PETROLOGY, CLAY MINERALOGY AND CONODONT DISTRIBUTION OF THE CHERRYVALE FORMATION, UPPER PENNSYLVANIAN, MIDCONTINENT

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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ABSTRACT

The Cherryvale Formation is an anomalous marine unit in the cyclic strata of the Upper Pennsylvanian, of Midcontinent North America. Petrology, clay mineralogy and conodont distribution were studied in five complete or nearly complete sections. These sections can be divided into three depositional settings: 1) rapid clastic influx (southeast Kansas); 2) gradational fluctuations in clastic sedimentation rate with periodic carbonate production during reduced influx (southwest Iowa); and 3) stable carbonate shelf with moderate to low fluctuating clastic sedimentation (southeast Nebraska).

The lateral variation and relatively high continuous clastic sedimentation, compared to other cyclic deposits, can be attributed to the small extent of the transgression responsible for marine Cherryvale deposits. A minor transgression would produce only small coastal sediment traps (estuaries and lagoons), which when full, would allow transportation of large amounts of clastics into the basin, in the form of deltaic and prodeltaic sediment.

Heckel and Baesemann (1975) proposed two minor transgressions during Cherryvale Formation and Drum Limestone deposition, based on conodont distribution in the Kansas

City area. Petrology, clay mineralogy and conodont distribution in the Cherryvale sections studied was compatible with the model proposed by Heckel and Baesemann (1975), but only the Nebraska section reflected the details of two transgressions, probably because of reduced clastic masking in that area. The Iowa and Kansas sections are dominantly shale and are interpreted as reflecting rapid to moderate rates of clastic sedimentation, which diluted conodont abundance and masked the abundance marker zones.

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INTRODUCTION

General

The Upper Pennsylvanian section in the Midcontinent outcrop belt consists of alternating widespread marine limestone formations with widespread marine to nonmarine shale formations. The cyclic nature of the Middle and Upper Pennsylvanian strata in Kansas was first recognized by R. C. Moore (1932). The term cyclothem, referring to repetitive units deposited in cycles, was first defined by Wanless and Weller (1932), and applied to the Kansas Upper Pennsylvanian strate by R. C. Moore (1936). More recently, the basic Kansas cyclothem has been described by Heckel (1977) as normally consisting of, in ascending order: outside shale, middle limestone, core shale, upper limestone and outside shale (Figure 1). Gross lithologic changes are interpreted as recording relative changes in water depth and vertical circulation. The lithologic changes from the outside shale to middle limestone to core shale is interpreted as recording an increase in water depth, culminating with the core shale deposited at maximum transgression of an epicontinental sea. The upper limestone and the outside shale are interpreted as recording a decrease in water depth, culminating with the outside shale deposited at maximum regression

Figure 1 -- General vertical sequence in single "typical Kansas cyclothem". Transgressive and regressive units, with minor modification, characterize the Marmaton, Kansas City, Lansing and Shawnee Groups, of the Midcontinent Pennsylvanian. Note the distinct differentiation of conodont faunas between the outside and core shales. (From Heckel, 1977).

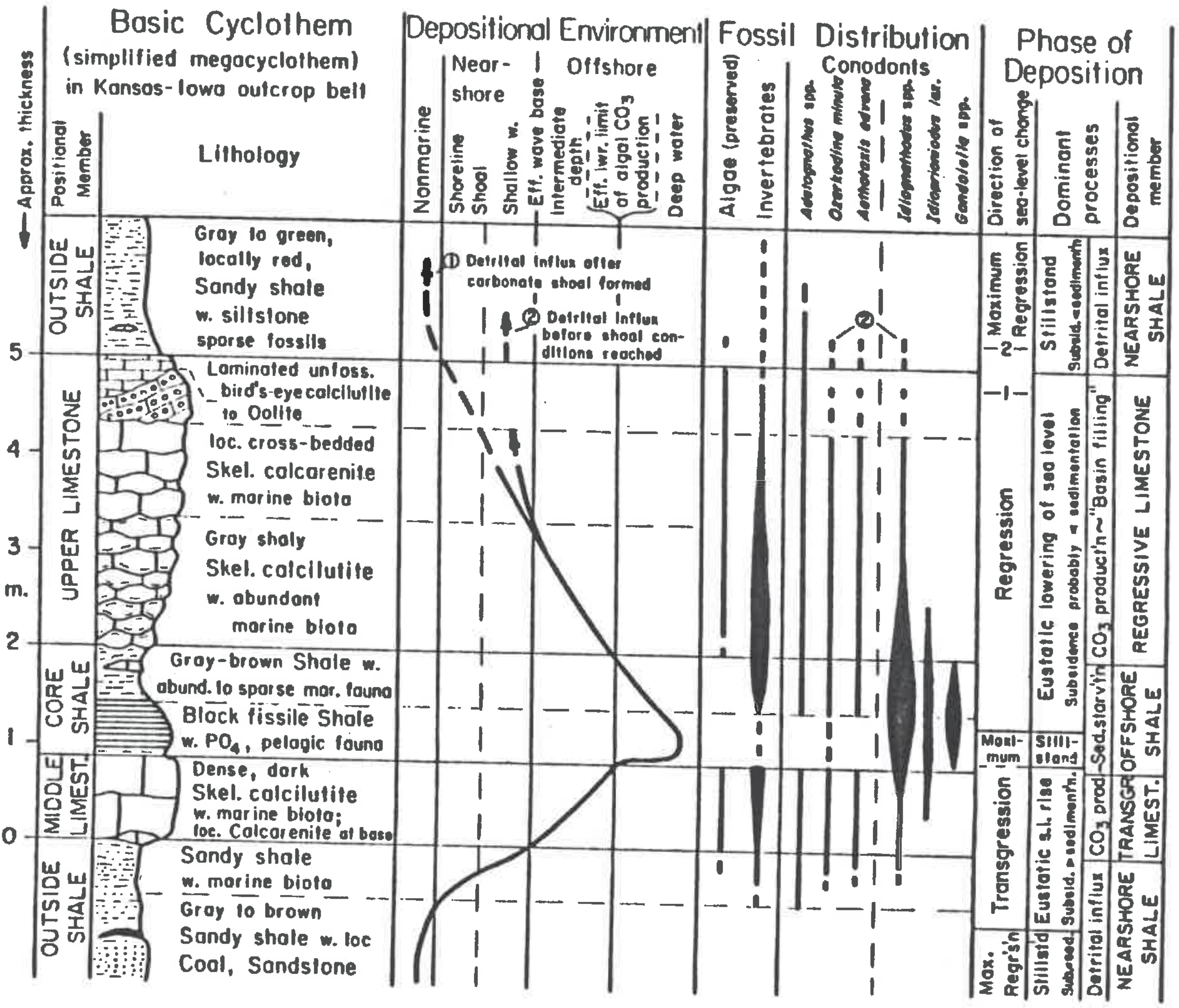

Basic Cyclothem
(simplified megacyclothem)
in Kansas-Iowa outcrop belt
Approx. thickness
Positional Member
Lithology
OUTSIDE SHALE
UPPER LIMESTONE
CORE SHALE
MIDDLE LIMEST.
OUTSIDE SHALE
5
4
3
m.
2
1
0
Gray to green, locally red, Sandy shale w. siltstone sparse fossils
Laminated unfoss. bird's-eye calcilutite to Oolite
loc. cross-bedded Skel. calcarenite w. marine biota
Gray shaly Skel. calcilutite w. abundant marine biota
Gray-brown Shale w. abund. to sparse mar. fauna
Black fissile Shale w. PO4, pelagic fauna
Dense, dark Skel. calcilutite w. marine biota; loc. Calcarenite at base
Sandy shale w. marine biota
Gray to brown Sandy shale w. loc Coal, Sandstone
Depositional Environment
Nonmarine
Near-shore
Shoreline
Shoal
Shallow w.
Eff. wave base
Offshore
Intermediate depth
Eff. lwr. limit of algal CO3 production
Deep water
① Detrital influx after carbonate shoal formed
② Detrital influx before shoal conditions reached
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Adetognathus spp.
Ozarkodina minuta
Aethotaxis advena
Idiognathodus spp.
Idioprioniodus lat.
Gondolella spp.
Phase of Deposition
Direction of sea-level change
Dominant processes
Depositional member
Maximum Regression
Regression
Maximum
Transgression
Max. Regr's'n
Stillstand
Subsid.≈sedimentn.
Eustatic lowering of sea level
Subsidence probably ≈ sedimentation
Still-stand
Eustatic s.l. rise
Subsid. ≈ sedimentn.
Stillstd
Subsed.
Detrital influx
CO3 product'n ~ "Basin filling"
Sed.starv'n
CO3 prod
Detrital influx
NEARSHORE SHALE
REGRESSIVE LIMESTONE
OFFSHORE SHALE
TRANSGR. LIMEST.
NEARSHORE SHALE

Figure 1

(Heckel, 1977). Due to the shallow paleoslope of the Midcontinent during the Pennsylvanian, minor sea level rises could inundate large areas of land, causing widespread deposition of units, with only slight time stratigraphic differences. Commonly individual cyclothem members, especially core shales, can be traced laterally across much of the Midcontinent outcrop belt, from southeast Kansas to Iowa.

Conflicting theories concerning deposition of the cyclic Pennsylvanian midcontinent strata have been put forth by Zangerl and Richardson (1963) and Merrill and Martin (1976, p. 234-271), which interpret the black shale facies as recording transgressive, shallow water deposition, occurring under an algal floatant. Due to the symmetry of the middle and upper marine limestone units about the laterally continuous black shale member and the apparent diastemic nature of the black shales, deep water (through still epicontinental) deposition of this unit is suggested (Heckel, 1977). The following interpretations of cyclothem members are based on Heckel and Baesemann (1975) and Heckel (1977, 1980).

Outside shales are interpreted as marking the maximum regression of an epicontinentantal sea. They are commonly deltaic and prodeltaic influxes of clastic sediment, and range from marine through non-marine.

The middle limestone is interpreted as marking the transgressive portion of the cyclothem, and suggests relatively shallow water with oxygenated bottom conditions, allowing for abundant growth of carbonate-producing organisms. It is generally thinner than the upper limestone, probably related to differences in the length of time that carbonate-producing organisms are in an optimum environment. The middle limestone is commonly a dense calcilutite, with calcarenites near the bottom in other areas, reflecting shallowest water deposition during early transgression. It is also relatively free from clastic influx, because of formation of sediment traps in the form of estuaries and embayments, away from the midcontinent during the transgression.

The core shale is interpreted as marking the maximum transgression of an epicontinental area. Core shales may be grey, with abundant benthic and pelagic fossils, and may contain a black phosphatic facies with abundant pelagic fossils, but lacking benthic fossils. The black core shale facies suggests anoxic bottom conditions, which allowed accumulation of organic matter and eliminated benthic life. Anoxic bottom conditions probably were caused by formation of a thermocline during maximum water stand, which inhibited vertical circulation of oxygenated surface waters. High concentration of pelagic fossils from the oxygenated water column above, especially conodonts,probably resulted from diastemic conditions caused by effective coastal sediment trapping during maximum transgression; the reduction in clastic sediment concentrated pelagic fossils by reducing the effect of sediment dilution.

The upper limestone is interpreted as marking the regressive portion of the cyclothem. It differs from the middle limestone in thickness, vertical lithologic changes and shale content. During regression, the thermocline was destroyed as water depth decreased, allowing light penetration and circulation of oxygenated surface water, to produce favorable conditions for carbonate-producing organisms. Petrographically, the unit is primarily an open marine calcilutite, with various calcarenites, and restricted calcilutites near the top, deposited in shoaling water. During regression of epicontinental seas, estuaries were destroyed and effective coastal sediment trapping was reduced, causing the upper limestone commonly to be interbedded with shale stringers. These clastic influxes often culminated in the formation of a deltaic wedge, which destroyed carbonate production and formed an outside shale.

Cherryvale Formation

The Cherryvale Formation appears somewhat anomalous in midcontinent cyclic sequences, because although it is a thick, laterally extensive shale formation, it lacks definite shoreline or non-marine facies. On outcrop, the unit contains zones of fossiliferous marine limestone and shale. The Cherryvale exposures near Kansas City, Kansas (Heckel and Baesemann, 1975) (Figure 2) and at Atlantic, Iowa (P. H. Heckel, personal notes, 1968) (Figure 3), exhibit shale and limestone units that are compatible with the cyclothem concept of Heckel (1977) (Figure 1). However, these units do not appear to be laterally continuous, and exposures elsewhere along the outcrop belt in southeast Kansas and south-central Iowa, and in cores from southwestern Iowa and southeastern Nebraska, vary widely in lithology, even though certain names have been applied far from type localities.

Purpose

The purpose of this study is to describe the Cherryvale Formation in a few good, complete or nearly complete exposures and cores, using modern petrographic and x-ray analysis, and identification of microfossils, primarily conodonts, in order to interpret environments of deposition. Due to the lack of lateral control, each section will be described independently, and any vertical changes that are detected will be compared laterally. Conodont distribution patterns will be compared with the pattern illustrated by Heckel and Baesemann (1975) in the Kansas City area (Figure 2).

Using the information collected above, I will attempt to determine the compatibility between the subtle changes in vertical sequences in lithology, macrofossils, and conodont distribution and abundance, in different sections of the Cherryvale Formation with the cyclothem model of Heckel (1977).

Figure 2 -- Distribution of conodont genera and species, abundance and diversity in members of the Cherryvale Shale and overlying Drum Limestone, from Kansas City area, based on data of Baesemann (1973). Form genera and species are marked (f), all others are multielement species. Diversity and abundance are extended to the right in partial picked samples by integration of adjacent samples (modified from Heckel and Baesemann, 1975).

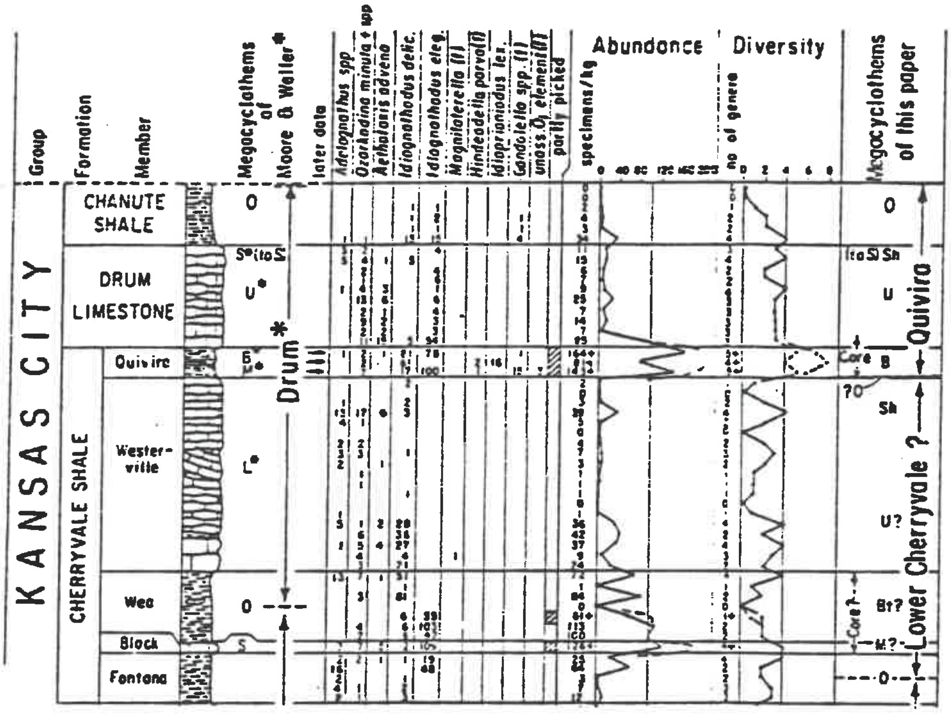
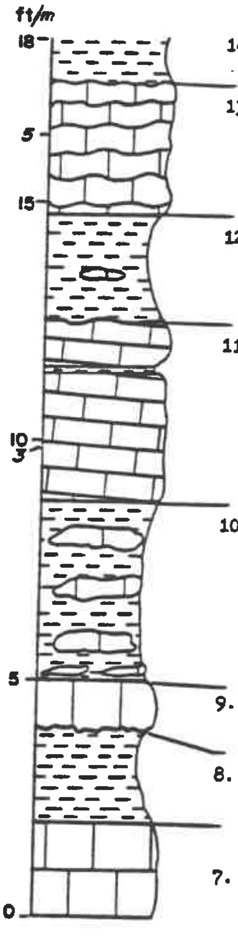

Group
Formation
Member
Megacyclothems of Moore & Weller*
later data
Adetognathus spp.
Ozarkodina minuta + spp.
Aethotaxis advena
Idiognathodus delic.
Idiognathodus eleg.
Magnilaterella (I)
Hindeodella parva (I)
Idioprioniodus lex.
Gondolella spp. (I)
unass. O₁ element (I)
partly picked
specimens/kg
Abundance
Diversity
no. of genera
Megacyclothems of this paper
KANSAS CITY
CHANUTE SHALE
DRUM LIMESTONE
CHERRYVALE SHALE
Quivira
Westerville
Wea
Block
Fontana
O
S* (to S)
U*
B*
M*
L*
S
Drum*
O
(to S) Sh
U
Core
B
?O
Sh
U?
Bt?
M?
Quivira
Lower Cherryvale ?

Figure 2

Figure 3 -- Description of Cherryvale Formation and overlying Drum Limestone, formerly exposed in Atlantic Quarry, Atlantic, Iowa. Location: Appendix E. (From P.H. Heckel, personal notes, 1968).



14. Chanute Shale

13. Several irregular ledges of limestone.
General skeletal calcarenite with zones of large Brachiopods.
Drum Limestone?

12. Chippy shale with chonetid brachiopods, fusulinids and local calcarenites.
Quivira Shale?

11. Medium thin bedded fossiliferous calcarenite with crinoids, brachiopods, fusulinids, coral?, and osagia. Large productids near base.
Westerville Limestone?

10. Chippy dark grey shale with limestone lenses.
Brachiopods, shell hash and calcilutites.
Wea Shale?

9. Lenticular?, osagia calcilutite-pebble calcarenite.
Calcilutite irregular in the top. Brachiopods, ecinoderms and gastropods. Block Limestone?

8. Fontana Shale? Covered

7. Winterset Limestone

Figure 3

STRATIGRAPHY

The Cherryvale Formation of the Kansas City Group is a poorly exposed unit consisting of shale, with mainly subordinate limestones (Figure 4). It crops out in a belt from southeastern Kansas, through northwestern Missouri, to southwestern Iowa and southeastern Nebraska (Figure 5). Poor exposure is caused primarily by: 1) dominance of shale units, which do not produce prominent escarpments and 2) Pleistocene glacial deposits, which blanket exposures north of Kansas City.

State geologic surveys from Oklahoma, Kansas, Missouri, Iowa and Nebraska, met in 1957 to attempt to standardize the stratigrpahic nomenclature of the Pennsylvanian strata present in each state. The Cherryvale was recognized as a formation, overlying the Winterset Limestone Member of the Dennis Limestone, and underlying the Drum Limestone. It is composed of the following members in ascending order: Fontana Shale, Block Limestone, Wea Shale, Westerville Limestone and Quivira Shale (Moore, 1948). Although the Kansas Geological Survey has utilized this nomenclature, usage in Iowa and Nebraska has differed.

The Iowa Geological Survey recognized the Cherryvale as a formation, with the following members in ascending

Figure 4 -- Columnar section of the exposed Upper Pennsylvanian (Missourian Stage) rocks in southeast Kansas. Member names are omitted, but lithologies are depicted within formations. Vertical scale is approximate. Limestones, black shales and coals are expanded at the expense of grey shales and sandstones. (From Heckel, et al., 1979).

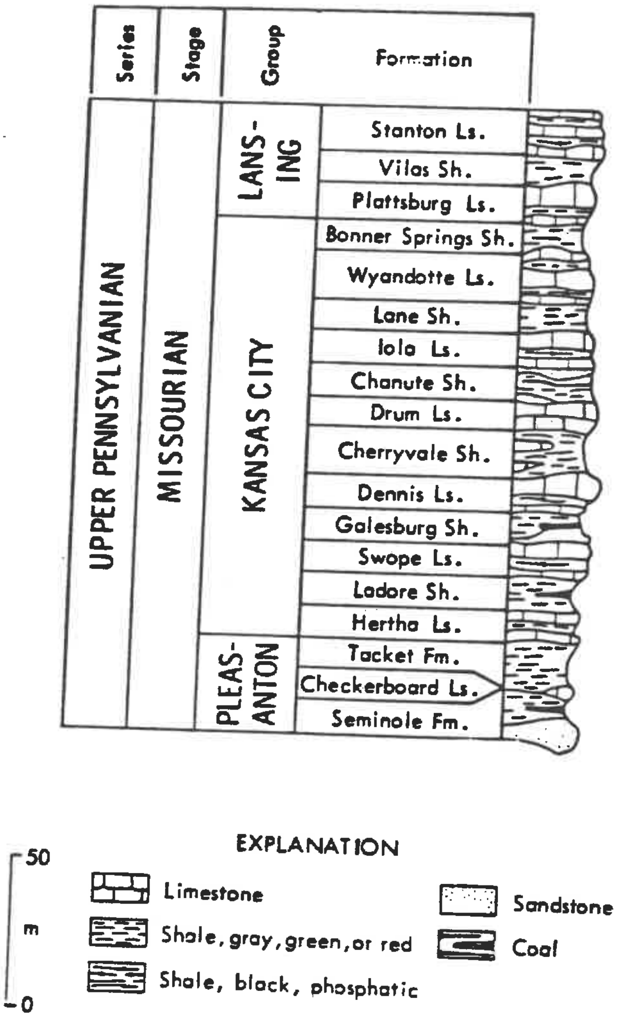

Series
Stage
Group
Formation
UPPER PENNSYLVANIAN
MISSOURIAN
LANS-ING
KANSAS CITY
PLEAS-ANTON
Stanton Ls.
Vilas Sh.
Plattsburg Ls.
Bonner Springs Sh.
Wyandotte Ls.
Lane Sh.
Iola Ls.
Chanute Sh.
Drum Ls.
Cherryvale Sh.
Dennis Ls.
Galesburg Sh.
Swope Ls.
Ladore Sh.
Hertha Ls.
Tacket Fm.
Checkerboard Ls.
Seminole Fm.
50
m
0
EXPLANATION
Limestone
Shale, gray, green, or red
Shale, black, phosphatic
Sandstone
Coal

Figure 4

Figure 5 -- Upper Pennsylvanian (Missourian Stage) outcrop belt. (△) denotes core locations; (▲) denotes outcrop locations; (■) denotes published data of Baesemann (1973) and Heckel and Baesemann (1975); (□) denotes unpublished data of P.H. Heckel (personal notes, 1968); (●) denotes location of cities. (Modified from Heckel, 1979).

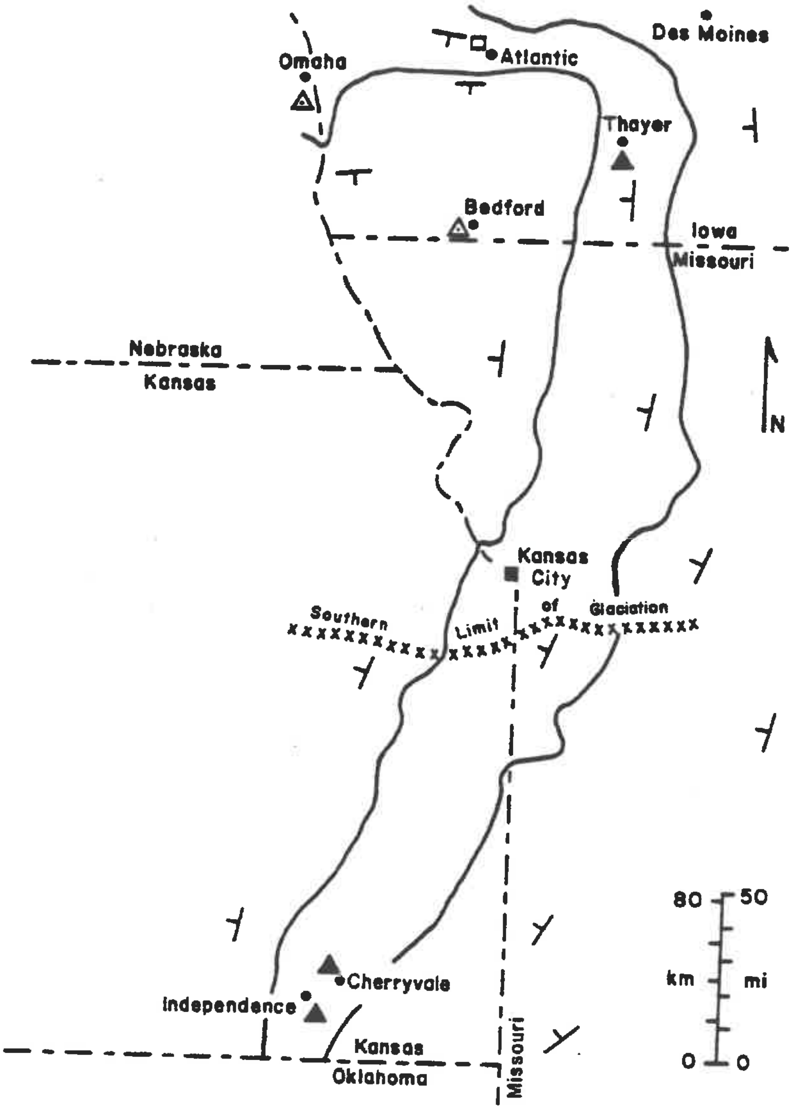

Des Moines
Atlantic
Omaha
Thayer
Bedford
Iowa
Missouri
Nebraska
Kansas
N
Kansas City
Southern Limit of Glaciation
80
50
km
mi
0
0
Cherryvale
Independence
Kansas
Oklahoma
Missouri

Figure 5

order: Fontana Shale, Block Limestone and Wea Shale. The Westerville Limestone and Quivira Shale were recognized as separate formations (Hershey, et al., 1960). A recent stratigraphic revision (Ravn, et al., in preparation), has altered the Iowa usage of the Cherryvale Formation and its members to match the Kansas usage of Moore (1948) (Figure 6).

