

In addition to field descriptions of localities along the outcrop, subsurface well log data and recently available cores from southeastern Kansas are incorporated. The subsurface data are used to delineate the three dimensional shape and the geometric relationship of rock units, thereby helping to constrain facies models.

Samples from both core and outcrop were slabbed, polished, stained, and acetate peels were made for microscopic analysis. Peels were used to complement and expand detailed field descriptions. Stains used were Alazarin Red S and Potassium Ferrocyanide, which are used to identify dolomite and reduced iron content, respectively (Adams et al., 1984).

SYNTHESIS OF PREVIOUS WORK

Introduction

The Iola Limestone, the overlying Lane Shale, and the underlying Chanute Shale are part of the Linn and Zarah Subgroups of the Kansas City Group (fig. 1). The age is known as the Missourian in large parts of North America, but corresponds to the lowermost Stephanian of northwestern Europe and lower Kasimovian of Harland et al. (1989).

Chanute Shale

Zeller (1969) recognized two members within the Chanute Shale--the Noxie Sandstone Member in the lower part and the Cottage Grove Sandstone Member in the upper part. Separating these two members is the Thayer Coal Bed, although it is not always present.

The Noxie Sandstone Member is well developed in southeastern Kansas where it can be up to 24 meters thick (Haggiagi, 1970). It is comprised of massive to platy beds of well-sorted, micaceous, fine sand sized quartz; ripple marks and cross-stratification can be seen at some locations. Where this member is not composed of sandstone there is an "Unnamed Shale" in the same stratigraphic position; this is most likely a lateral facies change (Haggiagi, 1970). Three lines of evidence suggest that the lower surface of the Noxie is erosional: 1) a basal conglomerate of clasts from underlying units, 2) approximately 30 meters of relief on the basal surface, and 3) rock units as low as the Stark Shale Member of the Dennis Limestone are missing in some places. In addition, a five kilometer wide channel oriented northeast-southwest has been mapped in Neosho County (Jungmann, 1966). The Noxie sandstone is not present in northeastern Kansas, but its lateral equivalent at the base the Chanute is described as a purple or red mudrock and a gray-green "marly" mudrock with calcareous nodules in Miami (Miller, 1966) and Johnson

(O'Connor, 1971) Counties. These descriptions strongly suggest paleosol development during subaerial exposure.

The Thayer Coal Bed, which separates the two recognized sandstone members of the Chanute, can be found along the entire Kansas outcrop belt from Wyandotte County in the north to Montgomery County in the south. It varies in thickness along the outcrop belt from a thin organic smut at the northern end to a sixty centimeter thick, minable coal bed in Linn County (Seevers, 1969). Thicker exposures of coal are often associated with an underclay and also contain partings of black, fissile shale (Haggiagi, 1970).

Overlying the Thayer Coal Bed is the Cottage Grove Sandstone Member, which resembles the Noxie sandstone lithologically. It is also thicker to the south, although there are discontinuous patches of it in northeastern Kansas (Zeller, 1969). Its maximum reported thickness is 19.5 meters (Haggiagi, 1970).

Haggiagi (1970) interpreted the sandstones of the Chanute as delta bar fingers with a southern source of sediment. Cores, however, indicate that there is strong tidal influence in the Cottage Grove sandstone (Archer, personal communication, 1993) and that a better model for these units may be an estuarine system analogous to that described in the Virgilian Douglas Group (Archer et al., 1993).

The members of the Chanute Shale are not differentiated in Missouri, and no extensive sandstones have been reported. In southern Platte County, the exposed Chanute is 3 to 5 meters thick and contains abundant fossils (particularly gastropods) although in other areas northeast of Kansas City a purple-maroon shale overlying a thin coal is reported at the base of this formation (Howe, 1986). The environments in which the Chanute was deposited in Missouri are generally lower energy than the sand formations of southeastern Kansas.

Iola Limestone

The Iola Limestone was named in 1894 by Haworth and Kirk to identify a prominent limestone ledge in southeastern Kansas. Through its history the name has been used incorrectly to describe the Wyandotte Limestone, especially in Missouri and northeastern Kansas--this is a notorious miscorrelation because where the Wyandotte is absent in southeastern Kansas, the Iola thickens and strongly resembles the Wyandotte in north-central Kansas. In north-central Kansas, the Wyandotte is very thick (more than 10 meters) and the Iola is reduced to a narrow ledge. (See Plate XII, Newell, 1935, for his revision of Hinds and Greene, 1915.)

Although the Iola is described in a general way in county geology bulletins (Miller, 1966, 1969; Jungmann

1966; Seevers, 1969; O'Connor, 1971; Howe, 1986), three recent studies have made it the focus of detailed analysis. Dawson and Carozzi (1986) examined the phylloid algal complex in Anderson, Allen, and Neosho Counties. Another study (Leonard, 1990) in Wyandotte, Johnson, and Miami Counties provides a northward continuation of the area examined by Dawson and Carozzi (1986). A study by Mitchell (1981) is important because it ties together and extends the area of the other studies southward into Oklahoma and into Iowa and Nebraska; the entire outcrop of the Iola Limestone. A serious deficiency in Mitchell's study, however, is his dismissal of the Iola in Missouri--a 210 kilometer gap--as "covered section omitted (Mitchell, 1981, fig. 8)."

Paola Limestone Member.--All three studies described the Paola Limestone as a thin, continuous wackestone (and sometimes packstone) deposited on a carbonate ramp below effective wave base. Mitchell (1981) reported that it is thin or missing in southwestern Iowa and Nebraska. He also divided the unit into a lower sandy bed at its contact with the Chanute Shale and an upper carbonate bed. Both Dawson and Carozzi (1986) and Leonard (1990) recognized a hardground or omission surface at the top of the Paola. Despite the agreement on its description, the interpretation of the Paola differs amongst these three

studies. Both Leonard (1990) and Mitchell (1981) interpret this unit as having been deposited as water depth increased, but Dawson and Carozzi (1986) regard it as the deepest water phase of Iola deposition.

Muncie Creek Shale Member.--This unit is more variable than the underlying Paola. In the region where Dawson and Carozzi (1986) worked, it is little more than a very thin (<10 centimeter) gray claystone, but can be recognized by the presence of phosphate nodules. Leonard's (1990) study area is very interesting because it covers the transition of the Muncie Creek shale from the thin gray lithology to a thicker (1 to 1.5 meter) black, fissile shale. Mitchell (1981) reported a similar distribution and also reported pockets of black mudrock (of differing thicknesses) in Neosho County, Kansas, and in Iowa and Nebraska. All three studies interpreted this change in lithology as being controlled by a bathymetric high in southeastern Kansas, which prevented the accumulation of a thick Muncie Creek. Leonard (1990) and Mitchell (1981) both agreed that the Muncie Creek represented deepest water deposition in the Iola cycle.

Raytown Limestone Member.--The most prominent feature of the Raytown on outcrop is a phylloid algal limestone in southeastern Kansas where the unit is 13 meters thick. The

phylloid algal limestone is thinner where the Raytown is mostly bryozoan and brachiopod wackestone (Leonard, 1990). South of the buildup, on the Kansas-Oklahoma border, the Raytown is an algal-poor skeletal wackestone-packstone with some minor sandstone (Mitchell, 1981). In Nebraska, the Raytown is drastically different than elsewhere--it is a laminated carbonate mudstone with possible desiccation cracks and evaporite molds which Mitchell (1981) interpreted as shoreline deposits.

Dawson and Carozzi (1986) focused on development of the phylloid algal thickening in southeastern Kansas. They described a complex depositional and diagenetic history that began as a bioclastic bar and evolved upward into a bioaccumulated-bioconstructed feature (the algal mound itself) with a variety of internal subfacies. They thought that because the originally aragonitic algal blades had been dissolved there must have been a period of fresh water diagenesis between submarine diagenetic events. Dawson and Carozzi (1993) have since found that moldic porosity of this type can be produced by burial pressures, which eliminates the need for an episode of fresh water diagenesis. Equant calcite spar, interpreted as a final fresh water diagenetic event, is equivocal without isotopic analysis (Walker, 1989). All three studies (Mitchell, 1981; Dawson and Carozzi, 1986; Leonard, 1990) interpreted the Raytown in Kansas as having been deposited at or above

effective wave base and representing a shallowing upward unit.

Unlike the relatively pure limestones of the Raytown in Kansas, this unit gets thinner (averaging 1.5 meters in southern Platte County) and increasingly argillaceous northeastward of the Kansas City area in Missouri (Howe, 1986).

Lane Shale

Overlying the Iola Limestone is the Lane Shale, which is less variable lithologically than the Chanute Shale. South of northern Allen County in Kansas, the Wyandotte Limestone, which separates the Lane Shale from the Bonner Springs Shale, is absent or reduced to a few calcareous flags, and the two shales are not differentiated (Zeller, 1969). The total thickness of the two shales in Neosho County is 20 meters, and the lithology is generally a blocky, gray mudrock. Locally, there is a dark gray to black mudrock interval up to 2.5 meters thick about 3 meters above the top of the Iola, and in the northwestern part of Neosho County a sandy, yellowish-gray mudrock occurs directly above the Iola (Jungmann, 1966). In Allen and Linn Counties, the combined Lane-Bonner Springs interval ranges from 10 to 30 meters and is thickest where it contains a dusky yellow, thin bedded, micaceous siltstone. Overall, it is reported as relatively

unfossiliferous, but contains occasional plant impressions and carbonaceous smudges (Miller, 1969; Seevers, 1969). In Miami County, the Wyandotte Limestone becomes increasingly prominent, separating the Lane from the Bonner Springs Shale. The Lane is 5 to 30 meters thick and is thicker and richer in silt and sand in the western part of Miami County (Miller, 1966). A similar pattern is found in Johnson County--greater thickness is generally correlated to coarser sediment. Beds of molluscan fossils, as well as crinoids, brachiopods, and bryozoans, occur in the Lane (O'Connor, 1971). Overall, the Lane Shale in Kansas appears to show a remarkable lack of variability.

In Missouri, the Lane is more variable, ranging in thickness from 14 meters in exposures in southern Platte County to as little as 2 to 3 meters in the subsurface of the same county. Northeastward of the Kansas City area, the Lane contains thin coal beds and locally includes conglomeratic or sandy channel-fill deposits (Howe, 1986).

Facies Models

Platform Limestone Facies.--Carbonate shelf-lagoon deposits have been thoroughly reviewed by Wilson (1975, 1983) and Enos (1983). The general conclusion of these reviews seems to be that there is no single, unequivocally diagnostic means by which to identify marine shelves.

Shallow-water, subtidal carbonates are generally homogenized because of pervasive bioturbation. Faunas range from restricted to extremely diverse depending on local circulation patterns, and the taxa involved will, in part, reflect the time period of deposition. In the Middle and Late Paleozoic, bioclastic particles were produced primarily by crinoids, bryozoans, and brachiopods. Other fossils especially characteristic of Missourian time include fusulinid and opthalmidid foraminiferids, an encrusting association of foraminiferids and blue-green algae (Henbest, 1963) referred to as "osagiids", and phylloid algae.

Waves, tides, and storms produce physical sedimentary structures characteristic of shelves. Criteria for recognition of storm deposits in epeiric basins are reviewed by Kreisa (1981) and include:

1. Interbedded coarse (storm) and fine (fair weather) beds
2. Beds with sharp-scoured bases--gradational-burrowed tops
3. Pot and gutter casts
4. Lag-suspension couplets
5. Thickening and thinning and lenticular beds
6. Reworked, but autochthonous fauna
7. Infiltration textures (e.g. shelter porosity)
8. Escape burrows
9. Wave-generated undulatory lamination
10. Vertical sequences of sedimentary structures from plane-lamination to wave generated lamination
11. Laminated beds with upward thinning laminae, increase in matrix, and weak grading.

Features of deposition produced under tidal influence on shelves are discussed by Stride (1982), although he primarily described temperate, siliciclastic deposits rather than tropical, carbonate sediments. Depositional bedforms range in size across three orders of magnitude from ripples (wavelength<60 centimeters, height<5 centimeters) to sand banks (wavelength≈5-20 kilometers, height≈40 meters), and are made of sand-sized or coarser grains. Erosional features, formed by daily tidal currents, can be cut into any type of sediment from mud to gravel. A very important point made by Stride (1982) concerning tidal sedimentary structures is that bedforms may appear to be the result of unidirectional flow if asymmetry exists between ebb and flood current velocities (i.e. herringbone crossbedding is not necessarily the only feature characteristic of tidal regimes). With regard to the Mid-Continent, Hamblin (1969) presented evidence for tidally controlled deposition in the limestones of the Kansas City Group (of which the Iola is part), including bimodal distribution of foreset dips.

Rock body geometry and recognition of transitions to facies with less equivocal criteria for identification are suggested as good ways to delineate lagoonal shelf environments. But this approach comes with a warning--although shelves can be broken into broad facies belts, the depositional environments within these belts produce a

diverse patchwork of different types of sediment. The distribution of this facies mosaic can be very difficult to discern in areas where rock exposures are few and far between, as is the case in the Mid-Continent.

Phylloid Algal Mounds.--Thick Permo-Carboniferous limestones in North America are often associated with accumulations of phylloid algal debris. They occur in the Four Corners Area, in eastern New Mexico, in both western and eastern Texas, and are characteristic of Pennsylvanian limestones in Kansas (Wilson, 1975). These features range in age from the Desmoinesian through the Wolfcampian, have a wide range of sizes (from square meters to kilometers in area and from 3 to 130 meters thick), and apparently developed both on platforms and along shelf margins. Interest in these features is closely tied to the fact that their typically high porosity and permeability make them excellent hydrocarbon traps.

The term "phylloid" is the most commonly used word to describe leaflike algal fossils. Following the usage established by Pray and Wray (1963) (see also Baars and Torres, 1991), it is a purely morphological term with no reference to mode of life or phylogenetic history. Taxonomically, these algae include a variety of genera most likely from the chlorophyte families Codiaceae (Ginsburg et al., 1971) and Udoteaceae (Kirkland et al., 1993), the

rhodophyte family Peyssoneliaceae (James et al., 1988), and the ancestral corallines (represented by Archaeolithophyllum, family uncertain; Wray, 1964). Unfortunately, their state of preservation most often leaves no trace of the original biological structure rendering more specific identification virtually impossible. Modes of life include erect leaves (Kirkland et al., 1993) or encrusting layers (Wray, 1964).

Most reports of thick phylloid algal occurences describe them as mounds or buildups with original positive relief, but Ball et al. (1977) have disputed this interpretation and claimed that, although phylloid algae contribute to increased limestone thicknesses, these masses did not protrude above the surrounding seafloor. To substantiate their case, they made the following points: 1) the framework of mounds is not that of a biologically bound reef; physical processes are reflected in the geometry and internal structure of mounds more than the biology of the algae, 2) algae are virtually never found *in situ* and associated with positive depositional topography, 3) the Winchell Limestone, one of their examples, intertongues laterally with correlative shales, and 4) they claimed that there is no evidence for the baffling abilities of upright algae or the binding ability of encrusting forms. Again, they do not dispute the volumetric contribution of phylloid algae to limestone accumulations; although they point out

that the mere presence of algal plates does not necessarily indicate a thickening.

Their (Ball et al., 1977) arguments are all well presented, and they are correct in pointing out the pervasive physical reworking of phylloid algal facies and the importance of physical control on the geometry of the carbonate. It should be pointed out, however, that even in modern, rigid coral reefs more than 75% (Shinn and Halley, 1993) of what is preserved is rubbly breccia and not *in situ* corals. In addition, many modern reefs (those on the Trucial Coast, for example [Heckel, 1972; Tucker and Wright, 1990]) have their areal geometry controlled by physical factors like tidal deltas and tidal channels. Ball et al.'s (1977) argument for the Winchell Limestone intertonguing laterally is equivocal with regard to the issue of positive seafloor topography--it only means that the full thickness of limestone was not the total relief. Also, regarding lateral transitions across phylloidal limestones, Pray and Wray (1963) described low angle flanking beds offlapping an algal mound; this is unequivocal evidence of depositional relief (not simply post-compactional draping). With regards to baffling and binding ability of some phylloid algae, Cross and Klosterman (1981a) reported in-place thickets of Eugonophyllum vases in a mound with up to 10 meters of original relief in the Sacramento Mountains of New Mexico.

They reported that these could easily have trapped and held sediment. Also, Heckel's (1972, 1978) descriptions of carbonate filled channels with bimodal current indicators in the Stanton Limestone of Kansas suggested a buildup above channel base level. He suggested that tidal channels between Trucial Coast reefs would serve as modern analogs (1972). And finally, perhaps the strongest argument for the possibility of bathymetric relief comes from modern Halimeda mounds (described below) which can be more than 50 meters higher than the surrounding sea bottom (Roberts et al., 1988).

Recently discovered and described Halimeda bioherms are the closest modern analogs to ancient phylloid algal deposits. Halimeda bioherms occur in Indonesia (Phipps and Roberts, 1988; Roberts et al., 1988; Roberts et al., 1987), Australia (Marshall and Davies, 1988; Orme and Salalma, 1988), and the Caribbean (Hine et al., 1988). They occur on both shelf margins and the outer shelf behind a coral reef barrier (although they originated before the coral reef did [Marshall and Davies, 1988]). Individual bioherms can be as high as 140 meters but are more typically between 15 and 50 meters. They are interpreted as the results of high rates of algal production due to high nutrient influx in agitated waters (Marshall and Davies, 1988).

Modern Halimeda bioherms present a number of implications for fossilized Permo-Carboniferous forms.

First, Halimeda is a udotacean alga and apparently so was Eugonophyllum, a major component of Late Pennsylvanian mounds (Kirkland et al., 1993). Although strict taxonomic uniformitarianism is a notoriously unreliable means of interpreting the past, the fact that modern udoteacean algae can produce large bioherms suggests that ancient forms could have had the same potential. Benthic green algae have been interpreted as indicative shallow, protected lagoonal environments (Ginsburg et al., 1971) or depths from less than 33 meters (Pray and Wray, 1963; Heckel and Cocke, 1969). However, the tops of some modern mounds are in water over 40 meters deep (Hine et al., 1988). Another important implication for the past is the point made by both Roberts et al. (1988) and Hine et al. (1988) that Halimeda mounds occur in areas where oceanographic characteristics seem to preclude reef building corals (although this is not a strict rule [Hine et al., 1988, p. 178]). This modern ecological separation of the two groups could have an evolutionary parallel in the late Paleozoic as described by West (1988). Algae appear to be able to build mounds when and where corals cannot for whatever reason--environmental or macroevolutionary--and the reason that algal buildups are not more prominent at other times in geologic history is that other groups precluded them. Another point of paleoecological significance is the gross similarity of

Toomey's (1976) ancient reconstruction of dense phylloidal thickets with the concentrations of algae found on some mounds of the Great Barrier Reef by Marshall and Davies (1988, their fig.4a). Those authors stated, "Irrespective of the description, it [the Halimeda overgrowth] forms both an effective stabilizer of the underlying sediment and a trap for sediment produced in and transported to the banks" (Marshall and Davies, 1988, p. 143). Further similarity between modern mounds and those preserved in the rock record is seen in their internal structure as revealed by seismic stratigraphy (Roberts et al., 1987; Roberts et al., 1988). Large mounds seem to be nonrigid piles which have coalesced from smaller bioherms. This is analogous to phylloid algal buildups in Texas (Pol, 1985) and the Paradox Basin (Pray and Wray, 1963), where smaller bioherms have accreted into large mound complexes. With regard to their relatively non-rigid structure, early diagenesis of modern algal mounds involves micritization of algal plates and development of isopachous aragonite cement (Roberts et al., 1988), which are also characteristic of ancient mounds.

Based on a thorough review of literature on phylloid algal mounds in the Permo-Carboniferous of North America (Cross and Klosterman, 1981a, 1981b; Peterson and Hite, 1969; Choquette, 1983; Pray and Wray, 1963; Elias, 1963; Cys, 1985; Mazzullo and Cys, 1979; Toomey, 1980; Toomey et

al., 1977; Pol, 1985; Toomey and Winland, 1973; Ball et al., 1977; Heckel and Cocke, 1969; Crowley, 1969; Dawson and Carozzi, 1986; Harbough, 1959; Heckel, 1972), a consistent pattern can be found in their structure. Three basic facies can be recognized, each of which varies in its expression, but nevertheless suggests similar environmental conditions (fig. 3). Algal thickenings almost invariably display shoaling upward characteristics starting from a basal limestone followed by the thickening, typically an algal wackestone or packstone, followed often by a cap facies of bioclastic or oolitic grainstone-packstone. This is a simplification of Wilson's (1975) description because the model must be applicable to poorly exposed and very scattered Mid-Continent outcrops to be useful in this study. Some of Wilson's (1975) facies are recognized by large scale geometry or relative position to more reliably defined facies--means that are very difficult, if not impossible, to use in Kansas. The basal limestone is typically a wackestone or packstone, contains a diverse marine assemblage, and is generally a thin (around 1-2 meter thick), flat sheet. Interestingly, it commonly overlies a black shale or other lithology indicative of an anoxic, restricted environment (Elias, 1963; Cys, 1985; Toomey and Winland, 1973; Choquette, 1983). Toomey (1980) described a mound in the Sangre de Cristo Mountains where no basal facies seems to be present

Phylloid Algal Mound Facies Model

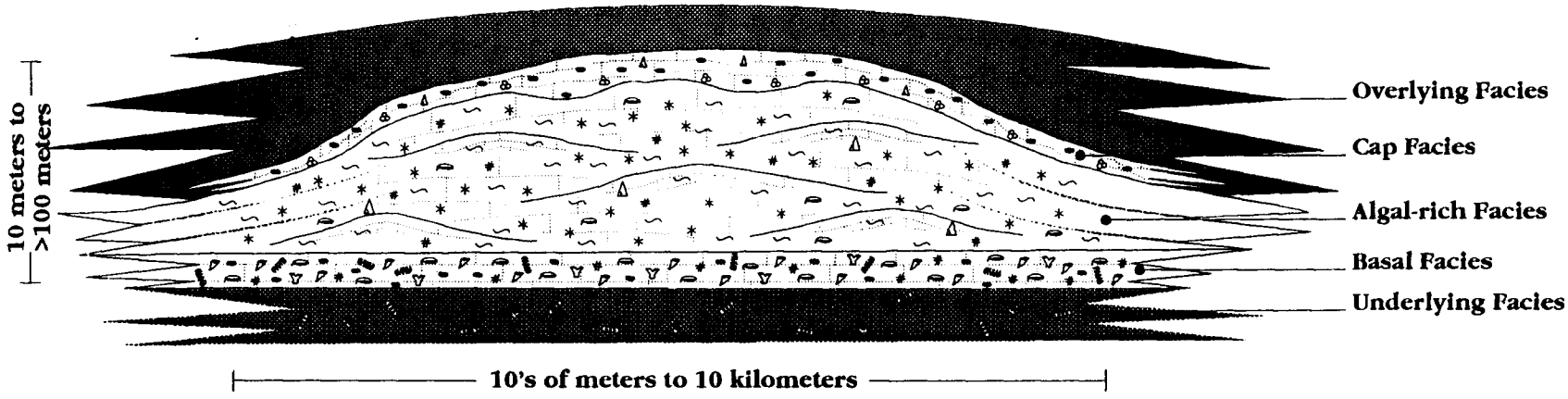

Figure 3. Generalized Facies Model for Phylloid Algal Mounds. Included in this depiction are the three primary limestone facies as well as the more variable over- and underlying lithologies. The underlying facies is commonly a black shale or a dark, micritic limestone suggestive of a restricted, anoxic environment, but it can also be the cemented cap of an underlying phylloid complex. The **basal facies** is typically a bioclastic wackestone with a high diversity of marine fossils (corals, bryozoans, brachiopods, crinoids, and dasycladacean algae). Its geometry is a thin sheet that often continues far beyond the margins of the thickening itself. Very rarely is it missing. The **algal-rich facies** is the lithology in which the thickening actually develops. It typically has a low diversity of macrofossils (usually only a few fenestrate bryozoans, *Composita*, and maybe gastropods) and contains a lot of spar (filling either primary porosity or neomorphically replacing dissolved algal blades). Lithologically, this unit can vary from a wackestone to a grainstone (often with conspicuous vertical and lateral trends in carbonate mud content). This facies develops as smaller phylloidal bioherms grow and coalesce; this leads to a complex internal structure made up of the cores and flanks of the smaller mounds. The large complex also has a core area and flanks, but lithologically, these are not much different than the equivalent parts of the smaller mounds. These mounds can pinch out to nothing or simply grade into thinner platform facies. The **cap facies** is the most variable lithology of the package, varying from bioclastic packstone or grainstone to oolite to peritidal muds. It can also be absent and replaced with a subaerial exposure surface. Where subtidal, it is usually described as rich in peloids and foraminiferids. Laterally, it can interfinger with the overlying facies or grade into platform deposits. The overlying facies can be dark, marine shale or another mound complex or paralic siliciclastic deposits. As a whole, mounds invariably display shallowing upward sequences (especially within the algal-rich facies). A noteworthy point is that this figure depicts the thickening as a symmetrical mound with a flat bottom–however, bathymetric relief cannot be assumed and mounds associated with shelf margins are not necessarily symmetrical across strike. However, criteria for distinguishing different sides of a given mound are not available in the literature. See appendix 1 for key to symbols.

and the algal-rich facies is initiated on a hardground. The middle algal-rich facies is the layer which actually thickens. It can range from a phylloid algae-rich wackestone to grainstone. Algal blades are virtually never in life position and are almost always fragmented to some degree. Other grains usually make up only a minute part of this facies, but they can include ooids, intraclasts, and fossil debris. The reason flanking and mound interior facies (presuming that positive depositional relief can be demonstrated) have been combined in this study is that often the two lithologies grade into one another and flanking beds are only recognized by the fact that they are draped over the mound core in outcrop. With the small and scattered outcrops of the Mid-Continent, the likelihood of recognizing foresets or drapes at mound margins is minimal. In addition, because the general pattern for the accretion of large scale mound complexes seems to be the coalescence of smaller, individual bioherms, distinguishing the cores and flanks of each of these smaller mounds is exceedingly difficult without sufficiently continuous outcrop. This does not mean to imply that the algal-rich facies is homogeneous or that lithology is independent of its position in a phylloid algal complex, just that such differences are gradational and are best defined by facies geometry rather than lithology. The third facies is the capping facies, which seems to be quite variable, ranging

from oolite, to bioclastic lags, to complex boundstones, to peritidal sediments and is not even always present. In the Paradox Basin, Pray and Wray (1963) reported that capping facies fill in and around mound flanks as well as tops, further strengthening the case that there was original depositional topography.

Studies of modern depositional environments in shallow, tropical seas have provided many modern analogs which have been directly applied to the interpretation of ancient rocks. However, strict application of the uniformitarian method breaks down if the specific circumstances of a region and time period are not incorporated into depositional and stratigraphic models. One example of a facies without a perfect modern example is the phylloid algal complexes characteristic of the Pennsylvanian and Permian periods. Their closest modern analogs are probably Halimeda bioherms found in modern tropical seas. In addition, those present in Kansas were part of a broad, epeiric embayment rather than a relatively narrow shelf or an isolated platform. A more successful approach to interpreting such facies is a process-response facies model; one with properties borrowed from modern environments, but modified for the physical circumstances of an epicontinental embayment and the biotic circumstances of the late Pennsylvanian. Because of the prominence of a mound complex in the Iola Limestone, understanding phylloid

algal buildups is critical to accurate recreation of the ancient Mid-Continent sea in which the limestone was deposited.

Black Shale.--The most controversial lithology of Mid-Continent cyclothems is the black, fissile phosphatic shale found in many cyclothems. Zangerl and Richardson (1963) presented the most comprehensive description of an "algal flotant" interpretation for its environment of deposition; an idea developed with nearshore, lagoonal black muds as analogs (including fresh or brackish water in coastal plains). Their evidence for shallow water deposition and high rates of sedimentation includes extremely well preserved, articulated fish fossils, fossils preserved at high angles to bedding, fresh or brackish water fossil assemblages at some localities, and the fact that the Mecca and Logan Quarry shales are almost coal in composition (they have a very high content of degraded plant detritus) and overall aspect.

An alternative interpretation of the black shales as offshore deeper water deposits emerged in the 1960's (Evans, 1967; Schenk, 1967) and was fully developed and presented by Heckel in 1977 (see Heckel, 1991 for the most recent published revision). This model proposed that black shale is the product of oceanic upwelling at the point of sea-level highstand. More recent geochemical evidence

(Wenger and Baker, 1986; Coveney et al., 1991) indicated that variation in the fissile, black shales requires a more sophisticated facies model than either the shallow or deep water extremes.

Boardman et al. (1984) took the side that black shales represent deep water (100 to 200 meters) and presented a series of points to support this interpretation:

1) Lateral Continuity of "Core" Shales--Many black shales can be traced over great distances; east-west across all of Kansas and into the Illinois Basin in some cases.

2) Midpoint Symmetry of Cyclothems--In the Missourian "Kansas-type" cyclothem, the black shale is most typically super- or subjacent or both to open marine, shallow water carbonates, implying a close association, if not deposition, in a sublittoral environment as opposed to somewhere more paralic.

3) Lack of Black, Fissile Phosphatic Shales in Unequivocally Nearshore Deposits--Some black shales, particularly when traced into Oklahoma from Kansas, grade into gray, silty, non-fissile lithologies. These units have sedimentologic and paleontologic signatures of open marine shelf deposits. According to Boardman et al. (1984), black shales are supposedly not found associated with indisputably shoreline facies.

4) Phosphate Distribution--Phosphorite nodules and peloids are generally restricted to the black shale facies

of the cyclothem. These deposits can be interpreted as having formed under the influence of marine upwelling.

5) Preserved Relief--Preserved relief on an erosional surface underlying a unit can be used to infer minimum water depth, presuming that the base of the fill is everywhere synchronous. Boardman et al. (1984) cited occurrences of 70 and 30 meters of relief underlying black shales in the Desmoinesian and Virgilian, respectively.

6) Petrologic Evidence--Diagenetic characteristics of the limestones typically underlying black shales show no evidence of subaerial exposure or freshwater diagenesis. Overlying limestones, on the other hand, frequently have well-developed exposure signatures.

These points, especially numbers one and three, make a strong case for black shales not being exclusively nearshore, lagoonal deposits (less than 10 meters as presented by Boardman et al., 1984). However, none of these traits demonstrate any positive proof for a water depth of 100 to 200 meters. Point three is not strictly true, the typical "Illinois Basin" black shale is intimately related with an underlying coal--clearly a very nearshore deposit (Heckel, 1977). (Although, in his ideal "Illinois Basin" cyclothem Heckel (1977) does place a marine limestone between the two.) The maximum possible depth extractable from preserved relief (point 5) is 70 meters--still a far cry from 100 to 200 meters. Petrologic

evidence only supports the assertion that black shales are not associated with subaerial exposure (point 6)--not that they were necessarily deep water. Also, with regards to point 4, Boardman et al. (1984) themselves pointed out that phosphates can be deposited in shallow, estuarine environments (Pevear, 1966) as well as areas of upwelling. A strict uniformitarian interpretation of phosphatic precipitation in nearshore nutrient traps is probably not appropriate in this case, but it makes the point that the physical-chemical conditions appropriate for deposition and preservation of inorganic phosphate are not limited to deep water.

A depositional model that may account for all the features of black shales was comprehensively described by Heckel in 1977, but it has since had a number of alterations and updates (Heckel, 1991). The following summarizes the more recent version and points out the major difference between the two. The black facies of Heckel's "Core" shale is frequently associated with a fossiliferous gray mudrock facies in conformable contact either above or below or both. According to Heckel (1991), the black shale itself contains no unequivocally benthic fossils or preserved bioturbation (although it is characterized by high concentrations of conodonts). It is up to 40% organic carbon and enriched in heavy metals (including uranium which gives a characteristic "kick" on subsurface gamma ray

logs). These traits indicate deposition of "Core" shale in dysoxic (grey facies) to anoxic (black facies) bottom water under conditions of sediment starvation at sea level highstand according to Heckel (1991). These conditions developed under a long term pycnocline, which inhibited vertical water circulation and led to oxygen depleted bottom water and sediment. To provide density stratification, Heckel described the establishment of a thermocline, which would have required "minimum high-stand water depths over the Midcontinent and Illinois basins of probably 100-200 meters...." (Heckel, 1991, p. 266). Heckel further proposed a two-layer quasi-estuarine circulation cell to produce anoxia below the pycnocline and upwelling, driven by trade winds, to account for non-skeletal phosphate distribution (although not necessarily all the way from the open ocean; Heckel, 1991, p. 267). In addition to the development of a thermocline, Heckel (1991) acknowledged the probable development of a halocline driven by freshwater runoff near the wet Appalachian highlands. This modification represented a significant departure from the oceanic upwelling model described in 1977 and will be further explored later in this section.

Despite the strong case for black shales not being uniformly nearshore deposits and the sophisticated model developed for a deep water environment of deposition, there is little unequivocal lithologic support for paleodepths of

100 to 200 meters or the occurrence of upwelling. The lithologic evidence accumulated by Zangerl and Richardson (1963) for shallow water deposition and high rates of sedimentation is very compelling for the Mecca Quarry Shale. Parrish (1982) used theoretical considerations to evaluate the importance of upwelling in the development of anoxic basins in the geologic past. She considered oceanic upwelling in the epeiric embayment of Late Pennsylvanian North America "unlikely because the many islands scattered through the area would have prevented the development of the required divergent flow" (Parrish, 1982, p. 770). As an alternative, she suggested the silled basin model of Demaison and Moore (1980) and pointed out that freshwater influx from wet equatorial highlands could create a persistent salinity stratification. This model does not require the extreme depths described by Heckel.

An increasingly sophisticated understanding of the variability both within and between black shales has emerged from geochemical studies in the last seven years (summarized by Coveney and Glascock, 1989). Wenger and Baker (1986) analyzed organic carbon in the Excello and Little Osage shales in southeastern Kansas and northeastern Oklahoma using both geochemical and petrographic methods. They found that organic constituents included both algal derived (liptinic) and terrestrial (humic) components in varying amounts through each shale sequence. The general

pattern was a sudden increase in the hydrogen index at the base of the black, fissile, phosphatic lithology which gradually decreased upward through the unit. This would imply increasing terrigenous input through the shale bed, which they interpreted as signifying deposition of the shale during rapid sea level rise. Implications for the development of the entire cyclothem will be discussed in a later section. Coveney and Shaffer (1988) found that $\delta^{34}S$ in black shales of Missourian "Kansas-type" cyclothems were more negative and less variable than $\delta^{34}S$ in Desmoinesian "Illinois Basin-type" black shales. They interpreted this signature to mean that the "Kansas-type" shales were deposited in more open marine conditions than the "Illinois Basin-type." A study with similar findings was that of Coveney et al. (1991), which presented new data on lateral variation of molybdenum abundance in several Desmoinesian shales which can be traced from Indiana and Illinois to Kansas and Oklahoma. In conjunction with published geochemical and stratigraphic information, they (Coveney et al., 1991) concluded that there are two intergradational types of Pennsylvanian black shale: nearshore "Mecca-type" and offshore "Heebner-type." Hatch and Leventhal (1992) used the criteria of Coveney et al. (Table 1, 1991) to interpret variation in a core of the Missourian Stark Shale from Wabaunsee County, Kansas. They found alternating layers, at a centimeter scale, of "Mecca-type" and

"Heebner-type" black shales, although they pointed out that the changes may not represent varying terrigenous input but, rather, could be due to changes in the strength of stratification in the water column.

In summary, traditional sedimentologic and stratigraphic techniques used to study Mid-Continent black shales have led to two opposing views for their genesis. The older one is that black shales were deposited very quickly in shallow water (on the order of 10 meters) and is given encyclopedic treatment by Zangerl and Richardson (1963). The other extreme is that presented by Heckel in 1977 (and subsequently revised in 1991), which interprets the black shales as deep water deposits (100 to 200 meter water depths). These two hypotheses share a number of points, and a synthesis based on newer information seems to be emerging. The first common point is that black shales of the Pennsylvanian Mid-Continent were most likely deposited under an anoxic water column (as indicated by their high organic carbon content and the lack of bioturbation and unequivocally benthic fossil assemblages). Also, this lithology is generally laterally extensive, although commonly its geochemical and sedimentary characteristics change subtly over its area. Finally, even though the fossils do not allow unambiguous paleoenvironmetal interpretation, they do suggest that a strong marine component was involved with black shale

deposition in most cases (Kidder, 1985; Boardman et al., 1984; Zangerl and Richardson, 1963). It seems generally agreed that some sort of water density stratification in the epeiric embayment would be the most plausible means of maintaining widespread anoxia (Demaison and Moore, 1980). Heckel (1992) preferred a thermocline associated with deep water upwelling as a means of accounting for the presence of non-skeletal phosphate in the black shales (see also Kidder, 1985). Another means of developing density stratification is through a halocline. The source of the lower density layer would be fresh water runoff from lands surrounding the embayment; this fits with the silled basin model of Demaison and Moore (1980). A lower density flow from nearshore would provide the means of supplying the great volume of mud which filled the basin by serving as an advective current (McCave, 1972; his case 5 off of a delta or under an advective mudstream). According to Schubel and Okubo (1972), suspended sediment can be moved extremely far across a shelf leading to sediment bypassing on modern shelves but leaving an even mud blanket in an epeiric basin. Long distance transport is also supported by the common presence of terrestrial plant fragments even in "Heebner-type" shales in Kansas (personal observation). Phosphate precipitation can be accounted for by the development of phosphorites in quasi-estuarine traps of freshwater nutrient supply (Pevear, 1966). A halocline

model escapes the necessity of deep water over vast expanses of the Mid-Continent. It also deals nicely with the continuum between "Mecca-type" and "Heebner-type" black shales as an onshore-offshore gradient; organic carbon and nutrients were sourced from land and passively rode with the freshwater upper layer of the pycnocline rather than with upwelling currents. Hatch and Leventhal's (1992) point about stratification controlling these two end members rather than shoreline proximity also fits the halocline model; if the influence of the halocline on water stratification decreases as it moves further away from its coastal source.

Stratigraphic Models

Kansas is renowned for Pennsylvanian cyclothems. That the order of the lithologies is not random was demonstrated statistically by Pearn in 1964, but this finding only confirmed the impressions and interpretations of earlier workers like Moore (1931, 1936, 1949), Elias (1937), and Weller (1930), who worked in different parts of the Mid-Continent. Cyclic stratigraphy requires a driving mechanism which cyclically controls the amount of accommodation space for sediment to fill and the rate and type of sediment filling it. Although it leaves the question of a driver open, sequence stratigraphy ("...the study of rock relationships within a chronostratigraphic

framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities [Van Wagoner et al., 1988, p. 39]") provides a conceptual model which can be used to predict the distribution of facies as they change and shift position through time. The specific circumstances of the model depend on the type of basin being analyzed, climate, sediment supply, tectonics, and any other factors which can influence the geometry and volume of accommodation and the nature of the fill. Two basic sequence stratigraphic models have become well known--the "Exxon" model for temperate, siliciclastic, passive margins (Vail et al., 1977; Posamentier et al., 1988; Van Wagoner et al., 1988) and a shallow water carbonate model (Read et al., 1986; Goldhammer et al., 1990). Neither can be applied wholesale to the epeiric sea of the Pennsylvanian Mid-Continent, but study of two models concerned with such different sedimentary systems provides insight to possible generalizations which are applicable.

"Exxon" Model.--The conceptual basis and terminology of the "Exxon" model is laid out in articles by Posamentier et al. (1988) and Van Wagoner et al. (1988), respectively. The conceptual basis of sequence stratigraphy concerns itself with the creation and filling of accommodation space (Posamentier et al., 1988), which in the "Exxon" model is

primarily driven by eustatic sea level change during essentially constant subsidence. Because this paradigm was developed to describe stratigraphic patterns on siliciclastic passive margins, it is assumed that the source of all sediment is essentially at the depositional-shoreline break (DSB) and that further offshore there will be a shelf-slope break overlooking a deeper basin. The DSB is "...a position on the shelf, landward of which the depositional surface is at or near base level, usually sea level, and seaward of which the depositional surface is below base level" (Van Wagoner et al., 1988, p. 41, i.e. the shoreward edge of accommodation space). Posamentier et al. (1988) described four systems tracts--lowstand, shelf-margin, transgressive, and highstand--controlled by the rate and extent of sea level change. These systems tracts lie between stratigraphic surfaces which were first identified by seismic stratigraphy but have definite lithologic expressions in core and outcrop. These surfaces include sequence boundary unconformities (types 1 and 2), the transgressive surface, and the maximum flooding surface. These surfaces are recognizable in the stratigraphic record and are the key to placing rocks within a chronostratigraphic framework.

Because a sequence is "a relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities" (Van

Wagoner et al., 1988, p. 39, after Mitchum, 1977), it seems logical to describe the conceptual model starting during the development of one of these sequence boundaries. There are two types of boundary unconformities: 1) a type 1 sequence boundary requires subaerial exposure and erosion and a basinward shift in facies on the shelf due to a relative fall in sea level at the DSB (i.e. accommodation space basinward of the DSB decreases due to sea level drop) (Van Wagoner et al., 1987), 2) a type 2 sequence boundary displays subaerial exposure, but there is no subaerial incision or basinward shift in facies because the rate of creation of accommodation is balanced by the rate of sediment input (the accommodation space basinward of the DSB is filled but base level stays at the same elevation) (Van Wagoner et al., 1987). A type 1 sequence boundary occurs when the rate of eustatic fall is greater than the rate of subsidence at the DSB--leading to erosion of the shelf because it stands higher than base level. In the type 2 situation, the rate of eustatic fall does not exceed subsidence so base level does not drop to a point where erosion can occur. However, if sediment aggrades all the way to base level, subaerial exposure features can then develop on the sediment surface. A vitally important point here is that unconformities do not form at eustatic lowstand; they develop during rapid eustatic drop in sea level because only then can dropping sea surface catch and

overtake the constantly subsiding basement (i.e. facies tracts are dependent on the **rate** of eustatic change relative to the **rate** of subsidence). If sea level drop does not exceed subsidence, then a type 2 boundary develops. Sediment, which is either removed from or bypasses the shelf, is deposited on the slope and in the basin as part of a lowstand systems tract or a shelf-margin systems tract, depending on whether the deposits lie directly above a type 1 boundary or a type 2 boundary, respectively (Van Wagoner et al., 1988). On the shelf only flooded river valleys are below base level and serve as sediment traps filled with estuarine deposits as sea level begins to rise--these are part of the lowstand systems tract according to Baum and Vail (1988).

Between the lowstand or shelf-margin systems tract and the overlying transgressive systems tract is the transgressive surface. This is "the first significant marine flooding surface across the shelf within the sequence (Van Wagoner et al., 1988, p. 44)." In siliciclastic, passive margin settings like those of the Atlantic Coast, this is commonly a ravinement surface carved by the beachslope environment as it (the beachslope) migrates landward and erodes the underlying sedimentary deposits (Baum and Vail, 1988). This systems tract forms during relative sea level rise, which starts just when the rate of eustatic fall equals the rate of subsidence and

continues as the rate of fall becomes less than the rate of subsidence. The effect of the relative sea level rise is to push the DSB landward and create accommodation space high on the shelf. Sediment is dropped right at the transgressing DSB and immediately flooded; as a result, it has a retrogradational character. Often, the transgressive systems tract is very thin or absent and the maximum flooding surface directly overlies the sequence boundary (Baum and Vail, 1988).

Between the transgressive systems tract and the highstand systems tract lies the surface of maximum flooding. This surface is synonymous with the downlap surface which "marks the change from a retrogradational to an aggradational parasequence set.... (Van Wagoner et al., 1987)" Following the example of Baum and Vail (1988) and Haq et al. (1987), "maximum flooding surface" is preferred to "downlap surface" because downlapping parasequence boundaries are difficult to identify and correlate without the aid of seismic stratigraphy. The change from retrogradation to aggradation occurs when sediment can fill accommodation space as fast space is created. Only when sea level is rising rapidly can enough space be created to force retrogradation. The maximum flooding surface, in siliciclastic, passive margin settings, is characterized by the development of a relatively deep water condensed section. These can be identified by shell accumulations,

bone beds, and glauconite (Baum and Vail, 1988). "The condensed section occurs largely within the transgressive and distal highstand systems tracts (Van Wagoner et al., 1987, p. 12)," when the DSB is rapidly transgressing or is as far landward as it will go and occurs on the rising limb of a eustatic curve rather than at highstand (Van Wagoner et al., 1987).

The highstand systems tract itself is characterized by aggradational and subsequent progradational facies patterns formed as relative sea level goes through highest stillstand and slowly starts to drop (Van Wagoner, 1987). The depositional pattern occurs because the rate of sediment input can stop the landward progress of the DSB and begin to push it seaward. If sea level drops below the shelf-slope break the highstand systems tract is overlain by a type 1 sequence boundary. If sea level does not go that far and the entire accommodation space over the shelf is filled with sediment, a type 2 sequence boundary develops and additional sediment is bypassed, becoming incorporated into the shelf-margin systems tract.

The model presented was developed for a very different kind of basin than the Pennsylvanian Mid-Continent, but a number of ideas can be usefully applied to an epeiric embayment. The first is that, although strict application of the "Exxon" model invokes eustacy as the external driving mechanism producing the facies patterns, the model

deals only with the creation of accommodation space and how it is filled. With the help of an explicit model such as this, facies tracts can be identified by their internal architecture and the types of surfaces which bound them, and they can be interpreted in their appropriate temporal context. A limitation of this model is the fact that siliciclastic sediments are virtually by definition allochthonous, and this means that accommodation space can only be filled at the DSB. In carbonates, which have the potential to be autochthonous (or at least parautochthonous), fill can aggrade from the bottom up or prograde from centers of production in the middle or at the edge of the shelf. Because Pennsylvanian cycles are mixed carbonates and siliciclastics, there is the potential for a very complex interaction between a number of sediment sources. Finally, the sequence model presented above is two dimensional and, therefore, when extended into the third dimension, is a cross-section of a system with a line source of sediment (at the DSB) where sediment can only be moved perpendicular to that source. In a large embayment, it would be possible that sediment could come from multiple directions producing a very complex, three dimensional internal architecture.

Shallow Water Carbonate Model.--Another application of sequence stratigraphy has been worked out for shallow water

carbonate environments (Read et al., 1986; Goldhammer et al., 1990). Because of the sediment type and general facies geometries, the bounding surfaces of systems tracts in carbonates can have very different expressions than those described in the "Exxon" model. The earliest models were one dimensional, but despite this limitation, they served to limit and define the parameters which could significantly affect stratigraphic patterns. More recent, two dimensional models (Goldhammer et al., 1993) have not significantly changed the findings of earlier models, except to delimit the diachroneity of surfaces and facies tracts.

Read et al. (1986) explored the influence of the following factors on carbonate sequence stratigraphy: lag time prior to sediment accumulation, sea level oscillation amplitude, sea level oscillation period, and subsidence rate. Other model inputs were depth dependent sedimentation rate and tidal range. (Lag time has since been largely replaced by lag depth which is a concept better grounded in facies processes [Goldhammer et al., 1990]. The difference between the two will be dealt with in a later section.) A lag between the time of initial flooding and the start of sedimentation was found necessary during low amplitude sea level oscillations to allow water to achieve subtidal depths before accommodation space was filled. Otherwise carbonate aggradation would always be

able to maintain peritidal conditions by keeping up with slow rise. Shorter lag times favor thicker intertidal caps at the expense of thinner subtidal bases because carbonate production would begin sooner and quickly fill the not yet maximized accommodation space. Increasing amplitude of the sea level curve increased the proportion of subtidal facies in an individual sedimentary cycle. Also, with a carbonate ramp of constant slope, increasing the rate of sea level drop (by increasing the amplitude or decreasing the period of the driving cycle) could strand tidal flats if their rate of progradation could not keep pace. This could produce entirely subtidal accumulations with or without subaerially exposed caps, depending on the rate of subsidence. Otherwise, increased subsidence rates generally led to thicker cycles with the same proportions of subtidal to peritidal facies if other factors were the same. Two very important lessons about sediment accumulation were learned from this relatively simple modeling excercise: 1) asymmetric sedimentary cycles in an aggrading system can only be produced by asymmetric driving cycles or when there is a lag before sediment can begin to accumulate and 2) although the sea level parameters being changed were period and amplitude the important factor controlling stratigraphic sections was the rate of sea level change. If sea level rose sufficiently fast only a short lag time would allow dominance by intertidal

deposits, and, conversely, if sea level dropped quickly enough, tidal flats would be stranded and cycles would lack intertidal caps. The important point here is that in the one dimensional model, just as in the more complex progradational sequences of the "Exxon" model, the factor controlling cycle structure is the **rate** of sea level change.

Before describing more sophisticated models for carbonate platforms, it is necessary to find a causal mechanism for the lag parameter. Goldhammer et al. (1990) abandoned the time component of lag and replaced it with lag depth. This is analogous to having a depth controlled depositional environment characterized by non-deposition or erosion. Enos (1991) suggested two possible causes for this to occur: 1) inhibition of carbonate production in very shallow water depths or 2) a physical or energetic, submarine limitation of the depth to which sediment can aggrade. Above this threshold depth sediment will be washed into other environments. A likely control on such a depth would be effective wave base. On a sloped ramp, such a depth will migrate laterally as relative sea level rises and falls. This physical surface of erosion is analogous to the erosive foreshore of the Mid-Atlantic coast (Swift, 1968), the migration of which cuts the transgressive surface of "Exxon" type sequences. Although comprehensive data is lacking, Enos (1991) cited some anecdotal data from

the Florida shelf and West Indies supporting this process interpretation of lag depth. If there really is a depth controlled environment creating the lag during transgression, then during regression it should not be surprising to see the same facies pass back over the same location. In his study of subtidal carbonate cycles, Osleger (1991, p. 917) said that "...processes such as storm and wave reworking and redistribution may act to inhibit aggradation..." above a given depth. He suggested that the existence of subtidal versus peritidal cycles in different sections may be controlled by the energy regime and platform morphology. Again, sediment accumulation is controlled by a physical threshold depth. If sediment locally fills this subtidal carbonate sink but production continues, what happens to the "excess"? It is swept either into deeper water or onto prograding tidal flats (Ginsburg, 1971). This is consistent with Read et al.'s (1986) point that tidal flats can be stranded if the rate of relative sea level fall is sufficiently high. This erosive or non-depositional "kink" in the base level surface is simply a reflection of basin geometry and energetics and can be present in both carbonate and siliciclastic environments. When it is present, and it must first be put into an appropriate facies context, it is recorded as the transgressive surface (the lag depth-time)

and can also serve as a cap to subtidal sediment accumulation.

Extensive field studies and complementary modeling by Goldhammer and a number of associates have built upon the original efforts of Read et al. (1986), especially with regards to patterns produced by heirarchies of cycles. Stratigraphic simulation of an isolated carbonate platform exposed in the Italian Dolomites (Goldhammer et al., 1990) with a one dimensional model demonstrated a way to recognize "missed" (i.e. unrecorded) eustatic beats. A series of cycles, based on the periodicity and shape of $\delta^{18}O$ curves from Pleistocene deep sea cores, was imposed upon a longer period third order eustatic curve. Cycle parameters were set at reasonable values that produced patterns like that seen in the Latemar buildup, a Triassic peritidal sequence. The model did include a lag depth in both the rising and falling legs of each cycle. Patterns produced mimicked the five part stacking of each megacycle (five fifth order cycles within each fourth order megacycle) and the variation in megacycle type was controlled by the superimposed third order cycle. Third order relative sea level rise produced amalgamated megacycles in which subtidal facies dominate and not every fifth order cycle was recorded by subaerial exposure. During relative fall, not every fifth order cycle was extensive enough to reinundate the platform, so exposure dominates the facies

and condensed megacycles are produced. (These peritidal condensed megacycles should not be confused with the condensed section of the "Exxon" model, which is produced by sediment starvation in an offshore environment.) At high or low sea level stillstand, the rate of accommodation is not changing fast enough to override the influence of fifth order cycles, so megacycles are made up of their full allotment of five subdivisions. One important point is that higher order cycles again reflect the **rate** of change in the third order eustatic cycle. Another is the potential of using higher order cycle architecture to define sequence boundaries. Because there are many subaerial exposure surfaces in the region, a third order sequence boundary is placed at the point where fourth order megacycles begin to thicken progressively upward. At the timescale of the entire sequence, sedimentation was continuous, so this is more like a type 2 than a type 1 boundary. They placed the maximum flooding surface in the region of amalgamated megacycles where they begin to thin sequentially upward through the section. No sediment starvation occurred, therefore no condensed section developed (sensu the "Exxon" model). The transgressive surface used to define the top of a third order lowstand systems tract is not sufficiently distinct from the transgressive surfaces of higher order cycles to clearly define the base of transgressive systems tract. The two

systems tracts are lumped together and grade into the highstand systems tract. The take-home message is that the architecture of sequences depends not only on the type of external driver, but also on the depositional environments which make up the overall system. The types of bounding surfaces and the actual characteristics of facies tracts can vary significantly in different basins because of differences in how accommodation space is filled (autochthonously or allochthonously) and how the filling process is recorded (the details of facies characteristics).

A final simulation of a previously published data set (Perkins, 1977) by Goldhammer et al. (1990), also has some relevance for the Missourian cycles of the Mid-Continent. Using δO^{18} data from deep sea cores as a proxy for Pleistocene sea level (scaled to 120 meters total change based on coral reef data), Goldhammer et al. (1990) attempted to recreate the stratigraphy of the Pleistocene Florida platform. Because fourth order sea level changes were so drastic, fifth order sea level beats were generally missed. Either relative sea level was so low that the platform remained exposed despite fifth order fluctuations or so high that fifth order beats did not recognizably influence bathymetric facies. If sea levels of similar magnitude and periodicity to those of the Pleistocene were occurring during the Carboniferous (Crowley and Baum, 1991;

Maynard and Leeder, 1992), then fifth order cycles could be missed due to extremely fast rates of rise and fall during the fourth order cycles for the same reasons.

Although Goldhammer et al.'s models (1990) are one dimensional and intended purely for autochthonous carbonate buildups, they have a number of important similarities and differences when compared to the siliciclastic "Exxon" sequences. In both cases, it is the **rate** of sea level change that controls the internal structure of systems tracts, even though the actual facies are grossly different. An important difference is the appearance of the important surfaces. Although the transgressive surface forms in a similar manner in both cases, the sequence boundaries and maximum flooding events may not be recorded by non-depositional or erosional surfaces if sedimentation is continuous and accommodation space is available. In these cases, careful measurement of higher order cycles and detailed facies analysis may be the only way to delineate these important boundaries even if they cannot be correlated to distinct, identifiable surfaces. And finally, the one dimensional models (Read et al., 1986; Goldhammer et al., 1990) concur, if sea level changes occur rapidly enough, then parasequences (higher order cycles) may not be recorded. This is because parasequences end up being amalgamated or condensed; they cannot be distinguished because the cycles which drove them were not

large enough to influence the facies. These generalities can be used as a guide in interpreting the Iola Limestone.

Heckel Cyclothem Model.--Heckel defined a cyclothem (Kansas-type) as follows (fig .4):

> "The basic vertical cyclic pattern that emerges to characterize particularly the Missourian (Kansas City-Lansing) part of the Upper Pennsylvanian is, in ascending order: sandy (outside) shale formation--middle limestone member--black (core) shale member--upper limestone member--sandy (outside) shale formation."
>
> (Heckel, 1977, p. 1046)

He interpreted this ideal sequence as a Waltherian transgressive-regressive package of depth controlled facies on a gradually sloping shelf (Heckel, 1984a; Heckel and Pope, 1992).

The transgressive limestone, as the name implies, is deposited during a sea level rise and overlies the outside shale. It is typically a thin (0.1 to 1 meter) wackestone with no evidence of meteoric diagenesis. Where it directly overlies a coal it is rarely expressed as more than a 1 to 5 centimeter thick shell accumulation. With regards to sequence stratigraphy, Heckel interpreted this limestone as the entire marine flooding package immediately overlying a sequence boundary represented by a paleosol or other terrestrial deposit (Heckel, 1984a; Heckel and Pope, 1992).

