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DEPOSITIONAL ENVIRONMENTS OF AN UPPER PENNSYLVANIAN (VIRGILIAN: WABAUNSEE GROUP) CYCLIC SEQUENCE IN NEBRASKA AND KANSAS

by

Donald C. Shields

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Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

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Dr. Watney (KGS) Thank you for your interest, & your support! Don Shields

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A THESIS

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Donald C. Shields, M.S.

University of Nebraska, 1987

Advisor: Professor Roger K. Pabian

Late Paleozoic rocks of Midcontinent North America are characterized by cyclic sedimentary deposits, particularly limestones and shales. Several depositional models have been developed to explain the genesis of these rocks. A lithostratigraphic and paleontologic study of an Upper Pennsylvanian (Virgilian; Wabaunsee Group) cyclic sequence in Nebraska and Kansas revealed a set of sedimentary rocks which do not completely fit any of the previously proposed depositional models. The stratigraphic units included in this study are (in ascending order): Pillsbury Formation, Dover Limestone Member, Dry Shale Member, and the Grandhaven Limestone Member (Stotler Limestone Formation).

The Pillsbury Formation was deposited in a nearshore, non-marine environment, during regression of an epeiric sea. As sea level rose again, the Dover Limestone was deposited. During maximum transgression, the Dry Shale deposition was initiated in an embayment near Humboldt, Nebraska. Dysaerobic conditions

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developed here and juvenile goniatite ammonoids dominate the fauna. Development of dysaerobic conditions in the Dry Shale near Humboldt is significant as these conditions are usually associated with deeper water deposits in the Midcontinent Paleozoic. The rest of the Dry Shale was deposited during regression, in a nearshore, non-marine environment. As relative sea level rose again, Grandhaven Limestone deposition began. Autocyclic controls may have been more influential in deposition of the Grandhaven than allocyclic (eustatic) controls.

LIST OF FIGURES

ACKNOWLEDGEMENTS

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Introduction

The Late Paleozoic strata of the Midcontinent United States are characterized by cyclic sedimentary deposits, primarily limestones and shales. Weller (in Wanless and Weller, 1932) first used the term cyclothem to describe these cyclic sequences. Midcontinent cyclothem research has since been concentrated on the Middle and Upper Pennsylvanian section. The Upper Pennsylvanian Wabaunsee Group (Virgil Stage) contains cyclic deposits of sandstones, shales and limestones. These are somewhat problematic in that they lack fissile, phosphatic black shales which are characteristic of most of the Middle and Upper Pennsylvanian (Desmoinesian-Missourian) cyclothems described by Heckel (1980, 1985) (Fig.1).

The lack of black shales and other features of the Wabausee Group prompted a lithostratigraphic and paleontologic study of a cyclic sequence within the Wabaunsee (this report) in order to determine the depositional environments of that sequence. The stratigraphic units included in this study are (in ascending order): the Pillsbury Formation, and the Dover Limestone, Dry Shale, and the Grandhaven Limestone members of the Stotler Limestone Formation (Fig.2).

Sixteen exposures of these stratigraphic units (Fig.3) in Nebraska and Kansas were studied. Stratigraphic sections were measured and described,

Figure 1. Middle and Upper Pennsylvanian stratigraphic sequence from Midcontinent North America. Letter B-P denote presence of black phosphatic shales (Heckel, 1985).

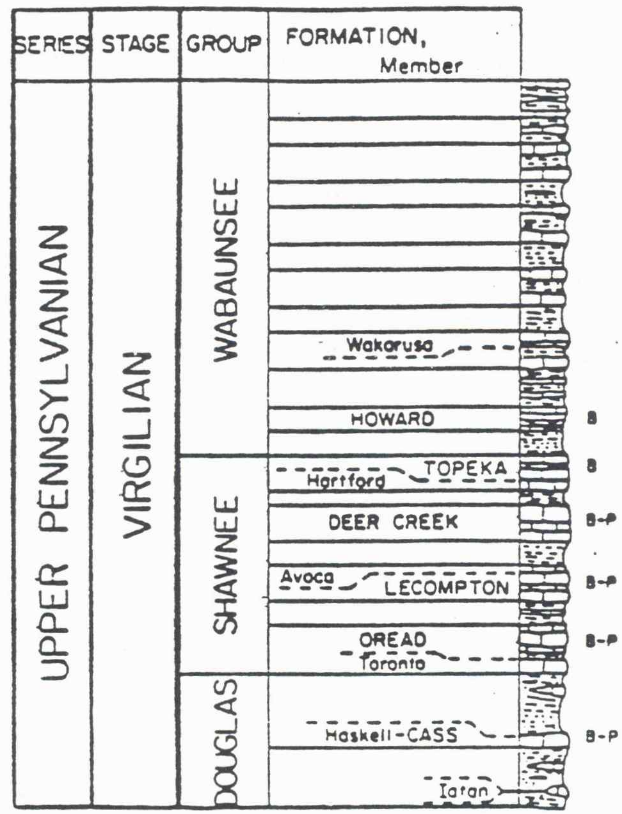
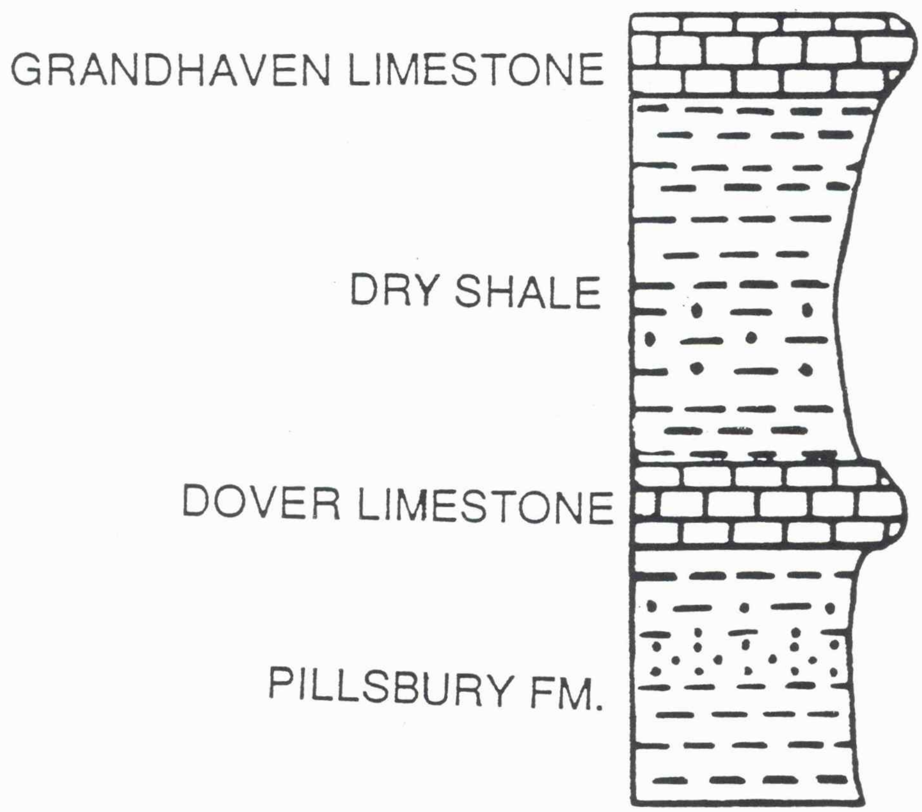
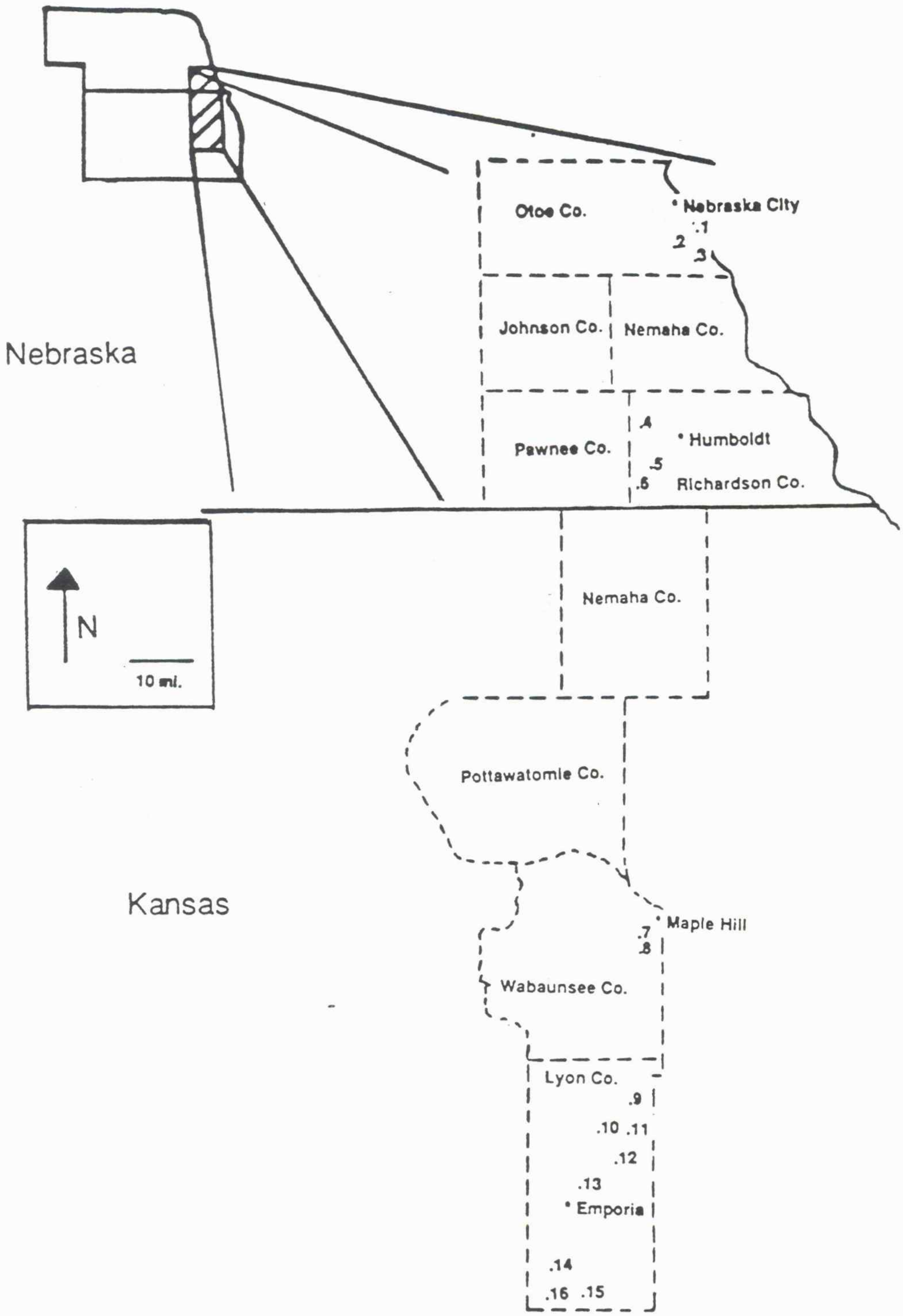