The Nebraska column recently has been revised by Heckel and Meacham (1981) using correlations based on fusulinids. Traditional Nebraska nomenclature (Condra, 1949; Burchett and Reed, 1967) recognized the Quivira Shale and Fontana Shale as separate formations. The Block Limestone-Wea Shale-Westerville Limestone sequence of members of the Cherryvale Formation in Kansas were grouped to form the Sarpy Formation in Nebraska. Revisions of correlations based on recent fusulinid work has shown, however, that the rocks recognized as the Sarpy Formation in Nebraska, actually correlate with the Dennis Limestone in Kansas and Iowa (Heckel and Meacham, 1981). This means that the entire Cherryvale Formation of Kansas and Iowa, is equivalent to the old Quivira Shale of Nebraska, or to the old Quivira Shale and the lower portion of the overlying Drum Foramtion, particularly the P.W.A. Quarry and Richfield Quarry Members (Burchett and Reed, 1967), and perhaps more (Figure 6).

Oklahoma and Missouri strata diverge in certain aspects of nomenclature, from interstate usage concerning the Cherryvale Formation. In west-central Missouri (Jackson

Figure 6 -- Stratigraphic correlation of Swope, Galesburg, Dennis, Cherryvale and Drum Formation and Member names across Oklahoma, Kansas, Iowa and Nebraska. In Nebraska, traditional names were used, but placed in positions newly recorrelated by Heckel and Meacham (1981). (■) members probably not recognized in Iowa. (▲) members probably not recognized in Nebraska.

OKLAHOMA (Fay, 1979).	KANSAS (Moore, 1948), IOWA revised (Ravn, et al., in prep), NEBRASKA recorrelated by Heckel and Meacham (1981).		IOWA traditional (Hershey, et al., 1960, Fig. 6) and (Avcin and Koch, 1979).		NEBRASKA traditional nomenclature (Condra, 1949) and (Burchett and Reed, 1967) in positions recorrelated by Heckel and Meacham (1981).	
DEWEY LS.	DRUM LS.	Corbin City Ls. ■▲	DRUM LS.		DRUM FM.	Corbin City - Cement City Ls.
		Cement City Ls. ■▲				
NELLIE BLY FM.	CHERRYVALE FM.	Quivira Sh. ▲	QUIVIRA SH.			
		Westerville Ls. ▲	WESTERVILLE LS.			- ? --- ? ---- -?- - Richfield Quarry Sh.
		Wea Sh. ▲	CHERRYVALE FM.	Wea Sh.		-? --- ? --- -?- P.W.A. Quarry Ls.
		Block Ls. ▲		Block Ls.		
		Fontana Sh. ▲		Fontana Sh.	?-?-	? --- ? ---- -?-- QUIVIRA FM.
HOGSHOOTER LS.	DENNIS LS.	Winterset Ls.	DENNIS LS.	Winterset Ls.	SARPY FM.	Westerville Ls.
		Stark Sh.		Stark Sh.		Wea Sh.
		Canville Ls.		Canville Ls.		Block Ls.
COFFEYVILLE FM.	GALESBURG SH.		GALESBURG SH.		FONTANA FM.	
	SWOPE LS.	Bethany Falls Ls.	SWOPE FM.	Bethany Falls Ls.	DENNIS FM.	Winterset Ls.
		Hushpuckney Sh.		Hushpuckney Sh.		Stark Sh.
		Middle Creek Ls.		Middle Creek Ls.		Canville Ls.

Figure 6

County and western Cass County) the Belton Sandstone consists of lens shaped sand bodies, which are elongate northeast-southwest and convex upward. Thicknesses vary from 0 to 34 feet, and deposits commonly rest on limestone. The unit originally was interpreted as channel sands, later was reinterpreted as offshore bars (Clair, 1943). The Cherryvale Formation equivalent in Oklahoma is the Nellie Bly Formation, which is composed primarily of siltstones, sandstones and shales. It is bounded below by the Hogshooter Formation (Dennis Limestone equivalent) or by the unconformity of the base of the overlying Chanute Shale. The Nellie Bly Formation is approximately 180 feet thick in Washington County (Oakes, 1940). Southward into Seminole County, the unit ranges from 440 to 460 feet thick and picks up beds of chert conglomerate, limestone and limestone conglomerate (Ries, 1954; Tanner, 1956).

PREVIOUS WORK

Because of the poor exposure, only studies that dealt with broad subjects mentioned the Cherryvale Formation. The Cherryvale Formation was first considered a member of the Kansas City Formation by Haworth (1898), and later designated a formation in the Kansas City Group and subdivided into the members listed above by Moore (1932, 1936). Stratigraphic work prior to Moore (1931), was done on a scale that proved inconsistent when attempting to correlate specific formations and members. Workers beginning with Moore, began tracing formations and members mile by mile. Nature of the named members follows:

The Fontana Shale is a green-grey clay shale lying above the Winterset Limestone. North of Linn County, Kansas, where the overlying Block Limestone is persistent, it can be differentiated from the higher Wea Shale. South of Linn County, the unit has been identified only in localities where the Block Limestone has tentatively been identified. The Fontana Shale ranges in thickness from 5 to 25 feet, and commonly contains calcareous nodules (Zeller, 1968). It is generally barren of fossils, except near the top, where there are abundant small brachiopods, Chonetina flemingi plebeia (Moore, 1936).

The Block Limestone is commonly a dense, dark-blue limestone. North of Linn County, Kansas, it is a persistent unit, 1 to 7 feet thick. South of Linn County it thins and is discontinuous, and thus is rarely noted (Seevers, 1969). Fusulinids are commonly found, and the brachiopod *Marginifera wabashensis* is abundant in many localities (Zeller, 1968).

The Wea Shale is commonly an olive-greeen, clay-rich shale, with thin silty maroon-colored beds in the upper part. Presence of the Westerville Limestone is needed to differentiate the Wea Shale from the Quivira Shale above. The Wea Shale is 10 to 30 feet thick (Zeller, 1968), and tends to become more calcareous northward (Moore, 1936).

The Westerville Limestone is a persistent , but variable lithologic unit north of Linn County, Kansas. South of Linn County, the unit is unknown. The upper part near Kansas City, Kansas, contains cross-bedded oolite. Elsewhere, pink chert can make up to 50% of some outcrops. The unit ranges from 1 to 19 feet thick (Zeller, 1968). The "DeKalb Limestone," named from southcentral Iowa, was originally thought to occupy this stratigraphic position (Moore, 1932). Later studies revealed that the "DeKalb Limestone" correlated with the Winterset Limestone Member of the Dennis Formation. The use of the name "DeKalb Limestone" was then dropped, and the Westerville Limestone, also named from south-central Iowa, became the top limestone unit in the Cherryvale Formation. Moreover, in early publications, the unit described as the

Drum Limestone in the Kansas City area, was in fact the Westerville Limestone. The Drum Limestone is now recognized above the Quivira Shale, which overlies the Westerville Limestone (Moore, 1936). Fossils are common only in the lower part of the Westerville, and in the oolite, which contains various mollusks, brachiopods and bryozoans. The oolite is replaced north of Kansas City by a fine-grained, blue-grey limestone containing abundant small fusulinids (Moore, 1936).

The Quivira Shale is an olive-green, clay-rich shale, 3 to 11 feet thick, generally containing a 1-foot-thick layer of maroon to black shale near the bottom or middle of the unit. Small brachiopods are found in the dark layer (Moore, 1951; Zeller, 1968). North of Linn County, Kansas, it is separated from the Wea Shale below, by the Westerville Limestone. South of Linn County, the contact cannot be practically determined, due to the absence of the Westerville Limestone. Where the boundary is uncertain, the name Wea-Quivira Shale is used. The combined thickness is 15 to 35 feet (Moore, 1951; Seevers, 1969). Originally the Quivira Shale was placed in the lower part of the Drum Limestone (Moore, 1932), but later was shifted to the top of the Cherryvale Formation (Moore, 1936).

The Drum Limestone is a laterally variable unit, consisting of: 1) fine-grained dense limestone, 2) oolite, 3) granular crinoidal limestone, 4) localized fine to coarse limestone conglomerate. A wide variety of fossils are abundant in many places. The unit ranges in thickness from 2 to 60 feet, but averages around 5 feet. The Drum Limestone is traceable from southern Kansas to Kansas City, Kansas. North of Kansas City, poor exposures have made identification uncertain (Moore, 1936). Therefore, the upper boundary of the Cherryville Formation is often uncertain north of Kansas City.

STUDY METHODS AND TOOLS

Petrology of the Cherryvale Formation was examined by description of both outcrops and cores. Further investigation included thin section petrographic analysis of carbonate units and x-ray diffraction analysis of clay minerals in shale units. Thin sections were stained for carbonate mineral identification using Dickson's (1965) method.

Clay mineralogy of 70 samples was examined by x-ray diffraction. Ceramic tile mounts were used in order to produce an oriented clay aggregate that would emphasize the basal (00ℓ) relections of the clay minerals (Appendix A). X-ray analysis was carried out using a Philips APD - 3500 diffractometer and a Philips XRG - 3000 generator. Clays were run at 40 K-volts and 20 milliamperes, using Cu K alpha radiation and a graphite monochrometer. Patterns were recorded on linear graph paper (400 counts/inch) run at 60 inches/hour.

Each ceramic tile was run: 1) untreated from 2 to 32 deg. 2θ (2 deg. 2θ/min.) slow from 24 to 28 deg. 2θ (.25 deg. 2θ/min.), 3) ethylene glycolated 2 to 18 deg. 2θ (2 deg. 2θ/min.), and 4) after heating for 1 hour at 300 deg. C, from 2 to 18 deg. 2θ (2 deg. 2θ/min.). These runs were for application of the identification methods of Warshaw and Roy (1961) and Carrol (1970), and primarily for application of the semi-quantitative method of Austin (1973) (Appendix B).

Conodont distribution in 164 samples was examined in order to determine any vertical and gross lateral variation, and to compare distribution trends with the model and interpretation proposed by Heckel and Baesemann (1975). Samples were disaggregated utilizing up to three methods, depending on lithologies (Appendix C). Carbonate samples were acidized using formic acid solution. Organic rich "black" shales were immersed in sodium hypochlorite bleach, and non-organic grey shales were immersed in Stoddards Solvent and dissaggregated in hot water. Some samples with intermediate lithologies required multiple treatments with several methods in order to produce a more complete disaggregation.

After processing, the samples were washed through a set of three sieves (#18 = 1 mm mesh size, #120 = 125 micron mesh size, #230 = 62 micron mesh size). Residues greater than 1 mm were reprocessed until eliminated or weight remained constant after processing. The 125 micron residue was examined for conodonts and additional petrologic data. The 62 micron residue was saved for future study.

Residues from the 125 micron sieve that were greater than 5 grams, were processed in Tetrabromoethane (Appendix D) in order to separate the conodonts from the lighter fraction, based on specific gravities. Light fractions were scanned for additional petrologic data, and heavy fractions were examined for conodonts.

PETROLOGY

Southeast Kansas

Stratigraphic Setting

South of Linn County, Cherryvale Formation member names are not applicable, because the Block Limestone and Westerville Limestone Members, which separate the shale members, are not present. The Cherryvale Formation in southeast Kansas is predominantly shale, with subordinate carbonate. North of Cherryvale Kansas, in its type area, the unit consists of approximately 95 feet of shale (Figure 7). Four miles north of this section, near quarries along U.S. 169, the Cherryvale thins to 15 and 20 feet, and overlies the Winterset algal mounds. Southward, flat bedded calcilutites appear in the Cherryvale. These units become more predominant in the upper portion of the southern sections, as seen in the Verdigris River-Clear Creek sections. Near the Oklahoma-Kansas border, on U.S. 166, west of Coffeyville, the Cherryvale has thinned to less than 5 feet (P. H. Heckel, personal notes, 1980) and is predominantly carbonate. Southward into Oklahoma, the Cherryvale Formation grades into the Nellie Bly Formation, which is dominantly silts and shales. Overlying the Cherryvale is the Drum

Figure 7 -- Schematic cross-section of trough-shaped depositional form of Cherryvale Formation in Southeastern Kansas. Solid vertical lines denote measured sections in this thesis. Dashed vertical lines denote observations in the field. Datum used is upper boundary of Cherryvale Formation. Recent detailed work by Stone (1979), acquired after present thesis was defended shows that thick Drum Limestone was deposited in a small basin, which supports the idea of a depositional trough in this region.

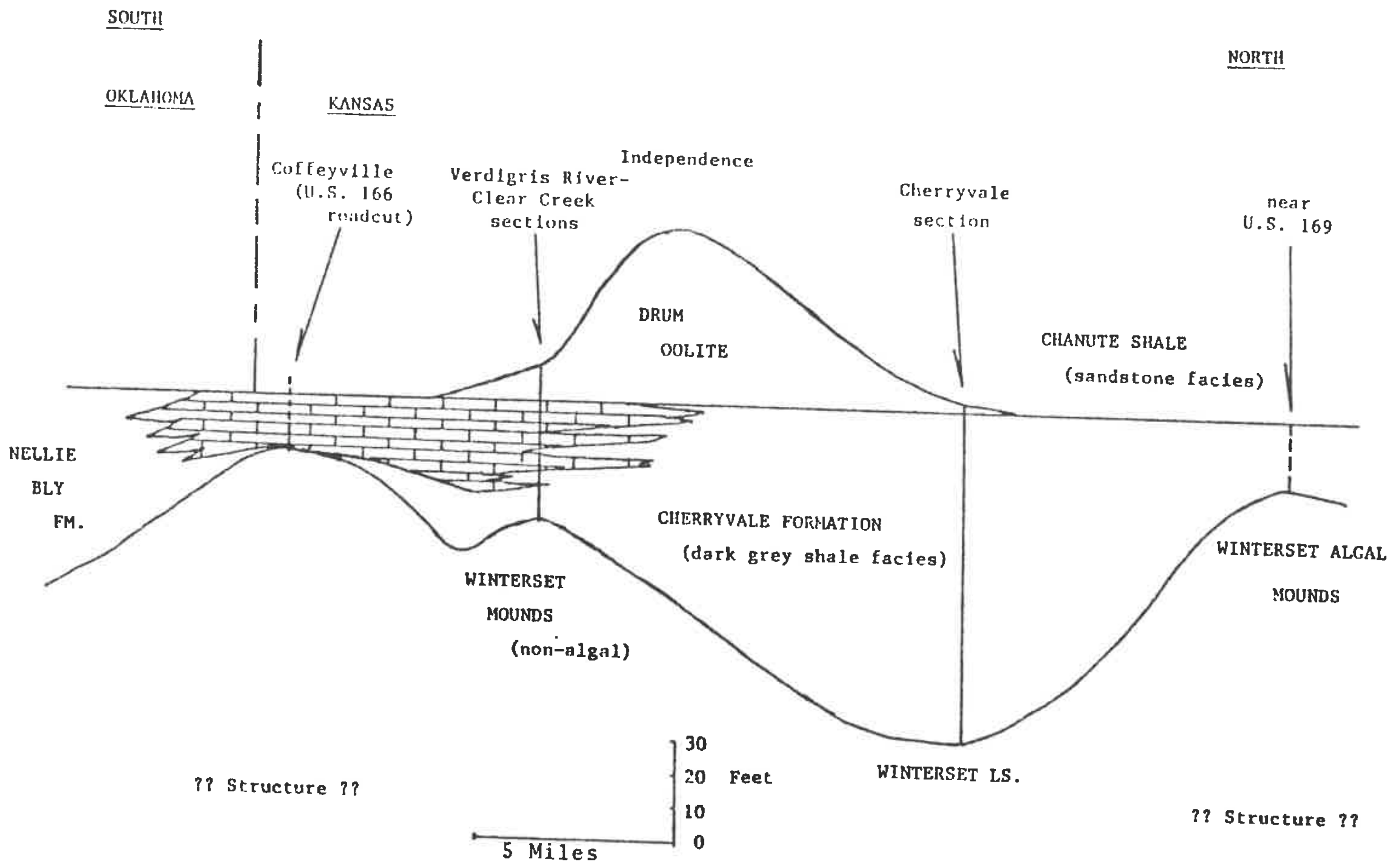

SOUTH
OKLAHOMA
KANSAS
NORTH
Coffeyville
(U.S. 166
roadcut)
Verdigris River-
Clear Creek
sections
Independence
Cherryvale
section
near
U.S. 169
DRUM
OOLITE
CHANUTE SHALE
(sandstone facies)
NELLIE
BLY
FM.
CHERRYVALE FORMATION
(dark grey shale facies)
WINTERSET
MOUNDS
(non-algal)
WINTERSET ALGAL
MOUNDS
WINTERSET LS.
?? Structure ??
?? Structure ??
30
20
10
0
Feet
5 Miles

Figure 7

Limestone (Dewey Limestone in Oklahoma) and the Chanute Shale. The Drum Limestone consists of 50 feet of oolite in the Independence area. Sandstone facies of the Chanute Shale uncoformably overly the Cherryvale in localized areas.

The changes in stratal thickness reflect a trough shaped structural low (Figure 7), bounded by the Winterset algal mounds on the north and the Coffeyville Dome on the south. A series of en echelon arches, parallel to the Bourbon Arch, were described by Jewett (1961; 1954). The Coffeyville Dome and the Cherryvale Anticline are two of these arches. The Cherryvale Anticline is located north of Cherryvale, Kansas and may be a possible structural control for portions of the Winterset algal mounds. Deposition appears controlled by this trough. The Coffeyville Dome separates the trough from the coarser clastics of the Nellie Bly Formation, and because thin carbonates are observed near the top of this structural high, the fine clastics were transported either through breaks in, or around, the structure and deposited in the trough.

Examination of the petrology, paleontology, clay mineralogy and conodont distribution, in a section north of Cherryvale, Kansas, and six sections on the Verdigris River and Clear Creek (Figure 5), was undertaken without attempting detailed lateral control. Therefore, observations will be primarily of vertical trends.

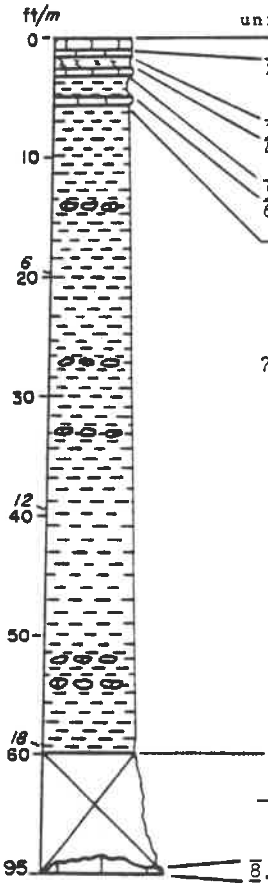
Description

Cherryvale Section

The section north of Cherryvale, Kansas, consists of approximately 90 feet of shale, overlying the Winterset Limestone exposed in Cherry Creek (Figure 8). Although the lower 35 foot portion of section is covered, it appears to be shale, with no visible surface expression of any major lithologic change. The upper 60 feet consist of 56.5 feet of lithologically uniform, dark grey, thin bedded (1-15 mm) shale, with nodular intervals (14', 27', 33', 52' and 54' from the top), overlain by 3.5 feet of interbedded carbonate and shale. No fossils were observed in the lower 56.5 feet of shale, either during examination of the outcrop, or in examination of continuous samples of the interval that were processed for conodonts. The carbonate nodules are microsparites, which contain minor amounts of angular quartz sand and are barren of fossils.

Upper carbonate beds 4 and 6 (Figure 8), are dark grey calcilutites in hand sample. Petrographically, they are echinodermal-brachiopod intraclast microsparites, with minor ostracodes. The upper 1.5 feet of carbonate can be divided into two beds. In hand sample, the lower 1 foot (unit 2) is a grey swirled calcilutite, with minor amounts of echinoderm, bryozoan, ostracode and brachiopod material, which grades upward into a light tan, mud-cracked calcilutite,

Figure 8 -- North Cherryvale (NCv) Lithologic Section.
Location: Appendix E.



units

1. Coated grain fossiliferous calcilutite
2. Grades upward from a grey swirled calcilutite to a light tan, mud-cracked calcilutite, with spar filled ooid molds on bedding planes and in cracks.
3. Yellow-brown, blocky shale, barren of fossils.
4. Dark grey echinodermal-brachiopod intraclast microsparite.
5. Yellow-brown, blocky to poorly bedded shale.
6. Dark grey echinodermal-brachiopod intraclast microsparite.

7. Lithologically uniform, dark grey thinnly bedded (1 - 15 mm) shale, with nodular intervals at 14', 27', 33', 52', 54' from the top. No fossils were observed.

—(35 foot covered interval)

8. Winterset Limestone

Figure 8

with spar-filled ooid molds on bedding planes and in mud cracks. The upper 0.5 feet (bed 1) is a coated grain fossiliferous calcilutite in hand sample. Petrographically, it is a fossiliferous oolitic microsparite with moderate amounts of pseudospar. Bryozoans, echinoderms, brachiopods, pelecypods and ostracodes are abundant. The ooids exhibit neomorphism, with few retaining minor amounts of internal structure (Plate 1a). Surrounding many grains is a gradational zone of pseudospar (Plate 1a). Irregular intergranular dissolution cavities with blocky spar fill are also present (Plate 1b). This bed may be the Drum Limestone.

The two shales that divide the upper three carbonate beds are yellow-brown clay-rich shales. The lower shale (unit 5) is poorly bedded to blocky, while the upper shale (unit 3) is blocky and lacks bedding. There were no fossils observed in either shale.

Verdigris River-Clear Creek Sections

The Verdigris River-Clear Creek sections (Figure 9) form an almost complete vertical exposure (Figure 10). The lower portion directly above the Winterset Limestone (between 710 and 740 feet above sea level) is predominantly shale with thin flat bedded calcilutites increasing upward. The upper portion (between 740 and 780 feet above sea level) is predominantly thin, wavy-bedded calcilutite, which appears

Figure 9 -- Map view of the Verdigris River-Clear Creek outcrop locations. Adapted from Independence Quadrangle (Montgomery County), Kansas, 7.5 minute Series (Topographic), 1979). Location: Appendix E.

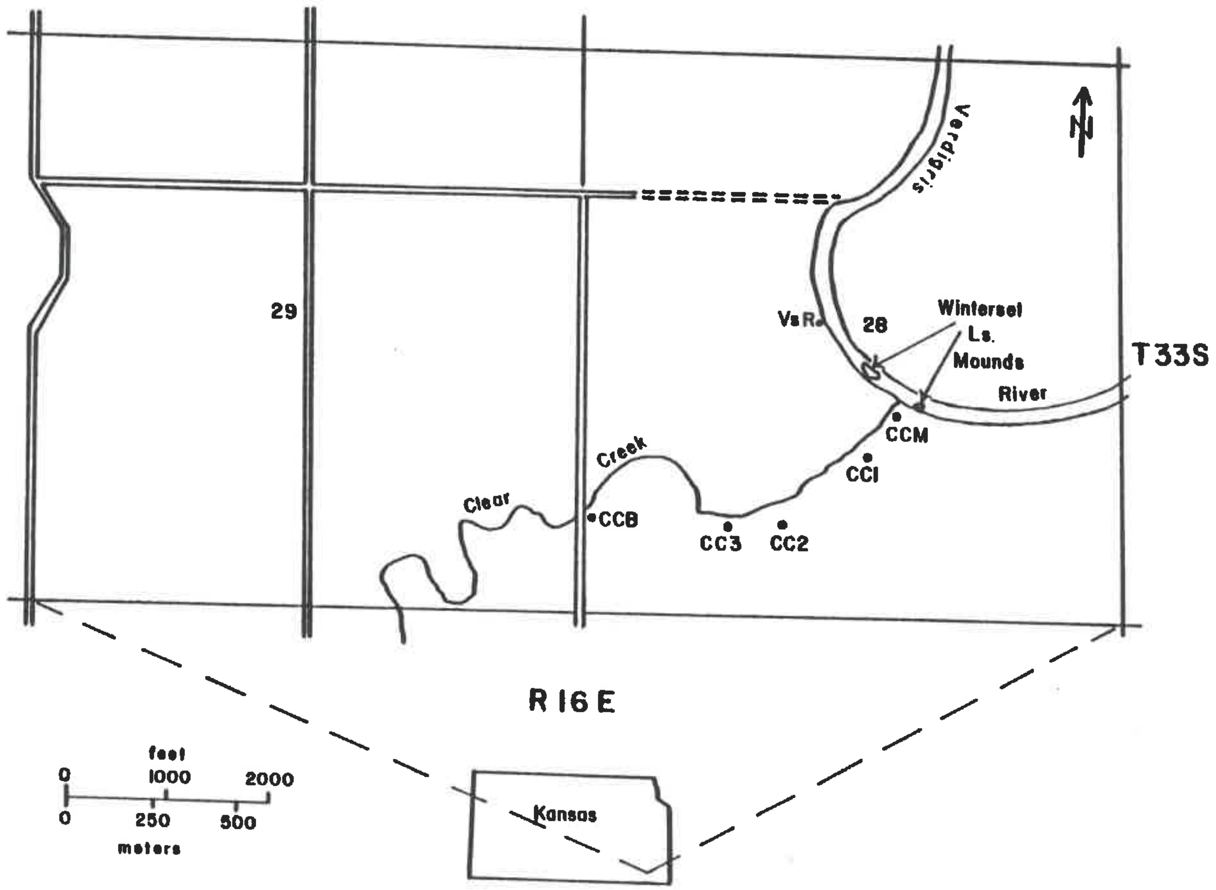

N
Verdigris
River
T33S
Wintersel
Ls.
Mounds
28
VsR.
CCM
CC1
CC2
CC3
CCB
Creek
Clear
29
R16E
Kansas
feet
0
1000
2000
0
250
500
meters

Figure 9

Figure 10 -- Lateral view of the Verdigris River-Clear Creek sections, showing relative topographic positions. Elevations were obtained by hand leveling and correlating with 7.5 minute topographic map. (*) denotes position of a channel shaped, quartz-rich carbonate unit that is anomalous in the lower section. The wavy bedded upper limestone (740 to 780 feet above sea level) is actually between 10 and 12 feet thick, with a sandstone unit similar to the top of section CC2, partially covered above section CCB. The exact cause of the vertical displacement between sections CC2 and CCB is unknown. The sandstone located at the top of section CC2 is a facies of the Chanute Shale.