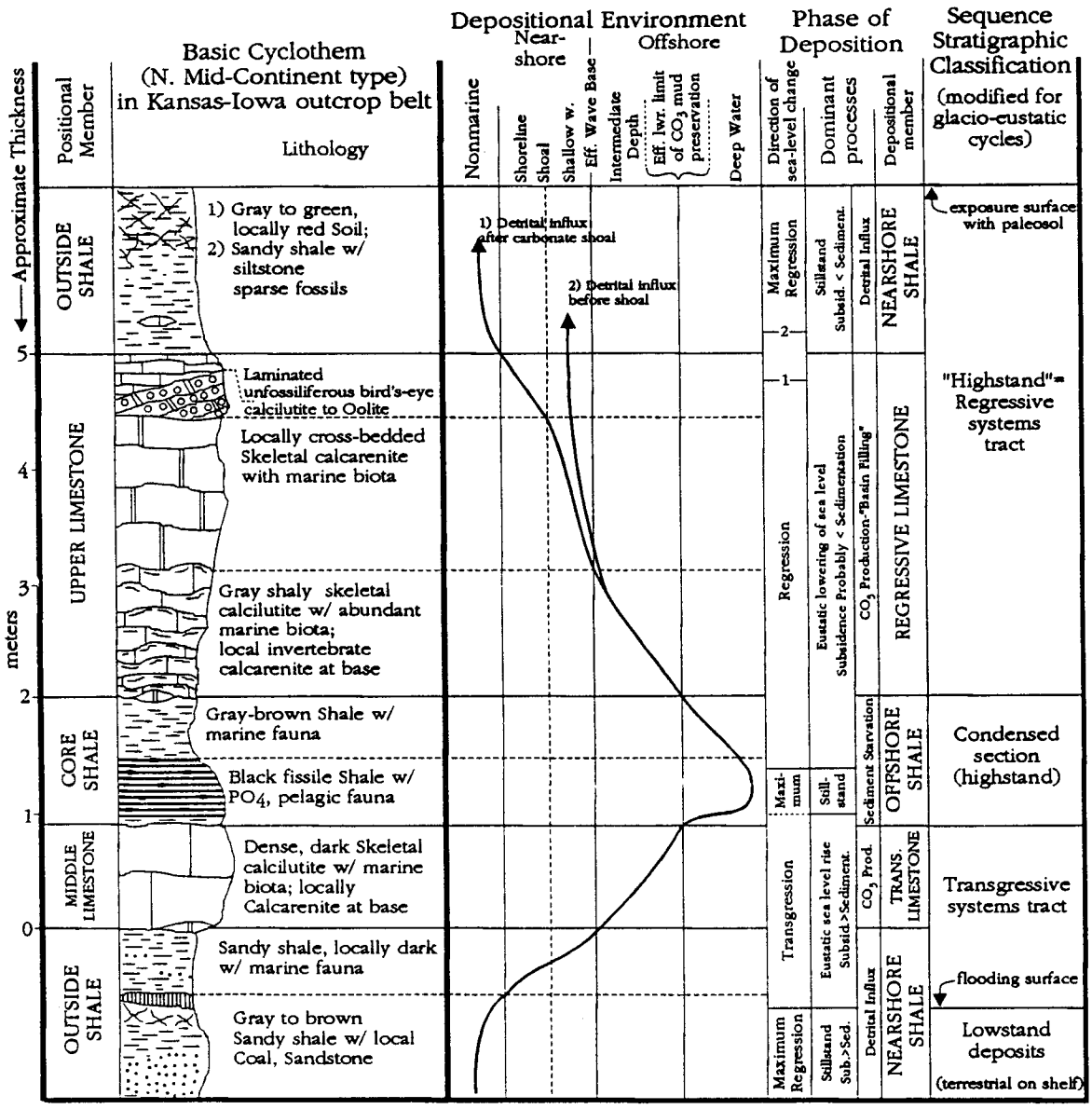

Figure 4. Basic Heckel Cyclothem. The vertical relationships between each of the positional members in the ideal Mid-Continent cyclothem. Note that the water depth curve the eustatic sea level curve are the same in this model (modified from Heckel and Pope, 1992).

The offshore "core" shale is typically a thin (0.1 to 1 meter) black, fissile, phosphatic shale to dark gray mudrock. The gray facies can be fossiliferous and represents a dysoxic zone separating the less restricted limestone facies from the entirely anoxic black shale (figs. 5a and 5b). The black facies contains essentially no benthic fossils and the biota is made up of nektonic or pelagic organisms like ammonoids and conodonts. This lithology is sediment starved and deposited under an anoxic water column far from shore during highstand. Anoxia and inorganic phosphate deposition are the results of a strong pycnocline produced by deep water upwelling and quasi-estuarine circulation (Heckel, 1991). In the terminology of sequence stratigraphy, Heckel described this unit as the condensed section.

The regressive limestone is deposited during sea level drop and represents shoaling upward conditions. The limestone is typically 1 to 8 meters thick and grades vertically from wackestones deposited below wave base to peritidal deposits at the top in some cycles. Heckel and Pope (1992) explicitly rejected the sequence stratigraphic term "**highstand** systems tract" because they interpreted this limestone to have formed during eustatic sea level fall. Differences between the transgressive and regressive limestone result from the effects of deepening versus shallowing water, respectively, and the different

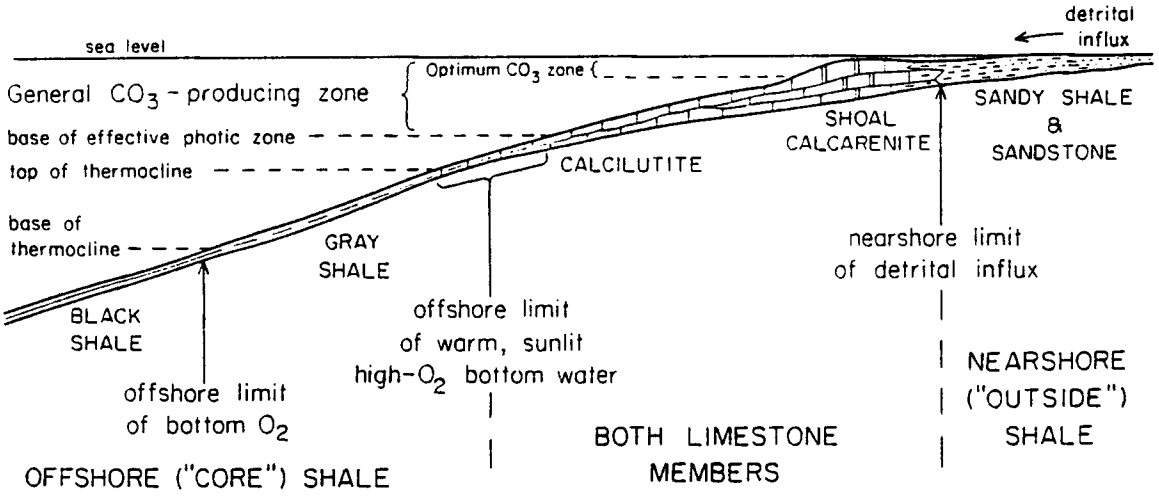

Figure 5a. Distribution of facies from shore to basin in the Heckel model. Note that the carbonate production zone lies between an offshore shale and a nearshore shale. A facies distribution such as this will only produce a Heckelian cyclothem centered on a "core" shale (fig. 4) where water depths on the ramp become sufficiently deep; elsewhere the T-R cycle will be centered on the carbonates (adapted from Heckel, 1984a).

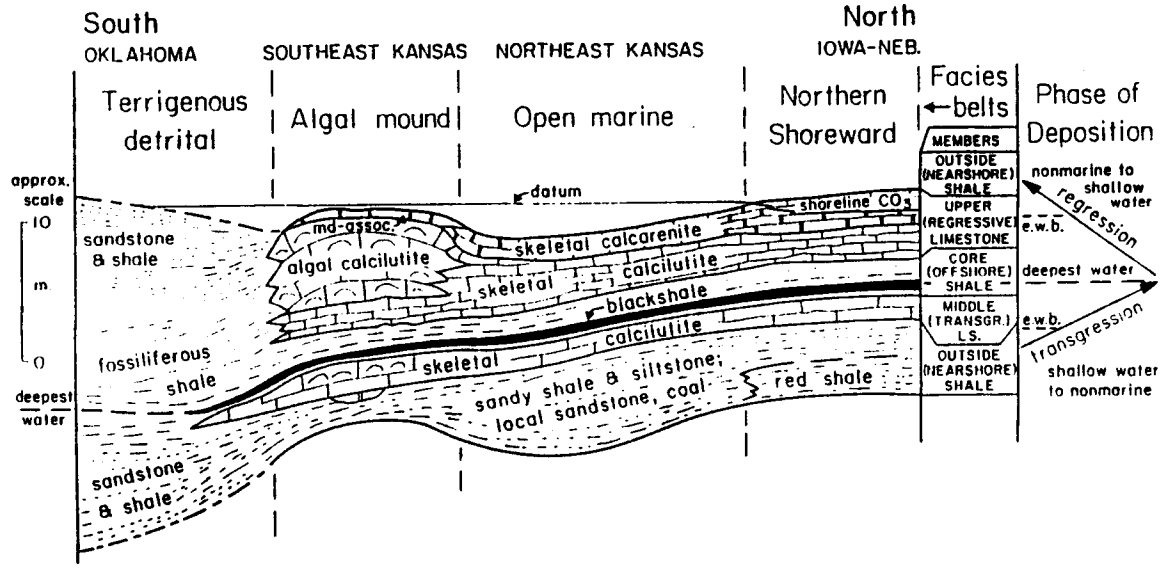

Figure 5b. Facies belts of "Kansas-type" cyclothem. Note that the limestone members do not converge anywhere in the Mid-Continent--as might be expected near the margins of the basin (i.e. the northern shoreward portion of the cyclothem). e.w.b. = effective wave base (adapted from Heckel, 1984a).

diagenetic histories that these two patterns incur (Heckel, 1983, 1984a).

The final member of Heckel's cyclothem is the "outside shale," which is composed of a wide variety of nearshore and terrestrial facies. These include prodeltaic mudrocks, paleosols, widespread coals, and tidal estuarine fills. These units can be anywhere from 1 to 30 meters thick and thickness is as variable as lithology. These compose the lowstand and part of the transgressive systems tracts and contain the sequence boundaries in sequence stratigraphic nomenclature (Heckel and Pope, 1992).

Heckel (1991) favored eustatic sea level changes, rather than local tectonism or autocyclic sedimentary patterns (i.e. delta lobe switching), as the driving mechanism of Pennsylvanian cycles. Eustacy could be controlled by Gondwanan glaciers or by regional tectonism related to the Appalachian orogen, but comparing the average period of cyclothems (235,000 to 400,000 years or less) to that of foreland basin tectonics (3 to 5 million years) the global climatic explanation is more likely. The lateral continuity and relatively short periodicity of the average cyclothem strongly support an extrabasinal "driver". Independent evidence of Gondwanan glacial deposits suggests continental ice sheets like those of the Pleistocene (Crowley and Baum, 1991; Maynard and Leeder, 1992); these must have affected global sea level and

probably affected deposition of the cyclothems through local climate changes.

Many Mid-Continent cycles, as identified by Heckel (1984a), are not entirely encompassed by the ideal because it requires sufficiently slow transgressions and regressions for the limestones to develop and sufficient water depths for a pycnocline to occur. If transgression is too fast, the "core" shale facies develops before the transgressive limestone can accumulate. If regression is too fast, detrital influx will swamp the regressive limestone. Also, sea level drop must be low enough and long enough for a soil to develop within the "outside" shale. With regard to the Iola Limestone, Heckel (1984a) identified it as a major cycle; that is, it has broad geographic extent, reflects high sea level rise, and sufficiently gentle rise and fall to develop both limestone members.

This section is a brief review of Heckel's concept of Mid-Continent, Pennsylvanian stratigraphy and is by no means comprehensive. Many of his arguments are more extensively developed in the references cited. Also, the model is a general one and cannot be expected to account entirely for the pattern found in every cycle. However, it does make predictions about the basic architecture and facies of any cyclothem and examining these features can serve as a test of the Heckel paradigm.

RESULTS

Wireline Log Study

A geophysical subsurface study of the Iola Limestone was undertaken with the aim of determining the three dimensional geometry of the unit, how this geometry might relate to the facies distribution, and how it might relate to the over- and underlying formations; in particular, to delineate the shape of a phylloid algal complex previously identified in surface exposures (Heckel and Cocke, 1969). The study area selected is bounded on the west by Range 10 East and extends to the outcrop belt. These data abut the eastern limit of subsurface studies by Watney in central and western Kansas (W.L. Watney, 1992, personal communication). The southern boundary is defined by the last detectable expression of the Iola Limestone on logs (Township 32 South); northward extension of the subsurface study area was limited by the availability of logs (which were not collected beyond Township 14 South).

Most available logs for this region are gamma ray-neutron pairs, which are very useful for lithologic correlation because they clearly distinguish limestones from intervening siliciclastic units. Initial log density was one per township where available; after preliminary subsurface mapping, density was increased in areas of

particular interest: namely in southeastern Kansas where the Iola Limestone is thicker.

The Iola was the focus of the study, but it was necessary to correlate the entire upper Kansas City through Lansing interval (from the Stark Shale Member of the Dennis Limestone to the South Bend Limestone Member of the Stanton Limestone) to prevent cross-correlation (see Zeller, 1964). Positive identification of the Iola was based on correlation to its surface exposure. The results of the subsurface study are presented as the series of maps in figures 6 through 9 and the northeast-southwest cross-section (Plate 1).

Lithologic units in Plate 1 are all labeled at the formation level as well as three stratigraphic members: the Block limestone, the Stark shale, and the Eudora shale, all of which have particularly robust expression in wireline logs. The cross-section orientation was chosen because it is perpendicular to the thick Iola trend in southeastern Kansas shown in figure 7. Basic description and interpretation of the Kansas City-Lansing interval is presented by formation starting with the Drum Limestone and ending with the Bonner Springs Shale.

Drum Limestone Interval.--The Drum Limestone is a fairly continuous limestone unit never exceeding 6 meters

in the study area. As shown in the cross-section, it pinches out in southern Coffey County.

The Drum is absent across the Bourbon Arch, a basement structural feature in southeastern Kansas. This feature overlies a region of Precambrian supracrustal sedimentary rocks deep in the subsurface (Rascoe and Adler, 1983), and, although subtle, seems to influence the stratigraphic section in the Upper Missourian. It is not clear whether the Drum Limestone was never deposited in this area or if it was removed by subsequent erosion prior to the deposition of the overlying Chanute Shale.

Chanute Shale Interval.--Outside the area of southern Coffey County the Chanute does not generally exceed 6 meters in thickness. Where the Drum Limestone is not present, the Chanute cannot be distinguished from the Cherryvale Shale. In many boreholes, SW SW NE 7-22S-16E for example, the radiation log signature for sandstone can be seen; presumably the Cottage Grove or Noxie sandstones or both.

Again, changes in this formation seem to be correlated with the position of the Bourbon Arch where the sands are generally best expressed as described by Haggiagi (1970). It is possible that the Drum was eroded in this area prior to the deposition of the Chanute Shale.

Iola Limestone Interval.--In this cross-section, the Iola Limestone gradually thickens from 4 meters in Johnson County to over 20 meters in Coffey County, where it then dramatically thins to 5 meters. The Muncie Creek shale is only well developed in the far northern end of the section, but is frequently present as a small "nick" in both neutron and gamma ray logs near the base of the Iola. In southeastern Kansas, the Muncie Creek signature is generally best developed where the overlying Raytown limestone is thickest (greater than 20 meters). No measurable trend in thickness occurs in either the Paola or the Muncie Creek members, so the differences in the thickness of the Iola primarily correspond with changes in the thickness of the Raytown limestone. Where the overlying Lane Shale is essentially absent, the top of the Raytown can be recognized on the neutron log; the neutron reading gradually decreases upward from the base and is capped by a double peaked spike, which has a consistent thickness of 6.5 meters. The uppermost peak in neutron values can be correlated from where the overlying Lane Shale can be clearly delineated in northern Coffey County.

The north to south trend of gradual thickening and then sudden thinning clearly indicates a sharp change in some factor influencing the geometry of the limestone. One suggestion for the cause of this change is the presence of a break in slope at the northern edge of the Anadarko-

Arkoma foreland basin (Watney et al., 1989). However, Watney et al. (1989) favored the deep water upwelling model for the deposition of the black shale, which implies that it should be best developed in the basin to the south. This is not the case for the Muncie Creek; it is absent south of Coffey County. Another suggestion is that the southern margin of the Bourbon Arch was an active feature at the time and created a break in slope where the algal bank developed (Mitchell, 1980). If structural movement was the cause of the thickening, it was only active for a brief period. Had it been active in the same way throughout the Upper Missourian, all the limestones and shales within the entire Stark-South Bend interval would be influenced in the same way.

Lane Shale-Wyandotte Limestone-Bonner Springs Shale Interval.--The Lane and Bonner Springs are considered together in this study because the Wyandotte Limestone is absent in much of southeastern Kansas and the two shale formations cannot be distinguished without it in radiation logs. Thickness along the transect ranges from 50 meters at both the northern and southern ends to as little as 20 meters in the southern part of Coffey County. The increases in thickness are sharp south from Coffey County but gradual to the north. Generally, the shale has homogeneous log characteristics throughout its thickness.

The Wyandotte Limestone is well developed in Johnson County but pinches out in southern Franklin County and only reappears in southern Coffey County, where it thickens to over 30 meters and disappears precipitously along the Woodson County line. Where present, it replaces siliciclastics and thus, the thickness of the entire interval (Lane through Bonner Springs) is relatively constant. The Wyandotte has no consistent log signature like the decreasing neutron trace of the Iola. The Lane Shale is reduced to 2 meters or less between the Wyandotte and the Iola in Coffey County.

Although its disappearance was known in outcrop, the reappearance of the Wyandotte Limestone is an unpredicted pattern. Because there is no evidence for either a subaerial or a submarine hiatus in southern Kansas in the Lane Shale, it is possible that the Wyandotte is simply an undisrupted continuation of Raytown Limestone deposition over the Bourbon Arch. Meanwhile, the laterally equivalent Lane Shale was being deposited contemporaneously.

Isopach Map of the Siliciclastic Interval Underlying the Iola Limestone (Figure 6).--This interval is from the top of the Block Limestone Member to the base of the Paola Limestone Member. The Chanute Shale alone could not be isopached because without the Drum Limestone, it cannot be consistently distinguished from the Cherryvale Shale. The

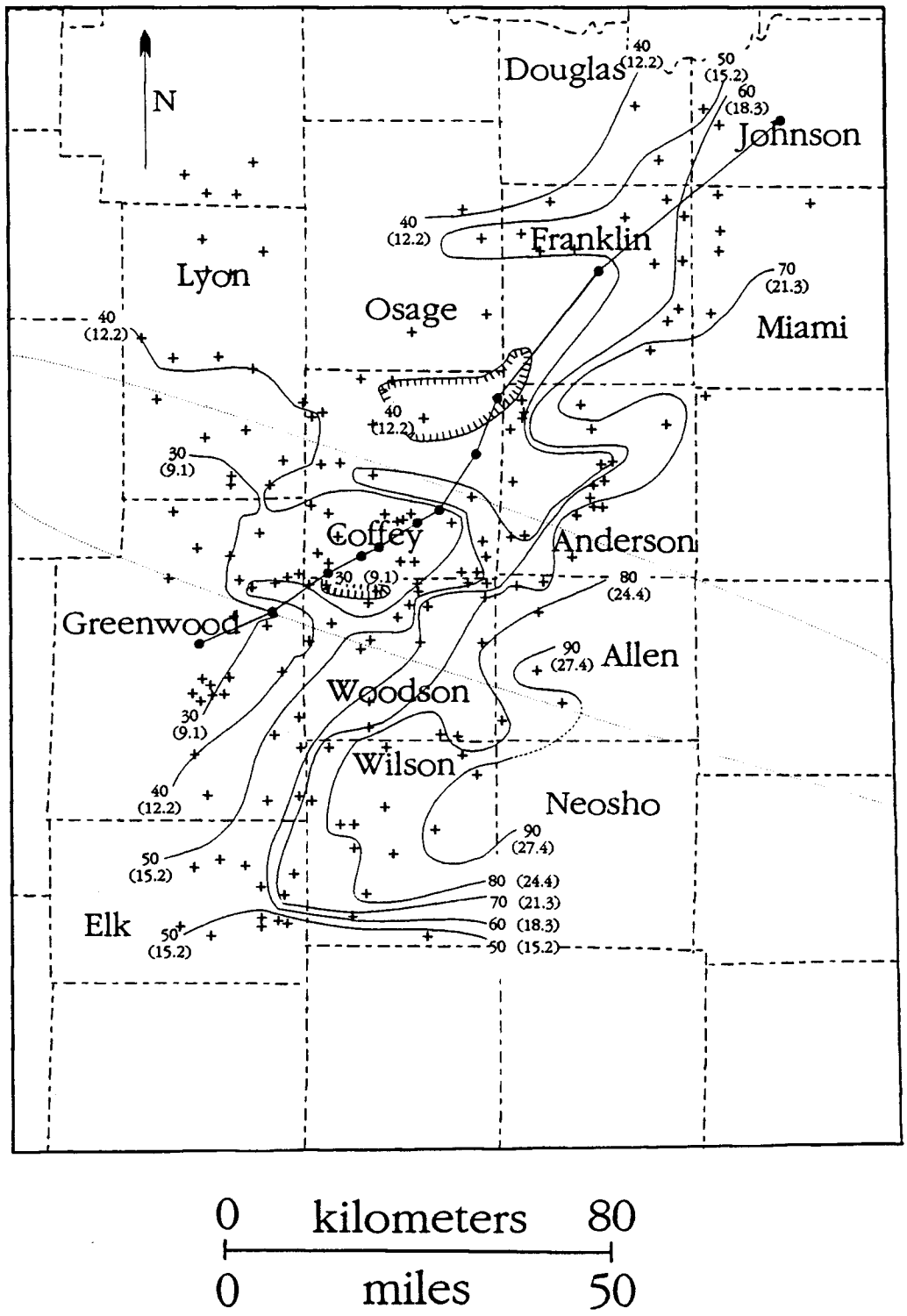

Figure 6. Isopach map of the thickness of the interval underlying the Iola Limestone (top of the Block limestone to the base of the Paola limestone). Contours are given in feet (meters). Dashed lines are inferred contours. Dotted lines mark the trend of the Bourbon Arch. Pluses are log data points. Circles are locations of logs used in Plate 1.

Block limestone was recognizable in logs, therefore it could serve as a base.

The Cherryvale-Drum-Chanute interval triples in thickness from the west (10 meters) to the east side (30 meters) of the map. This thick area has two very distinct lobes--one in Allen County and the other in Wilson County. Also noticeable, especially in the 12.2 meter (40 foot) and 15.2 meter (50 foot) contour intervals, are three roughly east-west tongues which thicken to the east. They can be seen in Franklin and Osage Counties, in Coffey County, and in Woodson and Greenwood Counties.

Despite lumping a number of lithologic units together, some distinct patterns emerge on this map. The lobate thickening in Allen, Neosho, and Wilson Counties is the area of Haggiagi's (1970) study, where he interpreted the presence of delta mouth bars. As mentioned before, however, later work (Archer, personal communication, 1993) has revealed tidal rhythmites in the Cottage Grove Sandstone Member of the Chanute Shale, suggesting that an estuarine fill interpretation analogous to that of sandstone deposits in the Douglas Group (Archer et al., 1993) is more likely. The isopached tongues, which thin to the west, suggest the shape of tributary stream valleys (now filled) along the western side of a larger estuarine valley or bay. Interestingly, the southern two tongues parallel the margins of the Bourbon Arch in southern Coffey

County. If the arch was active at the time it could have created a drainage divide between the two tributaries. Additionally, the sandstone signatures on the cross-section also appear at the margins of the Bourbon Arch directly under or near these possible tributary valleys. Geometry of the isopached Cherryvale-Drum-Chanute interval supports an estuarine fill interpretation rather than a prograding delta.

Isopach Map of the Iola Limestone (Figure 7).--The Iola Limestone is thickest in the middle of an irregular area oriented roughly northwest-southeast in Lyon, Coffey, and Allen Counties. Lobes on this mass are paired into two northeast-southwest extensions roughly perpendicular to the main axis of the thickening--a Coffey-Greenwood County pair and an Allen-Woodson County pair.

Parallel to the northeast-southwest axis of the lobe pairs is an elongate body defined by the 12.2 meter (40 feet) contour extending from Greenwood to Allen Counties. The southern margin of the Iola thickening displays a decrease in thickness of up to 13 meters in less than twenty kilometers, and the northern margin thins gradually; the same pattern as seen in the cross-section. In east-central Butler County (immediately west of Greenwood) the Iola, if present, is too thin to be detected on radiation logs.

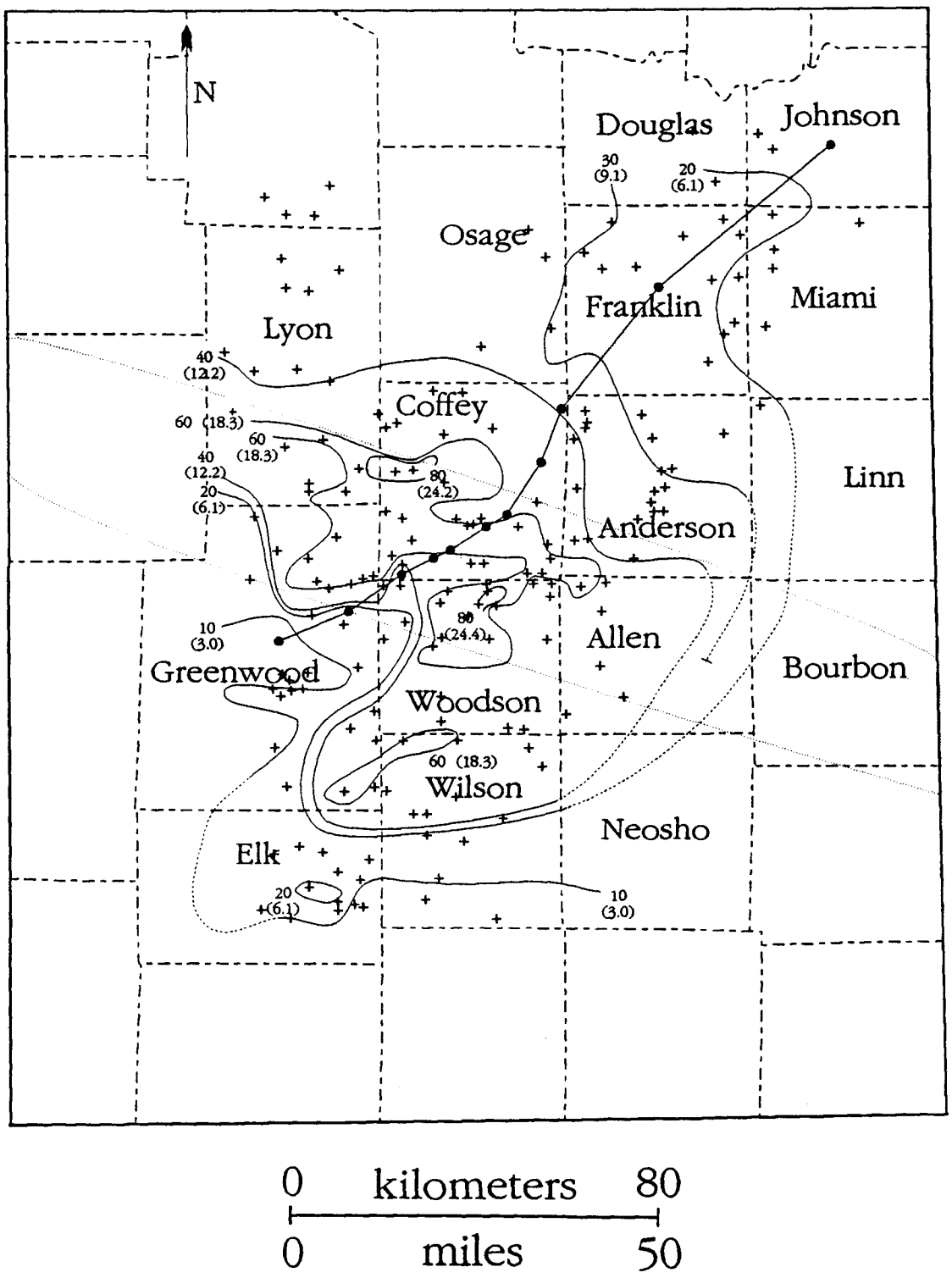

Figure 7. Isopach map of the thickness of the Iola Limestone. Contours are given in feet (meters). Dashed lines are inferred contours. Dotted Lines mark the trend of the Bourbon Arch. Pluses are log data points. Circles are locations of logs used in Plate 1.

Thickening of the Iola is the subsurface extension of the exposed phylloid algal mound in the Raytown Limestone mentioned by Heckel and Cocke (1969) and examined in detail by Dawson and Carrozzi (1986). The main part of the thickening parallels the Bourbon Arch but never intersects the outcrop belt. The anomalous width of the Raytown buildup relative to many of the other Missourian mounds (Heckel and Cocke, 1969) is due to the northeast-southwest trending "hook" adjacent to the main thickening. The paired lobes of the mound crest are strongly suggestive of ebb-flood tidal delta pairs through a phylloid algal mound (Olszewski, 1993). The northeast-southwest bidirectionality of the lobes parallels the bimodal current indicators found by Hamblin (1969) in many of the other limestones of the Kansas City-Lansing interval. Limestone-filled channels with bimodal current indicators are also reported from outcrop study of the Stanton Limestone (Heckel, 1972, 1978), and similar structures probably connect the isopached lobes through the mound. The isolated, elongate thickening defined by the 18.3 meter (60 foot) contour in northwest Wilson and southeast Greenwood Counties is one end of the broad outcrop thickening and could either be a current accumulated bar or spit parallel to the currents controlling the tidal lobes or a smaller phylloid algal mound perpendicular to the main trend. The latter possibility is not unlikely if Heckel's (1972)

assertion that phylloid algal mounds occur at breaks in slope is true. This outlier sits directly above a 6.5 meter drop in thickness of the Cherryvale-Drum-Chanute interval (and this could represent a topographic break in the pre-Iola paleoslope). This would only be local control of the Iola by the underlying interval because the overall correlation of the two is insignificantly low ($r=0.0354$, $df=170$, see appendix 5). In either case, the phylloid algal mound in the Iola is parallel to the strike of the Bourbon Arch and seems to thin over the thickest part of the underlying siliciclastic interval.

Isopach Map of the Siliciclastic Interval Overlying the Iola Limestone (Figure 8).--This interval is an agglomeration of the rock formations from the base of the Lane Shale to the top of the Bonner Springs Shale because the Lane, which directly overlies the Iola Limestone, cannot be distinguished from the Bonner Springs in the absence of the intervening Wyandotte Limestone on wireline log records. The interval is thickest (50 meters) at its northeastern and southwestern ends but thins to 13 meters in the southeast. A relatively thin band, 20 meters thick, cuts east-west through Coffey County and extends north-south into Osage County. It gets broader and thinner in Allen, Wilson, and Neosho Counties. Two thicker tongues protrude southward into Coffey and Anderson Counties from

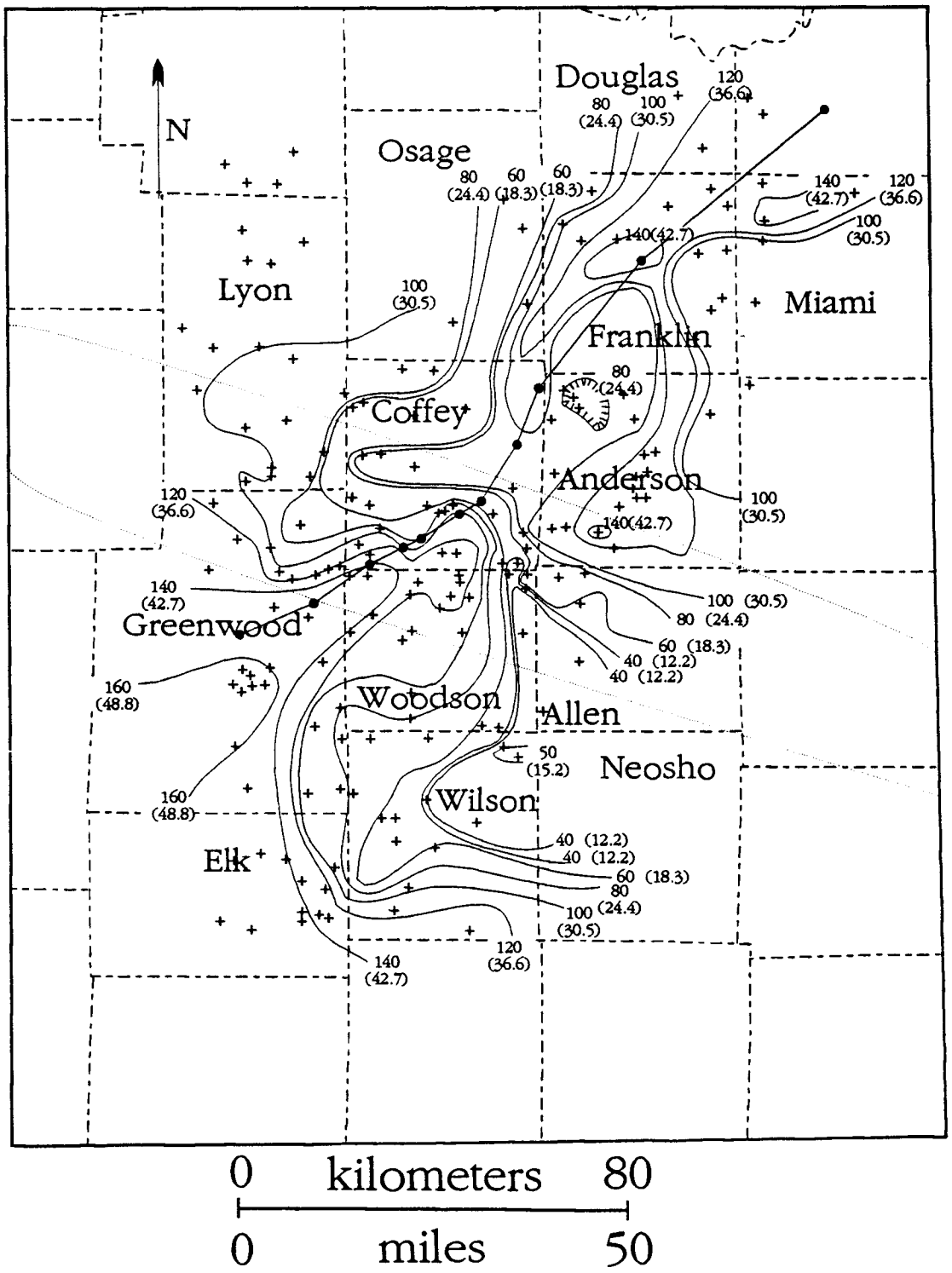

Figure 8. Isopach map of the thickness of the interval overlying the Iola Limestone (top of the Raytown limestone to the base of the Plattsburg Limestone). Contours are given in feet (meters). Dotted lines mark the trend of the Bourbon Arch. Pluses are log data points. Circles mark locations of logs used in Plate 1.

Franklin County and another, broader tongue protrudes northeastward from Greenwood County into Woodson County.

Incorporation of the thick Wyandotte Limestone into this interval may be obscuring any readily interpretable pattern. However, the thinnest part of this package is, again, over the Bourbon Arch. If the tongues from the northeast and southwest are interpreted as filled valleys, as in the Cherryvale-Drum-Chanute interval, then southern Coffey County must have been the location of a major drainage divide. However, there is little or no evidence for tidal estuarine influence in the formation of the Lane Shale. Interestingly, the thickness of this interval is significantly negatively correlated with the underlying Iola Limestone ($r=-0.5294$, $df=170$, see appendix 5). This suggests that the siliciclastic body overlying the Iola may have filled in around the original depositional relief of the limestone. If this is not the case, both the Iola and the overlying interval were influenced by the same external factor but with opposite effects on the two units.

Isopach Map of the Total Interval (Figure 9).--The sum of thicknesses of the previous three sub-intervals is thickest in the northeast and the southwest (>60 meters). A thinner band extends northwest-southeast through northern Allen and southern Coffey Counties.

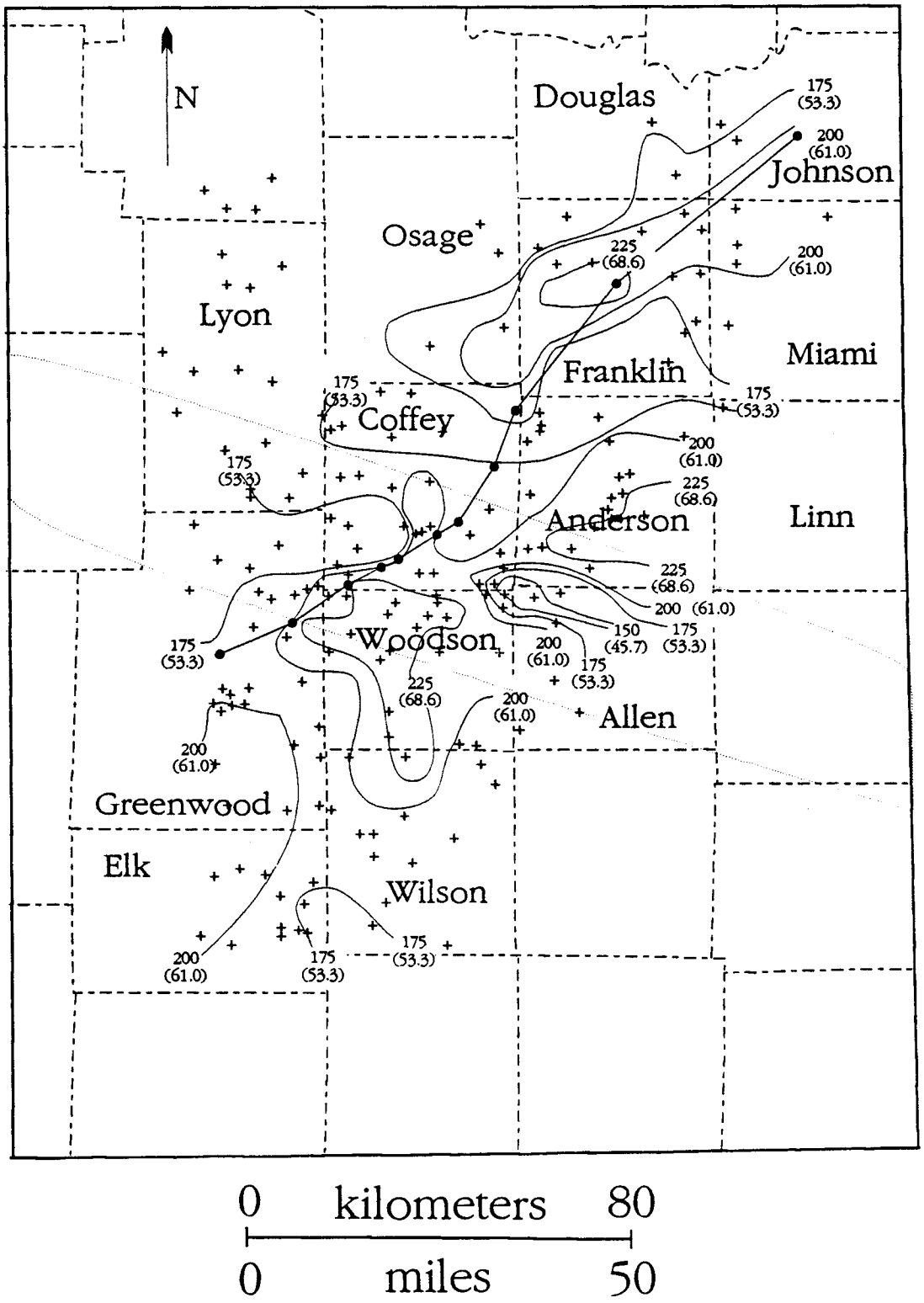

Figure 9. Isopach map of the thickness of the entire interval examined (top of the Block limestone to base of the Plattsburg Limestone). Contours are given in feet (meters). Dotted lines mark the trend of the Bourbon Arch. Pluses are log data points. Circles are locations of logs used in Plate 1.

The thickness of this interval, which includes more than three full cyclothems (the Drum, Iola and Wyandotte), is more likely to reflect long term accommodation filling patterns than any of the shorter intervals. Because long term accommodation primarily reflects subsidence, it should indicate the influence of any underlying structural controls. The thinner area over the Bourbon Arch suggests that the arch was active at this time, and that it must have been an area of slower subsidence than the regions to the north and south. However, the thickness of the isopached interval is very strongly correlated with (r=0.8269, df=170, see appendix 5) and has approximately the same relief (25-27 meters) as the Lane-Wyandotte-Bonner Springs interval. This suggests that the overall pattern may only reflect the direct or indirect influence of the Bourbon Arch on the uppermost and thickest of the three sub-intervals.

Conclusions.--A better understanding of the geometry of the Iola Limestone is provided by this subsurface study. The phylloid algal mound described in outcrop thickens into the subsurface over the Bourbon Arch and parallels the strike of that feature. The thickness of the Iola is not significantly correlated to the thickness of the underlying siliciclastic interval, although local breaks in slope may have focused the development of bars or biologic buildups.

In contrast to the underlying formations, the shape of the overlying interval is significantly negatively correlated with the Iola Limestone. This may indicate prograding siliciclastics filling accommodation space around the Iola.

Through all the intervals examined, the Bourbon Arch seems to have played a significant role, either directly or indirectly, in defining their geometries. Two of the limestones thicken in southern Coffey County (the Iola and the Wyandotte) and one disappears (the Drum). The siliciclastic units, in contrast, thin almost to nothing (the Lane and Bonner Springs) or get sandier in their log expression (the Cherryvale-Chanute) over the same area. The Bourbon Arch need only have been active during the deposition of one unit to influence all the units stratigraphically above it due to differential compaction of differing lithologies (the fine-grained siliciclastics compacting more than the carbonates).

Unit geometries for two units suggest possible depositional models for them. Lobes in the Iola suggest flood-ebb tidal delta sets across a phylloid algal mound. This implies positive relief and tidal current influence on the buildup. Geometry of the Cherryvale-Drum-Chanute interval suggests an estuarine valley fill sequence analogous to that described for the Douglas Group (Archer et al., 1993).

Facies Descriptions and Interpretations

Outcrop, slab, and microscopic descriptions of measured intervals are grouped into basic facies. These provide the basis for inferred depositional environments grounded in sedimentologic and paleontologic characteristics.

Laminated Dolomitic Mudstone (Figure 10).--This lithology is characterized by fenestrae and root traces. Laminations are cracked vertically and horizontally, suggesting desiccation and spalling features. Fossils are restricted to grainstone horizons less than 10 millimeters thick and are mostly ostracodes and miliolid-like foraminiferids.

This is a textbook example of a carbonate supratidal flat lithology associated with micro- to mesotidal conditions. The mudstone-grainstone laminations reflect the periodic inundation of spring or storm tides. Horizontal spalling cracks and possible desiccation cracks, as well as the fenestrae and root traces, indicate subaerial exposure. This lithology is found exclusively in core WM4 from Missouri near the Nebraska border. Mitchell (1981) described a similar facies from at his locality NEB in Sarpy County, Nebraska; his nearest locality to WM4.

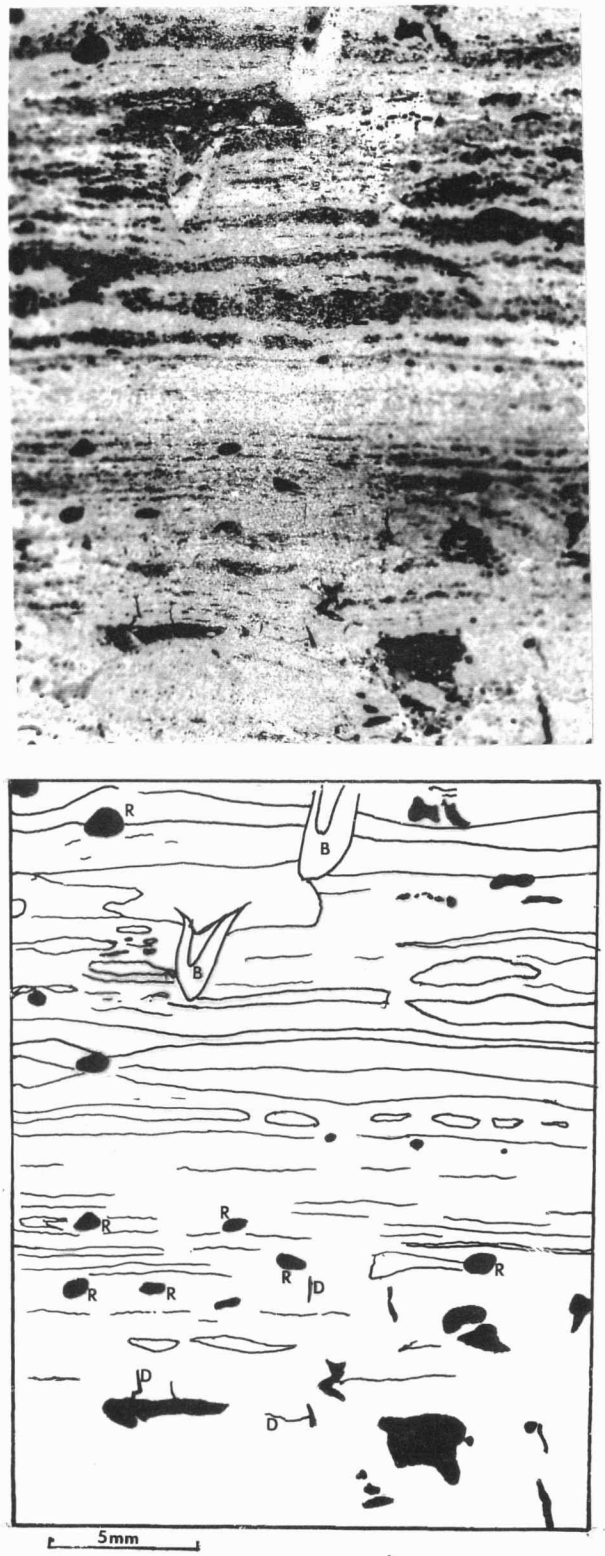

Figure 10. Laminated, Dolomitic Mudstone. R=Root Traces, B=Burrows, D=Possible Dessication Cracks. Negative acetate peel print. Sample WM4-12.

Skeletal Grainstone (Figure 11).--These are oncoidal or fusulinid grainstones and packstones with crinoids, brachiopods, and echinoids. These fossils generally contribute only a small fraction to the entire volume of the rock. The green alga Epimastopora is very common. Syntaxial cements are present on some echinoderm grains.

This facies is separated from the other carbonate packstones and grainstones because of the unusual fossil content--either dense amounts of fusulinids or granule sized oncoids (which are easily confused with ooids). Although the other fossils indicate marine conditions, this lithology is found exclusively in core WM4 in close association with the **laminated dolomitic mudstone;** this suggests that these are nearshore subtidal or low intertidal deposits. The well rounded grains indicate that these sediments were probably washed by wave action above fair weather wave base. This could be carbonate sand just washed onto tidal flats from offshore or possibly filling tidal channels.

Argillaceous Carbonate Mudstone and Calcareous Mudrock (Figure 12).--These two lithologies are end members of the same basic lithology but vary in the cement content of the rock. The more calcareous layers are often peloidal with up to 25% crinoidal debris, but more typically brachiopods are dominant (>90%). Bioclasts, which occasionally show

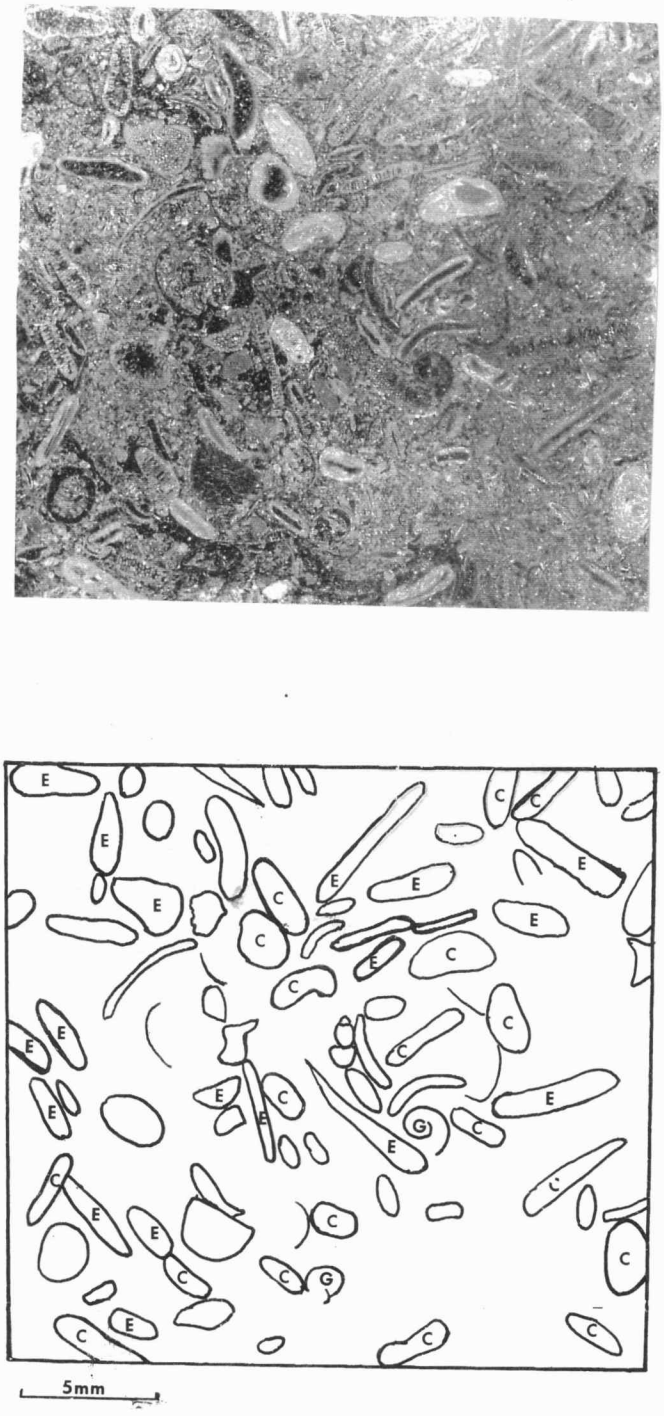

Figure 11. Skeletal Grainstone. E=Green Alga (provisionally identified as *Epimastopora*), G=Gastropods, C=Coated Grains (Oncoids). Negative acetate peel print. Sample WM5-11.

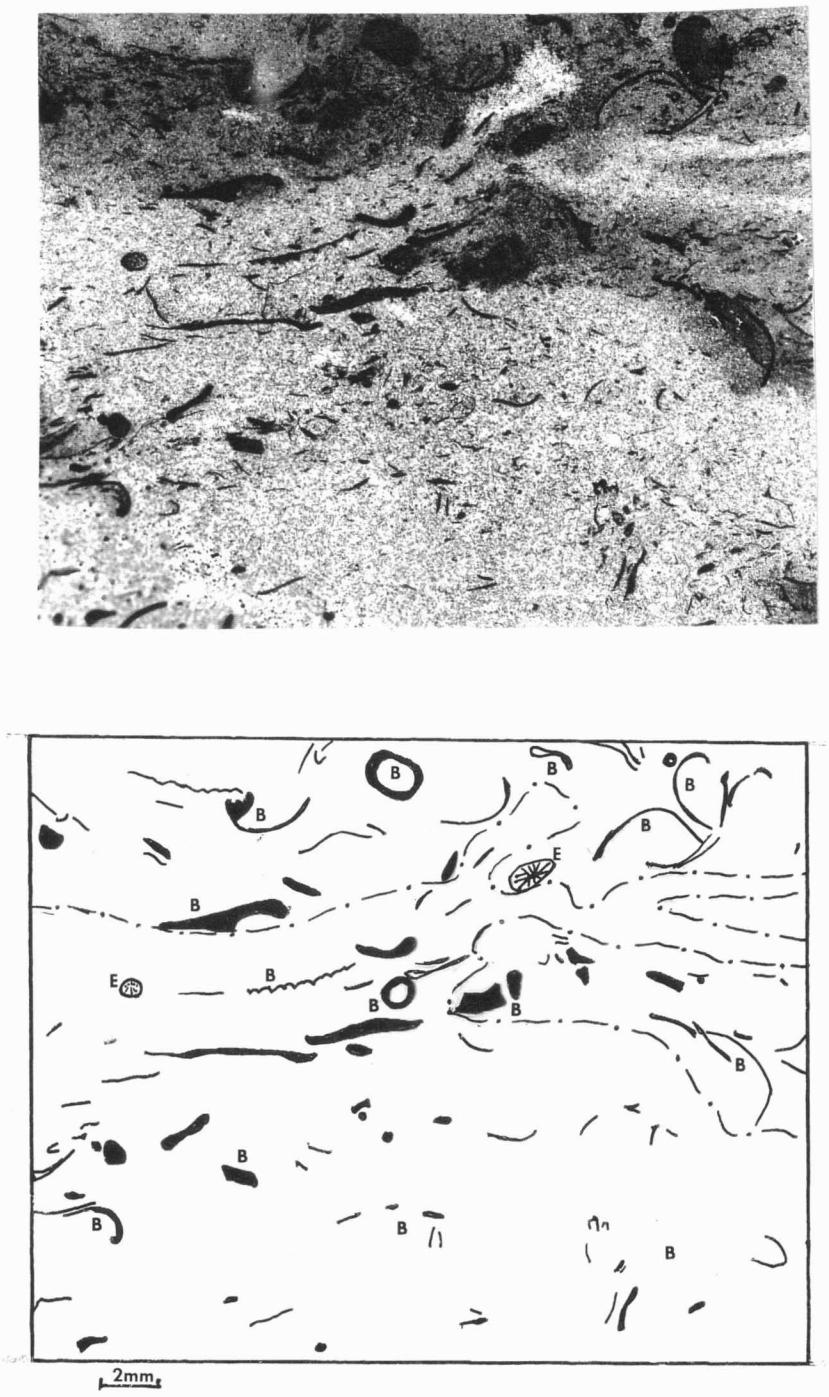

Figure 12. Argillaceous Carbonate Mudstone and Calcareous Mudrock. E=Echinoid Spine, B=Bioclast Fragments. Dash-dot line indicates contact between carbonate mudstone (above) and siliciclastic mudrock (below). Negative acetate peel print. Sample from section WM8 contact between beds 8 and 9.

imbrication or concave down shell orientation, are often found in layers one or two shells thick. In many layers, usually the more argillaceous, fossils are few and well dispersed. The dark color and sulfurous smell in HCl indicates a high organic carbon content. Bioturbation is evident on cut surfaces.

Invertebrate fossil content indicates a marine influence. Peloids, probably fecal pellets, and bioturbation, as well as benthic body fossils, show that organisms inhabited the sea floor. However, the fact that organic carbon was preserved and the low diversity in individual beds suggests a sparsely populated environment that could not take full advantage of organic input. Thin shell lag horizons displaying imbrication and concave down orientation are strong indications of current deposition and are probably winnowed storm concentrations. If current activity was more constant, the fine-grained mud would probably have been washed away. This lithology is probably very closely related to the **gray, fossiliferous mudrock** (described below), except that the argillaceous mudstone generally makes up most of the Iola Limestone interval in Missouri, whereas the other lithology is found as thin beds within otherwise "clean" carbonates.

Skeletal Wackestone (Figure 13).--These are micritic limestones (wackestones and packstones) with a diverse

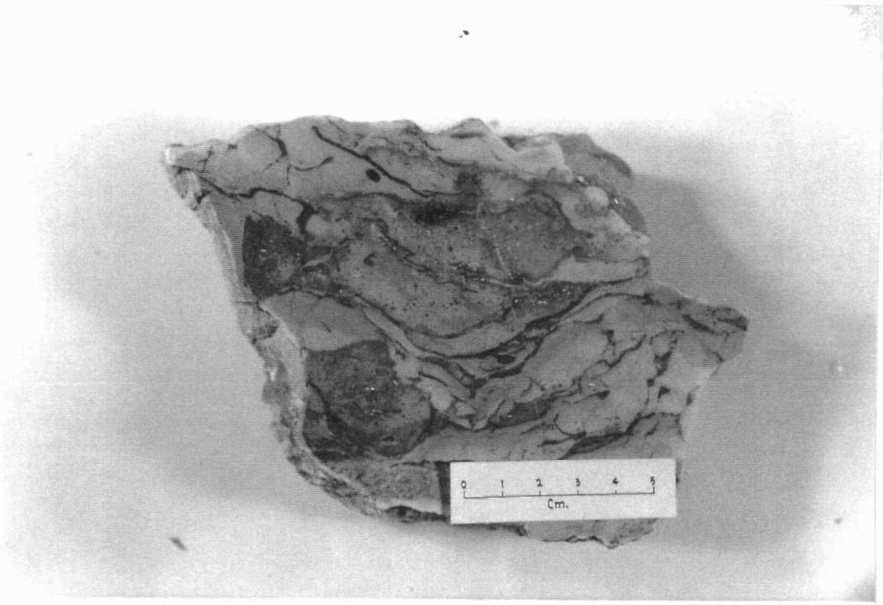

Figure 13. Skeletal Wackestone. This sample is an intermediate lithology between the skeletal wackestone and the phylloid algal limestone. Algal dishes contain darker wackestone in a matrix of mudstone. Other fossils include bryozoans and brachiopods. Sample HDB-12.