SERIES
STAGE
GROUP
FORMATION,
Member
UPPER PENNSYLVANIAN
VIRGILIAN
WABAUNSEE
SHAWNEE
DOUGLAS
Wakarusa
HOWARD
TOPEKA
Hartford
DEER CREEK
Avoca
LECOMPTON
OREAD
Toronto
Haskell-CASS
Iatan
B
B
B-P
B-P
B-P
B-P

Figure 2. **Generalized stratigraphic section.**



GRANDHAVEN LIMESTONE
DRY SHALE
DOVER LIMESTONE
PILLSBURY FM.

Figure 3. Map of the study area. Numbers denote locations of outcrops studied in this report. Measured stratigraphic sections for each location are in the Appendix.


Nebraska
Kansas
Otoe Co.
Nebraska City
.1
.2
.3
Johnson Co.
Nemaha Co.
Pawnee Co.
.4
Humboldt
.5
.6
Richardson Co.
Nemaha Co.
N
10 mi.
Pottawatomie Co.
Maple Hill
.7
.8
Wabaunsee Co.
Lyon Co.
.9
.10
.11
.12
.13
Emporia
.14
.16
.15

and rock samples were collected for subsequent laboratory study (see Methods of Investigation section). The area of study extends from near Nebraska City (Otoe County), Nebraska, in the north, to near Emporia (Lyon County), Kansas, in the south (Fig.3). Research on this project was initiated in the spring of 1986. The majority of the field work was done in the summer of that year.

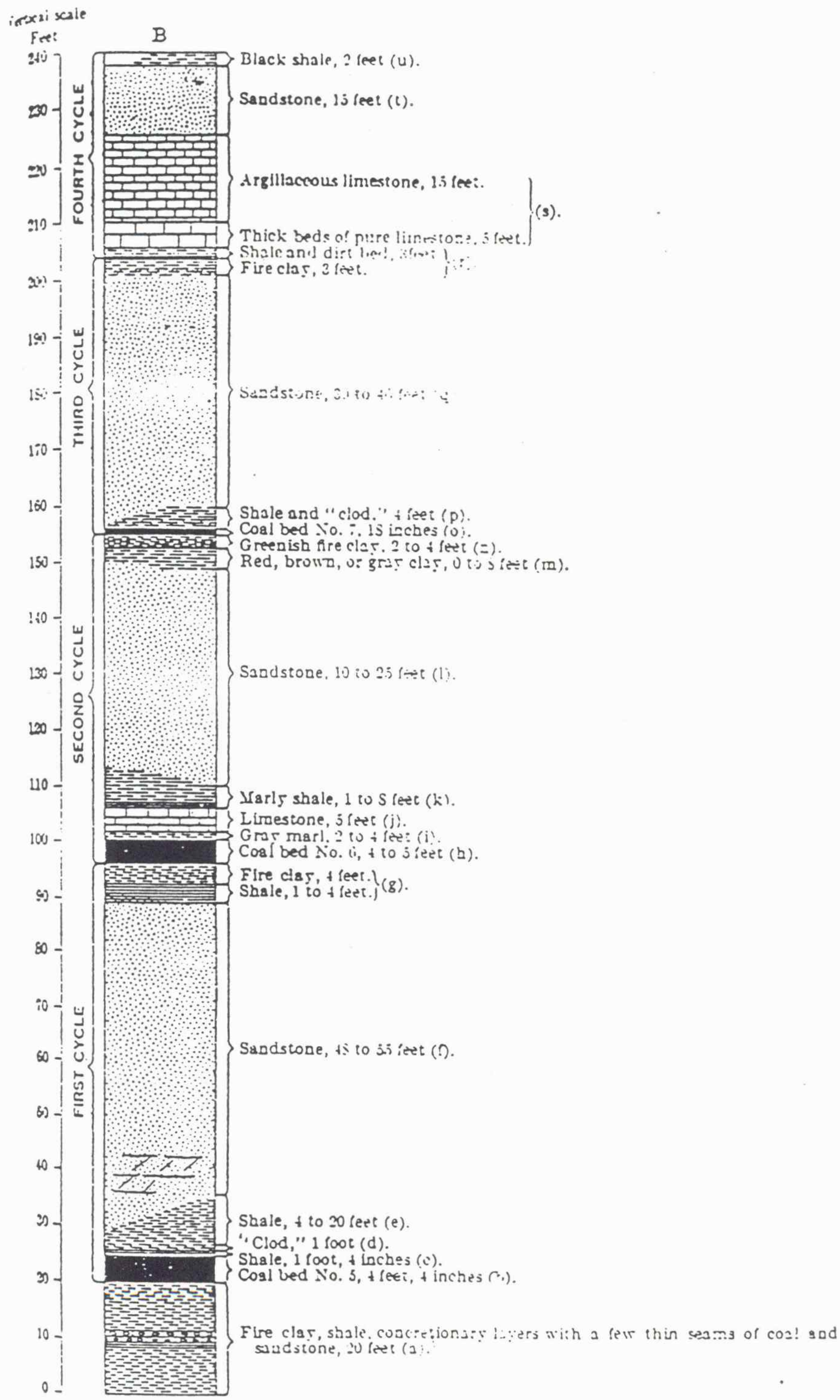
Evolution of the Cyclothem Concept

Udden (1912) was the first to recognize the cyclic nature of Midcontinent Pennsylvanian strata. While studying the geology of the Peoria (Illinois) Quadrangle, he noticed that coals in the Pennsylvanian section were associated with a consistent set of clay, shale, and sandstone lithologies (Fig.4). Udden called these associations "cycles of deposition" and maintained that they were the result of varying rates of sediment influx and that each cycle was deposited in four successive stages: 1) accumulation of vegetation, 2) deposition of calcareous material, 3) sand importation, 4) aggradation to sea level and soil making (Udden, 1912).

Weller (1930) expanded on Udden's work, recognizing that the Pennsylvanian strata throughout Illinois and much of the Midcontinent also exhibited cyclicity. Weller (Wanless and Weller, 1932) assigned the term cyclothem to these cycles of lithologies. He reinterpreted Udden's (1912) sediment influx mechanism, stating that episodes of continental uplift and subsidence resulted in the relative changes in sea level necessary for producing the cyclic nature of these strata.

Unlike Udden (1912) and Weller (1930), whose work was concentrated in Illinois, Moore (1936, 1950, 1964) studied Late Paleozoic cyclothems in Kansas and Nebraska. These are predominantly limestone-shale

Figure 4. Udden's cycles of deposition. From the Pennsylvanian section of the Peoria (Illinois) quadgrangle (Udden, 1912).



Vertical scale
Feet
B
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
FOURTH CYCLE
THIRD CYCLE
SECOND CYCLE
FIRST CYCLE
Black shale, 2 feet (u).
Sandstone, 15 feet (t).
Argillaceous limestone, 15 feet.
(s).
Thick beds of pure limestone, 5 feet.
Shale and dirt bed,
Fire clay, 3 feet.
Sandstone,
Shale and "clod," 4 feet (p).
Coal bed No. 7, 18 inches (o).
Greenish fire clay, 2 to 4 feet (n).
Red, brown, or gray clay, 0 to 5 feet (m).
Sandstone, 10 to 25 feet (l).
Marly shale, 1 to 8 feet (k).
Limestone, 5 feet (j).
Gray marl, 2 to 4 feet (i).
Coal bed No. 6, 4 to 5 feet (h).
Fire clay, 4 feet.
Shale, 1 to 4 feet.
(g).
Sandstone, 48 to 55 feet (f).
Shale, 4 to 20 feet (e).
"Clod," 1 foot (d).
Shale, 1 foot, 4 inches (c).
Coal bed No. 5, 4 feet, 4 inches
Fire clay, shale, concretionary layers with a few thin seams of coal and sandstone, 20 feet