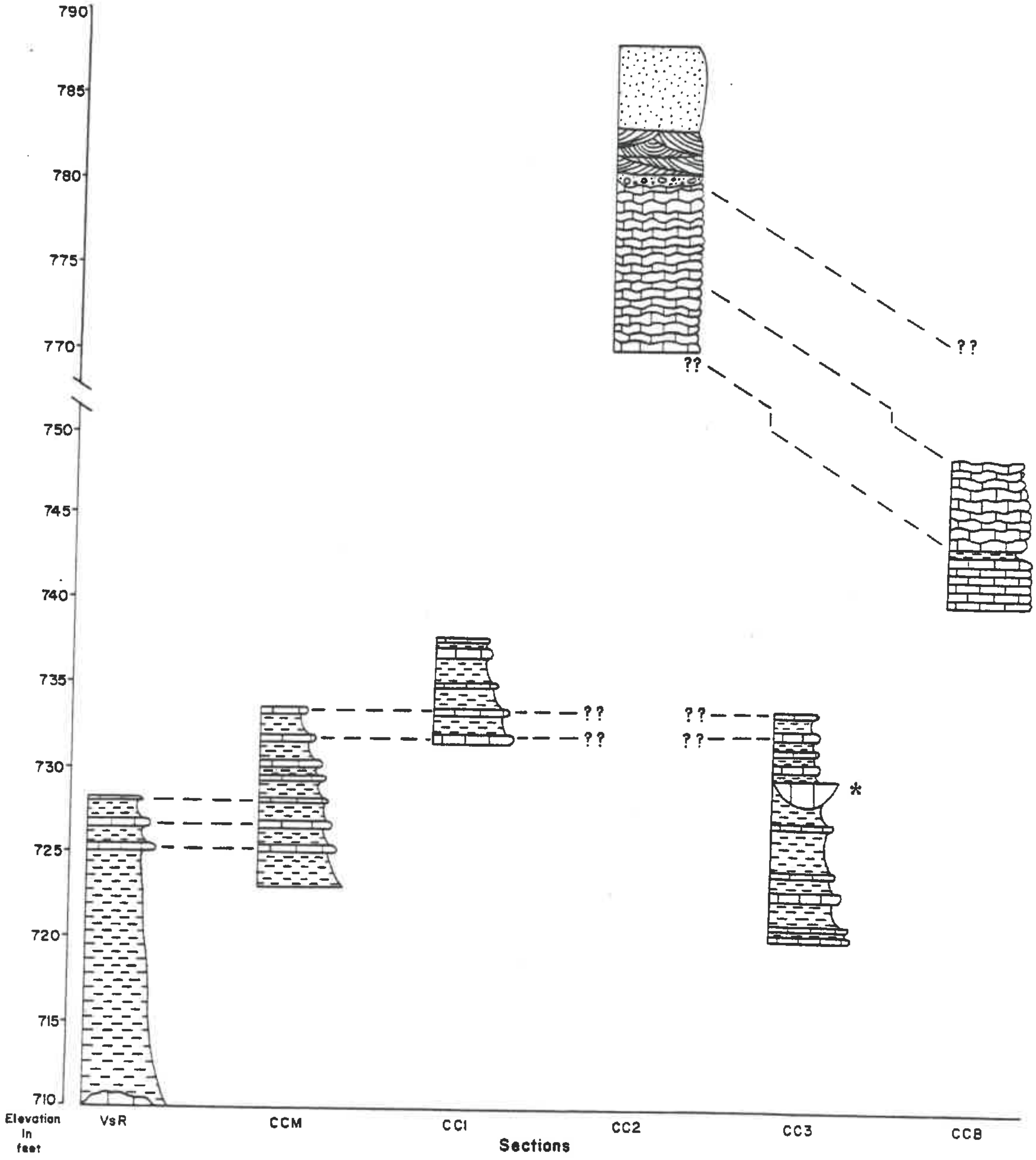

790
785
780
775
770
750
745
740
735
730
725
720
715
710
Elevation in feet
VsR
CCM
CCI
CC2
CC3
CCB
Sections
??
??
??
??
??
??
??
*

Figure 10

to be only 10 to 12 feet in actual thickness, perhaps due to local minor structure.

The lower shale units are all lithologically uniform, dark grey and thin bedded (1 to 15 mm thick). Conodonts were the only fossils observed in the shales. The thin shale unit in section CCB (Figure 10) is a green-grey, massive, non-bedded, clay rich shale. Only a single ostracode (Cavellina), quartz silt chips and muscovite were observed in this shale after processing for conodonts.

The flat-bedded carbonate units below 743 feet, in sections VsR, CCM, CC1, CC3 and lower CCB, are all similar, except for a channel-shaped carbonate bed in section CC3. The flat-bedded ("flagstone") carbonates are all dark grey, argillaceous calcilutites, which are gradational with the shales above and below. They exhibit planar and swirled laminations on fresh surfaces, and weather to rusty-colored thin plates parallel the shale beds. Petrographically, they contain ostracodes, subangular quartz sand, muscovite and rare, badly corroded echinoderms in a microspar matrix with scattered small dolomite rhombs. The channel-shaped carbonate bed in section CC3, is a dark grey fossiliferous calcarenite, which contains abundant subangular quartz sand, common echinoderms, molluscan fragments and brachiopods. All fragments are badly recrystallized and neomorphosed. The upper carbonate beds, above 743 feet, in sections CC2 and CCB are wavy bedded, light-colored granular appearing calcilutites with a mottled and swirled appearance, separated by shale stringers less than 5 cm thick. Petrographically, all of the upper carbonates, except for the upper two feet in section CC2, directly below the conglomerate, are pelmicrosparites, with a somewhat clotted fabric (Plate 1c). The upper two feet of carbonate in section CC2, consists of an oolitic pelsparite. Ostracodes, abraded echinoderms and rarely trilobites are found in minor amounts.

Depositional Environment

The near lack of fossils in the shale laid down in southeastern Kansas during Cherryvale deposition suggest overwhelming rapid clastic influx. This is compatible with the lack of conspicuous bioturbation and the lithologic uniformity in the shales. The reduced populations and low diversity in the carbonate suggest a stress environment. The argillaceous nature of most of the carbonate and the gradational contacts between the shale and carbonate suggests turbidity as a probable cause of stress. The presence of brachiopods and echinoderms suggest that salinity was not an important cause of stress, as they suggest more stable open marine salinities (Heckel, 1972). The presence of more carbonate than shale in the upper Clear Creek sections, suggests progressively more frequent periods of reduced clastic influx there. This may have coincided with deposition of the more fossiliferous, less argillaceous limestones, beds 1 and 2, in the north Cherryvale section. The upper limestones in both places contain ooids, intraclasts and coated grains, which suggest close proximity to agitated water. The dissolution features in the upper limestone (unit 1) at Cherryvale, the mud cracks in unit 2 below and the blocky, clay-rich nature of the upper two shales, units 3 and 5, suggests exposure to subaerial processes. This area reflects a shallowing-upward sequence, with subaerial exposure at the top, due either to complete basin fill, or to lowering of sea level.

Data from Heckel and Baesemann (1975) suggest that there were two minor transgressions during Cherryvale deposition in the Kansas City area. The lower transgression is not recognized in the sections in southwestern Kansas and, if present, is masked by the suggested rapid clastic influx early during Cherryvale deposition. The Drum Limestone above the Cherryvale Formation, marks the regressive portion of the second cycle, and is composed of over 50 feet of oolite in the Independence, Kansas area. The oolite found exclusively in the upper portions of both of the studied sections could be from the time period marking this regression. Although ooids by themselves are not indicative of only the Drum Limestone, their proximity to oolitic Drum Limestone and their restricted vertical position in both sections suggests compatibility.

Diagenesis

All carbonates apparently underwent neomorphism (Folk, 1965) to varying degrees. In the section north of Cherryvale, Kansas, all carbonate was neomorphosed to microspar, as defined by Folk (1965). Pseudospar was found in the upper limestone, unit 1 (Figure 8), isolated around grains. The gradation between microspar and pseudospar may have been controlled by permeability or original differences in grain size. In the Verdigris River-Clear Creek sections, all carbonate was neomorphosed to microspar, with minor amounts of pseudospar evident in preserved ooid and laminar coatings on grains found in the upper 2 feet of section CC2. Neomorphism appears to be a stability response, causing the alteration of an unstable mineral (i.e., crystal lattice), or grain size, to one that is more stable. Thus, the driving mechanisms are variable and at this time undifferentiated, but could be attributed to any combination of the following factors: 1) originally aragonitic mud, which would be less stable than the calcite of fossils, 2) initial grain size differences (i.e., more surface area in micrite than sparite), and 3) geochemical changes in ground water or pore water.

Some of the echinoderms in the channel-shaped unit (section CC3), exhibit retrograde neomorphism (Folk, 1965) (Plate 1d). This feature is easily noticed in the relatively large single crystals that echinoderms produce when they develop a polycrystalline mosaic extinction pattern. This retrograde neomorphism also is a result of instability. The fact that this effect occurred only in a carbonate unit with high quartz and content is important. The quartz sand produced stress in the echinoderm crystals during compaction, which mud or other carbonate particles would not. The crystal lattice then realigned itself into numerous smaller crystals, in order to relieve the stress, producing a polycrystalline mosaic.

Mineralogy in the carbonate is dominated by iron content in both the dolomite and calcite. The neomorphosed calcite is primarily ferroan, and ferroan dolomite rhombs are scattered throughout all carbonates. Ferroan carbonate minerals are believed to be late-stage diagenetic alterations and precipitations. The addition of iron and magnesium to the system could come from alteration of clays, especially mixed layer and smectite clays. Alteration of these clays is by replacement of any Fe, Mg, Na or Ca interlayer cations by K, forming an illitic structured clay. If this process occurs after burial, groundwater could become enriched with Fe and Mg ions in localized areas (McHargue and Price, in preparation). In the Cherryvale Formation, the fact that neomorphosed carbonates are primarily ferroan calcite, could be attributed to absorption of Fe into the crystal lattice during formation of the microspar. Relative amounts of ferroan dolomite to ferroan calcite is controlled by the relative amounts of Fe and Mg given off by clays during compation and diagenesis. The pervasive nature of iron in the Cherryvale carbonates is probably due to the relative thickness of shales (1 to 60 feet) compared to limestones (less than .5 feet), which would provide sufficient iron from the clays, for the relatively thin carbonates.

A few internal fossil pores that were not filled with micrite contain void-filling spar. This spar was differentiated from neomorphic spar by use of Bathurst's (1976) fabric criteria. Two types of spar are present: 1) a poorly formed, irregular rim of drusy high-Mg calcite or aragonite needles, and 2) a blocky interior spar fill. The presence of a drusy rim suggests possible early marine cementation in waters containing Mg poisoning of the calcite crystal, producing a needle-shaped high Mg calcite, or allowing growth only of aragonite crystals (Folk, 1974). The blocky, "dog tooth" crystals can be attributed to precipitation during meteoric ground water influences, or during later burial, each of which may have a lower ion content. The lower ion content inhibits Mg poisoning and allows lateral growth of the calcite crystals (Folk, 1974). The blocky spar does contain sufficient Fe to stain positive for ferroan calcite, and may be related to high Fe concentrations during later burial.

A possible paragenetic sequence is:

1. Early marine cementation of some larger grains to form a drusy rim.
2. Dissolution occurs in the upper north Cherryvale section. It appears to cut across microspar.
3. Meteoric ground water producing blocky spar fill.
4. Clay alteration releases additonal Fe and Mg into pore waters.
5. Late stage neomorphism, dolomitization, and remaining void fills utilize released Fe and Mg to produce a primarily ferroan mineralogy.

Southwest Iowa

Stratigraphic Setting

Moore (1979) noted that the Midcontinent north of southern Kansas, exhibited extremely low relief during Missourian deposition. The Cherryvale Formation in southwest Iowa, consists of shale, with subordinate interbedded limestones, many with gradational contacts. The Cherryvale section in the North Midcontinent thickens only slightly toward the southwest, based on cross-sections prepared by P. H. Heckel for presentation at the North Central Geological Society of America Conference (1981). A section south of Thayer, Iowa, and a core from near Bedford, Iowa (Figure 5), are described below.

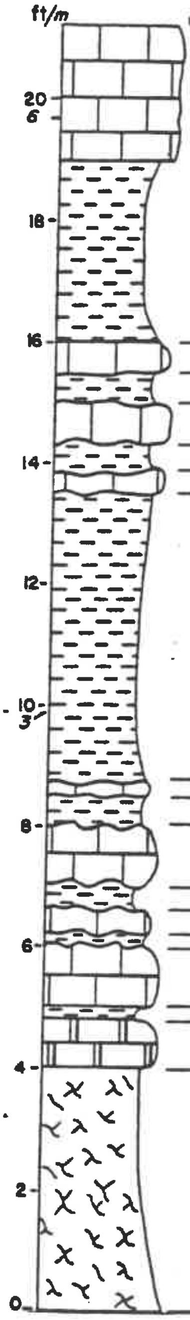
Description

Thayer Quarry

Thayer Quarry exposure is 21 feet thick and predominantly shale (Figure 11), which overlies and penetrates into the rubbly upper portion of the Winterset Limestone. The lower 4 feet of shale, unit 1, is massive, non-bedded, medium grey and contains brachiopod debris, bryozoan debris, gastropods, pelecypods and ostracodes (Cavellina). This shale is overlain, with a sharp contact, by unit 2, which is 0.8 feet of laterally variable, fossiliferous, coated-grain calcarenite (Plate 2a), with abundant microspar, and containing brachiopods, echinoderms, ostracodes, dasycladacean green algae (Epimastopora), and rare trilobite fragments. Above unit 2, all shale units are lithologically uniform, dark grey and thin bedded (1 to 15 mm). All shale units, except 11 and 17, contain productid and chonetid brachiopods, echinoderms, bryozoans, pelecypods, gastropods and ostracodes (Cavellina) in various amounts. Unit 11 contains only ostracodes (Cavellina) and grains identified as fecal pellets. Unit 17 contains only fecal pellets. Both units 11 and 17 are the only two intervals in the section that do not contain a relatively diverse faundal assemblage and are also the only two intervals that contain fecal pellets.

Units 4, 6, 8, 10, 12, 14 and 16 (Figure 11) are all dark grey argillaceous calcilutites, with gradational contacts

Figure 11 -- Thayer Quarry (TH) Lithologic and Paleontologic Section. Single vertical lines in carbonate units denote calcilutites. Double vertical lines in carbonate units denote calcarenites. (P) = present; (A) = relatively abundant; (-) = absent. Ostracode genera are differentiated only in samples processed for conodonts and generally are not differentiated in limestones. Location: Appendix E.



units	echinoderm	brachiopod debris	Chonetid	Productid	bryozoan	fusulinid	gastropod	pelecypod	*Cavellina*	fecal pellets	scolecodonts	fish debris
18	P	P	-	-	-	P	-	-	P	-	-	-
17	-	-	-	-	-	-	-	-	-	P	-	-
16	P	-	-	-	-	P	P	P	P	-	-	P
15	P	P	-	P	P	P	P	P	P	-	-	P
14	P	-	-	P	P	-	-	-	-	-	-	P
13	P	P	-	-	-	-	-	-	P	-	-	P
12	P	P	-	-	P	-	-	-	-	-	-	P
11	-	-	-	-	-	-	-	-	P	P	-	-
10	P	P	P	-	-	-	P	P	-	-	-	P
9	P	A	A	-	P	-	P	P	-	-	-	P
8	P	P	P	-	-	-	-	-	-	-	P	-
7												
6	P	P	P	-	P	-	-	-	-	-	-	P
5	P	P	-	-	P	-	-	-	-	-	-	P
4	P	P	-	-	P	-	-	-	-	-	-	P
3												
2	P	P	-	P	P	-	-	-	-	-	-	P
1	-	P	-	-	P	-	A	A	A	-	-	P

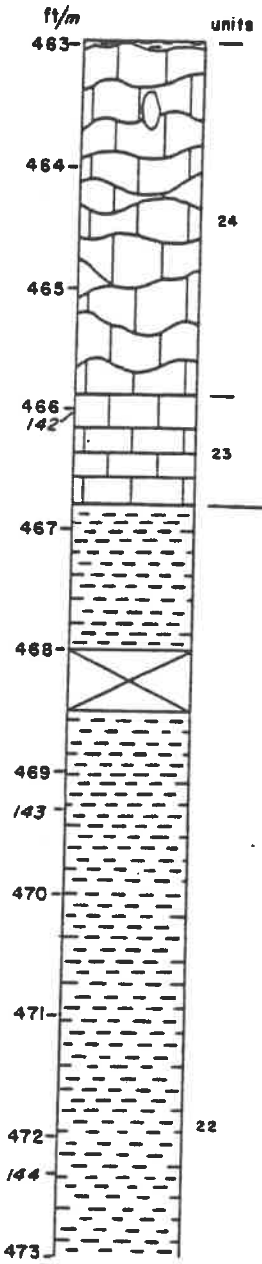
Figure 11

into shales above and below. Petrographically, they are echinoderm-brachiopod microsparites, with approximately 70% to 80% mud. Unit 18 is a light-colored, argillaceous, rubbly calcilutite in hand sample. Petrographically, it is a fusulinid calcilutite, with a few echinoderms, productid brachiopods and ostracodes (*Cavellina*).

Bedford Core

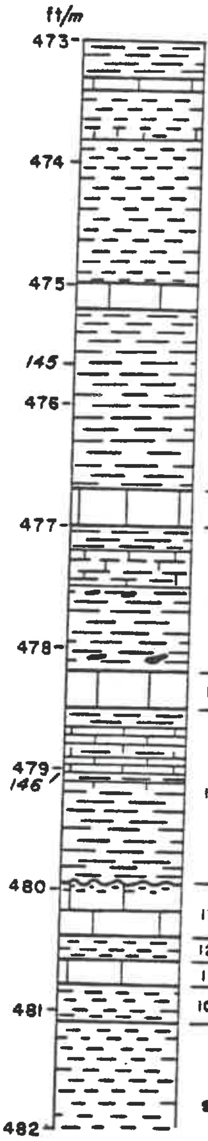
The Cherryvale in the Bedford Core is approximately 27 feet thick and is predominantly shale, but grades in and out of carbonates frequently (Figure 12). The lowest shale, unit 1, is blocky, clay rich, and contains *Cavellina* and gastropods in small numbers. It penetrates into the underlying Winterset Limestone, forming a rubbly zone. Unit 2 contains mainly *Cavellina*, fecal pellets and brachiopods (derbyids). This is the only occurrence of derbyid brachiopods, and they occur at the bottom of the interval. This is also the only occurrence of fecal pellets in the bottom 10 feet of core. Unit 3 contains *Cavellina* and is the first occurrence of chonetid brachiopods. Unit 4 is a fossiliferous calcarenite (Plate 2b), with abundant fine to coarse microspar. Petrographically, it contains abundant echinoderm, brachiopod, foraminifers, *Epimastopora* and a few pelecypods and coated grains, in a spar and microspar matrix. Many of the grains exhibit intense micritization. The remaining limestones and calcareous zones except unit 14 (at 479.0 feet),

Figure 12 -- Iowa Bedford Core (IBC) Lithologic and Paleontologic Section. Single vertical line in carbonate units denote calcilutites. Double vertical line in carbonate units denotes calcarenites. (P) = present; (A) = relatively abundant; (-) = absent. Ostracode genera are differentiated only in samples processed for conodonts and generally are not differentiated in limestones. Location: Appendix E.



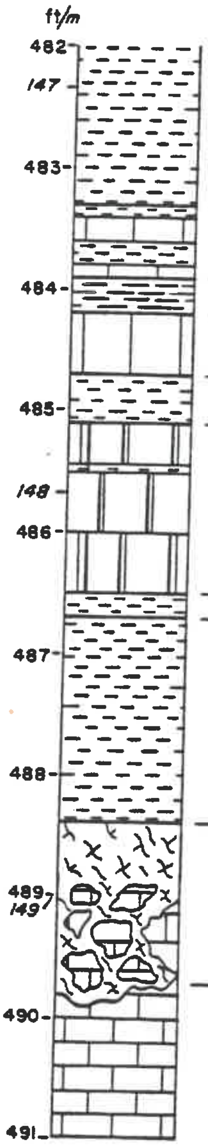
echinoderm	brachiopod debris	Chonetid	Derbyid	Productid	bryozoan	foraminifera	*Cavellina*	*Amphissites*	*Hollinella*	gastropod	pelecypod	fish debris	scolecodonts	fecal pellets	*Epimastopora*
-	A	P	-	-	-	-	P	-	P	-	-	-	-	A	-
P	-	P	-	-	-	-	P	-	-	-	-	-	-	A	-
-	-	A	-	-	-	-	P	-	P	-	-	-	-	A	-
-	-	-	-	-	-	-	P	P	P	-	-	-	-	A	-
P	P	A	-	-	-	P	A	A	A	-	-	-	-	P	-
P	-	P	-	P	-	P	A	P	P	-	-	-	-	P	-

Figure 12



units	echinoderm	brachiopod debris	Chonetid	Derbyid	Productid	bryozoan	foraminifers	Cavellina	Amphissites	Hollinella	gastropod	pelecypod	fish debris	scolecodonts	fecal pellets	Epimastopora
22	P	P	P	-	P	-	-	P	-	P	P	-	-	-	-	-
21	P	P	-	-	-	-	-	-	-	-	-	P	-	-	-	-
20	P	P	-	-	-	-	P	-	-	-	-	P	-	-	-	-
	P	P	-	-	-	-	-	-	-	-	-	-	-	-	P	-
19	P	P	-	-	-	-	-	-	-	-	-	P	-	-	-	-
18	P	-	P	-	P	P	P	P	-	P	-	-	-	-	P	-
	P	-	P	-	P	P	-	A	-	A	P	-	P	-	P	-
	A	P	P	-	-	-	P	A	-	P	-	-	-	-	A	-
17	P	P	-	-	-	P	-	-	-	-	-	-	P	-	-	-
16	A	A	-	-	-	P	-	A	-	A	-	-	-	-	-	-
	-	P	-	-	-	-	-	-	-	-	-	-	P	P	-	-
	-	-	-	-	-	-	-	A	A	A	-	-	-	-	P	-
	A	-	P	-	-	P	-	P	-	P	-	-	-	-	P	-
15	P	P	-	-	-	-	P	-	-	-	-	P	-	-	-	-
14	P	-	P	-	A	-	-	A	-	A	-	-	-	-	P	-
	P	-	A	-	A	-	-	P	-	P	-	-	-	-	P	-
	P	-	P	-	-	P	P	A	A	P	-	-	-	P	P	-
13	P	P	A	-	P	P	P	P	-	-	P	-	-	P	-	-
	P	P	P	-	-	P	-	P	-	-	P	-	-	P	-	-
12	P	-	A	-	A	P	-	P	P	P	A	P	-	-	-	-
11	P	P	-	-	-	-	-	-	-	-	-	P	-	-	-	-
10	P	A	-	-	-	-	-	P	-	-	P	P	-	-	-	-
9	-	P	-	-	-	-	-	P	-	-	-	-	-	-	-	-
	-	P	-	-	-	-	-	P	-	-	-	-	-	-	-	-

Figure 12 (cont'd)



units	echinoderm	brachiopod debris	Chonetid	Derbyid	Productid	bryozoan	foraminifera	*Cavellina*	*Amphissites*	*Hollinella*	gastropod	pelecypod	fish debris	scolecodonts	fecal pellets	*Epimastopora*
9	-	A	-	-	-	-	-	P	-	-	-	-	-	-	-	-
	-	P	-	-	-	-	-	P	-	-	-	-	-	-	-	-
	P	P	-	-	-	-	-	P	-	-	-	-	-	-	-	-
8	P	A	-	-	-	P	-	P	P	P	-	-	-	-	-	-
	P	P	-	-	-	-	-	P	-	-	-	-	-	P	-	-
	P	A	-	-	-	P	-	P	P	P	-	-	-	-	-	-
	P	P	-	-	-	-	-	P	-	P	-	-	-	P	-	-
7	P	A	-	-	-	A	-	P	P	-	-	-	-	-	-	-
6	P	P	-	-	-	-	P	-	-	-	-	-	P	P	-	-
5	P	A	-	-	A	A	-	P	P	-	-	-	-	P	-	-
4	P	P	-	-	-	-	P	-	-	-	P	P	P	P	-	P
	P	P	-	-	-	-	P	-	-	-	P	P	P	P	-	P
	P	P	-	-	-	-	P	-	-	-	P	P	P	P	-	P
3	P	-	P	-	-	-	-	P	-	-	-	-	P	-	-	-
2	-	-	-	-	-	-	-	P	-	P	P	-	-	-	P	-
	-	-	-	-	-	-	-	P	P	P	-	-	P	-	-	-
	-	P	-	P	P	-	-	P	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	P	-	-	P	-	-	-	-	-

Figure 12 (cont'd)

display a gradual upward reduction in fossils, while retaining the same faunal constituents, comprising: echinoderms, bryozoans, brachiopods, trilobites, foraminifers and ostracodes (*Cavellina*, *Hollinella* and *Amphissites*). Unit 14 (479.0 feet) contains a concentration of productid brachiopods near the bottom of a calcareous zone in a shale. The remaining shales contain the same general fauna mentioned for the limestones. Unit 22 is a light green-grey clay-rich shale that contains the only fecal pellets in the upper part of the section. The upper 4 feet of this unit is dominated by them. Ostracodes (*Cavinella* and *Amphissites*) are still common in unit 22, but only minor brachiopod debris remains. The upper limestone grades from a non-fossiliferous calcilutite (unit 23), upward to an increasingly argillaceous calcilutite, with clay stringers appearing at 463 feet. This upper limestone (units 23 and 24; Figure 12) might be the Drum Limestone, but correlation is undetermined at this time.

Depositional Environment

The rubbly, shale-penetrated limestone at the bottom of both sections, containing a blocky, non-bedded, clay-rich shale, suggests exposure to soil-forming weathering processes. The thicker interval at Thayer may suggest a longer period of exposure, or more intense weathering. The calcarenite of both sections, with coated grains and

Epimastopora, above each rubbly zone, suggests shallow, relatively clear agitated water. Nevertheless both have abundant primary micrite and heavily micritized grains (Plate 2a and 2b) suggesting slow deposition fluctuating above and below effective winnowing base. The diverse faunal assemblage in the calcarenite suggests open marine salinities. Above the calcarenite, both sections contain interbedded shales and limestone, with fairly consistent, diverse faunal assemblages, suggesting open marine salinities with fluctuating rates of clastic influx that produced a variable sequence of gradational shale and limestone beds.

The presence of ornamented ostracodes such as *Hollinella* and *Amphissites*, in conjunction with a diverse fauna that is suggestive of open marine salinities, is compatible with studies of ostracode ecology. Benson (1969) found a correlation between ornamentation and environment. The more ornamented genera were found in greater numbers in less restricted environments. In the Thayer Quarry, unit 11 contains only fecal pellets and ostracodes (*Cavellina*), an unornamented genus. This observation, together with the reduced diversity suggests a restricted environment. In most of the Bedford Core, a stable open marine environment is suggested by a relatively constant, diverse faunal group containing echinoderms, brachiopods, fusulinids, bryozoans, ostracodes (*Cavellina*, *Hollinella* and *Amphissites*), pelecypods and gastropods (Figure 12). Fluctuation in this environment is reflected in variations in abundance probably related to differing rates of basin fill.

