DEPOSITIONAL AND DIAGENETIC STUDY OF THE EXLINE LIMESTONE, PLEASANTON GROUP, UPPER PENNSYLVANIAN (MISSOURIAN) OF THE NORTHERN MIDCONTINENT

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Mark Andrew Nielsen

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Geology at the July 1987 graduation.

Thesis committee: ______________________
Thesis supervisor

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Member

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Member

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ABSTRACT

The Exline Limestone has three distinctive lithofacies: Shaly Crinoidal Calcilutite Facies in the south (north-central Missouri), Algal Calcilutite Facies across the central area (northern Missouri), and Mixed Skeletal Calcarenite Facies in the north (Iowa-Nebraska). All were at least initially transgressive above terrestrial strata.

The southern two facies were deposited in open marine water below effective wave base, the Shaly Crinoidal Calcilutite near the base of the photic zone, and the Algal Calcilutite within the photic zone. Both are overlain by deltaic to prodeltaic clastics. Both also contain overcompacted and crushed grains, neomorphic spar in aragonite and high-magnesium calcite fossils, and blocky calcite only within uncrushed portions of ostracode and gastropod shells. These features indicate burial and compaction before cementation in the marine phreatic environment, which is typical for a transgressive limestone.

The northern Mixed Skeletal Calcarenite Facies was deposited in turbulent shallow water, shoaling upward to a

restricted environment, thus is mainly a regressive limestone. It contains leached molds of unstable fossils filled with blocky calcite, syntaxial overgrowths on crinoids, and matrix alteration to microspar. These are typically regressive features created by fresh water infiltration from the soil horizon found directly above this facies of the Exline. While the soil formed here, the deltaic deposits were burying the mostly transgressive part of the limestone to the south.

Thus, by using a combination of the lithic and faunal criteria, and recognizing that most of the regressive phase over the southern two facies was deltaic, the Exline can be fit into the Midcontinent Pennsylvanian cyclothem model of transgression and regression of the sea.

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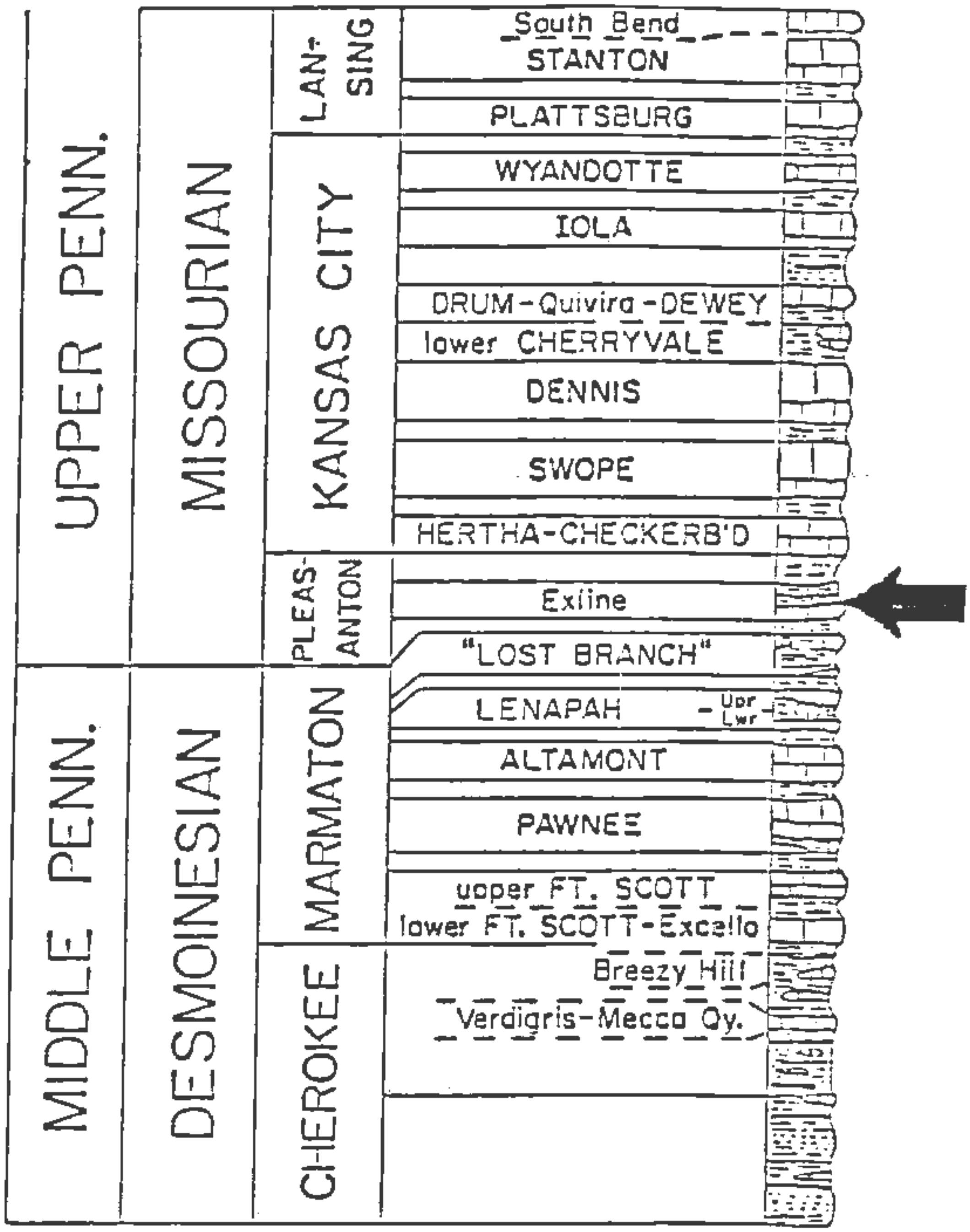
INTRODUCTION

The Exline Limestone is the lowest widespread marine horizon within the clastic-dominated Pleasanton Group at the base of the Missourian Series in the northern Midcontinent (Figure 1). Other than a brief summary of the Exline fauna by Cline and Burma (1949) and an excellent overview of Pleasanton stratigraphy by Howe (1982), little has been published in detail on any aspect of the Exline Limestone.

Previous Work

The Exline Limestone was named by Cline (1941) from an outcrop near the town of Exline in Appanoose County, Iowa. He reported that it extends as far northwestward as Dallas County, west of Des Moines, Iowa. Since its naming, the Exline Limestone has been dealt with only briefly by Cline and Burma (1949), Singler (1965), Willman et al. (1975), Howe (1982), and Ravn et al. (1984). Willman and others (1975) reported that the Exline Limestone extends as far east as Peoria, Illinois. Howe (1982) located many of the Exline outcrop localities in Iowa and Missouri, and identified the horizon as far south as Cass County, Missouri. Howe recognized the Exline as a member of a

Figure 1 - Position of Exline Limestone in generalized columnar section for Desmoinesian and Missourian Series in Midcontinent outcrop. (Adapted from Heckel, 1984)


UPPER PENN.
MIDDLE PENN.
MISSOURIAN
DESMOINESIAN
LAN-SING
KANSAS CITY
PLEAS-ANTON
MARMATON
CHEROKEE
South Bend
STANTON
PLATTSBURG
WYANDOTTE
IOLA
DRUM-Quivira-DEWEY
lower CHERRYVALE
DENNIS
SWOPE
HERTHA-CHECKERB'D
Exline
"LOST BRANCH"
LENAPAH
Upr
Lwr
ALTAMONT
PAWNEE
upper FT. SCOTT
lower FT. SCOTT-Excello
Breezy Hill
Verdigris-Mecca Qy.

tentatively named formation within the Pleasanton Group in Missouri. Ravn et al. (1984), working in Iowa, recognized the Exline as a member within the Pleasanton Formation.

Howe (1982) noted that both shale and limestone are included in the Exline member; the shale typically occurs as thin layers within the limestone, and the limestone occurs in two distinct facies. In western Missouri, a one-foot-thick friable crinoidal limestone with common shale stringers is predominant, and in northern Missouri, a three to five-foot-thick dense algal limestone is present. The major emphasis in Howe (1982) was given to outcrop locations and descriptions, which formed the basis for Pleasanton stratigraphy. Most of the outcrop localities used in this study were obtained from that report.

Swade (1985) briefly mentioned distinct changes in conodont faunas up into the Exline Limestone from the Desmoinesian units below, within a core in south-central Iowa. This information has been crucial in the identification of the Exline Limestone in cores not previously studied. The Exline in these cores is the limestone below the readily recognized Dennis-Swope-Hertha succession and above the newly named Lost Branch Formation (Heckel 1984, ms. in review), which can be identified by its distinctive Desmoinesian conodont fauna that was described by Swade (1985).

Current Models of Midcontinent Pennsylvanian Deposition and Diagenesis

The Midcontinent Pennsylvanian succession consists of an alternation of thin, laterally extensive limestone formations with sandy shale formations (Figure 1). Most of these limestone formations are composed of a repeating sequence of rock units called a cyclothem, first recognized in the Midcontinent by Moore (1931). Wanless and Shepard (1936) related these alternations of shale and limestone to periodic transgression and regression of the sea due to glaciation. Heckel (1977, 1980, 1986) supported this hypothesis and developed a model for the depositional interpretation of a cyclothem. The basic complete cycle currently recognized has, in ascending order: 1) thick, sandy nearshore to non-marine shale; 2) thin, transgressive limestone, typically a skeletal calcilutite; 3) thin, non-sandy offshore shale, commonly with a black phosphatic facies; 4) thick, regressive limestone, typically a skeletal calcilutite grading upward into a skeletal calcarenite; and 5) thick, sandy nearshore shale, like unit one. Differing abundance and diversity of conodont faunas characterize each member. The maximum transgression is represented in the offshore shale, within the black phosphatic facies when present, where conodonts are most abundant.

The diagenetic features present within transgressive and regressive carbonate rocks also are different. Longman (1980) recognized four diagenetic environments that are responsible for diagenetic features in a limestone: 1) fresh-water vadose zone; 2) fresh-water phreatic zone; 3) mixing zone; and 4) marine phreatic zone. Heckel (1983) contrasted the features of these environments with those expected in the deep burial connate zone to explain the differences in diagenetic features between transgressive and regressive limestones in Pennsylvanian rocks. Heckel (1983) observed that transgressive limestones generally have overcompacted grains, neomorphism of aragonitic shells and high-magnesium calcite algal blades, and ferroan calcite and dolomite cements. These features formed in response to diagenesis in the marine phreatic zone followed by the deeper burial connate zone, where compaction of the limestone occurred before cementation. In contrast, regressive limestones generally have early cement rims, leached aragonitic shells and high-magnesium calcite algal blades, blocky non-ferroan calcite cements, little compaction, and less development of ferroan calcite and dolomite cements. These features formed in response to diagenesis in the marine phreatic zone, followed by the fresh-water phreatic and vadose zones that developed as the sea regressed before burial in the deeper connate zone during subsequent transgression. The offshore shale apparently kept the transgressive limestone effectively sealed off from fresh water influences.

Purpose

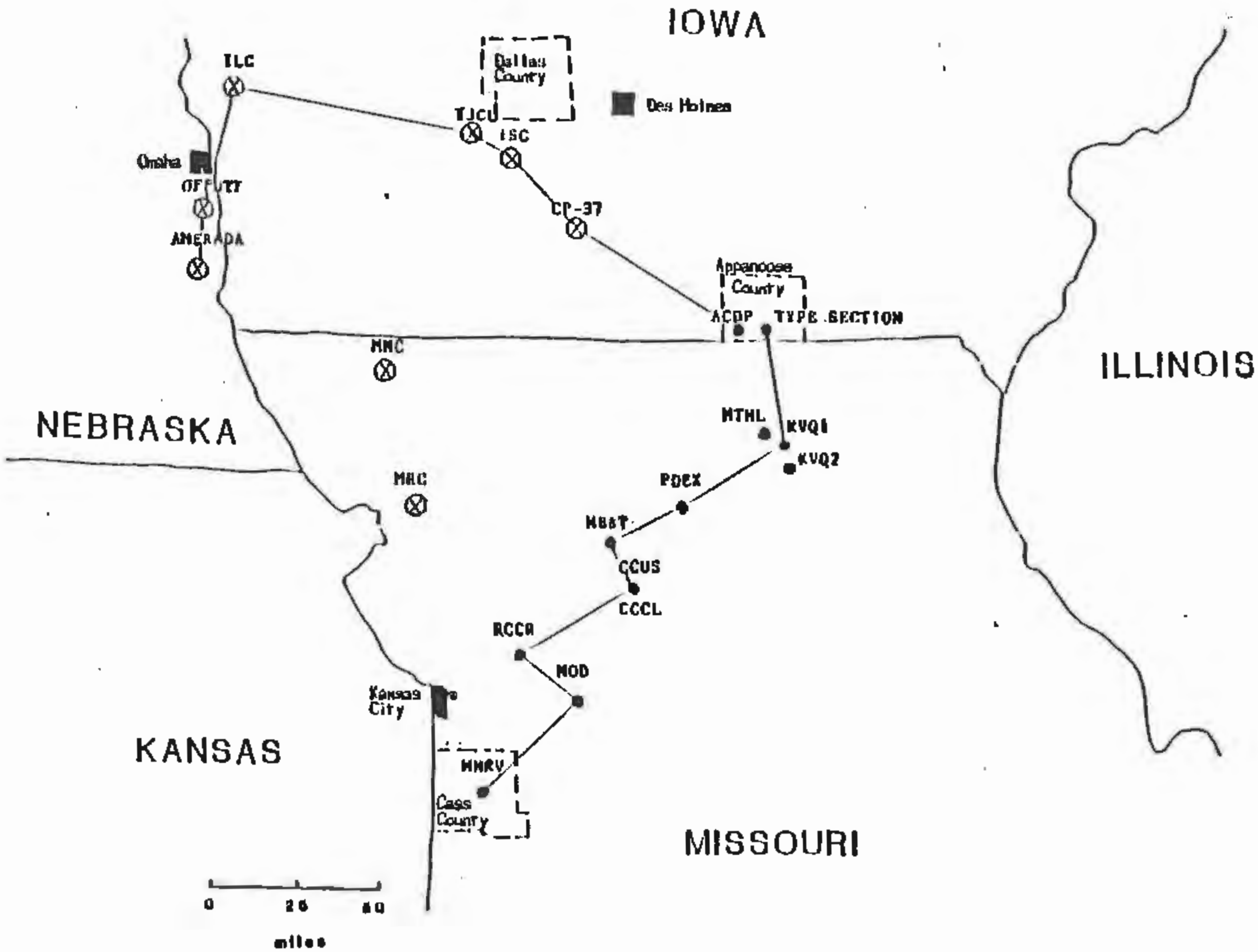
The purpose of studying the Exline Limestone is to determine if the general model of cyclothemic deposition for Pennsylvanian Midcontinent rocks applies to a thin, extensive, marine unit such as the Exline. Does the Exline relate to cyclothemic deposition, and if it does, is it possible to recognize its depositional and diagenetic positions within the cycle?

Study Area

The outcrop belt was studied from south-central Iowa through north-central Missouri to west-central Missouri (Figure 2). Since the field work in the 1950s and 1960s reported by Howe (1982), outcrop slumpage has destroyed many of his reported Exline localities in Missouri. In Illinois, slumping was also a major problem in relocating old outcrops and apparently caused misidentification of limestone units as Exline.