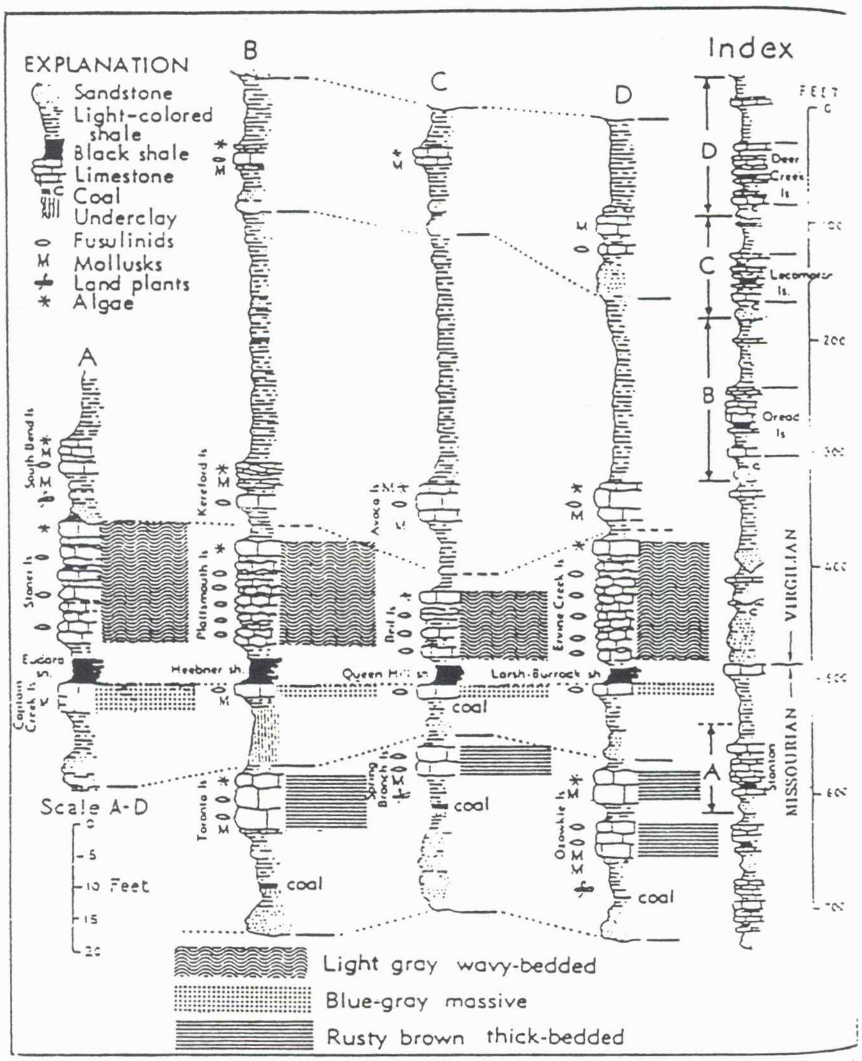
cycles. Coals are not as prominent as in the Illinois rocks studied by Udden (1912) and Weller (1930). This has led to the division of Midcontinent cyclothems into two major categories: Kansas cyclothems and Illinois cyclothems.

Moore (1936) determined that limestone and shale formations were deposited under marine and non-marine conditions, respectively. Thus, in order for these limestone-shale cyclothems to be deposited, relative sea level had to rise and fall in a cyclic fashion. Moore (1950) originally rejected the idea that waning and waxing of glaciers was responsible for the sea level change, but he also expressed doubts concerning Weller's (1930) uplift-subsidence mechanism. He eventually conceded that glaciation, in part, controlled deposition of these cyclothems (Moore, 1964).

Moore described several kinds of cyclothems and also noted that different cyclothems occurred in a consistent, vertically successive pattern. He called these cycles of cyclothems "megacyclothems" (Fig.5). Stout (1978) suggested that megacyclothems were the result of glacial cycles, such as those that produced the Quaternary valley fills in the central Great Plains.

Fissile black shales are present in both Kansan and Illinoian cyclothems. Although Weller (1930) and Moore

Figure 5. Upper Pennsylvanian cyclothems grouped into megacyclothems (Moore, 1964).


EXPLANATION
Sandstone
Light-colored shale
Black shale
Limestone
Coal
Underclay
Fusulinids
Mollusks
Land plants
Algae
A
B
C
D
Index
FEET
Deer Creek ls
Lecompton ls.
Oread ls
VIRGILIAN
MISSOURIAN
Stanton
South Bend ls
Stoner ls
Eudora
Captain Creek ls
Kereford ls
Plattsmouth ls
Heebner sh.
Toronto ls
Avoca ls
Beil ls
Queen Hill sh
Spring Branch ls
Ervine Creek ls
Larsh-Burroak sh
Oskaloosa ls
coal
Scale A-D
Feet
Light gray wavy-bedded
Blue-gray massive
Rusty brown thick-bedded

(1948) assigned a shallow water, low energy environment of deposition for this lithology, both conceded that it was the most problematic aspect of the Pennsylvanian cyclothems. Heckel and Baesemann (1975) used conodont paleoecology to reinterpret Moore's megacyclothem (Fig.6). They determined that the fissile black shales were deposited in very deep water (600 feet) below a thermocline. This is the deepest water deposit in a glacially induced, transgressive-regressive cyclothem depositional model, referred to as the Heckel depositional model throughout this report.

The Heckel depositional model divides cyclothems into four basic lithologies (in ascending order): nearshore shale, transgressive limestone, offshore shale, and regressive limestone (Fig.7). Nearshore shales are the shallowest water deposit, often exhibiting subaerial exposure features (Heckel, 1980; Watney, 1985). The black fissile shale is the deepest water lithology, deposited during maximum transgression. Transgressive and regressive limestones were deposited during sea level rise and fall, respectively. Heckel's work has been concentrated on Kansas cyclothems, but he also applies it to the Illinois cyclothem (Fig.8). Unlike Heckel, Merrill and von Bitter (1976) and Zangerl and Richardson (1963) consider the fissile black shales in the Illinois cyclothem to be shallow water, low energy deposits.

Figure 6. Reinterpreted Upper Pennsylvanian megacyclothem. Sea level curve 1 is after Moore (1936). Study of conodont distribution in the Upper Pennsylvanian section led Heckel and Baesemann (1975) to reinterpret the depositional environment of the black phosphatic shale (sea level curve 2) (Heckel and Baesemann, 1975).

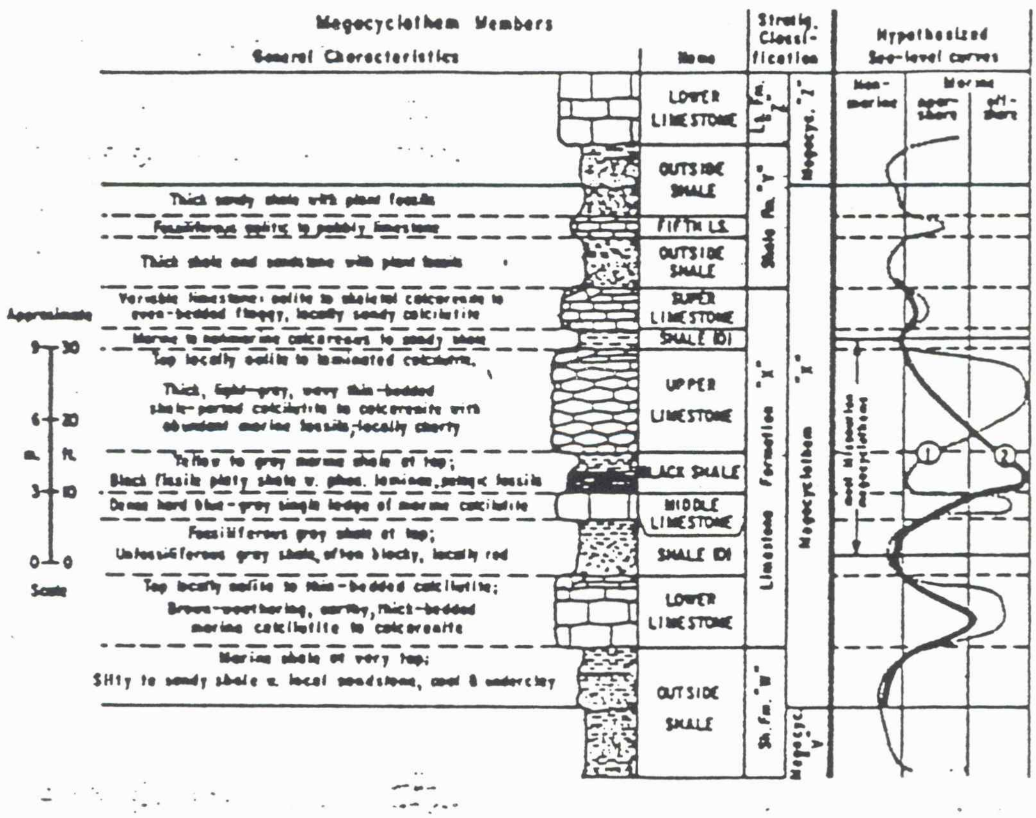
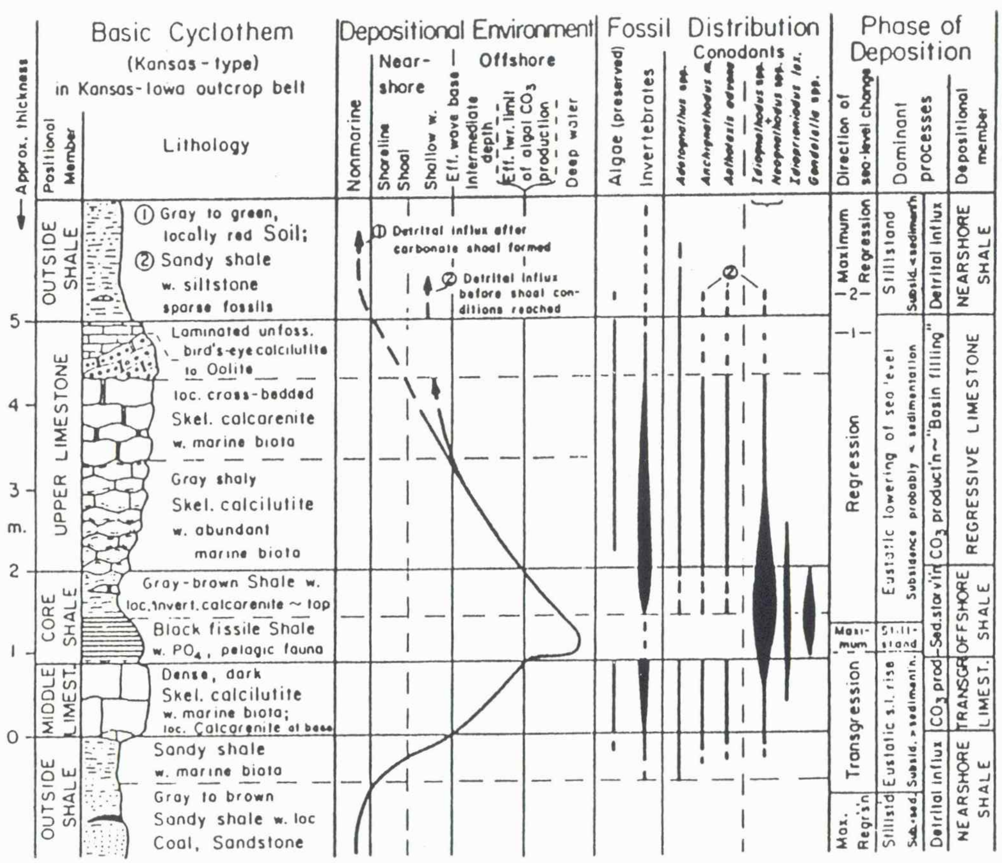
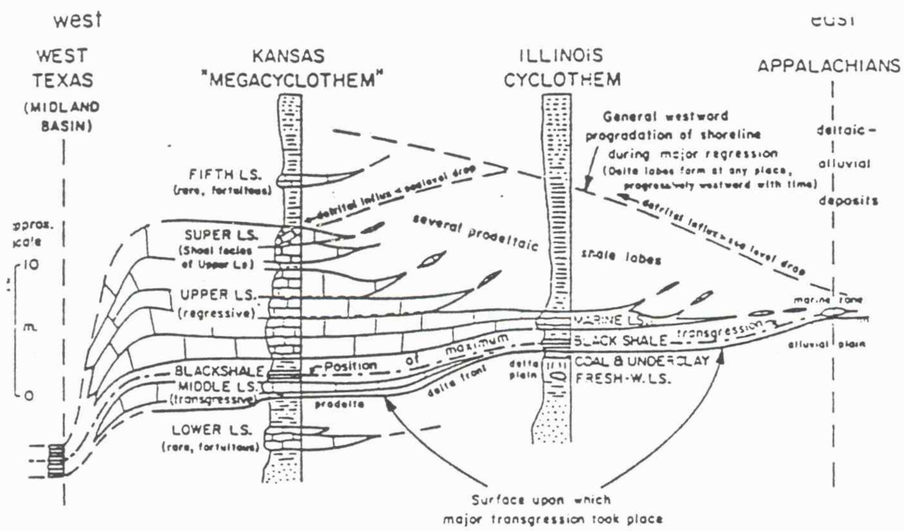