A faunal assemblage indicating a restricted environment, occurs at the bottom of the Bedford Core, below the calcarenite (unit 4) and at the tops of both the Bedford Core (upper unit 22) and Thayer Quarry (unit 17). The lower restricted fauna contains ostracodes (Cavellina), fish fragments and derbyid brachiopods. Both upper restricted environments contain only unornamented ostracodes (Cavellina), abundant fecal pellets, and rare unidentified brachiopod debris.

The lower restricted zone in the Bedford Core probably reflects the initial inundation of the soil profile. This coincided with continued soil weathering at the more northerly Thayer locality, where a thicker soil unit was produced. The overlying calcarenite in both sections, marks a more major transgression of the sea, at or above winnowing base, across the state. The remainder of the section reflects the fluctuations between rapid and slow clastic influx, which probably caused the fluctuations in fossil abundance. The upper restricted zone reflects approaching basin fill or sea level drop. The Iowa sections do not exhibit the double cycle illustrated by Heckel and Baesemann (1975) in the Kansas City area. Continued dominance of clastic influx or insufficient inundation could have caused masking of the minor cycles.

Diagenesis

All carbonate beds in the Thayer Quarry and Bedford Core have been neomorphosed to varying extents, as reflected by their microspar fabric. Evidence for substrate control of recrystallization is present in unit 11 in the Thayer Quarry and unit 19 in the Bedford Core, which contain neomorphic spar oriented perpendicular to a brachiopod shell and penetrating into microspar matrix (Plate 2c).

Mineralogically, calcite is the dominant carbonate species. Minor isolated dolomite rhombs occur in all carbonate units, and are interpreted as probably related to clay diagenesis (McHargue and Price, in preparation). The upper two carbonates in the Thayer Quarry, units 16 and 18, have rare ferroan calcite void filling in only the centers of a few fusulinid cavities. Ferroan carbonates are interpreted as late-stage minerals and may also be related to clay diagnetic release of Mg and Fe. There is no evidence of ferroan calcite in the calcarenite of either section. This may be due to earlier void filling in those beds, which effectively reduced porosity prior to increased Fe content in the diagenetic environment.

Void filling of intergranular spaces in both of the calcarenites, unit 2 (Figure 11) and unit 4 (Figure 12), is blocky, with somewhat smaller crystals at the edge of the pores. These small crystals are attributed to initial growth from small nucleation sites and not a drusy rim from marine cementation, because they seem blocky rather than needle-like in shape and thus were probably originally calcite. Blocky spar fill is related either to the influence of meteoric water or to late stage burial. Either can produce a lower Mg ion concentration, which reduces lateral poisoning of the calcite crystal.

Rare silification, replacing only portions of one or two brachipods and echinoderms, was noted in the Bedford Coare, units 4, 5 and 8. There are no cross-cutting relationships and no internal structure was preserved.

A possible paragenetic sequence is:

1. Deposition of calcarenites and micritization of the constituent grains. This is common in shallow-water environments undergoing slow deposition, in which boring algae proliferate and have enough time to thoroughly penetrate most grains.
2. Neomorphism of micrite to microspar in both the matrix and micritized grains.
3. Void filling with non-ferroan blocky calcite. The edges of the voids appear to reflect the coarser nature of the microspar in substrate control.
4. Dolomitization and ferroan calcite void filling. Dolomitization is interpreted as late stage because the rhombs cross-cut grains and appear to have clear edges, unaffected by neomorphism. Ferroan calcite is restricted to intragranular voids, which might have

remained open for longer periods of time. Also, ferroan calcite and isolated dolomite rhombs appear to be related to late stage diagenetic alteration of clays.

5. Time of silicification is now known as no cross-cutting relationships are present.

Southeast Nebraska

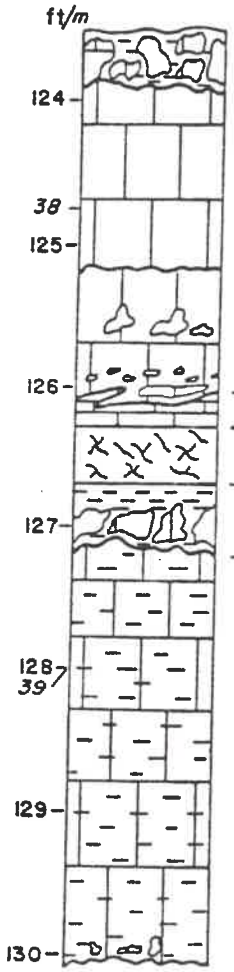
Stratigraphic Setting

The Cherryvale Formation in southeast Nebraska is predominantly carbonate with varying argillaceous content and subordinate shale units. Southeast Nebraska was in the northern portion of the Missourian epicontinental sea, and therefore was in an area of low relief (Moore, 1979). The Offutt core (Figure 5) is located on the northern extent of the Nemaha Ridge, which during Cherryvale deposition also appears to have been a low relief feature, as reflected by the dominance of carbonate in this sequence.

Description

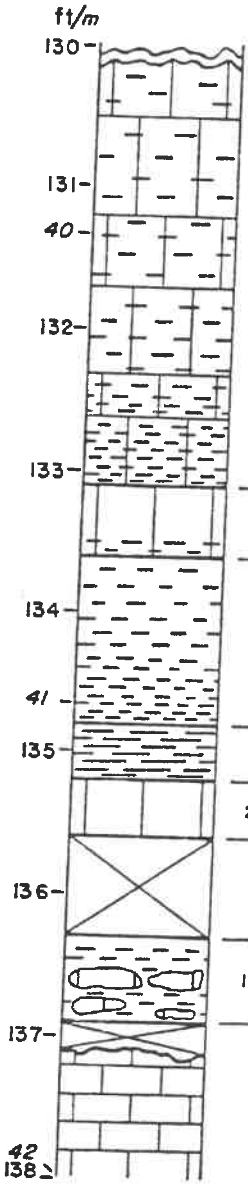
The Nebraska section was obtained from a core taken near the Offutt Air Force Base, south of Omaha, Nebraska. The section is approximately 14 feet thick and is predominantly carbonate with varying argillaceous content and four distinct shale units (Figure 13).

Figure 13 -- Nebraska Offutt Core (NOC) Lithologic and Paleontologic Section. Single vertical lines in carbonate units denote calcilutites. Double vertical line in carbonate units denote calcarenites. (P) = present; (A) = relatively abundant; (-) = absent. Ostracode genera are differentiated only in samples processed for conodonts and generally are not differentiated in limestones. Location: Appendix E.



units	echinoderm	brachiopod debris	Chonetid	Productid	bryozoan	fusulinid	*Cavellina*	gastropod	pelecypod	fish debris	scolecodonts
12											
11	-	-	-	-	-	P	-	-	-	-	-
	-	-	-	-	-	P	-	-	-	P	-
	P	P	-	-	P	P	-	P	P	P	-
10	P	P	-	-	-	-	-	-	-	P	-
	P	P	-	-	P	-	-	P	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	P	-	P	-	-	-
7	-	-	P	-	-	P	-	P	-	P	-
6	P	P	-	-	-	-	-	-	-	-	-
	P	P	-	-	-	-	-	-	-	-	-
	P	-	-	-	P	-	-	-	P	-	-
	P	-	-	-	P	-	-	-	P	-	-
	P	-	-	-	-	-	-	-	-	P	-
	P	-	-	-	P	-	-	-	P	P	-

Figure 13



units	echinoderm	brachiopod debris	Chonetid	Productid	bryozoan	fusulinid	*Cayellina*	gastropod	pelecypod	fish debris	scolecodonts
6	P	P	-	-	-	-	-	-	-	-	-
	P	-	-	-	-	-	-	-	-	P	-
	P	P	-	-	P	P	-	-	P	-	-
	P	P	-	-	P	P	-	-	P	-	-
	P	P	-	-	P	P	-	-	-	P	-
	P	-	-	-	P	P	-	-	-	-	-
5	P	P	-	-	-	P	-	-	-	-	-
4	P	P	-	-	P	P	-	-	-	-	-
	P	P	-	-	P	-	-	-	-	P	-
	P	P	-	-	-	P	-	-	-	-	-
3	P	-	-	-	-	P	-	P	P	P	-
2	P	P	-	-	P	-	P	P	P	-	-
1	- P -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	P P -	- P -

Figure 13 (cont'd)

The first 0.2 feet above the Winterset Limestine is missing, but within the upper Winterset Limestone and above the missing section is 0.6 feet of shale with limestone rubble (unit 1) (Figure 13). The shale contains only rare fish fragments and the limestone is petrographically a pelletal calcilutite with rare brachiopods and echinoderms, which have undergone fracturing. The lowest limestone bed, unit 2, is a fossiliferous microsparite, containing bryozoans, echinoderms and brachiopods. Rare subangular quartz sand and trilobite fragments are also present. Unit 3 is a splintery dark gray, weakly indurated shale containing common gastropods, pelecypods and fish fragments. Echinoderms and fusulinids are present but rare. The next 7.8 feet of section is a relatively continuous gradation from shale through argillaceous limestone, to a relatively clean limestone. The shale (unit 4) contains the same fossils as the carbonate. Unit 5 and the lower 2 feet of unit 6, are fossiliferous calcilutites with zones of abundant fusulinids at approximately 133.4 feet and 132.1 feet. Echinoderms, brachiopods, bryozoans and fish debris are also common. At approximately 131.2 feet in unit 6, osagia-coated grains appear, and micritization of constituents becomes intense. The fauna does not change vertically, except for the addition of encrusting foraminifers. Between 131.2 feet and 127.0 feet, the limestone constituents fluctuate among varous proportions of coated and uncoated grains. The carbonate that contains a higher percentage of coated grains exhibits the stronger micritization. At approximately 127.0 feet, the limestone becomes rubbly and is surrounded by a blocky shale (unit 7), containing fossil fragments of brachiopods, fusulinids and gastropods. The shale is quite coarse grained, shelly and contains some crude lamination. A blocky, clay-rich shale (unit 8) overlies the rubbly zone with a sharp contact but does not penetrate into unit 7. Unit 8 the clay-rich shale, contains gastropods and rare fusulinids. Its upper boundary is gradational into a laminated calcilutite (unit 9), which is barren of fossils. The upper surface of unit 9 is erosional, exhibiting rip-ups and laminated intraclasts suspended in the overlying calcarenitic limestone, unit 10. The next 1.5 feet of carbonate (unit 11) is a fossiliferous coated-grain calcarenite, with zones of calcilutite, grading upward into a fossiliferous coated-grain calcilutite. Encrusting foraminifers, pelecypods, gastropods, brachiopods and echinoderms are common. Fusulinids, quartz sand, trilobites and ostracodes are minor constituents. The calcarenite exhibits strong intergranular dissolution, with the fabric controlled by the amount and position of micrite (Plate 2d). A rubbly shale-penetrated carbonate (unit 12) overlies unit 11.

Depositional Environment

Fossil abundance and diversity, and the presence of echinoderms, brachiopods, fusulinids and trilobites throughout, suggest a relatively constant environment, with open marine salinities (Heckel, 1972). The argillaceous nature of most of the carbonates coupled with the diverse faunal assemblages, suggest a slow clastic influx, which allowed carbonate production to exceed clastic sedimentation.

The fluctuation between coated and non-coated grains, and micritized and non-micritized grains, suggests either slight changes in depth, or slight fluctuations in wave or current regime sedimentation rate, subsidence, and compaction, which control the vertical position of the sediment-water interface in regards to winnowing. Micritization is often associated with coated grain environment due to the proliferation of boring algae.

Major environmental fluctuation can be broken into several phases. First, the area was exposed, as suggested by the rubbly limestone at the base (unit 1) which reflects the regression ending the Dennis cycle. Above this (units 2,3,4,5,6) the rocks reflect a transgression with relatively continuous reduction in clastic influx culminating with deposition of a fairly pure limestone (upper unit 6). Minor fluctuations in the gradational sequence are reflected in the coated and non-coated grain intervals. A second depositional phase (units 7,8,9) begins with another rubbly zone (unit 7). This phase reflects the regression ending the Cherryvale cycle. The shale in this zone is not diagnostic of soil zones, yet lack of strong bedding and a rubbly penetrated carbonate are compatible with soil features. The contact between unit 8 and 9 is a gradational change from a clay-rich blocky shale to a laminated calcilutite, which suggests reduction of clastic influx through time and the formation of a carbonate supratidal zone. The blocky clay rich shale contains a restricted fauna of brachiopod fragments, fusulinids and gastropods, and the laminated calcilutite is barren. The occurrence of fusulinids can be attributed to transportation, as was noted by Phleger and Ewing (1962), in connection with transportation of analogous foraminifers into a series of more restricted lagoons in Baja, California, Mexico. The third depositional phase (units 10 and 11) reflects a second transgression and is denoted by subsequent resubmergence, suggested by the erosional nature (rip-ups, intraclasts) of the upper surface of the laminated calcilutite (unit 9). This interval (units 10 and 11) would correlate with deposition of the Drum Limestone. The upward gradation from intraclast-bearing calcarenite (unit 10) into fossiliferous calcilutite (unit 11), suggests deepening of the water by sea level rise or subsidence exceeding deposition. This interval is topped by a rubbly limestone, suggesting subaerial exposure again. This reflects the regressing ending deposition of the Drum

Limestone. The dissolution features in the calcarenite of unit 10 are also compatible with exposure.

The possible exposure suggested in unit 7 and unit 9 may: 1) represent the same period of Low sea level, as unit 8 may be a soil, or 2) reflect the culmination of the lower regressive portion of the two minor cycles illustrated by Heckel and Baesemann (1975) for the Cherryvale and Drum Formations in the Kansas City area. Lack of major clastic influx following any of these regressions may reflect local topography. The depositional area of the Offutt core is the northern extent of the Nemaha Ridge, which during Cherryvale deposition was apparently a low-relief topographic feature, as suggested by dominance of carbonate throughout the sequence.

Diagenesis

All micrite has been neomorphosed to microspar (Folk, 1965). Small dolomite rhombs are scattered throughout the carbonates. They are associated with either separate shale intervals, or suspended clays in the argillaceous limestones. During certain diagenetic alterations, clays can release Fe and Mg, which could have been utilized in the formation of scattered dolomite and ferroan carbonate minerals.

Three major periods of calcite precipitation can be noted. First, early drusy rims were formed and secondly, blocky calcite filled the intergranular and intragranular pores. Later dissolution in unit 10 produced secondary porosity which subsequently became filled with blocky calcite. The drusy rim cement reflects marine precipitation, while the blocky cement suggests precipitation in waters of lower ion concentration. The third period of cementation exhibits a gradation from small crystals near the pore edge and larger crystals in the pore center. Yet, the smaller crystals are not needle-like and appear to be smaller blocky crystals caused by nucleation on microspar pore walls.

Minor amounts of chalcedony are found as void fills and several have replaced carbonate outward from the void, retaining internal structure.

A possible paragenetic sequence is:

1. Deposition and early marine, drusy calcite cement.
2. Meteroic water influence causes blocky calcite precipitation.
3. Silicification fills original pores and replaces some cements.
4. Subaerial exposure produces secondary porosity in unit 10.
5. Clay diagenesis releases Fe and Mg, resulting in scattered dolomite rhombs (units 2,5,6,9,10 and 11) and ferroan calcite void fill in secondary pores (unit 10).

Plate 1 -- Photomicrographs

a. Neomorphosed ooid exhibiting concentric laminar structure and surrounded by a zone of psuedospar which grades outward into microspar matrix (plane-polarized light; NCv-0).

b. Dissolution feature with "dog tooth" blocky spar filling (crossed-polarized light; NCv-0).

c. Packed pelletal microsparite with clotted fabric (crossed-polarized light; CC2-6).

d. Retrograde neomorphism reflected in mosaic extinction pattern of echinoderm grain (cross-polarized light; CC3-8c).

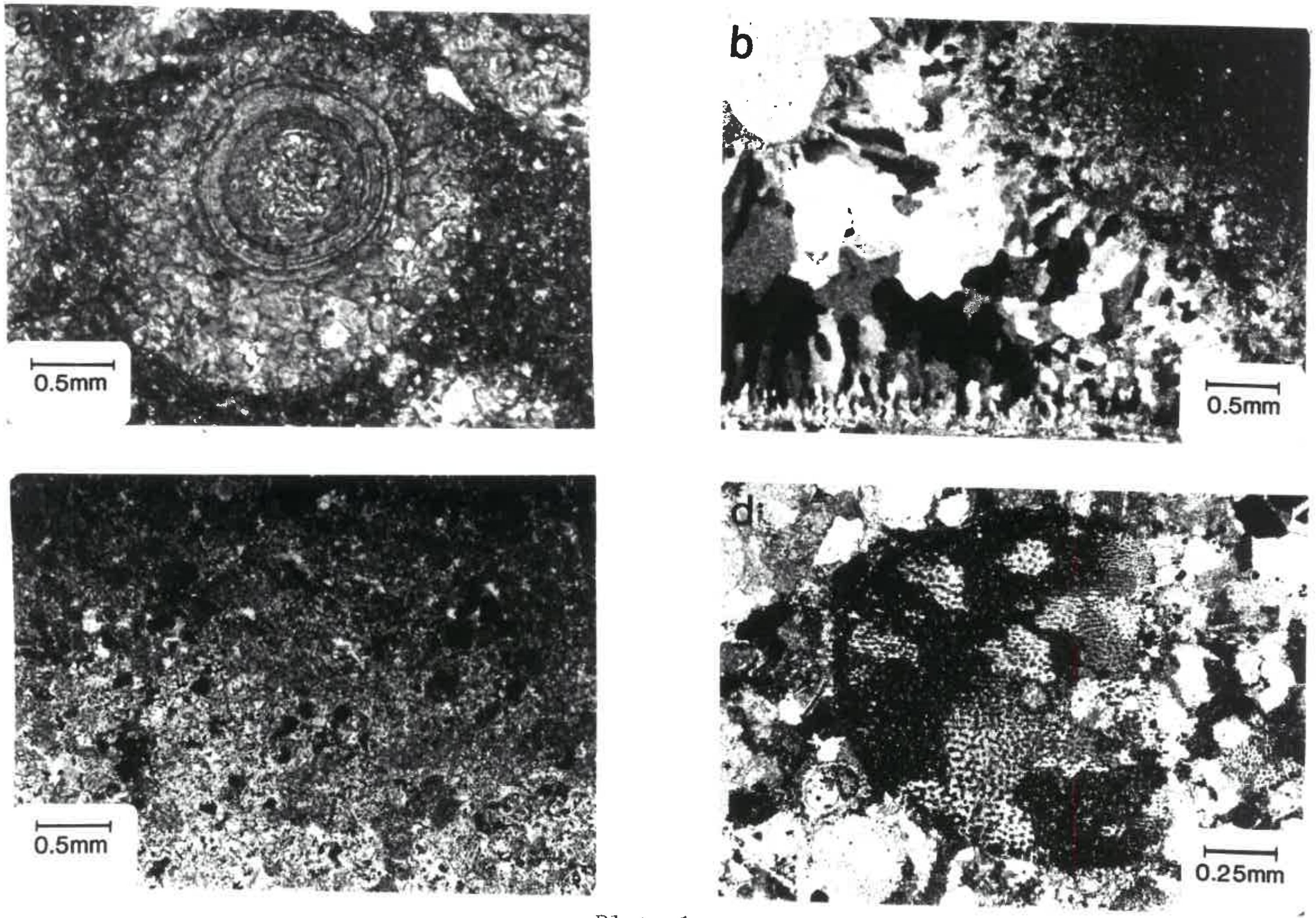


Plate 1

Plate 2 -- Photomicrographs

a. Fossiliferous calcarenite containing grains with micritized rims and encrusting foraminiferal coatings (plane-polarized light; TH-4.5). Note the micrite content in the matrix and the dasycladacean green algae (Epimastopora = E).

b. Fossiliferous calcarenite containing grains with micritized rims and encrusting foraminifers coatings (cross-polarized light; IBC-486). Note the micrite content in the matrix and the minor silicification in the center of the echinoderm grain.

c. Substrate controled recrystallization exhibited by psuedospar growing perpendicular to brachiopod shell fragment, into microspar matrix (plane-polarized light; IBC-475).

d. Fossiliferous coated-grain calcarenite exhibiting dissolution features and blocky calcite void fill (plane-polarized light; NOC-125.5). Note the sharp, irregular contacts between spar and micritic portions of the calcarenite, which suggests dissolution.

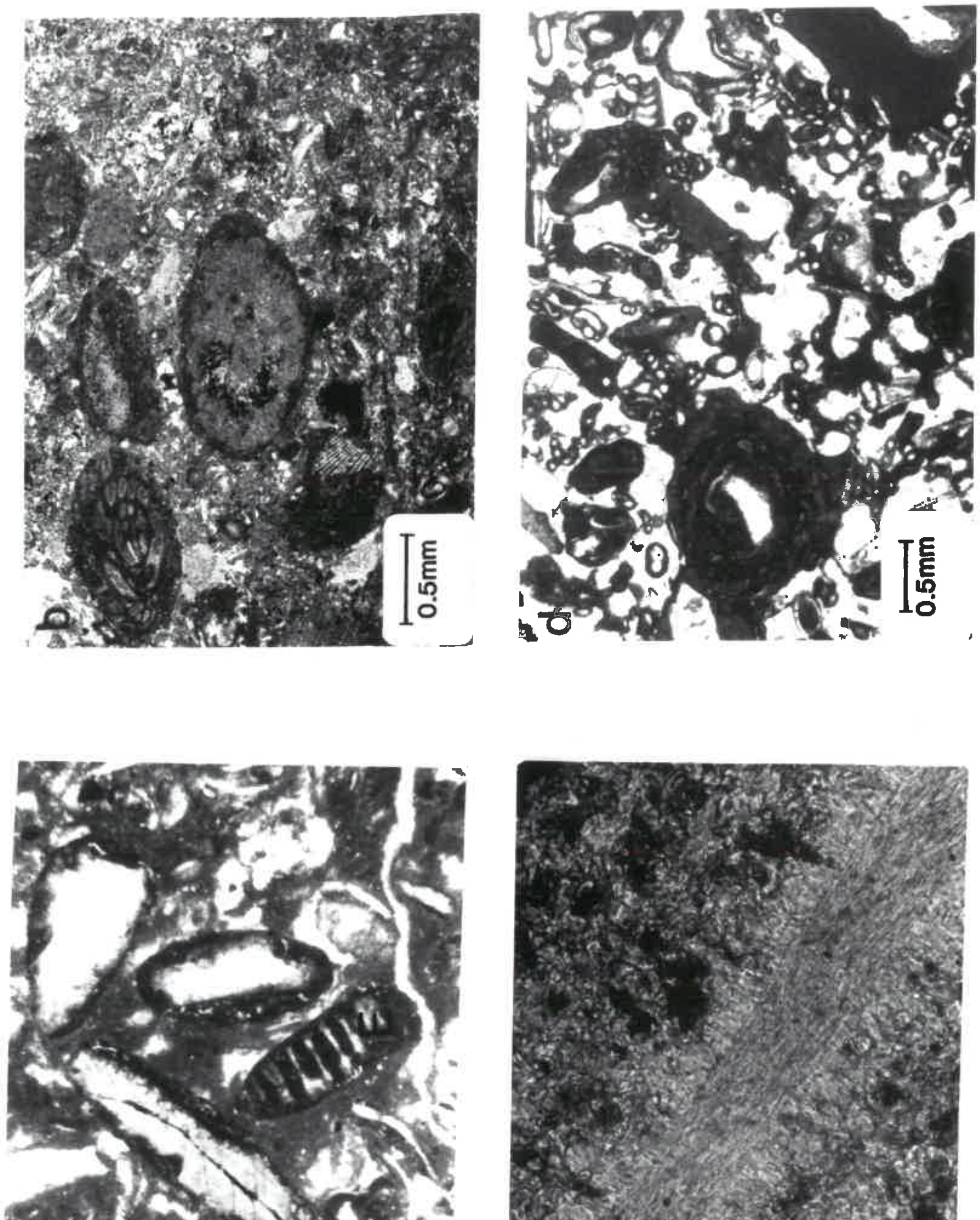


Plate 2

CLAY MINERALOGY

General Background

Clay mineral assemblages and distributions are systematic, and can be related to geologic events or processes, although they generally must be integrated with other available geologic data. With clay mineral data alone, identification of an individual environment might be difficult, but when dealing with vertical and lateral trends representing several environments, it is possible to assign them in a sequential order of "more continental" to "more marine" (Weaver, 1960).

Clay minerals, as a group, are layered alumino-silicates that are relatively stable at surface temperature and pressures, and are differentiated based on their structure and composition. Structurally, clays are made up of alternating layers of two types, tetrahedral (T) and octrahedral (O). The tetrahedral layer is composed of silicon and oxygen, and the octahedral layer of various cations surrounded by oxygen. Ion substitution occurs regularly in these lattices, causing various charge deficiencies, which are commonly balanced by absorption of other cations between repeatable T-O-T sequences (interlayer positions), or by cation substitution inside tetrahedral or octahedral layers.

The amount of substitution can be a reflection of weathering or crystallinity, and can be recognized in x-ray peak intensities and shapes.

Kaolin, illite, chlorite and mixed-layer clays are found in the Cherryvale Formation, in quantities measurable by x-ray diffraction. The following generalized clay formulas are commonly given in this order: interlayer ions, octahedral cations, tetrahedral cations, oxygen and hydrated ions (Grim, 1968).

Kaolin (Al_4 $[Si_4O_{10}]$ $[OH]_8$) has a T-O structure with approximately a 7 Å (001) spacing (12.4 deg. 2θ reflection). It is commonly formed from weathering of alkali-rich rocks in tropical acid environments (high H^+ and Al^{+3} activity).

Illite ($K_{1-1.5}Al_4$ $[Si_{7-6.5}Al_{1-1.5}O_{20}]$ $[OH]_4$) has a T-O-T structure with approximately a 10 Å (001) spacing (8.8 deg. 2θ reflection). It commonly forms from weathering in environments where K^+ activity is high relative to other cations, or by alteration of other clay minerals in the marine environment.

Chlorite ($[Mg,Al,Fe]_{12}[(Si,Al)_6O_{20}]$ $[OH]_{16}$) has a (T-O-T)-O-(T-O-T) structure, with approximately a 14 Å (001) spacing (6.2 deg. 2θ reflection). Today chlorite is more common in higher latitudes, where less intense weathering occurs. It can also form in the marine environment, where the Mg^+ activity is high.

Mixed-layer clays are poorly crystalline products of weathering and incomplete marine alteration. They commonly occur by degradation of any of the T-O-T structured clays in soil formation, or by incomplete "illitization" or "chloritization" of smectitic or mixed-layer clays in the marine environment, forming interlayered combinations of clay minerals (i.e., illite-kaolin or chlorite-kaolin). They can produce broad, poorly-defined peaks from 0 deg. 2θ to 8.8 deg. 2θ (001 reflections).