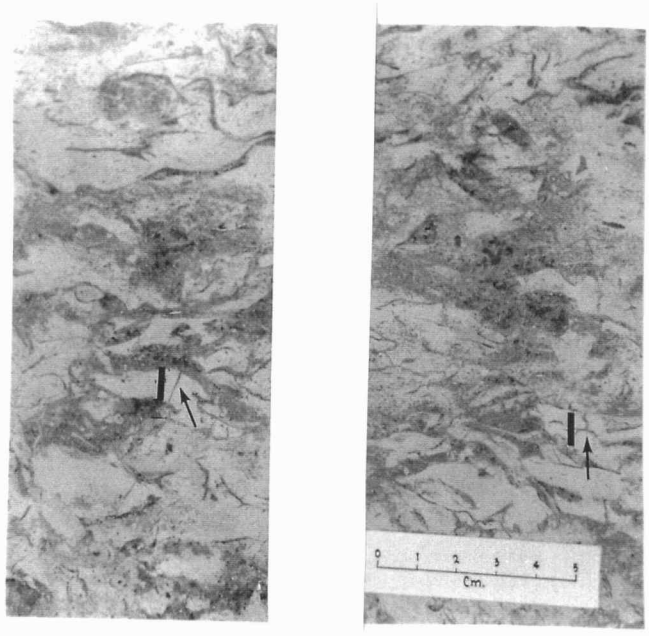

Figure 14. Phylloid Algal Limestone. I=Intraclasts. Arrows point to fractures filled with comminuted phylloid algal debris. Sample OSAN-7.

marine assemblage of brachiopods, echinoderms, bryozoans, and phylloid algae, as well as other fossils. This lithology rarely displays more than a few dispersed stylolites as a non-carbonate component. Phylloid algae, when present, are not dominant and do not create a framework of shelter voids. Isopachous cement rinds are common in intraparticle spaces.

This lithology was deposited as open marine, subtidal carbonate muds and sands. Early submarine cementation fills both intra- and interparticle voids. Preserved remains of algae indicate deposition in clear, sun-lit waters with very limited terrigenous input. The thin bedded character and an occasional monospecific lens of fossils, suggests that this facies was under the influence of storms which could concentrate the coarser fossil fragments but not remove the carbonate mud. Modern analogs for this kind of environment are the shallow, clear water carbonates of modern tropical and subtropical seas.

Phylloid Algal Limestone (Figure 14).--This is a heterogeneous lithology overwhelmed by the volume of phylloid algal blades in a very coarse grainstone to packstone. Biotic diversity is low; often limited to a few brachiopods and fenestrate bryozoans. Recrystallized ooids are common in some samples. Often the phylloid algal cups are filled geopetally with micrite and these intraclasts

are found overturned and frequently brecciated. Algal morphologies include blades and their fragments and a "cabbage head" morphology which breaks into small cups resembling thimbles in size and shape. Although many of these samples are micrite free, they can grade all the way to very muddy algal packstones with intermediates showing well developed peloids. Isopachous cement rinds are very common (as well as very rare neomorphosed acicular aragonite botryoids). At some outcrops, meter-scale cross-bedded dune forms occur in this lithology (fig. 15a and 15b).

This lithology is responsible for the thickening of the Raytown in southeastern Kansas, but it can be found as far north as Johnson County. Overturned intraclasts and recrystallized ooids in several locations indicate deposition in environments of consistently high energy. Cross-bedded dunes can be seen in outcrop in Allen and Miami Counties (figs. 15a and 15b)--they are typically framework supported rocks, which suppports a current washed interpretation. Locality AGQ, in Neosho County, Kansas (the thickest outcrop section) is biostromal and does not display the duneforms found elsewhere. Another locality where the Raytown is very thick (approximately 11 meters) and cross-bedded is location LF at the Allen County landfill. In the region where the well defined subsurface mound intersects the outcrop belt, this lithology gets

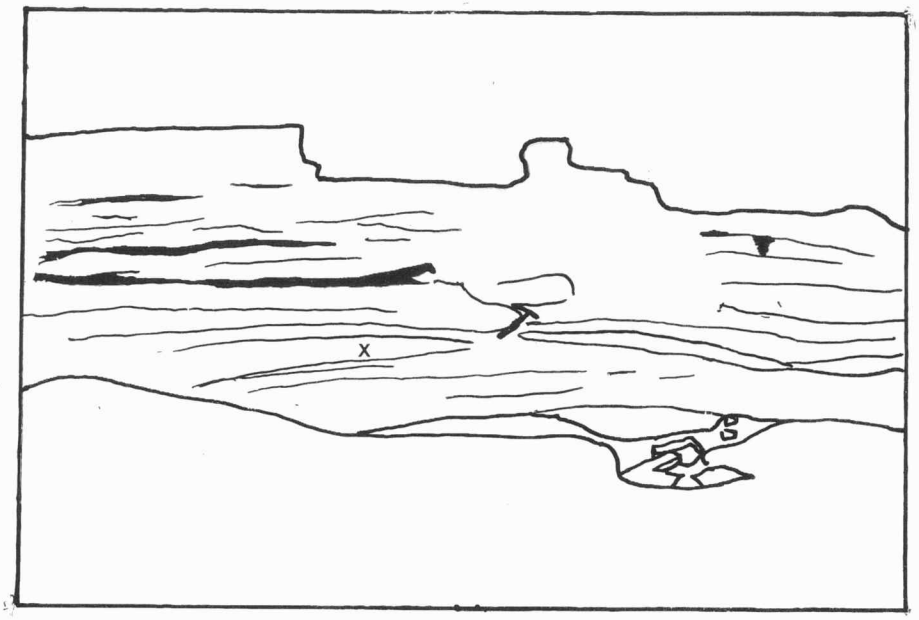

Figure 15a. Cross-bedded Dunes in the Phylloid Algal Limestone. Northern end of location OSAN in Miami County, Kansas. X indicates cross-bedded layer. Exposure trends roughly north-south. Hammer for scale.

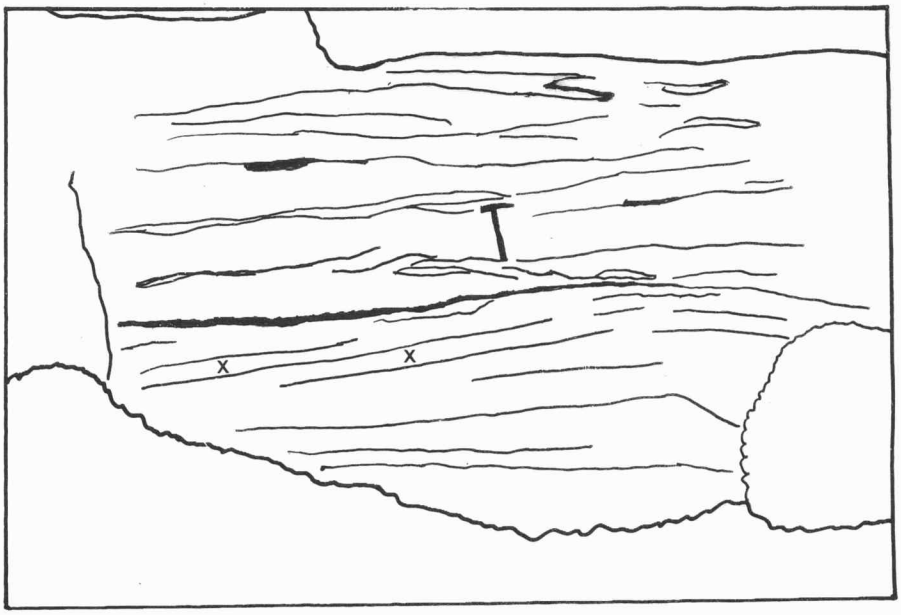

Figure 15b. Cross-bedded Dunes in the Phylloid Algal Limestone. Central part of location OSAN in Miami County, Kansas. X indicates cross-bedded layer. Exposure trends roughly north-south. Hammer for scale.

muddier upward indicating a shallowing upward sequence. The growing mound constricted circulation at the crest of the mound allowing carbonate mud to accumulate. Only when the mound grew to effective wave base did higher energy deposits begin to form (i.e. the rounded intraclastic breccias capping the mound at locality AGQ). In north-central Kansas, this facies is more closely associated with packstones than grainstones, but it is still dominated by phylloid algal particles. A transitional lithology between this lithology and the **skeletal wackestone** occurs in Johnson and Wyandotte Counties; it has phylloid algal cups, geopetally filled in life position (none are overturned in some layers)(fig. 13). The fabric of the phylloid algal dominated limestones suggests consistent, strong, unidirectional currents.

Osagiid Wackestone (Figure 16).--Samples of this lithology are dense carbonate rocks with conspicuous, well developed, oblate osagiid oncoids (up to 20 cm across). Other fossils are typically geopetal or geodiferous, articulated, and well preserved; a diverse assemblage includes gastropods, brachiopods, bryozoans (especially encrusters), crinoids, and corals. The matrix is commonly bioturbated.

This facies is another type of open marine wackestone with a diverse marine fossil assemblage. The large oncoids

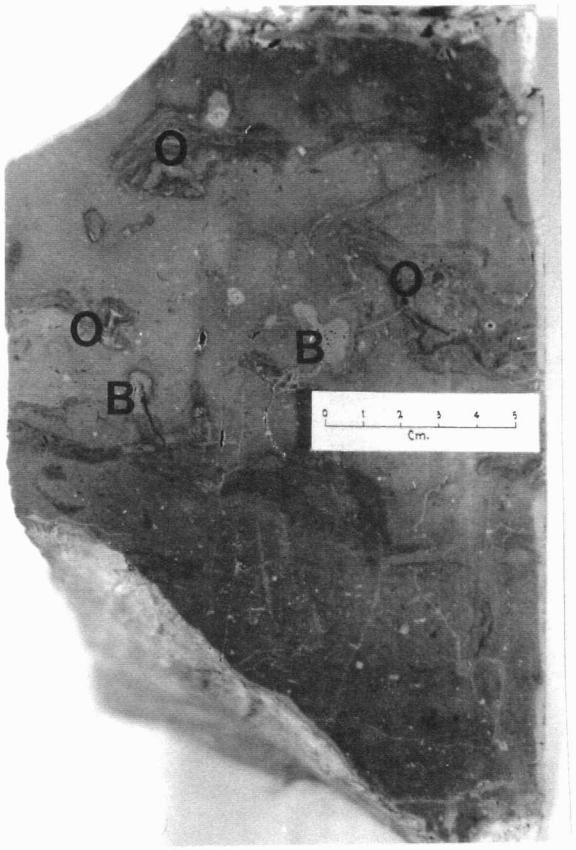

Figure 16. Osagiid Wackestone. O=Osagiid Oncoids, B=Burrow Fills from Overlying Firm/Hardground. Sample RR-6.

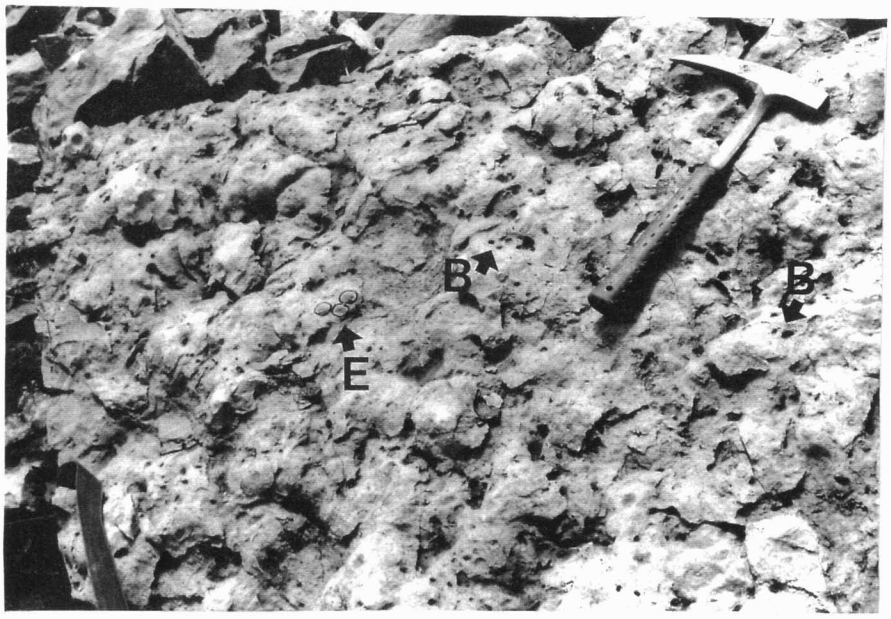

Figure 17. Firm/Hardground at the top of the Paola limestone. E=Encrusting Bryozoans (fistuliporids), B=Burrow openings. From section RR in southern Johnson County (same bed as shown in figure 16). Hammer for scale.

suggest deposition within the photic zone. Their flattened shapes suggest that they grew lying on the sea bottom but the presence of laminations on both sides indicates that they were turned over frequently. This could be due to grazing activity by a larger organism or by periodic current activity. Because there is no evidence for grazing (either scrape marks or truncated laminations) the latter hypothesis is favored. Enough energy to turn over large algal oncoids but retain the mud matrix suggests that this lithology was deposited above storm wave base but below the consistent winnowing action of fair weather wave base. This facies is found exclusively in the Paola Limestone Member.

Sandstone.--Generally, this lithology is a fine grained, well sorted sandstone or siltstone. It is virtually fossil free (except for some bioturbation and a few plant fragments). Frequently, it is calcite cemented.

Absence of marine invertebrate fossils and presence of plant fragments suggests that this lithology was relatively nearshore and close to a source of coarse siliciclastics. Because this lithology is exclusively part of the Chanute Shale, an interpretation, using other known properties of the Chanute, would be that these sandstones and siltstones were deposited at the mouth of an estuary as part of an estuarine fill sequence.

Gray, Fossiliferous Mudrock.--This facies usually occurs in thin (<30 cm) beds within limestone units. It contains a sparse marine biota of varying diversity--usually dominated by crinoids. Many are very similar, if not identical, to the **argillaceous carbonate mudstone** mentioned above, except for the amount of cementation. In core, it is usually expressed as horizons of dense stylolitization, but the fossil content is usually different from that of the surrounding carbonates; the **gray, fossiliferous mudrock** contains more crinoid material and different brachiopods (such as Crurithyris). It is often free of the grittiness which characterizes significant silt content.

These mudrocks are marine units, as evidenced by marine fossils and their close association with marine limestones. In core, they usually appear as nothing more than densely stylolized horizons less than 10 cm thick. They are, however, distinct beds and their fossils usually differ from those found in the immediately neighboring carbonates with which they probably intergrade. These may represent the very distal part of tempestites where only mud, not sand or silt, was carried and deposited. These are most frequently found interbedded with **skeletal wackestone** and not with the well washed **phylloid algal limestone.** They are also probably the same lithology, just

in thinner more clay rich beds, as the dark **argillaceous calcareous mudstone and calcareous mudrocks** which dominate the Iola in Missouri.

Black, Fissile Shale.--This lithology has a very high organic content, usually with phosphatic nodules or laminations. Fish scales and conodonts are common on fissility planes with organic plant matter at the center of the phosphate nodules. In core, or very fresh exposure, four or five graying upward beds about 10 cm thick with sharp bases make up this facies.

The organic carbon material which gives this rock its black color probably caused anoxia in the water column directly overlying the sediment. This is supported by a lack of unequivocally benthic body fossils and the absence of bioturbation. Inorganic phosphate nodules suggest slow rates of deposition, and the fine grained texture of the rock further suggests that deposition was from suspension. This lithology lacks any unequivocal bathymetric indicator. Faint graying upward sub-horizons, however, indicate greater stratigraphic complexity than simple accumulation of mud in a stagnant water basin. This facies occurs exclusively in the Muncie Creek Shale Member.

Gray, Non-fossiliferous Mudrock.--This is a bioturbated, calcareous mudrock with Zoophycus and

Chondrites traces common (frequently pyritized). Calcite body fossils are rare but conulariids are characteristic. It is only found directly above the **black, fissile shale.**

This lithology exclusively overlies the **black, fissile shale** of the Muncie Creek with which it shares a gradational boundary. The water column was no longer poisonous to benthic life as displayed by well developed burrows, but conditions were still restrictive as indicated by the low diversity of body fossils.

Gray-Green Siltstone.--This is a very sparsely fossiliferous siltstone. Fossils can include dense accumulations of crinoids or osagiid or ottonosid oncoids. More typically, however, only extremely sparse fenestrate bryozoans, pelecypods, and plant debris are present. Some degree of bioturbation is also typical. Fine-grained sandstone beds are not uncommon and are typically cross-laminated.

This facies makes up the bulk of the Lane Shale. A dense accumulation of marine fossils (usually at the contact with the Raytown Limestone Member) is not uncommon, but most frequently fossils are sparse and equivocally marine or brackish. Occasional thin, cross-laminated sandstones and cross-lamination in the siltstone suggests current reworking.

Stratigraphy

To understand changes in a stratigraphic unit, it is necessary not only to describe and interpret facies but also to have some understanding of the lateral and temporal relationships among them. Analysis of facies distributions, geometries, and contacts provides the data for building this kind of history. The following is a description of the facies distributions within and nature of contacts bounding each of the members of the Iola Limestone presented in Plate 2.

Cursory examination of Plate 2 shows a general pattern from north to south similar to that described by Heckel (1984a). On the Kansas-Oklahoma border there are coarse siliciclastics associated with the limestones. Northward, there is a thick phylloid algal mound in southeastern Kansas. The algal limestone grades into marine shelf facies from Miami County, Kansas through Platte and Clinton Counties in Missouri. Further north, however, is a section not included in the model described by Heckel--a region in northwestern Missouri where the interval equivalent to the Iola is dominated by dark, fine-grained siliciclastics. Finally, in Atchison County, Missouri, well developed carbonates displaying a tidal flat facies reappear. The Iola is different from the ideal "Kansas-type" cyclothem in that its "core" shale is poorly developed (often no more

than 15 centimeters thick) and only in north-central Kansas is the stereotypical **black, fissile shale** well developed.

Paola Limestone Member.--The Paola is the most laterally extensive and lithologically homogeneous member of the Iola. It ranges from 30 to 100 centimeters thick and is essentially a very thin sheet of limestone covering most of the study area. It is generally a mudstone to wackestone and in Kansas is consistently an **osagiid wackestone**. In Leavenworth County, Kansas, and where present in Missouri (Clay, Clinton, Platte, and Atchison Counties), it consists of relatively siliciclastic-free wackestones and packstones. In Buchanan, Andrew, and Nowaday Counties, Missouri, the Paola is replaced by **argillaceous carbonate mudstone** and cannot be recognized as a distinct limestone "ledge" in core.

The lower contact of the Paola with the underlying Chanute is generally quite abrupt, both in outcrop and core, with the transition always being less than the thickness of the limestone member. The Chanute, in Kansas, usually has a **sandstone** at the contact less than one meter below the Paola. This consistently sharp facies transition defines the lower contact of the Iola Limestone and is a significant stratigraphic surface.

At its upper contact, the Paola is overlain by either **black, fissile shale** or a thin bed of **gray, fossiliferous**

mudrock. In many places, there is clear evidence of hard-firmground development on the upper surface of the Paola (fig. 17); this includes encrusting bryozoans, irregular topography, lags of phosphate nodules resting directly on and tucked into overhangs on the surface, and large, vertical burrows-borings typical of hardgrounds (Wilson and Palmer, 1993). This surface can be traced from southern Montgomery County, Kansas on the Oklahoma border all the way to Clay County, Missouri.

Muncie Creek Shale Member.--The Muncie Creek is the "core" shale of the Iola cyclothem in Heckel's scheme. It consists of three facies: 1) **black, fissile shale,** 2) **gray, non-fossiliferous mudrock,** and 3) **gray, fossiliferous mudrock. Gray, non-fossiliferous mudrock** is present at only three localities: central Johnson County, Wyandotte County, and Leavenworth County. As mentioned before, this facies exclusively overlies the **black, fissile shale.** Besides these three locations, the only other place with a **black, fissile shale** is the core from the center of Woodson County, Kansas (CMM). At every other location examined, the Muncie Creek is represented by a bed of **gray, fossiliferous mudrock;** usually less than 15 centimeters thick if overlain by the Raytown limestone but thicker in Missouri where the Raytown is absent or poorly developed. In fact, the only way to distinguish the Muncie Creek from

thin gray mudrock horizons within the lower Raytown is by its phosphate nodules and the hardground upon which it rests.

Where the **black, fissile shale** rests on the Paola, there is usually a 1 to 2 centimeter thick argillaceous packstone or a fossiliferous, calcareous mudrock between the two, but this is the only transition--there is virtually no vertical facies gradation. At these same places, on outcrop, there is a lag of bored or encrusted micritic pebbles at the contact between the Muncie Creek shale and the Raytown limestone.

The presence of the Muncie Creek as a **gray, fossiliferous mudrock** bed coincides with the presence of the hardground at the top of the Paola. Phosphate nodules in this facies differ from those in the **black, fissile shale** in both morphology and physical condition. Those in the anoxic facies are lenticular and smooth and occur suspended in the black, muddy matrix (often with laminations compressed around them). All evidence points to them having formed within the black mud. Those in the **gray, fossiliferous mudrock**, on the other hand, occur resting on the basal contact of the unit; they are abraded and almost spherical in shape. They were not formed in the **gray, fossiliferous mudrock**; rather they probably represent the only remains of a more extensive sheet of **black, fissile shale** which was eroded prior to the deposition of

the Raytown limestone. Evidence for a submarine unconformity includes the following: 1) development of a hard-firmground at the top of the Paola, which usually requires burial and re-exhumation (Wilson and Palmer, 1992)--in this case the **black, fissile shale** (which never overlies the hard-firmground), 2) a lag of micritic intraclasts at the top of the Muncie Creek where it has not been entirely eroded, 3) truncation of laminations in a remnant of the **black, fissile shale** by the **gray, fossiliferous mudrock** at locality CMM (also, there is an abraded, spherical phosphate nodule directly on that contact), and 4) presence of phosphate nodules with a diagenetic origin from the **black, fissile shale** as clasts in the **gray, fossiliferous mudrock** on top of the hardground (and even tucked under small overhangs and pushed into burrows). In most of the study area, the time represented by the deposition of the Muncie Creek as a black shale has been entirely lost. Mitchell (1981) reported a few erosional remnants in Neosho County, Kansas, but these are not consistently present from locality to locality.

In Missouri, the Muncie Creek can be found separating the Paola from the Raytown where the two adjacent limestone members are clearly defined. Although there is often no more than a thin break in the sequence, it can be up to 1 meter thick, but it is not **black, fissile shale.** At

locality WM5, where the limestones are replaced with marine mudrocks, the contacts of the unit are not clear.

Raytown Limestone Member.--The Raytown is the most variable of the three Iola members with wide fluctuations in thickness and facies. Its facies can be roughly divided into a series of facies belts like those described by Heckel (1984a). The lower bounding surface is the erosional surface which resulted from the removal of the Muncie Creek in most places. The lower part of the Raytown often has two or three thin beds (~10 centimeters thick) of **gray, fossiliferous mudrock** which cannot be distinguished from the Muncie Creek except for the lack of phosphate nodules. Because there are either two or three beds, they cannot be correlated meaningfully without some means of distinguishing them (perhaps geochemically or paleontologically).

At the southern end of the outcrop belt, the Raytown is very poorly developed and is often absent, replaced by a calcareous sandstone with marine fossils. This may represent either a facies transition or erosion of the Raytown and subsequent filling by the siliciclastics.

The next facies belt is the phylloid algal limestone, which, in this case, probably does represent a true mound rising above the surrounding sea floor. The best support for this, as discussed previously, is by analogy with other

contemporaneous mounds in the Mid-Continent. If the lobes of the Raytown revealed by isopaching are really ebb-flood tidal deltas, they would require channels through the mound like those described in the Stanaton Limestone by Heckel (1972). The buildup displays all the characteristics of the generalized phylloid algal complex model presented earlier (fig. 3). The mound starts on **skeletal wackestone**, which serves as the basal unit; overlying it, the **phylloid algal limestone** appears relatively abruptly, and makes up the mass of the mound. Correlation, based on the presence of the "cabbage-head" algal morphology, indicates a remarkably uniform thickness to the basal facies phylloid algal mound (Plate 2). On the Wilson-Woodson County line and in northern Neosho County, the Cap Facies is represented by **gray-green siltstone** with dense accumulations of bored rugosan corals and ottonosid oncoids growing on bioclasts. This cap is missing in the core from the center of Woodson County, where the Raytown grades into beds of **argillaceous carbonate mudstones and calcareous mudrocks** less than 2 meters thick before the Wyandotte Limestone becomes fully developed. At the Ash Grove Cement Quarry (locality AGQ) in Neosho County and the Elk's Lodge Lake in Allen County (NE Sec. 2, T25S, R18E--examined but not measured), the buildup is about 14 meters thick and distinctly biostromal. Massive, uniform beds are traceable around the high walls at these two localities. The evenly

bedded pattern changes in the high wall of the Allen County Landfill (locality LF), locality IVE in Allen County, and locality OSAN in Miami County where the **phylloid algal limestone** displays distinct duneforms with crossbeds. These areas might best be described as the mound flanks, but as stated before, without more continuous outcrop the relationship of these bedforms to the thickening in the south makes this interpretation equivocal. These also may be related to whatever caused the northeast-southwest spreading along outcrop of the otherwise narrow phylloidal mound seen in the subsurface. The mound in the Raytown limestone seems to represent a single shallowing upward package with no internal, sharp facies changes discerned. Contrary to the general model presented earlier, which was symmetrical (fig. 3), the Iola mound is distinctly asymmetrical: thinning sharply to the south and gradually thinning to the north both in outcrop and in the subsurface.

Although there are a few tongues of the **phylloid algal limestone,** the dominant facies in the area around Kansas City is **skeletal wackestone.** Phylloid algal debris is common near the bottom of the Raytown, but grades upward into **skeletal wackestone.** Relatively thin beds of interlayered packstone, wackestone, and argillaceous limestone suggest a mosaic of depositional environments on a broad carbonate platform. In the upper half of the

Raytown in this area, there is often, though not always, a bed of **argillaceous carbonate mudstone or calcareous mudrock** of varying thickness. Also, again not consistently, there is a gross pattern in the Raytown of packstone grading upward to wackestone and then grading back to packstone at the top. Often the top packstone is no more than a few centimeters thick. This cap seems to be associated with or sometimes replaced by a particularly fossiliferous bed of the **gray-green siltstone** in the Lane Shale. In Johnson and Wyandotte Counties, Kansas and Clinton County, Missouri, the **gray-green siltstone** is dominated by crinoid remains--often including well-preserved crinoid plates.

In Buchanan, Andrew, and Nodaway Counties, Missouri, the interval correlative with the Iola Limestone in the south is an interval of **argillaceous carbonate mudstones and calcareous mudrocks**. In this region of Missouri, the Raytown is simply overwhelmed by siliciclastics. This terrigenous mud dominated facies belt is not part of Heckel's scheme (1984a). The pattern is, however, consistent with a noted increase in stylolitization at the measured sections from Clay and Platte Counties, in Missouri. This pattern, which seems to have influenced the Raytown more than the other two members of the Iola, is partly the explanation for why the exposure of the Iola is so poor in northwestern Missouri. Input of very fine-

grained siliciclastics, absent in other parts of the study area, suggests that this area was closer to a shoreline which provided this terrigenous detritus. However, it could not have been too close, because there is no evidence for exposure anywhere in the interval.

A single locality, in Atchison County, Missouri, displays the **laminated dolomitic mudstone** and closely associated **skeletal grainstone** lithologies. This is the nearshore facies belt of Heckel (1984a), and is clearly a carbonate coast.

Overall, the upper contact of the Raytown limestone with the Lane Shale is fairly sharp where there is a contact between carbonate and siliciclastics. It is often marked by a bioclastic lag--either of oncoids and corals, like those that cap the mound, or crinoid debris. Even if there is not a lag at the base of the overlying Lane, there is often a coarser carbonate lithology at the top of the Raytown. This may represent the maximum accumulation of carbonate before aggradational base level was reached. As suggested by Osleger (1991), aggrading subtidal cycles may have a limit determined by effective wave base. Where there is no lag, as in the center of Woodson County and in northwest Missouri, the overlying Lane Shale is **argillaceous carbonate mudstone and calcareous mudrock**--distinctly marine in origin, rather than the **gray-green siltstone** which overlies the "lag."

Summary.--The Iola Limestone contains stratigraphically significant surfaces which are recognizable, correlatable, and define distinct lithologic entities. They occur at the base of the Paola (a sharp facies change), at the base of the Raytown (a submarine erosional surface), and at the top of the Raytown, although this last surface is not as well developed as the previous two. These surfaces are not apparent in the terrigenous mud facies belt in northwestern Missouri, but can be consistently recognized in the southern part of the Missouri outcrop area as well as the entire Kansas outcrop belt.

Of the three members, the Paola is the most laterally extensive and lithologically homogeneous. The Muncie Creek probably was (as evidenced by the presence of phosphate nodules even where there is no **black, fissile shale**) equally continuous, but was eroded prior to deposition of the Raytown. The Raytown limestone is the most variable, both laterally and vertically, being particularly sensitive to the influences which produced the facies belts in the Pennsylvanian sea.

SEQUENCE STRATIGRAPHIC INTERPRETATION

Sequence stratigraphy "is the study of rock relationships within a chronostratigraphic framework of

repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative confromities. (Van Wagoner et al., 1988, p. 39)" Because surfaces can be recognized in the Iola Limestone and adjacent units, this approach can be used to interpret the depositional history of this unit.

The conceptual foundation of sequence stratigraphy, as discussed earlier, is based on how accommodation space is created and filled. The primary control on creation of accommodation space is a combination of tectonic subsidence and rate of eustatic sea level change. How fast that space fills is determined by the rate of sedimentation. Causes for change in these three factors and their interaction on sequences were explored by Galloway (1989), who described criteria for distinguishing the contribution of each factor.

Net long term subsidence must occur to produce the necessary accommodation space to preserve any sediment. Subsidence due to changes in horizontal crustal stress fields leads to base level changes of 0.01 millimeters per year (Galloway, 1989) near active tectonic zones--still just a fraction of the smallest rate of sea level change necessary to produce Mid-Continent cyclothems (Klein, 1992, Table 1). Isostacy can produce sufficiently fast changes in base level (Galloway, 1989, fig. 8), but it can only emphasize a pattern being driven by some other factor.

Without some other driver, isostacy will stop when it reaches an equilibrium. Klein (1993) made the point that some tectonic change can be very rapid (due to fault displacement and rapid uplift), but these kinds of changes cannot explain the widespread areal extent of many cyclothems or their repetitive character. Without calling on continent scale, rapid, periodic diastrophic fluctuations, tectonics cannot explain the origin of cyclothems. However, longer term tectonic eustacy can be a control on the variations between successive cyclothems as described in high-frequency, clastic sequences by Mitchum and Van Wagoner (1991) and in carbonates by Goldhammer et al. (1990).

As mentioned before, the rate of sedimentation controls how the space is filled. This is primarily governed by rates of erosion, weathering, and sediment transport, which, in turn, all reflect local climate. There were certainly rapid global and regional climate changes associated with the origin of Pennsylvanian cyclothems (Cecil, 1990), but how they affected the rate of sedimentation is still poorly understood. A simple rule is that wetter climates lead to siliciclastic deposition and drier climates lead to carbonate deposition (West, 1990). However, wet-dry cycles would best be tested by consistently comparing changes in either siliciclastics or carbonates through a cycle, not by comparing them to each

other. Galloway (1989) suggested that minimal paleogeographic change through a cycle and abrupt changes in average depositional rate, grain size, or mineralogic composition are suggestive of changes in sediment supply. Finally, changes in rate and type of sediment input overprinted on continuous, long-term subsidence (necessary to produce a net increase in accommodation) cannot lower base level beyond the top of the highest deposited sediment in a given cycle. This means that subaerial incision during "lowstand" cannot occur.

Crowley and Baum (1991) demonstrated that in the late Pennsylvanian there were continental ice sheets on the Gondwanan supercontinent in the southern hemisphere. Presuming that these experienced periodic expansions and withdrawals similar to Pleistocene ice sheets, there must have been glacioeustatic changes in sea level on the order of 100 meters or more (Crowley and Baum, 1991; Maynard and Leeder, 1992). Further, incision of up to 70 meters (Boardman et al., 1984) is known in the Upper Pennsylvanian Mid-Continent. This could only be caused by either rapid uplift or sea level drop. There is no known mechanism for continent-wide, cyclic diastophism, yet rapid changes in base level were occurring (250,000 to 400,000 years duration for an individual cyclothem [Heckel, 1991]). Because glaciation is known to have occurred during this time, it is reasonable to examine the stratigraphy of the

Mid-Continent in the context of a glacioeustatic driver. Rates of sedimentation would be influenced by the changing size of the basin--greater amounts of eroded, siliciclastics would be input during lowstand when a large area was above base level. There would be lower input during highstand when more of the drainage feeding the Mid-Continent embayment was below base level.

Facies tracts in sequence stratigraphy are defined by stratigraphic surfaces--the sequence boundary unconformity, transgressive surface, and maximum flooding surface. Identifying these surfaces sets up a framework for interpreting a sequence in space and time. Although the expression of surfaces and facies tracts in the Mid-Continent is different from those in siliciclastic passive margins or shallow water carboantes, the definitions explained previously are sufficiently general to be applied to the Iola sequence.

The sequence stratigraphic history of the Iola cycle in both a time and thickness dimension is depicted in figure 18. Within this cycle, which includes part of the Chanute and Lane formations, the sequence boundary is at the base of, or within, the Chanute Shale, the transgressive surface is at the base of the Paola limestone, the maximum flooding surface is at the base of the Raytown limestone, there may be a "regressive" surface

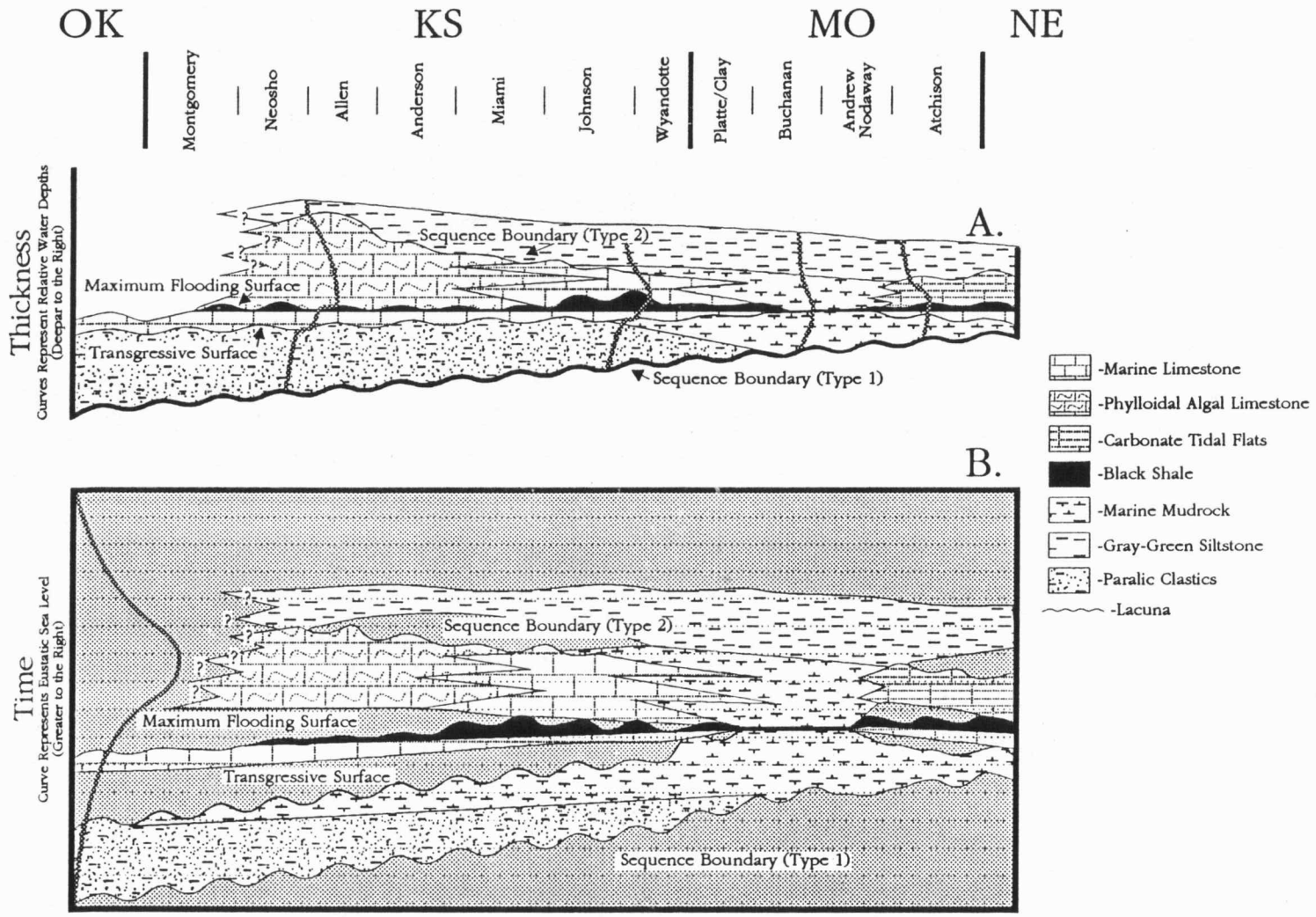

Figure 18. Conceptual model for the deposition of the Iola Limestone. A. Schematic diagram of the geometry of the Iola along the trend of this study. Basic facies belts described in text are shown. Note the lateral changes in the water depth curves. B. Wheeler diagram (Wheeler, 1964) of Iola deposition along a time axis. Gray areas represent non-depositional or erosional surfaces where time is not preserved. Note that the trend of the diagram follows the strike of the study area and is not simply perpendicular to the basin margin.

at the top of the Raytown, and the upper boundary of the sequence is within the Lane Shale.

Previous descriptions of the Chanute Shale clearly indicate an erosive lower surface at the base of the unit in southeastern Kansas. In northeastern Kansas, it has red and green variegated mudrocks at its base--probably paleosol horizons. This indicates subaerial exposure and erosion, which are the defining characteristics of a type 1 sequence boundary. This was formed during eustatic drop in sea level and partly during sea level lowstand. (Note: in this discussion sea level refers to eustacy and should not be confused with water depth.) It was at this time that the valley, which was later filled with estuarine deposits, was carved. At the start of transgression, accommodation space within this valley was filled first with fluvial deposits, then estuarine sediments, and finally siliciclastics characteristic of the estuarine-marine interface. This inferred pattern is like that of the sandstones and mudrocks in the Douglas Group described by Archer et al. (1993). These, together, make up the lowstand facies tract and were deposited during the initial phases of sea level rise.

The siliciclastic valley fill ends at the base of the Paola Limestone Member. This surface, defined by a drastic facies change from siliciclastic to carbonate with no lithologic intermediates, is the transgressive surface.

Lack of a facies gradation suggests that a non-depositional or erosive environment separated the siliciclastic outer estuarine depositional environment from the open marine carbonate environment. The **osagiid wackestone** which makes up the Paola is laterally continuous compared to modern, shallow-water carbonate environments, which suggests that it is a diachronous deposit. Even a depositional environment of limited areal extent can be preserved over a large area if it migrates through time, has enough accomodation space, and does not get reworked. The entire Paola represents aggradation up to base level after effective wave base rose above the sediment-water interface. Effective wave base, as it transgressed past a point, created the non-depositional-erosive transgressive surface (Enos, 1991), but then as sea level continued to rise this same base level defined the upper limit of aggradation. The facies interpretation of the **osagiid wackestone**, which filled the accomodation space, as a deposit that accumulated below fair weather wave base is consistent with this idea.

The Muncie Creek was also part of the transgressive systems tract, which is deposited during maximum rate of sea level rise. On an epeiric shelf, not only is sea level rising, but the coastline is being pushed further inland and significantly extending its length (like a balloon expanding) as the submerged part of the basin increases.

Also transgressing is the non-depositional-erosive environment which created the transgressive surface. As it progressed landward, it began to override the peat producing swamps farther inland. The overridden peat correlative to the Paola in the Illinois basin is preserved as the Witt coal (Wanless and Wright, 1978). Transgressed peat would have been comminuted and flushed into the marine basin, with coarser siliciclastics being trapped at the heads of estuaries (which were maintained by the rapid sea level rise). This reworked peat is the organic matter which gives the **black, fissile shale** its characteristic color. The fact that bits of wood can be found in the black shales indicates that organic carbon could easily be moved far into the basin. As pointed out by Demaison and Moore (1980), it is overwhelming amounts of organic carbon which lead to an anoxic water column, not vice-versa. It is unnecessary to call upon upwelling from a distant basin to create anaerobic conditions to preserve organic carbon as proposed by Heckel (1977). A terrigenous source of organic carbon brought by fresh water runoff is also consistent with the contribution of a halocline to water column stratification (Heckel, 1991). Evidence for increasing organic influx during black shale deposition is the geochemical trend of increasing terrigenous organic carbon upward (Wenger and Baker, 1986). Water depth may not have been changing if sedimentation could keep up with

sea level rise, but the depositional-shoreline break would be moving further inland as siliciclastic lobes prograded into the Kansas sea. The Paola limestone was deposited in the time between the passage of the transgressive surface and the first influence of the organic carbon input, which was the result of the same surface overriding the distant peat deposits of the continental interior. That abrupt change from limestone to organic-rich shale suggests that the start of organic input was sudden as the depositional-shoreline break moved inland. The **non-fossiliferous, gray mudrock** probably represents slowing down of sea level rise and less flushing of eroded organics--a gradual change when compared to the abrupt base of the **black, fissile shale** of the Muncie Creek.

The maximum flooding surface is the erosive surface at the base of the Raytown limestone which removed most of the Muncie Creek shale. Exactly why it was erosive is not clear, but there is no doubt erosion occurred. In fact, erosion probably would have cut down further if the Paola had not undergone shallow burial diagenesis and become more coherent than the overlying black mud. A possible reason for erosion is that the amount of mud being input to the system during **black, fissile shale** deposition exceeded the accommodation volume between the sea floor and submarine base level (defined by effective wave base). When the siliciclastic input slowed down, storm and wave energy

redistributed it into the deeper parts of the basin. This idea is somewhat supported by the existence of phosphatic laminations, which have the appearance of single grain lags of peloids (Kidder, 1985), possibly concentrated by slow bottom currents. Also, the graying upward beds with sharp bases within the Muncie Creek in the core from Leavenworth County, Kansas could be interpreted as event horizons.

The Raytown limestone itself is the highstand facies tract. The strongest evidence for its being deposited during a stillstand is the **dolomitic laminated mudstone.** Carbonate tidal flats autocyclically prograde and do not develop during sea level drop because they are left stranded as the shoreline recedes (Read, 1986). Further evidence for highstand during deposition of the Raytown is the existence of the phylloid algal limestone. This mound on the carbonate platform must have been aggrading during stillstand to get so massive; if it was deposited during sea level drop it would be expected to have an internal architecture consistent with progradation. Although water depth was certainly shallowing during deposition of the Raytown, it represents sediment filling available accommodation space--the mound aggraded and "caught-up" to sea level. When filled up to effective wave base, a coarse bioclastic or oncoidal lag began to develop. This is the top of many subtidal cycles as described by Osleger (1991). Vertical variation in the lower Raytown north of the

thickening, from grain supported lithologies upward to mud supported lithologies, probably reflects constriction of water circulation patterns in the basin as the mound grew. Isopached geometry, based on subsurface data, suggests that tidal channels passed through the phylloid algal mound (Olszewski, 1993). This is based on analogy with the algal mounds of the Stanton Limestone (Heckel, 1972, 1978), which are dissected by channels filled with marine limestone. Carbonate sands within these channels display bimodal foreset directions and were interpretted by Heckel (1972) as analogous to the tidal channels separating coral reefs of the Trucial Coast. The paired lobes of the Raytown mound are flood and ebb tidal deltas on either side of analogous passages.

The upper sequence boundary of the Iola cycle is the lag at the top of the Raytown. However, there is no evidence for pedogenesis or erosional downcutting in most of the study area. The only evidence for exposure of any sort is at the contact of the Lane with the Raytown limestone at core WM4, which has root traces, possible dessication cracks, and fenestrae. This is consistent with Osleger's (1991) suggestion that carbonates aggrade up to subtidal base level but a subtidal base level rather than subaerial base level. The **skeletal grainstone** which underlies **dolomitic, laminated mudstone** facies represents aggradation to subtidal base level before being overridden

by prograding tidal flats. This surface correlates to the bioclastic lag found elsewhere between the Iola and Lane. Because most of the shelf was not subaerially exposed, the sequence boundary is type 2. Sea level did not drop quickly enough to overtake subsidence and expose the shelf --it just allowed progradation of siliciclastics from the coast to overwhelm carbonate deposition which had already aggraded as far as it could. Siliciclastics of the Lane are part of the shelf margin facies tract of the overlying Wyandotte sequence.

The greatest difficulty with this interpretation is what to do with the section in Andrew, Nodaway, and Buchanan Counties in Missouri. In this region, the interval from the Block limestone to the base of the Wyandotte appears to be a continuously deposited marine mudrock with a few argillaceous limestone beds. Paleosols and valley fill in the Chanute Shale are lacking. Yet, in Platte County just to the south, the sequence is consistent with exposures in Kansas, and the Atchison County locality to the west closely matches sections in Nebraska (Mitchell, 1981). Searches of Caldwell, Dekalb, Daviess, Gentry, and Harrison Counties in Missouri failed to show any sign of the Iola on outcrop although other limestones (Bethany Falls, Dennis, and Argentine) could be identified. Over this large area, it seems, the Iola Limestone was swamped by siliciclastics. This part of the basin must have been

sufficiently close to the mouth of a river draining the craton that muds were dominant. This must have been very different from the coastline to the west which was sufficiently free from siliciclastic influence that tidal carbonate mudflats developed. A possible reason for the absence of any terrestrial facies, like paleosols, in the Chanute is that they were removed during transgression. There are no fluvio-estuarine sandstones simply because this area was an interfluve high on the platform and provided no space to fill during initial transgression. This implies a very different kind of coastline than described previously for the Mid-Continent limestones: one dominated by siliciclastic mud rather than carbonates. One only found at the mouths of large rivers--elsewhere, at the same time, carbonates were accumulating as tidal flats. It was a mud-rich section of the coast which must have been the conduit for the organics in the detrital black shale. If this is true, these marine muds must grade laterally into unequivocally prodeltaic deposits or estuarine deposits like those of the Chanute in southeastern Kansas. Hiatal surfaces become correlative conformities in this region because it was not controlled by subtle sea level changes like the more open parts of the basin; rather, there was virtually constant, monotonous sedimentation from a continental source swamping any pattern of eustatic sea level change.

Although sequence stratigraphic definitions and concepts were developed in other types of basins, they can be applied successfully to the Iola cyclothem. The type 1 sequence boundary and lowstand systems tract of the Chanute Shale are very similar to the incisement and filling of valleys on a siliciclastic passive margin described by Baum and Vail (1987). The transgressive surface is, as defined by Van Wagoner et al. (1987), the first significant marine flooding surface. In the case of the Iola, it is the transition from relatively nearshore clastics to marine carbonates at the base of the Paola limestone. The maximum flooding surface is not recognized by downlap of parasequences but rather by an extensive submarine erosion surface. The Muncie Creek is in a position equivalent to the condensed section of Van Wagoner et al. (1987), but it may not be very condensed When the **black, fissile shale** is preserved it can be as thick as the overlying highstand systems tract in the Raytown limestone (as in core BRD). The highstand systems tract did indeed form during high stillstand and not during sea level fall as asserted by Heckel and Pope (1992). Its development is like the carbonate cycles described by Read et al. (1986) when tidal flat facies are involved and by Osleger (1991) when the Raytown is entirely subtidal. The upper sequence boundary was only subaerial in northwest Missouri. There is, however, a subtidal hiatal surface at the top of the

Raytown equivalent to the exposure surface in Atchison County, Missouri. Carbonate aggradation filled available accommodation space but the shelf margin facies tract of the Wyandotte sequence (the Lane Shale) was deposited before the carbonate tidal flats could prograde across the entire shelf.

Implications of these findings for any cyclothem model are several. As applied to the Iola cycle, the basic transgressive-regressive interpretation is correct, but as can be seen in figure 18a, the water depth curves change along the strike of the study area (which is probably oblique to the paleocoastline). The shape of each curve depends on its position relative to a siliciclastic source and when in the sea level cycle deposition started filling accommodation space. In southeastern Kansas, where the sequence stratigraphic surfaces are well developed, some sediment deposited at a given water depth has not been preserved due to later submarine erosion. This causes the "kinks" in the curves. In Heckel's model, the water depth curve is considered equivalent to the eustatic sea level curve (fig. 19). Given that the Raytown preserves progradational carbonate tidal flat facies possible only during stillstand, highstand must have occurred during deposition of the Raytown rather than the Muncie Creek. The relationship between sea level and water depth in the

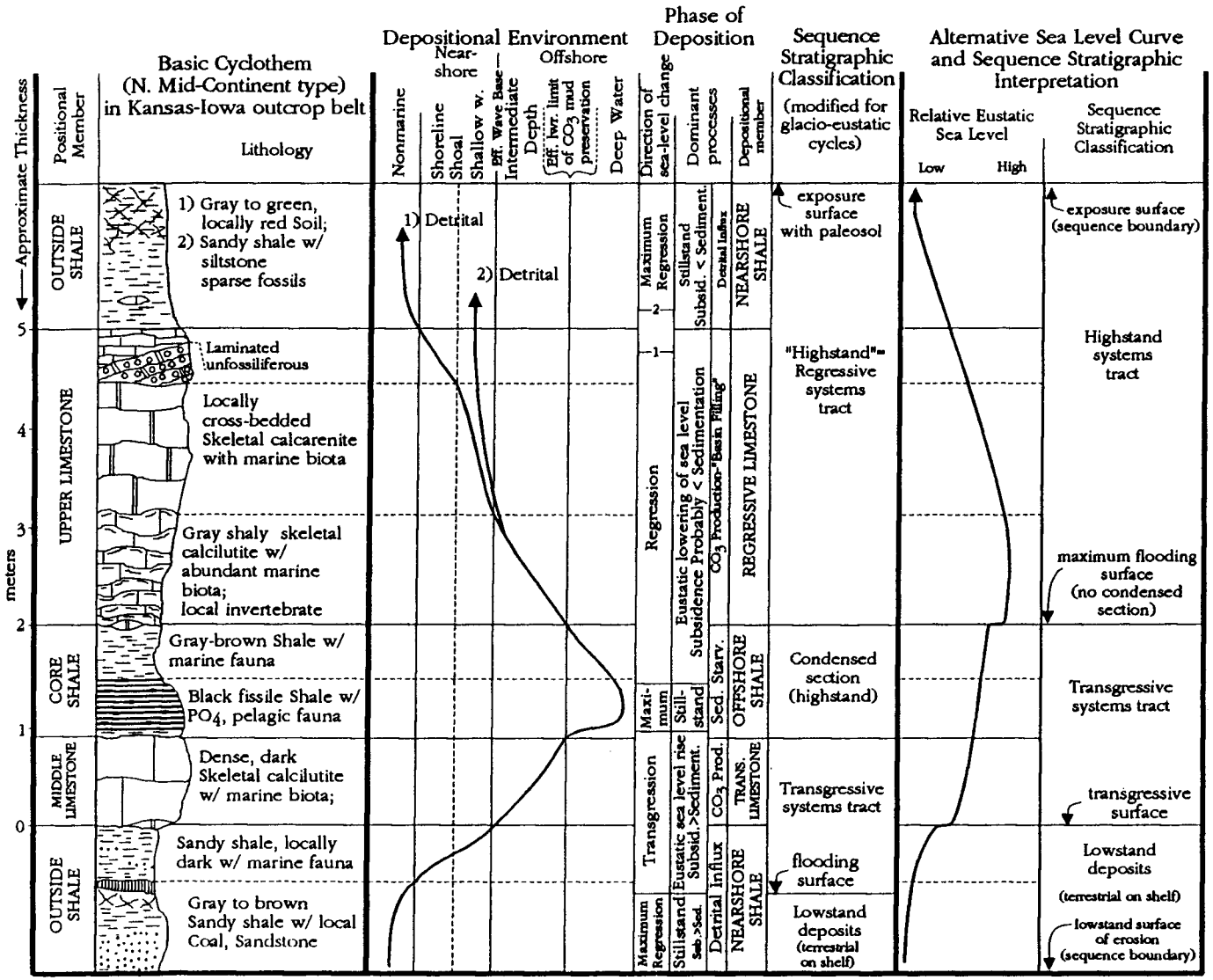

Figure 19. Sequence Stratigraphic Interpretation of the Heckelian Cyclothem. The sea level curve has been shifted one quarter phase as indicated by a sequence stratigraphic interpretation of the Iola Limestone. Kinks in the sea level curve at sequence stratigraphic surfaces are due to non-depositional or erosional episodes. The time during which those sea level changes occurred is not preserved in the rock record (modified from Heckel and Pope, 1992).

ideal Heckel cyclothem are shown in figure 19. Finally, the implicit assumption that deposition was continuous cannot be true; there are laterally traceable submarine hiatal surfaces (both erosional and non-depositional).

CONCLUSIONS

This study draws a number of new conclusions concerning the Iola Limestone. First, the shape of the phylloid algal mound is a ridge running roughly northwest-southeast parallel to the Bourbon Arch. Its crest has a number of lobes which are interpreted as ebb-flood tidal deltas. The thickness of the overlying Lane Shale is strongly negatively correlated with the Iola; this is interpreted as the result of siliciclastics filling space around the original depositional topography created by the phylloid algal mound.

New information indicates that the Iola interval is a fine-grained siliciclastic interval in the northwest corner of Missouri. This is interpreted as a part of the marine basin with a shoreline close enough to be the major influence in deposition rather than changes in sea level. Any siliciclastics in the more open part of the basin, namely the Muncie Creek, must have passed through this area, or similar areas along the coastline of the basin.

Finally, stratigraphically significant (i.e. laterally extensive and lithologically distinguishable) surfaces are

present within the Iola cycle. These can be interpreted in a sequence stratigraphic model as the upper and lower sequence boundaries, the transgressive surface, and the maximum flooding surface. Deposits within each of the facies tracts bounded by these surfaces are consistent with control of accommodation space by sea level rise and fall. In contrast to the Heckel cycle model, highstand is separate from maximum water depth; the greatest water depth occurred near the end of Muncie Creek deposition, whereas highstand occurred during deposition of the Raytown limestone. The Iola sequence overlies a type 1 sequence boundary and is capped by a type 2 boundary.