Figure 7. Heckel depositional model for Midcontinent Upper Pennsylvanian cyclothems (Heckel, 1985).



Basic Cyclothem
(Kansas-type)
in Kansas-Iowa outcrop belt
Approx. thickness
Positional Member
Lithology
Depositional Environment
Nonmarine
Near-shore
Offshore
Shoreline Shoal
Shallow w.
Eff. wave base
Intermediate depth
Eff. lwr. limit of algal CO3 production
Deep water
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Phase of Deposition
Direction of sea-level change
Dominant processes
Depositional member
OUTSIDE SHALE
UPPER LIMESTONE
CORE SHALE
MIDDLE LIMEST.
① Gray to green, locally red Soil;
② 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. loc. invert. calcarenite ~ top
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
① Detrital influx after carbonate shoal formed
② Detrital influx before shoal conditions reached
Maximum Regression
Regression
Maximum
Transgression
Max. Regr'sn
Stillstand
Subsid.<sedimentn
Detrital influx
Eustatic lowering of sea level
Subsidence probably < sedimentation
CO3 producti'n ~ "Basin filling"
Stillstand
Sed. starv'n
Eustatic s.l. rise
Subsid. > sedimentn.
CO3 prod.
Eustatic
Subsid. > sed.
Detrital influx
Stillstd
Sub.<sed.
Detrital influx
NEARSHORE SHALE
REGRESSIVE LIMESTONE
OFFSHORE SHALE
TRANSGR. LIMEST.
NEARSHORE SHALE
5
4
3
m.
2
1
0

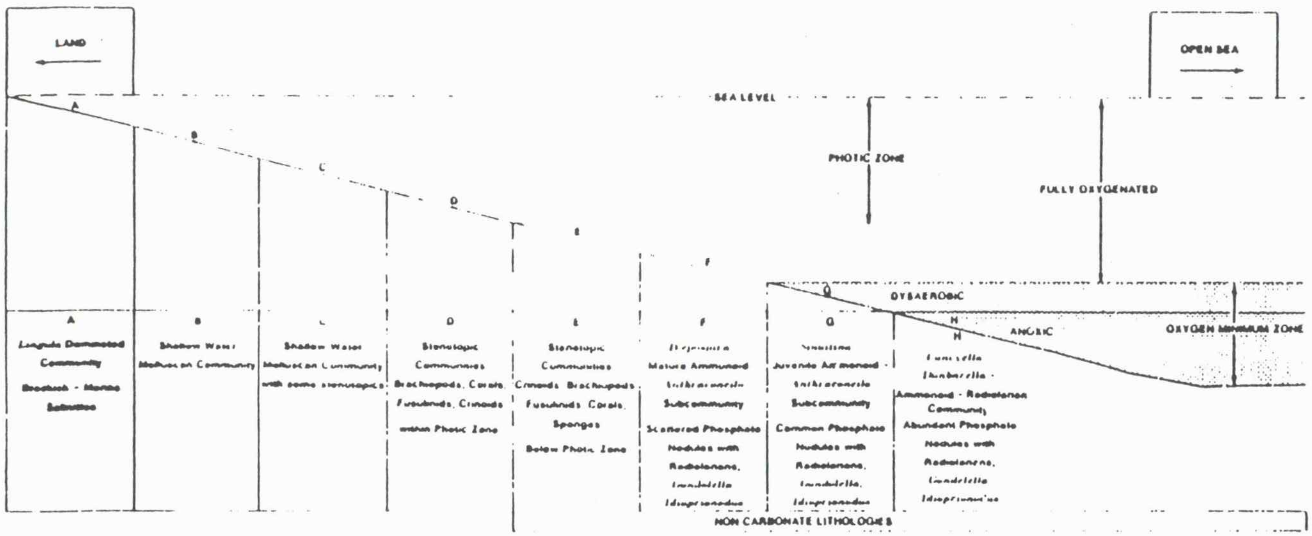
Figure 8. Generalized cross section of an Upper Pennsylvanian cyclothem (after the Heckel depositional model) along the axis of the Midcontinent sea (west Texas to the Appalachians) (Heckel, 1980).


west
east
WEST TEXAS
(MIDLAND BASIN)
KANSAS "MEGACYCLOTHEM"
ILLINOIS CYCLOTHEM
APPALACHIANS
General westword progradation of shoreline during major regression
(Delta lobes form at any place, progressively westward with time)
deltaic-alluvial deposits
FIFTH LS.
(rare, fortuitous)
SUPER LS.
(Shoal facies of Upper Ls)
UPPER LS.
(regressive)
BLACKSHALE
MIDDLE LS.
(transgressive)
LOWER LS.
(rare, fortuitous)
several prodeltaic shale lobes
detrital influx = sea level drop
Position of maximum transgression
MARINE LS.
BLACK SHALE
COAL & UNDERCLAY
FRESH-W. LS.
delta plain
delta front
prodelta
marine zone
alluvial plain
approx. scale
10
m
0
Surface upon which major transgression took place

Boardman et al. (1984) studied community succession of molluscs, crinoids, brachiopods, and fusulinids in Midcontinent Pennsylvanian cyclothems. Their results were in agreement with the Heckel depositional model, including his interpretation of the black fissile shale (Fig.9).

Recently, Busch and Rollins (1984) proposed that Midcontinent Permo-Carboniferous cyclic sequences are better described by a hierarchy of transgressive-regressive units, based on the punctuated aggradational cycle hypothesis (Anderson, Goodwin, and Sobieski, 1984), than by the Heckel depositional model. Heckel (1985) has argued against this, stating that a hierarchal approach is too rigid when applied to these rocks.

Figure 9. Depth controlled community succession model for Upper Pennsylvanian cyclothems (Boardman et al., 1984).



LAND
OPEN SEA
SEA LEVEL
PHOTIC ZONE
FULLY OXYGENATED
DYSAEROBIC
ANOXIC
OXYGEN MINIMUM ZONE
A
Shallow Water
Molluscan Community
Shallow Water
Molluscan Community
with some stenotopics
D
Stenotopic
Communities
Brachiopods, Corals,
Fusulinids, Crinoids
within Photic Zone
Stenotopic
Communities
Crinoids, Brachiopods,
Fusulinids, Corals,
Sponges
Below Photic Zone
Mature Ammonoid
Subcommunity
Scattered Phosphate
Nodules with
Radiolarians,
G
Juvenile Ammonoid -
Subcommunity
Common Phosphate
Nodules with
Radiolarians,
H
Ammonoid - Radiolarian
Community
Abundant Phosphate
Nodules with
Radiolarians,
NON CARBONATE LITHOLOGIES

Methods of Investigation

The objective of this study is to determine the depositional environments of the aforementioned cyclic sequence. The majority of field work took place during the summer of 1986. Time and financial considerations restricted the study to southeastern Nebraska and northeastern Kansas. Outcrops of this sequence within the study area were located through published reports (measured sections) and geologic maps. A great deal of time was spent searching for potential outcrops. Many previously described outcrops no longer exist (overgrown by vegetation, etc.). Sixteen outcrops were located and studied (Fig.3), of these, only four contained all four stratigraphic units of interest to this study (locations 1, 2, 7, and 8).

Stratigraphic sections were measured (see Appendix) at each outcrop. Material was collected from each lithology for sedimentologic, stratigraphic, and paleontologic studies. The Pillsbury and Dry were bulk sampled at many of the localities. This process involved removing the sediment (20-40 lbs. samples) from the outcrop with a shovel, placing it in a container, washing it through a strainer (in the laboratory) and analyzing the residue, specifically for fossil content.

Samples of the Dover and Grandhaven limestones were obtained by removing pieces of these units with a rock hammer. Petrographic thin sections and polished sections were made and analyzed.

As is the case with any sampling procedure, the interval at which the samples are taken is critical, and often represents a bias in the study. Initial studies of these units indicated that the base of the Dry Shale was extremely fossiliferous and represented an offshore shale of the Heckel depositional model. Thus, bulk sampling was concentrated at the base of the Dry Shale. These samples were taken at two foot intervals from the top of the Dover. As result of this bias, sampling of the carbonates was less precise. Carbonate samples were collected without noting their position (bottom, middle, top) within the unit.

Subsequent study of the materials collected revealed that the Dry shale was not as fossiliferous as had been predicted. Much of the information on the depositional environments of the sequence had to come from the petrologic study of the carbonates, but the original sampling of these units was not adequate for doing this. Thus, in May 1987, limestones from some key locations (2, 7, and 8) were sampled again, with greater precision.