Cores in which the Exline had been identified by P. H. Heckel (pers. commun. 1983) composed the entire source of data in northwestern Missouri, eastern Nebraska, and southwestern Iowa. Cores were necessary in these regions because of the thick Pleistocene section covering much of

Figure 2 - Location map of collected outcrops (●) and cores (⊗) from Exline Limestone showing locality symbol. Solid black line represents location of cross-section for Figure 5. Appendix B gives measured sections for most outcrops and cores shown on Figure 2. Information for CP-37 is from Swade (1985, p. 39) and for MNC, MRC, and MHRV from P. H. Heckel (pers. commun. 1984).


IOWA
Dallas County
Des Moines
TLC
TJCU
ESC
CP-37
Omaha
OFFUTT
AMERADA
Appanoose County
ACDP
TYPE SECTION
MMC
ILLINOIS
NEBRASKA
MTHL
KVQ1
KVQ2
PDEX
MBST
MRC
CCUS
CCCL
RCCR
MOD
Kansas City
KANSAS
MNRV
Cass County
MISSOURI
0
25
50
miles

the area. All outcrops and cores collected and studied are shown in Figure 2.

Method of Study

Nineteen reported outcrops of the Exline Limestone were visited. Twelve outcrops were found that had the Exline Limestone still exposed. Limestone and the adjacent shales were collected to obtain the entire Exline section at each of these locations. All cores where the Exline was reported to exist were collected for study from the respective State Geological Surveys.

The outcrop and core sections then were processed for conodonts using the methods of Swade (1985). A sample was taken from every four inches (0.1 m) of cored Exline. Where shale and limestone were interbedded or otherwise segregated in the same core segment, the shale residue was kept separate from the limestone residue. The conodonts were studied using identifications made by Baesemann (1973) and Swade (1985) with the help of P. H. Heckel (pers. commun. 1984) to determine the presence and abundance of certain genera through vertical sequences within the Exline sections. For comparison purposes, the abundance of each genus was converted to numbers per 1000-gram sample at all localites. Only elements of the genus *Idioprioniodus* and platform elements of the genera *Idiognathodus*, *Anchignathodus* (*sensu* Swade, 1985), *Diplognathodus*, and *Adetognathus* were counted. *Gondolella* and *Neognathodus* were searched for but only one *Gondolella* and no *Neognathodus* were found in the Exline. (*Neognathodus* was found in the Lost Branch in cores IJCL and ISC.) *Aethotaxis* and *Ellisonia* are probably present, but were not counted separately from undifferentiated ramiform elements of all genera.

Polished slabs and thin sections were prepared from the Exline Limestone at all localities. All thin sections were studied using a polarizing-petrographic microscope in order to observe the petrology, the diagenetic characteristics, and to approximate the abundance of the shelled fauna. Approximately half of each thin section was stained with alizarin red-S and potassium ferricyanide, according to the method suggested by Dickson (1965), to determine calcite vs. dolomite and ferroan vs. non-ferroan variants of these minerals.

From the data gathered, pertinent literature, and personal communications, three distinct lithofacies were recognized. Following analysis of their depositional and diagenetic characteristics, and interpretation of their probable environments of deposition, conclusions were drawn as to how the Exline Limestone fits into the Pennsylvanian cyclothem model.

LITHOFACIES OF THE EXLINE LIMESTONE

The Exline Limestone is composed of three distinct lithofacies that are reflected also in the dominant fossil assemblages present. Within the study area, there are only two locations that show a vertical succession of two facies. The remainder have only one facies per locality. The facies names are derived from the field-observable weathering characteristics: 1) Shaly Crinoidal Calcilutite, for the limestone exposures in which crinoids weather most distinctly; 2) Algal Calcilutite, for dense limestones in which phylloid algal blades appear conspicuous, with little observable crinoidal debris; and 3) Mixed Skeletal Calcarenite, for the facies in which grains are dominant, and other fossils as well as algae and crinoids are conspicuous in the limestone. These facies, adjacent strata, and vertical contacts are discussed below.

Shaly Crinoidal Calcilutite

The Shaly Crinoidal Calcilutite Facies is a dark gray friable limestone, in which shale and crinoid debris are the most readily observable constituents (Plates 1-A, 2-A). Another important aspect is that few preserved algal blades were found. This facies averages one to two feet in thickness, and extends across the entire southern portion of the study area (Figure 3). It becomes progressively richer in shale from north to south and eventually shales out south of Jackson County, Missouri. For some distance to the south, there appears to be mainly a marine shale equivalent to the Exline Limestone, as at locality MHRV in Cass County, Missouri, and southward in eastern Kansas (P. H. Heckel, pers. communs. 1984, 1986).

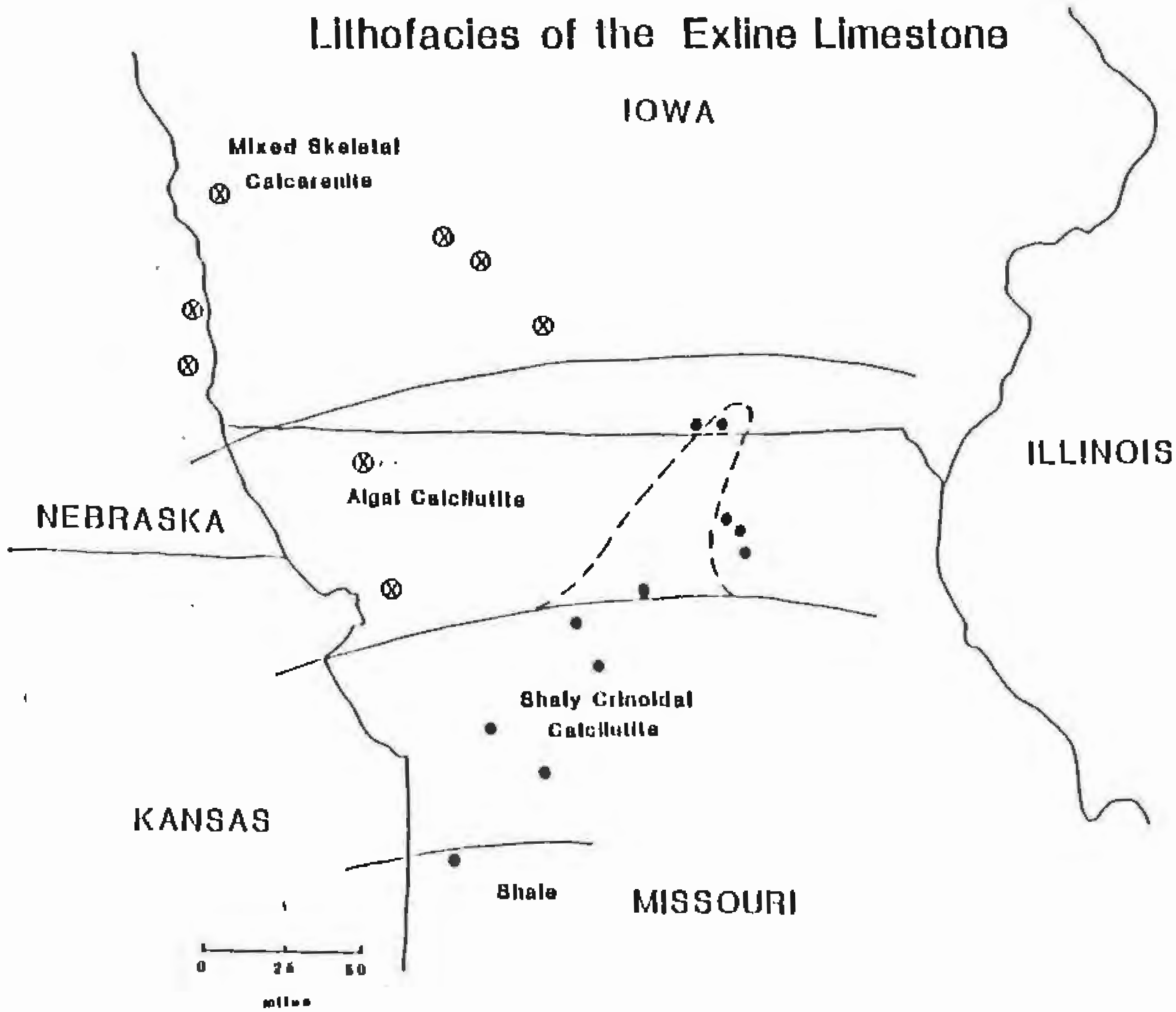
The limestone unit at a number of localities (e.g., MOD, CCUS) is commonly split by a thin shale parting, typically one to six inches thick. In all cases, this shale has similar color and macrofossil and microfossil assemblages as the limestone on either side of it. Toward the north, at locality MB&T, the shale parting appears to be only local and non-traceable.

The contact between the Exline Limestone and the shale beneath is transitional across a one-inch zone. In all outcrops studied, the underlying shale is gray, slightly calcareous, and contains a less abundant fauna than the limestone above. This shale grades downward into sandy shale to shaly sandstone at some localities (MB&T, MOD). In parts of western Missouri, a thin coal, named Grain Valley Coal by Howe (1982), lies not far below the Exline.

Fossils

Two skeletal types basically dominate this facies,

Figure 3- Map of Exline Limestone showing areas of occurrence of the lithofacies. Dashed line encloses area in which Shaly Crinoidal Calcilutite Facies overlies Algal Calcilutite Facies. The cores in northwestern Missouri were not seen by author, but were indicated to consist entirely of brown, dense phylloid algal-dominated calcilutite abruptly overlain by sandstone, by P. H. Heckel (pers. commun. 1984)



Lithofacies of the Exline Limestone
IOWA
Mixed Skeletal
Calcarenite
ILLINOIS
Algal Calcilutite
NEBRASKA
Shaly Crinoidal
Calcilutite
KANSAS
Shale
MISSOURI
0
25
50
miles

crinoids and gastropods. Although the crinoids weather more distinctly and are easier to identify in all outcrops, the polished slabs show that gastropods are the most abundant skeletal type in the northern part of the shaly crinoidal facies. In addition to the crinoids and gastropods, other macrofossil groups include pelecypods, ostracodes, trilobites, solitary corals, and brachiopods. A listing of relative abundances is presented in Appendix A. The fossil assemblage is consistent with deposition under normal, stable open marine water with low turbidity. Algal blades that are important in the other two facies are extremely rare.

Petrology

In thin section, this unit is a shaly crinoidal wackestone (Plate 2-A), composed entirely of non-ferroan calcite. No ferroan calcite or dolomite was detected in this facies.

The limestone consists of approximately fifty percent skeletal material with argillaceous calcilutite composing the rest. Although the rock is not generally grain-supported, it shows some crushed shells related to overcompaction, especially among the gastropods, ostracodes, and pelecypods (Plate 3-A).

There is very little void-filling calcite in the Shaly Crinoidal Calcilutite Facies. It exists only within uncrushed gastropod and ostracode shells, where it appears to have been deposited in two phases: 1) a thin drusy rim on the inside of the shells; and 2) blocky crystals filling the remainder of the opening.

The majority of the originally aragonitic shells have been altered while maintaining much of their original fabric (Plates 3-A, 4-A). This relict or ghost structure is obscured somewhat by the neomorphic spar, which can be seen more distinctly under crossed polarizers (Plate 4-B).

Among the originally calcite fossils, the echinoderm debris does not display syntaxial overgrowths in any of the thin sections from this facies. Nor do they display the unit extinction that normally is characteristic of echinoderms (Plates 5-A, 5-B). The echinoderms that show the most disjointed extinction are those that are in contact with other grains.

Conodonts

Conodonts are very abundant within this facies, ranging from 600 to 1800 elements per kilogram of sample (Appendix B, Figures 6, 7, 8, 9). This number generally is highest within the middle of the lower limestone and decreases slightly both upward and particularly downward. At locality RCCR, the total abundance figures are nearly mirror images across the middle shale parting, with the shale parting containing slightly fewer conodonts than the adjacent limestones. These abundances suggest that this facies was deposited slowly in normal marine conditions, with the middle of the lower limestone bed representing the slowest deposition for the facies.

The genus of conodont found in greatest abundance is Idiognathodus, with Idioprioniodus and Anchignathodus occurring in smaller numbers. Adetognathus was found in even fewer numbers, and only at the base and occasionally at the very top of this limestone unit. The only Gondolella found in this study was in a shale at the base of this facies at section MOD, the southernmost section examined in detail.

Algal Calcilutite Facies

The Algal Calcilutite Facies is a blue-gray to brownish, dense limestone unit (Plates 1-B, 2-B). Its name is derived from the dominance of phylloid algal blades, which are easily identifiable as the red alga Archaeolithophyllum in thin section. Echinoderm debris is greatly reduced to a small fraction of the skeletal material. This unit extends from southern Iowa into northern Missouri, across a belt that occupies the middle of the study area (Figure 3). It ranges in thickness from one foot in the Iowa outcrop to seven feet in the MNC core in Missouri, with five to six feet reported in exposures KVQ1 and KVQ2 around Kirksville, Missouri (Howe 1982).

Two localities in this belt contain the shaly crinoidal calcilutite above the algal calcilutite. The contact between these two units, although now obscured by slumpage, is sharp but does not appear to be irregular.

The unit below the algal calcilutite could be observed at only a few localities, as slumping of the thick algal limestone obscured the lower unit at most localities. In Iowa, at the Appanoose County Dump locality, there is a gray, blocky mudstone beneath the Exline. Based on the lack of fossils and the blocky structure of the mudstone, it could be interpreted as a soil horizon (Schutter & Heckel, 1985).

Fossils

The red alga Archaeolithophyllum constitutes approximately forty percent of this limestone unit. It is easily identified by its large blade-type morphology (Plates 2-B, 3-B, 3-C) and cellular internal structure (Plates 7-A, 7-B). Approximately five percent of this facies is composed of other skeletal material including ostracodes, trilobites, gastropods, clams, brachiopods, and some crinoid debris. The remaining fifty-five percent of the unit is mud. A listing of macrofossil groups and their relative abundances is presented in Appendix A. Although the fossils present are generally the same as in the shaly crinoidal facies, the abundances are much different. The high abundance of algae definitely places this environment in the the photic zone. The lack of coral and the small number of crinoids suggest a slightly more restricted, possibly more turbid, and certainly more algae-rich depositional environment than the shaly crinoidal facies.

Petrology

In thin section, this unit is an algal biomicrite, composed entirely of non-ferroan calcite. This unit does not appear to be generally grain-supported, and is a wackestone in Dunham's (1962) terminology. Some grains do touch however, and suggest a compacted character. There are also broken and crushed grains, especially among the gastropods (Plates 3-D, 6-A) and ostracodes. These fossils contain the only void-filling calcite within this unit (Plates 6-A, 6-B). As in the crinoidal facies, these shells were filled in a two-step process. First a thin rim of fibrous, perhaps high-magnesium calcite was deposited around the inside of the shell, and later blocky, probably low-magnesium calcite filled the rest of the opening.

The aragonite fossils (i.e., gastropods, pelecypods), and high-magnesium calcite algae, were not dissolved and replaced by blocky calcite. Instead, the original fabric has been preserved as a relict or ghost structure, with neomorphic spar replacing the original mineralogy of the skeletal material (Plates 6-A, 6-B, 7-A, 7-B). The matrix has also been altered to microspar (Plate 7-B).

Conodonts

Conodonts are less abundant in the algal facies than in the shaly crinoidal facies, and range from approximately 28 to 200 conodont elements per kilogram (Appendix B, Figures 10, 11). There were no noticeable abundance changes through either of the two vertical sequences at PDEX or at the type section. The conodont genus dominant in this facies is Idiognathodus, with Anchignathodus the only other genus identified.