Many studies disagree on the stability of clays, and the extent and rate of diagenesis. The Cherryvale Formation has not undergone regional metamorphism and therefore is below zeolite grade. Within these parameters, provenance and sedimentation rates are the major factors controlling clay mineral assemblages (Milne and Earley, 1958). Source determines the primary clay minerals that are produced from chemical and physical weathering of specific rock types under specific conditions. Sedimentation rate affects the length of time a clay mineral, under equilibrium with the source area, will have the re-equilibrate during transportation and deposition.

Milne and Earley (1958) noted that the difference between the montmorillonitic-rich Mississippi Delta sediment and the kaolin-rich Mississippi Sound-Mobile Bay sediment, was provenance. The Mississippi River drains midcontinent solids, rich in montmorillonitie, while the Mississippi

Sound-Mobile Bay sediment is derived primarily from the Appalachian Province and "red soils" of the southeastern United States.

At surface temperatures and pressures, the diagenetic changes in clay minerals occur slowly, and rates are not significantly changed in fluvial and marine environments. Nevertheless, clay minerals exposed to terrestial weathering are altered to a greater extent, depending on a wide variety of physical and chemical parameters (i.e., pH, Eh, ion concentrations, temperature ranges). Shover (1964) found that non-marine clay alteration in the Cisco Group (Upper Pennsylvanian) is much greater than in marine environments. Grim (1958) noted that some soil formation results in degradation of clay crystallinity, producing mixed-layer and swelling clays. Kaolin-rich soils are products of intense chemical weathering with abnormally high H^+ activity (low pH). Nevertheless, clay minerals in fluvial transit would experience little or no bulk change (Weaver, 1958). Rhoton and Smeck (1981) examined illite-rich soil sediment that had equilibrated after 217 days on the bottom of the Auglaize River in Ohio. They found: 1) reduction in carbonate, 2) reduction in particle size, 3) a slight reduction in Al^{+3} and Si^{+4}, and 4) no significant alterations in basal spacings. All this means that deposited clays have not undergone significant alteration during transportation and reflect weathering and provenance.

Clay minerals entering the marine environment would undergo alteration due to changes in equilibrium, but most alterations occur slowly enough that they would be incomplete by the time burial removed the clay mineral from direct contact with the marine environment (Grim, 1958). Marine alteration processes include: 1) increased K^+ concentration causing absorption by degraded illite and producing a more crystalline illite; 2) increased Mg^{+2} concentration causing absorption by degraded chlorite, and resulting in more crystalline chlorite; 3) montmorillonite absorbing K^+ and Mg^{+2} and causing marine alteration toward illite or chlorite, but because of slow rates, the alteration would probably be incomplete, and mixed-layer clays would result; 4) two-layer clays (i.e., kaolin, T-O structure) would be out of equilibrium also, but because of low cation exchange rates and low absorption capacity, one would expect only a slight reduction in the amount of two-layer clays deposited vs. those transported in (Grim, 1958). Whitehouse and McCarter (1958) found no significant alterations in kaolin and illite toward other clay minerals after exposure to artificial sea water for five years. Montmorillonitic clays subjected to the same environment altered to 7.8% chlorite, 4.1% illite and 10.6% indeterminate (chloritic-illitic). Milne and Earley (1958) noted montmorillonite to be the dominant clay mineal in the actively prograding portions of the Mississippi Delta, to a depth of several thousand feet. Areas of reduced sedimentation, such as the St. Bernard sub-delta, which has been inactive for approximately 400 years, contain dominantly illite sediments.

Other parameters should be considered when interpreting clay mineral distributions: 1) settling rates based on clay mineral sizes and flocculation (Gibbs, 1977), 2) organic-clay mineral complexes (Grim, 1968), and 3) oceanic chemical evolution (Harriss, 1967). All clay data should be integrated with available geologic data before interpreting the results.

In describing the clay mineral distribution in the Cherryvale Formation, four major factors will be examined: 1) semi-quantative percentages of clay minerals, 2) illite crystallinity, 3) K_2O content in the illites, and 4) non-quantitative variations in x-ray diffraction peak shapes. Due to time limitations, only shales were run for clay minerals. Two points that add validity to this method are: 1) carbonates tend to retard the disintegration of primary silicates (Grim, 1968); 2) types of clay suites and associates found in shales are commonly found in adjacent limestones (Weaver, 1960). X-ray diffraction of clay minerals in the limestone would only supplement the interpretation, and would be a recommended procedure for future studies.

Semi-quantitative methods have been proposed by many authors (Weaver, 1967; Fraser, 1970; Austin, 1973). Because of previous use of Austin's method by other workers in the area, and the potential for comparisons, I will use Austin's (1973) equations. Most methods are based on relative changes in peak height or area, after the clay mount has undergone different processes. Austin's (1973) method is described in Appendix D. These equations produce percentages that are internally compatible, but great care must be taken when comparing from sample to sample.

Weaver (1960) utilized illite crystallinity (10 Å / 10.5 Å peak height ratio) to denote relative degrees of low-grade metamorphism. The larger the ratio, the greater the degree of metamorphism, which produces a more crystalline illite, causing a sharper, narrower peak. Carrying this in the opposite direction, relative degrees of weathering and possible soil profiles might be recognized using the same ratio (S. R. Schutter, personal communication, 1981). The lower the ratio (< 1.2) (Table 1), the more degraded the illite, which reflects terrestrial weathering rather than fluvial transportation. Degraded illite should be differentiated from marine "illitized" montmorillonitic clays by peak symmetry. Degraded illite should remain with a relatively steep 8.8 deg. 2θ reflection and a flatter reflection on the low 2θ side. Marine generation of illite from montmorillonitic clays should produce various broad

Table 1

Illite Crystallinity Values in Shales of Known Metamorphic Grade

Degree of Metamorphism	Sharpness Ratio
Low grade metamorphism	12.1
Weak to very weak metamorphism	6.3
Incipient to weak metamorphism	4.5
Incipient metamorphism	2.3
Unmetamorphosed Stanley	2.3
Unmetamorphosed Atoka	1.8
Marine illite*	1.5-2.3*
Weathered illite*	< 1.2*

From Weaver (1960). * denotes possible adaptation of illite crystallinity to interpret degradation or soil weathering, based on observations by S. R. Schutter (personal communication, 1981).

intermediate mixed layer clay peaks nearer the original montmorillonite peak location (5.2-7.1 deg. 2θ). This interpretation should be examined closely. The calculation method is described in Appendix B.

K_2O variation will be examined using the peak ratio method of Weaver (1965). Weaver noted that as the K_2O content increased, the (00ℓ) reflection intensities of illite decreased, but with the (001) reflection decreasing more rapidly than the (002) reflection. Thus a ratio between the 10 Å and 5 Å reflections should be dependent on K_2O content. Presence of expandable layers, due to degradation, would decrease the percentage of K_2O in the clay. Weaver found a modal value of 9.3% K_2O for Paleozoic illites. This method is described in Appendix B.

Subtle variations in peak shape can often be more useful in delineating weathering or alteration, than gross semi-quantitative clay mineral composition (Shover, 1964). Peak width is generally considered a reflection of crystallinity, with a wide flat peak denoting poor crystallinity through scattering of the refracted x-rays by irregularities in the crystal lattice. The opposite is true of a narrow peak, which would be caused by less scattering, resulting in a narrower band of refractions from the crystal lattice. Organic complexes and coatings can mask peak shapes and reduce their effectiveness.

Southeastern Kansas

Kansas sections contain illite, chlorite, kaolin and mixed-layer clays. No montmorillonite was identified in any of the sections. In examining the clay mineral associations, illite crystallinity, % K_2O and peak shape, both minor vertical trends and minor lateral trends are apparent.

The north Cherryvale section (Figure 14) exhibits an addition of and subsequent increase in kaolin through time. Except for the uppermost sample, all illite crystallinity values are relatively high (1.33-4.03), and K_2O content is also relatively high (9.3%-10.0%). The Verdigris River section (Figure 15) exhibits a similar addition and increase in kaolin through time. The uppermost Verdigris River samples and all of the sample Clear Creek sections contain kaolin. The uppermost Verdigris River sample and all of the Clear Creek Mouth (CCM), Clear Creek 1 (CC1) and Clear Creek 3 (CC3) sections (Figures 15, 16, 17, 18) contain strongly weathered chlorite. All sections in this area have relatively high illite crystallinity (1.24-2.93) and K_2O content (9.07%-10.1%).

High illite crystallinity in all samples (except the uppermost shale at north Cherryvale) and high K_2O content suggests erosion of non-soil material. Strong marine alteration is not compatible with paleontologic evidence of dilution, and this suggests rapid deposition, which would remove the clay material from strong marine alteration, as

Figure 14 -- North Cherryvale (NCv) Lithologic Section and Clay Mineralogy. All lines are interpolated between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

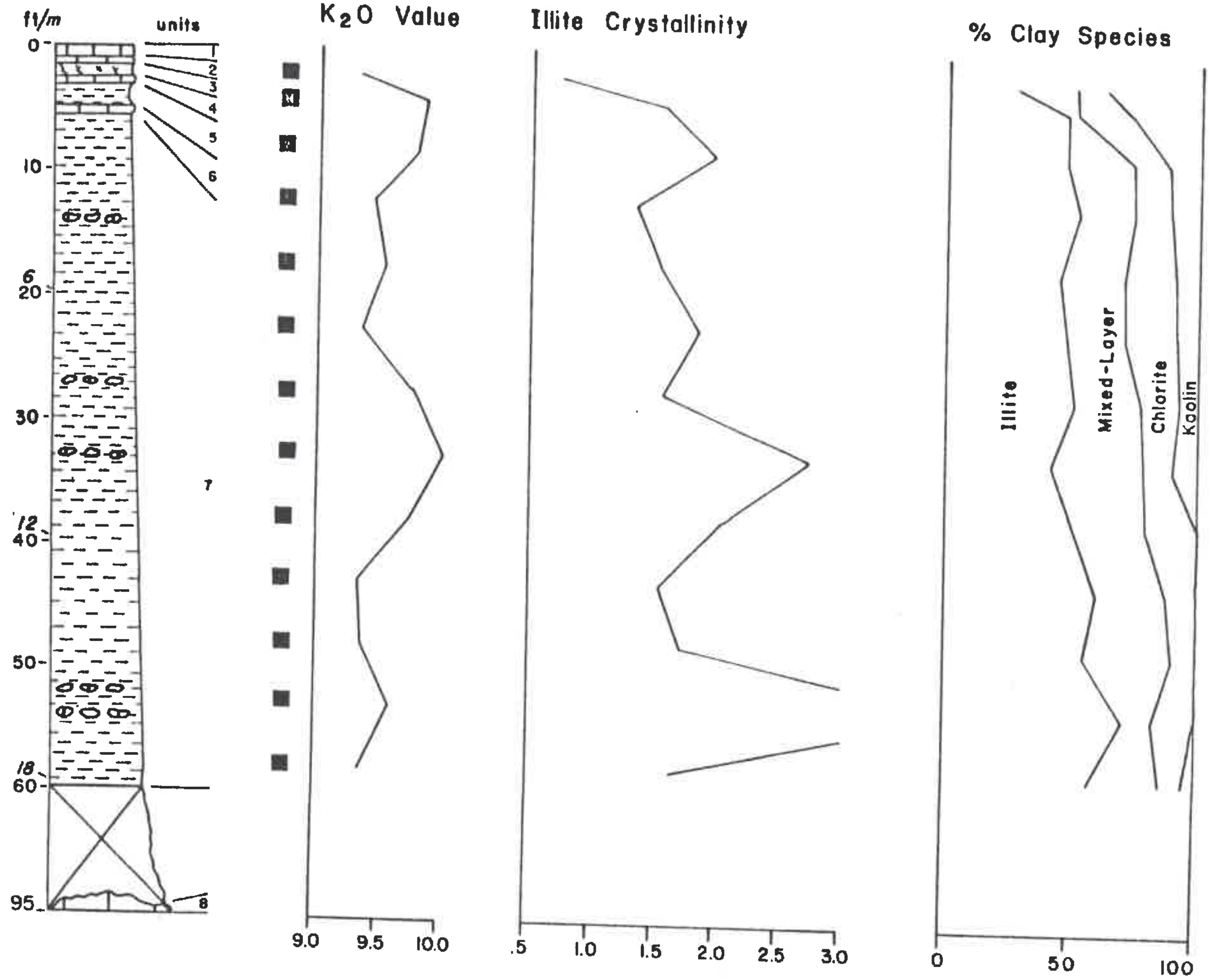

ft/m
units
0
10
6
20
30
12
40
50
18
60
95
1
2
3
4
5
6
7
8
K₂O Value
9.0
9.5
10.0
Illite Crystallinity
.5
1.0
1.5
2.0
2.5
3.0
% Clay Species
Illite
Mixed-Layer
Chlorite
Kaolin
0
50
100

Figure 14

Figure 15 -- Verdigris River (VsR) Lithologic Section and Clay Mineralogy. All lines are interpolated between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

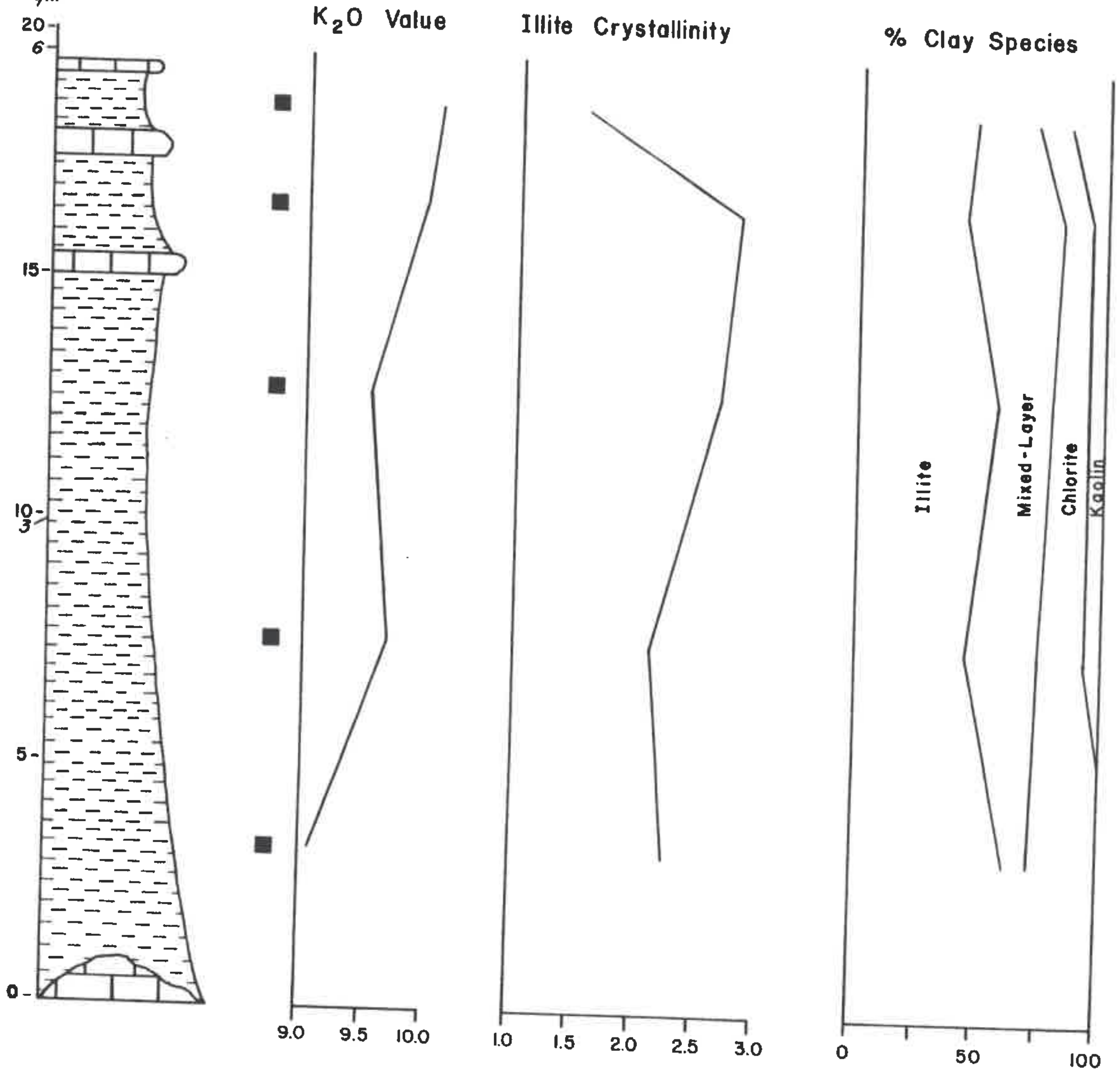

ft/m
20
6
15
10
3
5
0
K$_2$O Value
9.0
9.5
10.0
Illite Crystallinity
1.0
1.5
2.0
2.5
3.0
% Clay Species
0
50
100
Illite
Mixed-Layer
Chlorite
Kaolin

Figure 15

Figure 16 -- Clear Creek Mouth (CCM) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

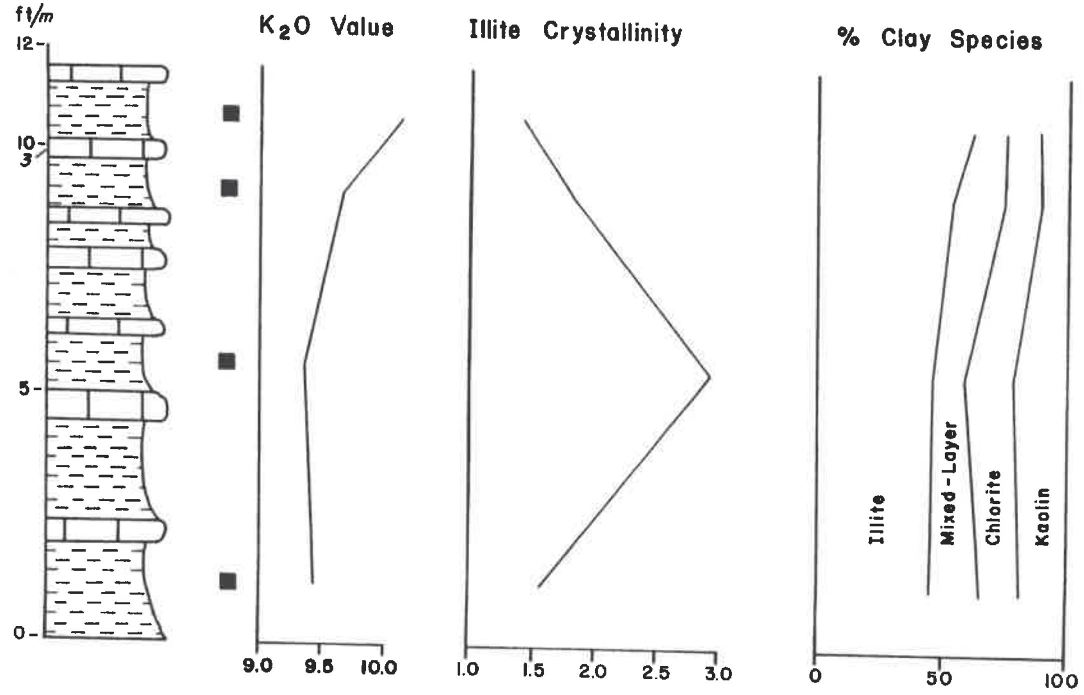

ft/m
12
10
3
5
0
K$_2$O Value
9.0
9.5
10.0
Illite Crystallinity
1.0
1.5
2.0
2.5
3.0
% Clay Species
Illite
Mixed-Layer
Chlorite
Kaolin
0
50
100

Figure 16

Figure 17 -- Clear Creek 1 (CC1) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample position. Location: Appendix E.

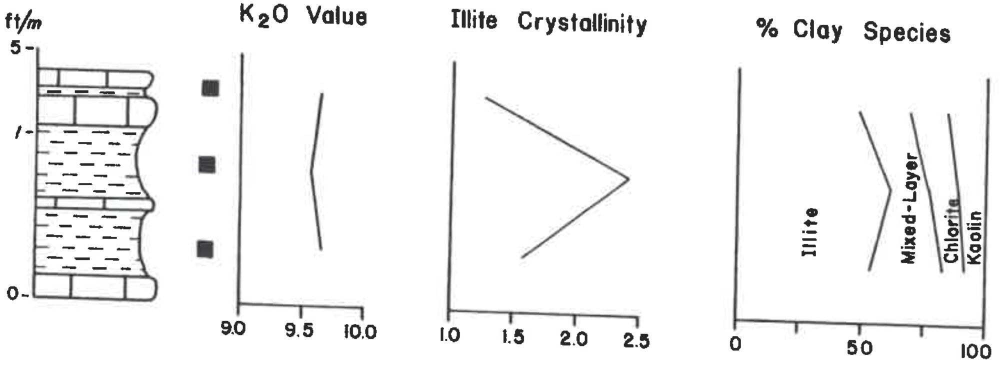

ft/m
5
1
0
K₂O Value
9.0
9.5
10.0
Illite Crystallinity
1.0
1.5
2.0
2.5
% Clay Species
Illite
Mixed-Layer
Chlorite
Kaolin
0
50
100

Figure 17

Figure 18 -- Clear Creek 3 (CC3) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

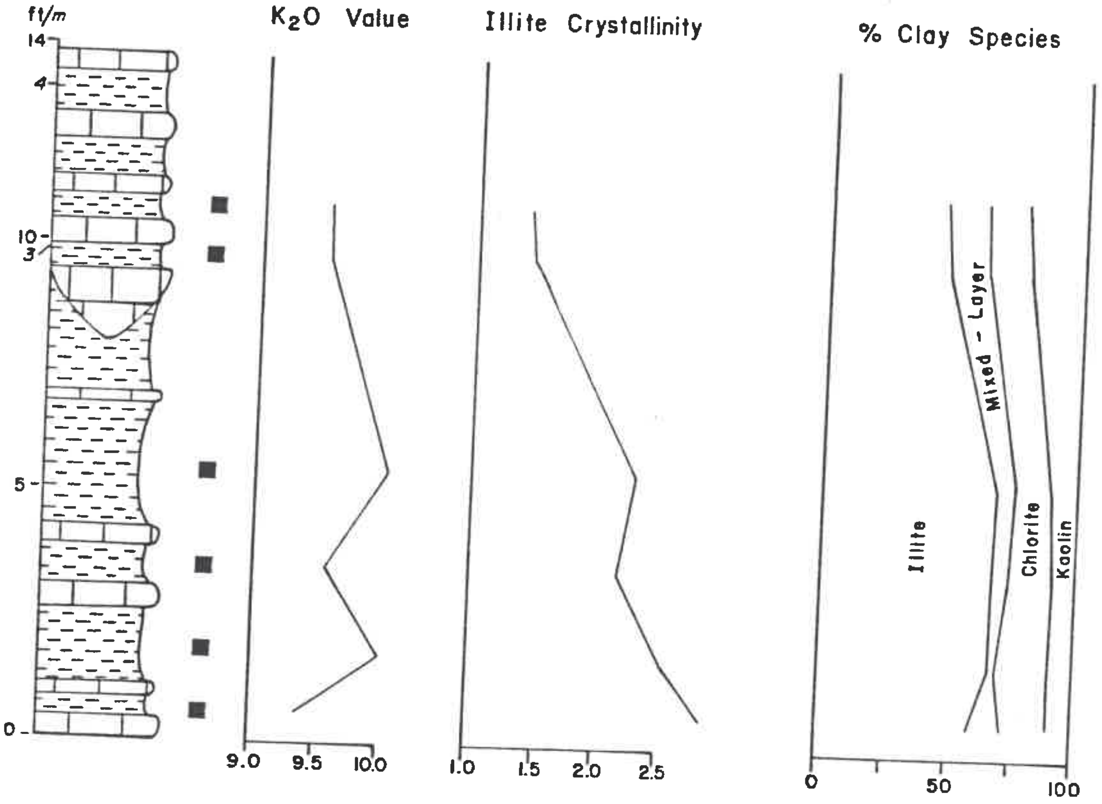

ft/m
14
4
10
3
5
0
K₂O Value
9.0
9.5
10.0
Illite Crystallinity
1.0
1.5
2.0
2.5
% Clay Species
0
50
100
Illite
Mixed - Layer
Chlorite
Kaolin

Figure 18

described by Milne and Earley (1958). The addition and subsequent increase in kaolin, conjunction with high illite crystallinity and K_2O content, suggests erosion of new source rock. Early deposition may have consisted of reworked marine shales, of earlier cycles, with a kaolin-rich source uncovered at a later time. The high illite to kaolin ratio suggests marine rather than non-marine deposition (Degens, et al., 1957). Earlier, Murray (1953) noted a similar trend in some Pennyslvanian cyclothems of Illinois. The Verdigris River section contains kaolin as low as 5 feet above the Winterset Limestone. The north Cherryvale section has the lower 35 feet covered, but does not contain an appreciable amount of kaolin until 25 feet above the covered interval. This suggests that the Verdigris River section is closer to the source area than the north Cherryvale section. All data are compatible with the Ouachita Uplift as a detrital source area for southeastern Kansas during deposition of the Cherryvale Formation.

The anomalously low illite crystallinity found in the upper shale in the North Cherryvale (NCv) section (Figure 14) suggests a weathered zone. The lack of bedding or laminations and its position adjacent to a mudcracked calcilutite is compatible with post-depositional weathering. Although recent outcrop weathering is a possibility, supportive data are insufficient to make a distinction.

Iowa and Nebraska

Iowa and Nebraska sections contain illite, chlorite and relatively high amounts of mixed-layer clays. There is no kaolin present in amounts measurable by x-ray diffraction methods. Slight vertical trends are present in some of the sections.

Thayer Quarry (Figure 19) exhibits moderate to low illite crystallinity (0.94-1.54), moderate to high K_2O content, and high mixed-layer content. Two zones contain both the lowest illite crystallinity and the highest mixed layer clay content (Unit 15 and Unit 1; Figure 19).

The combination of relatively low illite crystallinity and higher mixed-layer clay content suggests either soil zones, or at least sediment derived from soil zones. The lowest shale (Figure 19) is the blocky, non-bedded unit that penetrates into the rubbly top of the underlying Winterset Limestone. It contains a relatively large amount of mixed-layer clays and poorly crystalline illite. This suggests that the basal Cherryvale shale unit, overlying the Winterset Limestone here, has undergone weathering and soil formation processes. The upper zone (unit 15; Figure 19) that contains poorly crystalline illite (0.94) and approximately 54% mixed-layer clays, is laminated (1-3 cm), which is not as compatible with in-place soil formation. This suggests reworking of a nearby soil profile at this higher position.