Description of Lithostratigraphic Units

Stratigraphic Nomenclature

The stratigraphic position of the units of interest in this study (Pillsbury Formation, Dover Limestone, Dry Shale, and Grandhaven Limestone) is: Pennsylvanian System, Upper Pennsylvanian Series, Virgilian Stage, Wabaunsee Group. As might be expected, the stratigraphic nomenclature of these units has changed since they were first described.

Pillsbury Formation. The stratigraphic interval now occupied by the Pillsbury Formation was originally known as the Langdon Shale in Nebraska (Condra and Reed, 1943), and as the Table Creek Shale in Kansas (Moore, 1936). Moore and Mudge (1956) adopted the name Pillsbury Shale to include the strata between the Zeandale Limestone (below) and the Stotler Limestone (above). The Pillsbury retained its formational status after this revision.

Dover Limestone. The Dover Limestone was originally described by Beede (1898). It was considered part of the Admire Shale by Haworth and Bennett (1908). Condra (1949) defined the Dover Limestone as the stratigraphic interval between the Langdon Shale (below) and the Dry Shale (above) and assigned it formational status. Moore and Mudge (1956) reduced it to member status within the (then) newly named Stotler Limestone Formation.

Dry Shale. The Dry Shale was originally defined by Moore (1936) as the strata between the Dover Limestone below and the Grandhaven Limestone above. It was assigned formational status. Previously this interval was considered an unnamed part of the Admire Shale (Haworth and Bennett, 1908). Moore and Mudge (1956) reduced it to a member of the (then) newly named Stotler Limestone Formation.

Grandhaven Limestone. The Grandhaven Limestone was originally defined by Moore (1936) as the limestone between the Dover Limestone (below) and the Jim Creek Limestone (above). It was assigned formational status. Previously this interval was considered an unnamed part of the Admire Shale (Haworth and Bennett, 1908). Moore and Mudge (1956) reduced it to a member of the (then) newly named Stotler Limestone Formation, specifically the strata between the Dry Shale member (below) and the Friedrich Shale Member (Root Formation) (above).

In Nebraska, Condra (1949) referred to the limestone at the Grandhaven stratigraphic interval as the Morton Limestone. He did not believe that the Morton and Grandhaven were stratigraphically equivalent units. Burchett and Reed (1967) also referred to this interval as the Morton, but later, Burchett (1977) called it the Grandhaven Limestone.

Summary. The stratigraphic nomenclature of the units studied in this report is as follows:

Pennsylvanian System
  Upper Pennsylvanian Series
    Virgilian Stage
      Wabaunsee Group
        Stotler Limestone Formation
          Grandhaven Limestone Member
          Dry Shale Member
          Dover Limestone Member
        Pillsbury Formation

As this study is primarily concerned with the depositional environments of these units, and a change in lithology presumably reflects a a change in depositional environment, each of these units (Pillsbury, Dover, Dry, and Grandhaven) will be considered separately and equally, regardless of stratigraphic rank.

Petrology of Lithostratigraphic Units

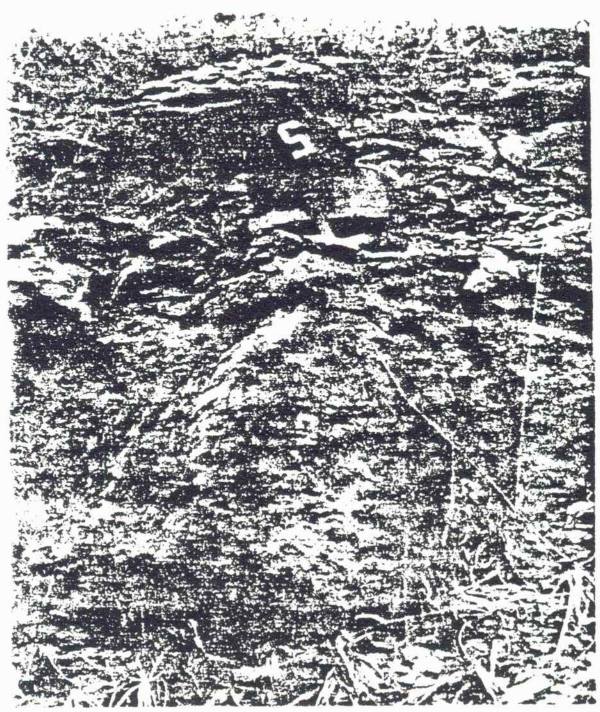
Pillsbury Formation. The Pillsbury Formation consists of shales, siltstones, sandstones and coals. Muscovite is a common constituent. Plant fossils and pyrite nodules are present. The base of the Pillsbury was not observed within the study area. The greatest thickness measured was over 28 feet near Nebraska City, Nebraska (location 3). Zeller (1968) reports that the Pillsbury is 50 feet thick in parts of Kansas. The Nyman coal is commonly present at the top of the Pillsbury in the northern part of the outcrop belt (Hershey et al., 1960; Burchett and Reed, 1967). In the course of this study the Nyman coal was observed only at those localities near Nebraska City, Nebraska (locations 1, 2, and 3).

<u>Dover Limestone.</u> In the northern part of the study area the Dover is represented by one limestone (biosparite) bed, ranging in thickness from 15 inches near Nebraska City, Nebraska (location 1) to 6 inches near Humboldt, Nebraska (location 6). It is grey and is dominated by phylloid algae and intraclasts. Hematite coated intraclasts are common.

In the southern part of the study area the Dover is represented by two beds of limestone separated by shale. The lower Dover Limestone bed has a fusulinid-rich, thinly-bedded base, which grades upward into a massive, hematite rich algal limestone. The fusulinid rich zone is 12 inches thick, the massive algal zone is 30 inches thick. The intervening shale is thin (6 inches), calcareous, and fossiliferous. Fossils present in the shale include fenestrate and rhomboporoid bryozoans, productid brachiopods, and crinoid columnals. The upper Dover limestone bed is a thinly-bedded biomicrite, up to 30 inches thick (Fig.10).

Fossils observed in the Dover limestone, within the study area, include: echinoderms, brachiopods, bellerophontid gastropods, phylloid algae, bryozoans, rugose corals, and fusulinids.

Figure 10. Dover Limestone in Wabaunsee County, Kansas (location 7). Fusulinid-rich zone is at bottom of the photograph, overlain by (in ascending order) massive algal limestone, marine shale (marked by head of hammer) and upper limestone.

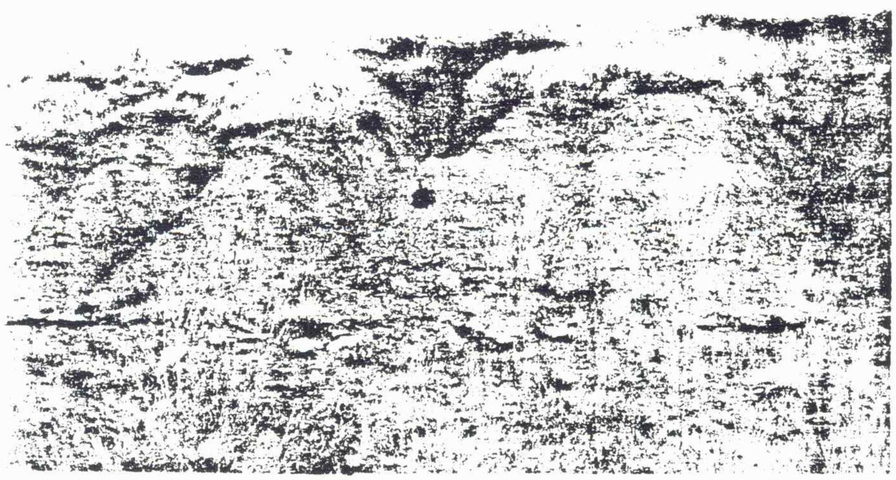


Dry shale. The lithologic and paleontologic nature of the Dry varies within the study area. For the most part, it is a thick (10-15 feet) shale and siltstone unit, with sandstones common at the top (Fig.11). It is grey and brown in color and muscovite rich. Marine fossils are rare; where they do occur they are located at the base and/or top of the unit. These could represent transitional zones from the under- and overlying limestones or they could be reworked from previously deposited sedimentary rocks. As they are often found in sandy parts of the unit and show signs of abrasion, reworking appears to be the better explanation. In southern Lyon County, Kansas, chonetoid brachiopods that do not appear to have been reworked are present within the Dry Shale. These may be from a thin "limestone stringer" described by Tasch (1953)

At outcrops near Humboldt, Nebraska, the Dry differs markedly from its normal lithologic and paleontologic character. At its base there is a well-developed juvenile goniatite fauna. Gastropods, and small nautiloids and pelecypods are also present. The fossils here are usually replaced by limonite and limonitic concretions are common. The top of the Dry near Humboldt is a red shale, which is also unique to this part of the study area.

Tasch (1953) performed an extensive study on small

Figure 11. Exposure of the Dry Shale in Wabaunsee County, Kansas (location 7). Hat for scale.