Mixed Skeletal Calcarenite Facies

The Mixed Skeletal Calcarenite Facies occupies the northernmost portion of the study area (Figure 3), and was found only in cored localites in Iowa and Nebraska because of the lack of adequate surface exposures. The southern part of this mixed skeletal facies is a massive limestone found at localities Amerada, CP-37, and the lower part of the Offutt core. In the top of the Offutt core and northward, at core localities ISC, ILC, and IJCL, the limestone is rubbly and apparently leached, with shale in fractures and cavities. Upon processing the northernmost locality ILC, half of the sample was found to be Exline Limestone, and the rest was a green, blocky mudstone with very few marine fossils. This mudstone apparently was deposited after the Exline and became incorporated into the limestone as leaching occurred. The entire mixed skeletal facies ranges from two to six feet in thickness. At localities ISC and IJCL, most of the core sequence probably belongs to the underlying Lost Branch Formation because the distinctive conodont fauna described by Swade (1985) was found in basal shale (P. H. Heckel, pers. commun. 1984). The increase in conodont abundance along with the appearance of Idioprioniodus at the top of the shaly limestone suggests that the Exline horizon may be present at the very top of the leached limestone in these two cores.

Fossils

The skeletal material in the Mixed Skeletal Calcarenite Facies includes basically the same major groups as do the other two facies, including algae, echinoderms, gastropods, pelecypods, ostracodes, brachiopods, corals, and foraminifers. It is termed "mixed skeletal" because no single skeletal type dominates. Another difference from the other two facies is that encrusting foraminifers are much more abundant. A listing of the macrofossil groups present and their relative abundances is given in Appendix A.

Petrology

In thin section, the main part of this unit is a skeletal grainstone to packstone. Grains appear to have been stongly abraded, both before and after coating by encrusting foraminifers and other organisms (Plates 8-A, 9). Skeletal material averages about sixty-five to seventy percent of the limestone. The rock is grain-supported, but there are not many broken or overcompacted grains (Plate 2-C). Loosely packed carbonate mud forms geopetal filling of some void space (Plates 8-A, 9). The grains are surrounded predominantly by non-ferroan calcite spar. This void-filling was preceded by a thin, fibrous, probably high-magnesium drusy calcite rim. The remainder of the voids was filled later with blocky calcite (Plate 8-B).

Unlike the previous two facies, those grains originally composed of aragonite (i.e., gastropods, pelecypods, and green algae), or very high-magnesium calcite (red algae), in this facies consist largely of clear, blocky void-filling calcite with little relict or ghost structure observed. This void-filling spar was preceded by an early cement rim found in some places on the outside of the relict fossil exterior (Plate 8-B). In other places the original fossil forms were preserved by the micritic and skeletal coating created largely by encrusting forams around most of the fossils (Plate 9). The encrusting forams were composed of calcite, which kept them from being easily dissolved like the aragonitic shells they encrusted.

The echinoderm debris, in contrast to the other facies, possesses syntaxial overgrowths and retains its distinctive unit extinction. The overgrowths extend into the voids between grains, and in places encompass the early cement rims around the voids (Plate 8-B). The more shaly, rubbly parts at the top of this facies were not thin sectioned, but consisted of pelleted packstones and laminated mudstones which contained less skeletal debris.

Conodonts

The conodonts in this facies were removed carefully to separate those in the green mudstone from those in the limestone. The number of conodonts was highly variable from outcrop to outcrop, ranging from 0 to 400 elements per kilogram (Appendix B, Figures 12, 13, 14, 15, 16). Many of the shales were barren of conodonts. In addition, the major genus found typically was *Adetognathus*. *Idiognathodus*, *Anchignathodus*, and scattered *Idioprioniodus* also were found, but typically in relatively small numbers.

Upper Pleasanton Unit, above the Exline

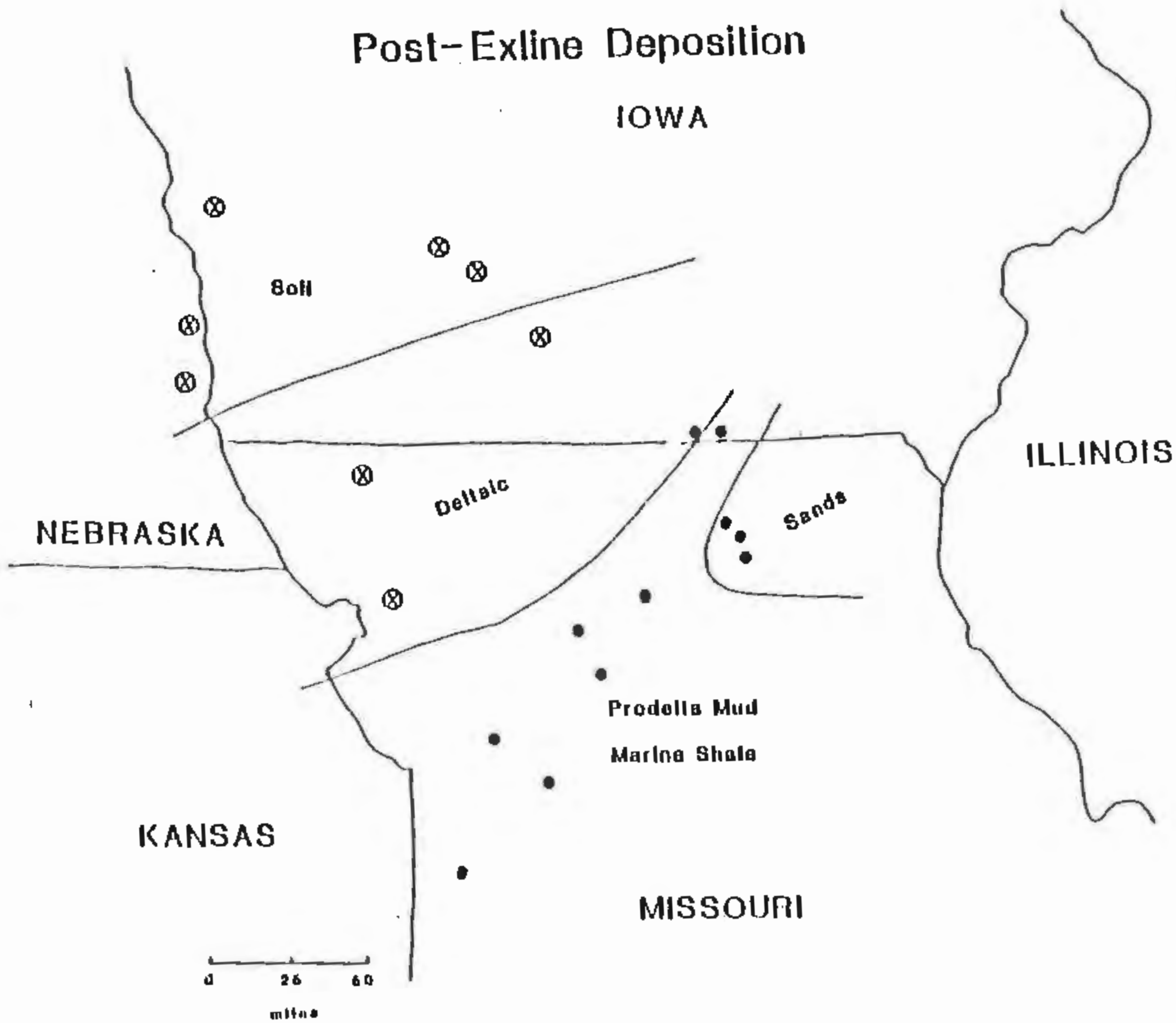
The post-Exline upper Pleasanton unit is predominantly a non-carbonate deposit, consisting of deltaic sands and prodeltaic muds in the south (Howe 1982), and blocky mudstones, probably ancient soils, in the north. The facies of this unit have distinct characteristics and boundaries within the study area (Figure 4).

The northern facies extends across most of the mixed skeletal limestone of the Exline. It is a green, blocky mudstone, with few to no marine fossils, and ranges in thickness from two to three feet. In the extreme northern part of this facies, the green mudstone encompassing fragments of the rubbly Exline Limestone grades upward to all mudstone.

The deltaic sands extend across most of the area above the Algal Calcilutite Facies, and range in thickness from three to sixty feet. This sandstone is massive, extremely friable, fine to medium grained, coarsely crossbedded, and commonly has a sharp, unconformable boundary with the Exline.

To the south, prodeltaic marine shales overlie the Exline. This marine shale is gray, laminated, slightly micaceous, moderately fossiliferous in the base, and ranges in thickness up to fifty feet at section MB&T. This facies has been interpreted as a prodeltaic sequence, which coarsens upward to deltaic sandstones (Howe 1982). The boundary between the limestone and the shale is distinct,

Figure 4- Lithofacies map of post-Exline Upper Pleasanton Unit. The trend is emergent in the north and deepening southward.


Post-Exline Deposition
IOWA
Soil
ILLINOIS
Deltaic
Sands
NEBRASKA
Prodelta Mud
Marine Shale
KANSAS
MISSOURI
0 25 50
miles

but apparently conformable.

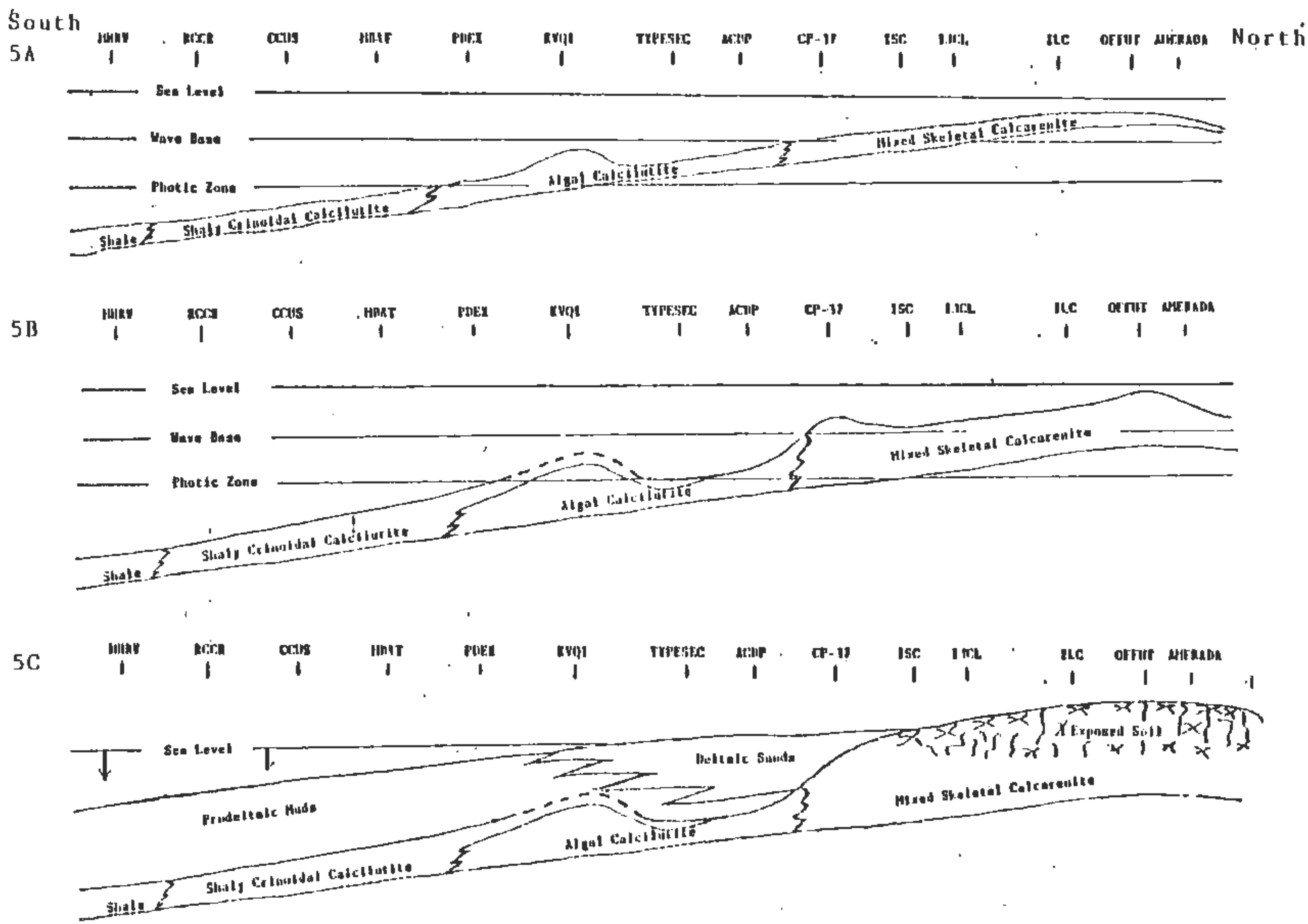
Where the crinoidal lithofacies overlies the algal facies, it is overlain by the prodeltaic mud facies. This suggests that the deltaic sands may have followed erosion of the crinoidal facies from above the algal facies in other areas.

INTERPRETATIONS

Depositional Environments

The depositional model used for the Exline Limestone relies extensively on gross lithofacies and fossil assemblages to interpret the depositional environments. The presence of benthic algae places the northern two of the three facies entirely within the photic zone (Figure 5). The water within this area was normal marine as indicated by the presence of echinoderms, corals (in the mixed facies), and a good representation of other invertebrate groups and algae. The environment of the southern two facies (algal, crinoidal) was not turbulent, based on the calcilutitic matrix and the unabraded character of the skeletal material, dominated by whole unbroken shells. In contrast, the northern mixed skeletal facies is dominated by calcarenite made up largely of highly abraded grains, some of which show several different stages of abrasion and coating. This indicates that this part of the Exline environment was in shallow turbulent water above effective wave base for much of its deposition, on the high northward extension of the northern Midcontinent shelf (Figure 5). The more calcilutitic

Figure 5- Cross-section showing Exline facies and interpreted depositional environments. A, Early transgressive phase of Exline deposition, with locality PDEX all Algal Calcilutite Facies. B, Maximum transgressive phase of Exline deposition, after deepening sea placed locality PDEX below the photic zone, resulting in deposition of Shaly Crinoidal Calcilutite Facies there and northward to Type Section. C, Phase of post-Exline deposition that occurred during regression of this cycle of marine inundation and retreat.


South
North
5A
5B
5C
TYPESEC
OFFUT
AMERADA
Sea Level
Wave Base
Photic Zone
Shale
Shaly Crinoidal Calcilutite
Algal Calcilutite
Mixed Skeletal Calcarenite
Deltaic Sands
Prodeltaic Muds
Exposed Soil

portions of this facies may represent protected shallow areas such as lagoons behind shoals. The appearance of barren laminated calcilutite at the top of this facies in the Offutt core suggests a regressive sequence in which a muddy shoreline became established upon a former subtidal shoal as sea level began dropping.

Diagenesis

Key petrologic differences occur between the northern and southern facies of the Exline Limestone. The southern two facies (Shaly Crinoidal Calcilutite, Algal Calcilutite), have similar characteristics, with overcompacted and crushed grains even in a mud matrix, neomorphic spar in originally aragonitic and high-magnesium calcite grains, blocky void-filling calcite only within gastropods and ostracode shells, and non-unit extinction within crinoids. All these diagenetic features suggest strong compaction before cementation and are compatible with a transgressive or offshore cyclothemic unit based on Heckel's 1983 diagenetic model.