Figure 19 -- Thayer Quarry (TH) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

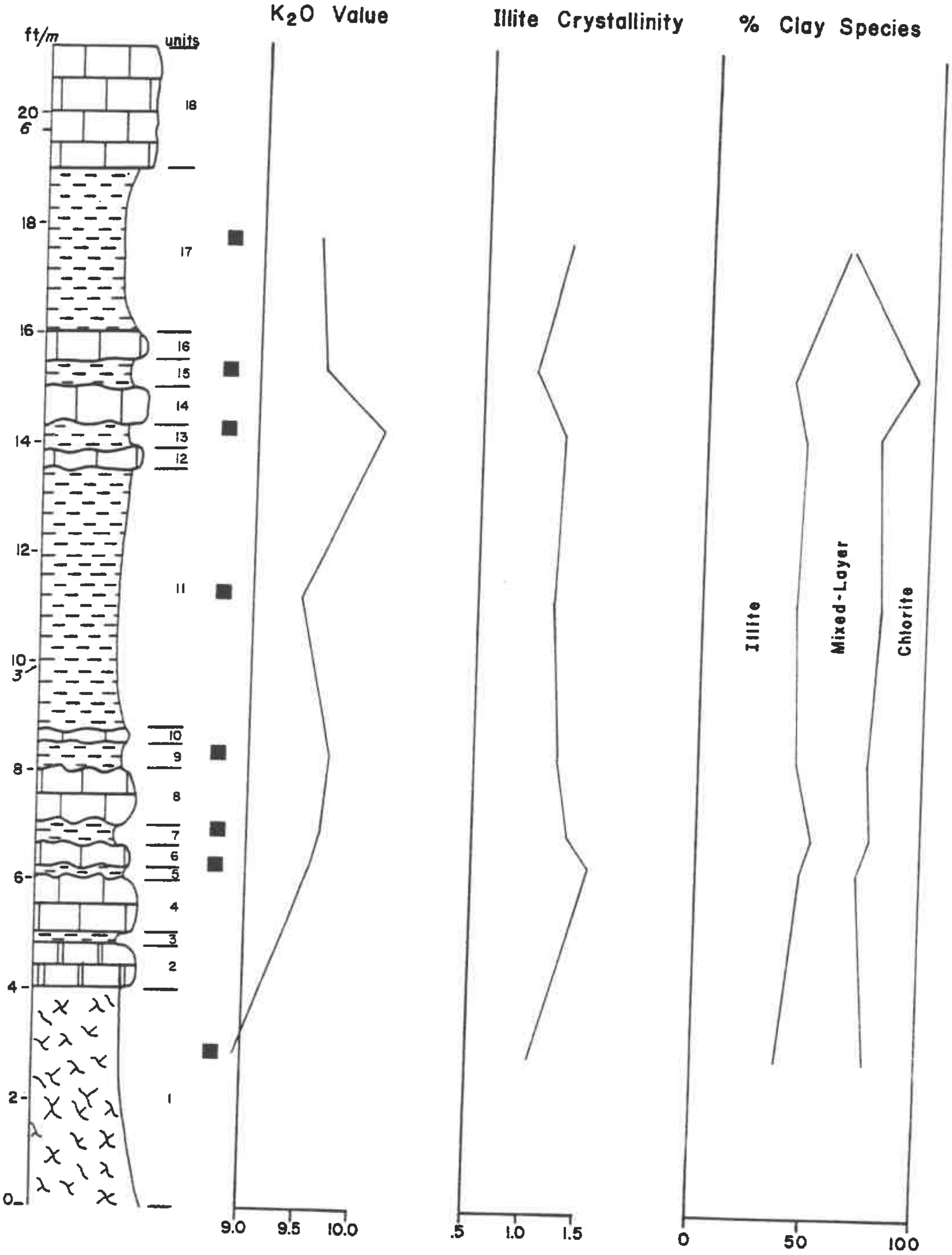

ft/m
units
20
6
18
16
14
12
10
3
8
6
4
2
0
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
K_2O Value
9.0
9.5
10.0
Illite Crystallinity
.5
1.0
1.5
% Clay Species
Illite
Mixed-Layer
Chlorite
0
50
100

Figure 19

The Iowa Bedford Core (Figure 20) displays a relatively consistent clay assemblage of low to moderate illite crystallinity, moderate K_2O content and a balanced clay mineral association. There are zones with very low illite crystallinity (units 2, 14, 18; Figure 20) and one other zone (unit 1, Figure 20) with moderate illite crystallinity (1.38) and moderate mixed-layer clay content (35%). None of the samples with illite crystallinites below 1.2 correspond to intervals with soil characteristics, such as lack of bedding, or anomalously high mixed-layer clay content. This suggests that these intervals are caused by deposition of material from eroded soil profiles somewhere else and deposited rapidly enough to prevent diagenetic increase in the illite crystallinity. The lower zone (unit 1; Figure 20) with illite of moderate crystallinity (1.38) and moderate mixed-layer clay content, does have some sedimentologic signs of soil weathering, such as blocky to massive bedding, and position above and penetrating into a rubbly limestone. It is possible that this sample was taken high enough above the limestone-shale contact, that it underwent less intense chemical weathering, and yet physical processes were sufficient to eliminate primary sedimentary structures.

The Nebraska Offcutt Core (Figure 21) contains a relatively constant clay mineral assemblage with low illite crystallinity, moderate to low K_2O content, and dominant mixed-layer clays. There are three zones with low illite

Figure 20 -- Iowa Bedford Core (IBC) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

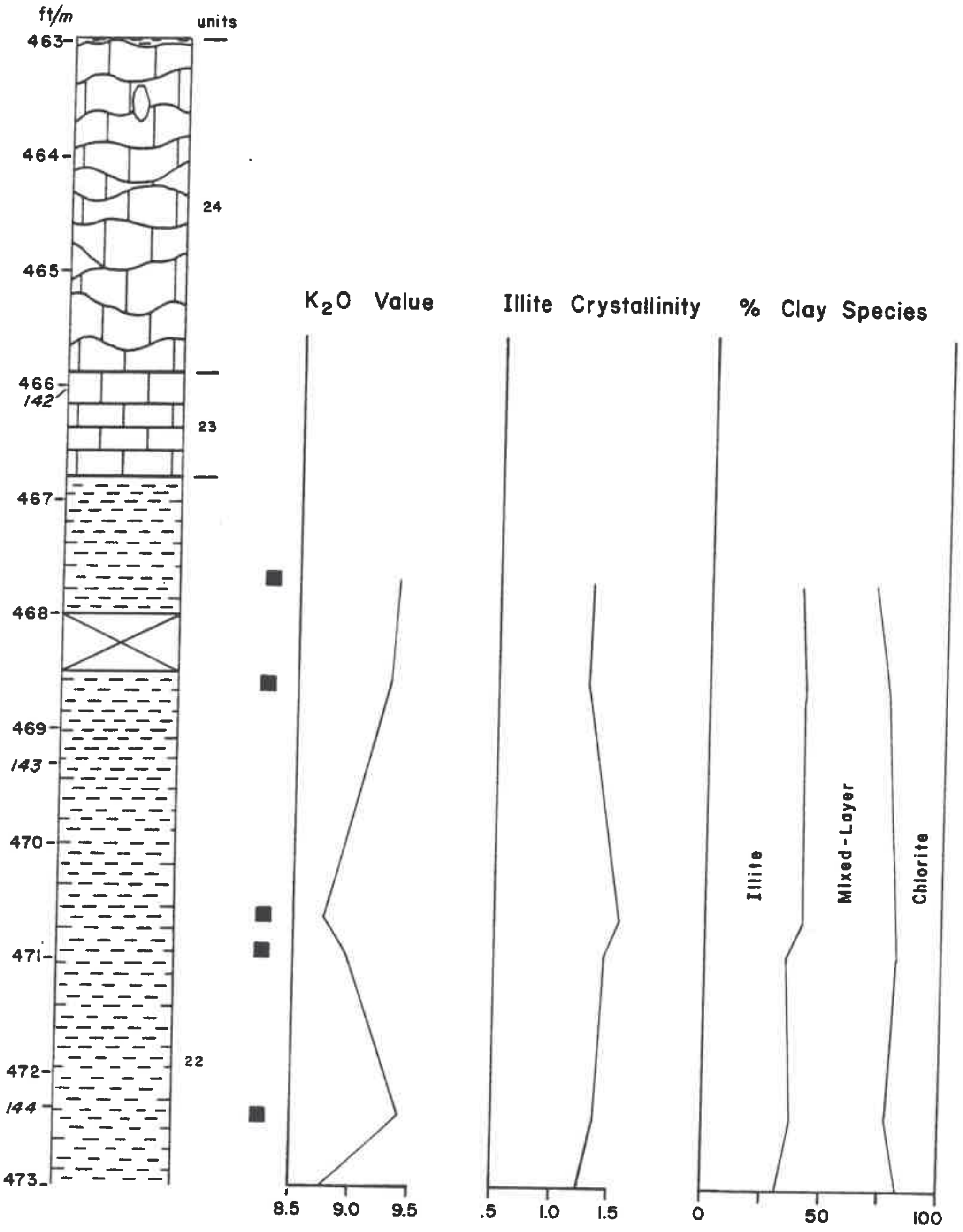

ft/m
units
463
464
465
466
142
467
468
469
143
470
471
472
144
473
24
23
22
K_2O Value
Illite Crystallinity
% Clay Species
Illite
Mixed-Layer
Chlorite
8.5
9.0
9.5
.5
1.0
1.5
0
50
100

Figure 20

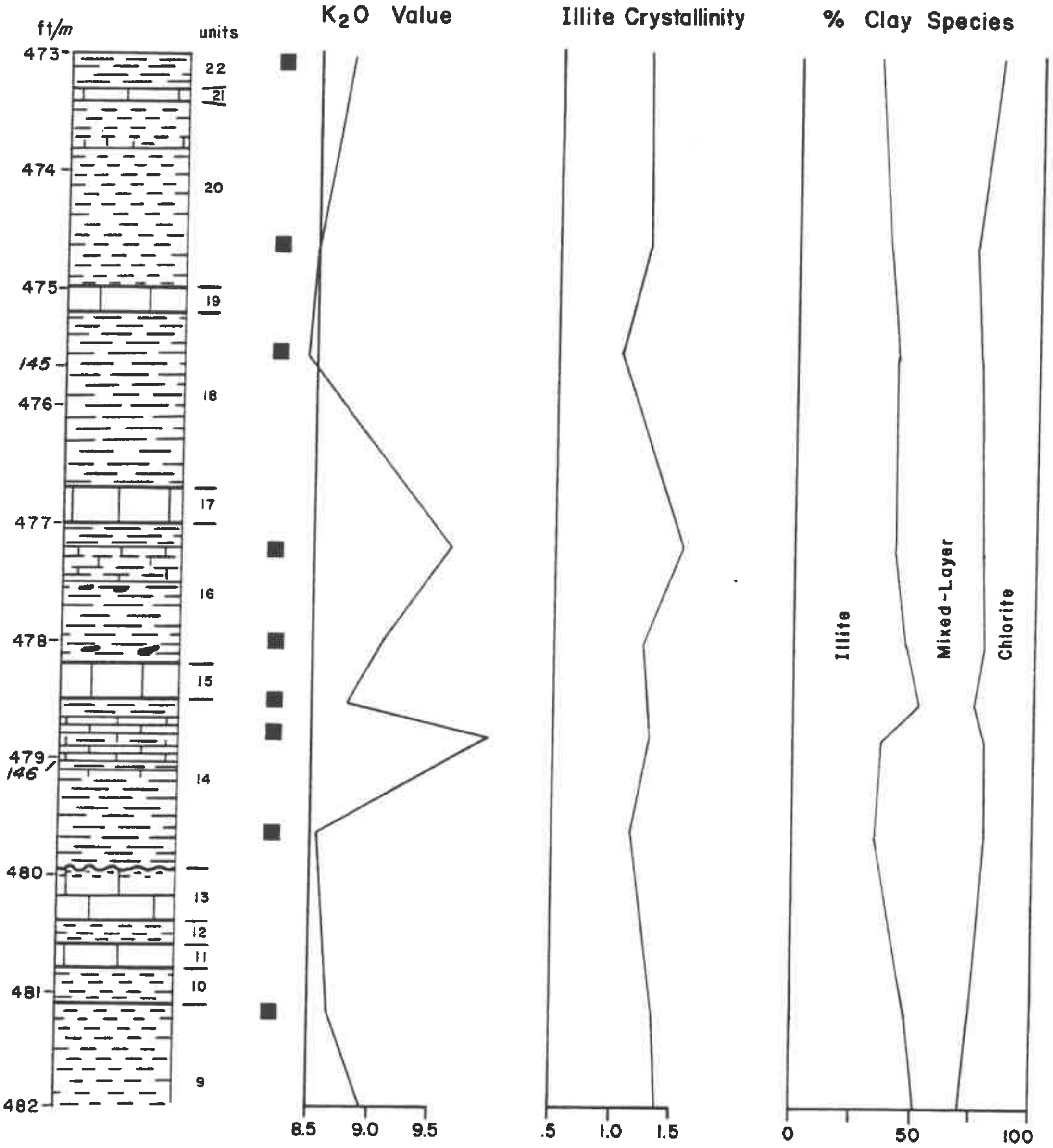


Figure 20 (cont'd)

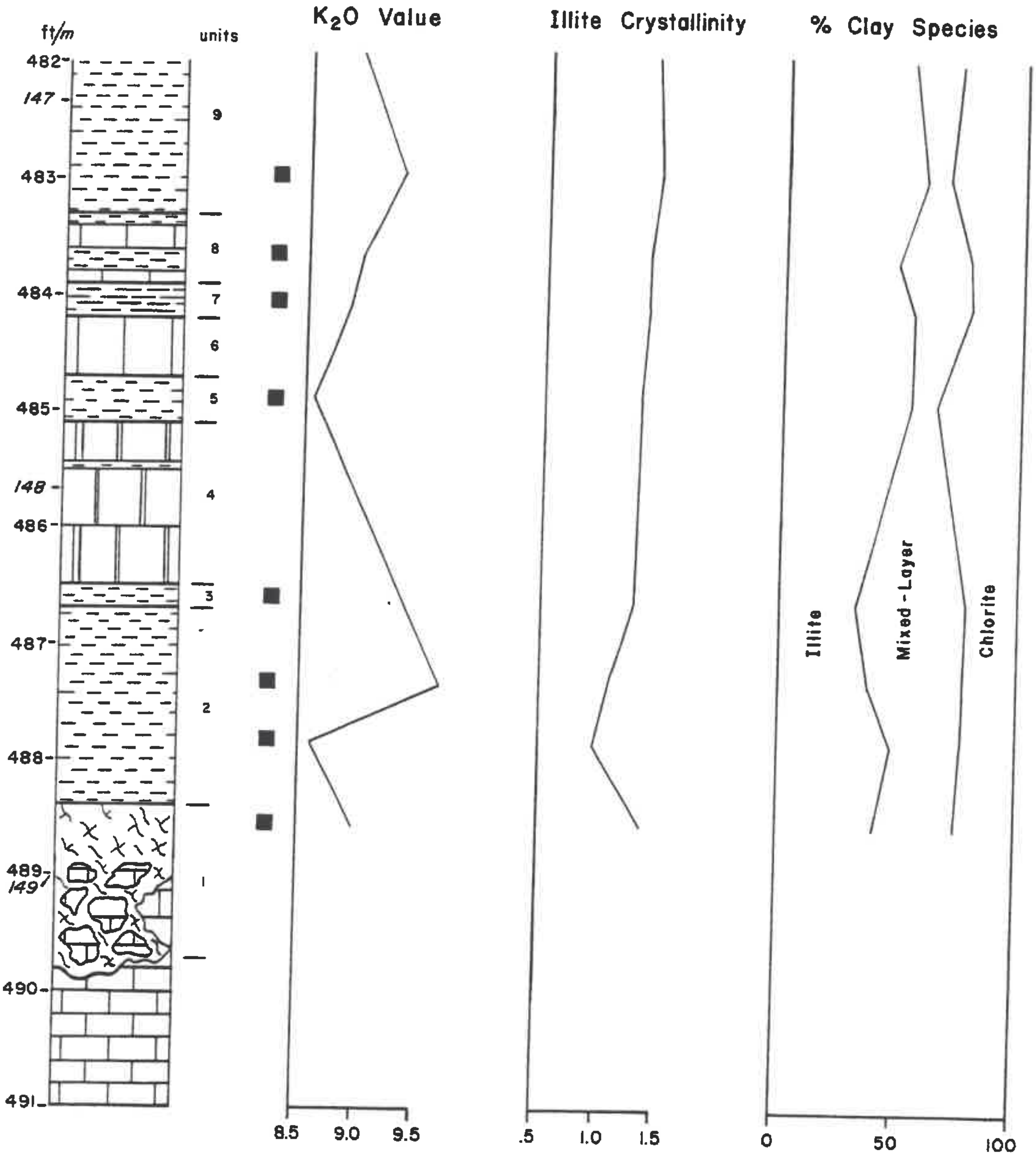


Figure 20 (cont'd)

Figure 21 -- Nebraska Offutt Core (NOC) Lithologic Section and Clay Mineralogy. All lines are interpolations between points representing x-rayed samples. (■) denotes sample positions. Location: Appendix E.

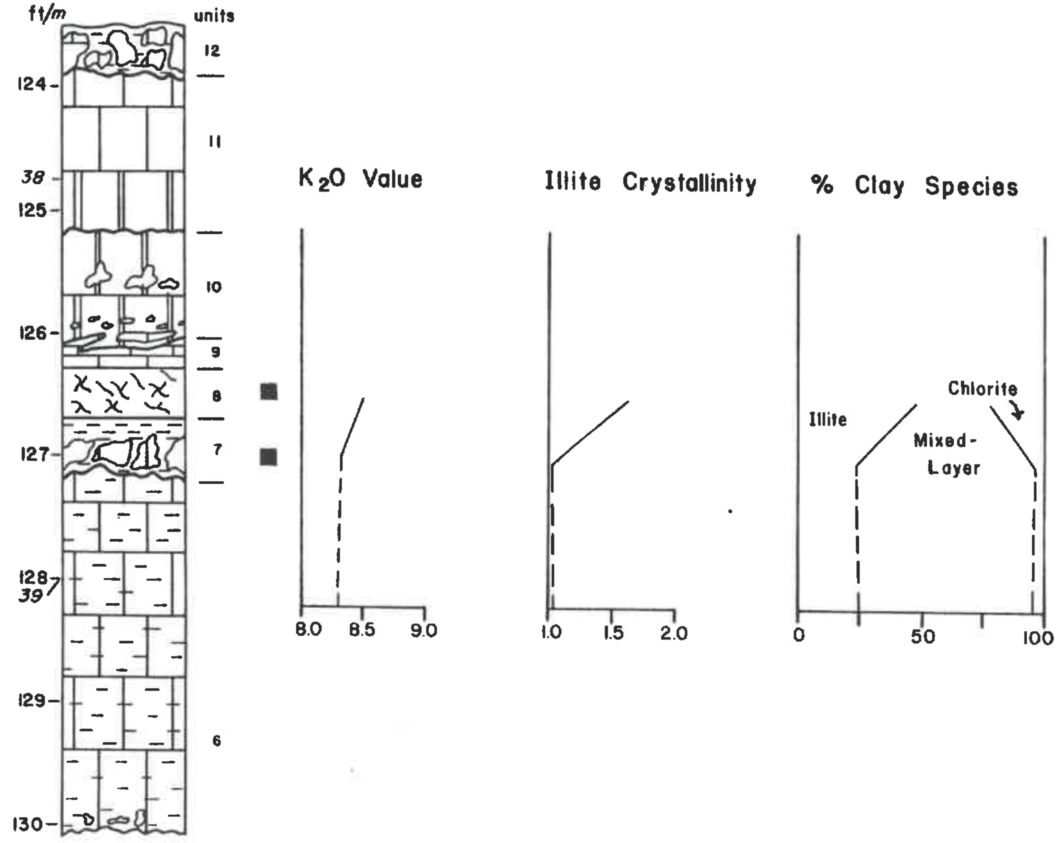

ft/m
units
124
38
125
126
127
128
39
129
130
12
11
10
9
8
7
6
K_2O Value
8.0
8.5
9.0
Illite Crystallinity
1.0
1.5
2.0
% Clay Species
0
50
100
Illite
Mixed-Layer
Chlorite

Figure 21

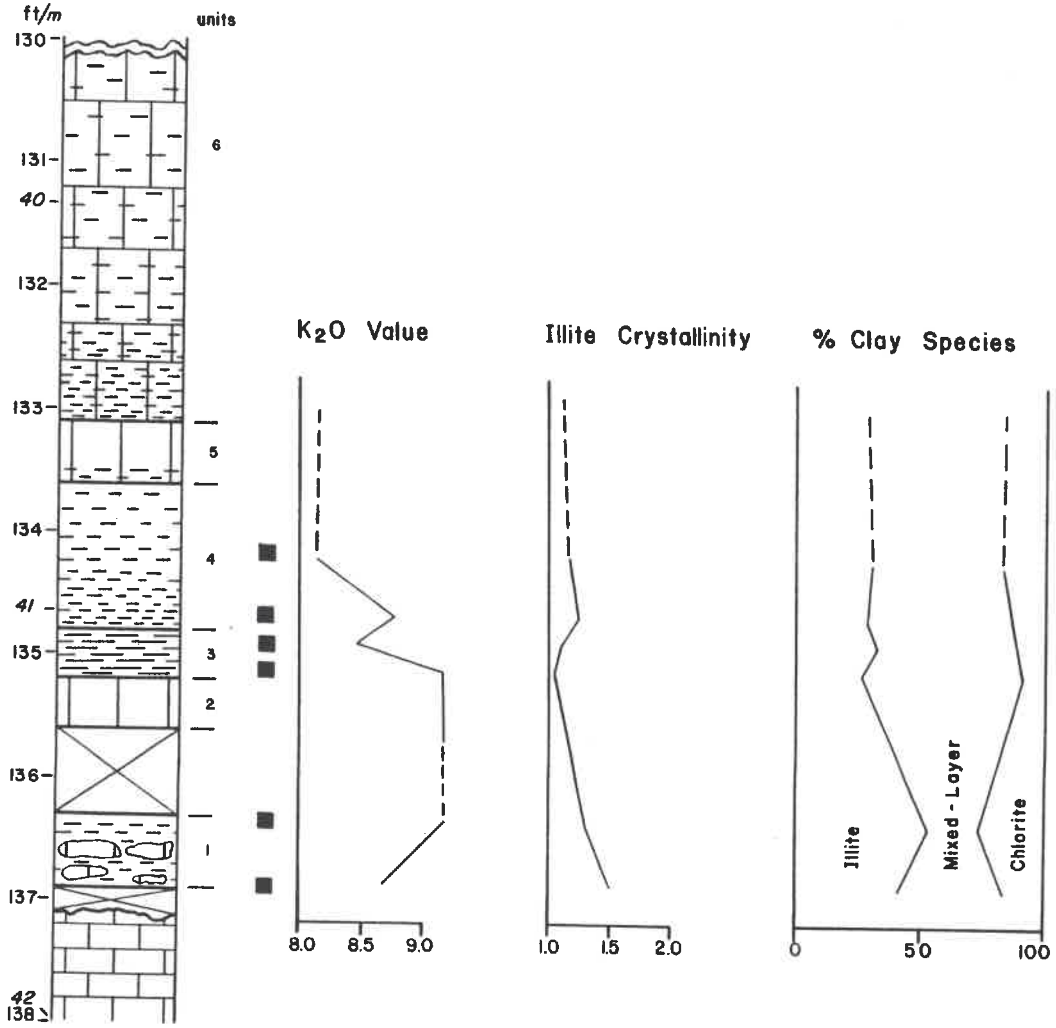


Figure 21 (cont'd)

crystallinity (units 3, 4, 7; Figure 21) which coincide with three of the four highest mixed layer contents. The low illite crystallinity and high mixed-layer content suggests deposition of sediment derived from soil horizons. Only unit 7 (127.0'; Figure 21) has a low illite crystallinity that coincides with some sedimentological signs of soil formation, such a blocky, non-bedded nature, and penetration into a rubbly limestone. This suggests a possible in-place soil horizon. The remaining three zones containing poorly crystalline illite are found in laminated shales, which suggest reworking of soil horizons and rapid enough deposition to reduce later diagenetic increase in illite crystallinity.

The Iowa and Nebraska sections suggest a relatively low relief area dominated by mixed-layer soil weathering, because of the general high mixed-layer content, low illite crystallinity and moderate to low K_2O content. The lack of major trends in any of the Kansas, Iowa or Nebraska Cherryvale sectios contrasts with the distinct trends in both clay mineralogy and depositional environments common in better defined cycles (Figure 22).

Figure 22 -- Lithologic section and clay mineralogy of well-defined cycle. Cyclic deposition is reflected in the Bethany Falls Limestone (0'), non-marine Galesburg Shale (2'), Davis City Coal, marine Stark Shale (4', 6') and Winterset Limestone (8') (courtesy of S. R. Schutter). (●) denotes sample positions. Location: Thayer Quarry, Appendix E.