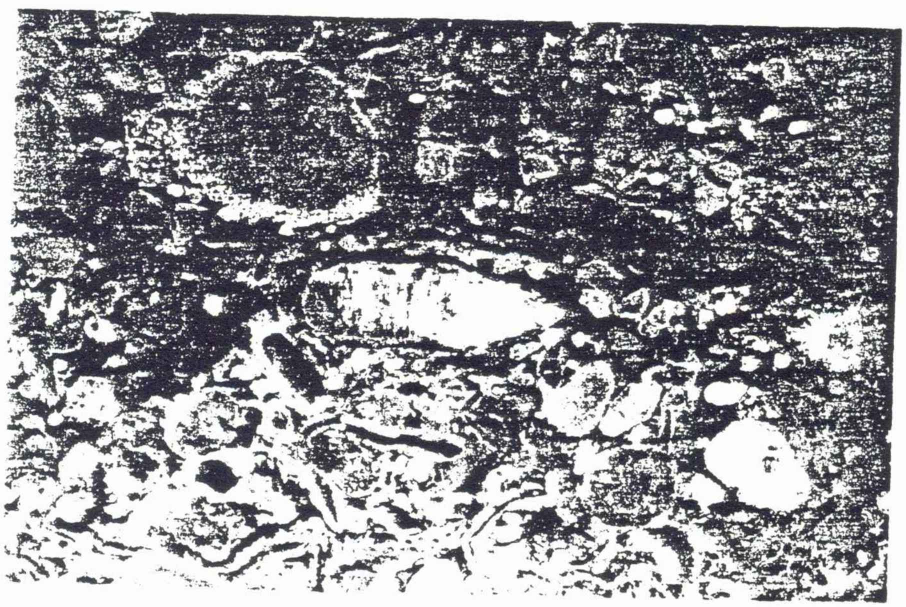


ammonoids from the Dry Shale to the south of the study area of this report (Lyon, Greenwood, and Elk counties, Kansas). The outcrops he described are more similar to the Humboldt, Nebraska, localities than to the other Dry Shale exposures studied in this report. Tasch briefly mentioned that some exposures of the Dry Shale are unfossiliferous. This suggests that Tasch may have preferentially sought out outcrops such as this and ignored the more common, sparsely fossiliferous ones (Tasch, 1953, p. 361).

Grandhaven Limestone. The Grandhaven is variable within the study area, especially with respect to the number and character of limestone beds and interbedded shales included in this unit. In the northern part of the study area , near Nebraska city, Nebraska (locations 1 and 2), there is no interbedded shale associated with the Grandhaven. Here the base of the unit is a thinly-bedded biosparite, 20 inches thick, that contains phylloid and coralline algae, brachiopods, and intraclasts (Fig.12). This grades upward into a massive algal biosparite, 19 inches thick, that contains bryozoans. Subsurface data (Burchett and Maroney, 1979) indicate that the Grandhaven includes an interbedded shale in southern Nebraska. An exposure of the Grandhaven in this area, however, does not contain an interbedded shale (location 5).

Mudge and Burton (1959) report that the Grandhaven

Figure 12. Photo negative print of thin section. Grandhaven limestone near Nebraska City, Otoe County, Nebraska (location 2). Note presence of coralline algae in center of figure (7X).



is represented by only one bed of limestone in Wabaunsee County, Kansas. Wabaunsee County, Kansas exposures of the Grandhaven examined in this study (locations 7 and 8) consist of only one limestone bed, supporting Mudge and Burton's claim. Here the Grandhaven is a hematite-rich, unfossiliferous calcarenite, 17 inches thick, with abundant intraclasts (Fig.13).

In Lyon County, Kansas, the Grandhaven is composed of two separate limestone beds. The interbedded unit is a shale (O'Connor, 1953;Mudge and Yochelson, 1962). The shale is covered by soil and vegetation in this area and was not observed during the course of this study. The lower Grandhaven Limestone bed is an unfossiliferous, micaceous, calcarenite, 19 inches thick, with abundant intraclasts (Fig.14). The upper Grandhaven Limestone bed is a micaceous, hematite-rich biomicrite, 8 inches thick (Fig.15). It is not laterally persistent (Mudge and Yochelson, 1962). Fossils present include: fusulinids, bryozoans, echinoderms, and brachiopods.

The three separate lithologies that comprise the Grandhaven in Lyon County, Kansas, differ, especially in fossil content, from the three Grandhaven units described by Mudge and Yochelson (1962, p. 9). This may be due to the variability of the Grandhaven over even short geographic distances.

Figure 13. Photo negative print of thin section. Grandhaven Limestone from Wabaunsee County, Kansas (location 7) (3.5 X).

Figure 14. Photo negative print of thin section. Lower Grandhaven Limestone from Lyon County, Kansas (location 11) (7.5 X).

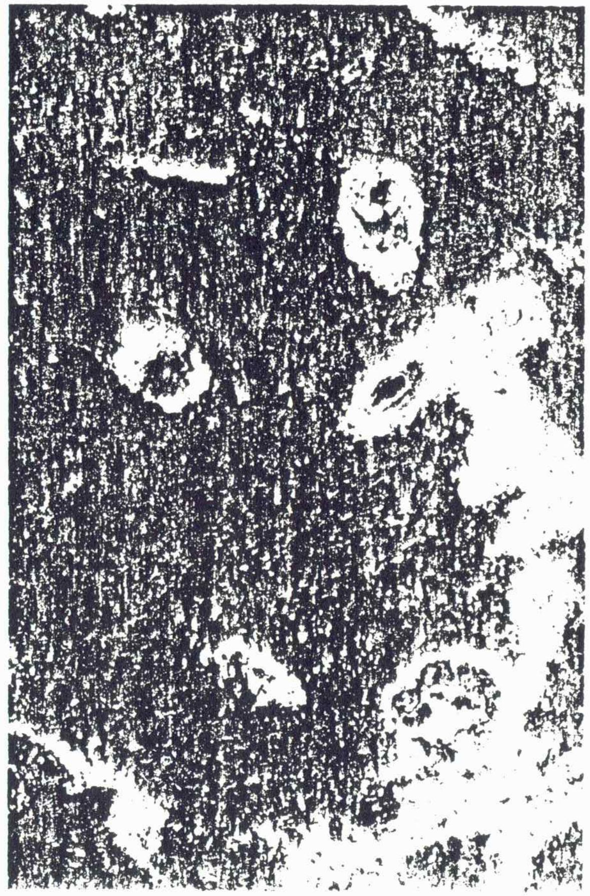
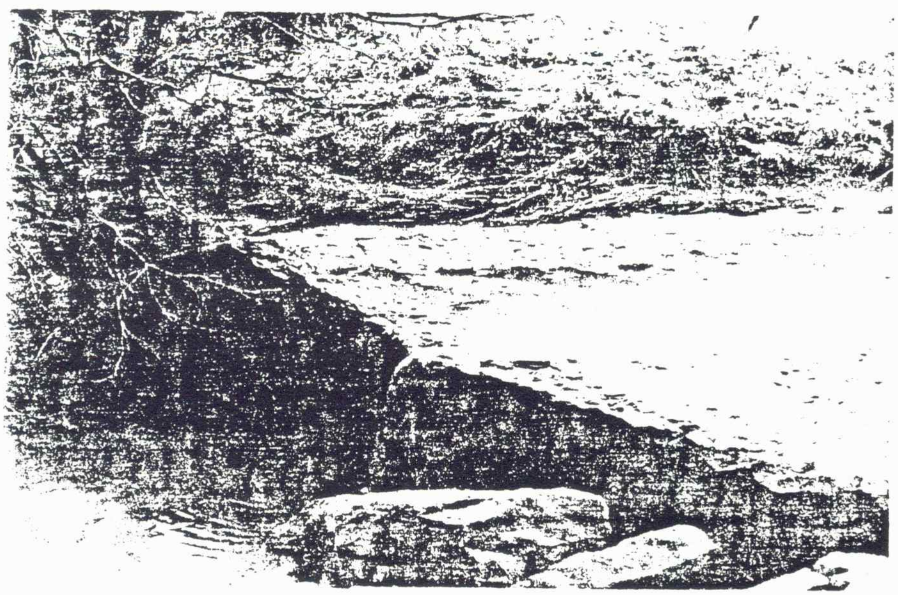


Figure 15. Upper Grandhaven Limestone from Lyon County Kansas (location 13). Hammer for scale.



Paleontology

Fossils are present in all four lithologic units. Fossils from the Pillsbury and Dry were analyzed under a binocular microscope after having been extracted through washing and sieving techniques (see Methods of Investigation section.). Fossils from the Dover and Grandhaven were analyzed in the field, in polished sections, and in thin section under a petrographic microscope.

Several geologists have studied the flora and fauna of these lithologic units. Mudge and Yochelson (1962, table 1, sheet 1) is recommended as the most comprehensive paleontologic study of these rocks. In this report, discussion will be concentrated on those fossils found by the author, within the study area.

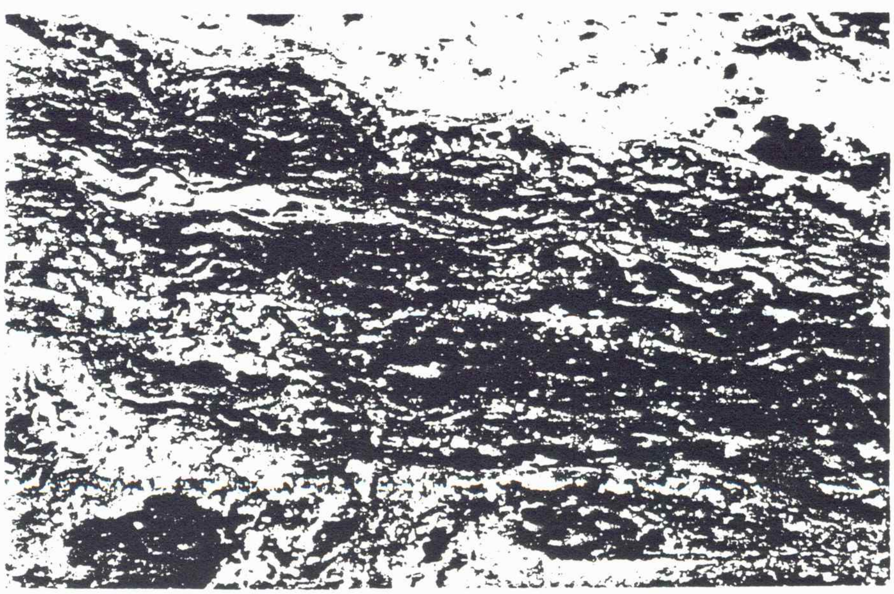
Algae

The Dover and Grandhaven are both algal-rich limestones throughout much of the study area. Both contain abundant phylloid and blue-green algae (Fig.16). Algal-coated grains are common in both limestones. Coralline algae are present in the Grandhaven near Nebraska City, Nebraska (Fig.12). In Wabaunsee County, Kansas blue-green algae is a major component of the lower Dover Limestone bed.

Figure 16. A. Photo negative print of thin section. Dover Limestone from Nebraska City, Otoe County, Nebraska (location 2). Note abundance of Phylloid algae (5 X). B. Photo negative print of thin section. Blue-green algae in the Dover Limestone from Wabaunsee County, Kansas (location 6) (3 X).