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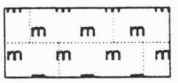
APPENDIX 1 - KEY TO MEASURED SECTIONS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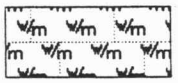
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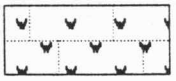
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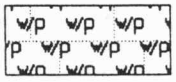
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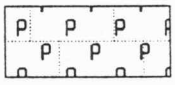
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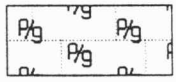
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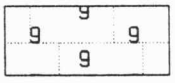
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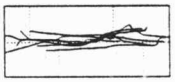
-argillaceous limestone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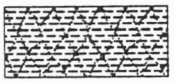
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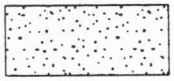
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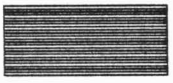
-siltstone

-calcareous siltstone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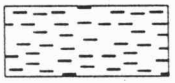
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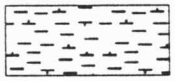
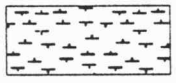

-calcareous mudrock

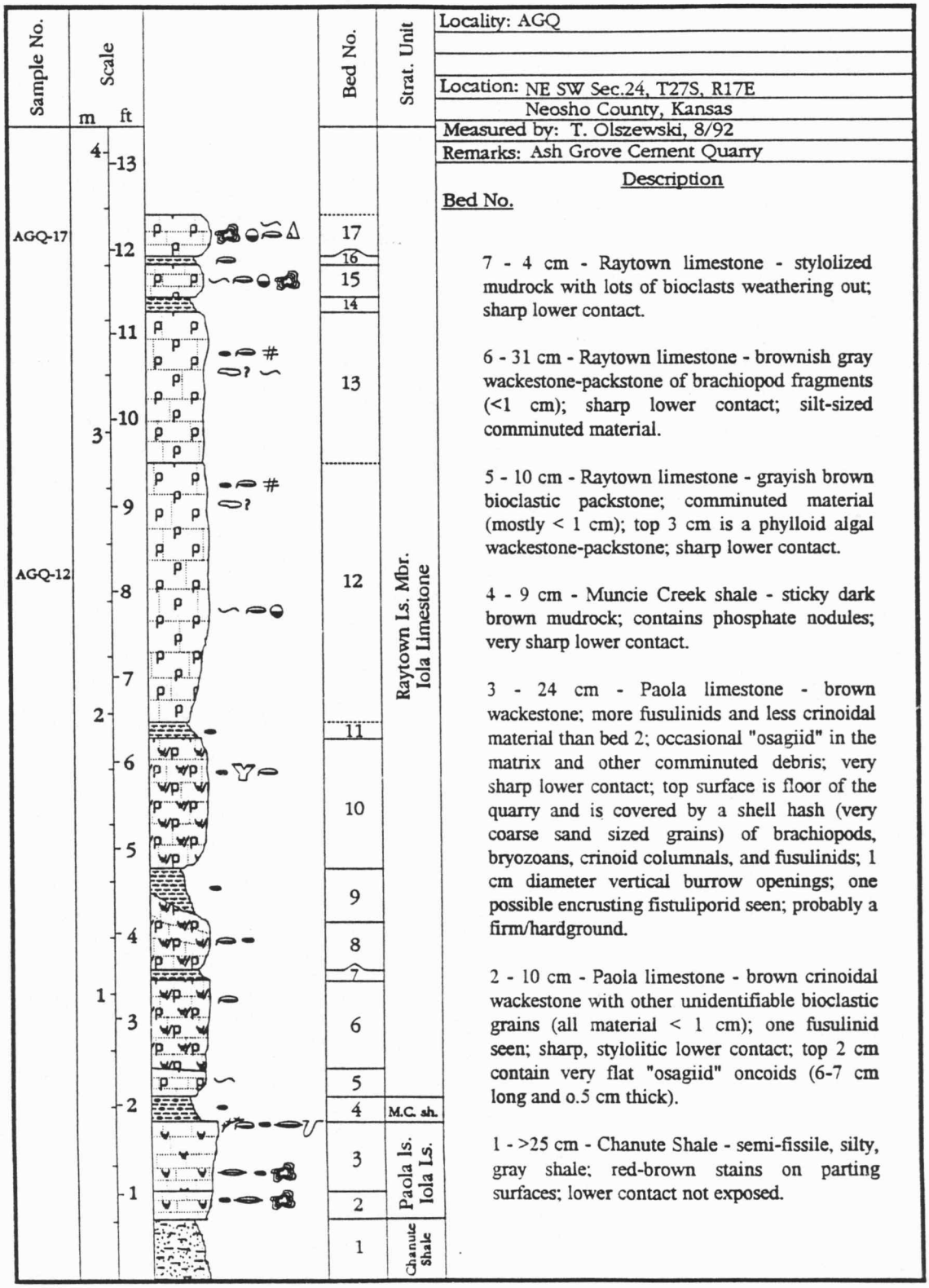

-calcite cemented mudrock

——— -sharp contact

····· -gradational contact

- -peloid
- -intraclast
- -phosphate nodule
- -pyrite
- -dolomite
- -stylolites
- -geopetal
- -cross laminae
- -coated bioclast
- -oncoid
- -ooid
- -shell lag
- $ -petroleum
- -fusulinid
- -opthalmid
- -phylloid algae
- -"cabbage head" algae
- -Epimastopora
- # -fenestrate bryozoan
- -ramose bryozoan
- -encrusting bryozoan
- -inarticulate brachiopod
- -articulate brachiopod
- -burrow/bioturbation
- -root trace
- -terrigenous plant fragments
- -fish scale
- -conulariid
- -girvanellid sponge
- -platy sponge
- -pelecypod
- -gastropod
- -cephalopod
- -rugose coral
- -crinoid
- -ostracode
- -trilobite

APPENDIX 2
MEASURED SECTION DESCRIPTIONS



Locality: AGQ

Location: NE SW Sec.24, T27S, R17E
Neosho County, Kansas

Measured by: T. Olszewski, 8/92

Remarks: Ash Grove Cement Quarry

Description

Bed No.

7 - 4 cm - Raytown limestone - stylolized mudrock with lots of bioclasts weathering out; sharp lower contact.

6 - 31 cm - Raytown limestone - brownish gray wackestone-packstone of brachiopod fragments (<1 cm); sharp lower contact; silt-sized comminuted material.

5 - 10 cm - Raytown limestone - grayish brown bioclastic packstone; comminuted material (mostly < 1 cm); top 3 cm is a phylloid algal wackestone-packstone; sharp lower contact.

4 - 9 cm - Muncie Creek shale - sticky dark brown mudrock; contains phosphate nodules; very sharp lower contact.

3 - 24 cm - Paola limestone - brown wackestone; more fusulinids and less crinoidal material than bed 2; occasional "osagiid" in the matrix and other comminuted debris; very sharp lower contact; top surface is floor of the quarry and is covered by a shell hash (very coarse sand sized grains) of brachiopods, bryozoans, crinoid columnals, and fusulinids; 1 cm diameter vertical burrow openings; one possible encrusting fistuliporid seen; probably a firm/hardground.

2 - 10 cm - Paola limestone - brown crinoidal wackestone with other unidentifiable bioclastic grains (all material < 1 cm); one fusulinid seen; sharp, stylolitic lower contact; top 2 cm contain very flat "osagiid" oncoids (6-7 cm long and o.5 cm thick).

1 - >25 cm - Chanute Shale - semi-fissile, silty, gray shale; red-brown stains on parting surfaces; lower contact not exposed.

AGQ, NE SW Sec. 24, T27S, R17E, Neosho County, Kansas

17 - 14-15 cm - Raytown limestone - gray wackestone-packstone of oncoids (one is hollow and geodiferous); sharp lower contact; other fossils include: brachiopod fragments, phylloid algal fragments, and gastropod.

16 - 6 cm - Raytown limestone - stylolitic bed with Composita; sharp lower contact.

15 - 23 cm - Raytown limestone - phylloid algae in a matrix of bioclastic packstone; sharp lower contact; lots of carbonate spar; geopetaliferous brachiopods (one productid) and oncoids on lower contacrt

14 - 5 cm - Raytown limestone - gray stylonodular argillaceous limestone; sharp lower contact.

13 - 53 cm - Raytown limestone - gray and orange phylloid algal packstone with subhorizontal vuggy porosity; gradational lower contact.

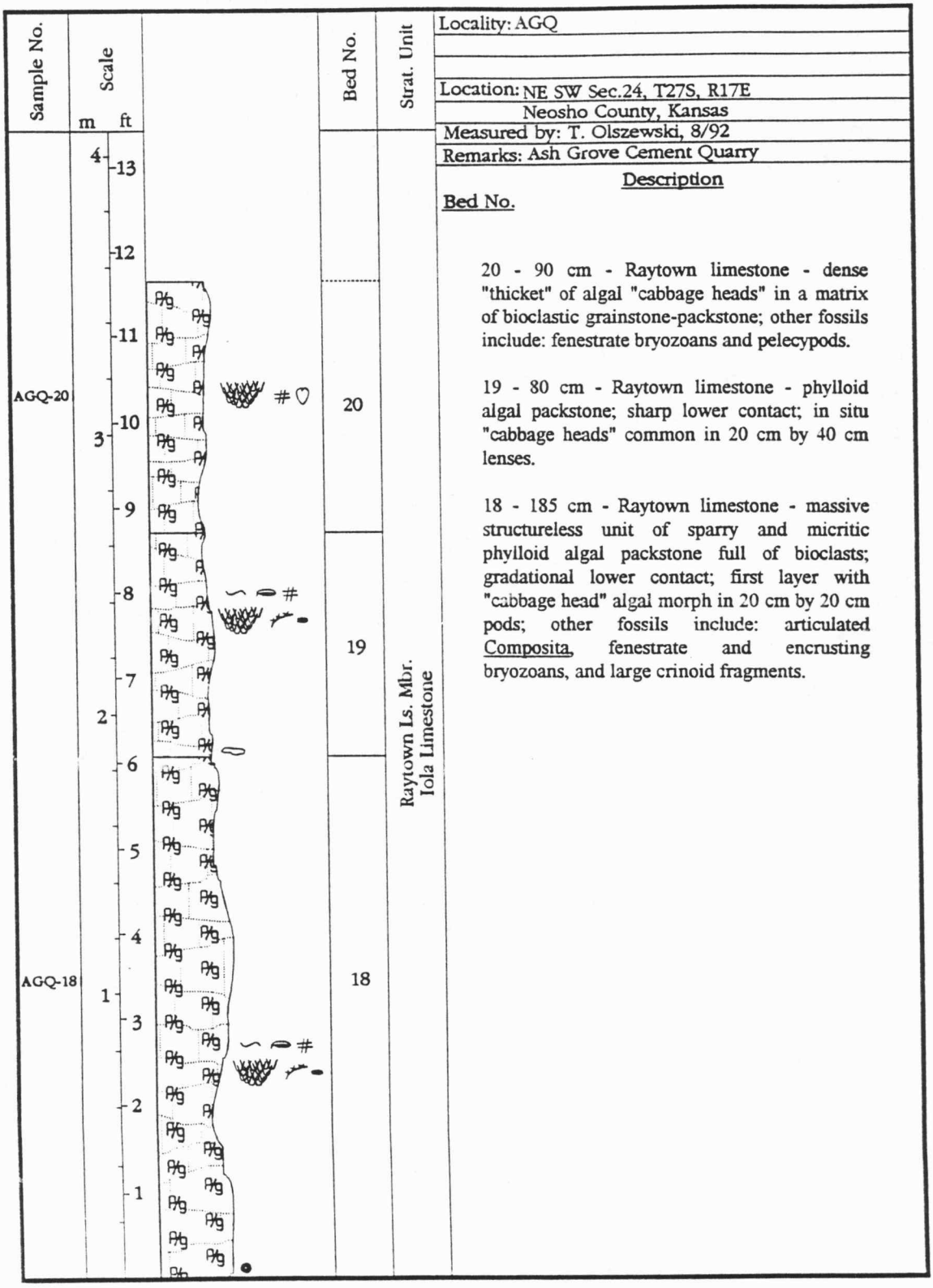
12 - 92 cm - Raytown limestone - gray (micrite) and orange (spar) phylloid algal packstone; sharp lower contact; lowest 10-12 cm contain disturbed phylloid algal plates, geopetaliferous brachiopods, comminuted algal material, all in a micritic matrix; upper part--very sparry bioclastic packstone including crinoids, brachiopod fragments, fenestrate bryozoans, and patches of gray micrite (reworked intraclasts?)-- framework supported-- gradational contact with lower part.

11 - 6 cm - Raytown limestone - stylonodular, calcareous mudrock; sharp lower contact; only crinoid fragments are identifiable.

10 - 46 cm - Raytown limestone - light yellowish gray wackestone-packstone; sharp lower contact; dispersed horsehair stylolites; fossils include: crinoid columnals, ramose bryozoans, and brachiopods (no algae evident); lag at upper contact.

9 - 19 cm - Raytown limestone - gray, calcareous, stylonodular mudrock; limestone nodules are gray wackestone-packstone; sharp lower contact; sand sized bioclasts as well as common crinoid columnals; upper part is more calcareous than lower part.

8 - 17-26 cm - Raytown limestone - brownish gray wackestone-packstone of bioclastic material; more crinoids and fewer brachiopods than in bed 6; sharp lower contact; fossils include: few crinoid columnals > 1 cm diameter; uppermost 6 cm is coarse bioclastic packstone-grainstone of mostly brachiopods and large crinoid fragments.



Locality: AGQ

Location: NE SW Sec.24, T27S, R17E
Neosho County, Kansas

Measured by: T. Olszewski, 8/92

Remarks: Ash Grove Cement Quarry

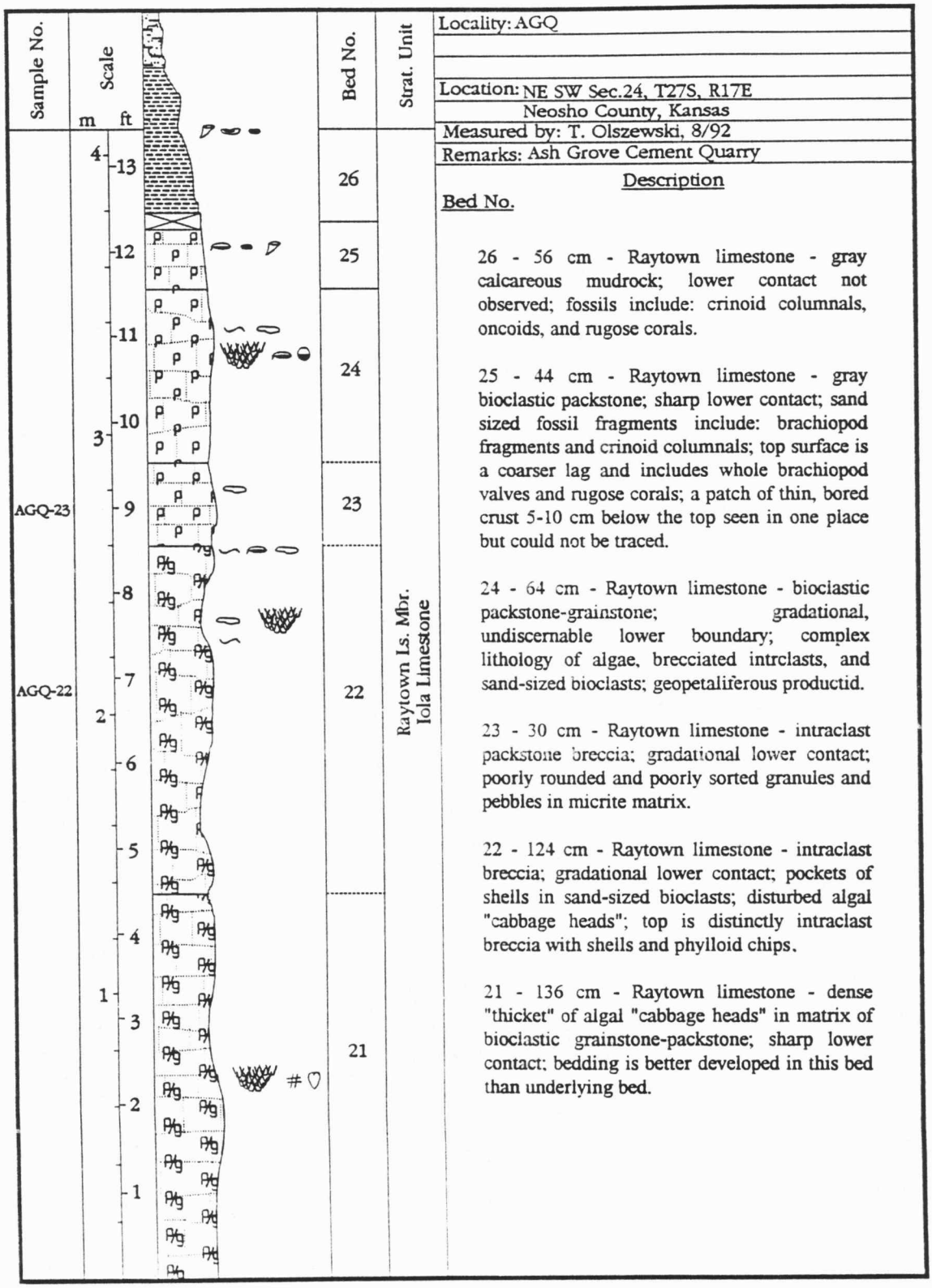
Description

Bed No.

20 - 90 cm - Raytown limestone - dense "thicket" of algal "cabbage heads" in a matrix of bioclastic grainstone-packstone; other fossils include: fenestrate bryozoans and pelecypods.

19 - 80 cm - Raytown limestone - phylloid algal packstone; sharp lower contact; in situ "cabbage heads" common in 20 cm by 40 cm lenses.

18 - 185 cm - Raytown limestone - massive structureless unit of sparry and micritic phylloid algal packstone full of bioclasts; gradational lower contact; first layer with "cabbage head" algal morph in 20 cm by 20 cm pods; other fossils include: articulated Composita, fenestrate and encrusting bryozoans, and large crinoid fragments.



Locality: AGQ

Location: NE SW Sec.24, T27S, R17E
Neosho County, Kansas

Measured by: T. Olszewski, 8/92

Remarks: Ash Grove Cement Quarry

Description

Bed No.

26 - 56 cm - Raytown limestone - gray calcareous mudrock; lower contact not observed; fossils include: crinoid columnals, oncoids, and rugose corals.

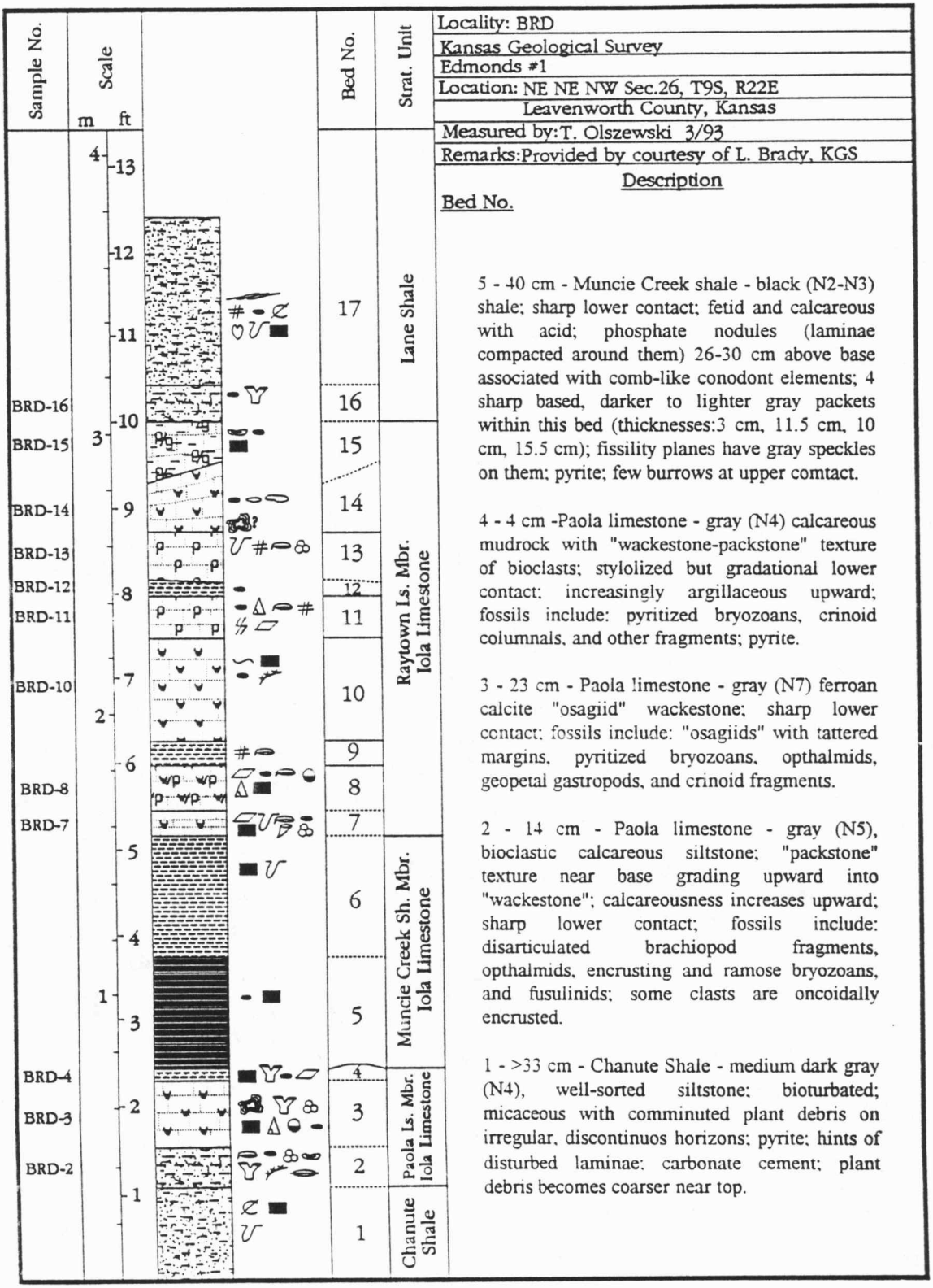
25 - 44 cm - Raytown limestone - gray bioclastic packstone; sharp lower contact; sand sized fossil fragments include: brachiopod fragments and crinoid columnals; top surface is a coarser lag and includes whole brachiopod valves and rugose corals; a patch of thin, bored crust 5-10 cm below the top seen in one place but could not be traced.

24 - 64 cm - Raytown limestone - bioclastic packstone-grainstone; gradational, undiscernable lower boundary; complex lithology of algae, brecciated intrclasts, and sand-sized bioclasts; geopetaliferous productid.

23 - 30 cm - Raytown limestone - intraclast packstone breccia; gradational lower contact; poorly rounded and poorly sorted granules and pebbles in micrite matrix.

22 - 124 cm - Raytown limestone - intraclast breccia; gradational lower contact; pockets of shells in sand-sized bioclasts; disturbed algal "cabbage heads"; top is distinctly intraclast breccia with shells and phylloid chips.

21 - 136 cm - Raytown limestone - dense "thicket" of algal "cabbage heads" in matrix of bioclastic grainstone-packstone; sharp lower contact; bedding is better developed in this bed than underlying bed.



Locality: BRD
Kansas Geological Survey
Edmonds #1
Location: NE NE NW Sec.26, T9S, R22E
Leavenworth County, Kansas
Measured by:T. Olszewski 3/93
Remarks:Provided by courtesy of L. Brady, KGS

Description

Bed No.

5 - 40 cm - Muncie Creek shale - black (N2-N3) shale; sharp lower contact; fetid and calcareous with acid; phosphate nodules (laminae compacted around them) 26-30 cm above base associated with comb-like conodont elements; 4 sharp based, darker to lighter gray packets within this bed (thicknesses:3 cm, 11.5 cm, 10 cm, 15.5 cm); fissility planes have gray speckles on them; pyrite; few burrows at upper comtact.

4 - 4 cm -Paola limestone - gray (N4) calcareous mudrock with "wackestone-packstone" texture of bioclasts; stylolized but gradational lower contact; increasingly argillaceous upward; fossils include: pyritized bryozoans, crinoid columnals, and other fragments; pyrite.

3 - 23 cm - Paola limestone - gray (N7) ferroan calcite "osagiid" wackestone; sharp lower contact; fossils include: "osagiids" with tattered margins, pyritized bryozoans, opthalmids, geopetal gastropods, and crinoid fragments.

2 - 14 cm - Paola limestone - gray (N5), bioclastic calcareous siltstone; "packstone" texture near base grading upward into "wackestone"; calcareousness increases upward; sharp lower contact; fossils include: disarticulated brachiopod fragments, opthalmids, encrusting and ramose bryozoans, and fusulinids; some clasts are oncoidally encrusted.

1 - >33 cm - Chanute Shale - medium dark gray (N4), well-sorted siltstone; bioturbated; micaceous with comminuted plant debris on irregular, discontinuos horizons; pyrite; hints of disturbed laminae; carbonate cement; plant debris becomes coarser near top.

BRD, NE NW NW Sec. 26, T9S, R22E, Leavenworth County, Kansas

17 - 425 cm - Lane Shale - laminated, calcareous, well sorted, gray (N5) siltstone; gradational lower contact; lenticles of fine sandstone dispersed throughout bed (sometimes displaying cross-lamination); mica; fossils very sparse, but include: fenestrate bryozoan molds, crinoid columnals, wood (comminuted and large fragments and possible seed pod), pelecypod periostraca, and burrows; argillaceous slickensides; upper contact is sharp, discontinuous, and cut down by an argillaceous bioclastic packstone.

16 - 13 cm - Lane Shale - gray (N5), calcareous siltstone with bioclasts; gradational lower contact; fossils include: crinoids and ramose bryozoans.

15 - 14-23 cm - Raytown limestone - argillaceous packstone-grainstone of unidentifiable bioclasts which appear coated; gradational lower contact; minor pyrite; crinoid columnals.

14 - 17-24 cm - Raytown limestone - gray (N4-N5) bioclastic wackestone of ferroan calcite; micrite appears peloidal; sharp lower contact defined by "osagiid" clast; fossils fragmented beyond recognition to size of well sorted, coarse sand; few crinoid bits recognizable.

13 - 17-18 cm - Raytown limestone - gray (N7-N8) bioclastic packstone with patches of wackestone (especially in lowest 6 cm); gradational lower contact; burrow mottled texture; dolomitized burrow present; fossils include: fenestrate bryozoans, crinoid columnals, brachiopod fragments, opthalmids, and some odd brown fills of bryozoan mesh or burrows (?).

12 - 5-6 cm - Raytown limestone - bioclastic, calcareous mudrock; sharp lower contact; pervasively stylolized; fossils include: crinoid columnals and unidentifiable bioclastic fragments.

11 - 15 cm - Raytown limestone - ferroan calcite, bioclastic packstone; lower contact is 2 cm thick zone of horsehair stylolites; fossils include: crinoid columnals, gastropods, bryozoan fragments, brachiopod fragments (including productid spines).

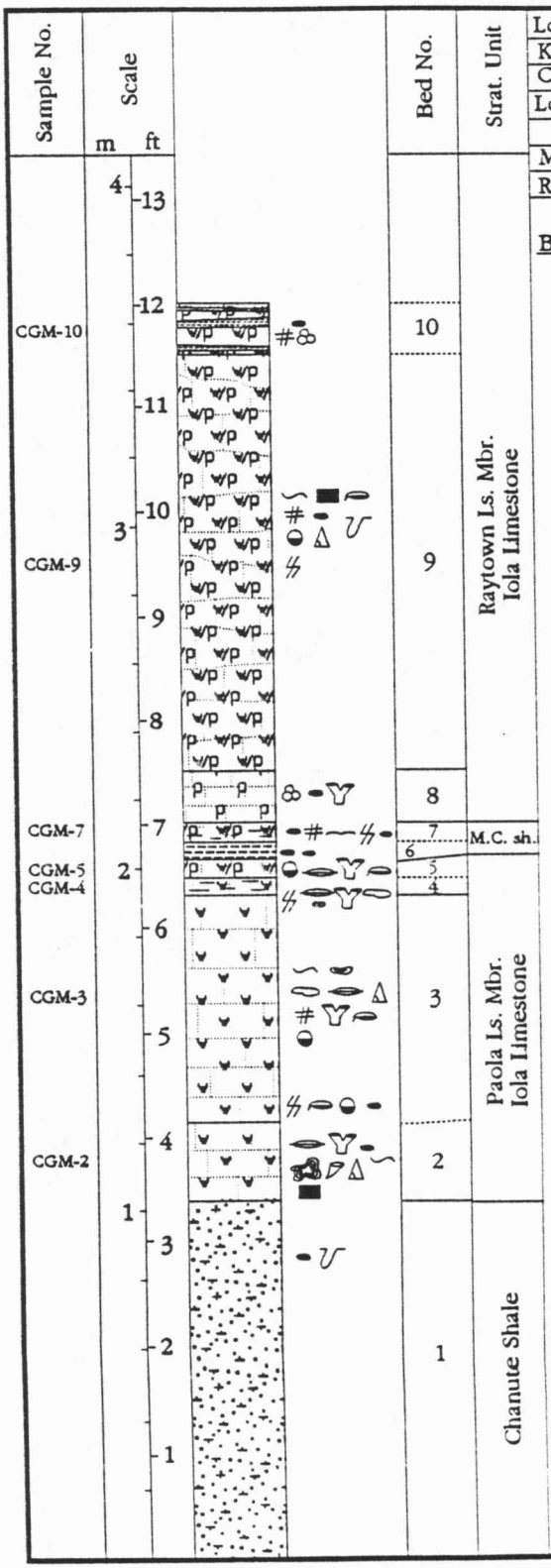
10 - 37 cm - Raytwon limestone - light gray (N5) wackestone-packstone; sharp lower contact; phylloid algal with stylonodular regions and 2 cm packstone base; disseminated pyrite; two tones of gray defined by algal blades and dissolution seams; fossils include: crinoid columnal, encrusting bryozoan (?), and comminuted debris.

9 - 8.5 cm - Raytown limestone - medium gray (N5), bioclastic, calcareous mudrock; sharp lower contact; fossils include: fenestrate bryozoans and brachiopods.

8 - 14.5 cm - Raytown limestone - light gray to very light gray (N7-N8) bioclastic wackestone with dolomitized packstone upper part; gradational lower contact; fossils include: crinoid columnals, mud-filled and geodiferous brachiopods, and small gastropod; packstones may be burrow fills.

7 - 9 cm - Raytown limestone - light brownish gray, argillaceous, bioclastic wackestone; gradational lower contact; burrow mottled; pyrite replacement of some fossils; heavily dolomitized; fossils include: brachiopod fragments, rugose coral, crinoid columnals, and opthalmids.

6 - 43 cm - Muncie Creek shale - bioturbated medium light gray (N6) mudrock; gradational lower contact; pyrite specks in some burrows; trace fossils include: Zoophycus and Chondrites (and their definition improves upwards); distinct, sharp based, graying upward beds 7.5 cm thick 15 cm above base and 3.5 cm thick at 30 cm above base.



Locality: CGM
Kansas Geological Survey Core
Cogeomap Proper #1
Location: SW SE SE Sec.35, T26S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 2/93
Remarks: Core courtesy of C. Maples

Description

Bed No.

4 - 5 cm - Paola limestone - brownish gray (5 YR 4/1), pervasively stylolized, bioclastic wackestone; sharp lower contact; fossils include: fusulinids, ramose bryozoans, and crinoid columnals; lighter shaded peloidal micrite intraclast(?) (2.5 by 0.5 cm) and possible mudrock clasts or burrow fillings (black/dark gray).

3 - 66 cm - Paola limestone - light olive gray (5 Y 7/1) phylloid algal wackestone; gradational lower contact; more micrite and less comminuted material than underlying bed; 3.5 cm stylolized zone 10.5 cm above base contains geopetaliferous Composita, large crinoid fragments, and miscellaneous biotic debris; underneath stylolized zone is wackestone of phylloid algae with encrusters and shelter void with a cracked micritic intraclast and phylloid algal base; fossils include: rare fusulinids, a gastropod, ramose and fenestrate bryozoans, and articulated, geodiferous, encrusted brachiopods.

2 - 23-24 cm - Paola limestone - light olive gray (5 Y 4/2) wackestone; sharp, stylolized lower contact; fossil debris includes: fusulinids, rugose coral, ramose bryozoans, crinoid columnals, small gastropods, phylloid algae (blades and comminuted), and 2-3 cm "osagiids"; pyrite replacement of bioclasts associated with a spar-folled vein.

1 - 103 cm - Chanute Shale - fine-medium quartz sandstone (5% mica) with brown-black disrupted and discontinuous clay or organic laminations; lower contact is gradational from dark gray, laminated siltstone-mudstone; lighter gray patches of carbonate cemented rock; fossils include: coarse sand to granule sized crinoid fragments; bioturbated; uppermost 4-5 cm particularly rich in clay and crinoid debris.

CGM, SW SE SE Sec. 35, T26E, R16E, Woodson County, Kansas

10 - 29 cm - Raytown limestone - interlayered bed of fine sand sized bioclastic packstone-wackestone with clay-rich pervasively stylolized beds; limestone sub-beds are 5 Y 8/1 bioturbated wackestones with pockets of packstone; comminuted fossils may be bryozoans or foraminiferids; the claystone beds are pervasively horsehair stylolized with crinoid columnals and other bioclasts; contacts (including basal contact) are stylolized but appear continuous.

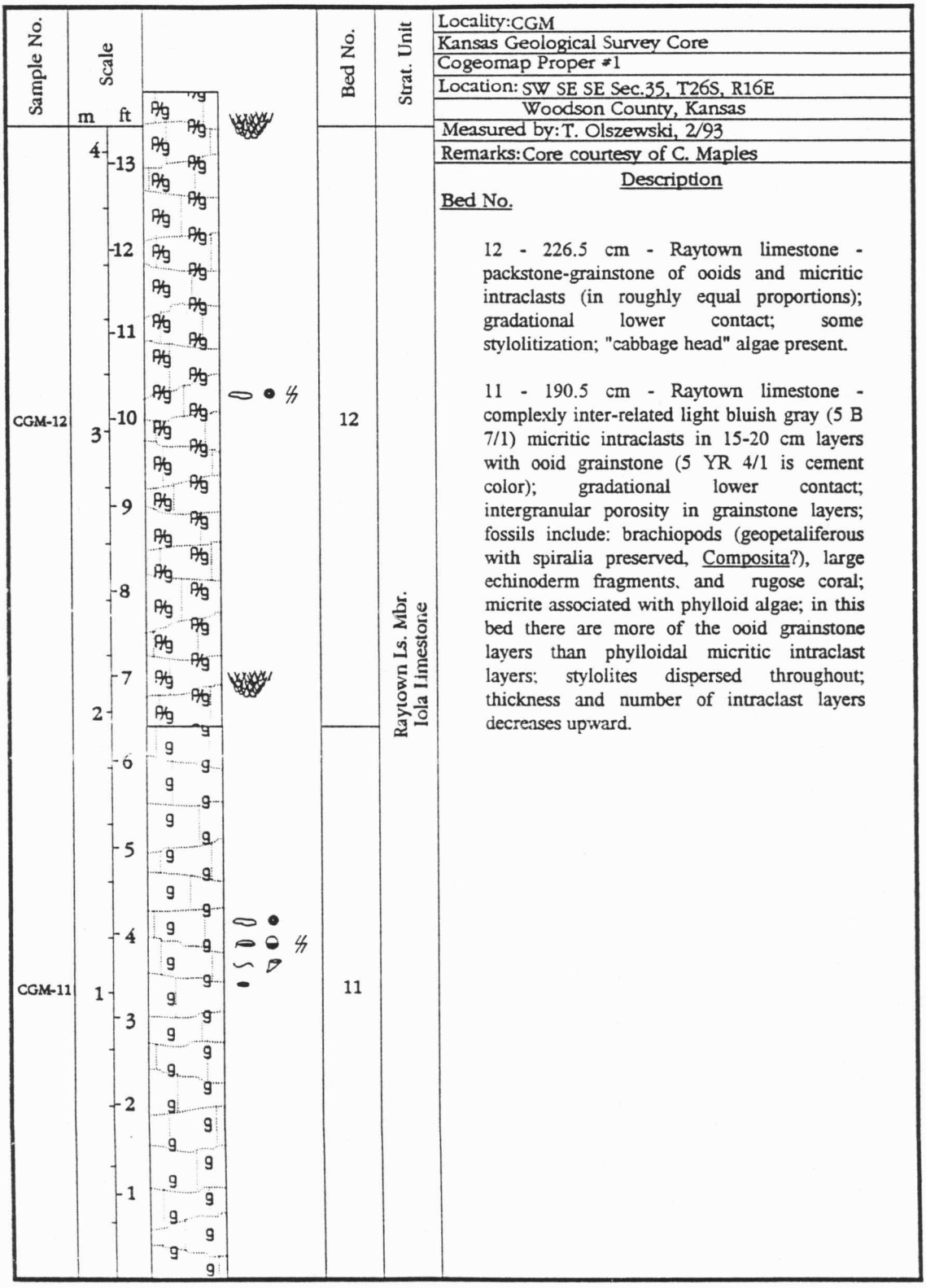
9 - 122 cm - Raytown limestone - yellowish gray (5 Y 8/1) wackestone-packstone of comminuted and fragmented phylloid algal material; interdigitate stylolite on lower contact; calcite spar where grains are particularly dense; minor pyrite replacement; fossils include: few brachiopods (some geodiferous), few bryozoans, geopetaliferous gastropod, and large crinoid columnals; bioturbated fabric; few stylolites associated with micritic zones.

8 - 30 cm - Raytown limestone - medium-coarse sand sized bioclastic packstone (5 Y 9/1); sharp lower contact; fossils include: foraminiferids(?), echinoderms, and bryozoans--all fragmented and well sorted.

7 - 6 cm - Muncie Creek shale - light brownish gray (5Y 6/2), argillaceous wackestone-packstone; sharp lower contact; fossils include: crinoids, trilobite(?), and fenestrate bryozoans; diffuse stylolitization; packstone lag at base incorporates a possibly phosphatic lithic clast; dispersed stylolites.

6 - 4.5-5.5 cm - Muncie Creek shale - dark gray to black (N3) mudrock with brownish gray mottles (5 YR 4/1); lower contact heavily stylolized; highly compacted--dense mass of stylolites; fossils include: crinoids and other carbonate clasts; phosphate nodule--aggregate of black and white phosphatic material but no calcite.

5 - 5-7 cm - Paola limestone - pinkish gray (5 YR 8/1) wackestone-packstone; very coarse sand sized bioclasts; stylolized lower contact; fossils include: fusulinids, foraminiferids, ramose bryozoans, brachiopod fragments; geopetals; bioturbated texture.



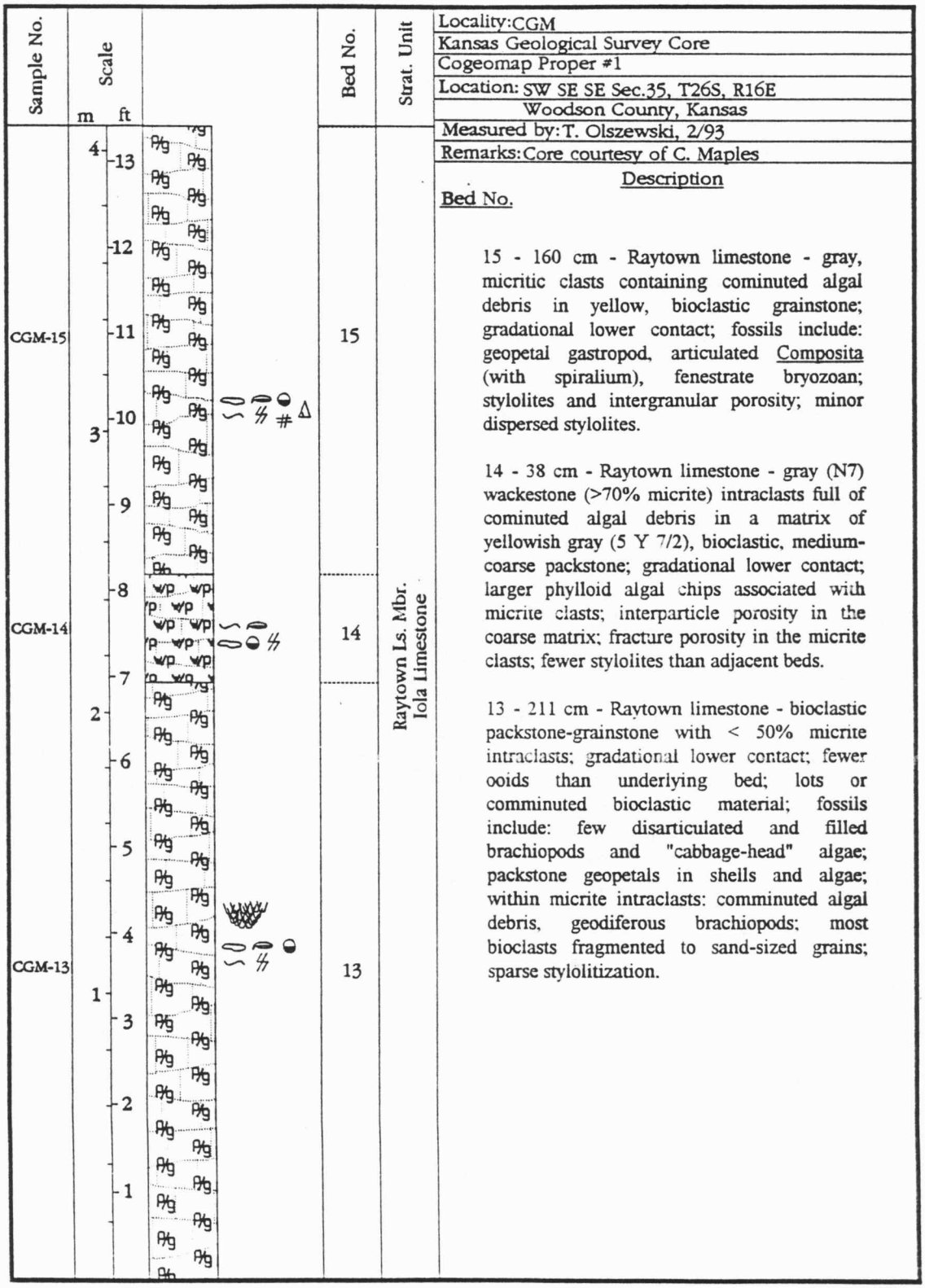
Locality: CGM
Kansas Geological Survey Core
Cogeomap Proper #1
Location: SW SE SE Sec.35, T26S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 2/93
Remarks: Core courtesy of C. Maples

Description

Bed No.

12 - 226.5 cm - Raytown limestone - packstone-grainstone of ooids and micritic intraclasts (in roughly equal proportions); gradational lower contact; some stylolitization; "cabbage head" algae present.

11 - 190.5 cm - Raytown limestone - complexly inter-related light bluish gray (5 B 7/1) micritic intraclasts in 15-20 cm layers with ooid grainstone (5 YR 4/1 is cement color); gradational lower contact; intergranular porosity in grainstone layers; fossils include: brachiopods (geopetaliferous with spiralia preserved, Composita?), large echinoderm fragments, and rugose coral; micrite associated with phylloid algae; in this bed there are more of the ooid grainstone layers than phylloidal micritic intraclast layers; stylolites dispersed throughout; thickness and number of intraclast layers decreases upward.



Locality: CGM
Kansas Geological Survey Core
Cogeomap Proper #1
Location: SW SE SE Sec.35, T26S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 2/93
Remarks: Core courtesy of C. Maples

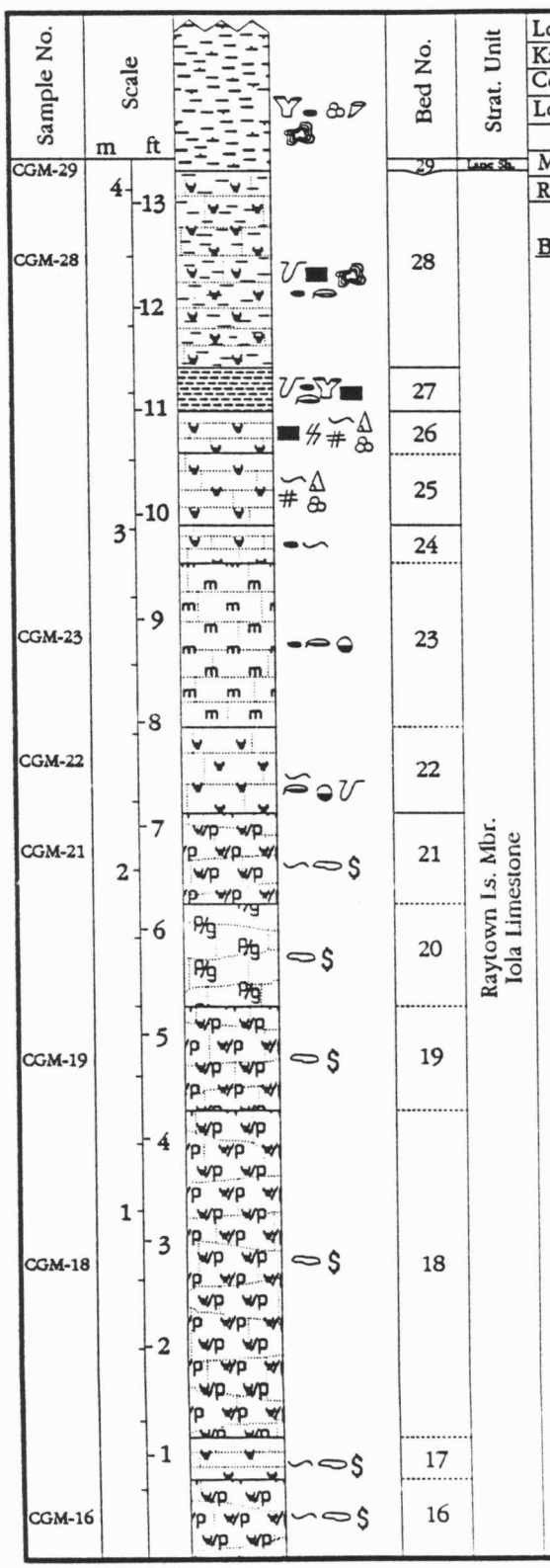
Description

Bed No.

15 - 160 cm - Raytown limestone - gray, micritic clasts containing cominuted algal debris in yellow, bioclastic grainstone; gradational lower contact; fossils include: geopetal gastropod, articulated Composita (with spiralium), fenestrate bryozoan; stylolites and intergranular porosity; minor dispersed stylolites.

14 - 38 cm - Raytown limestone - gray (N7) wackestone (>70% micrite) intraclasts full of cominuted algal debris in a matrix of yellowish gray (5 Y 7/2), bioclastic, medium-coarse packstone; gradational lower contact; larger phylloid algal chips associated with micrite clasts; interparticle porosity in the coarse matrix; fracture porosity in the micrite clasts; fewer stylolites than adjacent beds.

13 - 211 cm - Raytown limestone - bioclastic packstone-grainstone with < 50% micrite intraclasts; gradational lower contact; fewer ooids than underlying bed; lots or comminuted bioclastic material; fossils include: few disarticulated and filled brachiopods and "cabbage-head" algae; packstone geopetals in shells and algae; within micrite intraclasts: comminuted algal debris, geodiferous brachiopods; most bioclasts fragmented to sand-sized grains; sparse stylolitization.



Locality: CGM
Kansas Geological Survey Core
Cogeomap Proper #1
Location: SW SE SE Sec.35, T26S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 2/93
Remarks: Core courtesy of C. Maples

Description

Bed No.

20 - 33.5 cm - Raytown limestone - pinkish gray (5 YR 8/1) bioclastic packstone-grainstone; gradational lower contact; comminuted phylloid algal grains are medium to fine sand sized; oil fills porosity which never exceeds 50%; stylolites favor grainier zones and porosity favors micritic intraclast zones.

19 - 30.5 cm - Raytown limestone - yellowish gray wackestone-packstone lithology of medium size comminuted bioclasts with over 50% micritic intraclasts; gradational lower contact; vuggy porosity (about 1 cm in diameter) filled with oil; some porosity is fracture porosity in micritic intraclasts; many pores lined with or filled with very coarse calcite spar.

18 - 95 cm - Raytown limestone - yellowish gray wackestone-packstone of medium size, comminuted bioclastic debris with about 15% micritic intraclasts (mostly in the upper half); gradational lower contact; intraclasts are light bluish gray (5 B 7/1) and get darker toward their cores; porosity in comminuted matrix especially associated with intraclasts; oil lines many pores.

17 - 11.5 cm - Raytown limestone - gray wackestone; fewer bioclasts and more micrite than underlying bed; fracture porosity; gradational lower contact.

16 - 23 cm - Raytown limestone - light gray, bioclastic packstone-wackestone; gradational lower contact; cominuted algal debris; very coarse sand sized particles; porosity in lower half contains oil; coarse spar in some 2 cm diameter vuggy pores in upper half of bed.

CGM, SW SE SE Sec. 35, T26E, R16E, Woodson County, Kansas

*Beds 29, 30, and 31 are not depicted on the graphic section.

*31 - >15 cm - Wyandotte Limestone - dark geenish gray (5 G 4/1) mudrock; sharp lower boundary; bioturbated (Zoophycus); oncoids ("ottonosids"(?)); fossils include: foraminiferids, fenestrate bryozoans, and crinoid columnals.

*30 - 408 cm - Lane Shale - slightly calcareous dark geenish gray (5 G 4/1) mudrock with faint laminations in some parts; sharp lower contact; bioturbated; one concave up, butterflied pelcypod periostracum.

*29 - 75.5 cm - Lane Shale - dark greenish gray (5 GY 4/1) calcareous mudrock; gradational lower contact; texture is like an oncoidal "packstone" with brownish black (5 YR 2/1) argillaceous partings; fossils include: crinoid fragments, ramose bryozoans, foraminiferids, rugosan coral and most appear to be encrusted on all sides; siliciclastic content decreases upward while definition of oncoids improves upward.

28 - 58.5 cm - Raytown limestone - dark greenish gray (5 GY 4/1) argillaceous, bioclastic wackestone; sharp lower contact; pervasively burrow mottled with suggestion of Chondrites; fossils include: oncoids (1.5 cm diameters), crinoid columnals, brachiopods (fragments and articulated and filled); crinoidal material is often in 2-3 cm pockets; fossil material is preferentially pyritized; argillaceous partings at top and 15 cm below the top.

27 - 13.5 cm - Raytown limestone - medium dark gray (N7) mudrock; sharp lower contact; pervasively bioturbated (Zoophycus); fossils include: crinoid columnals, ramose bryozoans, brachiopod fragments, and a possible trilobite fragment; extensive pyritization of bioclasts and fractures in upper 1/3; coarser material near top.

26 - 13 cm - Raytown limestone - dark bluish gray (5 B 4/1) to greenish gray (5 GY 5/1) bioclastic wackestone; gradational lower contact; packstone texture nearer the top where pyrite replacement is pervasive; as a whole--very heterogeneous bed.

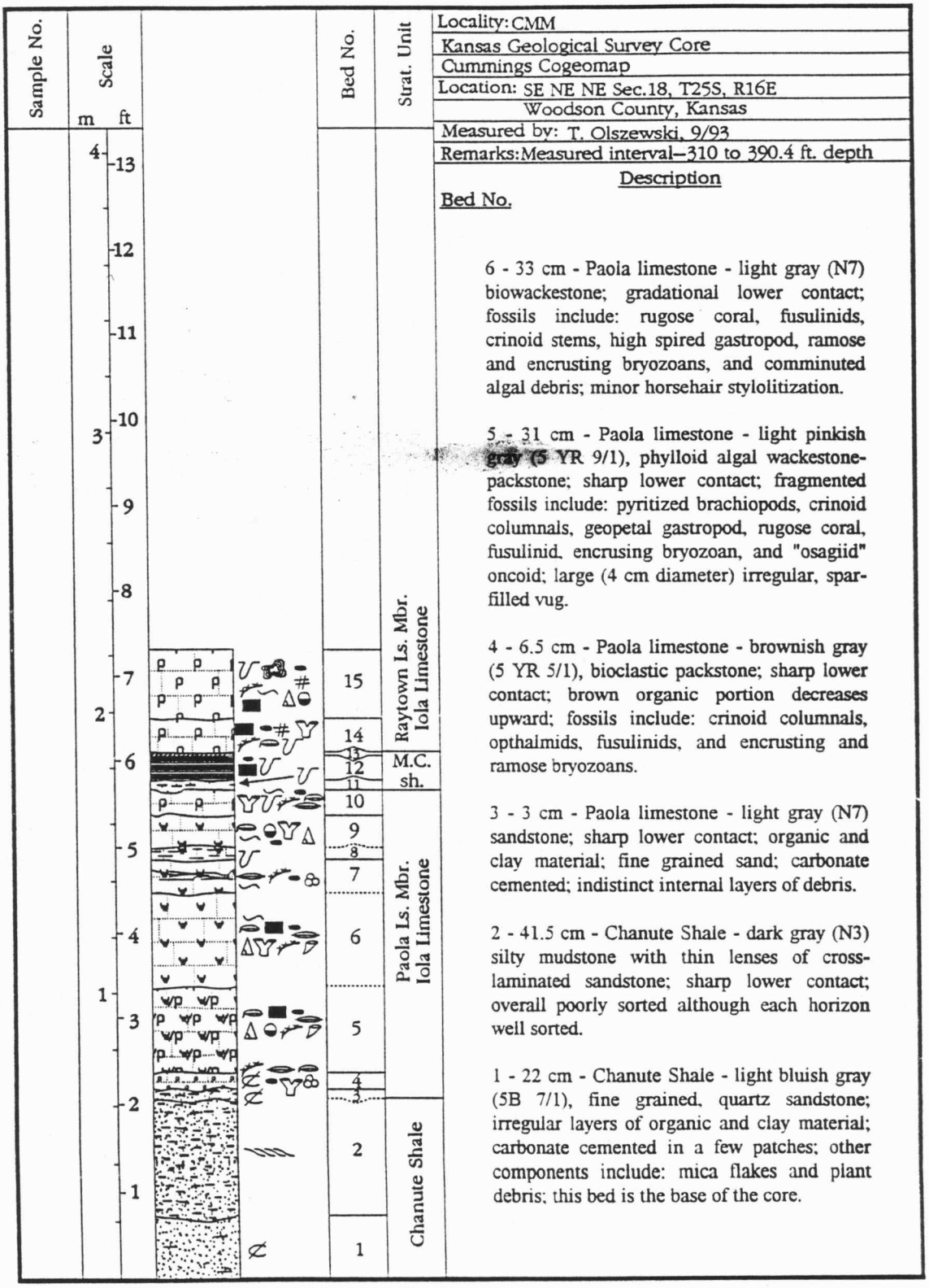
25 - 21.5 cm - Raytown limestone - gray (N7 to N5) bioclastic wackestone grading to a darker shade upward; lowest 6 cm mudstone without stylolites.

24 - 11 cm - Raytown limestone - light gray (N7) bioclastic wackestone (but densely packed for a wackestone); gradational lower contact; bioclasts up to 0.75 cm across; fossils include: echinoderms and other recrystallized shell or algal fragments.

23 - 48 cm - Raytown limestone - very pale orange (10 YR 8/2) mudstone; gradational lower contact; very coarse sand sized bioclasts sparsely distributed throughout; fossils include: crinoid columnal and geodiferous brachiopod; minor grain moldic porosity.

22 - 13 cm - Raytown limestone - light gray (N7) phylloid algal wackestone; sharp lower contact; bioturbated texture; patches of poorly sorted, very coarse sand sized algal packstone; porosity filled by calcite spar but includes some shelter voids and a geodiferous brachiopod.

21 - 26.5 cm - Raytown limestone - slate gray micrite intraclasts in pinkish gray packstone; gradational lower contact; mostly made up of recrystallized phylloid algal material; porosity filled with oil.



Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval–310 to 390.4 ft. depth

Description

Bed No.

6 - 33 cm - Paola limestone - light gray (N7) biowackestone; gradational lower contact; fossils include: rugose coral, fusulinids, crinoid stems, high spired gastropod, ramose and encrusting bryozoans, and comminuted algal debris; minor horsehair stylolitization.

5 - 31 cm - Paola limestone - light pinkish gray (5 YR 9/1), phylloid algal wackestone-packstone; sharp lower contact; fragmented fossils include: pyritized brachiopods, crinoid columnals, geopetal gastropod, rugose coral, fusulinid, encrusing bryozoan, and "osagiid" oncoid; large (4 cm diameter) irregular, spar-filled vug.

4 - 6.5 cm - Paola limestone - brownish gray (5 YR 5/1), bioclastic packstone; sharp lower contact; brown organic portion decreases upward; fossils include: crinoid columnals, opthalmids, fusulinids, and encrusting and ramose bryozoans.

3 - 3 cm - Paola limestone - light gray (N7) sandstone; sharp lower contact; organic and clay material; fine grained sand; carbonate cemented; indistinct internal layers of debris.

2 - 41.5 cm - Chanute Shale - dark gray (N3) silty mudstone with thin lenses of cross-laminated sandstone; sharp lower contact; overall poorly sorted although each horizon well sorted.

1 - 22 cm - Chanute Shale - light bluish gray (5B 7/1), fine grained, quartz sandstone; irregular layers of organic and clay material; carbonate cemented in a few patches; other components include: mica flakes and plant debris; this bed is the base of the core.

CMM, SE NE NE Sec. 18, T25S, R16E, Woodson County, Kansas

15* - 24.5 cm - Raytown limestone - yellowish gray (5 Y 7/1) packstone with wackestone patches; sharp lower contact; bioturbated fabric; cominuted fossil material includes: oncoid (2.5cm by 1 cm), crinoid debris, fenestrate and encrusting bryozoans, comminuted and fragmented phylloid algal blades, and high spired geopetal gastropods; pyrite.

14* - 12 cm - Raytown limestone - yellowish gray (N4 to 5 Y 6/1), bioclastic packstone; sharp lower contact; darker gray, broken up laminations; pyrite replacement of bioclasts; fossils include: crinoid fragments, encrusting, fenestrate, and ramose bryozoans, one brachiopod fragment, and one burrow.