The northern mixed skeletal facies has different characteristics from those of the two southern facies. This facies contains abundant early fibrous cement rims, leached grain molds, large amounts of blocky void-filling spar above geopetal debris, syntaxial echinoderm overgrowths, and no significant overcompacting from the original depositional calcarenitic fabric. This evidence is strongly compatible with deposition in warm shallow water (early fibrous rims) followed by meteoric water influx (leaching, blocky spar), which is typical of a regressive unit. Because this part of the Exline Limestone was initiated by a marine transgression, the lack of transgressive diagenetic features must be explained. The top of the northernmost Exline facies is a leached rubbly limestone, intricately mixed with a green blocky mudstone that is low in marine fossils. This green blocky mudstone probably was formed as a soil under subaerial conditions with strong fresh-water influence. Since the abundance of percolating fresh water, after the early marine cementation, is largely responsible for the petrologic features of a regressive limestone, the lack of a core shale allowed the transgressive limestone to be affected by the rapid influx of fresh water associated with soil formation. Fresh water and soil formation affected only the northern calcarenite facies of the Exline because southward, detrital influx during regression built deltas over the earlier-formed transgressive algal and offshore crinoidal facies. The prodeltaic muds buried and compacted the southern facies before fresh water had a chance to affect them. The lack of ferroan calcite and dolomite in the northern facies of the Exline is explained by its cementation in an oxidizing fresh-water environment. The lack of ferroan carbonate in the southern two facies may relate to their relatively rapid burial and compactional cementation, which may have taken place before the connate water became reduced enough to mobilize iron into carbonate minerals.

Conodont Data

The conodont data from the Exline support the interpretation of the lithofacies relations. The northern Mixed Skeletal Calcarenite Facies is lithologically the shallowest-water facies within the Exline. Abundance of conodonts is variable but low, averaging approximately 50 conodonts per kilogram. The genus *Adetognathus*, which is the most abundant conodont in this facies, combined with the absence or low numbers of *Idiognathodus* and *Idioprioniodus*, supports the shallow, nearshore depositional environment (Heckel & Baesemann 1975; Swade 1985). Southward, the Algal Calcilutite Facies was still in the photic zone, but below effective wave base and therefore slightly deeper. Its conodont abundance is slightly higher, averaging 60 conodonts per kilogram, with *Idiognathodus* dominant over *Anchignathodus*, and both *Adetognathus* and *Idioprioniodus* absent. This combination indicates a slightly more offshore environment than the northern facies, but still of relatively shallow depth.

The southernmost facies, the Shaly Crinoidal Calcilutite, with little algae but a rich fauna of invertebrates, represents the deepest, most open marine lithofacies. It has by far the highest conodont abundances, averaging between 600 and 1000 per kilogram. This indicates either better living conditions or slower deposition of sediment, or both. In addition, the high abundance of *Idiognathodus*, and presence of *Idioprioniodus* and one *Gondolella*, along with the near absence of *Adetognathus*, supports an interpretation of a much more offshore and therefore deeper environment, where sedimentation rates would be expected to be low (Heckel & Baesemann 1975; Swade 1985). The horizon of maximum depth of water and slowest deposition would be the portion of the sequence with the greatest abundance of conodonts. Within the Shaly Crinoidal Calcilutite Facies, this horizon is in the middle of the lower limestone in the southern part of the facies, with a mirror-image decrease in abundance above and below. Therefore, conodont faunas support the lithic evidence that the Shaly Crinoidal Calcilutite Facies generally represents the deepest water environment, and the Mixed Skeletal Calcarenite Facies generally represents the shallowest water environment. Between these two extremes, the Algal Calcilutite Facies has a transitional conodont fauna, which helps link all three facies together.

Vertical variation in conodont faunas within the lithofacies provides more insight into succession of environments. For example, the occurrence of Adetognathodus only in the base and top of the crinoidal facies suggests that this facies was deposited in relatively shallow water initially, deeper water during the major portion of its deposition, and perhaps slightly shallower water again toward the end of its deposition. In the northern mixed skeletal facies, higher abundances of conodonts and dominance of Idiognathodus in the lower middle part of Offutt and ILC cores suggest a horizon of maximum transgression within this generally shallow-water facies and allow the line of maximum transgression to be drawn on Figure 5B.

Other Considerations

The two outcrops that contain the shaly crinoidal calcilutite overlying the algal calcilutite are important to understanding the deposition of the Exline. Since the shaly crinoidal calcilutite is determined to be the deepest water facies of the Exline, the interpretation is straightforward. The deeper water unit above the shallower water unit indicates a deepening transgressive sea (Figure 5), and places formation of the Algal Calcilutite Facies relatively early during Exline deposition.

The observation that there are only two outcrops that show the shaly crinoidal calcilutite above the algal calcilutite in its region of development can be explained by the fact that sandstone directly overlies the Algal Calcilutite Facies where it is the only facies found in a complete exposure. These sands were deposited in a higher energy deltaic environment than the prodeltaic muds, and could have eroded the soft prodeltaic muds and the friable Shaly Crinoidal Calcilutite Facies, and left a sharp contact at the top of the massive, dense Algal Calcilutite Facies.

CONCLUSIONS

The Exline Limestone is composed of three distinct facies extending across an area from western Iowa to western Missouri. These facies, from north to south, are Mixed Skeletal Calcarenite, Algal Calcilutite, and Shaly Crinoidal Calcilutite. Although distinctly different in appearance, each facies contains roughly the same macrofauna: echinoderms, gastropods, pelecypods, ostracodes, brachiopods, foraminifers, and algae common in the north, with the algae being replaced by corals and trilobites toward the south. Each of these three facies was deposited over a large area, but in vertical sequence, the shaly crinoidal limestone lies above the algal limestone at two locations in the central region.

Lithologically, the Mixed Skeletal Calcarenite Facies with its abraded grains and spar cement shows that the shallowest, most turbulent water was to the north, deepening southward through the Algal Calcilutite Facies, still in the photic zone but below wave base, to the Shaly Crinoidal Calcilutite Facies in the deepest water to the south. Conodont faunas parallel this trend, with sparse *Adetognathus*-dominated faunas in the north giving way to abundant *Idiognathodus*-dominated faunas in the south.

Together the lithic and conodont lines of evidence complement each other to provide a powerful interpretive tool.

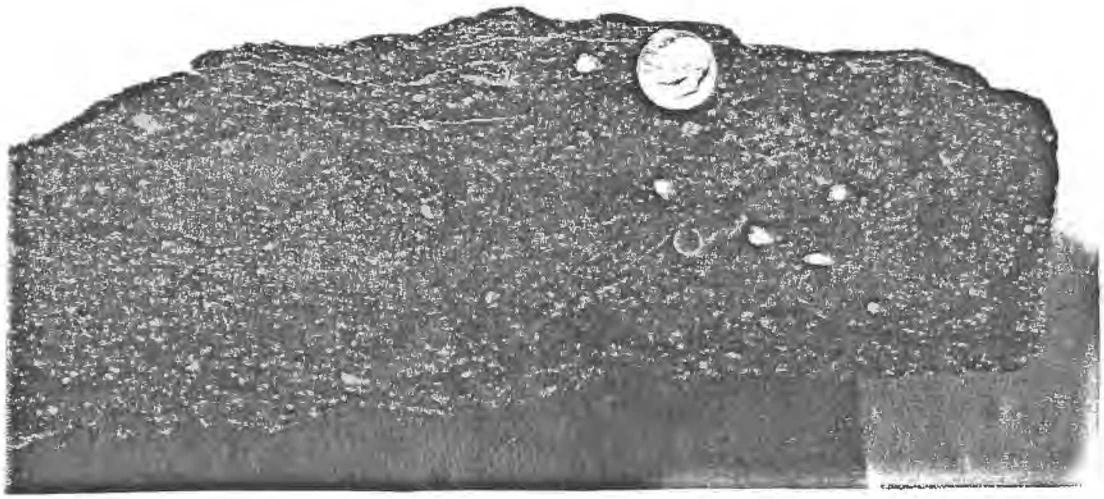
Although not previously classified, the Exline Limestone can be classified by the cyclothem model for Midcontinent Pennsylvanian units. From the south, the lower part of the Shaly Crinoidal Calcilutite Facies, probably all of the Algal Calcilutite Facies, and the very base of the Mixed Skeletal Calcarenite Facies represent the transgressive limestone. In the north, the main part of the Mixed Skeletal Calcarenite Facies represents the regressive limestone, capped by laminated shoreline calcilutite, with fresh water diagenesis and a weathering surface with probable soil formation at the top. Southward, the top of the Shaly Crinoidal Calcilutite Facies represents the beginning of regression in relatively deep water, with the overlying prodeltaic shales and deltaic sands representing most of the regressive part of the marine cycle in this region. The Exline is an intermediate cycle of marine inundation (Heckel 1986), in which water depths never became deep enough to form widespread depth stratification that gave rise to the black phosphatic shales characteristic of the major, well known cyclothems. This study shows that by using lithic and faunal criteria, the cyclothem model can be applied to interpret units lacking many of the classic "textbook" features described by Heckel (1977).

PLATE 1 Polished slabs of three lithofacies of Exline Limestone.

A) Polished slab of shaly crinoidal calcilutite from MB&T locality. Crinoidal debris (white specks) is common in this facies.

B) Polished slab of algal calcilutite from KVQ1 locality. The algal blades (dark lines) have a mostly horizontal orientation.

C) Polished slab of mixed skeletal calcarenite from Offutt core, Nebraska. Skeletal hash is apparent above dime, with crinoids (white specks) common. (Amerada core, footage 341.7 to 342.3)



A

B

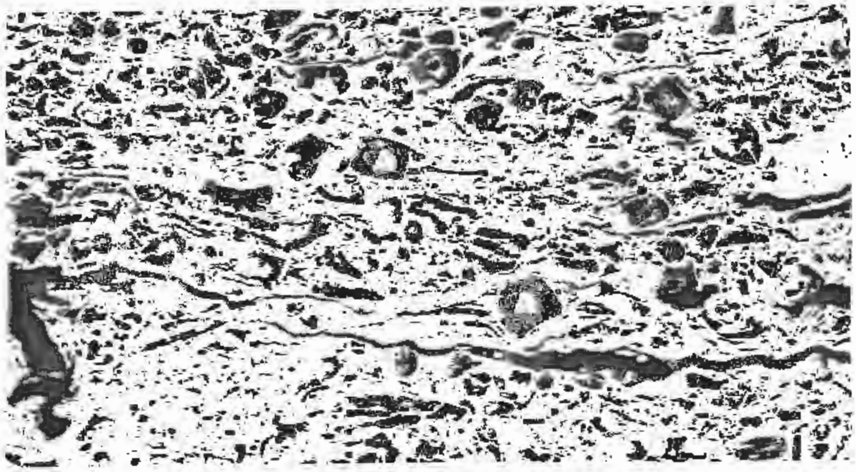
C

PLATE 2: Photonegative prints of Exline Limestone Facies

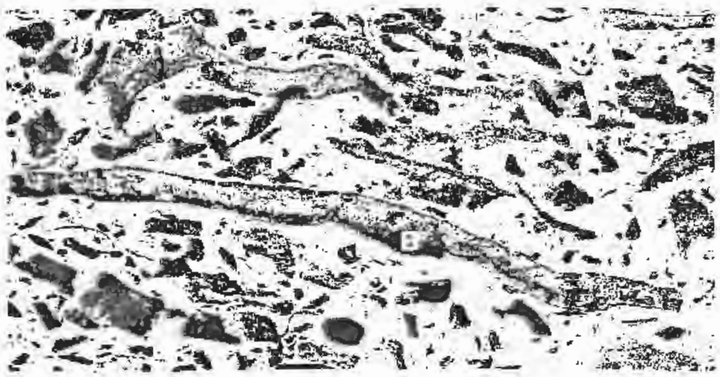
A) Photonegative print of Crinoidal Calcilutite Facies from MB&T locality. Dominant crinoids are shown by (A) and rarer pelecypod is shown by (C).

B) Photonegative print of Algal Calcilutite Facies from KVQ1 location. Algal blades (B) display structure of the red alga Archaeolithophyllum. (see Plate 7).

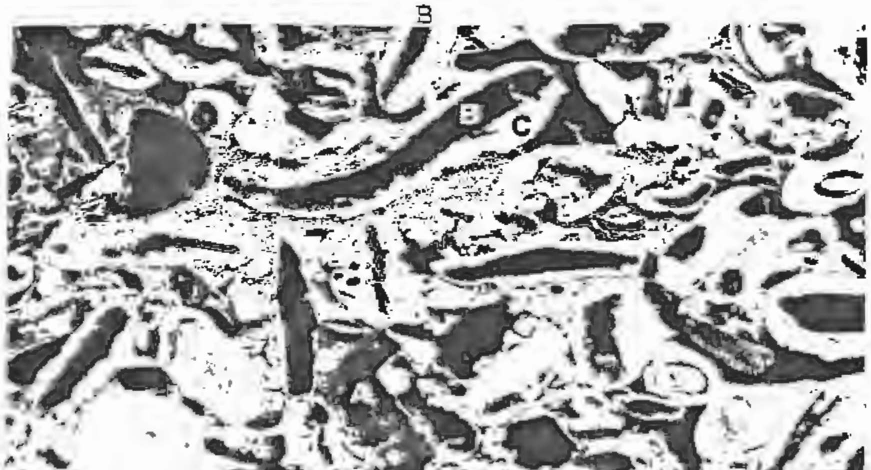
C) Photonegative print of Mixed Skeletal Calcarenite Facies from Offutt core Nebraska. Crinoids are shown by (A), molluscs by (B), and dominantly encrusting foraminiferal coating by (C). (Amerada core, footage 342.2)



A



B



C

Scale: 0 1 2 3 mm

PLATE 3: Photonegative prints of Exline Limestone Facies

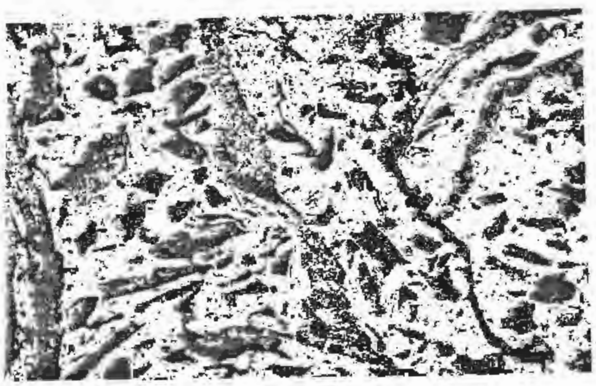
A) Photonegative print showing a crushed pelecypod shell in crinoidal limestone facies. (MB&T)

B) Photonegative print showing overcompacted grains of algae in algal limestone facies. (AcDp)

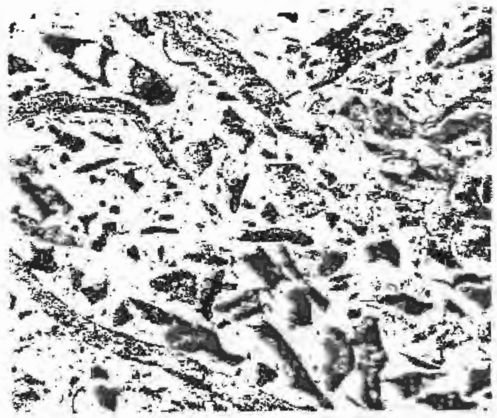
C) Photonegative print showing overcompacted grains of algae in algal limestone facies. (AcDp)

D) Photonegative print showing a crushed gastropod shell in algal limestone facies. (AcDp)