A

B



Fusulinids (Fig.17)

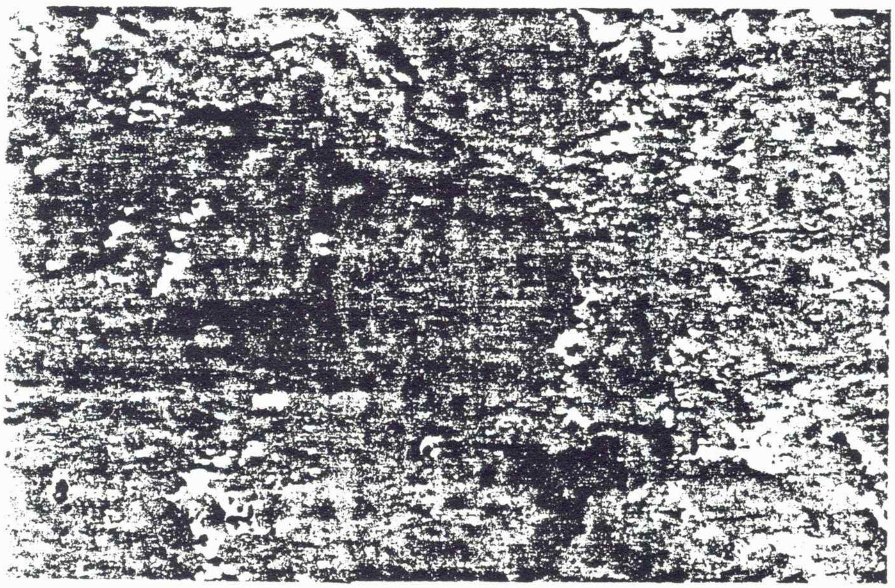
Fusulinids are present in the Dover Limestone, Dry Shale, and Grandhaven Limestone. They are more abundant in the southern part of the study area. In Wabaunsee County, Kansas, the base of the Dover Limestone is fusulinid-rich. The sandy top of the Dry Shale at location 12 contains abundant fusulinids and crinoid columnals, but these may have been reworked from previously deposited sedimentary rocks. In Kansas, fusulinids are locally abundant in the Grandhaven Limestone.

Echinodermata

Crinoid columnals are present in the Dover Limestone, Dry Shale, and Grandhaven Limestone. They are most abundant in the carbonates. At location 12 (Lyon County, Kansas) crinoid columnals are abundant at the top of the Dry Shale. Here, the Dry is sandy and fusulinids are also abundant. These may have been reworked from prêviously deposited sedimentary rocks. Evidence that suggests this includes: presence in a sandy matrix, uniform size, and weathered appearence of the fossils.

Echinoderm fragments are common allochems in both the Dover and Grandhaven limestones. They are easily identifiable as echinoderms in thin section, but in this study were not classified to lower taxonomic levels.

Figure 17. Photo negative print of thin section. Fusulinids from the Dover Limestone, Wabaunsee County, Kansas (location 7) (15 X).



Coelenterata

Rugose Corals (Fig. 18)

Rugose corals are present in both the Dover and Grandhaven Llimestones. In Wabaunsee County, Kansas, rugose corals are a common component in the lower limestone bed of the Dover Llimestone. Dibunophyllum has been previously observed in these units by Mudge and Yochelson (1962). Those collected in this study appear to be similar. Rugose corals were analyzed only in thin and polished sections.

Bryozoa

Bryozoans are present in the Dover Limestone, Dry Shale, and Grandhaven Limestone. At location 7 (Wabaunsee County, Kansas: (Fig.3) fenestrate (Fig.19) and rhomboporoid (Fig.20) bryozoans were collected from a shale layer within the Dover Limestone. The base of the Dry Shale contains rhomboporiod bryozoans at this locality.

Bryozoans are common allochems in both the Dover and Grandhaven Limestones. They are easily identifiable as bryozoans in thin section, but in this study were not classified to lower taxonomic levels.

Brachiopoda

Brachiopods were observed in the Dover Limestone, Dry Shale, and Grandhaven Limestone. Productoid brachiopods are present in the Grandhaven Limestone

Figure 18. Photo negative print of thin section. Rugose coral from the Dover Limeston, Wabaunsee County, Kansas (location 8) (12.5 X).

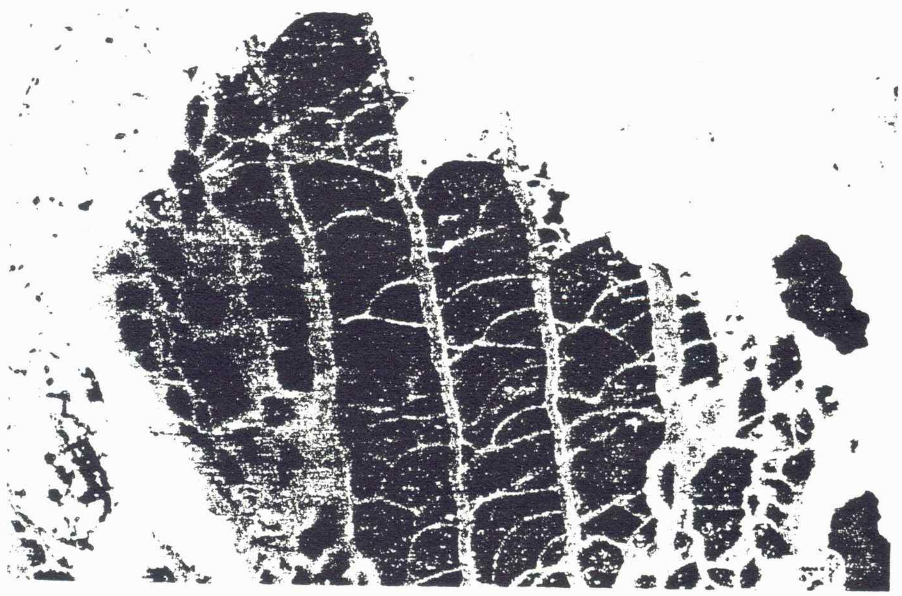


Figure 19. Fenestrate bryozoan from a marine shale within the Dover Limestone, Wabaunsee County, Kansas (location 8) (6.5 X).

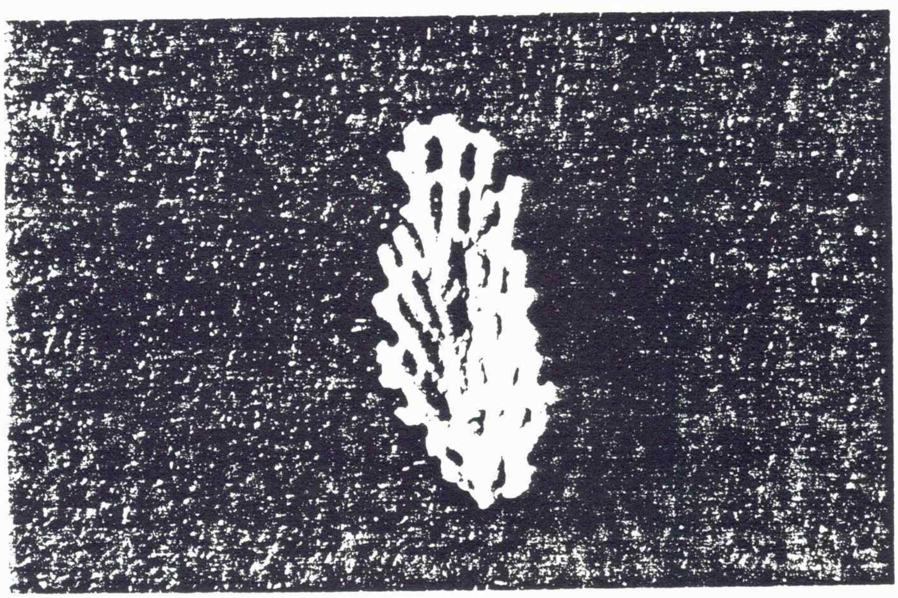
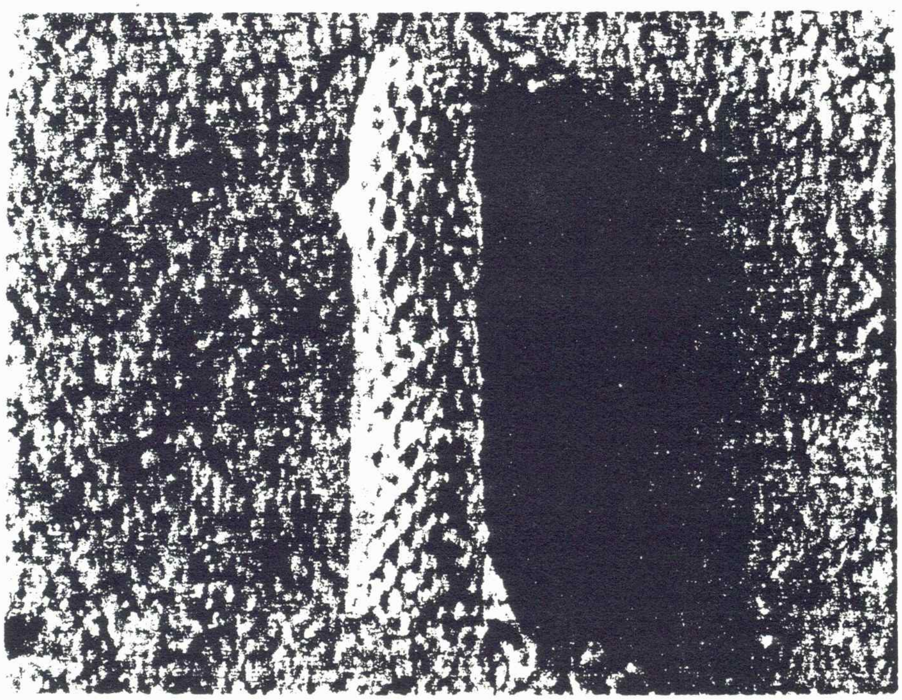


Figure 20. Rhomboporoid bryozoan from a marine shale within the Dover Limestone, Wabaunsee County, Kansas (location 8) (8 X).