13 - 1.5 cm - Muncie Creek shale - medium gray (N5) slightly calcareous mudrock with black, poorly sorted, phosphatic sand grains; sharp lower contact (erosive-truncates laminations in bed 12); reworked phosphate nodule resting on the base.

12 - 8.5 cm - Muncie Creek shale - dark grayish black (N2-N3) mudrock (fissile if weathered?); sharp lower contact (color change and burrowed); phosphatic, discontinuous laminations and pyritized burrows in upper part; comminuted debris in lower half; non-calcareous but fetid under HCl.

11 - 3.5 cm - Muncie Creek shale - medium gray (N5) calcareous mudrock; sharp, stylolized lower contact; fragmented fossils include: crinoids, ramose bryozoans, brachiopods and unidentifiable material; many hairy stylolites; variety of burrows.

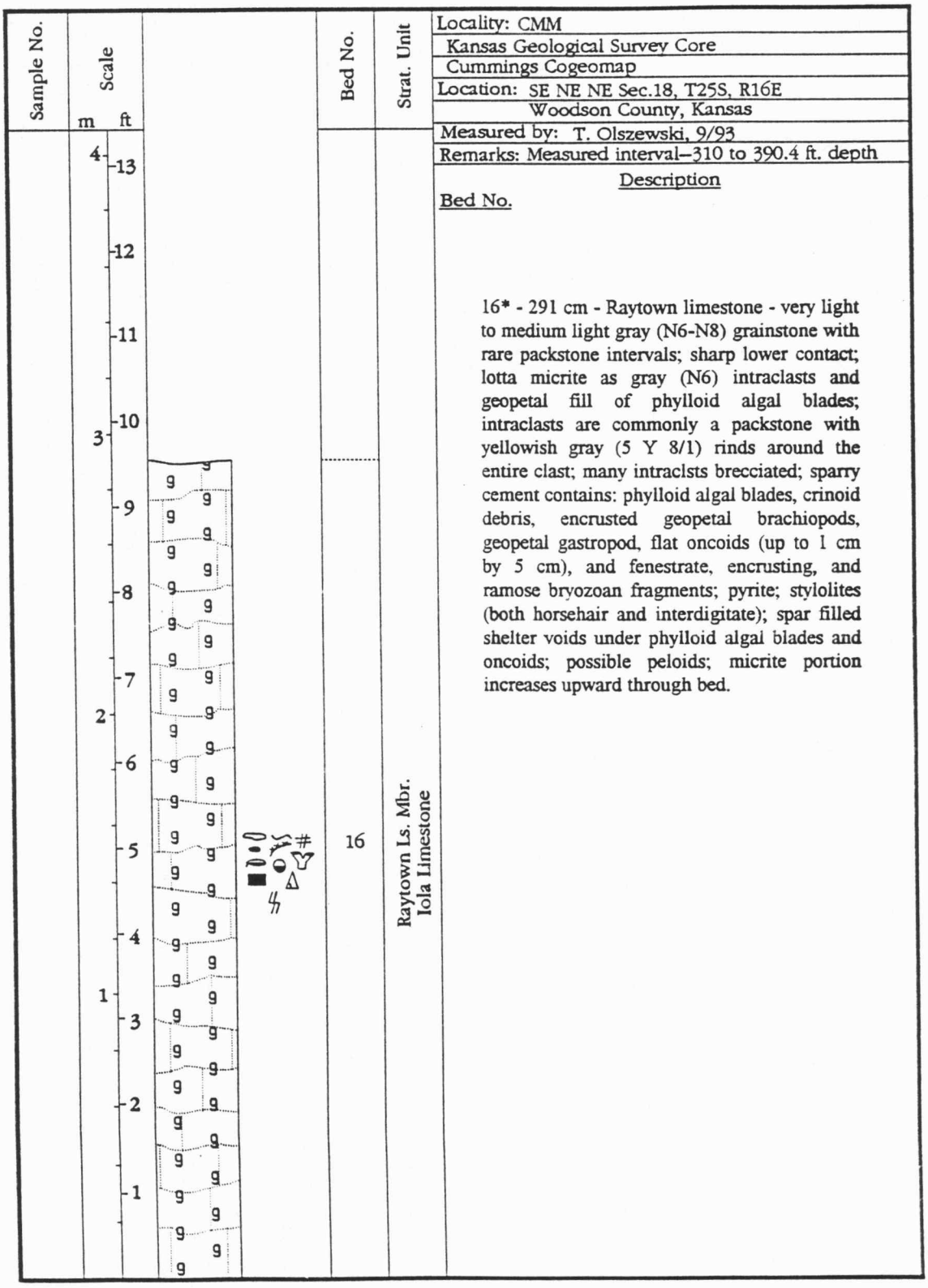
10 - 9 cm - Paola limestone - light olive gray (5 Y 6/1), bioclastic packstone; sharp lower contact; bioturbated; two burrows filled with black mudstone from overlying bed; fossils include: fusulinids, crinoids, ramose and encrusting bryozoans, brachiopod fragments, and phylloid algal fragments; much cominuted debris.

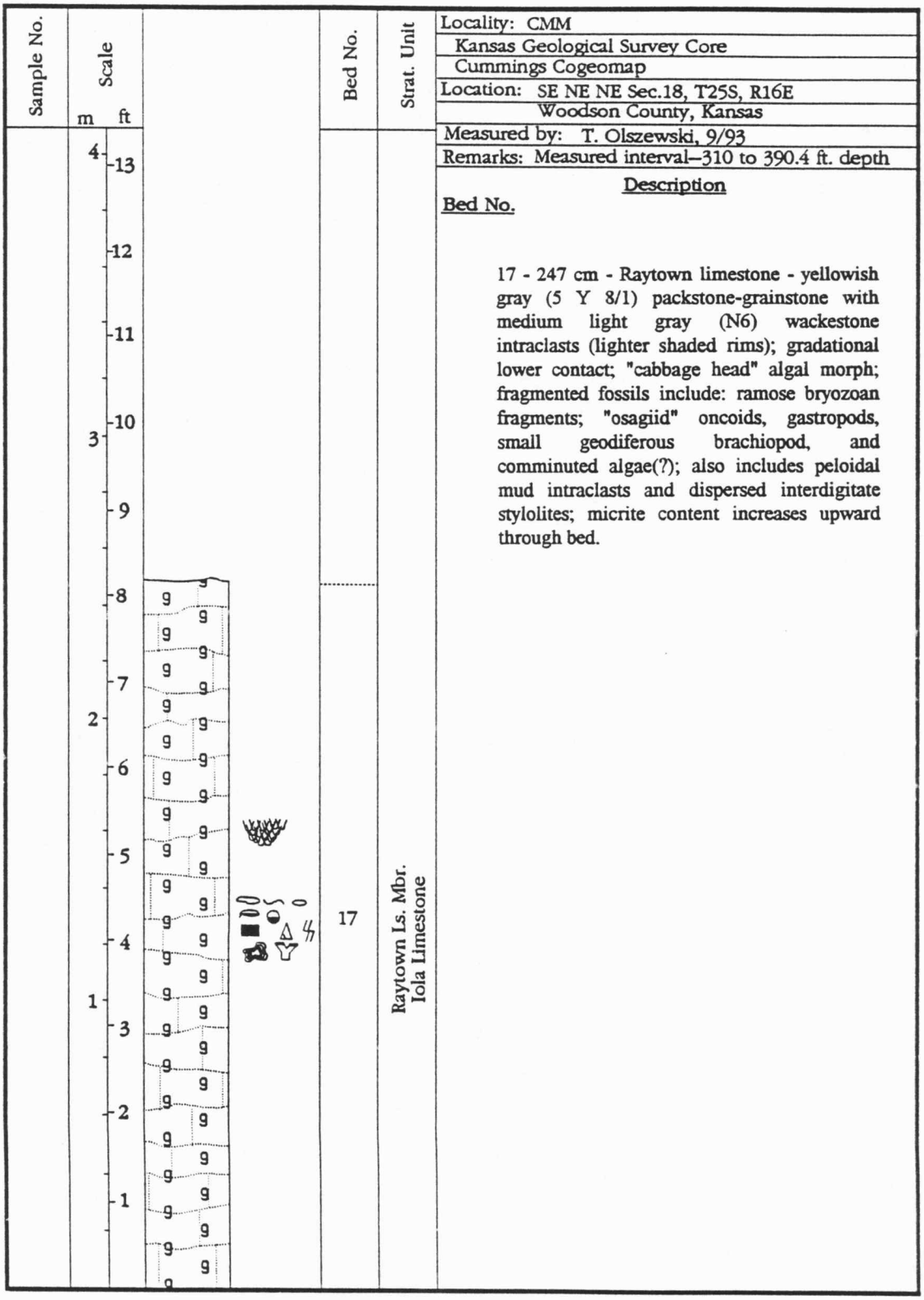
9 - 11. 5 cm - Paola limestone - pinkish gray (5 YR 8/1), bioclastic wackestone; gradational lower contact; fossils include: geopetal brachiopods, ramose bryozoans, phylloid algal blades, crinoid columnals, and gastropod; black, argillaceous, peloidal(?) mudstone filled burrows (from overlying Muncie Creek).

8 - 4 cm - Paola limestone - brownish gray (5 YR 4/1), stylolized, argillaceous wackestone; irregular, burrowed(?) lower contact associated with a sharp color change.

7 - 12 cm - Paola limestone - light gray (N7) bioclastic wackestone; gradational lower contact; fossils include: phylloid algal blades, fusulinids, encrusting bryozoans, few crinoids, opthalmids(?) and "osagiid" oncoids; 1/2 way up from base is an irregular horizon of non-stylolized, black, argiallaceous limestone.

* - 20 feet (6 meters) or more or core were lost at this point during drilling. Beds are described as continuous because it is not known exactly where the loss occurred.


Sample No.
Scale
m
ft
Bed No.
Strat. Unit
Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval--310 to 390.4 ft. depth
Description
Bed No.
16* - 291 cm - Raytown limestone - very light to medium light gray (N6-N8) grainstone with rare packstone intervals; sharp lower contact; lotta micrite as gray (N6) intraclasts and geopetal fill of phylloid algal blades; intraclasts are commonly a packstone with yellowish gray (5 Y 8/1) rinds around the entire clast; many intraclsts brecciated; sparry cement contains: phylloid algal blades, crinoid debris, encrusted geopetal brachiopods, geopetal gastropod, flat oncoids (up to 1 cm by 5 cm), and fenestrate, encrusting, and ramose bryozoan fragments; pyrite; stylolites (both horsehair and interdigitate); spar filled shelter voids under phylloid algal blades and oncoids; possible peloids; micrite portion increases upward through bed.
16
Raytown Ls. Mbr.
Iola Limestone

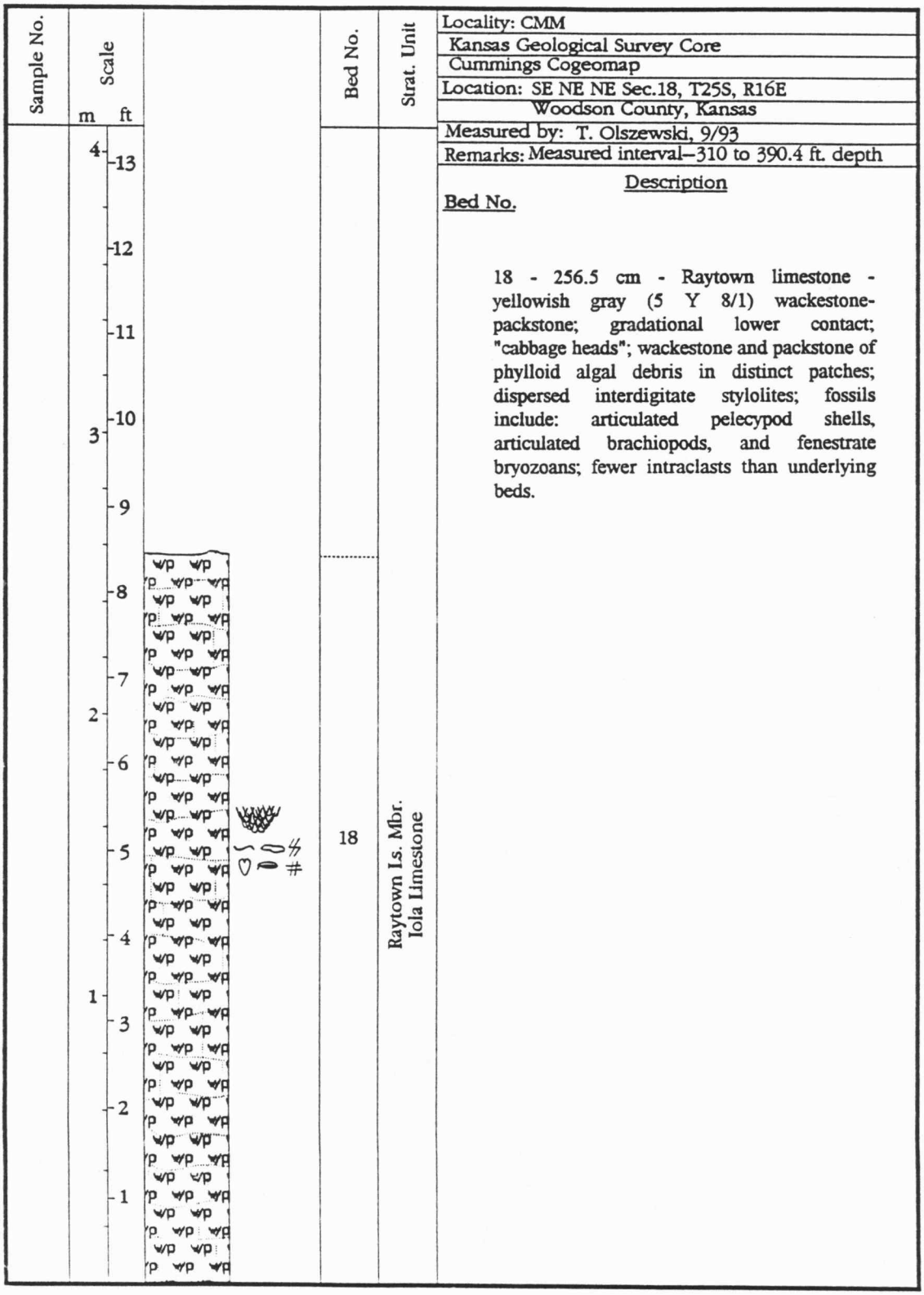


Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval–310 to 390.4 ft. depth

Description

Bed No.

17 - 247 cm - Raytown limestone - yellowish gray (5 Y 8/1) packstone-grainstone with medium light gray (N6) wackestone intraclasts (lighter shaded rims); gradational lower contact; "cabbage head" algal morph; fragmented fossils include: ramose bryozoan fragments; "osagiid" oncoids, gastropods, small geodiferous brachiopod, and comminuted algae(?); also includes peloidal mud intraclasts and dispersed interdigitate stylolites; micrite content increases upward through bed.

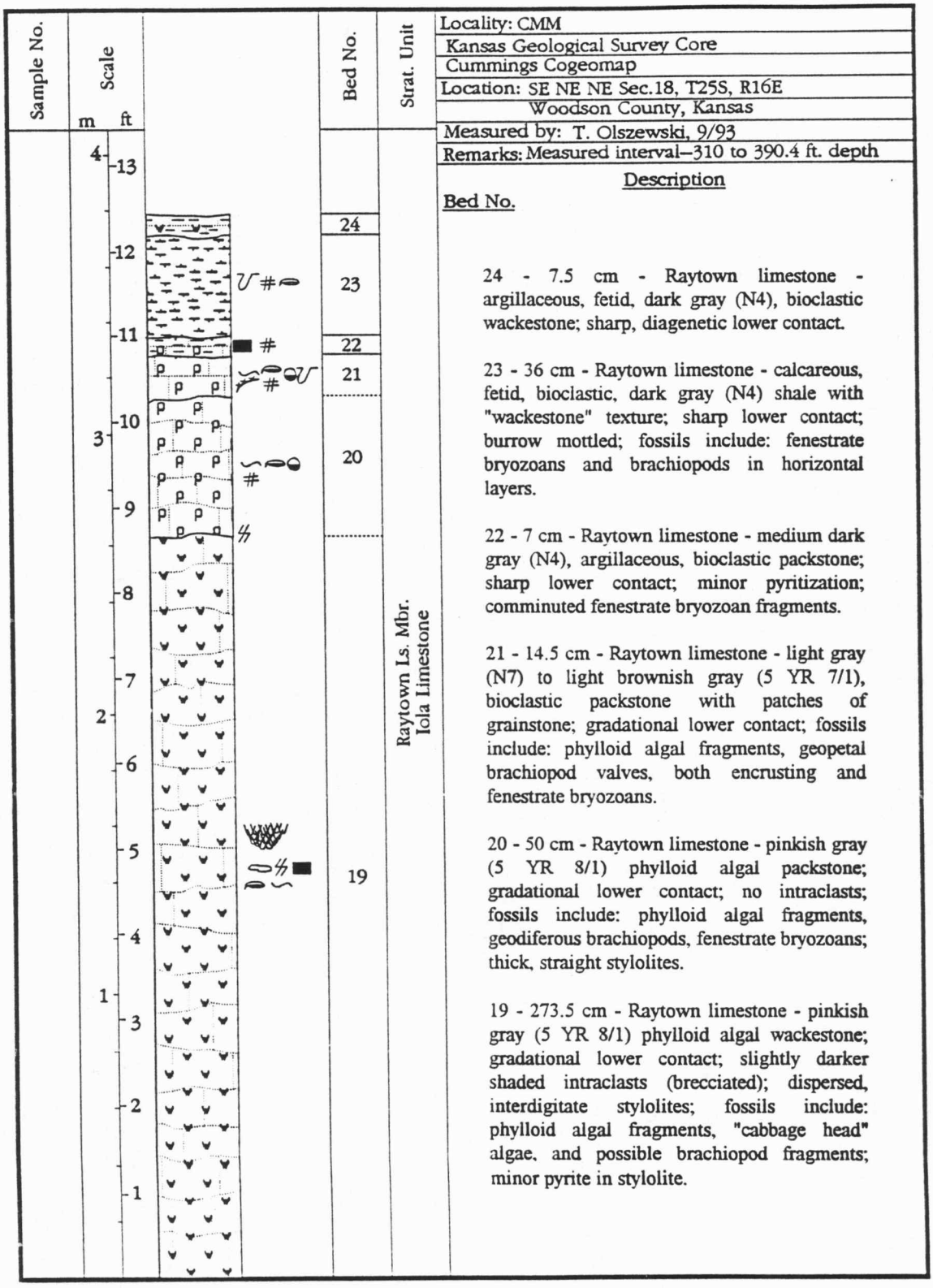


Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval--310 to 390.4 ft. depth

Description

Bed No.

18 - 256.5 cm - Raytown limestone - yellowish gray (5 Y 8/1) wackestone-packstone; gradational lower contact; "cabbage heads"; wackestone and packstone of phylloid algal debris in distinct patches; dispersed interdigitate stylolites; fossils include: articulated pelecypod shells, articulated brachiopods, and fenestrate bryozoans; fewer intraclasts than underlying beds.



Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval–310 to 390.4 ft. depth

Description

Bed No.

24 - 7.5 cm - Raytown limestone - argillaceous, fetid, dark gray (N4), bioclastic wackestone; sharp, diagenetic lower contact.

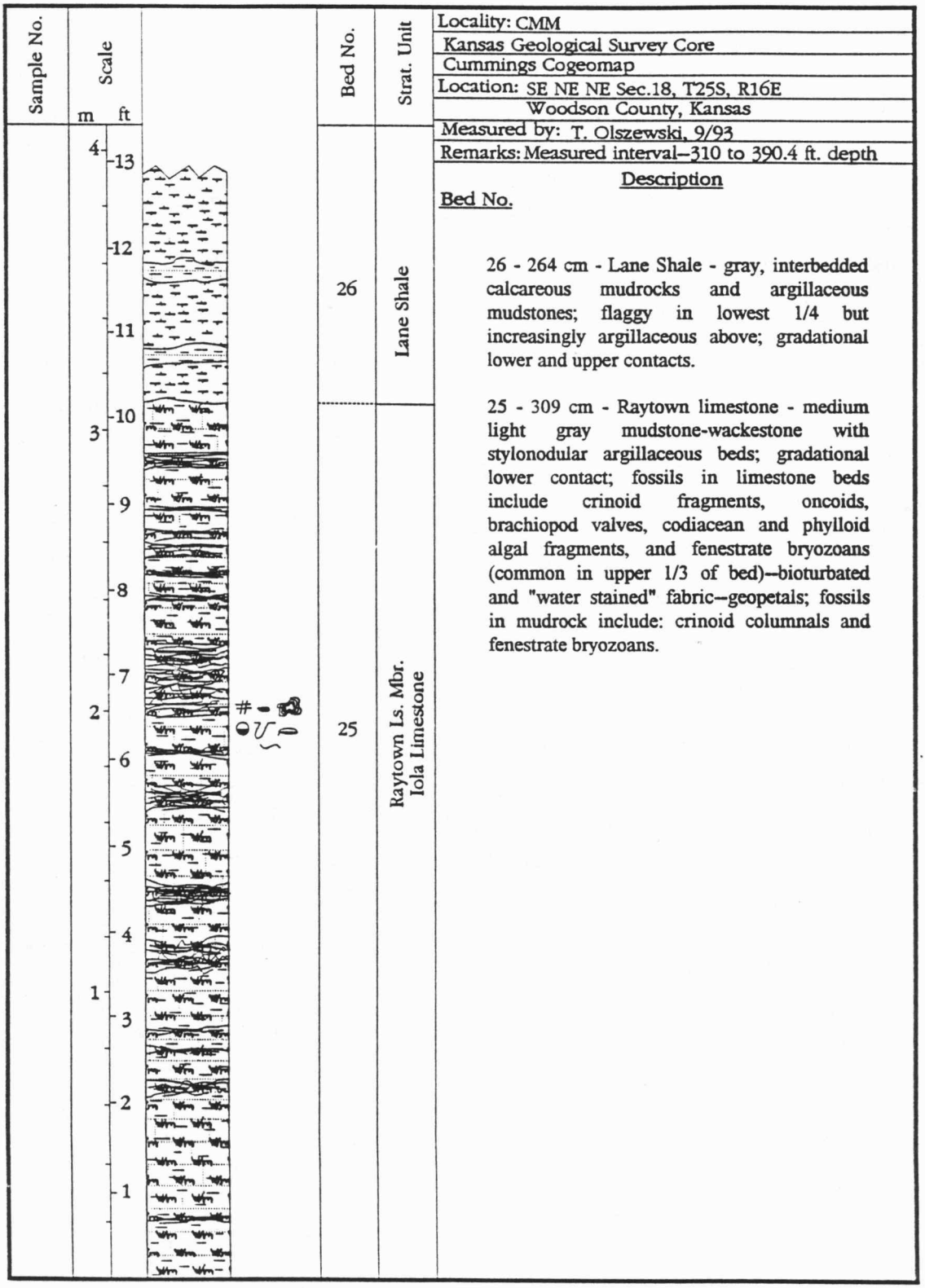
23 - 36 cm - Raytown limestone - calcareous, fetid, bioclastic, dark gray (N4) shale with "wackestone" texture; sharp lower contact; burrow mottled; fossils include: fenestrate bryozoans and brachiopods in horizontal layers.

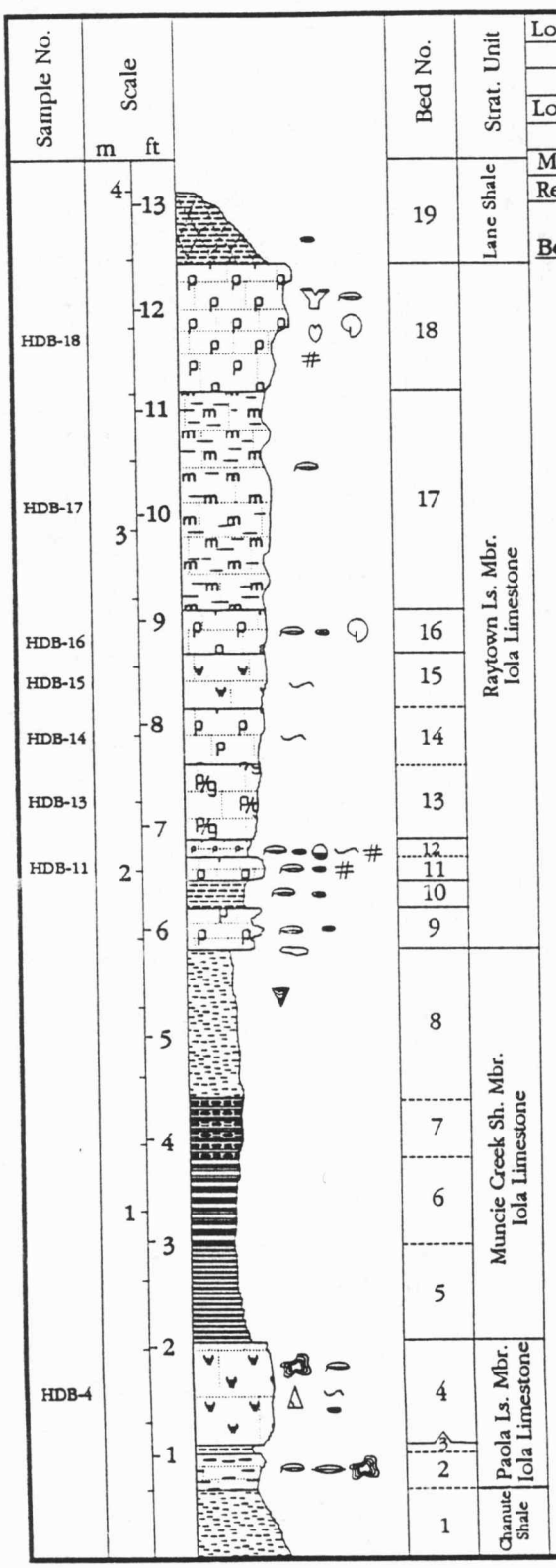
22 - 7 cm - Raytown limestone - medium dark gray (N4), argillaceous, bioclastic packstone; sharp lower contact; minor pyritization; comminuted fenestrate bryozoan fragments.

21 - 14.5 cm - Raytown limestone - light gray (N7) to light brownish gray (5 YR 7/1), bioclastic packstone with patches of grainstone; gradational lower contact; fossils include: phylloid algal fragments, geopetal brachiopod valves, both encrusting and fenestrate bryozoans.

20 - 50 cm - Raytown limestone - pinkish gray (5 YR 8/1) phylloid algal packstone; gradational lower contact; no intraclasts; fossils include: phylloid algal fragments, geodiferous brachiopods, fenestrate bryozoans; thick, straight stylolites.

19 - 273.5 cm - Raytown limestone - pinkish gray (5 YR 8/1) phylloid algal wackestone; gradational lower contact; slightly darker shaded intraclasts (brecciated); dispersed, interdigitate stylolites; fossils include: phylloid algal fragments, "cabbage head" algae, and possible brachiopod fragments; minor pyrite in stylolite.


Sample No.
Scale
m
ft
Bed No.
Strat. Unit
Locality: CMM
Kansas Geological Survey Core
Cummings Cogeomap
Location: SE NE NE Sec.18, T25S, R16E
Woodson County, Kansas
Measured by: T. Olszewski, 9/93
Remarks: Measured interval--310 to 390.4 ft. depth
Description
Bed No.
26 - 264 cm - Lane Shale - gray, interbedded calcareous mudrocks and argillaceous mudstones; flaggy in lowest 1/4 but increasingly argillaceous above; gradational lower and upper contacts.
25 - 309 cm - Raytown limestone - medium light gray mudstone-wackestone with stylonodular argillaceous beds; gradational lower contact; fossils in limestone beds include crinoid fragments, oncoids, brachiopod valves, codiacean and phylloid algal fragments, and fenestrate bryozoans (common in upper 1/3 of bed)--bioturbated and "water stained" fabric--geopetals; fossils in mudrock include: crinoid columnals and fenestrate bryozoans.
26
25
Lane Shale
Raytown Ls. Mbr.
Iola Limestone



Locality: HDB

Location: SW NE NW Sec.6, T12S, R24E
Johnson County, Kansas

Measured by: T. Olszewski, 7/92

Remarks: Holliday Drive Roadcut

Description

Bed No.

8 - 44 cm - Muncie Creek shale - blocky, grayish green mudrock; gradational lower contact; fossils include: conulariids and thin burrows (1 mm diameter and 3-4 cm long); uppermost 3 cm are olive green.

7 - 17 cm - Muncie Creek shale - black, fissile shale full of phosphate nodules; gradational lower contact.

6 - 25 cm - Muncie Creek shale - black, fissile shale with orange and black discontinuous stripes; gradational lower contact.

5 - 29 cm - Muncie Creek shale - black, fissile shale; sharp lower contact; no fossils evident.

4 - 29 cm - Paola limestone - greenish brown wackestone; sharp lower contact; fossils include: "osagiids," phylloid algal blades, large and small brachiopods, gastropods, and crinoid columnals; most material is <1 cm diameter; top grades into 1.5 cm thick packstone.

3 - 2 cm - Paola limestone - very sticky, green and orange clay layer; slightly calcareous; gradational lower contact.

2 - 11 cm - Paola limestone - dark gray to brownish green argillaceous limestone; fossils include: brachiopod and very small oncoids or very worn fusulinids.

1 - >10 cm -Chanute Shale - grayish green, crumbly, mudrock; no structures or fossils.

HDB, SW NE NW Sec. 6, T21E, R24E, Johnson County, Kansas

18 - Raytown limestone - poorly sorted, gray, bioclastic packstone; sharp lower contact; fossil material: large pelecypod, ramose and fenestrate bryozoans, brachiopod valves (Neospirifer?), nautiloid, productid spines.

17 - 64 cm - Raytown limestone - argillaceous, gray mudstone; sharp lower contact--brachiopod valves can be found resting on base; large productids--articulated and some in life position (some are geodiferous).

16 - 13 cm - Raytown limestone - medium gray packstone; sharp lower contact; shell hash of brachiopod fragments and crinoid bits; large productids; truncated nautiloid shell (along the upper surface).

15 - 16 cm - Raytown limestone - light gray, jumbled algal wackestone; gradational lower contact; disseminated, comminuted bioclastic material; possible intraclsts in spar.

14 - 17 cm - Raytown limestone - phylloid algal wackestone; gradational lower contact; geopetal algal cups filled with brownish gray wackestone setting in a matrix of light gray, cross-laminated mudstone; algal cups 12 cm across x 3 cm deep.

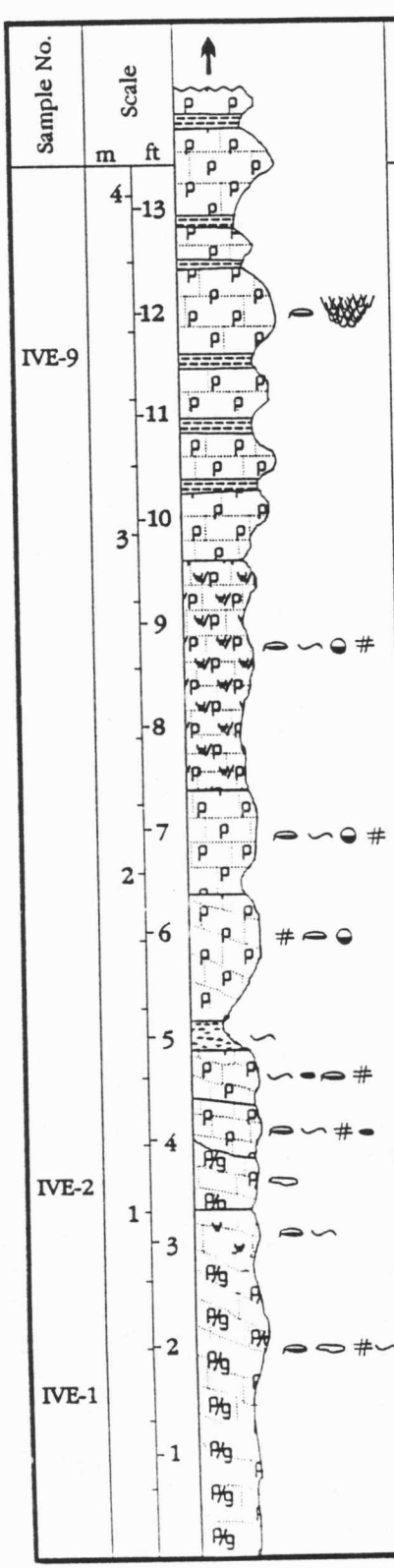
13 - 22 cm - Raytown limestone - phylloid algal wackestone with calcite filled shelter voids; argillaceous (stylolized); sharp lower contact; mudstone and wackestone nodules in a sparry matrix.

12 - 5 m - Raytown limestone - phylloid algal packstone; distinct but gradational lower contact; fossils include: geopetal Composita and crinoid fragments; top contact stylolized and has a lot of fenestrate bryozoans.

11 - 7 cm - Raytown limestone - light gray packstone; sharp lower contact; coarse to granule sized brachiopod and crinoid fragments.

10 - 8 cm - Raytown limestone - grayish green calcareous mudrock; lower part is argillaceous limestone; gradational lower contact; one Chonetid fragment taken from upper part; more brachiopods in lower part.

9 - 12 cm - Raytown limestone - dark brownish gray, argillaceous packstone; sharp lower contact; fossils include poorly sorted crinoid fragments and possibly brachiopod fragments; well-rounded, flattened, bored micrite cobbles on lower surface.



Locality: IVE

Location: NE NE SE Sec.3, T24S, R20E
Allen County, Kansas

Measured by: T. Olszewski, 8/92

Remarks: Abandoned farm quarry-floor is Paola ls.

Description

Bed No.

5 - 8-9 cm - Raytown limestone - gray stylonodular mudstone; gradational lower contact; mudstone contains algal debris and crystalline veins.

4 - 17.5 cm - Raytown limestone - algal packstone; gradational lower contact; bioturbated texture; algae comminuted to coarse sand size; patches of mudstone-wackestone and patches of coares calcite spar; fossils include: crinoids, brachiopods, and fenestrate bryozoans; upper few cm have coarser algal clasts in micritic matrix.

3 - 12-15 cm - Raytown limestone - algal and brachiopod packstone; bioclasts comminuted to very coarse sand size; sharp lower contact; fossils include: a few larger fenestrate bryozoans and crinoid columnals.

2 - 18 cm - Raytown limestone - intraclastic grainstone; bed discontinuous on outcrop; very open framework of micritic intraclasts (amorphous but rounded) but all spces filled with very coarse calcite spar; laterally becomes indistinguishable from underlying conglomerates.

1 - >101 cm - Raytown limestone - micritic intraclastic breccia with very coarse calcite spar cement; interspersed lenses of coarse, bioclastic sand with fragmented brachiopods and fenestrate bryozoans; comminuted phylloid algal debris; base of exposure is well-developed packstone of the same material but lower contact is obscured.

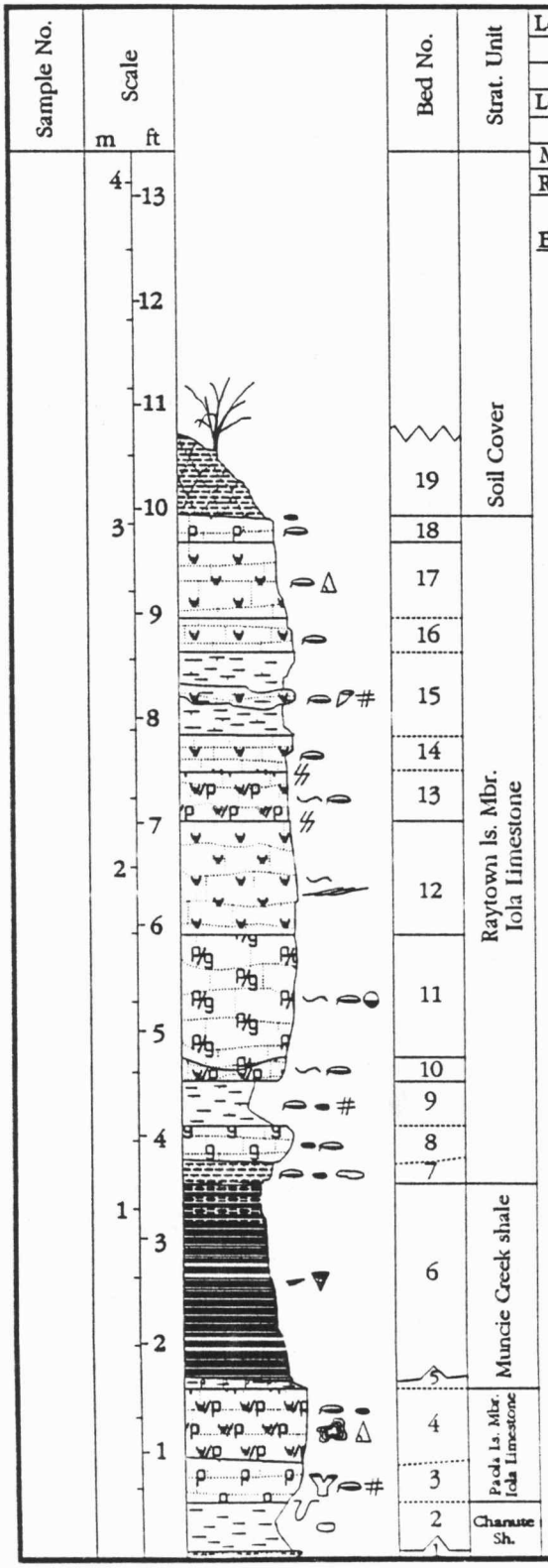
IVE, NE NE SE Sec. 3, T24S, R20E, Allen County, Kansas

9 - >152 cm - Raytown limestone - yellowish gray brachiopod packstone; lower contact obscured; very flaggy weathering; "cabbage head" algae.

8 - 69 cm - Raytown limestone - yellowish gray wackestone-packstone of algae and brachiopods; gradational lower contact; burrow mottled; brachiopods geodiferous and up to 2.5 cm long; bryozoans.

7 - 30 cm - Raytown limestone - lower part is a brachiopod and algal packstone (very densely packed); there are small geodiferous brachiopods in this part; upper part has less comminuted algal material and more micrite; bioturbated; sharp lower contact; fossils include: large spiriferids, large productids (disturbed and micrite filled), and fenestrate bryozoans.

6 - 37 cm - Raytown limestone - bioclastic packstone with mudstone patches; gradational lower contact; bioturbated texture; large patches of coarse sparry calcite; fossils include: fenestrate bryozoans and a few small brachiopods (one geodiferous).



Locality: K32R

Location: SW SW SE Sec.12, T11S, R24E
Wyandotte County, Kansas

Measured by: T. Olszewski, 8/93

Remarks: Roadcut on north side of K32

Description

Bed No.

6 - 58 cm - Muncie Creek shale - black, fissile shale; dark brown layers (about 10 cm thick) 8 and 30 cm from base; sharp lower contact; uppermost 16 cm has oblate and lenticular phosphate concretions; fossils include: fish fragment and a conulariid; no fizz, but fetid odor in HCl; most fissility planes have dense scatter of gray flecks on them.

5 - 1-2 cm - Muncie Creek shale - dark gray, argillaceous bioclastic packstone; gradational lower contact; transition layer between Paola and Muncie Creek; fossils unidentifiable.

4 - 21 cm - Paola limestone - light gray, bioclastic wackestone-packstone; gradational lower contact; fossils are mostly comminuted but include: "osagiids," pieces of phylloid algae, gastropods, brachiopods (spiriferids), and crinoid columnals.

3 - 5-6 cm - Paola limestone - grayish brown, aargillaceous, bioclastic packstone; gradational lower contact; fossils are sand to granule sized fragments and are thoroughly fragmented; they include : ramose bryozoans, brachiopod fragments, and fenestrate bryozoans; may be burrowed along contact with underlying mudrock.

2 - 14 cm - Chanute Shale - dark olive-brown mudrock; sharp lower contact; very slightly silty; not very calcareous; possible small pockets of leached fossils (ostracodes).

1 - 1-2 cm - Chanute Shale - bluish gray, poorly sorted sandstone; medium-fine grained; irregular surfaces at top and base; carbonate cemented.

K32R, SW SW SE Sec. 12, T11S, R24E, Wyandotte County, Kansas

19 - soil cover - crinoid columnal and plate horizon at the base of the Lane Shale from Holliday Drive seems to weathering out of this layer.

18 - 8 cm - Raytown limestone - light gray, bioclastic packstone; sharp lower contact; slightly stylolized; a brachiopod hash.

17 - 21 cm - Raytown limestone - light yellowish gray bioclastic wackestone; gradational lower contact; fossils include: brachiopod valves and very small gastropods.

16 - 10 cm - Raytown limestone - argillaceous, productid wackestone; slight orange weathering color; gradational lower contact.

15 - 24 cm - Raytown limestone - light yellowish gray, calcareous mudrock with a 5-7 cm limestone bed in the center; gradational lower contact; the limestone contains in situ productids, rugose corals, and fenestrate bryozoans.

14 - 10 cm - Raytown limestone - brachiopod wackestone; stylolized but gradational contact; only fossils are disarticulated productid valves.

13 - 14 cm - Raytown limestone - light gray wackestone-packstone; sharp, stylolized lower contact; fossils include: torn and comminuted phylloid algal blades and articulated Composita.

12 - 34 cm - Raytown limestone - phylloid algal wackestone with dark gray, geopetal micritic fills in the algal blades; the lighter colored matrix displays cross-lamination; sharp lower contact.

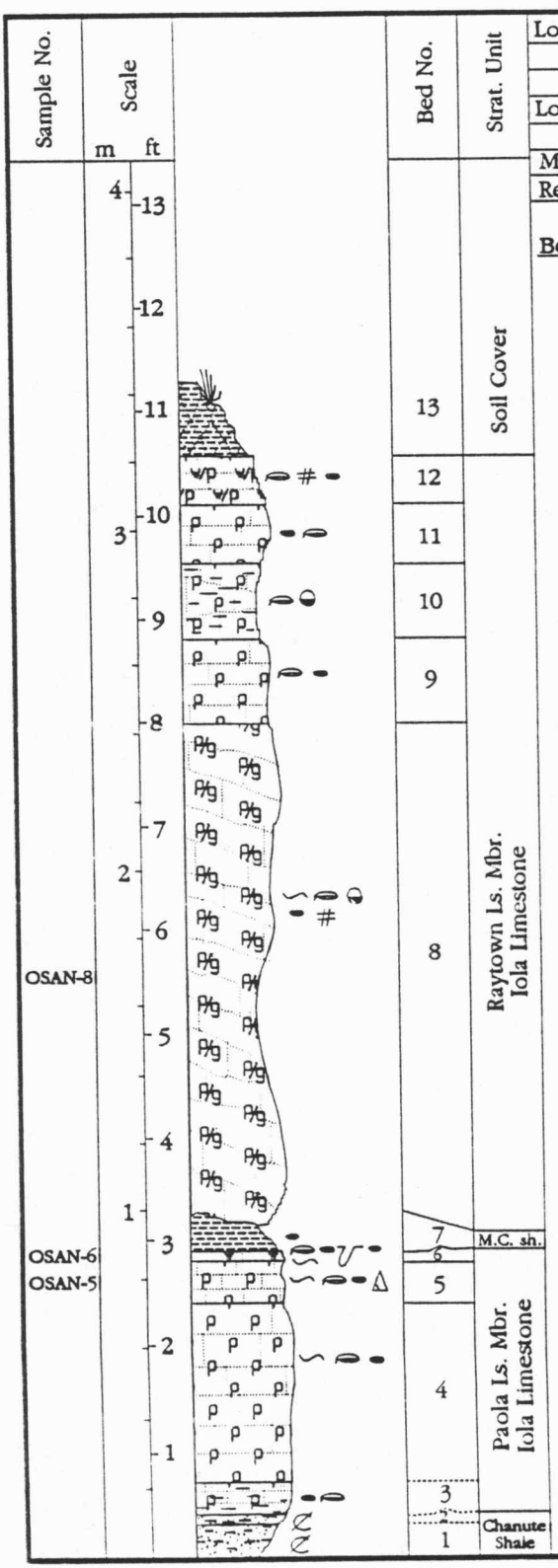
11 - 36 cm - Raytown limestone - phylloid algal/intraclastic packstone-grainstone; sharp lower contact; lots of spar-filled shelter porosity; fossils include: comminuted phylloid algal debris and geopetal brachiopods; clasts are gray to yellowish gray; spar is yellowish brown.

10 - 0-6.5 cm - Raytown limestone - light gray phylloid algal wackestone-packstone; sharp lower contact; individual phylloid algal blades are mostly broken and flat lying; only other fossil seen is articulated Composita; bed pinches from 6.5 cm to 0 cm over 3 m.

9 - 13 cm - Raytown limestone - grayish green, fossiliferous, calcareous mudrock; lower contact is irregular and gradational; fossils are disarticulated chonetellids, crinoid columnals, and bits of fenestrate bryozoans.

8 - 9.5-15 cm - Raytown limestone - dark gray, argillaceous crinoidal grainstone; gradational lower contact; other fossils include chonetids.

7 - 5-6 cm - Raytown limestone - light olive gray, bioclastic, calcareous shale; sharp lower contact; bioclasts are in a "packstone" texture and are the size of coarse sand; identifiable fossils include chonetellids and crinoid columnals; lower contact has large, dense micritic intraclasts.



Locality: OSAN

Location: SE NW NW Sec.6, T18S, R23E
Miami County, Kansas

Measured by: T. Olszewski, 7/92

Remarks: 1.5 mi. north of Osawatomie on Rt.169

Description

Bed No.

8 - 143 cm - Raytown limestone - dune cross-bedded sparry packstone; fossils include: phylloid algal fragments, geodiferous and geopetal Composita, and crinoid fragments; wavelength of duneforms 3 to 5 m; amplitude is < 50 cm; fenestrate bryozoans in spar cement; stylolized lower boundary; pervasive stylolitization.

7 - 5-12 cm - Muncie Creek shale - dark grayish green mudrock; no fizz under HCl; phosphatic nodules lying on base; sharp lower contact.

6 - 3-4 cm - Paola limestone - crinoid and brachiopod wackestone; sharp lower contact; top surface is irregular; sharp bounded burrows start at the top surface (top 1-2 cm filled with overlying mudrock).

5 - 24 cm - Paola liemstone - phylloid algal packstone; fossils include: geopetaliferous Composita, crinoid columnals, and gastropod; sharp lower contact.

4 - 51 cm - Paola limestone - algal packstone; phylloid algal blades sub-horizontal (pseudo-laminar); fossils include: erticulated Composita (micrite filled), and crinoid columnals; gradational lower contact.

3 - 10 cm - Paola limestone - dark gray, argillaceous packstone; fossils include: brachiopod and crinoid fragments; gradational lower contact.

2 - 2-3 cm - Chanute Shale - gray, calcareous, silty mudrock with plant(?) material; gradational lower contact.

1 - >10 cm - Chanute Shale - gray, silty mudrock; wood fragments; poorly exposed.

OSAN SE NW NW Sec. 6, T18S, R23E, Miami County, Kansas

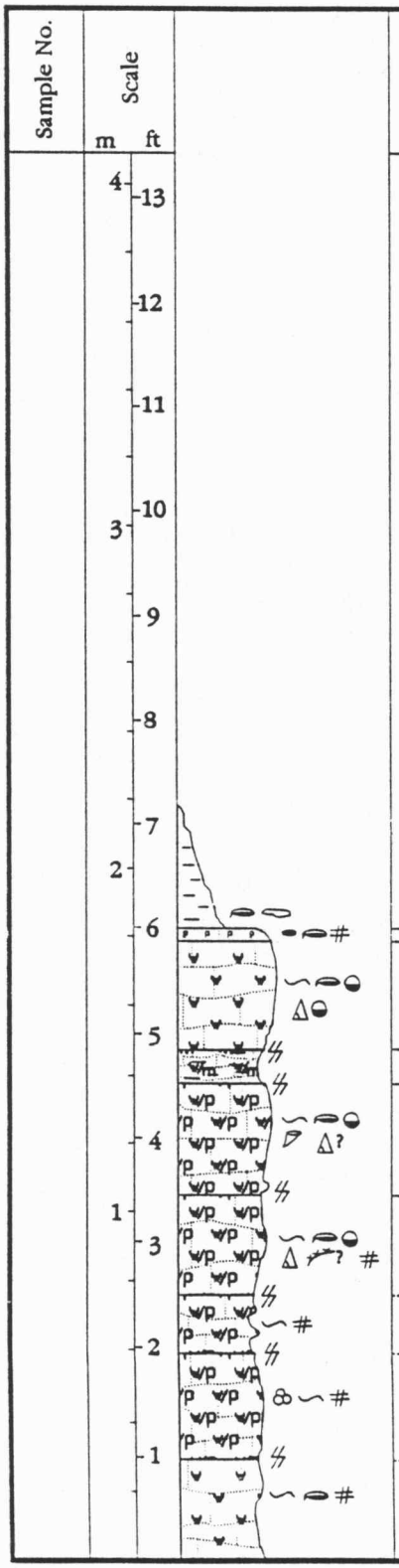
13 - soil cover

12 - 14 cm - Raytown limestone - gray wackestone-packstone; fossil hash including: productids, fenestrate bryozoans, and crinoid columnals; on exposed upper surface--packstone in patches on wackestone; stylolized lower contact.

11 - 18 cm - Raytown limestone - crinoid columnal packstone; grains 1 cm diameter; fossils include: productids (disarticulated, geodiferous) and Composita (articulated, geodiferous); stylolized lower contact.

10 - 22 cm - Raytown limestone - sparry, bioclastic packstone; fossils include: Composita (geodiferous) and other brachiopods; stylolized lower contact.

9 - 27 cm - Raytown limestone - pale yellow, brachiopod packstone; lower contact stylolized; large crinoid columnals and productids.



Locality: PP

Location: NW NW SW Sec.31, T54N, R30W
Clinton County, Missouri

Measured by: T. Olszewski

Remarks: Gravel pit 1.5 miles east of I-35 on PP

Description

Bed No.

6 - 9-10 cm - Raytown limestone - flaggy bedded, argillaceous carbonate horizon; brown wackestone-mudstone; sharp, stylolized lower contact; unidentified, fragmented bioclasts.

5 - 33 cm - Raytown limestone - massive, gray blue phylloid algal packstone-wackestone; algae are in blades; fossils include: gepoetal Composita, rugose coral, and possible gastropods; lower contact is flaggy bedded and stylolized.

4 - 29 cm - Raytown limestone - massive, gray blue phylloid algal wackestone-packstone; lower contact stylolized but not discontinuous; diverse fossils include: geopetal Composita, gastropods, bryozoans (possible fistuliporids), and bladed and comminuted phylloid algae.

3 - 17 cm - Raytown limestone - flaggy bedded, light gray to dark blue gray phylloid algal wackestone-packstone; algae are bladed and comminuted; fossils include: fenestrate bryozoans; lower contact is stylolized but not discontinuous.

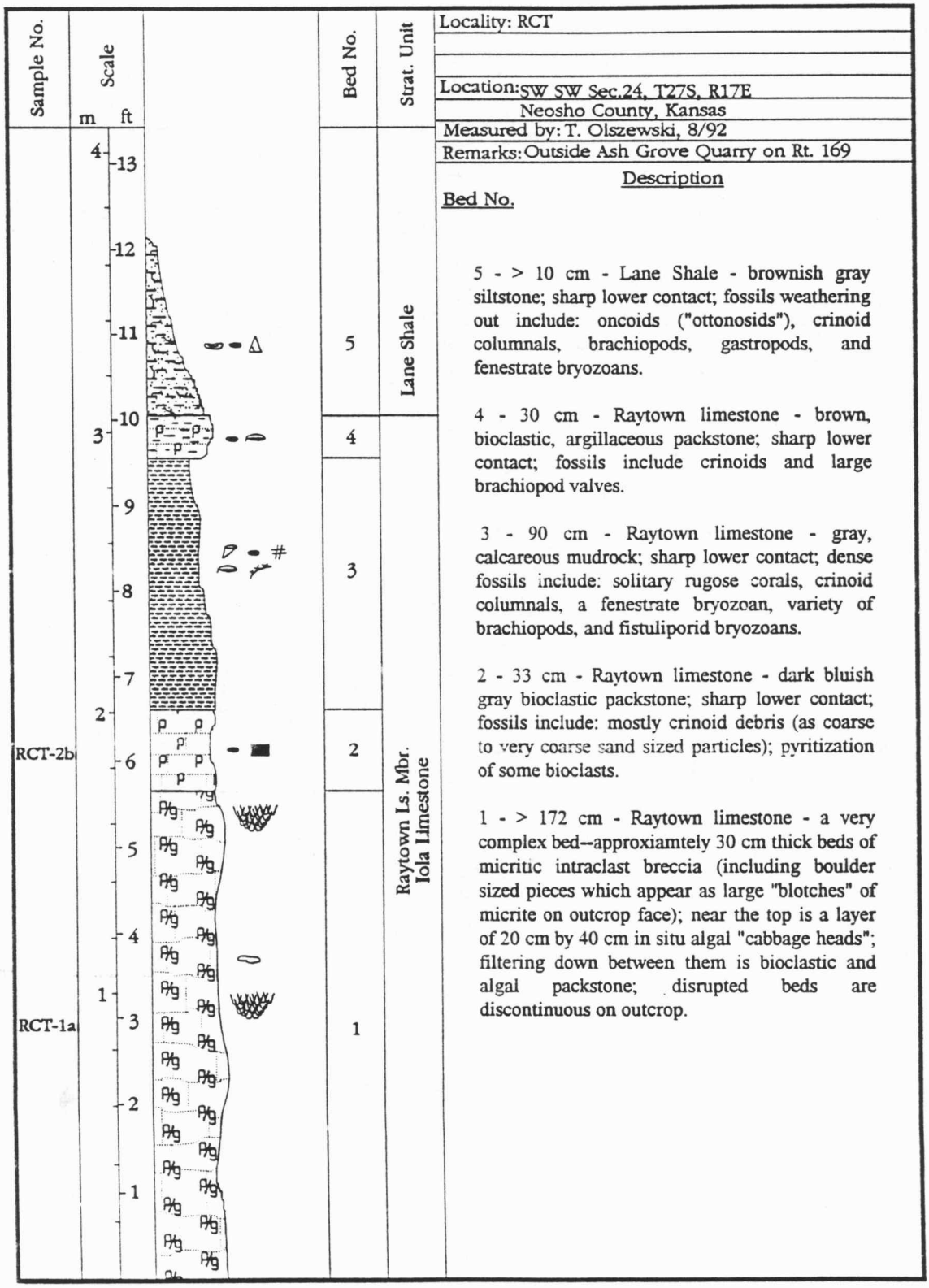
2 - 30 cm - Raytown limestone - pink and yellowish gray bioclastic wackestone-packstone; lower contact obscured but appears sharp, stylolized; fossils include: opthalmidids, bryozoan fragments, and comminuted phylloid algae.

1 - 29 cm - Raytown limestone - yellowish gray phylloid algal wackestone with light brown crystalline spar in patches; lower contact is not exposed; fossils include: comminuted and bladed algae, articulated Composita, and fenestrate bryozoans in the spar pockets.

PP, NW NW SW Sec. 31, T54N, R30W, Clinton County, Missouri

8 - 4.5 cm - Raytown limestone - yellow gray, dense crinoidal packstone; sharp lower contact; fossils include: mostly crinoid columnals, but also crinoid plates, brachiopod valves, and fenestrate bryozoans; the soil capping this bed also has micritic intraclasts and a large Neospirifer.

7 - 31 cm - Raytown limestone - light blue gray phylloid algal wackestone with comminuted but mostly bladed algae; sharp, stylolized lower contact; fossils include: articulated Composita (some in a horizon 8 cm from the top and a geopetal gastropod; many dispersed stylolites.



Locality: RCT

Location: SW SW Sec.24, T27S, R17E
Neosho County, Kansas

Measured by: T. Olszewski, 8/92

Remarks: Outside Ash Grove Quarry on Rt. 169

Description

Bed No.