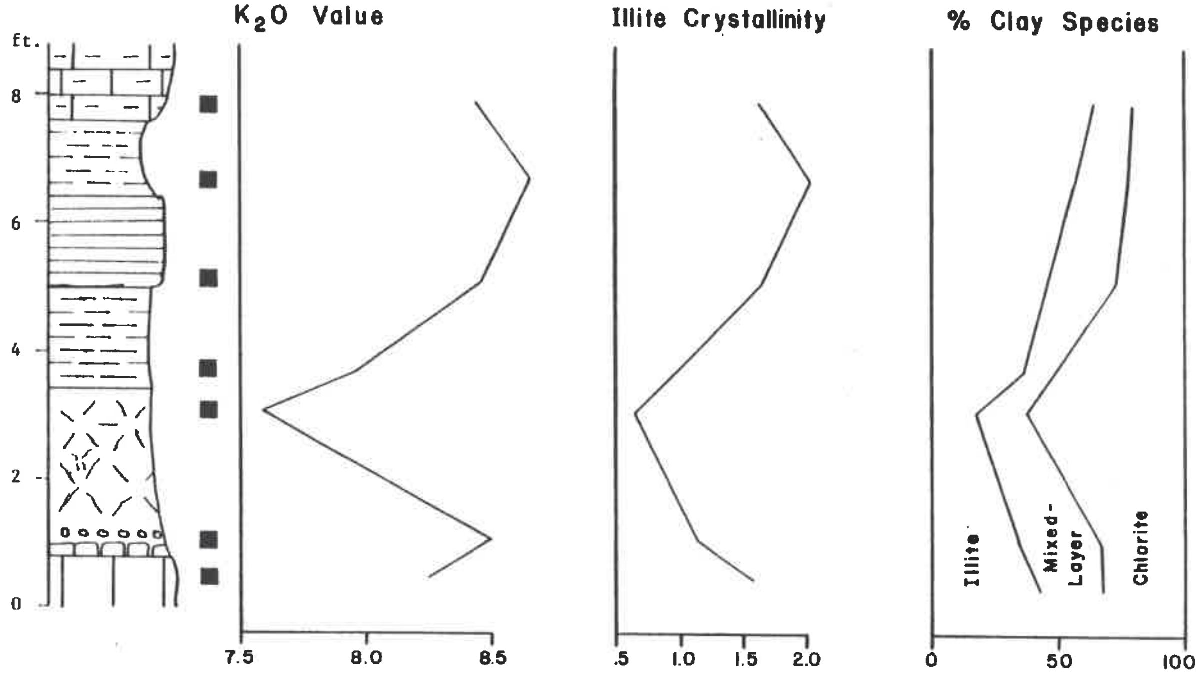

ft.
8
6
4
2
0
K_2O Value
7.5
8.0
8.5
Illite Crystallinity
.5
1.0
1.5
2.0
% Clay Species
Illite
Mixed-Layer
Chlorite
0
50
100

Figure 22

CONODONT DISTRIBUTION

General Background

Conodonts have been used to interpret paleoecology by numerous workers, based on differing criteria (Seddon and Sweet, 1971; Barnes and Fahraeus, 1975). Seddon and Sweet (1971) hypothesized a planktonic conodont animal and devised a depth stratification model to explain biofacies trends. A pelagic model contains a one-way vertical filter, in which conodonts settle out of depth-stratified populations and impinge on the a sloped sediment surface, to cause increased diversity in deeper water. This pelagic model was based primarily on: 1) wide distribution of conodonts, 2) their independence of substrate, and 3) their presence in units devoid of benthic biota (i.e., anoxic "black shales"). Barnes and Fahraeus (1975) hypothesized a nektobenthic conodont animal. They believed that: 1) samples collected from contemporaneous nearshore to offshore environments will exhibit distinct faunal changes, and 2) there is only a minority of taxa that exhibit wide distributions and wide lithofacies tolerance. Klapper and Barrick (1978), concluded that spatial and lithologic distribution patterns are not sufficient to discriminate pelagic vs. nektobenthic modes of life. This is based on examination of published distribution patterns in modern possible conodont analogues of both benthic and pelagic habitats.

Baesemann (1973), examined the conodont distribution of the Upper Pennsylvanian (Missourian) strata, in the Kansas City, Kansas, area. This information was integrated with observations by P. H. Heckel, on cyclic deposition and lithologies, to propose environmental interpretations based on conodont distribution (Heckel and Baesemann, 1975). Heckel and Baesemann suggested that Missourian conodonts were subject to pelagic depth stratification, as described by Seddon and Sweet (1971), based on: 1) the restriction of the genera Idioprioniodus and Gondolella to the most diverse associations in the cyclothem cores, and 2) the consistent presence of Adetognathus and Idiognathodus in almost all units of the cyclothem, and their domination of shallow-water environments (Figure 23).

Heckel and Baesemann (1975) showed two zones of relatively high conodont abundance in the Cherryvale Formation exposed near Kansas City (Figure 2). They were located in the: 1) Block-Wea Shale Members, and 2) Quivira Shale Member. Zones of high abundance are interpreated as being caused by a reduction in sediment dilution and is commonly associated with deposition of the "core shale" during maximum transgression of the sea. These two high abundance zones suggest the presence of two transgressive-regressive cyclothems in the Cherryvale Formation, in the Kansas City area.

Figure 23 -- Reconstruction of probable living-depth zones of Eastern Kansas Missourian conodont genera. Only the upper limit, indicated by position of first appearance is readily delineated. Lower limits were based on changes in relative abundance caused by dilution in deeper water. Conodont associations in sediment are listed in general order of decreasing abundance. High conodont abundance in certain core shales and limestones result from very slow deposition in deeper water away from detrital influx and below most algal carbonate production. (Modified from Heckel and Baesemann, 1975). Ozarkodina minuta = Anchignathodus minuta in the text.

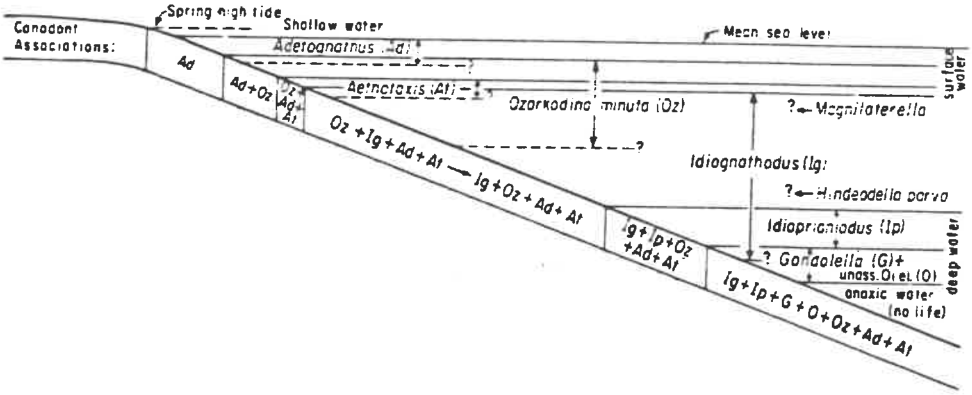

Canodont Associations:
Spring high tide
Shallow water
Mean sea level
Adetognathus (Ad)
Aethotaxis (At)
Ozarkodina minuta (Oz)
?← Magnilaterella
Idiognathodus (Ig)
?← Hindeodella parva
Idioprioniodus (Ip)
? Gondolella (G)+
unass. Or el. (O)
anoxic water
(no life)
surface water
deep water
Ad
Ad+Oz
Oz+Ad+At
Oz+Ig+Ad+At → Ig+Oz+Ad+At
Ig+Ip+Oz+Ad+At
Ig+Ip+G+O+Oz+Ad+At

Figure 23

However, the lack of traceability of either conodont-rich shale or at least one regressive limestone member (Westerville Limestone), suggests that the Cherryvale and overlying Drum transgressions were minor, in terms of depth achieved over large areas. The lack of a truly high abundance zone (> 1000 specimens/kg sample) is compatible with this suggestion.

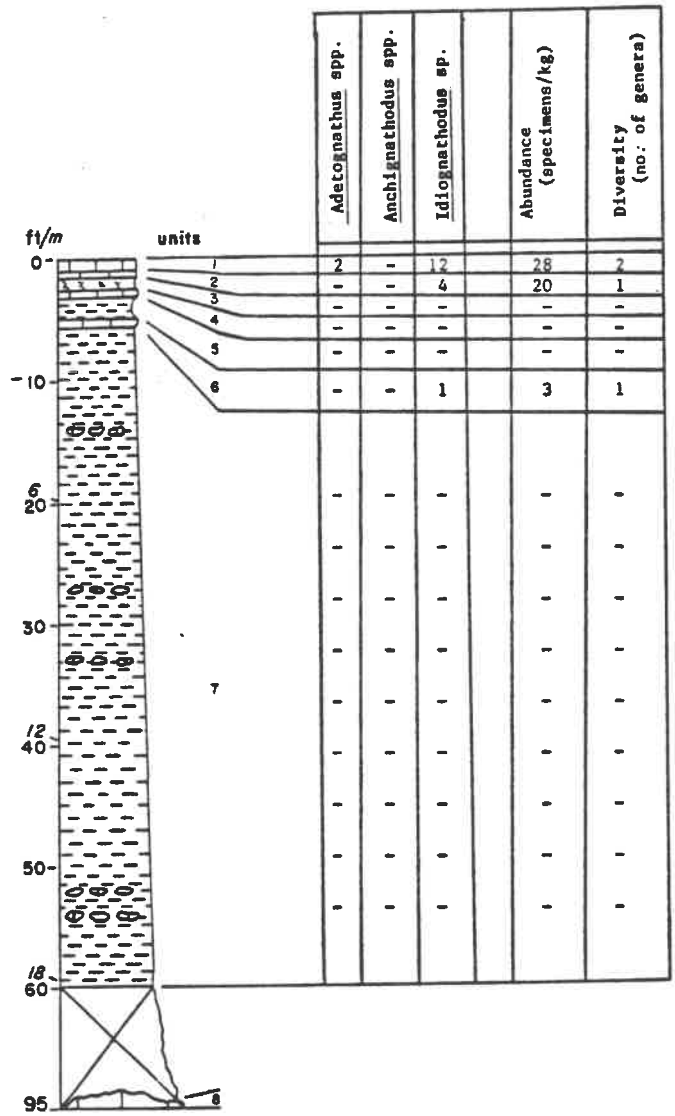
I will describe the conodont distribution, abundance and diversity in each of my sections, and compare it with trends illustrated by Heckel and Baesemann (1975) for the Kansas City area. All populations are standardized to 1 kilogram for the purpose of comparison with the data of Heckel and Baesemann (1975). Any trends were examined with consideration towards data validity. In most cases, the data base is small enough to cast doubt on identification of non-platform elements, and any trends noted, should be weighed against this fact.

Southeast Kansas

Description

Samples in southeast Kansas were obtained from the same sections described earlier in petrology and clay mineralogy. The major trend in both areas is one of very low abundance and diversity at and near the bottom, small populations near the top and relatively high diversity in the overlying Drum Limestone (Figures 24, 25, 26, 27). Idiognathodus sp.

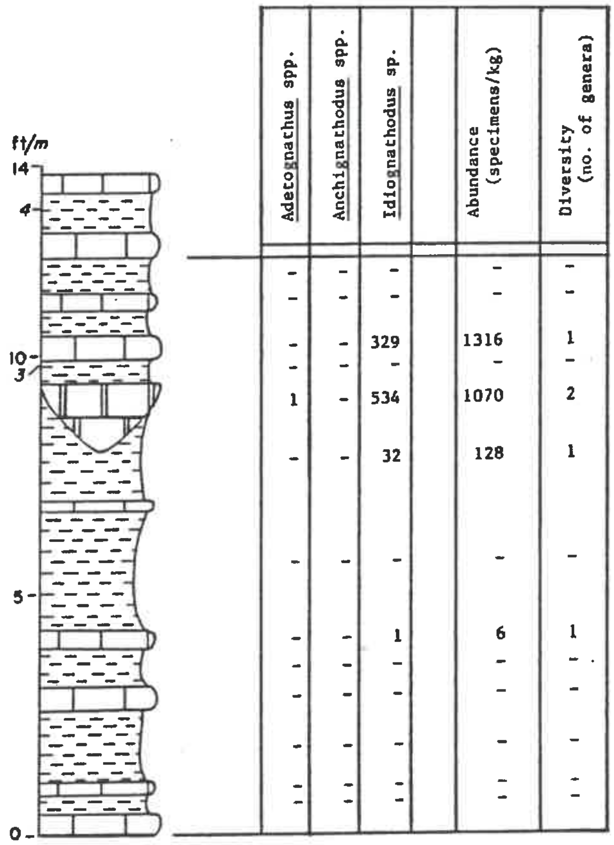
Figure 24 -- North Cherryvale (NCv) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. Location: Appendix E.



units	Adetognathus spp.	Anchignathodus spp.	Idiognathodus sp.		Abundance (specimens/kg)	Diversity (no: of genera)
1	2	-	12		28	2
2	-	-	4		20	1
3	-	-	-		-	-
4	-	-	-		-	-
5	-	-	-		-	-
6	-	-	1		3	1
7	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-
	-	-	-		-	-

Figure 24

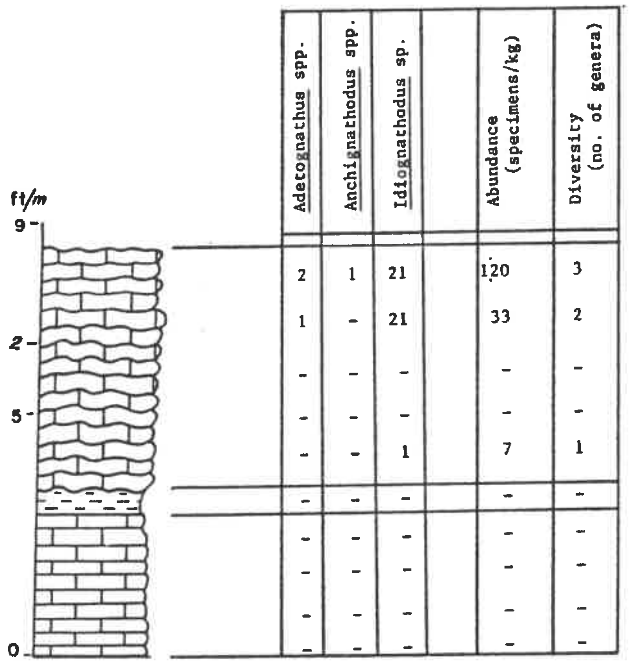
Figure 25 -- Clear Creek 3 (CC3) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. Location: Appendix E.



Adetognathus spp.	*Anchignathodus* spp.	*Idiognathodus* sp.		Abundance (specimens/kg)	Diversity (no. of genera)
-	-	-		-	-
-	-	-		-	-
-	-	329		1316	1
-	-	-		-	-
1	-	534		1070	2
-	-	32		128	1
-	-	-		-	-
-	-	1		6	1
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-

Figure 25

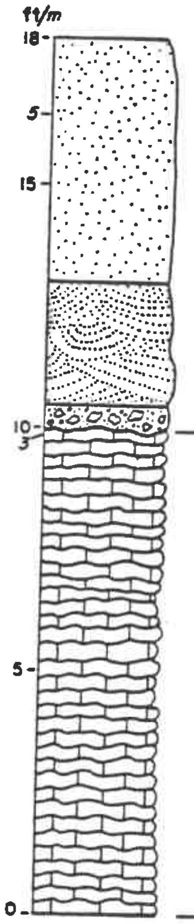
Figure 26 -- Clear Creek Bridge (CCB) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. Location: Appendix E.



Adetognathus spp.	*Anchignathodus* spp.	*Idiognathodus* sp.		Abundance (specimens/kg)	Diversity (no. of genera)
2	1	21		120	3
1	-	21		33	2
-	-	-		-	-
-	-	-		-	-
-	-	1		7	1
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-
-	-	-		-	-

Figure 26

Figure 27 -- Clear Creek 2 (CC2) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. Location: Appendix E.



Adetognathus spp.	Anchignathodus spp.	Idiognathodus sp.		Abundance (specimens/kg)	Diversity (no. of genera)
-	-	68		1496	1
-	-	10		81	1
1	-	3		36	2
-	1	10		88	2
1	1	29		93	3

Figure 27

platform elements are dominant, with scattered occurrences of Idiognathodus sp. O_1, N, and A elements, and rare Adetognathus gigantus and A. lautus elements. There are three occurrences of abnormally high abundances of Idiognathodus sp. platform elements. One sample near the top of section CC2 (Figure 27), which might be synchronous with the Drum Oolite, contains 65 Idiognathodus sp. platform elements in a 46 gram sample, which normalizes to 1496/kg. The other two zones occur near the top of section CC3 (Figure 25) in carbonate layers with abundant quartz sand. The lower zone is 8 feet from the base and occurred in a channel-like structure. It contains 534 Idiognathodus sp. platform elements, which normalizes to 1070/kg. The limestone unit above the channel (10 feet above base) contains 325 Idiognathodus sp. platform elements, which normalizes to 1316/kg. In all cases the average individual size was less than 0.5 mm and very few retained the free blade. Some abrasion was evident. Out of the total populations of all three zones, only one individual was not an Idiognathodus.

Interpretation

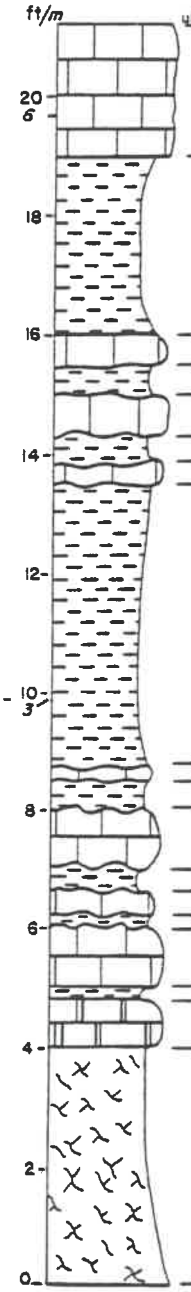
Low population and low diversity associated with a relatively thick and uniform shale unit suggests rapid sedimentation and high turbidity, which caused both dilution of the population and a stress environment, limiting diversity. The scarcity of macrobiota is compatible with this suggestion. Small populations of Idiognathodus sp. as the dominant genus is comparable with the distributions in Heckel and Baesemann (1975), who found outside shales to be characterized by absence or low populations of either Adetognathus or Idiognathodus. The three anomalously high populations can be interpreted as caused by hydrodynamic sorting. The two zones in section CC3, are found in conjunction with high quartz sand content, and one channel feature. The third zone, in the Drum Limestone (section CC2), is associated with ooids, suggesting at least nearby agitated water. All three populations exhibit evidence compatible with transport, specifically, small size, good sorting, lack of free blades, high platform/non-platform ratio, and some abrasion.

Southwest Iowa

Description

Samples in southwest Iowa were obtained from the same sections described earlier in petrology and clay mineralogy. In Iowa there is a scattered population from bottom to top, but both population size and diversity are low (Figures 28, 29). The major trend is a change in dominance from Adetognathus near the bottom, to Idiognathodus nearer the top. Anchignathodus is present in small numbers near the middle intervals of both sections. The Thayer Quarry section

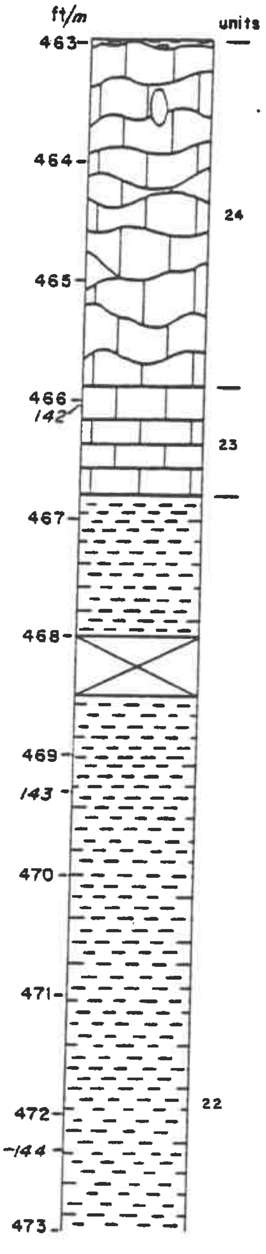
Figure 28 -- Thayer Quarry (TH) Lithological Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. (*) denotes use of *Gondolella* based on identification from Baesemann's (1973; Plate 1, Figure 3) unassigned O_1 element and von Bitter's (1976; Figure 8) Hi element. No *Gondolella* platform elements were present. Location: Appendix E.



units	*Adetognathus* spp.	*Anchignathodus* spp.	*Idiognathodus* sp.	*Gondolella* sp. *	*Aethotaxis* sp.		Abundance (specimens/kg)	Diversity (no. of genera)
18	-	1	11	-	-		24	2
17	-	-	-	-	-		-	-
16	-	2	22	-	-		44	2
15	-	-	5	-	-		10	1
14	-	-	1	-	-		2	1
13	-	-	-	-	-		-	-
12	2	1	1	-	3		14	4
11	1	1	-	-	-		2	2
10	-	6	9	-	-		30	2
9	-	-	2	-	-		4	1
8	14	-	-	-	-		28	1
7								
6	1	-	-	-	-		1	1
5	2	-	-	2	-		4	2
4	3	-	-	-	-		6	1
3								
2	12	-	-	-	-		24	1
1	14	-	-	-	-		14	1

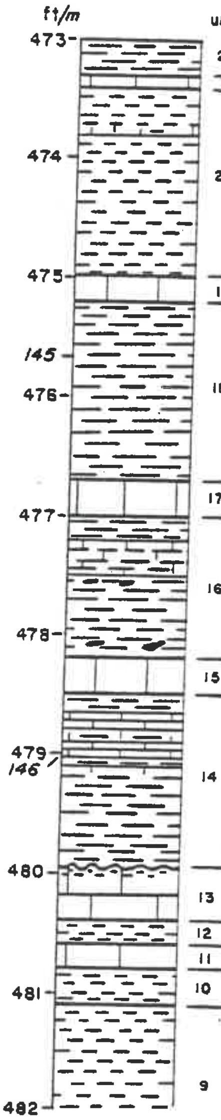
Figure 28

Figure 29 -- Iowa Bedford Core (IBC) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. (*) denotes use of *Gondolella* based on identification from Baesemann's (1973; Plate 1, Figure 3) unassigned O_1 element and von Bitter's (1976; Figure 8) ^{1}Hi element. No *Gondolella* platform elements were present. Location: Appendix E.



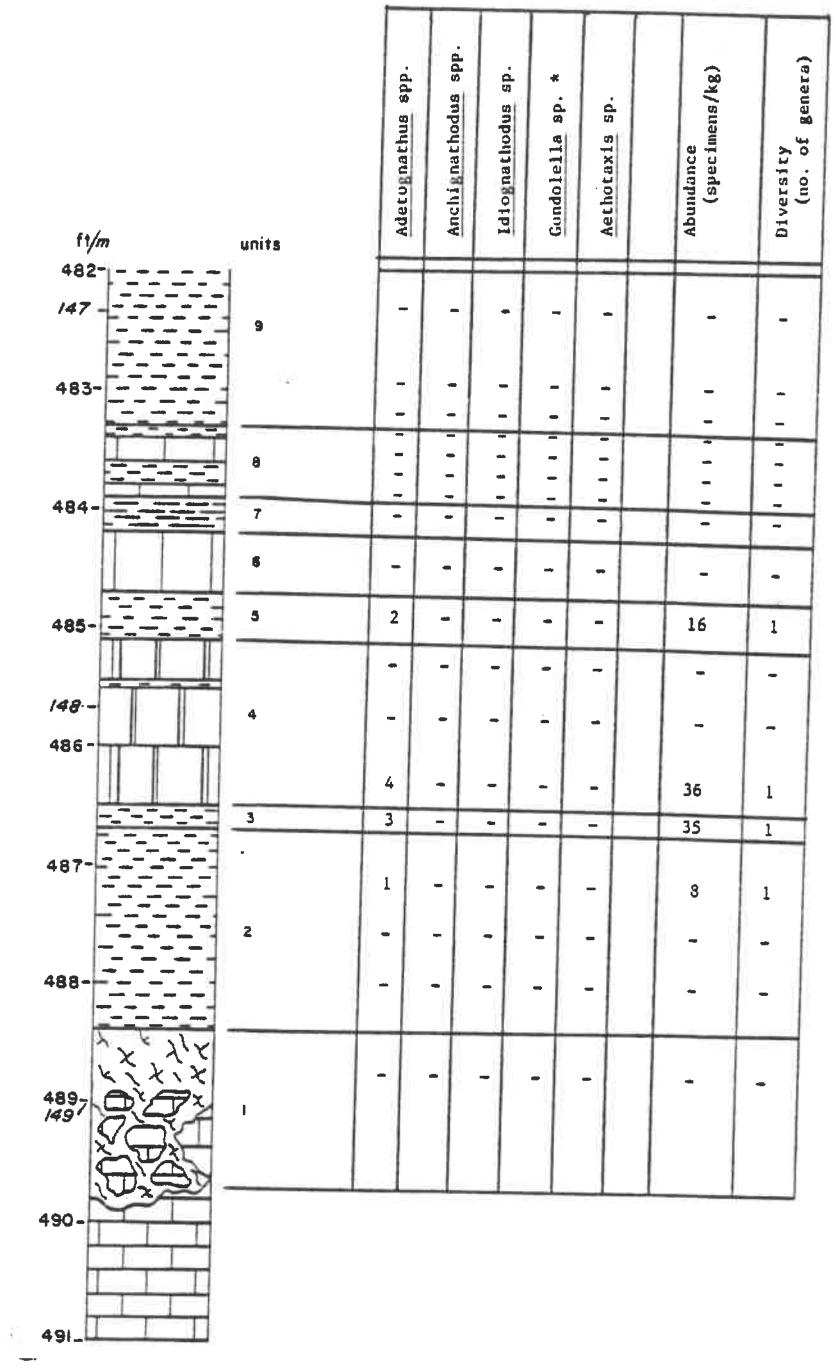
Adetognathus spp.	*Anchignathodus* spp.	*Idiognathodus* sp.	*Gondolella* sp. *	*Aethotaxis* sp.		Abundance (specimens/kg)	Diversity (no. of genera)
-	-	-	-	-		-	-
-	-	-	-	-		-	-
-	-	-	-	-		-	-
-	-	1	-	-		5	1
-	-	1	-	-		6	1
-	-	1	1	-		14	2

Figure 29



units	Adetognathus spp.	Anchignathodus spp.	Idiognathodus sp.	Gondolella sp. *	Aethotaxis sp.		Abundance (specimens/kg)	Diversity (no. of genera)
22	-	-	5	-	-		50	1
21	-	-	-	-	-		-	-
20	-	1	1	-	-		5	2
	-	-	3	-	-		12	1
19	-	-	1	-	-		10	1
18	-	-	1	-	-		6	1
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
17	-	-	-	-	-		-	-
16	-	-	-	-	-		-	-
	-	1	-	-	-		10	1
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
15	-	-	-	-	-		-	-
14	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
13	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
12	-	-	-	-	-		-	-
11	-	-	-	-	-		-	-
10	-	-	-	-	-		-	-
9	-	-	-	-	-		-	-
	-	-	-	-	-		-	-

Figure 29 (cont'd)



units	*Adetognathus* spp.	*Anchignathodus* spp.	*Idiognathodus* sp.	*Gondolella* sp. *	*Aethotaxis* sp.		Abundance (specimens/kg)	Diversity (no. of genera)
9	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
8	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
7	-	-	-	-	-		-	-
6	-	-	-	-	-		-	-
5	2	-	-	-	-		16	1
4	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
	4	-	-	-	-		36	1
3	3	-	-	-	-		35	1
2	1	-	-	-	-		8	1
	-	-	-	-	-		-	-
	-	-	-	-	-		-	-
1	-	-	-	-	-		-	-

Figure 29 (cont'd)

contains more non-platform elements, perhaps because the sample weights were closer to 1 kilogram.