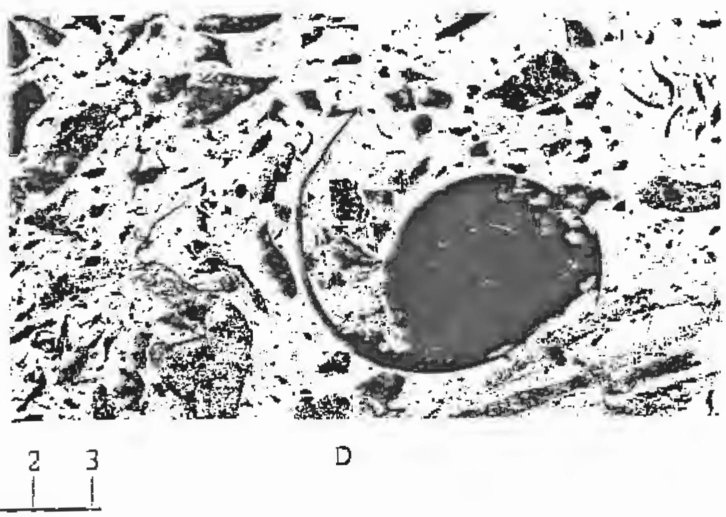
A



B



C



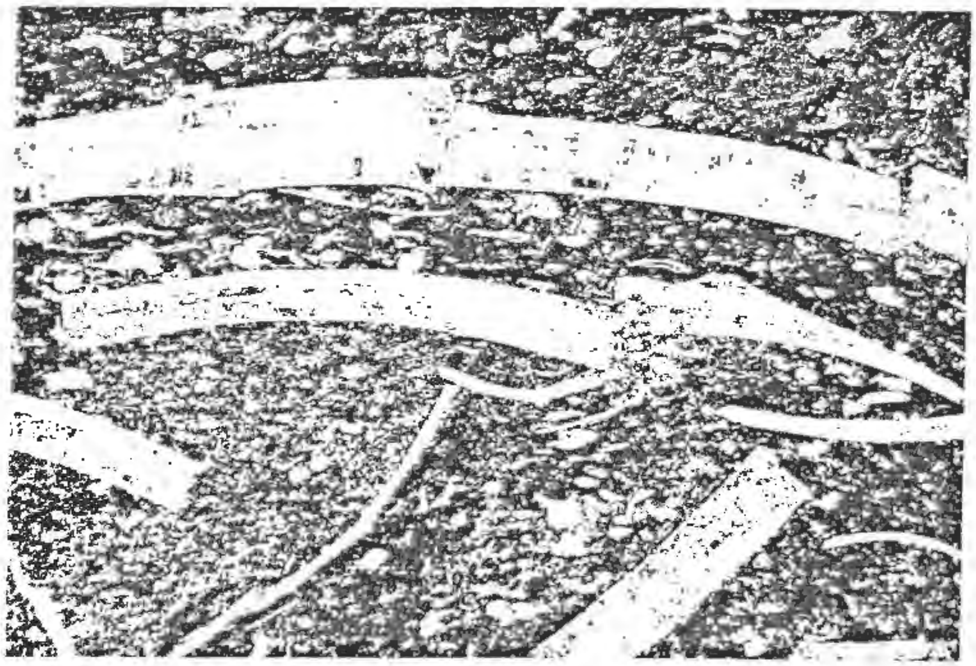
D

Scale: 0 1 2 3 mm

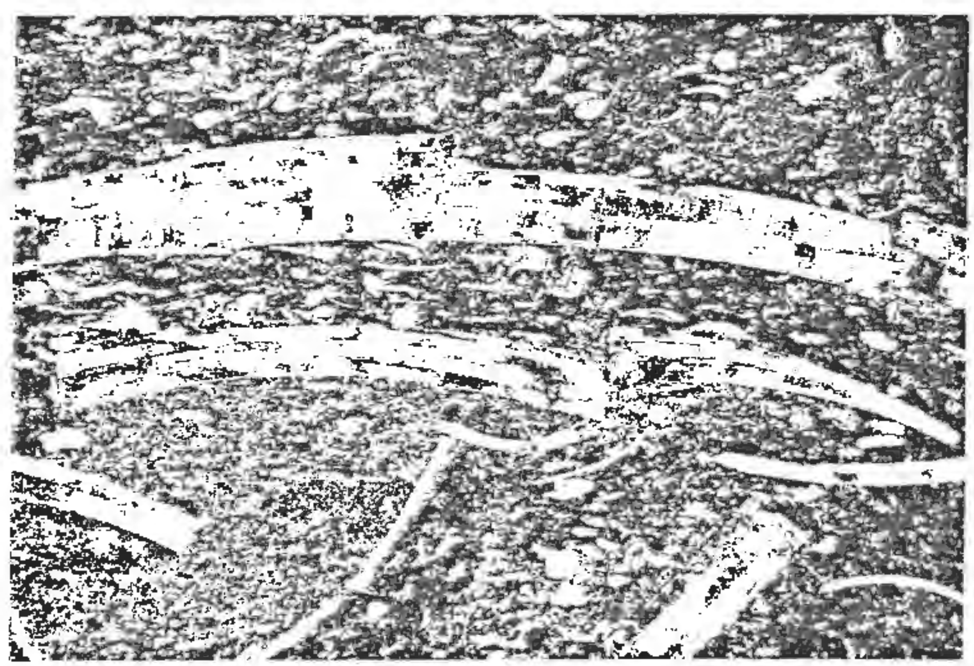
PLATE 4: Photomicrographs of Crinoidal Calcilutite Facies

A) Photomicrograph of part of originally aragonitic pelecypod shells shown in Plate 3-A, under singly polarized light. (MB&T)

B) Photomicrograph of same shells in Plate 4-A, under crossed polarizers, showing ghost (relict) layered structure. (MB&T)



A



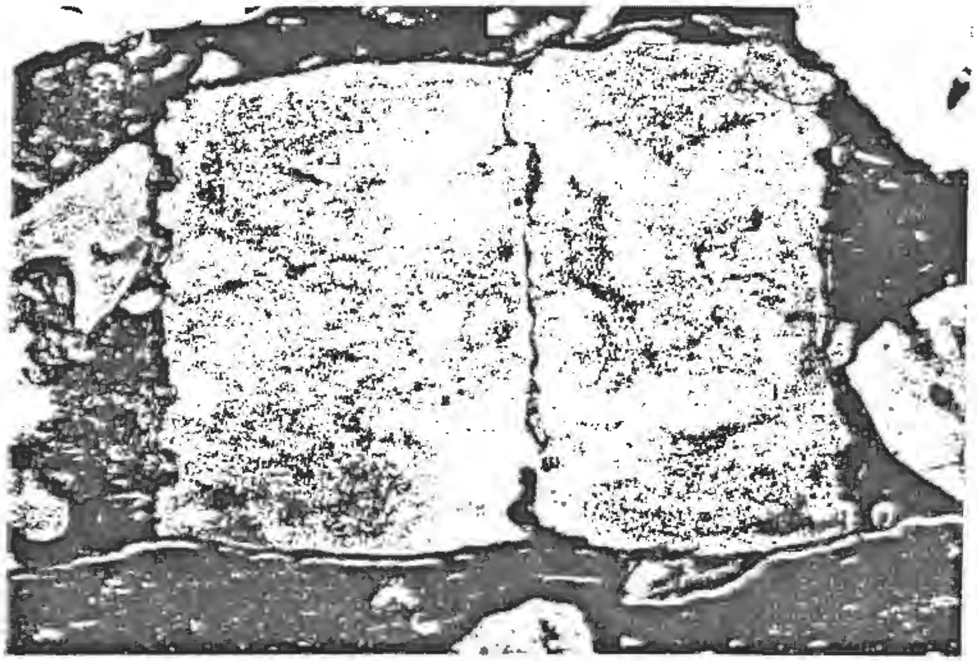
B

Scale: 0 — 1 mm

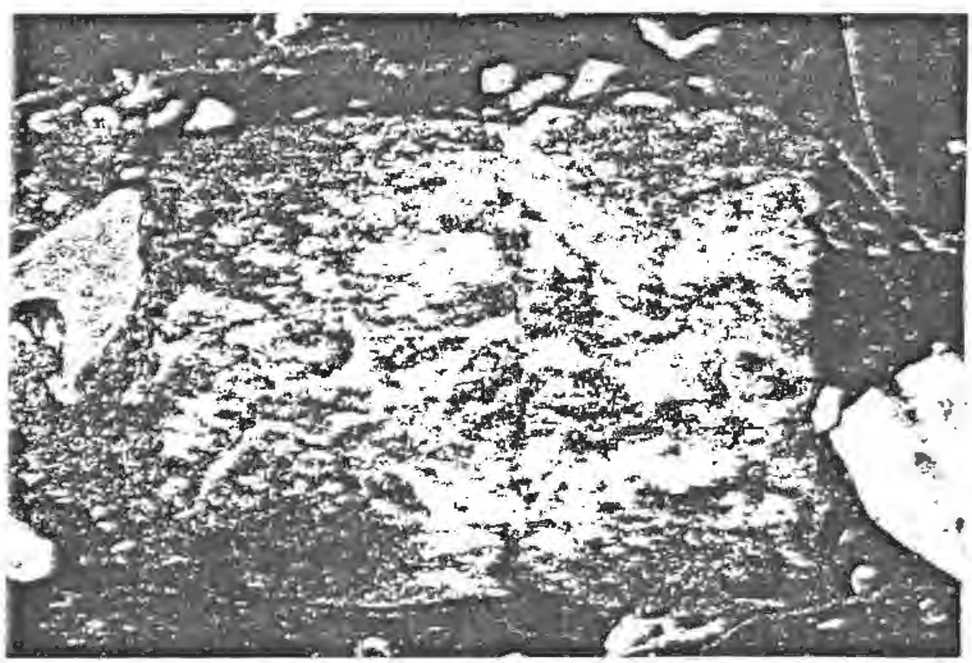
PLATE 5: Photomicrographs of Crinoidal Calcilutite Facies

A) Photomicrograph of a crinoid columnal from crinoidal limestone facies, viewed under singly polarized light. (RCCR)

B) Photomicrograph of same crinoid columnal shown in Plate 5-A, viewed under crossed polarizers. The extinction is irregular and disjointed, with many grains in contact with each other. (RCCR)



A



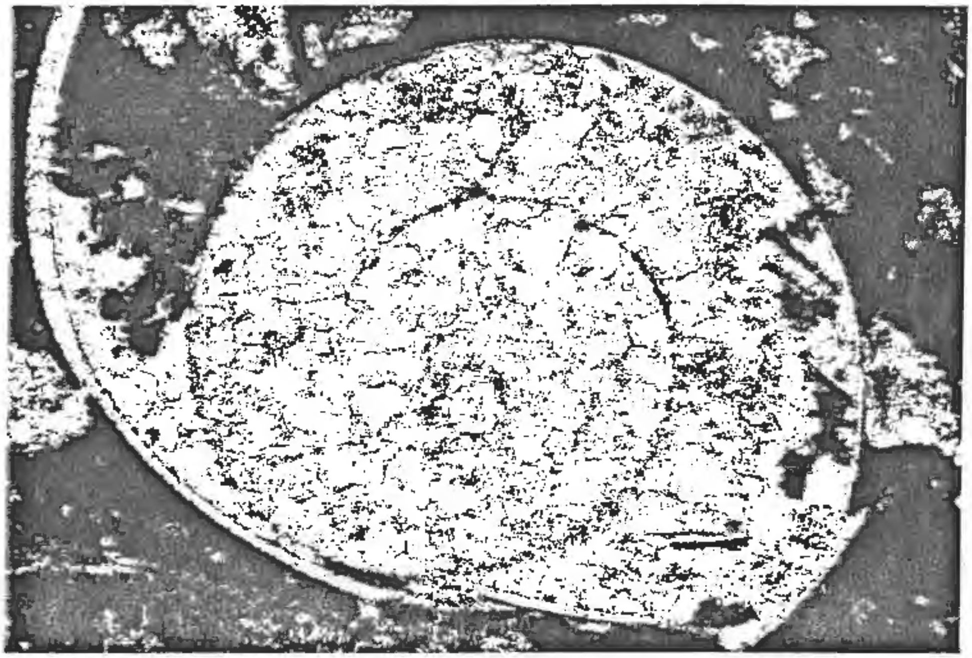
B

Scale: 0 — 1 mm

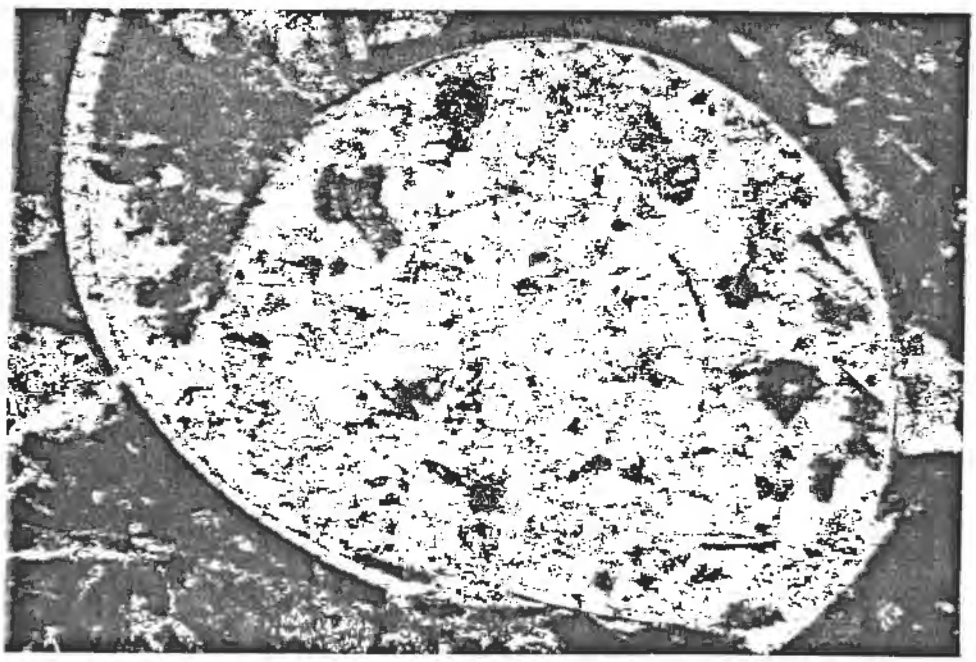
PLATE 6: Photomicrographs of Algal Calcilutite Facies

A) Photomicrograph showing crushed gastropod with void-filling spar in the Algal Calcilutite Facies. Singly polarized light. (AcDp)

B) Photomicrograph of same gastropod shown in Plate 6-A, viewed under crossed polarizers. Relict internal structure is still visible and may have been neomorphosed as the voids were filled by blocky calcite. (AcDp)