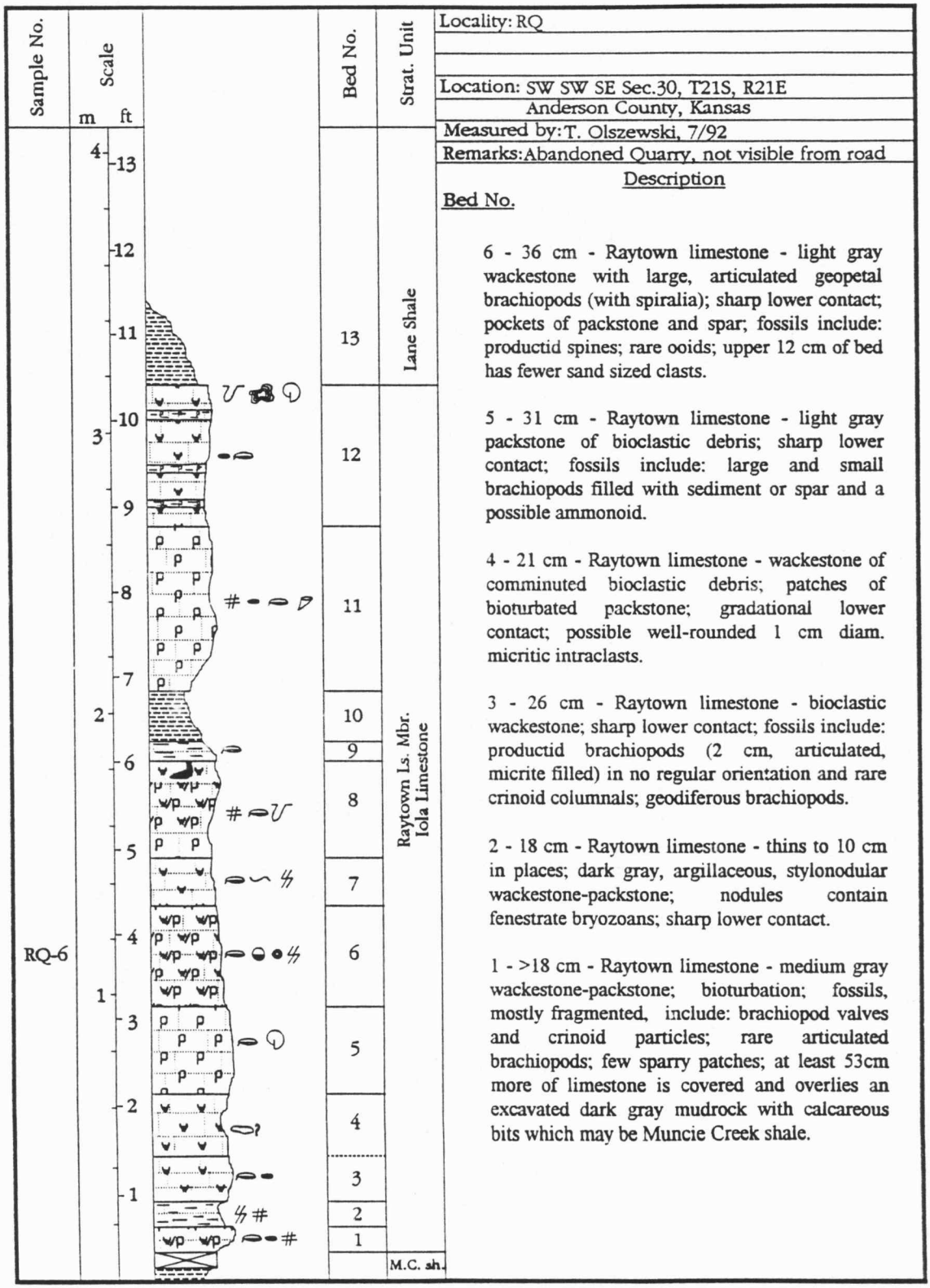
5 - > 10 cm - Lane Shale - brownish gray siltstone; sharp lower contact; fossils weathering out include: oncoids ("ottonosids"), crinoid columnals, brachiopods, gastropods, and fenestrate bryozoans.

4 - 30 cm - Raytown limestone - brown, bioclastic, argillaceous packstone; sharp lower contact; fossils include crinoids and large brachiopod valves.

3 - 90 cm - Raytown limestone - gray, calcareous mudrock; sharp lower contact; dense fossils include: solitary rugose corals, crinoid columnals, a fenestrate bryozoan, variety of brachiopods, and fistuliporid bryozoans.

2 - 33 cm - Raytown limestone - dark bluish gray bioclastic packstone; sharp lower contact; fossils include: mostly crinoid debris (as coarse to very coarse sand sized particles); pyritization of some bioclasts.

1 - > 172 cm - Raytown limestone - a very complex bed--approxiamtely 30 cm thick beds of micritic intraclast breccia (including boulder sized pieces which appear as large "blotches" of micrite on outcrop face); near the top is a layer of 20 cm by 40 cm in situ algal "cabbage heads"; filtering down between them is bioclastic and algal packstone; disrupted beds are discontinuous on outcrop.



Locality: RQ

Location: SW SW SE Sec.30, T21S, R21E
Anderson County, Kansas

Measured by: T. Olszewski, 7/92

Remarks: Abandoned Quarry, not visible from road

Description

Bed No.

6 - 36 cm - Raytown limestone - light gray wackestone with large, articulated geopetal brachiopods (with spiralia); sharp lower contact; pockets of packstone and spar; fossils include: productid spines; rare ooids; upper 12 cm of bed has fewer sand sized clasts.

5 - 31 cm - Raytown limestone - light gray packstone of bioclastic debris; sharp lower contact; fossils include: large and small brachiopods filled with sediment or spar and a possible ammonoid.

4 - 21 cm - Raytown limestone - wackestone of comminuted bioclastic debris; patches of bioturbated packstone; gradational lower contact; possible well-rounded 1 cm diam. micritic intraclasts.

3 - 26 cm - Raytown limestone - bioclastic wackestone; sharp lower contact; fossils include: productid brachiopods (2 cm, articulated, micrite filled) in no regular orientation and rare crinoid columnals; geodiferous brachiopods.

2 - 18 cm - Raytown limestone - thins to 10 cm in places; dark gray, argillaceous, stylonodular wackestone-packstone; nodules contain fenestrate bryozoans; sharp lower contact.

1 - >18 cm - Raytown limestone - medium gray wackestone-packstone; bioturbation; fossils, mostly fragmented, include: brachiopod valves and crinoid particles; rare articulated brachiopods; few sparry patches; at least 53cm more of limestone is covered and overlies an excavated dark gray mudrock with calcareous bits which may be Muncie Creek shale.

RQ, SW SW SE Sec. 30, T21S, R21E, Anderson County, Kansas

13 - >30 cm - Lane Shale - Gray mudrock, in place.

12 - 49 cm - Raytown limestone - wackestone with thin layers of packstone along stylolites; sharp lower contact; 4 red layers resembling horizontal burrow networks; fossils include: crinoid debris and brachiopods; top surface pervasively burrowed; large oncoids in the upper portion of bed; large coiled cephalopod on top surface.

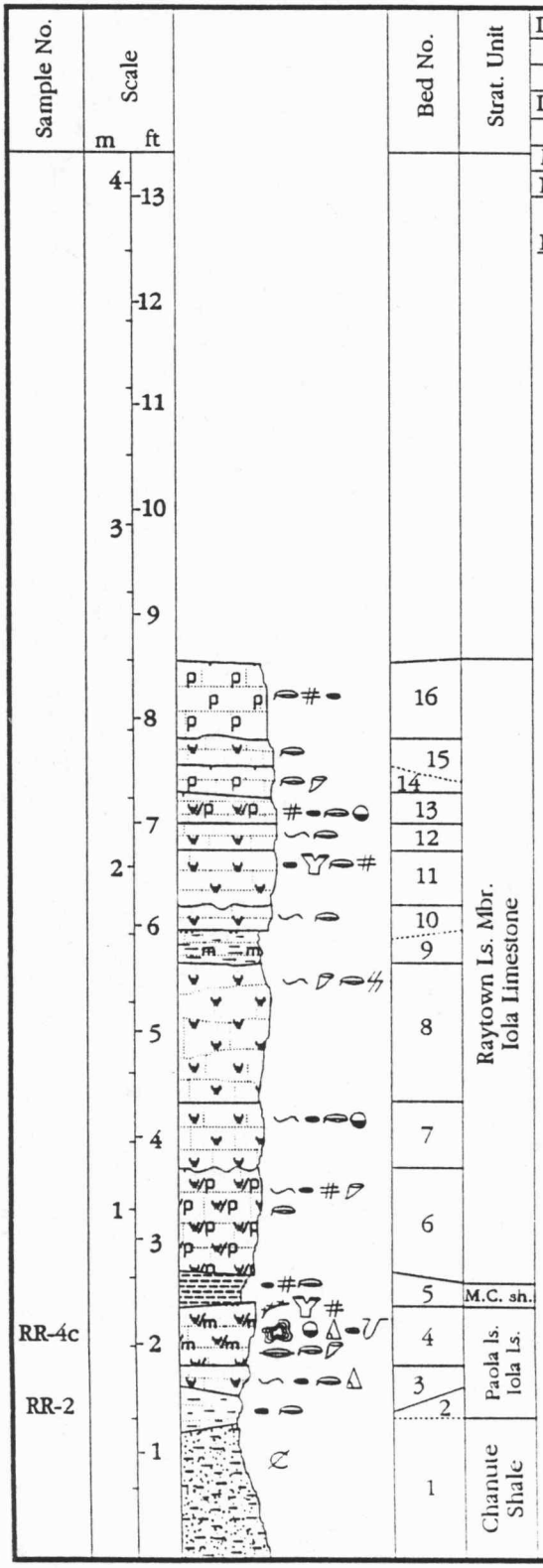
11 - 59 cm - Raytown limestone - light gray packstone of granule-sized bioclasts; sharp, stylolar lower contact; 20 cm above base is horizon of sparry vugs; fossils include: bryozoans, rugose coral, crinoid debris, and brachiopods; high diversity but mostly fragmented.

10 - 18 cm - dark gray olive to black mudrock; sharp lower contact; distinct horizons rich in organic carbon; no fossils found;

9 - 7 cm - Raytown limestone - dark brown-green argillaceous mudstone; sharp lower contact; fossils include: productid and other brachiopods.

8 - 35 cm - Raytown limestone - yellowish gray limestone; base is very coarse (granule sized bioclasts) packstone; grades upward to wackestone near top; sharp lower contact; faint bioturbational fabric (alignment of bioclasts in vertical strings); chert nodule replacing rock (maybe burrow fill).

7 - 17 cm - Raytown limestone - light gray wackestone with sand sized bioclasts; sharp, heavily stylolized at upper and lower contacts; fossils include: rare phylloid algal blades and geodiferous Composita.



Locality: RR

Location: NW NW NE Sec.29, T14S, R25E
Johnson County, Kansas

Measured by: T. Olszewski, 7/92

Remarks: Missouri Pacific Railroad cut

Description

Bed No.

5 - 7-10 cm - Muncie Creek shale - calcareous, dark gray mudrock; sharp lower contact--fills in relief of underlying layer; fossils include: fenestrate bryozoans and >3 species brachiopod; abraded phosphate concretions.

4 - 17 cm - Paola limestone - brownish gray mudstone-wackestone; sharp lower contact; fossils include: large "osagiids" (up to 10 cm across and varying from flat ovoid to subspherical in shape), geopetal gastropods, crinoids, fusulinids, small brachiopods, and rugose coral; upper surface has very complex relief (up to 6 cm) and is the source of cylindrical (1 cm diameter) burrows which weather orange and are filled with coarser debris (crinoid columnals, ramose bryozoans, brachiopod fragments, and fenestrate bryozoans); upper surface encrusted by fistuliporid bryozoans and has small borings; firm/hardground.

3 - 13 cm - Paola limestone - phylloid algal wackestone; dark brownish green micritic matrix; sharp lower contact; fossils include: Composita, crinoid columnals, productid spines, small gastropods, and comminuted debris; no spar filled voids; patches of packstone (probably bioturbation).

2 - 2-4 cm - Paola limestone - dark gray argillaceous packstone; gradational lower contact; grains poorly sorted and range from silt to very coarse sand; only echinoderm fragments identifiable; when bed thickens up to 9 cm -- contains less siliciclastic materialand, becomes brachiopod/echinoderm hash, and upper and lower contacts sharpen.

1 - >122 cm - Chanute shale - gray siltstone; moderately laminated in places; some brown iron staining; plant material common.

RR, NW NW NE Sec. 29, T14S, R25E, Johnson County, Kansas

16 - 22-23 cm - Raytown limestone - yellowish gray packstone; sharp lower contact; fossils include: brachiopods, fenestrate bryozoans, and crinoid columnals; very coarse sand to granule sized bioclasts; sediment filled brachiopods.

15 - 13 cm - Raytown limestone - bioclastic wackestone of large, sediment filled, productid brachiopods; gradational lower contact.

14 - 3-8 cm - Raytown limestone - discontinuous layer of brachiopod packstone; brachiopods are 1-2 cm and articulated; sharp lower contact; fossils include: productid, spiriferids, and rugosan coral.

13 - 9 cm - Raytown limestone - yellowish gray color; lower part wackestone, upper part packstone; sharp lower contact; lower half includes: fragments (coarse sand sized) of fenestrate bryozoan, crinoids, and brachiopods; upper half includes: 2-3 cm geopetal Composita, crinoid plates and columnals, and fenestrate bryozoans.

12 - 8 cm - Raytown limestone - light gray, algal wackestone; sharp, undulose lower contact; geopetal Composita and many small (3 mm) brachiopod fragments.

11 - 16 cm - Raytown limestone - light yellowish gray crinoidal wackestone; sharp, undulose lower contact; other fossils include: ramose bryozoan and small brachiopods; top a 2-4 cm crinoidal packstone but also includes sediment filled brachiopods and broad sheets of fenestrate bryozoans-- much of this packstone is granule and very coarse sand sized bioclast fragments-- one large, articulated brachiopod is sediment filled but has spiralium in place-- brachiopods have internal and external encrusters--some free bryozoan sheets are > 10 cm long.

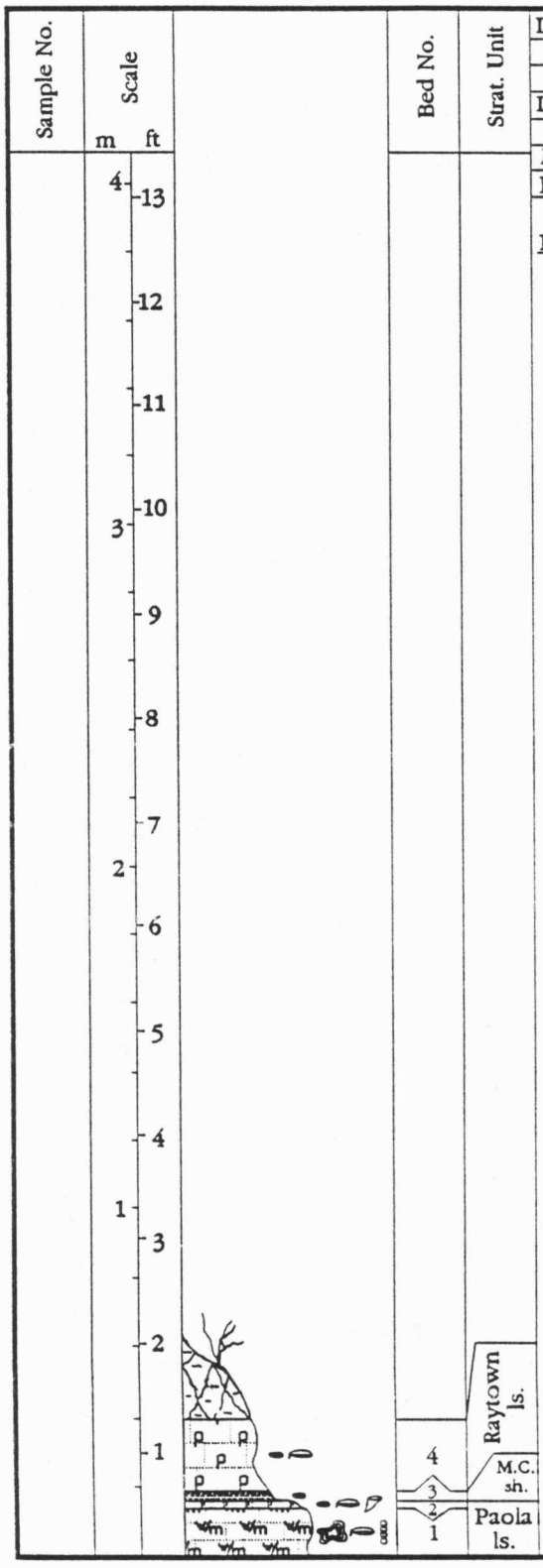
10 - 10 cm - Raytown limestone - phylloid algal wackestone; gradational lower contact; few, small geodiferous Composita.

9 - 7-10 cm - Raytown limestone - light yellowish gray argillaceous mudstone; overlies thin argillaceous layer; sharp lower contact; faint, deformed laminations which are very sharply truncated within bed--perhaps part of an intraclast.

8 - 40 cm - Raytown limestone - light gray algal wackestone; sharp lower contact; comminuted algal chips; fossils include: rugose coral and variety of brachiopods (including geodiferous Composita).

7 - 25 cm - Raytown limestone - light gray, phylloid algal wackestone with large sparry patches; sharp lower contact with 10 cm relief; less cominuted material than underlying bed; geopetal and geodiferous Composita.

6 - 31 cm - Raytown limestone - gray phylloid algal wackestone-packstone; sharp lower contact; upper half has more algal blades which lie subhorizontally and more pockets of comminuted debris; fossils include: 2 types fenestrate bryozoans, rugose corals, and > 4 species brachiopod; brachiopods both geopetal and geodiferous.



Locality: SPE

Location: NW NE Sec.32, T34S, R15E
Montgomery County, Kansas

Measured by: T. Olszewski, 7/93

Remarks: Road ditch on south side of section road

Description

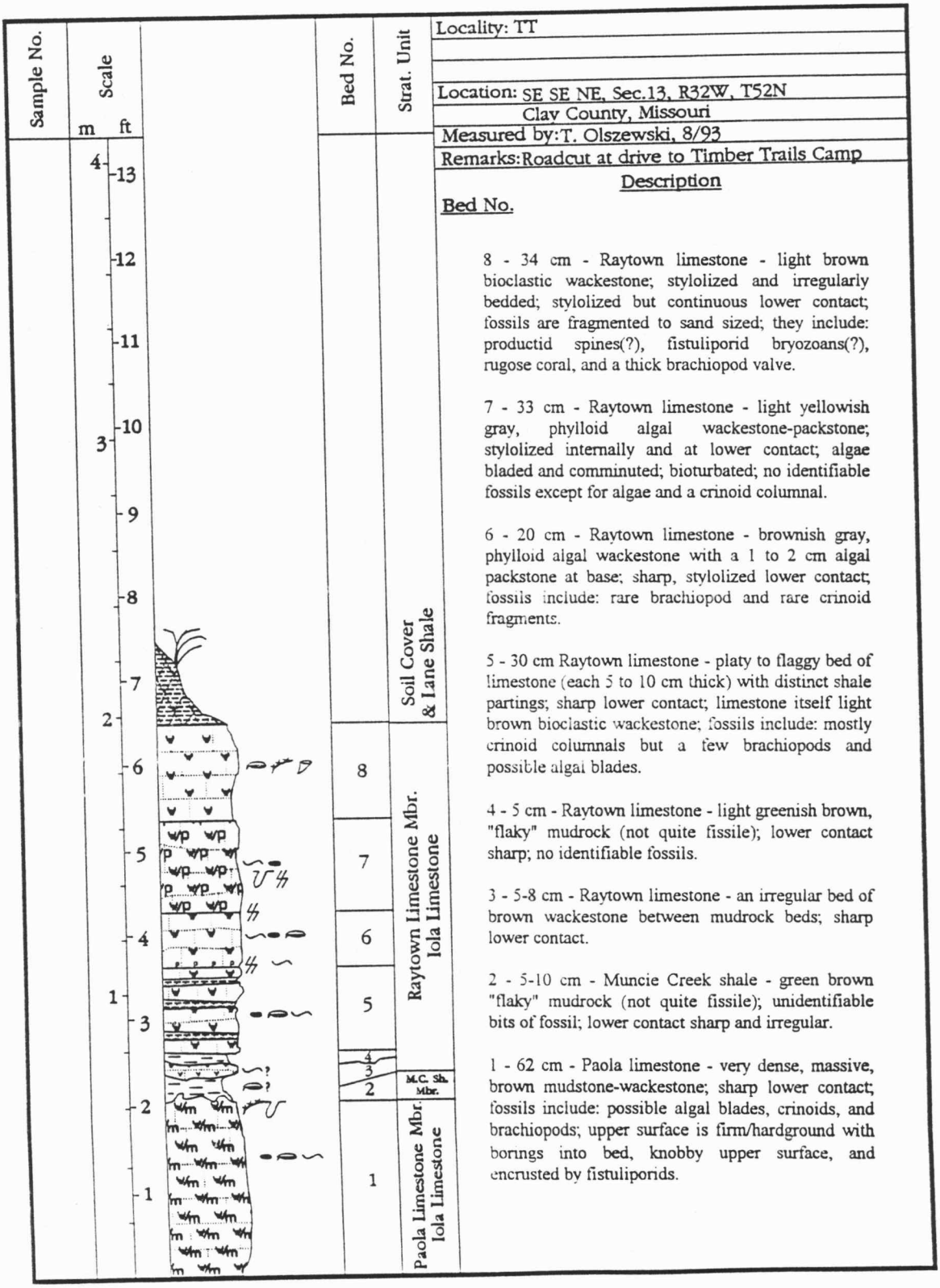
Bed No.

4 - 41 cm - Raytown limestone - bioclastic packstone; obscured lower contact--sharp but with limestone chips in the underlying shale; fossils include: crinoids, brachiopods, and an agglutinated tube of crinoid columnals; overlain by soil.

3 - 3 cm - Muncie Creek shale - greenish brown, clay-rich, very weathered mudrock; sharp lower contact; lots of fossils include: crinoids and spines of some sort.

2 - 2 cm - Paola limestone - orange, bioclastic packstone; lower contact obscured; fossils include: crinoids, brachiopod fragments, and rugose corals; top has fistuliporid encrusters; fresh surface is dark brown and crystalline.

1 - >14 cm - Paola limestone - gray mudstone-wackestone; lower contact not exposed; fossils include: "osagiids," sponges, and brachiopods.



Locality: TT

Location: SE SE NE, Sec.13, R32W, T52N
Clay County, Missouri

Measured by: T. Olszewski, 8/93

Remarks: Roadcut at drive to Timber Trails Camp

Description

Bed No.

8 - 34 cm - Raytown limestone - light brown bioclastic wackestone; stylolized and irregularly bedded; stylolized but continuous lower contact; fossils are fragmented to sand sized; they include: productid spines(?), fistuliporid bryozoans(?), rugose coral, and a thick brachiopod valve.

7 - 33 cm - Raytown limestone - light yellowish gray, phylloid algal wackestone-packstone; stylolized internally and at lower contact; algae bladed and comminuted; bioturbated; no identifiable fossils except for algae and a crinoid columnal.

6 - 20 cm - Raytown limestone - brownish gray, phylloid algal wackestone with a 1 to 2 cm algal packstone at base; sharp, stylolized lower contact; fossils include: rare brachiopod and rare crinoid fragments.

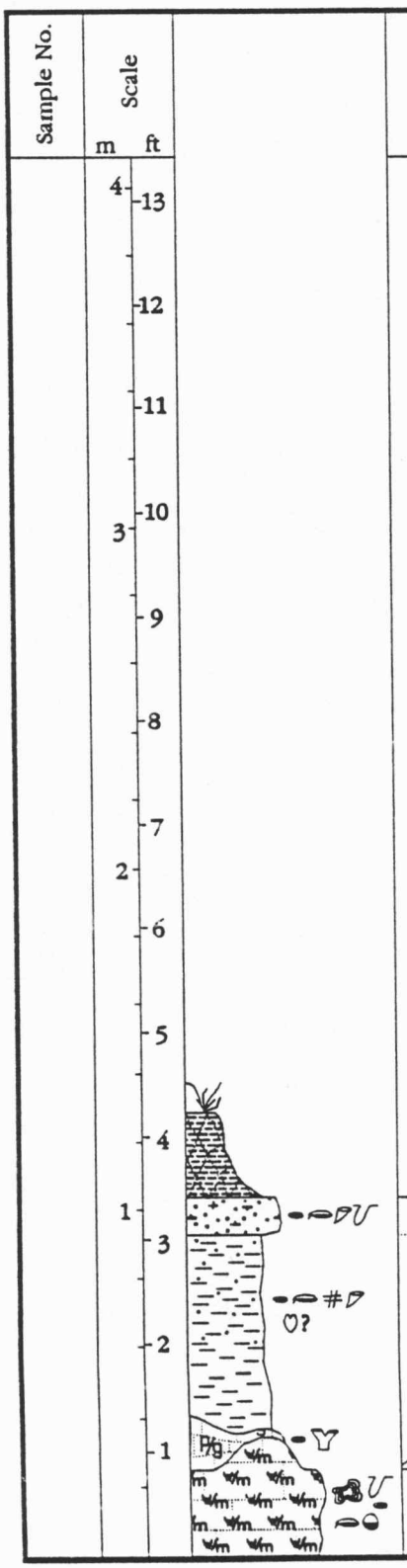
5 - 30 cm Raytown limestone - platy to flaggy bed of limestone (each 5 to 10 cm thick) with distinct shale partings; sharp lower contact; limestone itself light brown bioclastic wackestone; fossils include: mostly crinoid columnals but a few brachiopods and possible algal blades.

4 - 5 cm - Raytown limestone - light greenish brown, "flaky" mudrock (not quite fissile); lower contact sharp; no identifiable fossils.

3 - 5-8 cm - Raytown limestone - an irregular bed of brown wackestone between mudrock beds; sharp lower contact.

2 - 5-10 cm - Muncie Creek shale - green brown "flaky" mudrock (not quite fissile); unidentifiable bits of fossil; lower contact sharp and irregular.

1 - 62 cm - Paola limestone - very dense, massive, brown mudstone-wackestone; sharp lower contact; fossils include: possible algal blades, crinoids, and brachiopods; upper surface is firm/hardground with borings into bed, knobby upper surface, and encrusted by fistuliporids.



Locality: TYE

Location: NW NW Sec.4, T35S, R15E
Montgomery County, Kansas

Measured by: T. Olszewski, 7/93

Remarks: Road ditch on south side of 166

Description

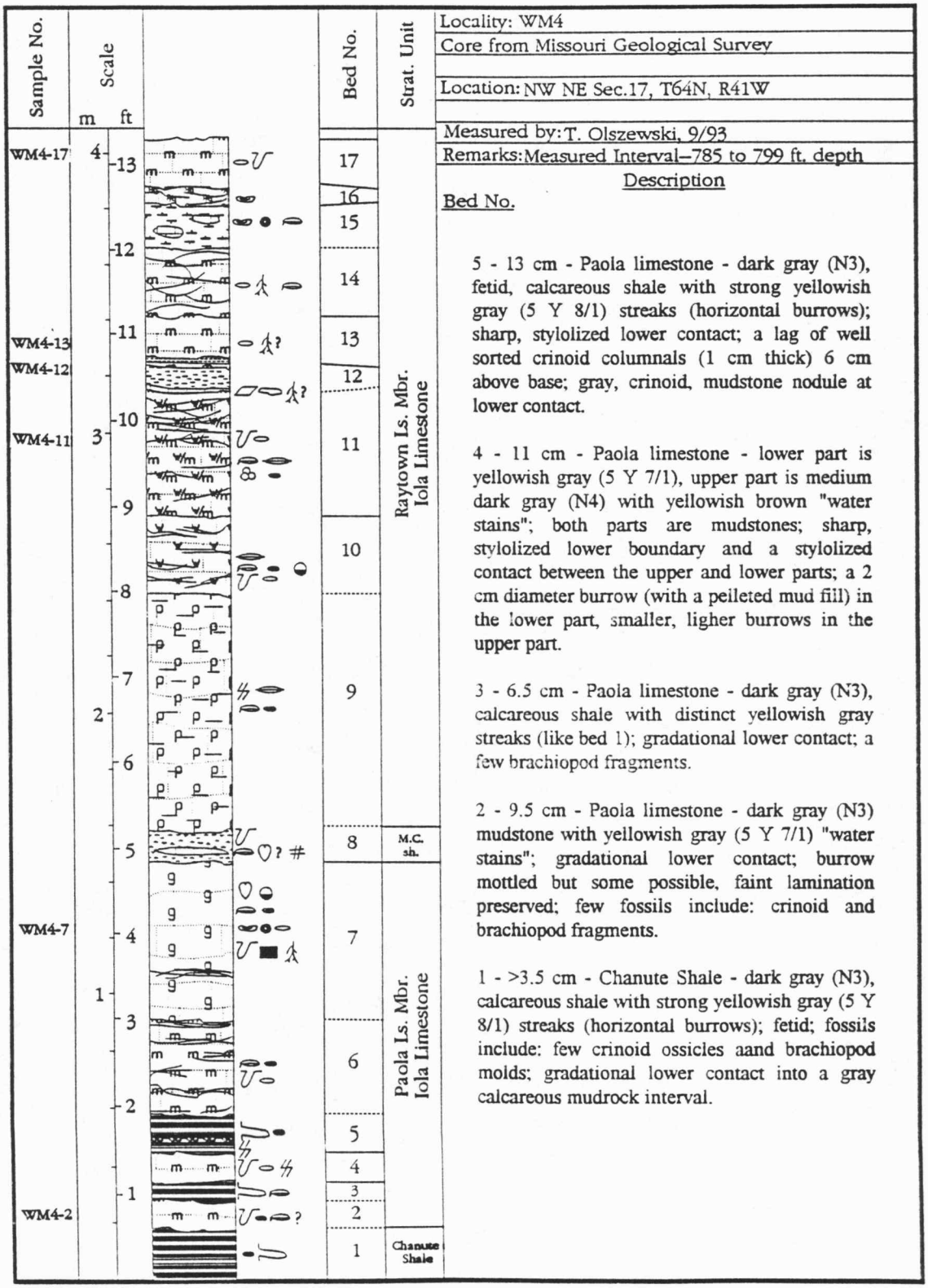
Bed No.

4 - 11 cm - Raytown limestone? - light gray, bioclastic, carbonate cemented, quartz sandstone; well sorted, medium grained; lower contact gradational; fossils include: bored crinoid columnals, brachiopods, rugose corals; pervasively bioturbated with 1 cm diameter burrow holes on top surface.

3 - 67 cm - Muncie Creek shale? - very fossiliferous, olive green mudrock; sharp lower contact; fossils include: crinoid fragments, brachiopods, fenestrate bryozoans, shark teeth, rugosan coral, and possible pelecypods; weathered surface look like homogenized bioclastic sand with argillaceous matrix in upper 56 cm whereas mud content is higher near base.

2 - 1-15 cm - Paola limestone - coarse, bioclastic packstone-grainstone; sharp lower contact; grains piped through burrows (>5 cm diameter) into the underlying bed; fossils include: mostly crinoids and few ramose bryozoans and 1 brachiopod fragment; coarse, sparry recrystallization in places.

1 - >25cm - Paola limestone - dark grayish brown mudstone-wackestone; lower contact not exposed; fossils include: "osagiids" (up to 5 cm across), brachipods (articulated geopetals and unfragmented, free valves), and some crinoid debris material, also contains an overturned productid and a nautiloid; "hummocks" >30 cm at the top of this bed .



Locality: WM4

Core from Missouri Geological Survey

Location: NW NE Sec.17, T64N, R41W

Measured by: T. Olszewski, 9/93

Remarks: Measured Interval--785 to 799 ft. depth

Description

Bed No.

5 - 13 cm - Paola limestone - dark gray (N3), fetid, calcareous shale with strong yellowish gray (5 Y 8/1) streaks (horizontal burrows); sharp, stylolized lower contact; a lag of well sorted crinoid columnals (1 cm thick) 6 cm above base; gray, crinoid, mudstone nodule at lower contact.

4 - 11 cm - Paola limestone - lower part is yellowish gray (5 Y 7/1), upper part is medium dark gray (N4) with yellowish brown "water stains"; both parts are mudstones; sharp, stylolized lower boundary and a stylolized contact between the upper and lower parts; a 2 cm diameter burrow (with a pelleted mud fill) in the lower part, smaller, ligher burrows in the upper part.

3 - 6.5 cm - Paola limestone - dark gray (N3), calcareous shale with distinct yellowish gray streaks (like bed 1); gradational lower contact; a few brachiopod fragments.

2 - 9.5 cm - Paola limestone - dark gray (N3) mudstone with yellowish gray (5 Y 7/1) "water stains"; gradational lower contact; burrow mottled but some possible, faint lamination preserved; few fossils include: crinoid and brachiopod fragments.

1 - >3.5 cm - Chanute Shale - dark gray (N3), calcareous shale with strong yellowish gray (5 Y 8/1) streaks (horizontal burrows); fetid; fossils include: few crinoid ossicles aand brachiopod molds; gradational lower contact into a gray calcareous mudrock interval.

WM4, NW NE Sec. 17, T64N, R41W, Atchison County, Missouri

17 - 18 cm - Raytown limestone - yellowish gray (5 Y 8/1) with traces of greenish gray (5 GY 6/1) peloidal mudstone; sharp lower contact; hazy medium gray stylolites; Thallasinoides burrow 3-5 cm from the base filled with coated grains (probably from the overlying bed).

16 - 6-8 cm - Raytown limestone - yellowish gray (5 Y 8/1) oncoidal grainstone to packstone with gray green stylolites; sharp lower contact; oncoidal coats on bioclasts.

15 - 15-16 cm - Raytown limestone - medium bluish-green gray (5 B/G 4.5/1) calcareous mudrock with yellowish gray (5 Y 8/1) limestone nodules; gradational lower contact; limestone nodules are oncoidal bioclastic grainstone (fossils include brachiopod valves and possible sponges).

14 - 25 cm - Raytown limestone - light yellowish brownish gray (5YR 7/1) nodular peloidal mudstone nodules in medium bluish gray (5 B 5/1) claystone matrix; gradational lower contact; few fossils look "spongy" and coated; increasing root traces with oxidation rims upward; few brachiopod valves in the claystone.

13 - 17 cm - Raytown limestone - light brownish gray (5 YR 7/1) peloidal mudstone; sharp lower contact; comminuted bioclastic debris in lowest 2 cm; from 2 to 3.5 cm above the base is a bluish-green claystone layer with limestone nodule; few irregular stylolites; root traces.

12 - 9-10 cm - Raytown limestone - non-calcareous grayish yellow green (5 GY 6/2) mudrock; 1.5-2 cm crust at base is limestone and has a gradational but distinct lower contact; this crust has little, rounded intraclasts and possible root traces; green claystone has a small slickensided surface and some shell debris.

11 - 44-46 cm - Raytown limestone - light brownish gray (5 Y 7/1) bioclastic mudstone (almost a wackestone); sharp lower contact; increasingly argillaceous and stylolar in upper 21 cm; faint bioturbation; peloidal texture (especially in burrows); some patches of bioclastic packstone; fossils include: brachiopod fragments (rare productid spines), rare fusulinids, and one opthalmidid encruster, and possibly badly degraded crinoid fragments.

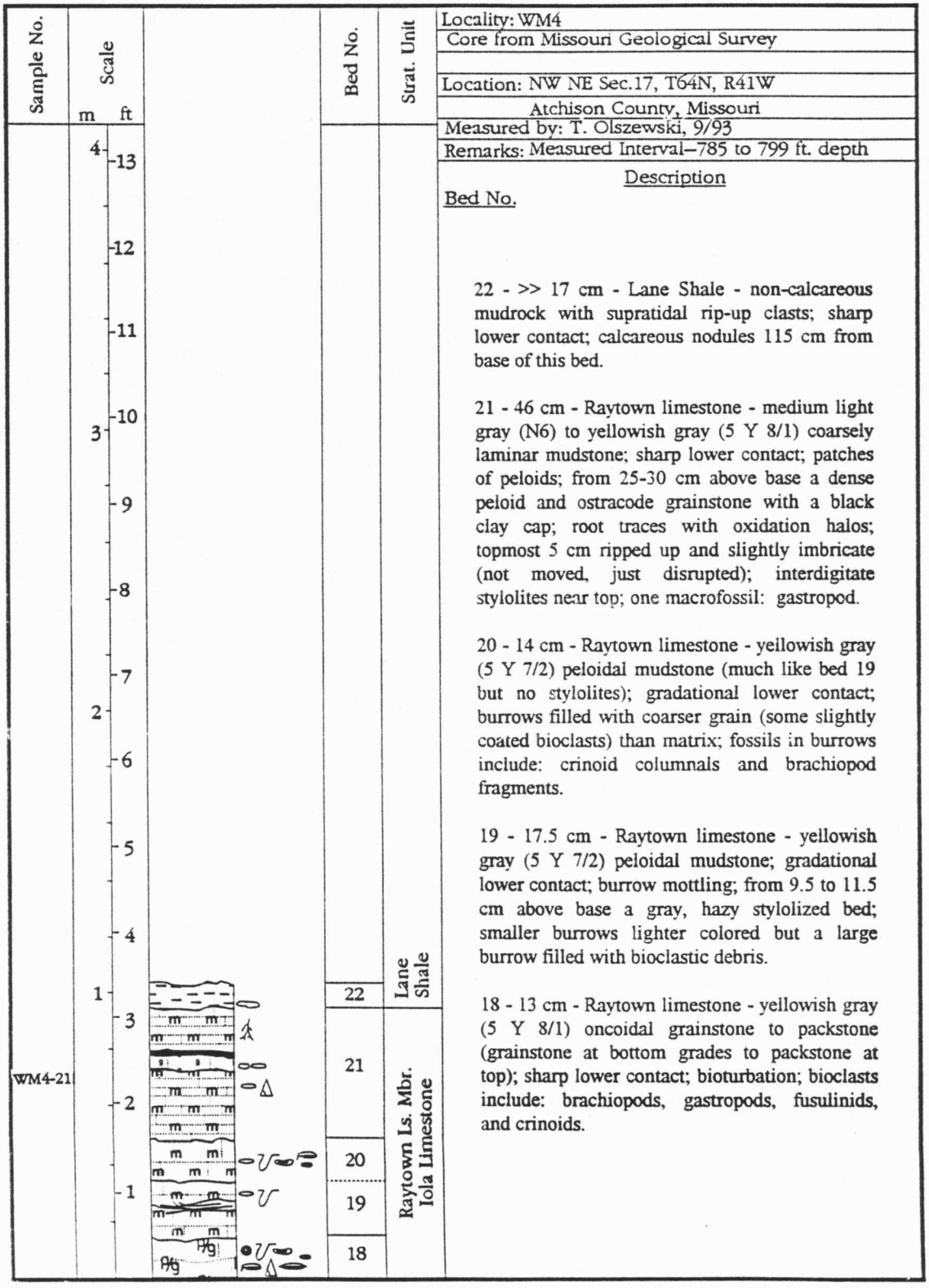
10 - 27.5 cm - Raytown limestone - yellowish gray (5 Y 8/1) bioclastic wackestone with medium bluish gray (5 B 5/1) (especially from 11-19 cm from the bottom) horsehair stylolites; gradational lower contact but many fewer fusulinids than underlying bed; other fossil include: brachiopod valves, productid spines, and crinoid columnals; some grainstone pockets in burrows; peloidal mud; few geopetal brachiopods.

9 - 82 cm - Raytown limestone - yellowish gray (5 Y 8/1) nodules in a medium bluish gray (5 B 5/1) horsehair stylolar clay matrix; gradational lower contact; both nodules and matrix are fusulinid packstone in most places; other fossils include: a few brachiopod valves and crinoid columnals.

8 - 13 cm - Muncie Creek shale - grayish black (N2) to olive black (5 Y 2/1), fetid, calcareous mudrock; sharp lower contact; fossils include: brachiopod valves, possible pelecypod mold, and a fenestrate bryozoan; suggestion of bioturbation near the top.

7 - 56 cm - Paola limestone - yellow gray (5 YR 7/1), poorly sorted, coated bioclastic (oolitic) grainstone; with some peloids; gradational but distinct lower contact; bioturbation; a large pyritic root trace (?); fossils include: brachiopod and crinoid fragments, possible sponge fragment, and a tiny, upside down geopetal pelecypod; possible, minor chert replacement of a few bioclasts; a black stylolar layer 14.5 to 16.5 cm from the bottom.

6 - 32.5 cm - Paola limestone - yellowish gray (5Y 7/1), mudstone with black stylolar horizons and a few (N4) burrow mottles; gradational lower contact; fossils include: brachiopod vlaves, crinoid columnals; one partial burrow filled with bioclastic and peloidal grainstone.



Locality: WM4
Core from Missouri Geological Survey

Location: NW NE Sec.17, T64N, R41W
Atchison County, Missouri
Measured by: T. Olszewski, 9/93
Remarks: Measured Interval–785 to 799 ft. depth

Description

Bed No.

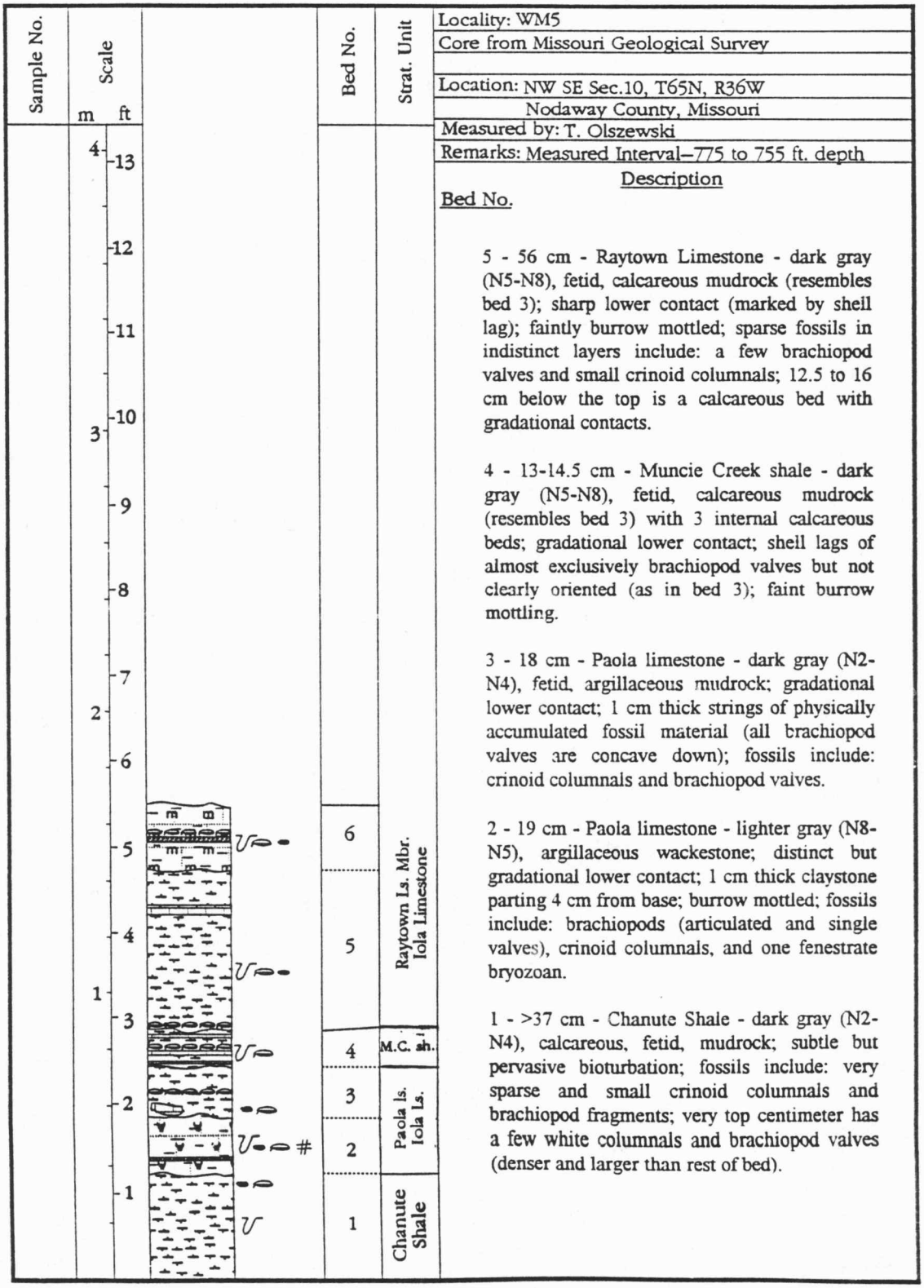
22 - >> 17 cm - Lane Shale - non-calcareous mudrock with supratidal rip-up clasts; sharp lower contact; calcareous nodules 115 cm from base of this bed.

21 - 46 cm - Raytown limestone - medium light gray (N6) to yellowish gray (5 Y 8/1) coarsely laminar mudstone; sharp lower contact; patches of peloids; from 25-30 cm above base a dense peloid and ostracode grainstone with a black clay cap; root traces with oxidation halos; topmost 5 cm ripped up and slightly imbricate (not moved, just disrupted); interdigitate stylolites near top; one macrofossil: gastropod.

20 - 14 cm - Raytown limestone - yellowish gray (5 Y 7/2) peloidal mudstone (much like bed 19 but no stylolites); gradational lower contact; burrows filled with coarser grain (some slightly coated bioclasts) than matrix; fossils in burrows include: crinoid columnals and brachiopod fragments.

19 - 17.5 cm - Raytown limestone - yellowish gray (5 Y 7/2) peloidal mudstone; gradational lower contact; burrow mottling; from 9.5 to 11.5 cm above base a gray, hazy stylolized bed; smaller burrows lighter colored but a large burrow filled with bioclastic debris.

18 - 13 cm - Raytown limestone - yellowish gray (5 Y 8/1) oncoidal grainstone to packstone (grainstone at bottom grades to packstone at top); sharp lower contact; bioturbation; bioclasts include: brachiopods, gastropods, fusulinids, and crinoids.



Locality: WM5
Core from Missouri Geological Survey

Location: NW SE Sec.10, T65N, R36W
Nodaway County, Missouri
Measured by: T. Olszewski
Remarks: Measured Interval--775 to 755 ft. depth

Description

Bed No.

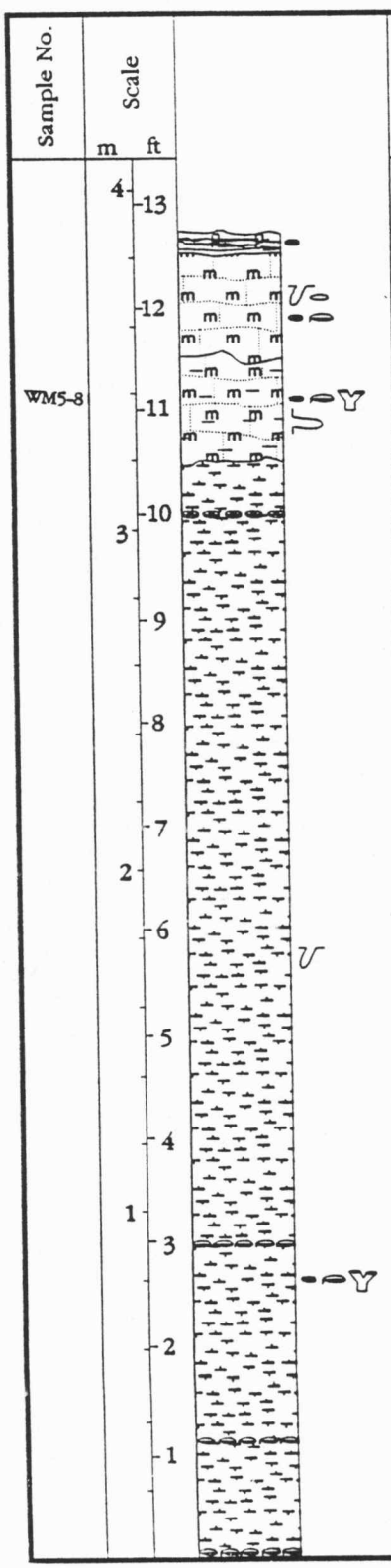
5 - 56 cm - Raytown Limestone - dark gray (N5-N8), fetid, calcareous mudrock (resembles bed 3); sharp lower contact (marked by shell lag); faintly burrow mottled; sparse fossils in indistinct layers include: a few brachiopod valves and small crinoid columnals; 12.5 to 16 cm below the top is a calcareous bed with gradational contacts.

4 - 13-14.5 cm - Muncie Creek shale - dark gray (N5-N8), fetid, calcareous mudrock (resembles bed 3) with 3 internal calcareous beds; gradational lower contact; shell lags of almost exclusively brachiopod valves but not clearly oriented (as in bed 3); faint burrow mottling.

3 - 18 cm - Paola limestone - dark gray (N2-N4), fetid, argillaceous mudrock; gradational lower contact; 1 cm thick strings of physically accumulated fossil material (all brachiopod valves are concave down); fossils include: crinoid columnals and brachiopod valves.

2 - 19 cm - Paola limestone - lighter gray (N8-N5), argillaceous wackestone; distinct but gradational lower contact; 1 cm thick claystone parting 4 cm from base; burrow mottled; fossils include: brachiopods (articulated and single valves), crinoid columnals, and one fenestrate bryozoan.

1 - >37 cm - Chanute Shale - dark gray (N2-N4), calcareous, fetid, mudrock; subtle but pervasive bioturbation; fossils include: very sparse and small crinoid columnals and brachiopod fragments; very top centimeter has a few white columnals and brachiopod valves (denser and larger than rest of bed).



Bed No. | Strat. Unit

10 | Wyandotte Limestone
9 | Wyandotte Limestone
8 | Wyandotte Limestone
7 | Lane Shale

Locality: WM5
Core from Missouri Geological Survey

Location: NW SE Sec.10, T65N, R36W
Nodaway County, Missouri
Measured by: T. Olszewski
Remarks: Measured Interval--775 to 755 ft. depth

Description

Bed No.

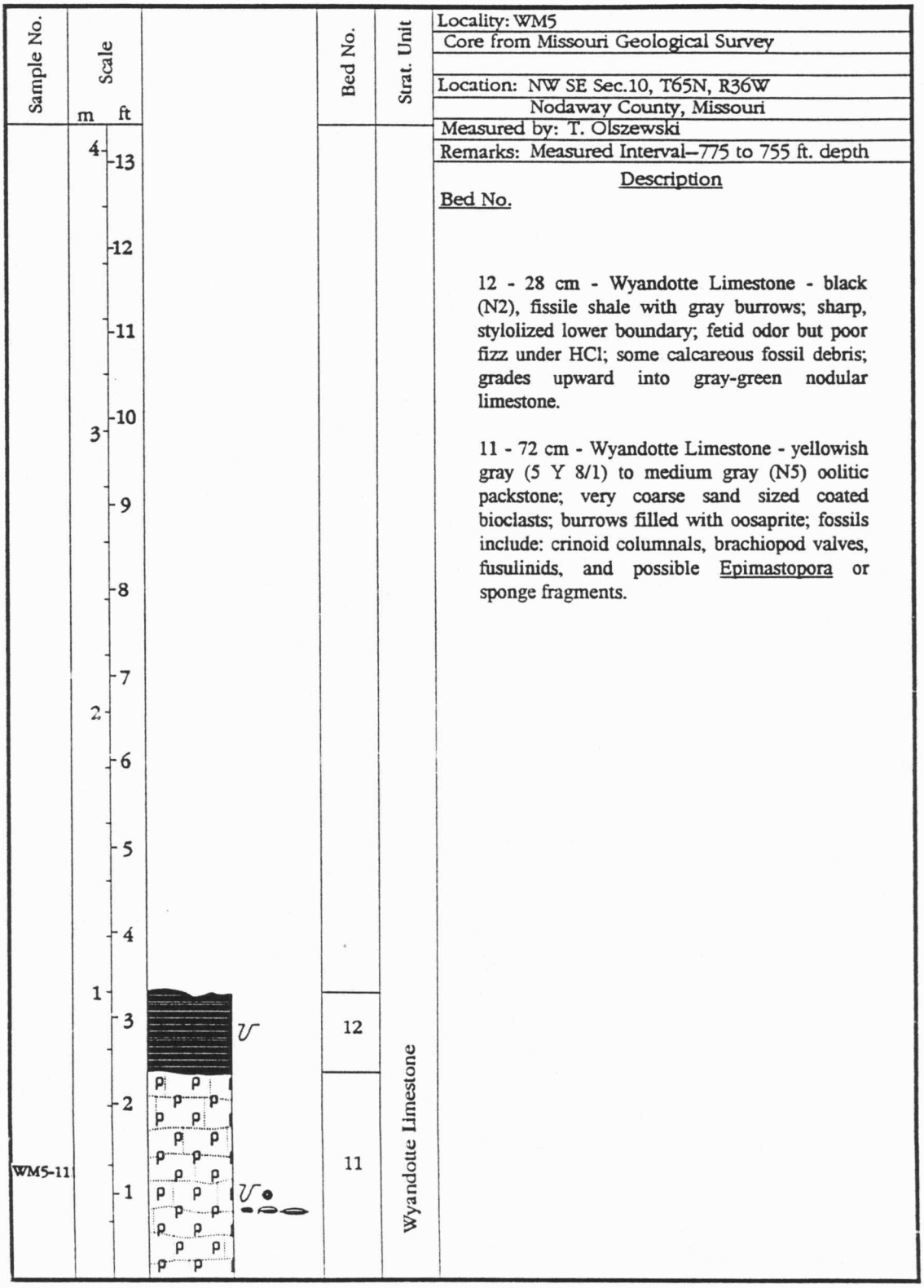
10 - 6 cm - Wyandotte Limestone - light brown gray (5 YR 6/1) bioclastic packstone full of black horsehair stylolites; gradational but stylolized lower contact; fossil include: crinoid coumnals and other poorly preserved skeletal grains.

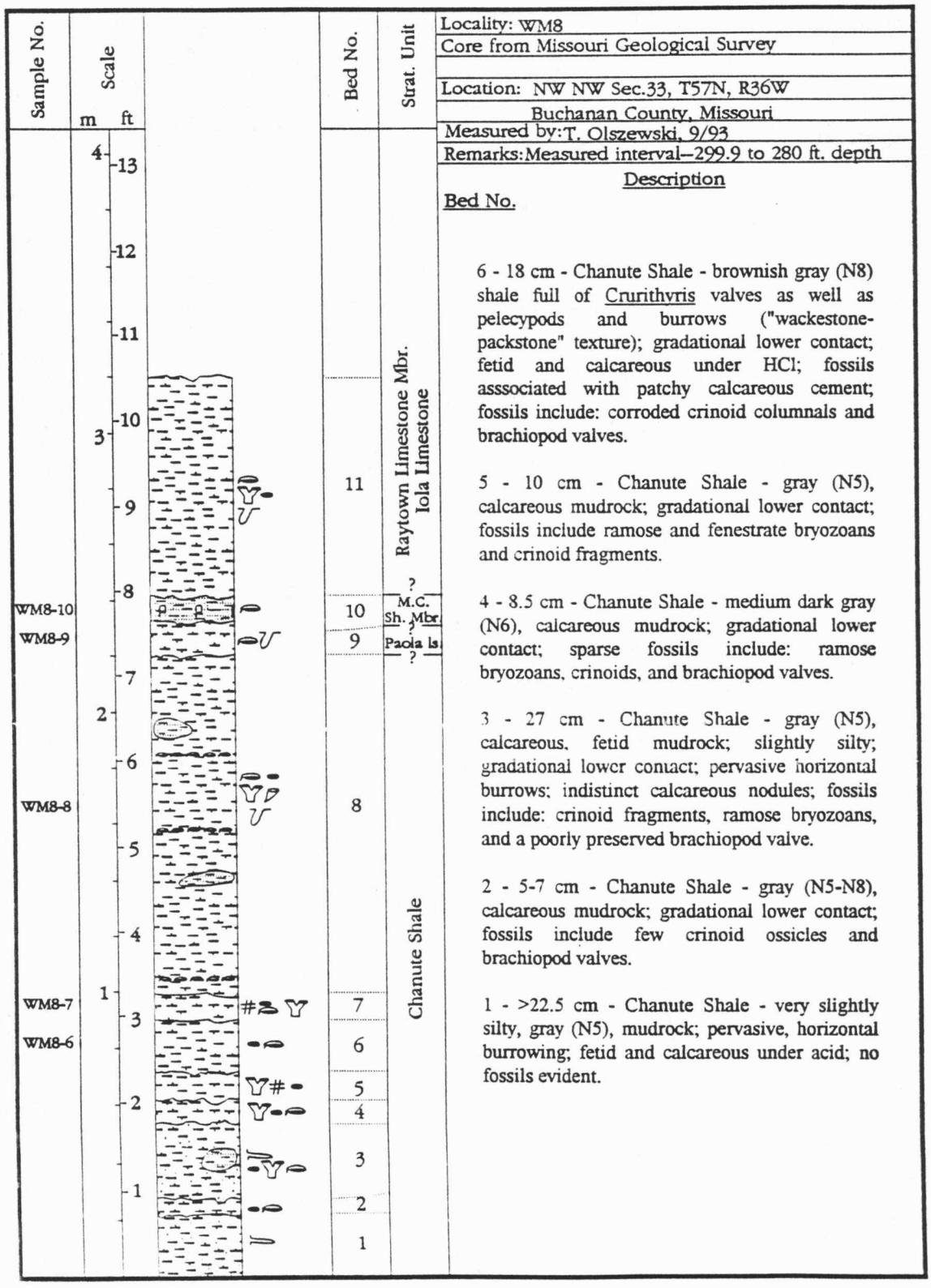
9 - 31 cm - Wyandotte Limestone - light brown gray (5 YR 6/1) mudstone with a few patches of bioclastic packstone near the base; gradational lower contact; burrows resembling "water stains" in a gray matrix (N4); fossils include: crinoid columnals, brachiopod valves, productid spines, and possible Epimastopora; these are concentrated near the base; some peloids; Thallasinoides burrow.