Interpretation

The change in dominance from Adetognathus near the bottom, to Idiognathodus near the top, is comparable with the sequence illustrated by Heckel and Baesemann (1975) at Kansas City, and it may suggest a deepening of water during transgression (Figure 23), or at least change in the conditions present in outside shales, which cause some to be dominated by Adetognathus and others to be dominated by Idiognathodus. The relatively low abundance and diversity suggests rapid sedimentation which caused dilution and produced a stress environment. Typical open marine faunas are present in both sections (i.e., brachiopods, echinoderms, fusulinids), but they also show low diversity. Interspersed with the open marine fauna, are typically restricted associations, with various numbers of ostracodes, pelecypods, gastropods and forams. Together, these factors suggest a fluctuating environment of generally rapid sedimentation during slowly deepening water which caused transitions between open marine and restricted fauna.

Southeast Nebraska

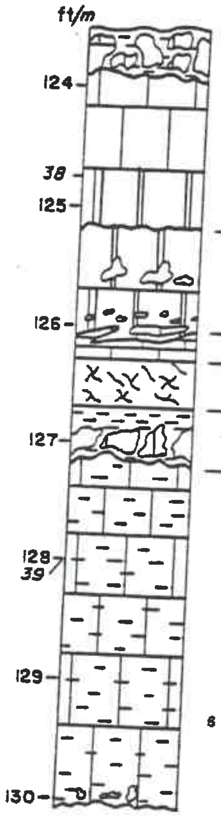
Description

Samples from southeast Nebraska were obtained from the Offutt Air Force Base core described earlier in petrology and clay mineralogy. Here there is a relatively even distribution, with low population, but a generally higher diversity (2-4 genera/sample) (Figure 30). The only vertical trend appears to be a minor change in dominance, from *Adetognathus* near the bottom, through *Idiognathodus* throughout the middle to *Adetognathus* and *Anchignathodus* near the top. *Aethotaxis* is rare but found near the middle. *Adetognathus* is scattered throughout and slightly more abundant near the bottom. *Anchignathodus* and *Idiognathodus* are the most consistently present and the most dominant, with *Idiognathodus* having slightly larger abundances near the middle. Platform elements dominate the samples in all genera except *Aethotaxis*.

Interpretation

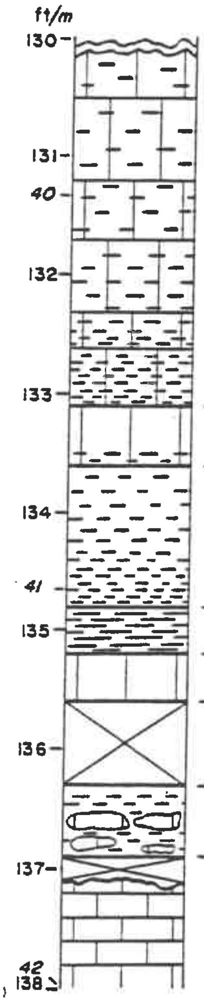
The relatively even distribution, low abundance and high diversity when compared to other Cherryvale sections, suggests a relatively stable, low stress environment with moderate sedimentation, which is compatible with the predominance of carbonate in this section. The argillaceous nature of this carbonate does suggest a stress environment that is reflected in the low diversity when compared to

Figure 30 -- Nebraska Offutt Core (NOC) Lithologic Section and Conodont Distribution. All genera are named using multi-element nomenclature. Numbers under genera represent total identifiable elements. (*) denotes use of *Gondolella* based on idetification from Baesemann's (1973; Plate 1, Figure 3) unassigned O_1 element and von Bitter's (1973; Figure 8) Hi element. No *Gondolella* platform elements were present. Location: Appendix E.



units	Adetognathus spp.	Anchignathodus spp.	Idiognathodus sp.	Gondolella sp. *	Aethotaxis sp.		Abundance (specimens/kg)	Diversity (no. of genera)
12								
11	-	-	-	-	-		-	-
	-	1	-	-	-		2	1
	-	-	-	-	-		-	-
10	-	1	-	-	-		2	1
	2	-	-	-	-		6	1
9	-	-	-	-	-		-	-
8	-	-	-	-	-		-	-
7	-	-	-	-	-		-	-
6	3	2	-	-	-		20	2
	1	1	-	-	-		4	2
	-	2	2	-	1		10	3
	-	2	-	-	-		4	1
	-	-	12	-	-		24	1
	-	7	34	-	-		82	2

Figure 30



units	Adetognathus spp.	Anchignathodus spp.	Idiognathodus sp.	Gondolella sp. *	Aethotaxis sp.		Abundance (specimens/kg)	Diversity (no. of genera)
6	-	1	-	-	-		3	1
	2	5	-	-	-		14	2
	-	-	11	-	2		39	2
	-	-	6	-	-		12	1
	1	1	11	-	-		29	3
	-	-	10	-	-		30	1
5	-	2	7	-	2		33	3
4	-	-	1	-	-		3	1
	-	-	-	-	-		-	-
	-	-	3	-	-		9	1
3	-	-	1	1	-		4	2
2	3	4	5	-	-		72	3
1	4 1 -	2 - -	- - -	- - -	- - -		36 4 -	2 1 -

Figure 30 (cont'd)

purer limestones of better defined cycles. The slight change in dominance from Adetognathus near the bottom, through the higher numbers of Idiognathodus in the middle to both Adetognathus and Anchignathodus near the top, is compatible with a transgression to only moderate depth followed by a regression, as interpretated by Heckel and Baesemann (1975) (Figure 23). The interpreted conodont living-zone at moderate depth comprises: 1) Anchignathodus minutus, 2) Idiognathodus, 3) Adetognathus and Aethotaxis; with slightly shallower water at the base and top dominated by either Adetoganthus or Anchignathodus. The lack of any conodonts in the blocky shale (unit 8), which mineralogically may be an in-place soil horizon, would support the soil interpretation and would be compatible with the previous suggestion of two marine transgressions here separated by the blocky shale. Unlike the older transgression, the younger transgression is not reflected in the sparse conodont faunas and perhaps achieved only very shallow depths in this area.

CONCLUSIONS

Regionally, the five studied Cherryvale sections fall into three depositional settings: 1) rapid clastic influx (southeast Kansas), 2) moderate, gradational fluctuations in clastic sedimentation rate with periodic carbonate production during reduced clastic influx (southwest Iowa), and 3) stable carbonate shelf with moderate to low fluctuating clastic sedimentation (southeast Nebraska). The data illustrated by Heckel and Baesemann (1975) appear to suggest a fourth setting in the Kansas City area.

Southeast Kansas sections record rapid deposition in a sequence that shallows upward at the top. Petrologically, this is reflected in the lower section being predominantly shale, and the upper section becoming dominated by carbonate. The carbonate in the lower section, when present, is dark argillaceous calcilutite, whereas the upper carbonate contains evidence of shallow water, such as ooids, intraclasts, peloids, coated grains, dissolution features and mudcracks. Clay mineralogy suggests early reworking and deposition of illitic marine shales from an area that underwent little soil weathering. This is suggested by high illite crystallinity and low mixed-layer clay content. Through time, kaolin-rich source rocks were exposed and deposition occurred from the Verdigris River-Clear Creek area toward the Cherryvale area. Laterite weathering is not considered a valid source of kaolin because of the lack of weathering evident in high illite crystallinity and low mixed-layer content. The Ouachita uplift is a potential source area for this sediment. Paleontologic evidence is compatible with rapid deposition, and is reflected in the absence or scarcity of fossils in the lower portion, which suggests dilution. The upper section contains conodonts and fossiliferous limestones, but the diversity and abundance are still relatively low, suggesting stress environments. The stress environments of the upper section probably are associated with shoaling and exposure, evident in the mudcracked calcilutite and the dissolution features in the upper limestone bed north of Cherryvale. Dominance of *Adetognathus* and *Idiognathodus* in low numbers suggests deposition in shallow water, nearshore environments. These genera often dominate the assemblages found in nearshore ("outside") shales elsewhere in the sequence. Rapid deposition probably masked the subtle variations required to compare deposition in southeast Kansas, to that of the Kansas City area, as illustrated by Heckel and Baesemann (1975). Nevertheless, the data are compatible with the model proposed by Heckel (1977) in that it reflects insufficient inundation to produce coastal sediment trapping, which would have cut off the relatively continuous clastic influx.

The Iowa sections record a slower basin filling with fluctuating clastic sedimentation. Petrologically, both contain probable in-place soil horizons at the bottom, overlain by calcarenites, suggesting that the transgression here initially caused sufficient coastal sediment trapping to allow shallow-water carbonates to form. This initial trapping was probably miles from the area of deposition, because the shallow paleoslope would have required only a few feet of sea level rise to cause miles of lateral submergence. If the transgression were minor, coastal sediment traps would soon fill and clastic wedges would prograde out. This is recorded in the overlying clastic dominated sequence. Fluctuations in clastic deposition are recorded in the presence of thin carbonate beds at several horizons. These carbonate units are gradational with adjacent shales, suggesting only slow changes in intensity of clastic sedimentation. Clay mineralogy suggests deposition of detrital sediment derived more generally from soils, as seen in high mixed layer content and low illite crystallinities. The lack of kaolinite in the Iowa section suggests: 1) lack of primary kaolinite-bearing source rock, 2) lack of acidic soil weathering (laterites), and 3) soil weathering of only moderate relief. Clay mineralogy is compatible with the trend described by Heckel and Baesemann (1975), which suggests that the Cherryvale Formation reflects only minor transgressions. This is seen in the relative consistency of clay minerals, with only minor variation in closely related lithologies, and lack of any major vertical trends that are detectable in major, well defined transgressions such as the underlying Dennis (S. R. Schutter, personal communication, 1981). Paleontologic evidence also is compatible with this model. Fossil assemblages contain fauna suggestive of both restricted environments (ostracodes, pelecypods, gastropods) and normal marine environments (brachiopods, echinoderms, bryozoan), although Thayer Quarry contains only _Cavellina_ ostracodes, while Bedfore Core contains _Cavellina_ and two ornamented genera, _Hollinella_ and _Amphissites_, which is compatible with the Bedford area being more basinward and less restricted than the Thayer area. Conodont distribution again shows dominance by low numbers of the interpreted nearshore genera, _Adetognathus_ and _Idiognathodus_. Vertical change from _Adetognathus_ to _Idiognathodus_ dominance is interpreted as reflecting slight deepening during minor transgression as _Idiognathodus_ dominates all offshore faunas as well as some nearshore ones. The details of conodont distribution noted by Heckel and Baesemann (1975) in the Kansas City area is not present in the Iowa sections, although distribution is compatible within the model proposed by Heckel and Baesemann (1975). Differences in distribution can be attributed to continual proximity to shoreline, resulting in slightly differing facies. Minor transgressions would not produce large scale, laterally continuous facies as in the well developed cyclothems which are shown to contain similar vertical conodont distribution patterns across large portions of the outcrop belt (Wood, 1977; Mitchell, 1981).

The southeast Nebraska section reflects a relatively constant carbonate shelf environment. Petrologically, carbonate dominates this section. Deposition occurred on or near the submerged northern tip of the Nemaha Ridge, which was quiescent during Missourian time. Similar to Thayer and Bedford, a probable in-place soil horizon underlies the section. Above this a shale gradually grades upward into a relatively pure carbonate, reflecting gradual reduction in clastic influx through time. This is culminated by a laminated supratidal carbonate which reflects emergence and produced intraclasts and rip-ups in the overlying calcilutite. Above this is a calcarenite that exhibits dissolution, suggesting exposure to meteoric waters. Clay mineralogy trends are similar to those described in Iowa, with high mixed layer clay content, no kaolin, and low illite crystallinity, suggesting deposition of soil-derived sediment. Paleontologic evidence is compatible with a stable open marine environment. Limestones contain abundant, diverse faunas, except for the laminated calcilutite. Conodont distribution exhibits the most constant and diverse distribution of the five sections. Nevertheless sedimentation and stress remained sufficiently high to keep the abundance and diversity below those of larger, better defined cycles. The possible in-place soil horizon (units 7, 8; Figure 21) overlying a shallowing-upward sequence and underlying a slightly deepening sequence suggests compatibility with the model of Heckel and Baesemann (1975). This vertical sequence reflects: 1) a transgression, seen as open marine sediment overlying a probable soil (units 7, 8; Figure 21) and a laminated supratidal calcilutite, and 3) another transgression, reflected in the inundation producing rip-ups and intraclasts in a shallow-water calcilutite, grading upward into below-winnowing base open marine calcilutites.

It appears that the Kansas City area was located closer to the basin center of the epicontinental sea, and this reduced clastic influx and enabled the interpreted minor transgressions to be better recorded lithically, there in the relatively more open marine conditions. The lack of traceable member units and the less obviously traceable eustatic events are compatible with minor transgressions and regressions. More detailed work in problem areas is required before facies relationships can be predicted with consistency.

APPENDIX A

PREPARATION OF CERAMIC TILE X-RAY MOUNTS

1. Grind sample (20 to 25 grams) to less than 62 microns (#230 mesh sieve).
2. Immerse powder in distilled water for 24 hours.
3. a. If clays flocculate, decant water and cover with fresh distilled water.
   b. If clay is still flocculated, add a few drops of ammonium hydroxide (NH_4OH) and remix. If clays do not disperse, repeat step 3a.
   c. If clays are not dispersed after repeating step 3a, add a few crystals of sodium hexametaphosphate $(NaPO_4)_6$ and remix. If clays are still flocculated repeat step 3a. Note, if too much sodium hexametaphosphate is used, adhesion to glass slides or ceramic tiles will be difficult.
4. Place ceramic tile on vacuum chamber (single hole rubber stopper in flask attached to vacuum pump will work).
5. After clays are dispersed, allow the beaker to remain undisturbed for 10 minutes. Then pipette off enough surface suspension to produce a meniscus on the ceramic tile. The vacuum may be off or on during application of

suspension to ceramic tile.

6. Allow clay aggregates to dry on tiles at room temperature. This procedure produces a mount with the C-axis strongly oriented perpendicular to the face of the tile, resulting in intensified basal (00ℓ) reflections.

APPENDIX B
SEMI-QUANTITATIVE CLAY ANALYSIS

% Clay Species

I. X-ray runs (modified from Austin, 1973):

  A. untreated clay mount (initial run)

    2 to 35 deg. 2θ (2 deg. 2θ/min.)

  B. untreated clay mount (slow run)

    24 to 28 deg. 2θ (.25 deg. 2θ/min.)

  C. after processing clay mount in ethylene glycol (24 hours)

    2 to 18 deg. 2θ (2 deg. 2θ/ min.)

  D. after processing clay mount in oven at 300 deg. C. (1 hour)

    2 to 18 deg. 2θ (2 deg. 2θ/min.)

II. Peak height (or area) above background used in equations (peak positions may vary slightly from angles noted below):

  A. initial run

    1. $K_{(1)}$ at 12.4 deg. 2θ
    2. $I_{(2)}$ at 17.8 deg. 2θ
    3. $C_{(3)}$ at 18.4 deg. 2θ

  B. slow run

    1. $K_{(2)}$ at 24.9 deg. 2θ
    2. $C_{(4)}$ at 25.1 deg. 2θ

C. ethylene glycol run

1. $M_{(1*)}$ at 5.2 deg. 2θ
2. $I_{(1*)}$ at 8.8 deg. 2θ

D. heated run

1. $I_{(1**)}$ at 8.8 deg. 2θ

III. Equations:

A. Total Counts (T)

1. if chlorite present

$$T = I_{(1**)} + K_{(1)}$$

2. if chlorite absent

$$T = I_{(1**)} + \frac{(C_{(3)})(I_{(1*)})}{I_{(2)}} + \frac{(K_{(2)})(C_{(3)})(I_{(1*)})}{2(C_{(4)})(I_{(2)})}$$

B. Illite (I)

$$I = \frac{I_{(1*)}}{T} \text{ X } 100$$

C. Montmorillonite (M)

$$M = \frac{\frac{I_{(1*)}}{4}}{T} \text{ X } 100$$

D. Chlorite (C)

$$C = \frac{C_{(3)}}{I_{(2)}} \times \frac{I_{(1*)}}{T} \times 100$$

E. Mixed-layer (ML)

$$ML = \frac{I_{(1**)} - (I_{(1*)} + \frac{M_{(I*)}}{4})}{T} \times 100$$

F. Kaolin (K)

1. if chlorite absent

$$K = \frac{K_{(1)}}{T} \times 100$$

2. if chlorite present

$$K = \frac{K_{(2)}}{2C_{(4)}} \times \frac{C_{(3)}}{I_{(2)}} \times \frac{I_{(1*)}}{T} \times 100$$

IV. Abbreviations:

A. 2θ = 2 theta angle

B. (n) = (00ℓ) basal reflections (i.e., (1) = (001)).

C. * = peak intensity from ethylene glycol x-ray run.

D. ** = peak intensity from heated x-ray run.

Illite Crystallinity

I. Peak height above background, from initial run, used in equation:

A. 10 A , $I_{(001)}$ at 8.8 deg. 2θ

B. 10.5 A , $I_{(001)}$ at 8.3 deg. 2θ (this is not a peak position, but the intensity of the illite reflection at a 2θ position ½ deg. lower.

II. Equation:

$$\text{Illite Crystallinity} = \frac{I_{(001)} \text{ at } 10 \text{ A}}{I_{(001)} \text{ at } 10.5 \text{ A}}$$

K_2O Value

I. Peak height above background, from initial run, used in equation:

A. $I_{(001)}$ at 8.8 deg. 2θ

B. $I_{(002)}$ at 17.8 deg. 2θ

II. Equation:

$$K_2O \text{ Value} = 11.5 - \left(\frac{I_{(001)}}{I_{(001)}} \text{ X } 1.23\right)$$

Note: 11.5 = highest K_2O value possible in illites.

1.23 = calculated slope of best fit line through 19 points representing variations in illite (001) to (002) ratios with known percentages of K_2O.

APPENDIX C

LIMESTONE AND SHALE DISAGGREGATION PROCESSES

Limestone

Acidization

1. Each sample should be crushed and sieved in order to produce 500 grams of carbonate chips with a size range between approximately 2 mm and 30 mm. If the chips are smaller, they will neutralize the acid too rapidly, and if the chips are larger, dissolution may be incomplete.
2. The sample (500 grams) is spread evenly across the bottom of a plastic or rubber bucket and approximately 7.5 liters of 10% formic acid is added. Preparation of formic acid solution should be done under a vented hood. Care should be taken during addition of the acid, which sometimes produces violent bubbling and might cause spilling and contamination.
3. The bucket is left under the vented hood for 24 hours. If the sample is left longer, any remaining acid will begin etching the conodonts.
4. After 24 hours, the liquid in the bucket is decanted off and the bucket filled with fresh water. This is done 2 or 3 times to reduce any remaining acid, which would harm the sieves.

5. Any remaining residue is washed through 3 sieves (#18 = 1mm; #120 = .125mm; #230 = 62.5 microns).
6. Residue remaining in the #18 sieve can be reprocessed in acid. In argillaceous limestones, non-carbonate residues may be processed in Stoddard Solvent, for further disaggregation.
7. Samples that are less than or greater than 500 grams should be processed in an amount of 10% formic acid that approximates the 500 gram sample/7.5 liter acid ratio.

Shale

Stoddard Solvent

1. Shales which do not contain abundant organic matter may be disaggregated using Stoddard Solvent.
2. A sample is air or oven dried to remove any moisture which would inhibit penetration of Stoddard Solvent into the shale (caution: Stoddard Solvent flash point is 140 deg. F.).
3. The sample is immersed in the solvent and allowed to soak. The amount of soaking time varies with the amount of shale induration. Non-fissile, clay rich shales may need to soak only 1 hour, while well-indurated, laminated shales may need to soak for up to 24 hours.
4. The Stoddard Solvent is decanted off, filtered and can be reused.

5. Immediately immerse the sample in water. The solvent is immiscible in water and will be replaced in the shale by the water, causing disaggregation. A combination of longer immersion in the solvent and the use of hot or boiling water, may aid in breaking down shales that do not seem to be affected by the initial Stoddard Solvent treatment.
6. The water is allowed to soak for a variable amount of time, depending upon the shale induration. If little effect is noted, longer soaking times may be needed (24 hours was required for many of the Cherryvale Formation shale units).
7. Disaggregated samples are washed through 3 sieves (same as those used in acidizing), and can be reprocessed. Many samples require multiple treatments.

Sodium Hypochlorite Bleach

1. Organic-rich, "black shales" can often be disaggregated using sodium hypochlorite bleach as an oxidizing agent.
2. Shales may be split along bedding planes to increase surface area and are immersed in bleach.
3. Depending on the organic content and induration, the length of processing time may vary from 1 or 2 weeks to 1 year.
4. Samples should be washed periodically and re-immersed in fresh bleach.

5. Alternating Stoddard Solvent and bleach treatments may aid in disaggregation.

APPENDIX D
HEAVY LIQUID METHOD OF CONODONT SEPARATION

Tetrabromoethane ($Br_2CHCHBr_2$) may be used to separate conodonts from lighter shale, quartz or carbonate chip residues. Because of toxicity in both the liquid and vapor phases of tetrabromoethane, all work should be done under a vented hood and great care must be taken to minimize any spills. All aspects of the process, including removal of waste paper and cloth, should be kept separate from other lab processes.

1. Funnels with clamped tubing below were filled 1/3 to 1/2 full with tetrabromoethane, and a residue slowly sprinkled in. If the residue is poured too fast, the heavy portion may settle rapidly and pull part of the light fraction down with it, causing poor separation. The amount of residue used depends on the surface area of the liquid in the funnel. A layer approximately 1/2 inch thick will require 5 to 6 hours of settling time, while a layer approximately 1 inch thick will require 10 or 11 hours.
2. The residue should be stirred once an hour with a glass rod. The number of hours depends on the amount of residue, discussed above.

3. After the appropriate settling time has been used, place 2, one foot square, pieces of cloth (or paper towel) across the top of two beakers and push them down 1/3 to 1/2 the beaker's depth. These should be clamped around the top to stablize the cloth and form a bag-like filter.
4. Place one beaker under the funnel and slowly release the clamp, allowing the heavy fraction of the residue to flow into the cloth bag. You must open the clamp wide enough to allow the flow of the heavy fraction, but not wide enough to allow the light fraction to flow out. Caution must be taken to reduce splattering as the liquid flows into the bag.
5. Stop the flow as soon as the light fraction enters the funnel tubing.
6. Fold the cloth into a bag and clamp the top. Drape this bag in an empty beaker to drain.
7. Place the second beaker under the funnel (watch for drips). Open the clamp and slowly allow the light fraction to flow into the second bag. Use the heavy liquids that passed through the first bag to wash any residue that remains in the funnel. Caution must be used when pouring the tetrabromoethane into the funnel. If the liquid is poured too fast, part of the light fraction may clog the tubing and the rate of flow will

be hard to control, resulting in spills and splattering.

8. Fold the cloth with the light fraction into a bag similar to the heavy fraction, clamp and suspend in an empty beaker to drain. Both the light and heavy fractions should drain for 10 to 15 minutes. Tetrabromoethane which has passed through the bags may be filtered and reused. Again caution must be taken during filtering in order to minimize splattering.
9. The light and heavy fraction bags are run through a series of 3 iso-propyl alcohol baths. They are suspended in each bath for approximately 1 hour and should be at least 1 inch above the bottom of the beaker in order for the density difference between the two liquids to form a downward flow of tetrabromoethane.
10. As the first bath loses alcohol through evaporation, it is refilled from the cleaner alcohol in bath 2, and as bath 2 loses alcohol, it is refilled from the cleaner alcohol in bath 3. This allow the residue bags to always move into a cleaner bath, which maximizes the density difference, producing greater separation of the tetrabromoethane from the residues.
11. After the last bath, the residue bags are hung until dry and then opened in order to dry flat. This aids in evaporation of any heavy liquids and alcohol from the tightly folded portions, near the clamp. Drying should

continue until tetrabromoethane odor cannot be detected.

Size of processing and processing time are variable and should be checked by scanning the light fraction for conodonts which would suggest a poor separation and require longer settling time.

Procedure and lab technique should be stressed in order to reduce contamination and the potential harmful effects of tetrabromoethane. All spills, no matter how minor, should be wiped up immediately with alcohol. Drips on the outside of beakers should be washed and rubber gloves should probably be worn until your procedure is practiced. Any spills or splatters on your skin or clothes should be washed immediately with alcohol.

APPENDIX E

LOCATIONS OF DESCRIBED SECTIONS

North Cherryvale (NCv) section:
approximately 1.5 miles north of Cherryvale, Kansas (Montgomery County), along east line SE, SE, SE, sec. 32, T31S, R17E, and west up hill.

Verdigris River (VsR) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), near center SE, SE, NW, sec. 28, T33S, R16E, on west bank of Verdigris River.

Clear Creek Mouth (CCM) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), at junction of Clear Creek and Verdigris River, SW, NW, SE, sec. 28, T33S, R16E, on south bank of Clear Creek.

Clear Creek 1 (CC1) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), upstream from section CCM, in southwest corner, SW, NW, SE, sec. 28, T33S, R16E, on south bank of Clear Creek.

Clear Creek 2 (CC2) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), upstream from section CC1, below highest topographic point, in southeast corner, NW, SE, SW, sec. 28, T33S, R16E, on south bank of Clear Creek.

Clear Creek 3 (CC3) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), upstream from section CC2, in southwest corner, NW, SE, SW, sec. 28, T33S, R16E, on south bank of Clear Creek.

Clear Creek Bridge (CCB) section:
approximately 5 miles southeast of Independence, Kansas (Montgomery County), upstream from section CC3, under bridge , along west line NW, SW, SW, sec. 28, T33S, R16E, on south bank of Clear Creek and under east edge of bridge.

Data from Baesemann (1973) and Heckel and Baesemann (1975):
Inland Drive, N½, sec. 27, T11S, R24E, Shawnee Quadrangle (Wyandotte County), Kansas (Fontana Shale, Block Limestone, Wea Shale and Westerville Limestone Members of Cherryvale Formation collected at this locality).

Highway 32 roadcut, S½, sec. 12, T11S, R24E, Shawnee Quadrangle (Wyandotte County), Kansas (Westerville Limestone and Quivira Shale collected at this locality).

Thayer Quarry (TH) section:
south wall of quarry, 2 miles south of Thayer, Iowa (Union County), NW, NE, sec. 35, T72N, R 28W, just east of highway P64.

Iowa Bedford Core (IBC):
cored near southeast edge of Bedford, Iowa (Taylor County), NE, NE, NE, sec. 35, T68N, R34W, approximately .5 miles east of highway N44.

Atlantic Quarry (P.H. Heckel, personal notes, 1968):
older quarry, west of Atlantic, Iowa (Cass County), near center east half, sec. 6, T76N, R36W, north of Route 83.

Nebraska Offutt Core (NOC):
cored near Offutt Air Force Base, south of Omaha, Nebraska (Sarpy County), CS½, SE, SE, NW, sec. 11, T13N, R13E.

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