A



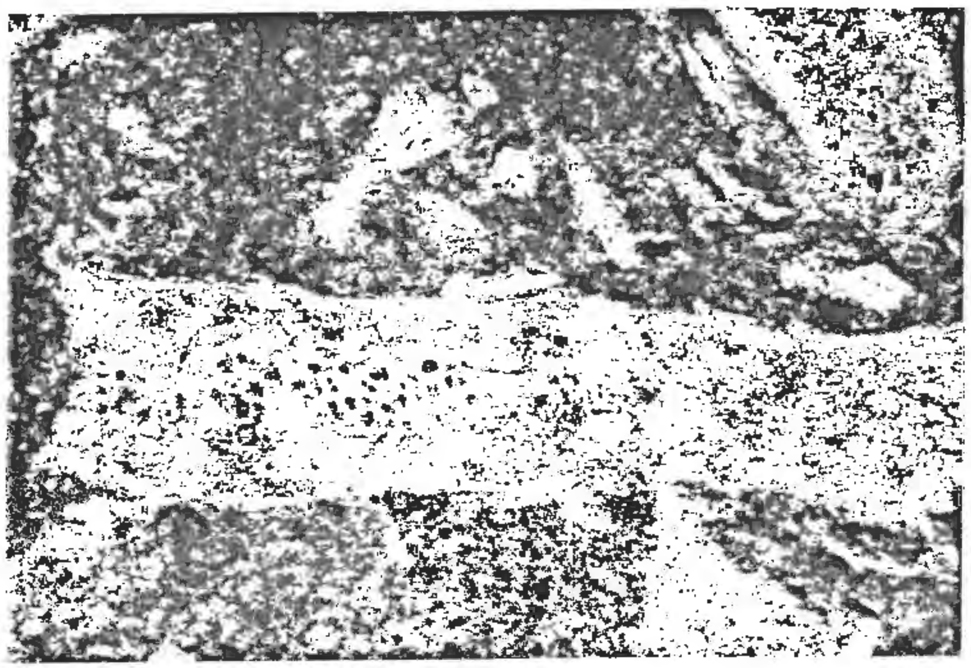
B

Scale: 0 — 1 mm

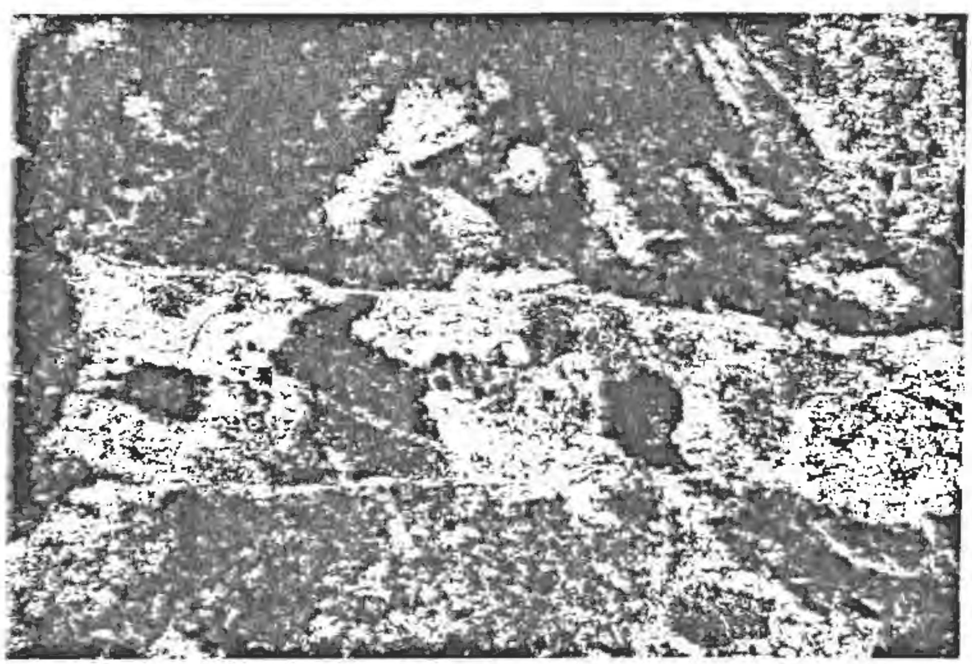
PLATE 7: Photomicrographs of Algal Calcilutite Facies

A) Photomicrograph showing an algal blade with internal structure of red alga Archaeolithophyllum from the Algal Calcilutite Facies viewed under singly polarized light. (Type Section)

B) Photomicrograph of the same algal blade shown in Plate 7-A. Viewed under crossed polarized light, the relict structure is still visible through the blocky neomorphic spar. Microspar is apparent in the mud around the algal blades. (Type Section)



A



B

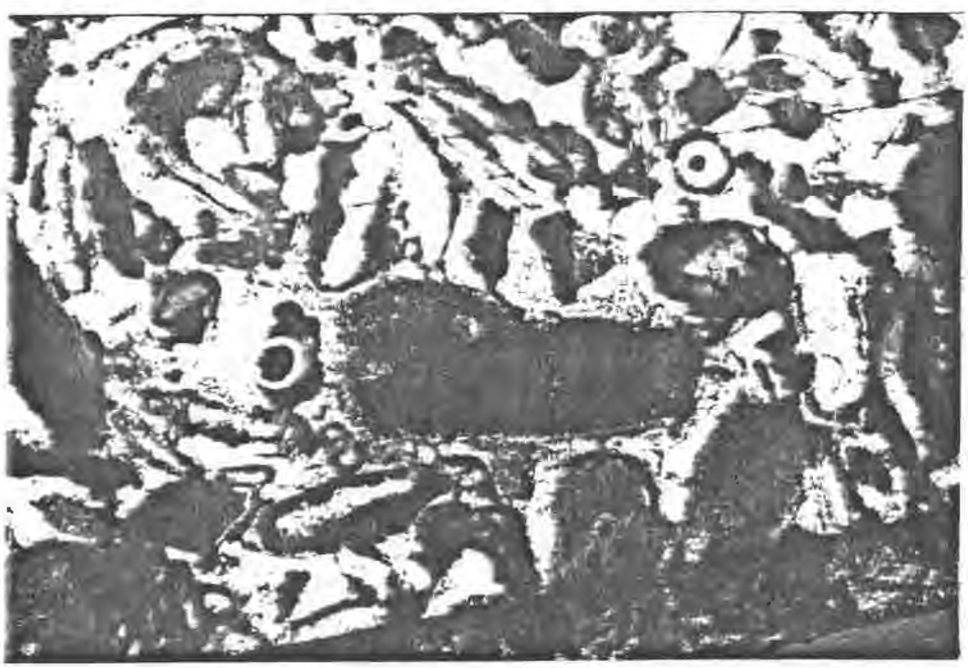
Scale: 0 1 mm

PLATE 8: Photomicrographs of Mixed Skeletal Calcarenite Facies

A) Photomicrograph of Mixed Skeletal Calcarenite Facies showing depositional packing and well developed encrusting foraminiferal rims around shells (A), some of which are largely dissolved and now filled with blocky calcite. Geopetal fillings of loosely packed mud occur in the bases of some intergranular voids (B). Also note partial neomorphism of some shells. (Amerada core, footage 341.8)

B) Photomicrograph of Mixed Skeletal Calcarenite Facies showing intergranular voids with an early thin fibrous rim, possibly of high magnesium calcite, around the interior (A), followed by the syntaxial overgrowth of a crinoid (B). (Amerada core, footage 341.8)

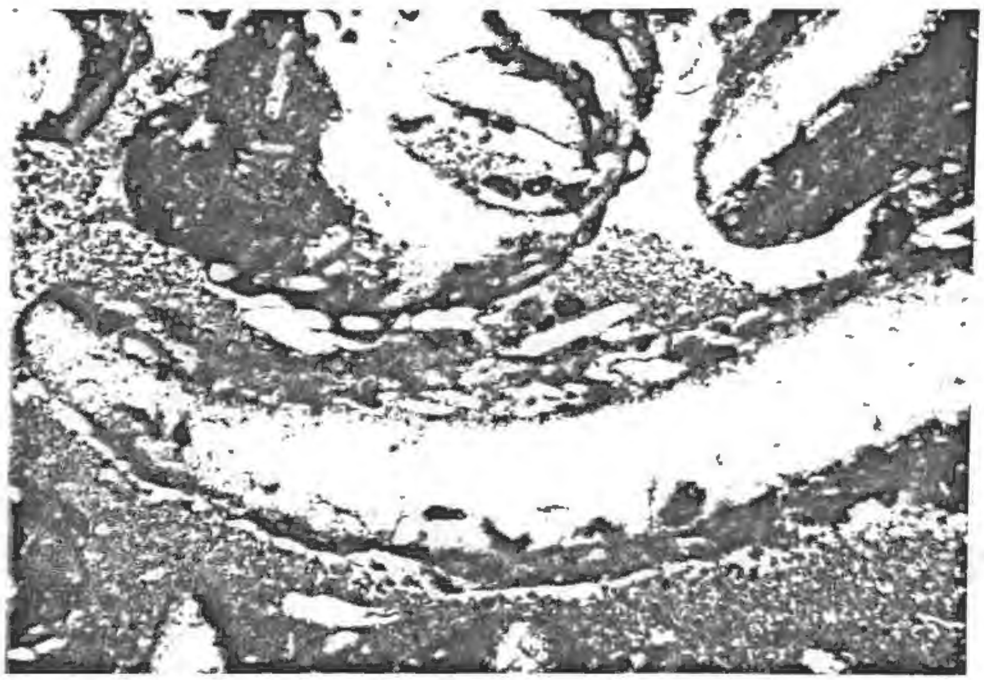
A



B

Scale: 0 1 mm

PLATE 9: Photomicrograph of Mixed Skeletal Calcarenite Facies showing encrusting foraminifers around grains that appear to have been mostly leached (white area) then filled later with blocky calcite. (Amerada core, footage 342.2)



Scale: 0 — 1 mm

APPENDIX A

FOSSIL GROUPS FROM RECOGNIZED EXLINE FACIES

TABLE 1
Fossil groups from recognized Exline facies.

Major Fossil Group	Exline Facies		
	Crinoidal Calcilutite	Algal Calcilutite	Mixed Skeletal Calcarenite
ECHINODERMATA	A	R	A
RED ALGAE (Archaeolithophyllum)	R	A	R
MOLLUSCA-Gastropoda	A	R	A
MOLLUSCA-Pelecypoda	A	R	A
OSTRACODA	C	C	C
FORAMINIFERA	-	-	A
BRACHIOPODA	C	-	R
COELENTERATA	C	-	-
BRYOZOA	C	-	-
ARTHROPODA-Trilobita	R	-	-

Letter designation: A=abundant, C=common, R=rare

APPENDIX B

STRATIGRAPHIC SECTIONS AND CONODONT DATA

Measured sections and cores listed from south to north. Conodont species: Ad = *Adetognathus*, An = *Anchignathodus*, Dp = *Diplonathodus*, Ig = *Idiognathodus*, Ip = *Idioprioniodus*; Totals are given for the number of conodont elements per sample and the number of conodont elements per kilogram, Actual/Kg. Differences between the total and the sum of the genera is the number of unidentified, mostly ramiform elements. When shale and limestone values are listed for the same sample, the shale fraction and limestone fraction have been processed and picked separately.

MOD (OUTCROP)

Roadcut on I-70, North of Odessa, Lafayette County, Missouri, on north side road; SE1/4 NW1/4 sec. 36, T. 49 N., R. 28 W.; Shaly Crinoidal Calcilutite Facies, (Same as Howe 1982, Strat. Section 8). Note: One Gondolella was found in sample 2.

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	BP	IG	IP
7 sh	1000	20	1			6	
6 sh	1000	75	8			65	2
5 ls	500	54/108		1/2		46/90	1/2
4 sh	1000	149		7		98	
3 ls	500	374/748		4/8		321/642	9/18
2 sh	800	318/397	1/1	2/3		174/217	41/51
1 sh	1000	1					

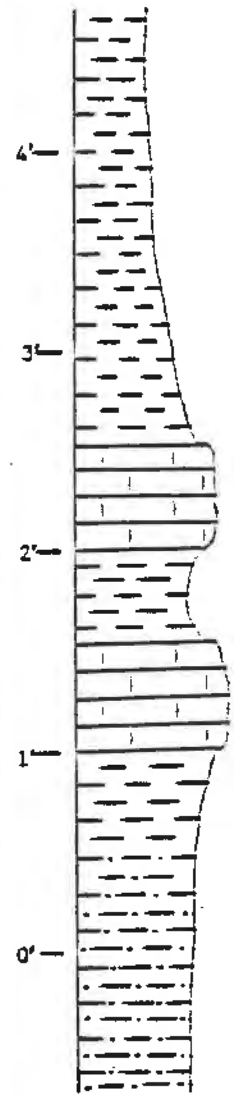


FIGURE 6

Stratigraphic section

Upper Pleasanton-
Shale; primary fossils are crinoids, molluscs, ostracodes, and forams

Exline -
Limestone, dark gray,argillaceous, rubbly; primary fossils are crinoids, bryozoan, brachiopods, and corals.

Shale, dark gray; primary fossils are crinoids, bryozoans, brachiopods, and corals.

Limestone, dark gray, argillaceous, rubbly; primary fossils are crinoids, brachiopods, molluscs, and corals.

Lower Pleasanton-
Shale, gray; primary fossils are crinoids and brachiopods.

Silty shale, coaly fragments.

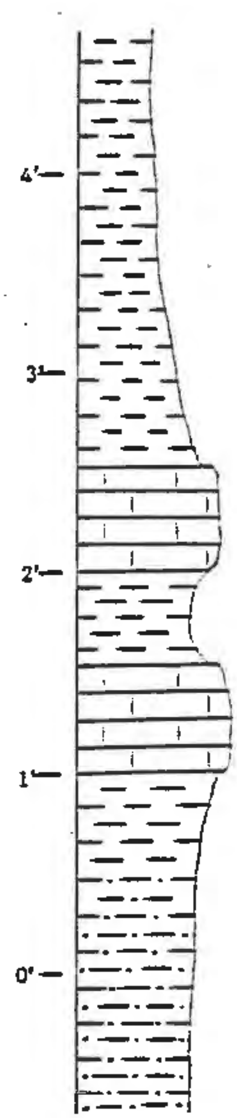


FIGURE 6--continued

RCCR (OUTCROP)

West bank of Crooked River, Ray County, Missouri; NW1/4 sec.20, T.52 N., R. 28 W.; Shaly Crinoidal Calcilutite Facies, (Same as Howe 1982, Strat. Section 15)

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
6sh	1391g	9/6				2/2	
5ls	828g	450/543		4/5		317/380	2/2
4ls	829g	1100/1320		8/10		602/722	11/13
3ls	500g	900/1800	3/6	13/26		450/900	20/40
2ls	500g	430/860	16/32	9/18		185/370	27/54
1sh	1387g	53/38	16/11			10/7	

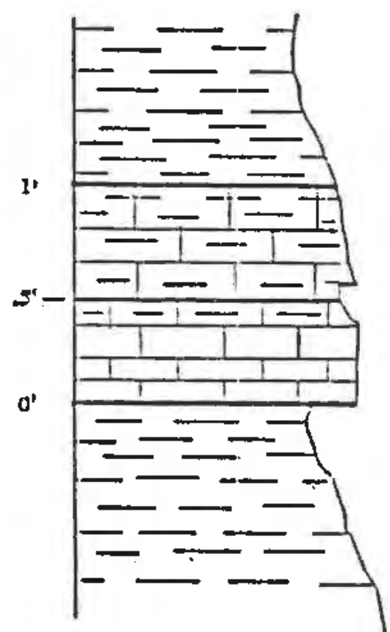


FIGURE 7

Stratigraphic section

Upper Pleasanton-
Shale, medium gray, calcareous; thickness is approximately 60 feet.

Exline -
Limestone and calcareous shale: primary fossils are crinoids and gastropods; it is rubbly with sideritic limestone masses; thickness is .5 feet.

Limestone, massive with a conchoidal fracture; primary fossils are crinoids and gastropods: thickness is .5 feet.

Lower Pleasanton-
Shale and siltstone, carbonaceous; approximately 2 feet exposed.