8- 30 cm - Lane Shale - gray (N4) argillaceous mudstone with light brown gray (5 YR 6/1) "water stain" burrows; gradational lower contact; fossils occur in patchy packstones as well as floating bioclasts, and include: brachiopod valves, crinoid columnals, some ramose bryozoans.

7 - 320.5 cm - Lane Shale - dark gray (N5-N8) calcareous, fetid, mudrock (minor fissility); sharp lower contact (marked by a shell lag); a few bioclastic lags in the bottom third; fossils include: brachiopods, few crinoid columnals, and ramose bryozoan fragment; fossil are very sparse above the bottom third of the bed (except for a crinoid fragment lag 15 cm below the top).

6 - 23 cm - Raytown limestone - dark gray (N2-N4), argillaceous, fetid mudstone; gradational lower contact; burrow mottled; fossils include: sparsely distributed crinoid columnals and thin shelled brachiopods; bed capped by a concave-down brachiopod shell lag.


Sample No.
Scale
m
ft
Bed No.
Strat. Unit
Locality: WM5
Core from Missouri Geological Survey
Location: NW SE Sec.10, T65N, R36W
Nodaway County, Missouri
Measured by: T. Olszewski
Remarks: Measured Interval--775 to 755 ft. depth
Description
Bed No.
12 - 28 cm - Wyandotte Limestone - black (N2), fissile shale with gray burrows; sharp, stylolized lower boundary; fetid odor but poor fizz under HCl; some calcareous fossil debris; grades upward into gray-green nodular limestone.
11 - 72 cm - Wyandotte Limestone - yellowish gray (5 Y 8/1) to medium gray (N5) oolitic packstone; very coarse sand sized coated bioclasts; burrows filled with oosaprite; fossils include: crinoid columnals, brachiopod valves, fusulinids, and possible Epimastopora or sponge fragments.
4
3
2
1
13
12
11
10
9
8
7
6
5
4
3
2
1
12
11
Wyandotte Limestone
WM5-11



Locality: WM8
Core from Missouri Geological Survey

Location: NW NW Sec.33, T57N, R36W
Buchanan County, Missouri
Measured by: T. Olszewski, 9/93
Remarks: Measured interval--299.9 to 280 ft. depth

Description

Bed No.

6 - 18 cm - Chanute Shale - brownish gray (N8) shale full of Crurithyris valves as well as pelecypods and burrows ("wackestone-packstone" texture); gradational lower contact; fetid and calcareous under HCl; fossils asssociated with patchy calcareous cement; fossils include: corroded crinoid columnals and brachiopod valves.

5 - 10 cm - Chanute Shale - gray (N5), calcareous mudrock; gradational lower contact; fossils include ramose and fenestrate bryozoans and crinoid fragments.

4 - 8.5 cm - Chanute Shale - medium dark gray (N6), calcareous mudrock; gradational lower contact; sparse fossils include: ramose bryozoans, crinoids, and brachiopod valves.

3 - 27 cm - Chanute Shale - gray (N5), calcareous, fetid mudrock; slightly silty; gradational lower contact; pervasive horizontal burrows; indistinct calcareous nodules; fossils include: crinoid fragments, ramose bryozoans, and a poorly preserved brachiopod valve.

2 - 5-7 cm - Chanute Shale - gray (N5-N8), calcareous mudrock; gradational lower contact; fossils include few crinoid ossicles and brachiopod valves.

1 - >22.5 cm - Chanute Shale - very slightly silty, gray (N5), mudrock; pervasive, horizontal burrowing; fetid and calcareous under acid; no fossils evident.

WM8, NW NW Sec. 33, T57N, R36W, Buchanan County, Missouri

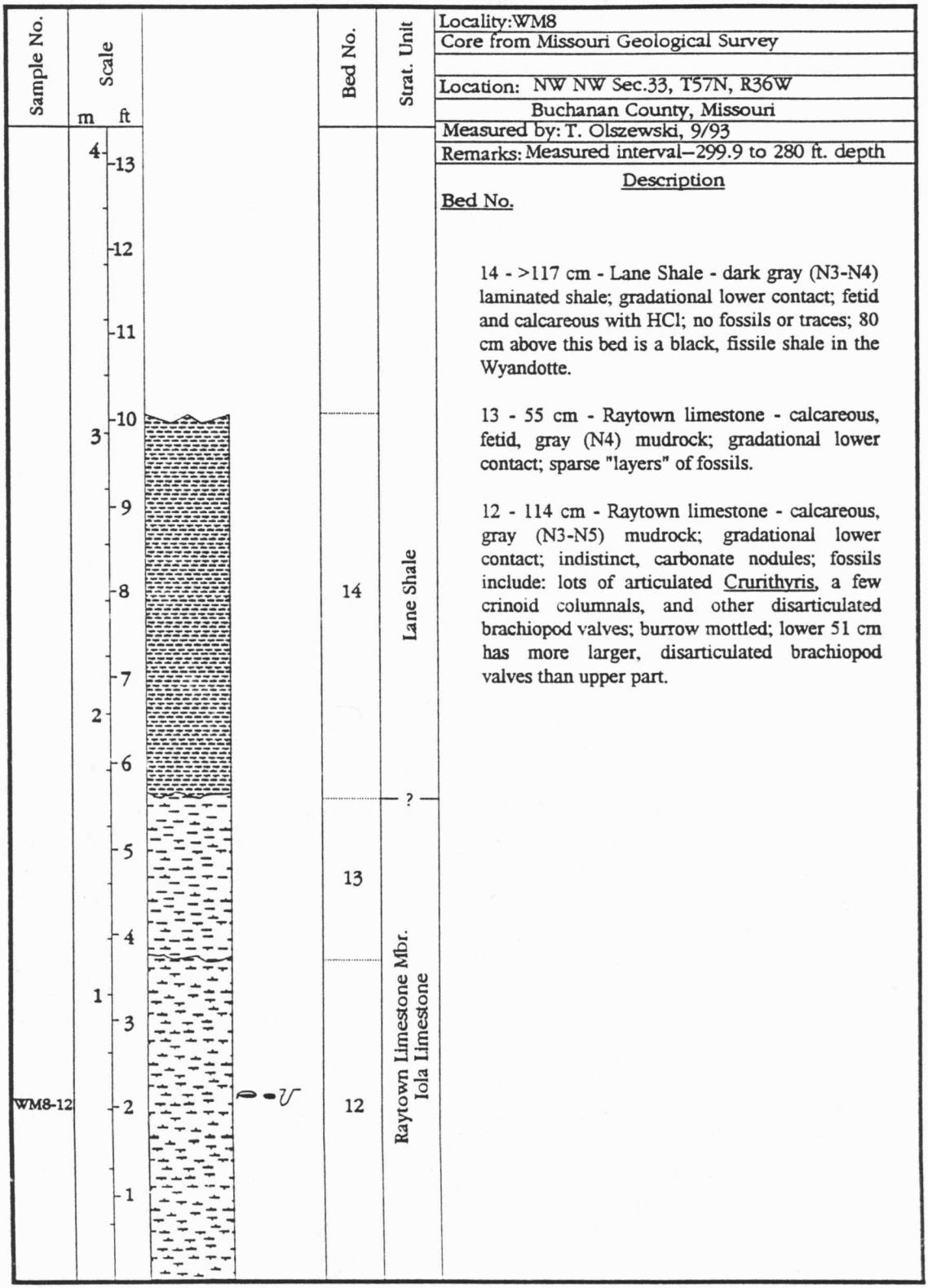
11 - 78 cm - Raytown limestone - calcareous, fetid, gray (N3-N5) mudrock; brachiopod valves in "wackestone" texture; gradational lower contact; fossils include: ramose bryozoans, brachiopods, and crinoid fragments; burrow mottled and Chondrites present.

10 - 10.5 cm - Muncie Creek shale(?) - very dark gray (N2-N3) mudrock matrix with a "packstone" texture of white fossil fragments; fetid and calcareous under HCl; fossils are all disarticulated.

9 - 8-10 cm - Paola limestone(?) - gray (N8) argillaceous mudstone; gradational lower contact; bioturbated; fossils include: articulated and disarticualted brachiopod valves.

8 - 121 cm - Chanute Shale - gray (N5) calcareous mudrock; gradational lower contact; indistinct, limestone nodules; bioturbated; fossils in poorly defined layers include: punctate chonetids, crinoid fragments, ramose bryozoans, and rugose coral; brachiopod layers have shells oriented concave up.

7 - 10 cm - Chanute Shale - gray (N5) argillaceous wackestone-packstone; gradational, anastamosing boundaries; burrow mottled; fossils include: corroded crinoid fragments, ramose bryozoans, fenestrate bryozoans, and brachiopods.



Locality: WM8
Core from Missouri Geological Survey

Location: NW NW Sec.33, T57N, R36W
Buchanan County, Missouri
Measured by: T. Olszewski, 9/93
Remarks: Measured interval–299.9 to 280 ft. depth

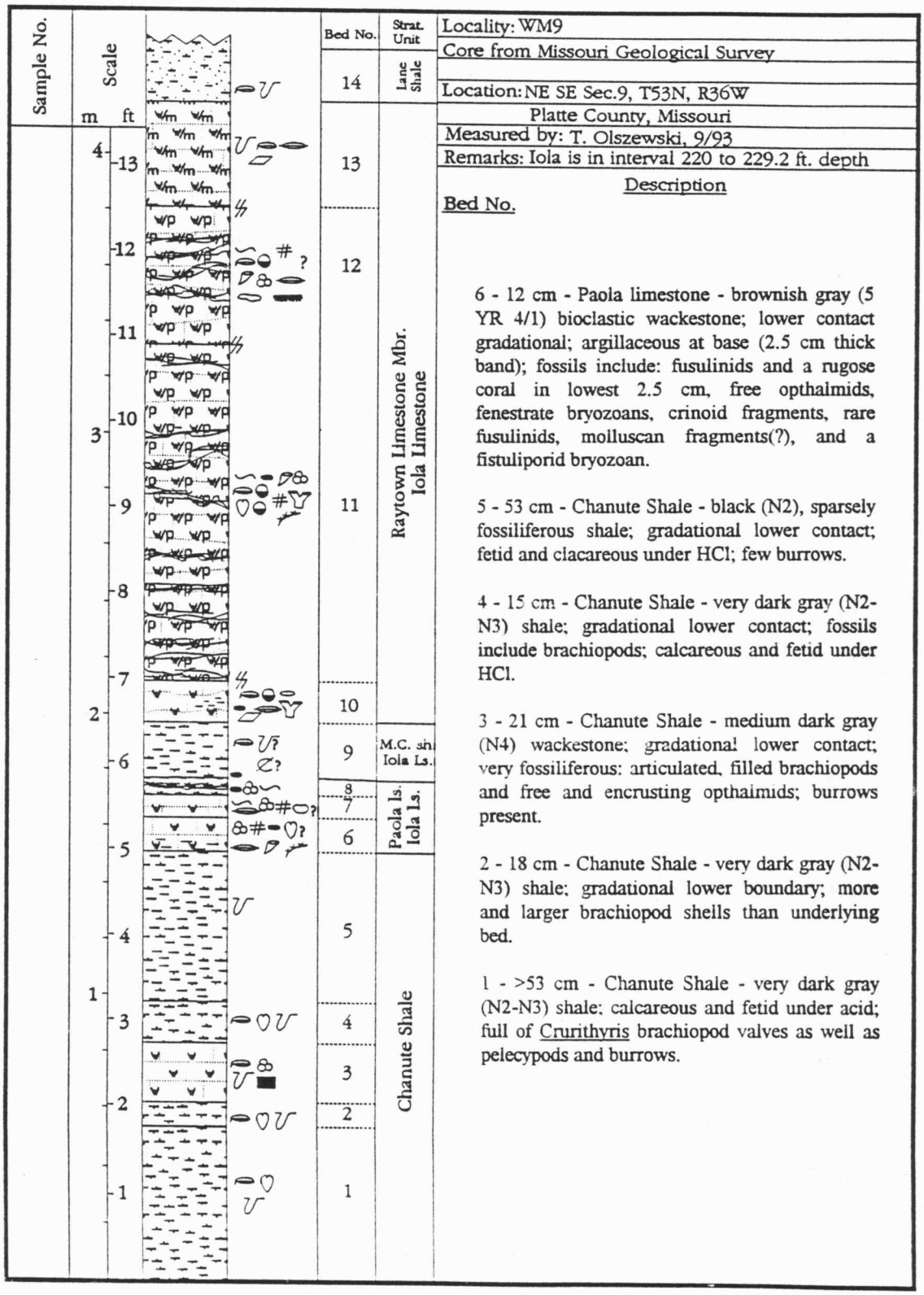
Description

Bed No.

14 - >117 cm - Lane Shale - dark gray (N3-N4) laminated shale; gradational lower contact; fetid and calcareous with HCl; no fossils or traces; 80 cm above this bed is a black, fissile shale in the Wyandotte.

13 - 55 cm - Raytown limestone - calcareous, fetid, gray (N4) mudrock; gradational lower contact; sparse "layers" of fossils.

12 - 114 cm - Raytown limestone - calcareous, gray (N3-N5) mudrock; gradational lower contact; indistinct, carbonate nodules; fossils include: lots of articulated Crurithyris, a few crinoid columnals, and other disarticulated brachiopod valves; burrow mottled; lower 51 cm has more larger, disarticulated brachiopod valves than upper part.


Sample No.
Scale
m
ft
Bed No.
Strat. Unit
Lane Shale
Raytown Limestone Mbr.
Iola Limestone
M.C. sh
Iola Ls.
Paola ls.
Iola Ls.
Chanute Shale
Locality: WM9
Core from Missouri Geological Survey
Location: NE SE Sec.9, T53N, R36W
Platte County, Missouri
Measured by: T. Olszewski, 9/93
Remarks: Iola is in interval 220 to 229.2 ft. depth
Description
Bed No.
6 - 12 cm - Paola limestone - brownish gray (5 YR 4/1) bioclastic wackestone; lower contact gradational; argillaceous at base (2.5 cm thick band); fossils include: fusulinids and a rugose coral in lowest 2.5 cm, free opthalmids, fenestrate bryozoans, crinoid fragments, rare fusulinids, molluscan fragments(?), and a fistuliporid bryozoan.
5 - 53 cm - Chanute Shale - black (N2), sparsely fossiliferous shale; gradational lower contact; fetid and clacareous under HCl; few burrows.
4 - 15 cm - Chanute Shale - very dark gray (N2-N3) shale; gradational lower contact; fossils include brachiopods; calcareous and fetid under HCl.
3 - 21 cm - Chanute Shale - medium dark gray (N4) wackestone; gradational lower contact; very fossiliferous: articulated, filled brachiopods and free and encrusting opthalmids; burrows present.
2 - 18 cm - Chanute Shale - very dark gray (N2-N3) shale; gradational lower boundary; more and larger brachiopod shells than underlying bed.
1 - >53 cm - Chanute Shale - very dark gray (N2-N3) shale; calcareous and fetid under acid; full of Crurithyris brachiopod valves as well as pelecypods and burrows.

WM9, NE SE Sec. 9, T53N, R36W, Platte County, Missouri

14 - >>45 cm - Lane Shale - dark gray (N5-N3), slightly silty, fissile shale; gradational lower contact (associated with brachiopod valves); calcareous and fetid under HCl; one or two siltstone and "siderite" layers and strings (possible burrows).

13 - 38 cm - Raytown limestone - brownish gray (5 YR 4/1) mudstone-wackestone; dolomitic (does not fizz easily); stylolized lower contact (appears gradational); horizontal burrows throughout; fossils include: brachiopod valves (mostly concave up) and fusulinids.

12 - 51.5 cm - Raytown limestone - pinkish gray (5 YR 8/1) to light brownish gray (5 YR 6/1) wackestone-packstone; gradational contact with underlying bed; fossils fragmented and sorted; horizontal burrows evident near base and top; stylolized, argillaceous layers; minor chert.

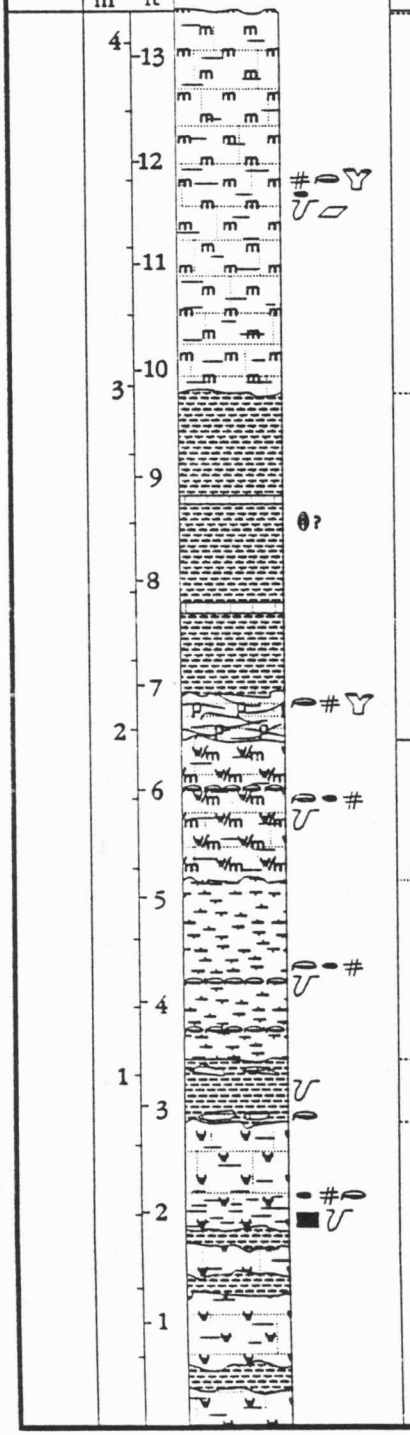
11 - 120 cm - Raytown limestone - pinkish gray (5 YR 8/1) to light brownish gray (5 YR 6/1) bioclastic wackestone with packstone areas; gradational lower contact; peloids in geopetals; fossils include: phylloid algae, geopetal brachiopods, crinoid columnals, geopetal pelecypod (shell is spar replaced), rugose coral, opthalmidids, fusulinids, ramose bryozoans, one fenestrate bryozoan, flat productids, and one encrusting, fistuliporid bryozoan; lots of fragmentation and comminution as well as articulated, whole preservation; medium gray (N5) shale or stylolar layers throughout.

10 - 15.5 cm - Raytown limestone - brownish gray (5 YR 5/1) wackestone with argillaceous layers; gradational lower contact; fossils include: large crinoid columnal, geopetal brachiopods, other brachiopod fragments, fusulinids, and ramose bryozoans; peloids in brachiopod geopetals; slow fizz suggests that this bed is somewhat dolomitic.

9 - 20 cm - Muncie Creek shale - medium dark gray (N4) shale; gradational lower contact with lag at base of unidentifiable fossil debris (one crinoid columnal seen); fossils include: brachiopods, ribbed plates in fragments.

8 - 5.5-6 cm - Paola limestone - pale brown (5 YR 5/2) wackestone-mudstone; gradational lower contact; fossils include: crinoid columnals, opthalmids, and comminuted phylloid algal debris; gray stylolar horizon about 1 cm thick.

7 - 8 cm - Paola limestone - light brownish gray (5 YR 6/1) phylloid algal wackestone; gradational lower contact; fossils include: cominuted and bladed phylloid algal blades (including reproductive bulges?), rare fusulinids, rare opthalmids, fenestrate bryozoans, and a possible ostracode; small area of spar filled porosity; also incorporated are dark greenish gray (5 GY 4/1) mud clasts--irregular, squashed margins up to 1 by 6 cm--flat with clotted texture.



Locality: WM10

Core from Missouri Geological Survey

Location: SE SE Sec.4, T59N, R34W

Andrew County, Missouri

Measured by: T. Olszewski, 9/15/93

Remarks: Measured interval--400 to 425 ft. depth

Description

Bed No.

6- 112 cm -Raytown limestone-gray to grayish black (N3-N6) argillaceous mudstone; slow fizz suggests dolomitization; very gradational lower contact; fossils are sparse but are in distinct but poorly defined layers; fossils include: ramose and fenestrate bryozoans, brachiopod valves, and rare crinoid particles.

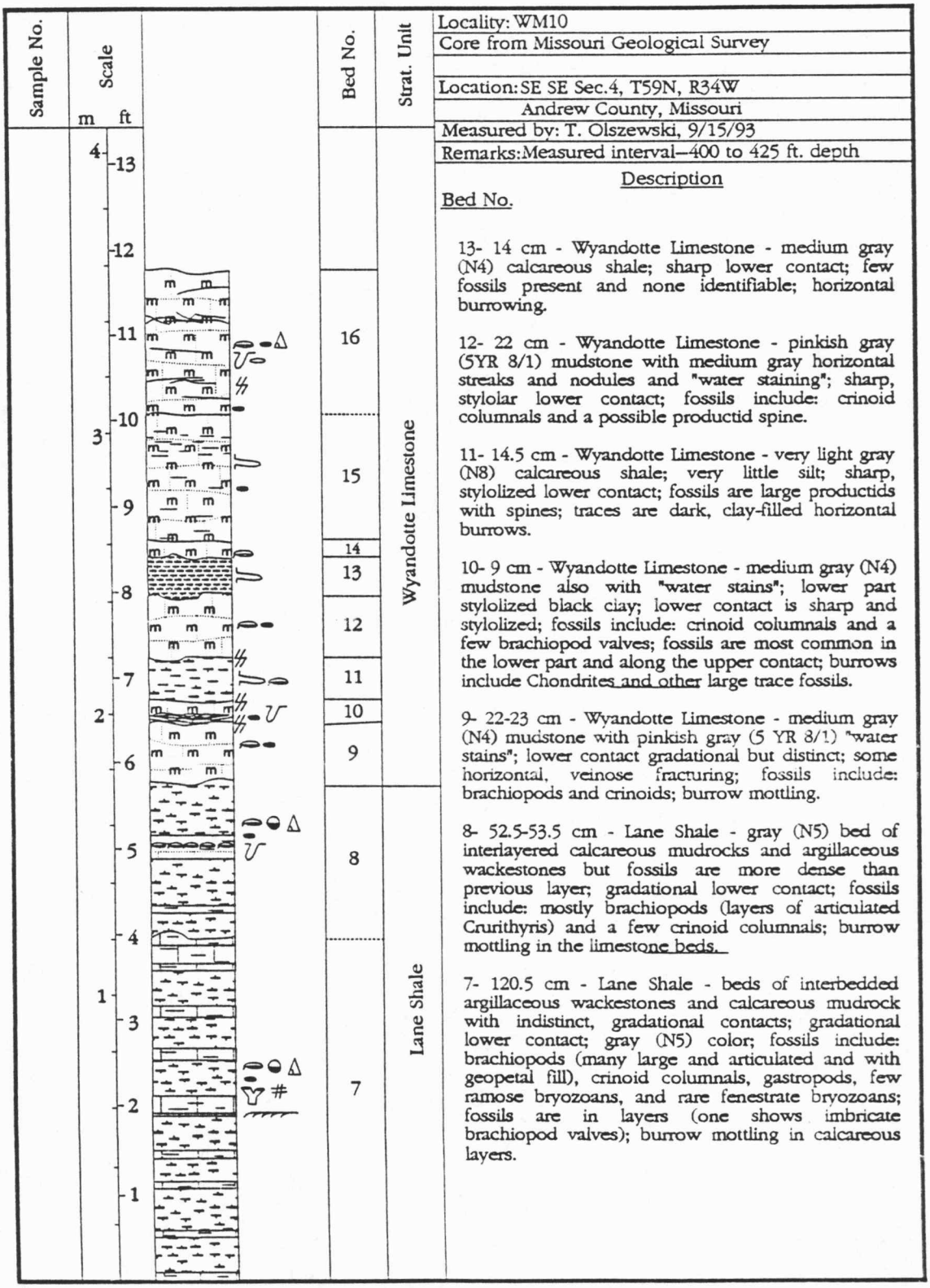
5- 101 cm -Muncie Creek shale-grayish black (N3-N2) calcareous fissile shale; sharp lower contact; fossils are sparse but include lingulid(?) fragments; there are fossil packstones in the lowest 14 cm and in layers which are about 1 cm thick and occur about every 25 cm; packstones are lags and show a lot of fragmentation; fossil include chonetids, fenestrate bryozoans, rare ramose bryozoans, and other, larger brachiopod molds; fizzes and smells fetid under HCl.

4- 40 cm -Paola limestone - gray (N5) argillaceous mudstone; gradational lower contact; irregular, diffuse carbonate cemented layers; fossils include brachiopods, fenestrate bryozoans, and crinoid fragments (they are more abundant than in Bed 3); distinct burrow mottling; fizzes and smells fetid under HCl.

3- 52 cm -Chanute Shale-medium gray (N4) calcareous mudrock; gradational lower contact; carbonate cemetation in irregular, diffuse layers and filling articulated brachiopod valves; fossils include: Crurithyris (articulated and in layers), other brachiopods, crinoid columnals, and fenestrate bryozoans; faint burrow mottling; fizzes and smells fetid under HCl.

2- 18 cm -Chanute Shale-very dark gray fissile shale; gradational lower contact; upper and lower third of the bed contain indistinct calcareous nodules; fossils include: Crurithyris at the bottom (abundant and articulated), and other articulated brachiopods; pyrite-stained trace fossils (?); fizzes and smells fetid under HCl.

1- >87 cm -Chanute Shale - bed starts at the 424.9 ft depth mark; medium dark gray (N4) argillaceous wackestone with grayish black (N2) clay partings (packstone texture); carbonate beds burrow mottled; fossils include: crinoid columnals, fenestrate bryozoans, and brachiopod valves (few, >2 cm across, articulated, near top of bed); pyritization of some bioclasts; fizzes and smells fetid under HCl.



Locality: WM10
Core from Missouri Geological Survey

Location: SE SE Sec.4, T59N, R34W
Andrew County, Missouri
Measured by: T. Olszewski, 9/15/93
Remarks: Measured interval—400 to 425 ft. depth

Description

Bed No.

13- 14 cm - Wyandotte Limestone - medium gray (N4) calcareous shale; sharp lower contact; few fossils present and none identifiable; horizontal burrowing.

12- 22 cm - Wyandotte Limestone - pinkish gray (5YR 8/1) mudstone with medium gray horizontal streaks and nodules and "water staining"; sharp, stylolar lower contact; fossils include: crinoid columnals and a possible productid spine.

11- 14.5 cm - Wyandotte Limestone - very light gray (N8) calcareous shale; very little silt; sharp, stylolized lower contact; fossils are large productids with spines; traces are dark, clay-filled horizontal burrows.

10- 9 cm - Wyandotte Limestone - medium gray (N4) mudstone also with "water stains"; lower part stylolized black clay; lower contact is sharp and stylolized; fossils include: crinoid columnals and a few brachiopod valves; fossils are most common in the lower part and along the upper contact; burrows include Chondrites and other large trace fossils.

9- 22-23 cm - Wyandotte Limestone - medium gray (N4) mudstone with pinkish gray (5 YR 8/1) "water stains"; lower contact gradational but distinct; some horizontal, veinose fracturing; fossils include: brachiopods and crinoids; burrow mottling.

8- 52.5-53.5 cm - Lane Shale - gray (N5) bed of interlayered calcareous mudrocks and argillaceous wackestones but fossils are more dense than previous layer; gradational lower contact; fossils include: mostly brachiopods (layers of articulated Crurithyris) and a few crinoid columnals; burrow mottling in the limestone beds.

7- 120.5 cm - Lane Shale - beds of interbedded argillaceous wackestones and calcareous mudrock with indistinct, gradational contacts; gradational lower contact; gray (N5) color; fossils include: brachiopods (many large and articulated and with geopetal fill), crinoid columnals, gastropods, few ramose bryozoans, and rare fenestrate bryozoans; fossils are in layers (one shows imbricate brachiopod valves); burrow mottling in calcareous layers.

WM10 , SE SE Sec. 4, T59N, R34S, Andrew County, Missouri

Bed 16 - >50 cm - Wyandotte Limestone - yellowish gray (5 Y 8/1) stylonodular mudstone with olive medium light gray mudrock partings; gradational lower contact; stylolites decrease in number from bottom to top; crinoids at base in mudrock partings; fossils in the carboante include: brachiopod valves, crinoid columnals, and gastrpods; the bed is peloidal and has mudrock-filled burrows.

Bed 15 - 44.5 cm - Wyandotte Limestone - medium dark gray (N4) to light brownish gray (5 YR 6/1) calcareous shale; sharp lower contact; horizontal burrows; fossils include possible crinoidal debris, but poorly preserved; clay rich layers 13 cm and 4 cm below top.

Bed 14 - 6 cm - Wyandotte Limestone - medium gray (N4) mudstone; sharp lower contact; "water stained" horizontal burrows; comminuted fossil debris at base (mostly brachiopods).

APPENDIX 3
MICROSCOPIC DESCRIPTIONS OF ACETATE PEELS

Explanation

Letter code refers to measured section
Number following letter code refers to bed number
rare equals less than 2% of grains
sparse refers to less than 5% of rock
percentages refer to percent of grains, not volume of rock

AGQ-12-intrasparrudite

matrix--coarse mosaic of ferroan dolomite (baroque?) replacing a blocky, equant, ferroan calcite cement and ferroan calcite bioclasts; calcite cement does not truncate bioclasts; some stylolitization; in some areas allochems have isopachous rind of ferroan dolomite cement between themselves and a mass of equant, non-ferroan dolomite cement

allochems--within the calcite patches; many retain isopachous cement rind

intraclasts--brecciated; ferroan calcite micrite

calcispheres

brachiopods--fragments; productid spines

bryozoans--ramose fragments; encrusters

echinoderm particles--rare

foraminiferids--opthalmid

peloids--poorly defined boundaries; patches of micrite often in contact with one another

AGQ-17-packed biomicrite

matrix--non-ferroan calcite with some opaque grains--pervasive neomorphism

allochems--

brachiopods--geopetal with spiralia preserved (and isopachous rinds in inside); many large fragments

foraminiferids--opthalmids(?)-large variety

phylloid algae--coarse, crystalline calcite replacement cement; some shelter porosity

echinoid spine

AGQ-18-intrabiorudsparite

matrix--coarse calcite, free of opaque detritus with fine calcite rinds around clasts, these rinds are bladed to blocky, isopachous, non-ferroan calcite mixed with ferroan dolomite

allochems--

brachiopods--productid spines and shell fragments

ovoid peloids

bryozoans

phylloid algae--very thin non-ferroan sparry replacement; individual blades are probably uncollapsed, but a few micrite envelopes are broken; opthalmid encrusters on some blades

intraclasts--minor brecciation; non-ferroan calcite micrite; incorporate--opthalmid foraminiferids, peloids, and other anomalous foraminiferids

AGQ-20-oobiosparite

matrix--ferroan calcite: ranges from coarse to microsparite; ferroan dolomite (<10%): some replacement, some void filling

allochems--

phylloid algae or molluscs--neomorphosed with coarse calcite spar

gastropod--fragment

ooid ghosts--some cracked

bryozoans--mostly encrusting; few fenestrate fragments

brachiopods--rare

micritized bioclasts

AGQ-22-biointrasparrudite

matrix--late stage ferroan dolomite, fine spar; coarse, blocky, non-ferroan dolomitic cement with less coarse rims around some intraclasts

allochems--

intraclasts--ferroan calcite mictrite; sometimes with crisp boundaries (suggests fills of phylloid algal blades); poorly sorted and not well rounded but definitely transported

peloids--poorly defined; part of matrix fill between intraclasts

bioclasts include--foraminiferids, echinoderms, fenestrate bryozoans, neomorphosed phylloid algae

geopetal (object not identifiable)--interior lined with isopachous cement

AGQ-23-intrasparrudite

matrix--clean dolomitic spar filling shelter pores; isopachous around intraclasts where late stage ferroan dolomite cement occurs; no destructive contacts with allochems

allochems--

intraclasts--rounded; ferroan calcite micrite; some with disseminated opaque grains

echinoid spine

brachiopod--geodiferous

peloids--densely packed and well sorted

BRD-2-calcareous shale with biopackstone texture

matrix--coarse, equant sparry cement in a geodiferous brachiopod; ferroan dolomite in bryozoan pores

allochems--grains crushed; edges corroded; overpacked

brachiopods--30%; disarticulated; fragmented; spines; many are micritized all the way around the margin and are bored

fusulinids--30%; crushed during compaction

bryozoans--10%; ramose, fenestrate, and encrusting

ostracodes--5%; partly filled with dolomite rhombs

echinoderms--15%; crinoid debris

opthalmids

"osagiid" coated grains--on brachiopods and bryozoans

red algal fragment(?) with internal structure preserved

gastropod

BRD-3-sparse biomicrite

matrix--ferroan calcite microspar; uniformly dispersed euhedral dolomite rhombs

allochems--

fusulinids--25%

gastropods--20%

brachiopods--25%

"osagiids"--20%; replaced by ferroan dolomite spar (xenotopic)

echinoderms--10%; crinoid and echinoid

calcispheres

ostracodes

bryozoans--encrusting

opthalmids

BRD-4-packed biomicrite

matrix--ferroan calcite microspar; uniformly dispersed, fine, euhedral, ferroan dolomite rhombs (idiotopic even when >90% dolomite, dolomite content increases upward through bed)

allochems--

echinoderms--25%; crinoid; some partly replaced by dolomite rhombs

brachiopods--75%; fragments

bryozoans

BRD-7-sparse biomicrite

matrix--ferroan calcite microspar; 40% fine, euhedral dolomite rhombs (uniformly dispersed); isopachous calcite rims in coral partitions

allochems--

brachiopods--60%; fragments
ostracodes
bryozoans--fenestrate
crinoids--40%; some articulated columnals
rugosan coral

BRD-8-packed biomicrite

matrix--ferroan calcite microspar; patches of uniformly dispersed, fine rhombs of ferroan dolomite (>50% in places); geopetal between two crinoid columnals filled with murky syntaxial cement

allochems--diversity and abundance increase upward

crinoids--60%; dominant in lower half
brachiopods--30%; fragments and spines
gastropods
"osagiid" coated grains--10%; in upper part of bed
opthalmid
red algae(?)
echinoid spine
bryozoan

BRD-10-biomicrite

matrix--ferroan and non-ferroan calcite microspar with strings of fine dolomite rhombs associated with horsehair stylolites; pelloidal texture (especially in upper half); fibrous, isopachous cements inside ostracodes

allochems--

bryozoans--fenestrate, ramose, and encrusting (on an intraclast?)
echinoderms
brachiopods--geopetals; spines
ostracodes
a biocoated grain
phylloid algae--many blades; replaced by coarse spar; common in peloidal areas where it occurs in fragments
opthalmids--in shelter voids

BRD-11-packed biomicrite to biosparite
matrix--ferroan and non-ferroan calcite microspar; fine dolomite crystals (an- to subhedral)
allochems--well sorted fragmented bioclasts (coarse/very coarse sand sized)
brachiopods--40%; fragmented valves and productid spaines
phylloid algae(?)--30%; comminuted bits replaced by equant spar mosaic
echinoderms--15%
gastropods--few; high spired
bryozoans
opthalmids

BRD-12-sparse biodolomicrite
matrix--ferroan dolomitic microspar with dispersed, fine-grained euhedral rhombs
allochems--bioclastic fragments with corroded margins
bryozoans
crinoids
brachiopods--fragments and productid spines

BRD-13-packed biomicrite to sparite
matrix--non-ferroan calcite microspar; dolomite: few dispersed rhombs but mostly filling inter- and intraparticle spaces, 10-20%; one patch is 100% dolomitized (very fine xenotopic)
allochems--mostly quite faint
phylloid algal chips
bryozoans
"osagiids"
opthalmids
brachiopods
echinoderms

BRD-14-biodismicrite
matrix--heavily recrystallized; fine calcite spar texture; ferroan dolomite 10-20%; particle replacement
allochems--
phylloid algae(?)--maybe molluscan--micrite envelopes and recrystallization
brachiopods--fragments
echinoderms--fragments
peloids(?)

BRD-15-sparse to packed biomicrite
matrix--some horsehair stylolitization near bottom of bed; ferroan calcite microspar; radial isopachous cement in ostracodes; bioturbation
allochems--
brachiopod--90%; fragments and spines
ostracodes
bryozoans--ramose
echinoid spines--and other echinoderm debris
near base--crinoids, fusulinids
very plastic mudclasts

BRD-16-argillaceous packed biomicrite
matrix--opaque grains; horsehair stylolitization; overpacked; well-sorted
allochems--
brachiopods--spines and fragments
bryozoan--ramose
oncoids

CGM-2-sparse biomicrite
matrix--ferroan calcite microspar; opaque grains; sub- to anhedral dolomite crystals (20-30 μm across) but do not cut any allochems; suggestion of peloidal texture; few patches of ferroan dolomite cement
allochems--
phylloid algal blades--85%; fragmented and neomorphosed; some encrusted by bryozoans
calcispheres
brachiopods--fragments and spines
echinoderm fragments--13%; only in upper half of bed
fusulinids
bryozoans
ostracodes
geopetal bivlave(?)

CGM-3-packed biomicrite
matrix--ferroan calcite microspar with patches inverted to ferroan dolomite (anhedral crystal and patches); stylonodular band on the middle of the bed
allochems--near stylolized areas: slight interpenetration and dissolved edges
brachiopods--15%; valve fragments
echinoderms--70%; crinoid fragments
phylloid algae--5%; recrystallized
fusulinid--5%

CGM-4-sparse biomicrite

matrix--ferroan calcite microspar (xenotopic) with dispersed porphyrotopic dolomite; some larger patches of ferroan dolomite and distinct areas of coarser calcite; void filling isopachous cement

allochems--

calcispheres--lined with isopachous bladed cements
echinoderms--echinoids(?)
brachiopods--fragmented and one geodiferous
fusulinids
bryozoan--encrusting a brachiopod valve

CGM-5-Paola-Muncie Creek Contact-sparse biomicrite

matrix--ferroan calcite with ghosts of fossil fragments (brachiopods, ramose (?) bryozoans, crinoid fragments, and some calcispheres), contains irregular blebs of ferroan dolomite with corrosive margins recrystallizing the calcite matrix and may be replacing bioclasts

contact--sharp and stylolized full of crinoid fragments and fusulinids

CGM-7-Muncie Creek-Raytown Contact-sparse dismicrite

matrix--full of opaque grains and ferroan dolomite rhombs and coarse ferroan dolomite spar as well

allochems--corroded margins

crinoid fragments-95%
echinoid spine
brachiopod fragments

contact--sharp, emphasized by dolomitization

CGM-9-packed biomicrite

matrix--ferroan calcite/dolomite microspar (some areas >75% dolomite rhombs); void filling isopachous, bladed/acicular rinds

allochems--

phylliod algal blades--80%; neomorphosed; micrite envelopes
dolomitized crinoid/bryozoan ball with "osagiid"(?) encruster on top
bryozoans--5%; fenestrate and ramose
calcispheres
ostracode
echinoderms--3%
brachiopods--10%

CGM-10-biointrasparrudite

matrix--very coarse calcite (hypidiotopic) with some non-ferroan euhedral dolomite rhombs and ferroan dolomite inversion; fibrous, isopachous cements (coarser on interior of voids); exterior rinds equant to bladed

allochems--resembles a boundstone of phylloid algae with shelter porosity and wacke/packstone geopetal fill; large micritized spheres (ooids?)

phylloid algae--fragmented; micrite envelopes

bryozoans--encrusters

opthalmid

brachiopods--articulated

CGM-11-biointrarudsparite

matrix--hypidiotopic/xenotopic calcite spar; 20% of rock is coarse ferroan dolomite (baroque?); rims (sometimes spalled off) of isopachous, fibrous, calcite; micrite pre- and post- isopachous cement

allochems--

intraclasts--sparse micrite; mostly contain calcispheres and ghosts of other bioclasts; fractured and veined (post isopachous cement rims); corroded edges

micritized ooids--65%; internal structure recrystallized but very well sorted, spherical, and some retain ghosts of concentric structure

bryozoans--10%; fenestrate, ramose, and encrusting

brachiopods--15%; valve and spine fragments

echinoderms--5%

phylloid algal molds--5%

CGM-12-sparite

matrix--twinned, hypidiotopic coarse equant calcite spar; ferroan dolomite replacement; xenotopic finer calcite cement (hints of isopachous fibrous cements on rare bioclasts)

allochems--very rare; all fragmented and micritized

echinoderms

brachiopods

spherical peloids (neomorphosed ooids?)

intraclasts

CGM-13-biointrasparite

matrix--equant calcite spar; 20-25% euhedral ferroan dolomite rhombs

allochems--mostly fragmented

brachiopods--fragmented

phylloid algae--90%; fragments; micrite envelopes; isopachous lining inside and out

sperical peloids (ooids?)--5%; overpressure compacted

intraclasts--opaque-ridden ferroan calcite with bioclast ghosts and isopachous rinds

crinoid columnal

macroscopically--geopetal brachiopods and phylloid algae creating shelter porosity (filled with cement)

CGM-14-biointrasparrudite

matrix--coarse, hypidiotopic calcite spar with finer isopachous rinds on clasts; micrite envelopes generally faint; 20% of rock is ferroan dolomite patches

allochems--

brachiopod geopetal

phylloid algae--90%; comminuted and fragmented with micrite envelopes

"intraclasts"--sharp lower boundaries; possibly in situ fill of phylloid algal cups

CGM-15-packed biopelmicrite

matrix--very complex; patches of medium calcite equant spar; other places have geopetal peloids; some fibrous rims away from peloids; dispersed and patchy rhombohedral, ferroan dolomite (up to 30% of sample)

allochems--

neomorphosed peloids

phylloid algae--micrite envelopes on blade fragments

brachiopods--rare

micritized ooids(?)-rare

CGM-16-packed biopelmicrite

matrix--peloidal, xenotopic, opaque-ridden fine calcite spar; peloids settled geopetally

allochems--

micritized ooids(?)--rare

phylloid algae--95%; largely comminuted but a few in situ blades

brachiopods--geopetal; isolated valves

CGM-18-packed biopelmicrite
matrix--peloidal, opaque-ridden fine calcite spar; >10% ferroan dolomite rhombs
allochems--
phylloid algae--90%; comminuted
micritized ooids(?)
few small intraclasts of peloidal material

CGM-19-packed pelmicrite
matrix--ferroan calcite microspar; 15% ferroan dolomite rhombs
allochems--
peloids-->90%; poorly defined boundaries
phylloid algae--comminuted and neomorphosed
ostracodes
brachiopods--rare

CGM-21-packed intrapelmicrite
matrix--ferroan calcite microspar; 10-20% ferroan dolomite spar
allochems--
brecciated intraclasts--identical to peloidal matrix
peloids--95%; poorly defined margins
echinoderms--rare
brachiopods--rare; geodiferous

CGM-22-dismicrite
matrix--ferroan calcite micro to fine equant spar; 20-30% coarse ferroan dolomite
allochems--very sparse
geopetal brachiopod
bioclast ghosts
intraclasts--brecciated

CGM-23-micrite
matrix--ferroan calcite peloidal microsparite; ferroan dolomite rhombs in patches and scattered
allochems--
bioclast ghosts
brachiopod--crushed, geodiferous; other fragments
echinoderms--suggestion of echinoids and crinoids; hints of syntaxial cement
pseudointraclasts--due to in place brecciation
trilobite(?)

CGM-28-sparse dolobiomicrite
matrix--100% micritic ferroan dolomite
allochems--many pyritized
echinoderms--70%; irregular, corroded margins; echinoids and crinoids
brachiopods--20%; articulated and filled with micrite; some geodiferous; fragments and spines
bryozoans--ramose and fenestrate
"osagiids"--covering bryozoans
ostracode
trilobite(?)--articulated

CGM-29-argillaceous packed biomicrite
matrix--calcareous mudrock with a lot of ferroan calcite
allochems--fragmented and disarticulated; many are "osagiid" coated on all sides; densely packed and interpenetrative overpacking
echinoderms--60%; mostly crinoids; some echinoids
brachiopods--20%; fragmented; geopetals
bryozoans--10%; fenestrate and ramose
coral--solitary rugosan
foraminiferids
gastropod--small
trilobite

CGM-Base of Wyandotte Cycle-oncoidal micrite
matrix--non-ferroan microspar matrix with large amount of opaque grains
bedding--dual contact--lower one is sharp and has a lck of fossils and is 1 to 1.5 cm below the next one--upper one is more gradational and has fewer opaque grains and marks start of fossils
allochems--most biotically encrusted
bryozoans--ramose and pyritized, only non-encrusted particles
oncoids--made of ferroan calcite and are structureless, coating is even on all sides--they coat: fenestrate bryozoans, brachiopod fragments, crinoid fragments
the foraminiferid component is opthalmid(?) ferroan calcite

HDB-4-sparse biomicrite
matrix--ferroan calcite micrite with dispersed, dolomite rhombs and disseminated opaque grains
allochems--virtually all fragmented or abraded
calcispheres
brachiopods--disarticulated, lined with bladed, isopachous cement pre-dating further micrite fill
foraminiferids--fusulinids and opthalmid encrusters
bryozoans--ramose fragments
upper surface--
packstone--lots of opaque grains
much larger bioclasts (ramose bryozoans, crinoid debris, "osagiid")

HDB-11-packed biomicrite
lower half--
matrix--ferroan and non-ferroan calcite micrite; disseminated opaque material
allochems--coated with opthalmid encrusters or "osagiids"; borings rare
echinoderms--fragments; some abraded
bryozoans--fragmented
foraminiferids--fusulinids; opthalmids
gastropods
ostracodes
upper half--gradual transition from lower half
matrix--ferroan and non-ferroan calcite micrite; less opaque grains and slightly more bioclastic material
allochems--
bryozoans--fenestrate; some opthalmid encrusted
phylloid algal blades--some filled with ferroan dolomite
geopetal gastropods
brachiopods--disarticulated valves

HDB-13-heterogeneous rock--cross-laminated biocalcarenite in patches with micrite in others
matrix--non-ferroan calcite with microspar patches; microspar in "streaks" and only in certain areas ("osagiid" ghosts); isopachous fill in some ostracodes;
cross-laminations--well-sorted fine-sand sized comminuted brachiopods and some calcispheres; patches of blocky microspar; lower contact is irregular
allochems--
foraminiferids--opthalmids
bryzoans--possible fragments
lot of ghosts of bioclasts
phylloid algal blades--molded to upper surface of ripples

HDB-14-heterogeneous rock; cross-laminated biocalcarenite in patches with micrite in other places
matrix--ferroan and non-ferroan calcite micrite
allochems--
phylloid algae--neomorphosed but filled geopetally with non-ferroan micrite while they sit in ferroan, laminated micrite
bryozoans--encrusting and fenestrate
brachiopods--shell fragments
foraminiferids
lots of neomorphosed material
some patches of comminuted fossil material make up the calcarenitic layers which are overlain by algae and were deformed as soft-sediment

HDB-15-sparse biomicrite
2 types of texture
1) wackestone--ferroan calcite microspar matrix; well sorted; cross-laminated; coarser bioclastic zones directly overlie mudstone (type 2 texture); possibly peloidal
allochems--
phylloid algal material--45%; comminuted
bryozoan debris--45%; comminuted
ostracode
echinoderms--10%; fragments
2)mudstone--non-ferroan calcite micrite; vaguely burrow mottled; overlies and fills phylloid algal blade which, in turn, overlies coarse ferroan calcite.
allochems--
phylloid algae--90%; comminuted; recrystallized; show rhizomes and micrite filled partings

HDB-17-packed biomicrite
matrix--ferroan calcite micospar with lots of opaque grains
allochems--
crinoid particles
brachiopods--fragmented and lots of productid spines
bryozoans--few ramose fragments
gastropods--geopetal fill
opthalmid foraminiferids
phylloid algal blade--calcite spar replaced
intraclast--ferroan calcite, contains brachiopod with void filling isopachous cement, margins defined by recrystallized phylloid algal blades

HDB-18-sparse biomicrite
matrix--ferroan calcite microspar; 30% dispersed dolomite rhombs; distinctly burrowed texture (mottling on scale of 0.5 cm)
allochems--
bryozoans--85%; fenestrate and encrusting
brachiopods--10%; fragmented
echinoderms--<5%
ostracodes

HDB-18-packed biomicrudite-from top of bed
matrix--ferroan calcite microspar, dispersed opaque grains, and a few dolomite rhombs, overall, a very compressed appearance with many stylolized boundaries between grains and a few bioturbation "swirls", overpacked
allochems--
brachiopods--90%; all fragments; many productid spines
bryozoans--few ramose types
echinoderm fragment--possibly

HDE-1=HDB-15-packed biomicrite
matrix--ferroan calcite microspar; <5% non-ferroan dolomite rhombs dispersed throughout; filling shelter voids: wackestone of algal fragments, brachiopod fragments, and foraminiferids
allochems--largely comminuted; well sorted fine sand sized
phylloid algae--recrystallized; bryozoan encrusters; rhizomes preserved(?)
algal ghosts
bryozoans--fenestrate
crinoid fragments
brachiopods--productid spines
ostracode--isopachous cement lining

HDE-2=HDB-16-dismicrite
matrix--ferroan micritic calcite; >5% dispersed, small dolomite rhombs (>silt-sized)
allochems--coarse sand sized
brachiopods--40%; fragments and spines; wide variety of types
bryozoans--30%; fragments; encrusters on brachiopods and algal blades
phylloid algae--20%; recrystallized
crinoid material--10%
recrystallized gastropod
disarticulated ostracodes

IVE-1-dolomitic intrasparite

matrix--coarse, crystalline ferroan dolomite matrix (baroque dolomite?)

allochems--within the matrix bioclasts are badly neomorphosed and corroded

brachiopods--productid spines and articulated valves

echinoderm plate

intraclasts--ferroan calcite micrite with corroded margins, one is breccia fractured with calcite spar fill, contain neomorphosed bioclasts (phylloid algal chips, opthalmid encruster)

IVE-2-intrasparrudite

matrix--very coarse calcite spar with minor ferroan dolomitization

allochems--

ferroan calcite intraclasts floating in coarse spar bounded by stylolitic margins; made up of micro- and pseudospar with coarse spar veins and ghosts of bioclasts

bioclasts include: productid spines, brachiopod fragments with isopachous fringe, recrystallized algal fragments; foraminiferids, bryozoan fragments

IVE-9-packed biomicrite

matrix--non-ferroan calcite micrite

allochems--sorted from very coarse sand to granule sized particles; >90% have been neomorphosed to blocky, equant spar (shape suggests phylloid algae)

ostracode(?)

opthalmid foraminiferid

ramose bryozoan fragment(?)

a geopetal in a neomorphosed structure

LF-1-intrasparite

matrix--very coarse calcite(?) spar with hints of long radial fibrous structure which has been neomorphosed

allochems--

intraclasts--ferroan calcite micrite; brecciated; stylolitic boundaries; contain: calcispheres or ostracodes and fenestrate bryozoans

brachiopods--fragments and spines

LF-2-packed biomicrite

matrix--ferroan calcite micrite; sparry, equant calcite cement in shelter pores and neomorphosed bioclasts; isopachous rims lining pores; geopetals in some voids; <2% dolomite in spar; some opaque grains in micrite

allochems--

phylloid algae--75%; comminuted and recrystallized; bryozoan encrusted

bryozoans--20%; fenestrate and encrusting

ostracodes--some articulated

brachiopods--some disarticulated; geopetals; few spiralia preserved; cement splinters valves in a few cases

"osagiid"(?)--a complex foliated mass

OSAN-5&6-samples from top of Paola-Intrasparite

matrix--coarse, equant dolomite, less than 90% of rock in places

white clay in pockets

allochems--

intraclasts--brecciated, ferroan calcite micrite, contain ghosts of bioclasts and peloids (like micritized calcarenite)

bioclasts-brachiopod fragments, fusulinids, bryozoans, other foraminiferids

may be brecciated in place

OSAN2-8=OSAN2-12-intrasparrudite

matrix--coarse, clean, blocky, equant, dolomitic (baroque?) spar

allochems--

peloids--possibly neomorphosed ooids; poorly defined recrystallized boundaries

coated grain?--bored?

brachiopods--fragments, very small; few productid spines; few articulated with internal, isopachous rind

bryozoans--fenestrate; encruster on mold of an algal blade

intraclasts--ferroan calcite; poorly defined boundaries; contain pelloids and replaced bioclasts; brecciated

phylloid algae?--defined by micrite envelopes; entirely recrystallized; only fragments in intraclasts

pelecypod--recrystallized, geopetal, articulated

foraminiferids--opthalmid(?) encruster on an algal blade

RCT-1a-intrasparrudite

matrix--blocky, equant calcite spar; faint, finer-grained, blocky, ferroan dolomite cements preserved as isopachous rims around some clasts

allochems--

intraclasts--ferroan calcite micrite; homogeneous; rounded to angular; contain peloids, foraminiferids(?), and ramose bryozoans; minor brecciation cracks in a few clasts

RCT-2b-intrasparrudite

matrix--coarse, equant dolomite crytals--less coarse, ferroan dolomite on contact with calcite intraclasts

allochems--

bryozoans--rare, fenestrate

peloids(?)

intraclasts--ferroan calcite, micritc and brecciated, ghosts of bioclasts internally

RQ-6-sparse biodolomicrite

matrix--ferroan calcite micrite; peloidal; 30-40% dolomite in fine rhombs; minor silicification(?) of brachiopods

allochems--

brachiopods--40%; disarticulated and fragmented; often crushed; spines; few geopetals with isopachous internal rinds

ostracodes--40%; often articulated

micritized ooids(?)--<5%

bryozoans--20%; fenestrate hash

RR-2-packed biomicrite

matrix--ferroan calcite microspar with amorphous, crystalline, ferroan dolomite in matrix and often replacing allochems

minor pressure solution seams-no interpenetration

lots of disseminated, opaque grains

allochems--many larger grains have corroded margins

echinoderms--primarily disarticulated crinoids

brachiopods--fragmented; productid spines, often outer wall preserved

bryozoans--fragmented; ramose and encrusting

forminifera--abraded fusulinids; opthalmid encrusters

ostracode--disarticulated; sediment filled

quartz sand grains--10% of allochems; well sorted, sub-angular, very fine

"osagiid"(?)--<3mm thick on a brachiopod spine;

RR-4c-barely fossiliferous micrite

matrix--ferroan calcite microspar

in burrows--dense accumulations of dolomite micro-rhombs--opaque material defines menisci in places

two generations of cement filling molds-- isopachous calcite(?) and equant ferroan dolomite core

allochems--all less than 3mm

crinoids--micritized

brachiopods--fragments and productid spines

gastropods--thin shelled, partly micrite filled

bryozoans--fenestrate

foraminiferids--fusulinids

phylloid algal fragments(?)--entirely neomorphosed

"osagiid" clasts--one coats a rugosan coral--include foraminiferids, algae, and a bryozoan--thicker on up side than down with bulbous upward protrusion

WM4-2-biopelsparite

matrix--ferroan calcite microspar; some horizons of opaque grains with crinoids and brachiopod fragments and free of peloids; burrow swirls; no spar in upper half

allochems--

peloids--70%

ostracodes--25%

brachiopods--5%; fragments

WM4-7-biopelsparite

matrix--equant ferroan calcite microspar; isolated dolomite rhombs; root trace?--baroque, ferroan dolomite with ragged adges

allochems--

ostracodes

echinoderms--crinoids with syntaxial(?) cement; echinoid spines

miliolid-like foraminiferids

bivalve--fragment; replaced

peloids-->50%

WM4-11-biopelsparite
matrix--equant, ferroan calcite fine spar; disseminated dolomite rhombs
allochems--very comminuted and fragmented
peloids-->50%
brachiopods--fragments and spines; some bored
green algal fragment
fusulinid
quartz silt grains
ostracodes
echinoderms

WM4-12-dolomicrite
matrix--ferroan dolomicrospar with fenestrae; fenestrae filled with coarse equant spar
allochems--
ostracode
brachiopods--fragments and spines
replaced rectangular void--evaporite mold(?)

WM4-13-packed fusulinid biomicrite
matrix--ferroan dolomite microspar with disseminate opaque grains; equant calcite spar cement in fusulinid chambers; isopachous blades in a productid spine and in a split brachiopod valve
allochems--interpenetrative overpacking
fusulinids--90%
brachiopods--valves frgaments and spines
echinoid spines
crinoid columnals
green algae--Epimastopora(?)
sub-bed--pelsparite
matrix--equant ferroan dolomite cement
allochems--well sorted; minor stylolitization
peloids--75%; ferroan calcite
quartz silt--10%
bioclasts--15%; include crinoid columnals; mollusc shell molds; ostracodes

WM4-17-biopelmicrosparite

matrix--very recrystallized ferroan calcite microspar; isolated, tiny dolomite rhombs (also disseminated and in clumps); some sharply defined layers of calcite spar under and over dolomicrospar

allochems--many with "osagiid"(?) coatings; overpacked near top in a ferroan dolomitic layer with lots of opaques
gastropods
crinoids
foraminiferids--fusulinids and other types
brachiopods--fragments and spines; many with bladed, isopachous rinds
echinoid spines--with syntaxial overgrowths

WM4-21-dolomicrite

matrix--ferroan dolomitic microspar; sometimes laminations are visible; possible neomorphosed peloidal clotting; fenestrae and root traces filled with coarse ferroan dolomite spar; coarser, bioclastic ferroan dolomitic, equant spar in biosparite layers; spalling cracks along laminations--dessication features

allochems--in layers of fragmented debris
ostracodes-20%
opthalmid foraminiferids--40%
brachiopods(?)--30%; fragments and spines
gastropods and bivlaves--recrystallized and geopetal
echinoderms--fragments and spines
"osagiid"(?)--few biocoated grains; one on a piece of green algae
intraclasts--few; silt-sized
peloids-->50%

WM5-8-fossiliferous micrite

matrix--ferroan dolomitic microspar; lots of opaque grains; burrow swirls and layers of allochems

allochems--fragmented down to silt size
brachiopods--80%; valves and spines
echinoderms--20%; crinoids and echinoids
lotta microfragments
bryozoans--encrusters and ramose
ostracodes
trilobite

WM5-11-biopelsparite
matrix--ferroan calcite microspar; overcompaction in stylolized areas
allochems--
Epimastopora(?)
miliolid-like foraminiferids
peloids--75%
"osagiids"(?)--definitely granule-sized oncoids, probably "osagia"; cover >50% of bioclasts
echinoderms--crinoids and echinoids
fusulinids
brachiopods--few spines
ostracodes

WM8-6-sparse biomicrite
matrix--non-ferroan dolomitic microspar; disseminated opaque grains; tiny isopachous rinds in a few productid spines
allochems--overpacked with corroded margins
echinoderms--65%; crinoids and a few echinoid spines
brachiopods--30%; fragments and spines
gastropods--5%
ostracodes
ramose bryozoan

WM8-7-biopelsparite
matrix--ferroan dolomite equant spar; non-ferroan calcite or dolomite isopachous rind on allochems; microspar burrow fills
allochems--
peloids--50%; ferroan calcite
brachiopods--25%; productid spines (one with borings); geopetal peloidal fillings
echinoderms--25%; crinoid and echinoid
bryozoans--encrusters on productid spines; ramose and fenestrate
gastropod
ostracodes
calcispheres

WM8-8-sparse biomicrite
matrix--ferroan calcite microspar with dolomite rhombs; sparse opaque grains; isopachous fringes on inside and outside of some allochems
allochems--corroded margins
brachiopods--99%; fragments and spines; one articulated with spiralia
echinoderms
ramose bryozoan

WM8-9-biomicrite

matrix--ferroan dolomitic microspar; disseminated opaques; isopachous cements on inside and outside

allochems--

brachiopods--95%; fragments and spines

bryozoans--ramose

echinoderms

replaced molluscan material--gastropod and pelecypod fragments

WM8-10-packed biomicrite

matrix--ferroan calcite microspar; lots of opaque grains; coarse, equant ferroan dolomite cement in voids

allochems--overpacked

brachiopods-99%; fragments and productid spines; layered in places and swirled (bioturbaion) in places

ramose bryozoan

WM8-12-sparse biomicrite

matrix--dolomitic microspar; lots of opaque grains; some isopachous rinds; equant ferroan dolomitic fill in brachiopod spines

allochems--

brachiopods--99%; fragments and productid spines

ostracodes

echinoderms

opthalmid encrusters--on brachiopod material

microgastropod

APPENDIX 4
WIRELINE LOG DATA

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth							
							Block-top		Iola-base		Iola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
14	11	31	SW	NW	SW	Wabaunsee	1726	526.08	1626	495.60	1567	477.62	1340	408.43
14	12	20	C	SE	SE	Wabaunsee	1516	462.08	1396	425.50	1340	408.43	1132	345.03
14	20	3		SE	SW	Douglas	296	90.22	252	76.81	235	71.63	118	35.97
14	21	1		NE	NE	Johnson	272	82.91	234	71.32	221	67.36	110	33.53
14	22	7	NE	NE	NE	Johnson	223	67.97	162	49.38	154	46.94	26	7.92
14	23	6	N/2	E/2	SW	Johnson	271	82.60	208	63.40	198	60.35	66	20.12
15	11	10	NW	SE	NE	Wabaunsee	1682	512.67	1645	501.40	1625	495.30	1545	470.92
15	12	7	N/2	SE	NW	Wabaunsee	1534	467.56	1495	455.68	1469	447.75	1398	426.11
15	18	35		S/2	SW	Franklin	578	176.17	537	163.68	507	154.53	427	130.15
15	20	1		NW	SE	Douglas	442	134.72	391	119.18	367	111.86	244	74.37
15	21	30	NE	NW	SW	Franklin	420	128.02	362	110.34	334	101.80	200	60.96
15	22	6	SE	SE	NW	Johnson	273	83.21	206	62.79	180	54.86	67	20.42
15	24	31	NW	SE	NW	Miami	144	43.89	76	23.16	65	19.81		
16	11	15	SW	SW	NE	Lyon	1548	471.83	1512	460.86	1439	438.61	1373	418.49
16	12	25	NE	SW	SW	Greenwood	833	253.90	788	240.18	730	222.50	626	190.80
16	16	23	NW	NE	NW	Osage	755	230.12	716	218.24	663	202.08	603	183.79
16	18	30	W/2	E/2	SE	Franklin	621	189.28	563	171.60	535	163.07	403	122.83
16	20	8	NE	SE	NE	Franklin	306	93.27	253	77.11	230	70.10	103	31.39
16	21	3	SW	NW	NW	Franklin	303	92.35	227	69.19	204	62.18	70	21.34
16	22	29			SW	Miami	283	86.26	223	67.97	204	62.18	62	18.90
17	11	13	NE	SE	NE	Lyon	1376	419.40	1319	402.03	1287	392.28	1227	373.99
17	12	7	C	SW	SW	Lyon	1398	426.11	1338	407.82	1301	396.54	1240	377.95
17	17	5	NE	SE	SE	Osage	536	163.37	480	146.30	448	136.55	378	115.21
17	18	15	SW	SW	SE	Franklin	445	135.64	392	119.48	364	110.95	202	61.57
17	19	14		SW	NW	Franklin	339	103.33	292	89.00	264	80.47	110	33.53
17	19	9		NW	SE	Franklin	332	101.19	278	84.73	250	76.20	103	31.39
17	20	1		NE	SE	Franklin	197	60.05	139	42.37	116	35.36	26	7.92
17	21	5	NE	SE	SW	Franklin	260	79.25	198	60.35	178	54.25	88	26.82
17	22	5		SE	SE	Miami	269	81.99	203	61.87	185	56.39	86	26.21
18	10	23	NW	SW	NW	Lyon	1550	472.44	1510	460.25	1466	446.84	1358	413.92
18	11	31	NE	NW	SE	Lyon	1430	435.86	1383	421.54	1340	408.43	1235	376.43
18	12	32	SE	SE	SE	Lyon	1243	378.87	1197	364.85	1158	352.96	1062	323.70
18	15	14	SE	NW	SE	Osage	830	252.98	783	238.66	745	227.08	640	195.07
18	17	9	NE	NE	NW	Osage	606	184.71	564	171.91	535	163.07	397	121.01

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth							
							Block-top		Iola-base		Iola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
18	18	16	SW	SW	SE	Franklin	618	188.37	578	176.17	546	166.42	469	142.95
18	20	34	SE	SE	SW	Franklin	314	95.71	241	73.46	220	67.06	54	16.46
18	20	13	SE	NW	SE	Franklin	289	88.09	220	67.06	199	60.66	121	36.88
18	21	6		SE	SE	Franklin	286	87.17	220	67.06	200	60.96	109	33.22
18	21	1	SE	SW	SW	Miami	197	60.05	127	38.71	108	32.92	19	5.79
19	10	23	NW	NW	SE	Lyon	1395	425.20	1362	415.14	1317	401.42	1202	366.37
19	12	2	NE	SW	NE	Lyon	1152	351.13	1112	338.94	1070	326.14	979	298.40
19	13	34	SE	NE	SE	Lyon	1015	309.37	974	296.88	912	277.98	825	251.46
19	14	1	SE	NE	SE	Coffey	906	276.15	860	262.13	813	247.80	729	222.20
19	15	5	NE	NE	NW	Coffey	903	275.23	863	263.04	820	249.94	733	223.42
19	17	34	NW	NW	NE	Coffey	631	192.33	592	180.44	556	169.47	438	133.50
19	18	31				Anderson	444	135.33	403	122.83	369	112.47	283	86.26
19	21	23	C	SW	NE	Linn	273	83.21	202	61.57	179	54.56	98	29.87
20	11	22	NE	NE	SW	Lyon	1325	403.86	1293	394.11	1233	375.82	1137	346.56
20	12	17	E/2	NE	SE	Lyon	1246	379.78	1209	368.50	1153	351.43	1065	324.61
20	13	2	NE	NE	NW	Coffey	974	296.88	947	288.65	890	271.27	812	247.50
20	14	6	SE	SE	SE	Coffey	914	278.59	873	266.09	817	249.02	740	225.55
20	15	8	NE	NE	NE	Coffey	870	265.18	823	250.85	767	233.78	721	219.76
20	16	5	NE	NE	NW	Coffey	812	247.50	776	236.52	735	224.03	657	200.25
20	17	14	SE	SE	NW	Anderson	619	188.67	576	175.56	532	162.15	468	142.65
20	18	5	SE	SW	SW	Anderson	376	114.60	335	102.11	296	90.22	215	65.53
20	18	7	SE	SE	SW	Anderson	392	119.48	347	105.77	309	94.18	242	73.76
20	19	8		SE	SE	Anderson	322	98.15	249	75.90	224	68.28		
20	19	21	NW	SW	SW	Anderson	298	90.83	233	71.02	207	63.09	91	27.74
20	20	13	NE	NE	SW	Anderson	235	71.63	174	53.04	148	45.11		
20	21	27		N/2	SW	Anderson	155	47.24	76	23.16	52	15.85		
21	11	24	NE	NE	NW	Lyon	1311	399.59	1288	392.58	1250	381.00	1148	349.91
21	11	25	NE	NW	NW	Lyon	1300	396.24	1273	388.01	1208	368.20	1126	343.20
21	12	25	NW	SE	SE	Lyon	1193	363.63	1153	351.43	1084	330.40	994	302.97
21	12	29	NE	SE	NW	Lyon	1256	382.83	1231	375.21	1215	370.33	1102	335.89
21	13	8	NE	SE	NW	Lyon	1061	323.39	1028	313.33	944	287.73	867	264.26
21	14	5	SW	SW	NE	Coffey	642	195.68	598	182.27	548	167.03	452	137.77
21	14	3	SE	SE	NE	Coffey	867	264.26	838	255.42	753	229.51	669	203.91
21	15	16	NW	NE	NE	Coffey	687	209.40	628	191.41	553	168.55	470	143.26

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth							
							Block-top		Iola-base		Iola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
21	16	11	NW	NW	SW	Coffey	618	188.37	578	176.17	530	161.54	446	135.94
21	16	25	NE	NE	NE	Coffey	598	182.27	548	167.03	497	151.49	409	124.66
21	17	24	NE	NE	NW	Anderson	473	144.17	426	129.84	384	117.04		
21	19	34		SW	NW	Anderson	354	107.90	285	86.87	250	76.20	133	40.54
21	19	14	NE	NE	SW	Anderson	284	86.56	247	75.29	214	65.23	128	39.01
21	19	27		SE	NE	Anderson	266	81.08	199	60.66	164	49.99	45	13.72
21	19	23		SW	NE	Anderson	330	100.58	262	79.86	226	68.88	94	28.65
21	20	7	SW	SW	SW	Anderson	250	76.20	211	64.31	182	55.47		
22	11	5		SE	SE	Greenwood	1364	415.75	1340	408.43	1322	402.95	1205	367.28
22	12	25		NW	SW	Greenwood	964	293.83	926	282.24	868	264.57	821	250.24
22	13	2	NE	SE	NW	Coffey	1004	306.02	969	295.35	906	276.15	864	263.35
22	14	7	SW	SW	NE	Coffey	928	282.85	896	273.10	825	251.46	762	232.26
22	14	27	NW	NE	SW	Coffey	858	261.52	819	249.63	756	230.43	707	215.49
22	15	14	NE	SE	NE	Coffey	700	213.36	664	202.39	602	183.49	493	150.27
22	15	29	SE	SE	NW	Coffey	778	237.13	740	225.55	676	206.04	563	171.60
22	15	9	SE	SE	SE	Coffey	740	225.55	703	214.27	649	197.82	585	178.31
22	15	13	NE	NE	SE	Coffey	654	199.34	623	189.89	562	171.30	493	150.27
22	16	11	NE	NE	NW	Coffey	530	161.54	492	149.96	432	131.67	370	112.78
22	16	17	SE	NE	SE	Coffey	528	160.93	492	149.96	426	129.84	377	114.91
22	16	7	SW	SW	NE	Coffey	587	178.92	550	167.64	493	150.27	418	127.41
22	16	3	NE	NE	SW	Coffey	516	157.28	477	145.39	412	125.58	387	117.96
22	17	29	SE	NW	SW	Coffey	491	149.66	435	132.59	381	116.13	278	84.73
22	18	29	NE	SE	SE	Anderson	347	105.77	288	87.78	256	78.03	100	30.48
22	18	28	NW	NE	SW	Anderson	342	104.24	300	91.44	256	78.03	116	35.36
22	19	3		SE	NE	Anderson	355	108.20	282	85.95	250	76.20	121	36.88
22	19	9		NW	SE	Anderson	355	108.20	280	85.34	244	74.37	119	36.27
22	19	2		NW	NE	Anderson	352	107.29	276	84.12	238	72.54	114	34.75
23	11	3	NE	NE	SW	Greenwood	1280	390.14	1262	384.66	1245	379.48	1109	338.02
23	12	9				Greenwood	1051	320.34	1021	311.20	950	289.56	869	264.87
23	13	32				Greenwood	796	242.62	763	232.56	706	215.19	590	179.83
23	13	23	SE	SW	NE	Woodson	981	299.01	948	288.95	883	269.14	760	231.65
23	13	27	C	NE	NW	Greenwood	947	288.65	916	279.20	857	261.21	736	224.33
23	13	1	C	SE	SE	Coffey	945	288.04	915	278.89	846	257.86	732	223.11
23	14	16	SE	SW	NE	Coffey	831	253.29	796	242.62	758	231.04	602	183.49

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth Block-top		lola-base		lola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
23	14	19	NW	SE	SE	Woodson	821	250.24	796	242.62	753	229.51	604	184.10
23	14	1		W/2	SE	Coffey	705	214.88	669	203.91	613	186.84	519	158.19
23	14	9	SW	SE	SW	Coffey	823	250.85	788	240.18	756	230.43	598	182.27
23	15	1		SW	SE	Coffey	571	174.04	539	164.29	481	146.61	352	107.29
23	16	13		SE	NW	Coffey	430	131.06	382	116.43	324	98.76	287	87.48
23	16	6	NW	NE	NW	Coffey	551	167.94	518	157.89	460	140.21	334	101.80
23	16	29	SE	NE	NE	Woodson	556	169.47	516	157.28	432	131.67	337	102.72
23	16	32		NW	NE	Woodson	615	187.45	572	174.35	490	149.35	389	118.57
23	17	18		NE	SE	Coffey	395	120.40	346	105.46	272	82.91	266	81.08
23	17	29			SW	Woodson	358	109.12	318	96.93	268	81.69	186	56.69
23	17	33		NE	SW	Woodson	308	93.88	252	76.81	198	60.35	182	55.47
23	17	7		NW	NW	Coffey	416	126.80	363	110.64	286	87.17	276	84.12
23	18	36			NE	Allen	240	73.15	175	53.34	132	40.23	56	17.07
23	18	29		SE	NW	Allen	290	88.39	220	67.06	152	46.33	139	42.37
23	19	4		SE	SW	Anderson	264	80.47	193	58.83	153	46.63	47	14.33
24	11	6	NE	NE	SW	Greenwood	1370	417.58	1345	409.96	1332	405.99	1200	365.76
24	12	11	SW	NE	SE	Greenwood	958	292.00	905	275.84	893	272.19	735	224.03
24	12	25	SW	SW	SE	Greenwood	912	277.98	882	268.83	861	262.43	716	218.24
24	12	36	NW	SE	SE	Greenwood	896	273.10	862	262.74	853	259.99	676	206.04
24	12	4		SE	SE	Greenwood	958	292.00	926	282.24	876	267.00	774	235.92
24	12	30	SW	SW	SE	Greenwood	1009	307.54	980	298.70	971	295.96	822	250.55
24	12	16	NW	SW	SE	Greenwood	854	260.30	823	250.85	813	247.80	666	203.00
24	13	31		SW	NW	Greenwood	841	256.34	811	247.19	796	242.62	623	189.89
24	13	5				Greenwood	757	230.73	713	217.32	700	213.36	525	160.02
24	14	28		SW	SW	Woodson	850	259.08	804	245.06	798	243.23	624	190.20
24	15	12		SE	SE	Woodson	587	178.92	540	164.59	459	139.90	348	106.07
24	15	22	NE	NE	NE	Woodson	646	196.90	603	183.79	523	159.41	421	128.32
24	15	6	NW	NW	NW	Woodson	692	210.92	660	201.17	594	181.05	482	146.91
24	15	5		SE	SW	Woodson	662	201.78	633	192.94	568	173.13	436	132.89
24	16	8		NW	NW	Woodson	471	143.56	409	124.66	353	107.59	246	74.98
24	17	4			SW	Woodson	310	94.49	240	73.15	191	58.22		
24	18	10		NW	SW	Allen	174	53.04	94	28.65	46	14.02		
25	11	32	SW	SW	SW	Greenwood	1193	363.63	1166	355.40	1153	351.43	993	302.67
25	12	31		SE	NW	Greenwood	954	290.78	922	281.03	910	277.37	764	232.87

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth							
							Block-top		Iola-base		Iola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
25	13	14	NW	SE	SW	Woodson	694	211.53	657	200.25	647	197.21	511	155.75
25	13	31	NW	NE	NE	Greenwood	800	243.84	760	231.65	749	228.30	618	188.37
25	14	12	NE	SW	NW	Woodson	713	217.32	659	200.86	598	182.27	485	147.83
25	15	6				Woodson	656	199.95	605	184.40	546	166.42	438	133.50
25	16	6	SE	SE	SE	Woodson	427	130.15	367	111.86	304	92.66	214	65.23
25	16	18	S/2	NE	NE	Woodson			380	115.82	322	98.15	232	70.71
25	17	16		NW	SW	Woodson	306	93.27	224	68.28	176	53.64		
25	18	16		SW	SE	Allen	152	46.33	58	17.68	16	4.88		
26	11	10	NW	SE	NE	Greenwood	1152	351.13	1122	341.99	1113	339.24	948	288.95
26	11	3		SW	SE	Greenwood	1174	357.84	1145	349.00	1135	345.95	972	296.27
26	11	8				Greenwood	1189	362.41	1063	324.00	1054	321.26	895	272.80
26	11	16				Greenwood	1097	334.37	1070	326.14	1062	323.70	892	271.88
26	12	7	NW	NW	NW	Greenwood	1032	314.55	1000	304.80	990	301.75	830	252.98
26	13	22	NE	SW	SW	Greenwood	708	215.80	653	199.03	596	181.66	516	157.28
26	14	24		NE	NE	Woodson	550	167.64	480	146.30	422	128.63	340	103.63
26	15	5	NE	NE	SW	Woodson	672	204.83	505	153.92	451	137.46	342	104.24
26	16	35	SW	SE	SE	Woodson	313	95.40	245	74.68	195	59.44	174	53.04
26	16	34	SE	SE	SW	Woodson	336	102.41	243	74.07	194	59.13	173	52.73
26	17	13	NW	SE	NE	Allen	179	54.56	97	29.57	54	16.46		
26	19	5	NW	NW	SW	Allen	113	34.44	27	8.23	4	1.22		
27	11	7		SE	SE	Greenwood	1098	334.67	1058	322.48	1048	319.43	877	267.31
27	12	1		NE	NE	Greenwood	835	254.51	782	238.35	725	220.98	635	193.55
27	13	10	SE	SE	SW	Greenwood	734	223.72	678	206.65	633	192.94	553	168.55
27	13	10	C	W/2	SW	Greenwood	727	221.59	668	203.61	608	185.32	541	164.90
27	14	5	NW	SE	SE	Wilson	624	190.20	546	166.42	486	148.13	413	125.88
27	15	4	C	NW	NE	Wilson	445	135.64	340	103.63	292	89.00	217	66.14
27	16	12		S/2	SW	Neosho	339	103.33	252	76.81	208	63.40	158	48.16
27	17	19		S/2	SW	Wilson	336	102.41	242	73.76	200	60.96	154	46.94
28	11	8	NW	SE	NE	Greenwood	1084	330.40	1049	319.74	1038	316.38	881	268.53
28	12	3	SW	NW	SW	Greenwood	868	264.57	814	248.11	753	229.51	659	200.86
28	13	3				Greenwood	685	208.79	620	188.98	570	173.74	490	149.35
28	13	2	SW	SE	SW	Wilson	667	203.30	594	181.05	542	165.20	478	145.69
28	14	27				Wilson	303	92.35	222	67.67	179	54.56	149	45.42
28	14	28		C	NW	Wilson	421	128.32	335	102.11	288	87.78		

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Depth							
							Block-top		Iola-base		Iola-top		Bonner Springs-top	
							feet	meters	feet	meters	feet	meters	feet	meters
28	15	9	NE	SW	NE	Wilson	317	96.62	232	70.71	186	56.69	142	43.28
28	16	19		NW	NE	Wilson	488	148.74	398	121.31	350	106.68	306	93.27
29	11	12	NE	SW	SW	Elk	1089	331.93	1032	314.55	1018	310.29		
29	11	17	NW	NW	SE	Elk	1155	352.04	1104	336.50	1086	331.01	939	286.21
29	12	24	NE	NE	NW	Elk	876	267.00	821	250.24	808	246.28	680	207.26
29	12	9	C	SE	NW	Elk	888	270.66	832	253.59	818	249.33	687	209.40
29	13	16	NE	SW	NE	Elk	689	210.01	617	188.06	604	184.10		
29	14	1		SE	NE	Wilson	312	95.10	233	71.02	218	66.45		
29	15	31		W/2	NW	Wilson	288	87.78	160	48.77	146	44.50		
29	13	29				Elk	897	273.41	800	243.84	784	238.96	746	227.38
29	15	9	SW	SE	NE	Wilson	360	109.73	239	72.85	223	67.97	160	48.77
30	11	27	C	SE	SW	Elk	1017	309.98	982	299.31	972	296.27	822	250.55
30	11	19	C	SW	SE	Elk	1160	353.57	1110	338.33	1097	334.37	904	275.54
30	12	24			NE	Elk	740	225.55	695	211.84	679	206.96	545	166.12
30	12	1	NW	NW	SW	Elk	809	246.58	770	234.70	745	227.08	626	190.80
30	12	13	SE	NW	NW	Elk	761	231.95	713	217.32	691	210.62	574	174.96
30	13	8		SE	SW	Elk	708	215.80	670	204.22	661	201.47	529	161.24
30	13	7	SE	SW	NE	Elk	740	225.55	698	212.75	687	209.40	560	170.69
30	14	12		C	NE	Wilson	378	115.21	315	96.01	308	93.88	147	44.81
30	14	13	NE	SW	NW	Wilson	405	123.44			280	85.34	180	54.86
30	16	6	SW	SW	SW	Wilson	214	65.23	184	56.08	175	53.34	69	21.03

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
14	11	31	SW	NW	SW	Wabaunsee	100	30.48	59	17.98	227	69.19	386	117.65
14	12	20	C	SE	SE	Wabaunsee	120	36.58	56	17.07	208	63.40	384	117.04
14	20	3		SE	SW	Douglas	44	13.41	17	5.18	117	35.66	178	54.25
14	21	1		NE	NE	Johnson	38	11.58	13	3.96	111	33.83	162	49.38
14	22	7	NE	NE	NE	Johnson	61	18.59	8	2.44	128	39.01	197	60.05
14	23	6	N/2	E/2	SW	Johnson	63	19.20	10	3.05	132	40.23	205	62.48
15	11	10	NW	SE	NE	Wabaunsee	37	11.28	20	6.10	80	24.38	137	41.76
15	12	7	N/2	SE	NW	Wabaunsee	39	11.89	26	7.92	71	21.64	136	41.45
15	18	35		S/2	SW	Franklin	41	12.50	30	9.14	80	24.38	151	46.02
15	20	1		NW	SE	Douglas	51	15.54	24	7.32	123	37.49	198	60.35
15	21	30	NE	NW	SW	Franklin	58	17.68	28	8.53	134	40.84	220	67.06
15	22	6	SE	SE	NW	Johnson	67	20.42	26	7.92	113	34.44	206	62.79
15	24	31	NW	SE	NW	Miami	68	20.73	11	3.35				
16	11	15	SW	SW	NE	Lyon	36	10.97	73	22.25	66	20.12	175	53.34
16	12	25	NE	SW	SW	Greenwood	45	13.72	58	17.68	104	31.70	207	63.09
16	16	23	NW	NE	NW	Osage	39	11.89	53	16.15	60	18.29	152	46.33
16	18	30	W/2	E/2	SE	Franklin	58	17.68	28	8.53	132	40.23	218	66.45
16	20	8	NE	SE	NE	Franklin	53	16.15	23	7.01	127	38.71	203	61.87
16	21	3	SW	NW	NW	Franklin	76	23.16	23	7.01	134	40.84	233	71.02
16	22	29			SW	Miami	60	18.29	19	5.79	142	43.28	221	67.36
17	11	13	NE	SE	NE	Lyon	57	17.37	32	9.75	60	18.29	149	45.42
17	12	7	C	SW	SW	Lyon	60	18.29	37	11.28	61	18.59	158	48.16
17	17	5	NE	SE	SE	Osage	56	17.07	32	9.75	70	21.34	158	48.16
17	18	15	SW	SW	SE	Franklin	53	16.15	28	8.53	162	49.38	243	74.07
17	19	14		SW	NW	Franklin	47	14.33	28	8.53	154	46.94	229	69.80
17	19	9		NW	SE	Franklin	54	16.46	28	8.53	147	44.81	229	69.80
17	20	1		NE	SE	Franklin	58	17.68	23	7.01	90	27.43	171	52.12
17	21	5	NE	SE	SW	Franklin	62	18.90	20	6.10	90	27.43	172	52.43
17	22	5		SE	SE	Miami	66	20.12	18	5.49	99	30.18	183	55.78
18	10	23	NW	SW	NW	Lyon	40	12.19	44	13.41	108	32.92	192	58.52
18	11	31	NE	NW	SE	Lyon	47	14.33	43	13.11	105	32.00	195	59.44
18	12	32	SE	SE	SE	Lyon	46	14.02	39	11.89	96	29.26	181	55.17
18	15	14	SE	NW	SE	Osage	47	14.33	38	11.58	105	32.00	190	57.91
18	17	9	NE	NE	NW	Osage	42	12.80	29	8.84	138	42.06	209	63.70

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
18	18	16	SW	SW	SE	Franklin	40	12.19	32	9.75	77	23.47	149	45.42
18	20	34	SE	SE	SW	Franklin	73	22.25	21	6.40	166	50.60	260	79.25
18	20	13	SE	NW	SE	Franklin	69	21.03	21	6.40	78	23.77	168	51.21
18	21	6		SE	SE	Franklin	66	20.12	20	6.10	91	27.74	177	53.95
18	21	1	SE	SW	SW	Miami	70	21.34	19	5.79	89	27.13	178	54.25
19	10	23	NW	NW	SE	Lyon	33	10.06	45	13.72	115	35.05	193	58.83
19	12	2	NE	SW	NE	Lyon	40	12.19	42	12.80	91	27.74	173	52.73
19	13	34	SE	NE	SE	Lyon	41	12.50	62	18.90	87	26.52	190	57.91
19	14	1	SE	NE	SE	Coffey	46	14.02	47	14.33	84	25.60	177	53.95
19	15	5	NE	NE	NW	Coffey	40	12.19	43	13.11	87	26.52	170	51.82
19	17	34	NW	NW	NE	Coffey	39	11.89	36	10.97	118	35.97	193	58.83
19	18	31				Anderson	41	12.50	34	10.36	86	26.21	161	49.07
19	21	23	C	SW	NE	Linn	71	21.64	23	7.01	81	24.69	175	53.34
20	11	22	NE	NE	SW	Lyon	32	9.75	60	18.29	96	29.26	188	57.30
20	12	17	E/2	NE	SE	Lyon	37	11.28	56	17.07	88	26.82	181	55.17
20	13	2	NE	NE	NW	Coffey	27	8.23	57	17.37	78	23.77	162	49.38
20	14	6	SE	SE	SE	Coffey	41	12.50	56	17.07	77	23.47	174	53.04
20	15	8	NE	NE	NE	Coffey	47	14.33	56	17.07	46	14.02	149	45.42
20	16	5	NE	NE	NW	Coffey	36	10.97	41	12.50	78	23.77	155	47.24
20	17	14	SE	SE	NW	Anderson	43	13.11	44	13.41	64	19.51	151	46.02
20	18	5	SE	SW	SW	Anderson	41	12.50	39	11.89	81	24.69	161	49.07
20	18	7	SE	SE	SW	Anderson	45	13.72	38	11.58	67	20.42	150	45.72
20	19	8		SE	SE	Anderson	73	22.25	25	7.62				
20	19	21	NW	SW	SW	Anderson	65	19.81	26	7.92	116	35.36	207	63.09
20	20	13	NE	NE	SW	Anderson	61	18.59	26	7.92				
20	21	27		N/2	SW	Anderson	79	24.08	24	7.32				
21	11	24	NE	NE	NW	Lyon	23	7.01	38	11.58	102	31.09	163	49.68
21	11	25	NE	NW	NW	Lyon	27	8.23	65	19.81	82	24.99	174	53.04
21	12	25	NW	SE	SE	Lyon	40	12.19	69	21.03	90	27.43	199	60.66
21	12	29	NE	SE	NW	Lyon	25	7.62	16	4.88	113	34.44	154	46.94
21	13	8	NE	SE	NW	Lyon	33	10.06	84	25.60	77	23.47	194	59.13
21	14	5	SW	SW	NE	Coffey	44	13.41	50	15.24	96	29.26	190	57.91
21	14	3	SE	SE	NE	Coffey	29	8.84	85	25.91	84	25.60	198	60.35
21	15	16	NW	NE	NE	Coffey	59	17.98	75	22.86	83	25.30	217	66.14

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
21	16	11	NW	NW	SW	Coffey	40	12.19	48	14.63	84	25.60	172	52.43
21	16	25	NE	NE	NE	Coffey	50	15.24	51	15.54	88	26.82	189	57.61
21	17	24	NE	NE	NW	Anderson	47	14.33	42	12.80				
21	19	34		SW	NW	Anderson	69	21.03	35	10.67	117	35.66	221	67.36
21	19	14	NE	NE	SW	Anderson	37	11.28	33	10.06	86	26.21	156	47.55
21	19	27		SE	NE	Anderson	67	20.42	35	10.67	119	36.27	221	67.36
21	19	23		SW	NE	Anderson	68	20.73	36	10.97	132	40.23	236	71.93
21	20	7	SW	SW	SW	Anderson	39	11.89	29	8.84				
22	11	5		SE	SE	Greenwood	24	7.32	18	5.49	117	35.66	159	48.46
22	12	25		NW	SW	Greenwood	38	11.58	58	17.68	47	14.33	143	43.59
22	13	2	NE	SE	NW	Coffey	35	10.67	63	19.20	42	12.80	140	42.67
22	14	7	SW	SW	NE	Coffey	32	9.75	71	21.64	63	19.20	166	50.60
22	14	27	NW	NE	SW	Coffey	39	11.89	63	19.20	49	14.94	151	46.02
22	15	14	NE	SE	NE	Coffey	36	10.97	62	18.90	109	33.22	207	63.09
22	15	29	SE	SE	NW	Coffey	38	11.58	64	19.51	113	34.44	215	65.53
22	15	9	SE	SE	SE	Coffey	37	11.28	54	16.46	64	19.51	155	47.24
22	15	13	NE	NE	SE	Coffey	31	9.45	61	18.59	69	21.03	161	49.07
22	16	11	NE	NE	NW	Coffey	38	11.58	60	18.29	62	18.90	160	48.77
22	16	17	SE	NE	SE	Coffey	36	10.97	66	20.12	49	14.94	151	46.02
22	16	7	SW	SW	NE	Coffey	37	11.28	57	17.37	75	22.86	169	51.51
22	16	3	NE	NE	SW	Coffey	39	11.89	65	19.81	25	7.62	129	39.32
22	17	29	SE	NW	SW	Coffey	56	17.07	54	16.46	103	31.39	213	64.92
22	18	29	NE	SE	SE	Anderson	59	17.98	32	9.75	156	47.55	247	75.29
22	18	28	NW	NE	SW	Anderson	42	12.80	44	13.41	140	42.67	226	68.88
22	19	3		SE	NE	Anderson	73	22.25	32	9.75	129	39.32	234	71.32
22	19	9		NW	SE	Anderson	75	22.86	36	10.97	125	38.10	236	71.93
22	19	2		NW	NE	Anderson	76	23.16	38	11.58	124	37.80	238	72.54
23	11	3	NE	NE	SW	Greenwood	18	5.49	17	5.18	136	41.45	171	52.12
23	12	9				Greenwood	30	9.14	71	21.64	81	24.69	182	55.47
23	13	32				Greenwood	33	10.06	57	17.37	116	35.36	206	62.79
23	13	23	SE	SW	NE	Woodson	33	10.06	65	19.81	123	37.49	221	67.36
23	13	27	C	NE	NW	Greenwood	31	9.45	59	17.98	121	36.88	211	64.31
23	13	1	C	SE	SE	Coffey	30	9.14	69	21.03	114	34.75	213	64.92
23	14	16	SE	SW	NE	Coffey	35	10.67	38	11.58	156	47.55	229	69.80

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
23	14	19	NW	SE	SE	Woodson	25	7.62	43	13.11	149	45.42	217	66.14
23	14	1		W/2	SE	Coffey	36	10.97	56	17.07	94	28.65	186	56.69
23	14	9	SW	SE	SW	Coffey	35	10.67	32	9.75	158	48.16	225	68.58
23	15	1		SW	SE	Coffey	32	9.75	58	17.68	129	39.32	219	66.75
23	16	13		SE	NW	Coffey	48	14.63	58	17.68	37	11.28	143	43.59
23	16	6	NW	NE	NW	Coffey	33	10.06	58	17.68	126	38.40	217	66.14
23	16	29	SE	NE	NE	Woodson	40	12.19	84	25.60	95	28.96	219	66.75
23	16	32		NW	NE	Woodson	43	13.11	82	24.99	101	30.78	226	68.88
23	17	18		NE	SE	Coffey	49	14.94	74	22.56	6	1.83	129	39.32
23	17	29			SW	Woodson	40	12.19	50	15.24	82	24.99	172	52.43
23	17	33		NE	SW	Woodson	56	17.07	54	16.46	16	4.88	126	38.40
23	17	7		NW	NW	Coffey	53	16.15	77	23.47	10	3.05	140	42.67
23	18	36			NE	Allen	65	19.81	43	13.11	76	23.16	184	56.08
23	18	29		SE	NW	Allen	70	21.34	68	20.73	13	3.96	151	46.02
23	19	4		SE	SW	Anderson	71	21.64	40	12.19	106	32.31	217	66.14
24	11	6	NE	NE	SW	Greenwood	25	7.62	13	3.96	132	40.23	170	51.82
24	12	11	SW	NE	SE	Greenwood	53	16.15	12	3.66	158	48.16	223	67.97
24	12	25	SW	SW	SE	Greenwood	30	9.14	21	6.40	145	44.20	196	59.74
24	12	36	NW	SE	SE	Greenwood	34	10.36	9	2.74	177	53.95	220	67.06
24	12	4		SE	SE	Greenwood	32	9.75	50	15.24	102	31.09	184	56.08
24	12	30	SW	SW	SE	Greenwood	29	8.84	9	2.74	149	45.42	187	57.00
24	12	16	NW	SW	SE	Greenwood	31	9.45	10	3.05	147	44.81	188	57.30
24	13	31		SW	NW	Greenwood	30	9.14	15	4.57	173	52.73	218	66.45
24	13	5				Greenwood	44	13.41	13	3.96	175	53.34	232	70.71
24	14	28		SW	SW	Woodson	46	14.02	6	1.83	174	53.04	226	68.88
24	15	12		SE	SE	Woodson	47	14.33	81	24.69	111	33.83	239	72.85
24	15	22	NE	NE	NE	Woodson	43	13.11	80	24.38	102	31.09	225	68.58
24	15	6	NW	NW	NW	Woodson	32	9.75	66	20.12	112	34.14	210	64.01
24	15	5		SE	SW	Woodson	29	8.84	65	19.81	132	40.23	226	68.88
24	16	8		NW	NW	Woodson	62	18.90	56	17.07	107	32.61	225	68.58
24	17	4			SW	Woodson	70	21.34	49	14.94				
24	18	10		NW	SW	Allen	80	24.38	48	14.63				
25	11	32	SW	SW	SW	Greenwood	27	8.23	13	3.96	160	48.77	200	60.96
25	12	31		SE	NW	Greenwood	32	9.75	12	3.66	146	44.50	190	57.91

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
25	13	14	NW	SE	SW	Woodson	37	11.28	10	3.05	136	41.45	183	55.78
25	13	31	NW	NE	NE	Greenwood	40	12.19	11	3.35	131	39.93	182	55.47
25	14	12	NE	SW	NW	Woodson	54	16.46	61	18.59	113	34.44	228	69.49
25	15	6				Woodson	51	15.54	59	17.98	108	32.92	218	66.45
25	16	6	SE	SE	SE	Woodson	60	18.29	63	19.20	90	27.43	213	64.92
25	16	18	S/2	NE	NE	Woodson			58	17.68	90	27.43		
25	17	16		NW	SW	Woodson	82	24.99	48	14.63				
25	18	16		SW	SE	Allen	94	28.65	48	14.63				
26	11	10	NW	SE	NE	Greenwood	30	9.14	9	2.74	165	50.29	204	62.18
26	11	3		SW	SE	Greenwood	29	8.84	10	3.05	163	49.68	202	61.57
26	11	8				Greenwood	126	38.40	9	2.74	159	48.46	294	89.61
26	11	16				Greenwood	27	8.23	8	2.44	170	51.82	205	62.48
26	12	7	NW	NW	NW	Greenwood	32	9.75	10	3.05	160	48.77	202	61.57
26	13	22	NE	SW	SW	Greenwood	55	16.76	57	17.37	80	24.38	192	58.52
26	14	24		NE	NE	Woodson	70	21.34	58	17.68	82	24.99	210	64.01
26	15	5	NE	NE	SW	Woodson	167	50.90	54	16.46	109	33.22	330	100.58
26	16	35	SW	SE	SE	Woodson	68	20.73	50	15.24	21	6.40	139	42.37
26	16	34	SE	SE	SW	Woodson	93	28.35	49	14.94	21	6.40	163	49.68
26	17	13	NW	SE	NE	Allen	82	24.99	43	13.11				
26	19	5	NW	NW	SW	Allen	86	26.21	23	7.01				
27	11	7		SE	SE	Greenwood	40	12.19	10	3.05	171	52.12	221	67.36
27	12	1		NE	NE	Greenwood	53	16.15	57	17.37	90	27.43	200	60.96
27	13	10	SE	SE	SW	Greenwood	56	17.07	45	13.72	80	24.38	181	55.17
27	13	10	C	W/2	SW	Greenwood	59	17.98	60	18.29	67	20.42	186	56.69
27	14	5	NW	SE	SE	Wilson	78	23.77	60	18.29	73	22.25	211	64.31
27	15	4	C	NW	NE	Wilson	105	32.00	48	14.63	75	22.86	228	69.49
27	16	12		S/2	SW	Neosho	87	26.52	44	13.41	50	15.24	181	55.17
27	17	19		S/2	SW	Wilson	94	28.65	42	12.80	46	14.02	182	55.47
28	11	8	NW	SE	NE	Greenwood	35	10.67	11	3.35	157	47.85	203	61.87
28	12	3	SW	NW	SW	Greenwood	54	16.46	61	18.59	94	28.65	209	63.70
28	13	3				Greenwood	65	19.81	50	15.24	80	24.38	195	59.44
28	13	2	SW	SE	SW	Wilson	73	22.25	52	15.85	64	19.51	189	57.61
28	14	27				Wilson	81	24.69	43	13.11	30	9.14	154	46.94
28	14	28		C	NW	Wilson	86	26.21	47	14.33				

Twn.(S)	Ran.(E)	Sec.	1/64	1/16	1/4	County	Thicknesses							
							Underlying Clastics		Iola Limestone		Overlying Clastics		Total Interval	
							feet	meters	feet	meters	feet	meters	feet	meters
28	15	9	NE	SW	NE	Wilson	85	25.91	46	14.02	44	13.41	175	53.34
28	16	19		NW	NE	Wilson	90	27.43	48	14.63	44	13.41	182	55.47
29	11	12	NE	SW	SW	Elk	57	17.37	14	4.27				
29	11	17	NW	NW	SE	Elk	51	15.54	18	5.49	147	44.81	216	65.84
29	12	24	NE	NE	NW	Elk	55	16.76	13	3.96	128	39.01	196	59.74
29	12	9	C	SE	NW	Elk	56	17.07	14	4.27	131	39.93	201	61.26
29	13	16	NE	SW	NE	Elk	72	21.95	13	3.96				
29	14	1		SE	NE	Wilson	79	24.08	15	4.57				
29	15	31		W/2	NW	Wilson	128	39.01	14	4.27				
29	13	29				Elk	97	29.57	16	4.88	38	11.58	151	46.02
29	15	9	SW	SE	NE	Wilson	121	36.88	16	4.88	63	19.20	200	60.96
30	11	27	C	SE	SW	Elk	35	10.67	10	3.05	150	45.72	195	59.44
30	11	19	C	SW	SE	Elk	50	15.24	13	3.96	193	58.83	256	78.03
30	12	24			NE	Elk	45	13.72	16	4.88	134	40.84	195	59.44
30	12	1	NW	NW	SW	Elk	39	11.89	25	7.62	119	36.27	183	55.78
30	12	13	SE	NW	NW	Elk	48	14.63	22	6.71	117	35.66	187	57.00
30	13	8		SE	SW	Elk	38	11.58	9	2.74	132	40.23	179	54.56
30	13	7	SE	SW	NE	Elk	42	12.80	11	3.35	127	38.71	180	54.86
30	14	12		C	NE	Wilson	63	19.20	7	2.13	161	49.07	231	70.41
30	14	13	NE	SW	NW	Wilson					100	30.48	225	68.58
30	16	6	SW	SW	SW	Wilson	30	9.14	9	2.74	106	32.31	145	44.20

APPENDIX 5
ISOPACH STATISTICS

Thickness Correlations

Regression Output:
Underlying Siliciclastics versus Iola

Regression Output:
Underlying Siliciclastics versus Iola

Constant	41.55102
Std Err of Y Est	21.20169
R Squared	0.001251
No. of Observations	172
Degrees of Freedom	170
X Coefficient(s)	-0.03465
Std Err of Coef.	0.075093

Regression Output:
Overlying Siliciclastics versus Iola

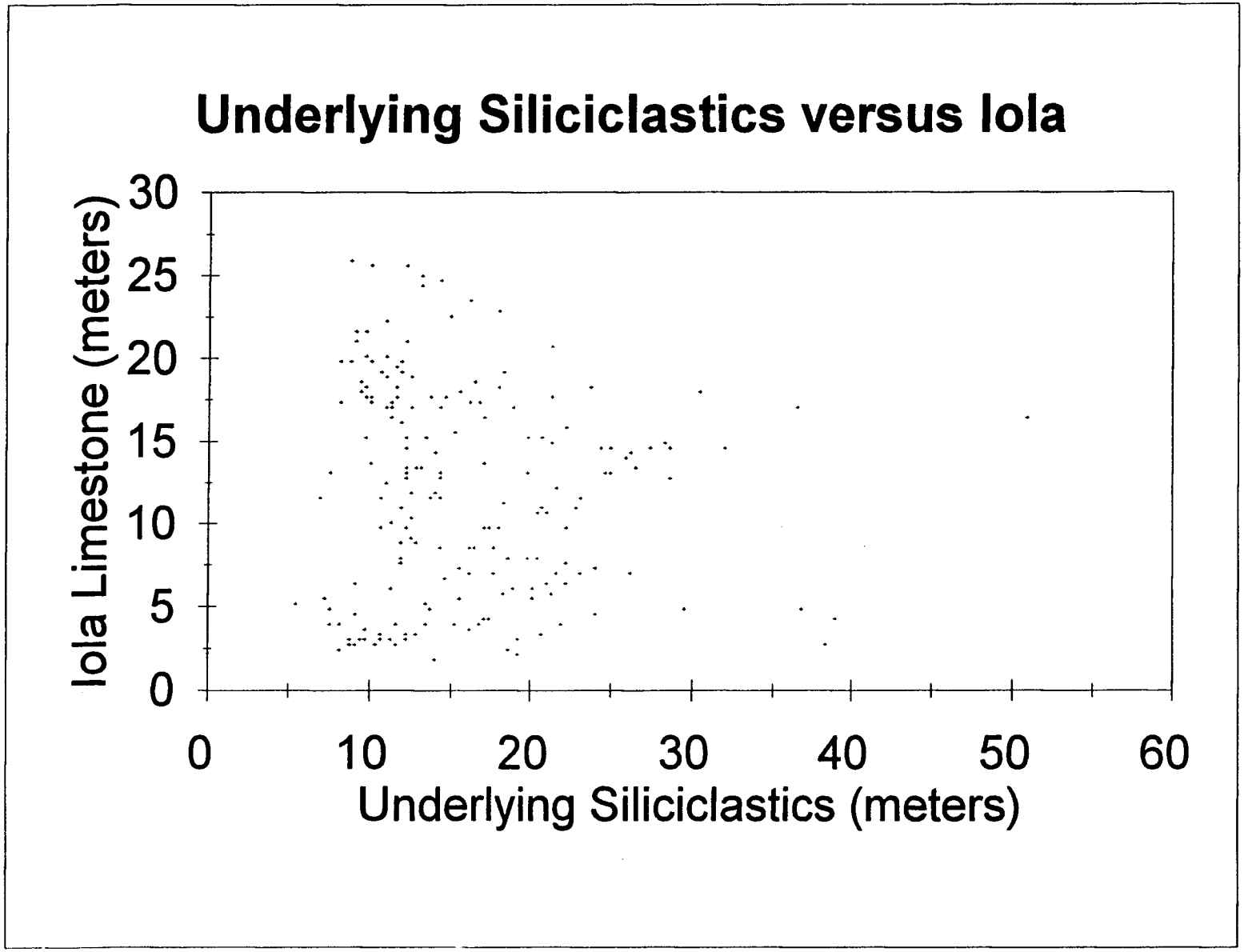
Regression Output:
Overlying Siliciclastics versus Iola

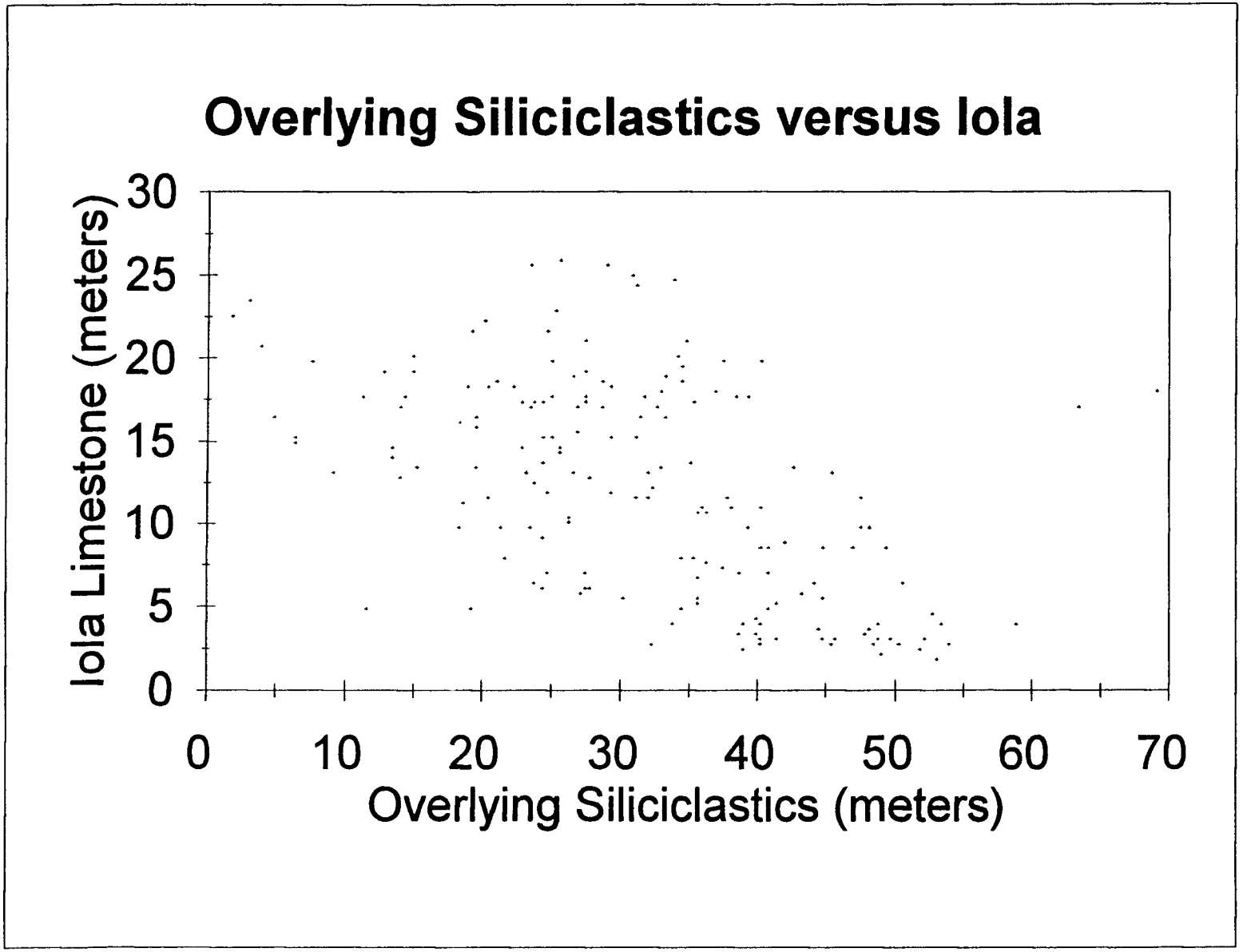
Constant	68.31876
Std Err of Y Est	17.99867
R Squared	0.280226
No. of Observations	172
Degrees of Freedom	170
X Coefficient(s)	-0.27403
Std Err of Coef.	0.033684

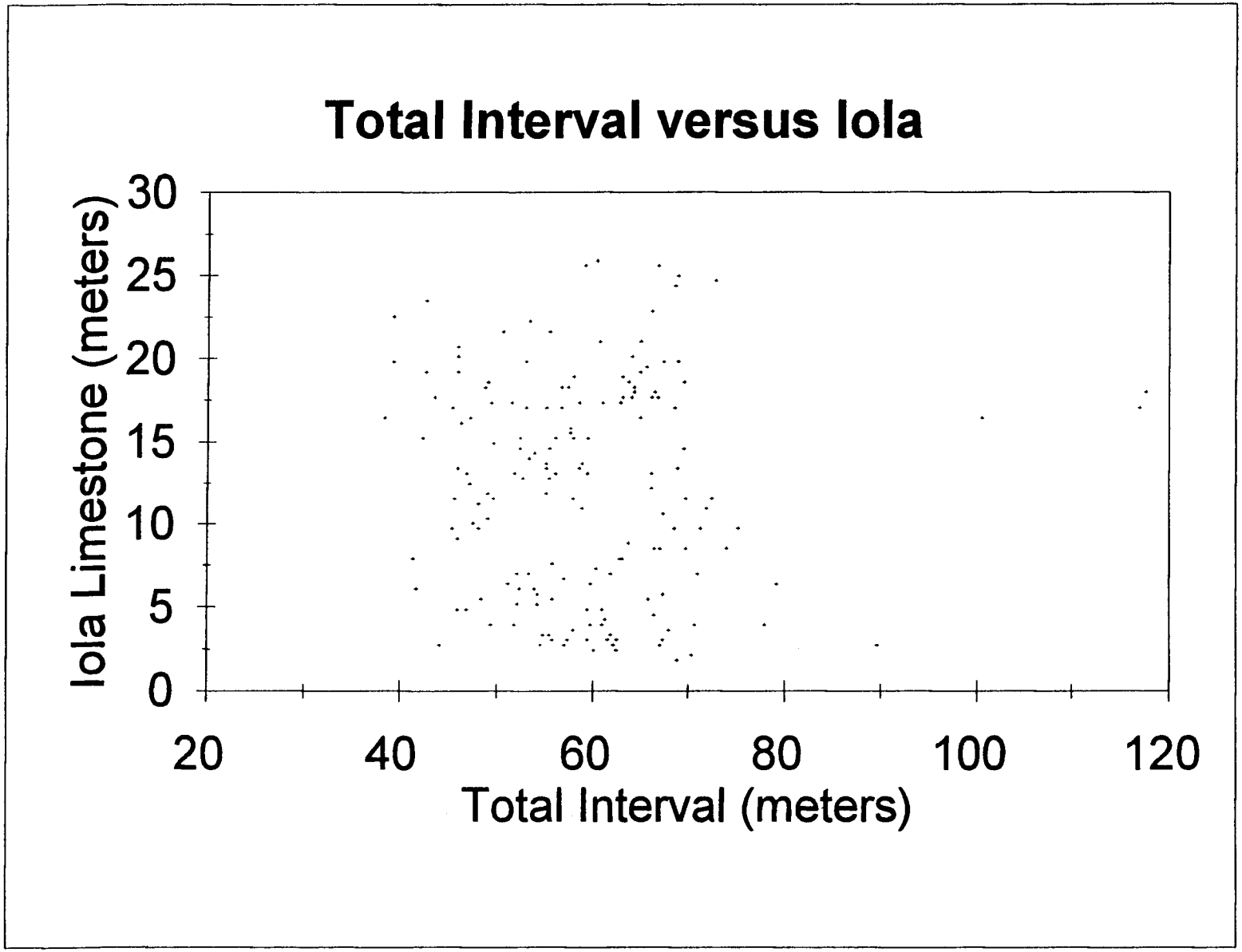
Regression Output:
Total Interval versus Iola

Regression Output:
Total Interval versus Iola

Constant	43.35075
Std Err of Y Est	21.2036
R Squared	0.001071
No. of Observations	172
Degrees of Freedom	170
X Coefficient(s)	-0.01825
Std Err of Coef.	0.042739


Underlying Siliciclastics versus Iola
Iola Limestone (meters)
30
25
20
15
10
5
0
0
10
20
30
40
50
60
Underlying Siliciclastics (meters)


Overlying Siliciclastics versus Iola
Iola Limestone (meters)
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
Overlying Siliciclastics (meters)


Total Interval versus Iola
Iola Limestone (meters)
30
25
20
15
10
5
0
20
40
60
80
100
120
Total Interval (meters)