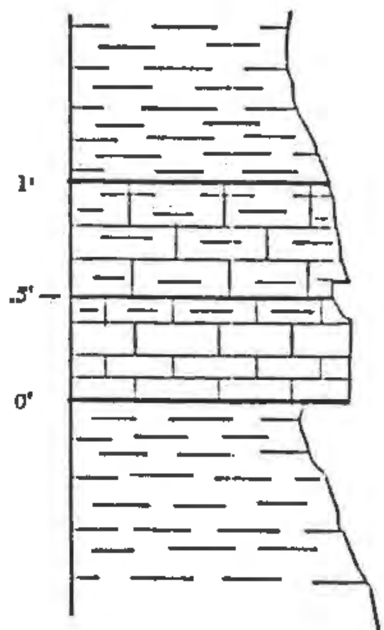


FIGURE 7--continued

CCUS (OUTCROP)

Stream cut 300 feet east of road, Carroll County, Missouri; NW1/4 SW1/4 sec. 5, T. 55 N., R. 23 W.; Shaly Crinoidal Calcilutite Facies, (Same as Howe 1982, Strat. Section 21)

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
8sh	1000g	1000/1000	8/8	24/24		400/400	6/6
7ls	500g	270/540		7/14		170/240	3/6
6sh	380g	195/513		3/8		60/158	
5ls	500g	400/800	1/2	10/20		209/418	2/4
4ls	500g	800/1600		16/32		100/200	9/18
3ls	456g	600/1315		14/31		249/545	7/15
2ls	662g	700/1050	2/3	13/20		242/363	31/47
2sh	406g	434/1135	2/5	8/20		150/375	3/8
1sh	1000g	7/7	2/2			3/3	1/1

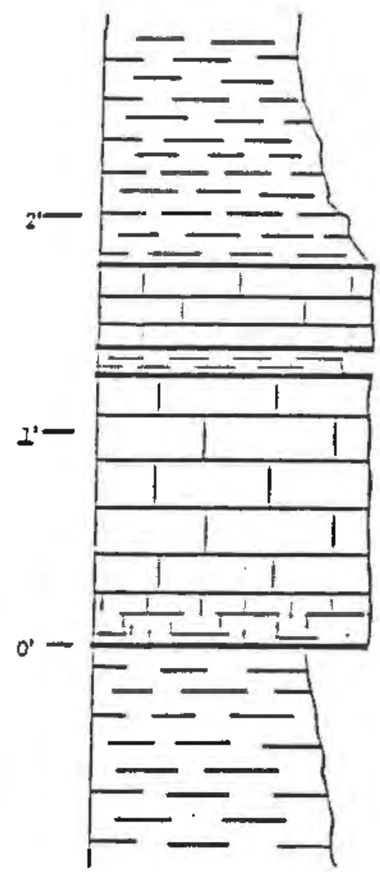


FIGURE 8

Stratigraphic section

Upper Pleasanton-
Shale, ochre; approximately 6 feet exposed.

Exline -
Limestone, ochre, argillaceous; very abundant crinoid columnals; thickness is .3 feet.

Limestone, medium gray, weathering tan; primary fossil is the crinoid; grades laterally from a massive ledge-former to a shaly limestone; separated from limestone above by a 1 inch calcareous shale; thickness is 1 to 2 feet.

Limestone, ochre, dense, and argillaceous; fractured and crumbly.

Lower Pleasanton -
Silty shale, gray; gradational with Exline

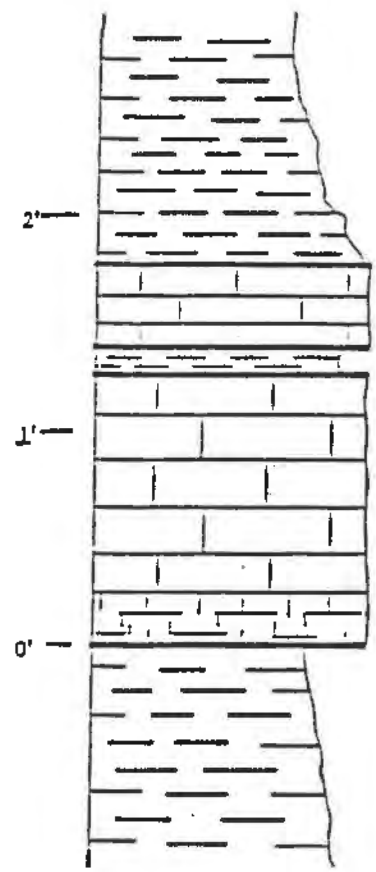


FIGURE 8--continued

MB&T (OUTCROP)

Shale pit for Midland Brick and Tile Co., Livingston County, Missouri; NE1/4 SE1/4 sec. 18, T. 57 N., R. 24 W.; Shaly Crinoidal Calcilutite Facies, (Same as Howe 1982, Strat. Section 25)

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
8 sh	1000	160		6		125	
7 ls	500	225/450		9/18		195/390	6/12
6 sh	1000	272		13		218	5
5 ls	500	348/696		23/46		270/540	11/22
4 ls	500	702/1404		25/50		576/1152	21/42
3 ls	500	324/648		13/26		253/506	23/46
2 ls	500	227/454		11/22		181/362	14/28
1 sh	1000	10	1			9	

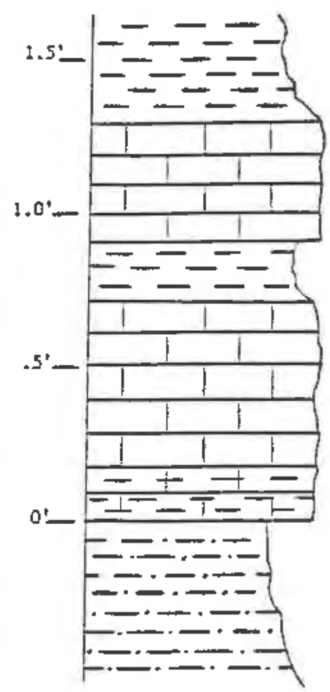


FIGURE 9

Stratigraphic section

Upper Pleasanton-
Shale, dark gray, fossiliferous at base; upward, leaf impressions on bedding planes; thickness is approximately 60 feet.

Exline -
Limestone, medium gray, massive, ledge-former; crinoids weather distinctly

Shale, dark gray; abundant macrofossils

Limestone, medium gray, massive; small molluscs and echinoderms

Shaly limestone, light gray, friable; conspicuous snails

Lower Pleasanton-
Sandy shale, light gray, micaceous; scattered brachiopods at the top; thickness is approximately 20 feet

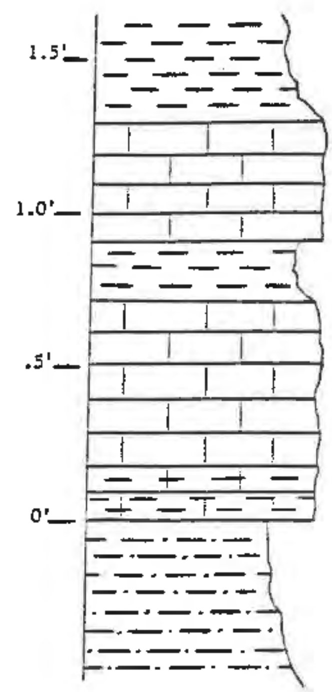


FIGURE 9--continued

PDEX (OUTCROP)

Northwest-trending ravine, Linn County, Missouri; sec. 13, T. 59 N., R. 21 W.; Algal Calcilutite Facies, (Same as Howe 1982, Strat. Section 26). Shale sample 6 was collected largely from slumped material and probably represents higher strata than the crinoidal facies shown above the massive limestone by Howe (1982).

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
6sh	1000g	0					
5ls	500g	17/34		2/4		3/6	
4ls	500g	52/104		1/2		9/18	
3ls	500g	47/94		1/2		10/20	
2ls	500g	14/28		1/2		3/6	
1sh	1000g	0					

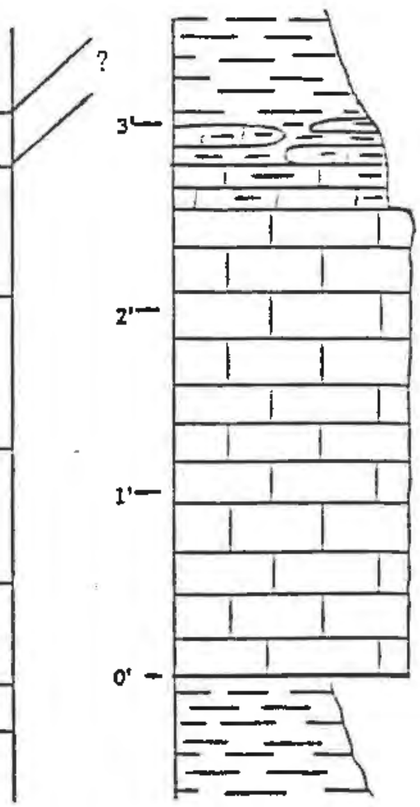


FIGURE 10

Stratigraphic section

Upper Pleasanton-
Silty shale, gray; approximately 1 foot exposed.

Exline -
Limestone, argillaceous, and calcareous shale; primary fossils are crinoids with some corals; thickness .3 feet. Reported by Howe 1982, not exposed at time of field work.

Limestone, blue gray, ledge-former; primary fossil constituent is phylloid algae; thickness is 2.5 feet.

Lower Pleasanton -
Silty shale, ochre

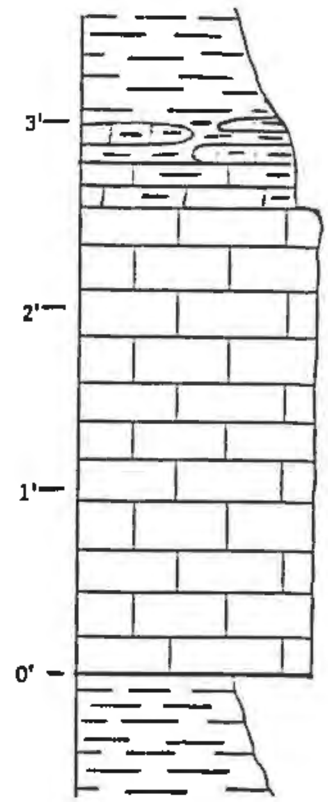


FIGURE 10--continued

TYPE SECTION (OUTCROP)

Stream cut along North Shoal Creek, Appanoose County, Iowa; SE1/4 sec. 6, T. 67 N., R. 17 W.; Algal Calcilutite Facies; (Same as Howe 1982, Strat. Section 40). Shale sample 5 was collected largely from slumped material and probably represents higher strata than the crinoidal facies shown above the massive limestone by Howe (1982).

Conodont data

SPL NO.	WT(g)	TOTAL	AD	AN	DP	IG	IP
5sh	1000	0					
4ls	500	72/144				22/44	
3ls	500	38/76		4/8		17/34	
2ls	500	54/108		1/2		25/50	
1sh	1000	0					

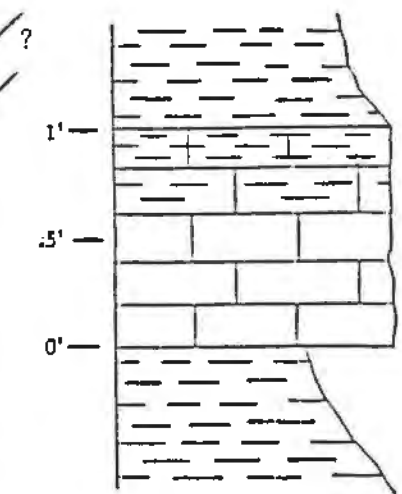


FIGURE 11

Stratigraphic section

Upper Pleasanton-
Silty shale, gray, silty; scattered ironstone concretions; thickness is approximately 2 feet exposed.

Exline -
Limestone, ochre, weathers into thin earthy slabs; primary fossil is crinoid; thickness is .3 feet.

Limestone, blue gray, massive, ledge-former; primary fossil is phylloid algae; thickness is .7 feet.

Lower Pleasanton -
Shale, ochre, silty; interval mostly covered

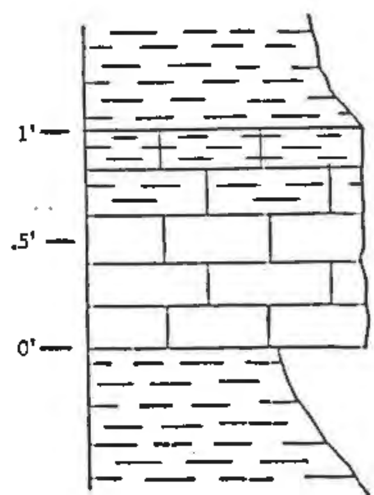


FIGURE 11--continued

ISC (CORE)

Madison County, Iowa; Hole 12-68 (hwy 92); SW-NE sec. 5, T. 75 N., R. 29 W.; Mixed Skeletal Calcarenite Facies. The conodont fauna in samples 1-9 (particularly Diplognathodus and species of Idiognathodus) is similar to that reported by Swade (1985) from the Lost Branch Formation in core CP-37, whereas that in samples 10-12 (particularly Idioprioniodus and species of Idiognathodus) is more similar to that reported by Swade (1985) from the Exline Limestone in the same core.

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
12 ls	268	12/44				2/7	1/3
12 sh	50	17/340	1/20			4/80	
11 ls	214	5/23	1/4	1/4		1/4	
11 sh	70	5/60	1/12			2/24	
10 ls	281	3/10		1/3			
10 sh	96	8/80				4/40	1/10
9 ls	262	8/30			2/7		
9 sh	99	1/10					
8 ls	198	4/20			1/5	1/5	
8 sh	167	0					
7 ls	149	3/20				1/6	
7 sh	50	2/40					
6 ls	247	6/24			2/8	1/4	
6 sh	113	4/35			1/8		
5 ls	243	9/37			2/8	1/4	
5 sh	69	0					
4 ls	244	7/28			1/4	1/4	
4 sh	69	2/28				1/14	
3 ls	179	7/39	2/11	1/5		2/11	
3 sh	21	1/48					
2 ls	322	17/52		1/3		4/12	
2 sh	100	3/30				1/10	
1 ls	143	117/818		4/27		28/195	2/13
1 sh	76	137/1802	1/13		1/13	29/381	7/92

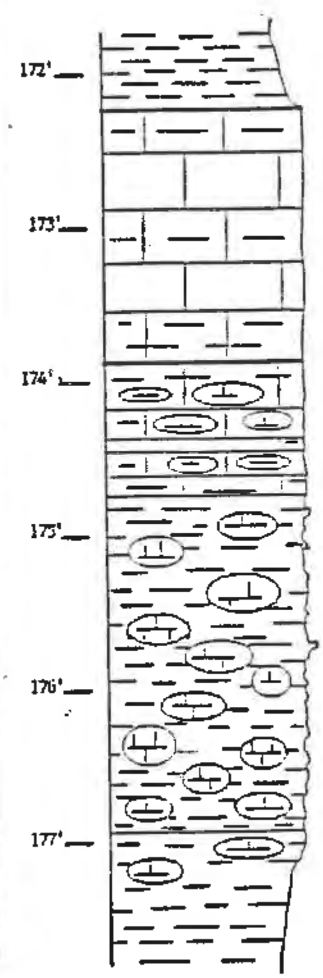


FIGURE 12

Stratigraphic section

Upper Pleasanton -
Mudstone, blocky, green; many limestone nodules throughout

Exline -
Limestone, tan, rubbly, fractured, leached and, weathered; interbedded with shale; Shale, green-gray, no visible fossils; gradational contact with the unit above

Lost Branch Formation -
Limestone, tan, rubbly, fractured, appears as nodules interbedded with the shale; Shale, green-gray with no visible fossils

Shale, green with limestone nodules in the upper part, and abundant conodonts (below 177 feet) characteristic of lower shale in Lost Branch Formation (P. H. Heckel, pers. commun. 1986)

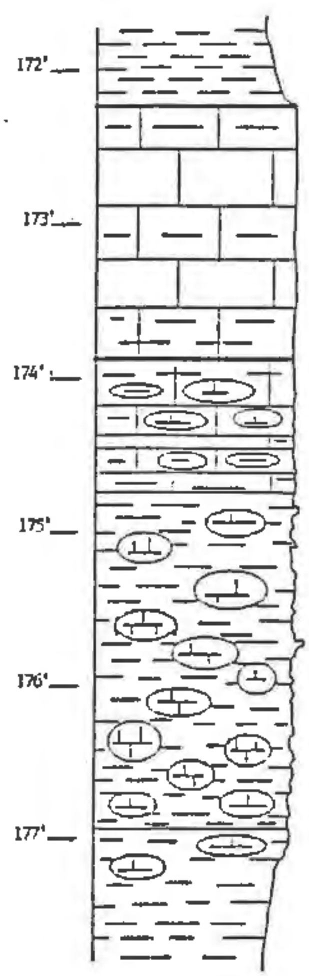


FIGURE 12--continued

IJCL (CORE)

Adair County, Iowa; Hole 41-74; SW-NW sec. 17, T. 77 N., R. 31 W.; Mixed Skeletal Calcarenite Facies. Although not as clearly shown as in core ISC, the conodont faunas from samples 1-9 probably represent the Lost Branch Formation, whereas that from sample 11 probably represents the Exline Limestone, based on comparison with data of Swade (1985) from core CP-37, and the pattern seen in core ISC.

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
11ls	111	2/18				1/9	
11sh	101	5/50	1/10			4/40	
10ls	218	0					
10sh	42	0					
9ls	231	10/43				5/21	
8ls	300	12/40			1/3	3/10	1/3
7ls	243	11/44		1/4		1/4	
6ls	241	5/20				1/5	
5ls	169	4/24					
4ls	215	6/29				1/5	
3ls	146	9/54				2/13	
2ls	94	10/106				1/11	1/11
2sh	13	4/—					
1sh	125	1/9					

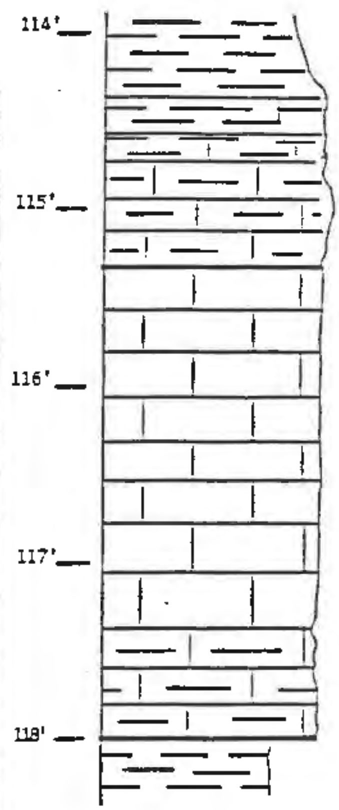


FIGURE 13

Stratigraphic section

Upper Pleasanton -
Shale, green-gray; slightly calcareous, no limestone nodules

Exline -
Limestone and shale interbedded, green-gray color; gradational contacts with the shale above and the limestone below

Lost Branch Formation (?) -
Limestone, light gray, massive, dense character; some skeletal grains have been dissolved and filled with clear calcite, few shale partings but they do exist

Lost Branch -
Limestone, light gray to green-gray; rubbly character, interbedded with shale

Shale, green-gray with a gradational contact with the limestone

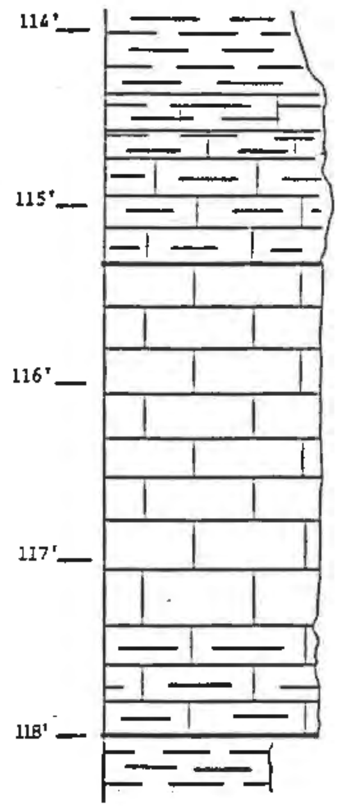


FIGURE 13--continued

ILC-3 (CORE)

Harrison County, Iowa; Hole WC-22; NE-NE sec 19, T. 79 N., R. 42 W.; Mixed Skeletal Calcarenite Facies. In this core the Lost Branch Formation appears as a separate limestone unit below the Exline and its underlying shale.

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	IF	IG	IP
11 sh	131	0					
10 ls	69	2/22	1/11				
10 sh	201	0					
9 ls	218	7/32	6/27				
9 sh	29	2/69	2/69				
8 ls	[illegible]	5/11	2/7				
8 sh	[illegible]						
7 ls	99	6/60	1/10				
7 sh	8	1/125	1/125				
6 ls	291	7/24	4/14	1/3		1/3	
6 sh	9	0					
5 ls	298	32/107	8/26	3/10		6/20	
5 sh	2	0					
4 ls	307	37/120	10/32	1/3		3/9	
4 sh	5	0					
3 ls	229	8/34	4/17			1/4	
3 sh	7	0					
2 ls	169	19/112	9/53	1/5			
2 sh	31	1/32					
1 ls	183	6/32	1/10				
1 sh	102	9/90	2/10	1/10			

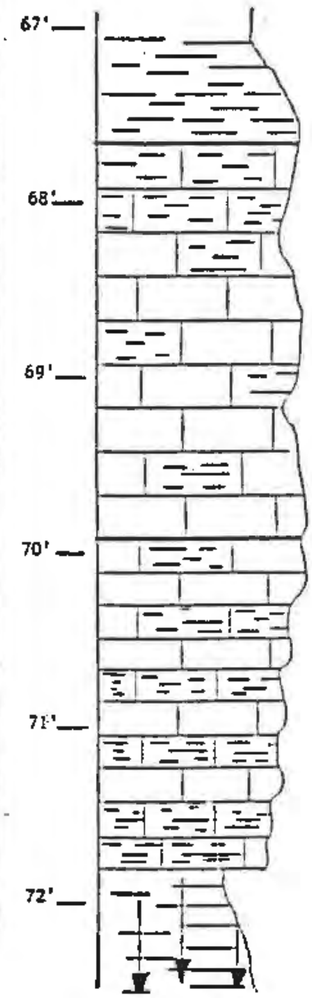


FIGURE 14

Stratigraphic section

Upper Pleasanton -
Mudstone, light gray

Exline -
Limestone, skeletal to pelletal calcarenite to skeletal calcilutite, with shale interbedded, green-gray color; limestone is rubbly, fractured, and has many holes filled with shale; gradational contact with the unit above

Limestone, skeletal calcilutite, light gray to green-gray, rubbly character, interbedded with shale

Lower Pleasanton -
Mudstone, red

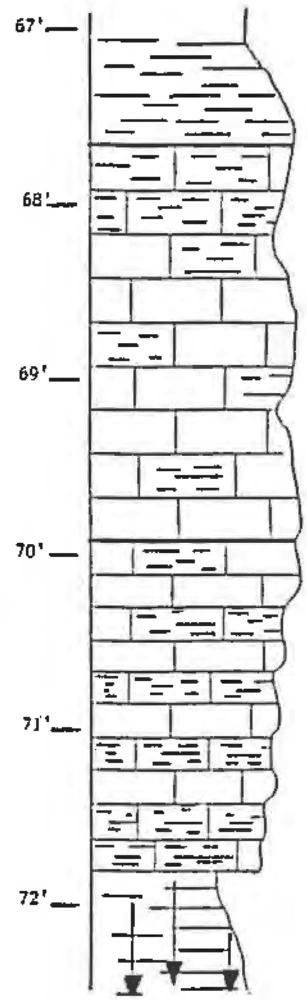


FIGURE 14--continued

OFFUTT AFB DH #247 (CORE)

Cass County, Nebraska; C-S1/2-SE-SE-NW sec. 11, T. 13 N., R. 13 E.; Mixed Skeletal Calcarenite Facies. In this core the Lost Branch Formation appears as a separate limestone unit below the Exline Limestone and its underlying shale.

Conodont data

spl no.	WT(g)	TOTAL	AO	AM	IP	IG	IP
19 sh	492	0					
18 sh	396	0					
17 ls	13	0					
17 sh	382	0					
16 ls	41	0					
16 sh	338	0					
15 ls	407	1/2	1/3				
15 sh	177	0					
14 ls	246	7/28	4/16				
14 sh	[illegible]	1/20					
13 ls	71	1/14					
13 sh	77	[illegible]					
12 ls	214	10/50	2/10	2/10			
12 sh	7	0					
11 ls	378	15/38	7/18	1/3		1/3	
11 sh	37	1/27				1/27	
10 ls	576	20/34	9/15			7/12	
9 ls	494	12/24	3/6	1/2		2/4	
8 ls	349	7/20				2/5	
7 ls	404	69/170	19/47	3/7		20/49	1/2
6 ls	401	161/401	15/37	5/12		90/199	1/2
5 ls	400	59/147	5/12	3/7		20/50	
4 ls	409	37/90	10/24	3/7		11/26	
3 ls	473	36/76	8/16	2/4		6/12	
2 ls	252	18/71	8/36	2/8		2/8	
2 sh	21	9/35	4/19			1/14	
1 ls	95	6/63	4/42			1/10	

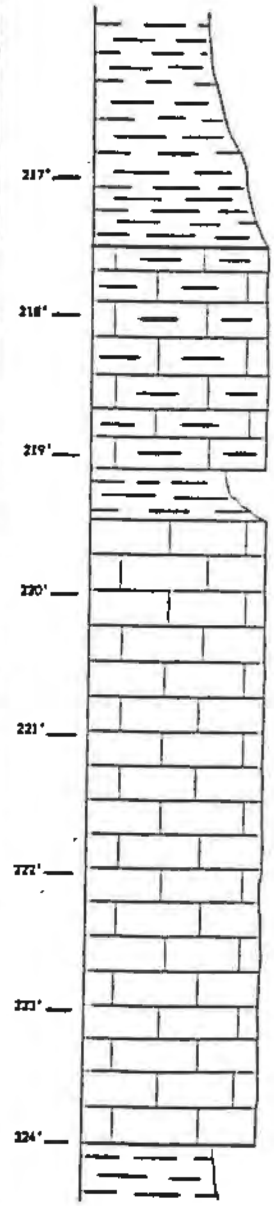
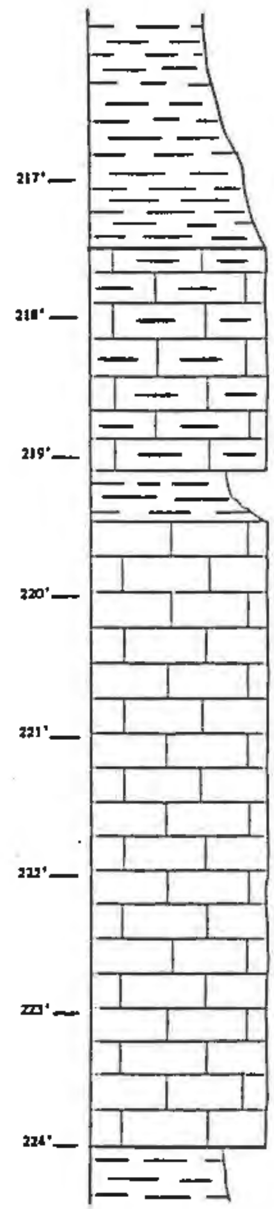


FIGURE 15

Stratigraphic section



Upper Pleasanton -
Mudstone, green-gray, blocky, slightly calcareous

Exline -
Limestone, tan, rubbly, earthy with shale pockets; has a leached and dissolved contact with unit above

Faintly laminated sparcely skeletal calcilutite

Shale, gray, friable, and crumbly

Limestone, tan, massive, skeletal calcarenite with abraded grains; has a leached and dissolved contact with the shale above. Well sorted grainstone in upper half, poorly sorted packstone in lower part with many larger grains coated by algal encrustations

Lower Pleasanton -
Shale, gray, crumbly; has a sharp contact with the Exline Limestone

FIGURE 15--continued

AMERADA SCHROEDER #1 (CORE)
Cass County, Nebraska; NE-SE sec. 26, T. 11 N., R. 12 E.; Mixed Skeletal Calcarenite Facies. Above the Exline the Hertha extends from 322.0 to 338.2 in this core. Below the Exline the Lost Branch extneds from 348.0 to 353.0.

Conodont data

spl no.	WT(g)	TOTAL	AD	AN	DP	IG	IP
5 sh	317	0					
4 ls	500	10/20		1/2		4/8	
3 ls	283	2/7					
2 ls	[illegible]	0					
1 sh	500	0					

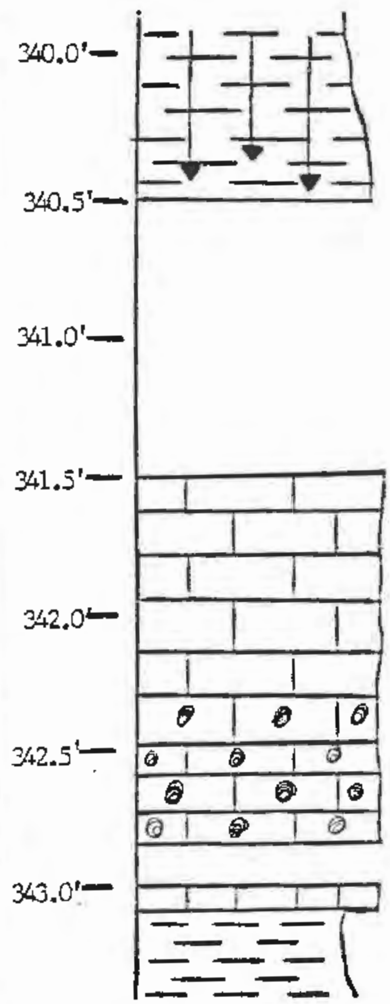


FIGURE 16

Stratigraphic section

Upper Pleasanton-
Mudstone, green-gray; crumbly

Noted as missing.

Exline -
Limestone, tan, massive, osagia grain calcarenite, abraided grains

Limestone, tan, skeletal calcilutite with oncolites 2 cm. in diameter

Missing
Limestone, dark gray, skeletal calcilutite with osagia grains

Lower Pleasanton -
Mudstone, green, crumbly

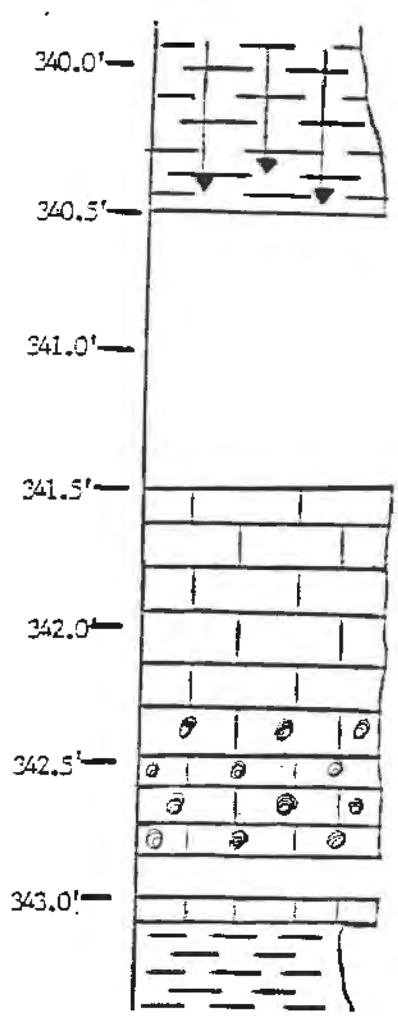


FIGURE 16--continued

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