(Lyon County, Kansas) and in a shale within the Dover Limestone (Wabaunsee County, Kansas) (Fig.21). Chonetoid brachiopods are present within the Dry Shale in southern Lyon County, Kansas (locations 14 and 16) (Fig.22).

Brachiopods are common allochems in both the Dover and Grandhaven limestones. They are easily identifiable as brachiopods in thin section, but in this study were not classified to lower taxonomic levels.

Mollusca

Ammonoids

Ammonoids were found only at location 6 (Fig.3), near Humboldt, Nebraska. The Dry Shale is the only unit here that contains ammonoids, and juveniles dominate the fauna. No adult ammonoids were observed. The juvenile goniatites present include: Gonioloboceras goniolobum (Fig.23), Neoaganides grahamense, and Glaphyrites (Eoasinites?) (Fig.24) (Mapes, 1987, personal communication). The majority of these fossils are limonitic, possibly weathered from pyrite. The fauna at this locality was originally reported by Pabian et al. (1984).

Presence of juvenile ammonoids is significant. Boardman et al. (1984) have demonstrated that faunas such as this represent mass-mortality events due to fluctuations in the dysaerobic zone of the water column.

Figure 21. Productoid brachiopod fragment from a marine shale within the Dover Limestone, Wabaunsee County, Kansas (location 8) (7 X).

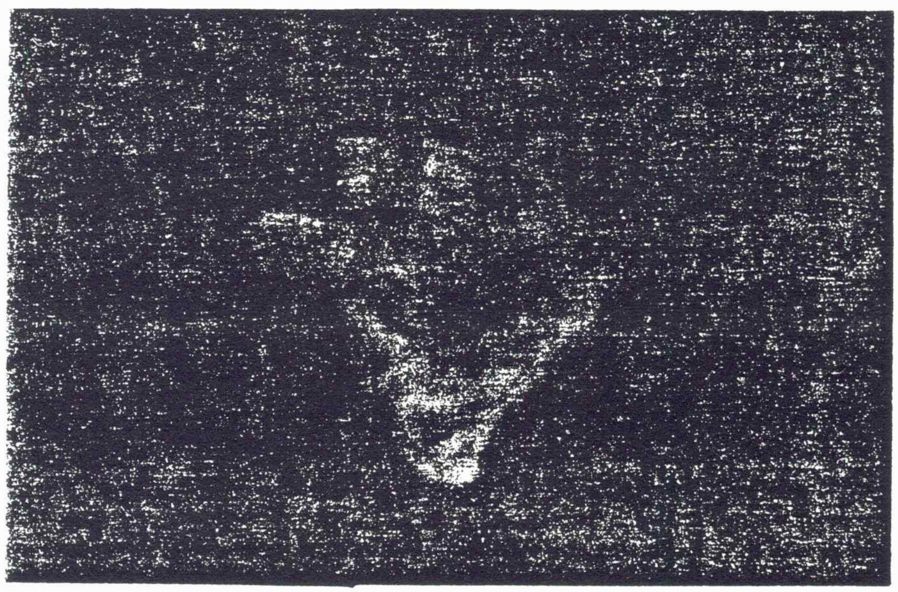


Figure 22. Chonetoid brachiopod from the Dry Shale, Lyon County, Kansas (location 16) (3X).

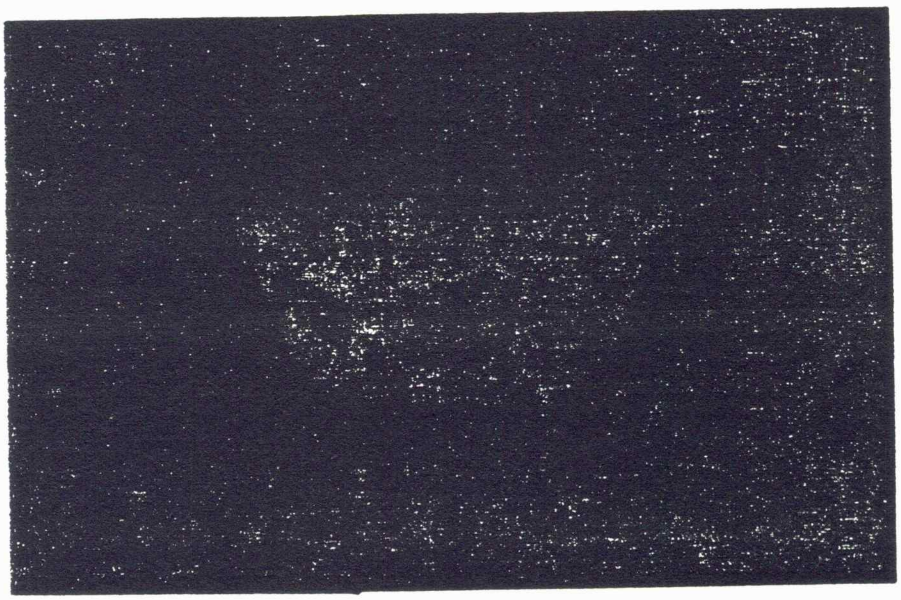


Figure 23. Gonioloboceras goniolobum from the Dry Shale near Humboldt, Richardson County, Nebraska (location 6) (9 X).

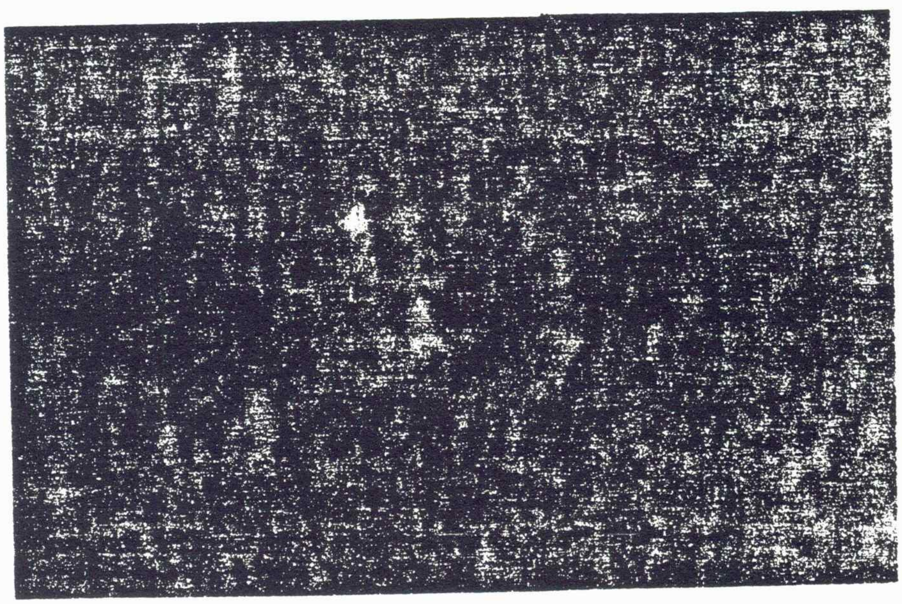
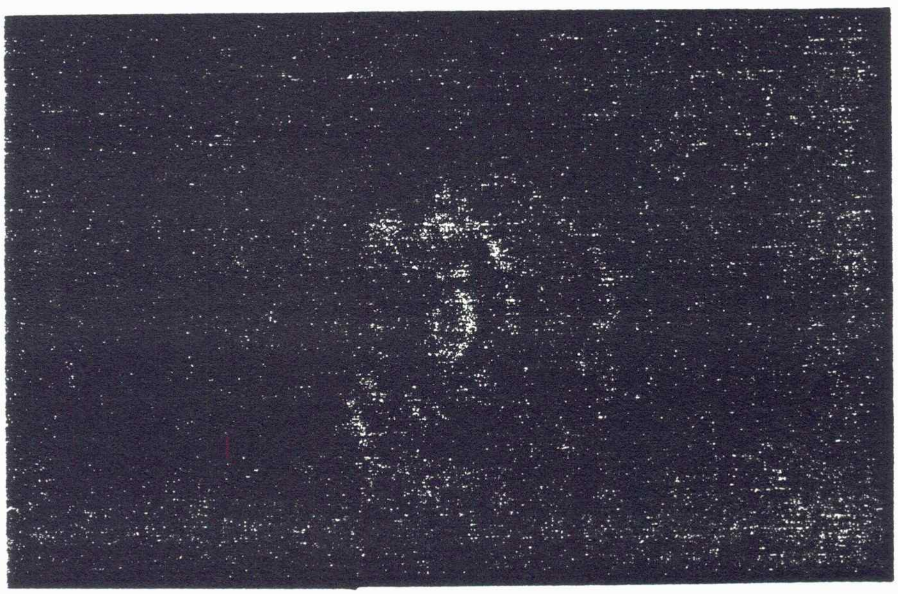


Figure 24. Glaphyrites (Eoasinites?) from the Dry Shale near Humboldt, Richardson County, Nebraska (location 6) (7 X).



In Late Paleozoic cyclothems these conditions are usually associated with the non-black facies of the offshore shales in the Heckel depositional model. Sedimentologic and paleontologic evidence from this study, however, indicates that the Dry shale was deposited in a nearshore environment. The presence of juvenile goniatites here is thus problematic (see discussion in Depositional Environments section.).

Nautiloids

Nautiloids were observed only at locality 6, near Humboldt, Nebraska. They are present in the Dry Shale, but are not nearly as abundant as the juvenile goniatites that dominate the fauna here. Nautiloids present include Pseudorthoceras sp. and others which are early stages of coiling and difficult to identify (Mapes, 1987, personal communication).

Gastropods (Fig.25)

Gastropods are rare in the lithologic units of this study. One bellerophontid gastropod was observed in the Dover limestone near Nebraska City, Nebraska (locality 1). At locality 6, near Humboldt, Nebraska, medium- to high-spired, limonitic gastropods are present in the Dry Shale. They are not nearly as abundant as the juvenile goniatites that dominate the fauna here.

Pelecypods (Fig.26)

Pelecypods were observed only at locality 6, near

Figure 25. Gastropod from the Dry Shale near Humboldt, Richardson County, Nebraska (location 6) (8 X).

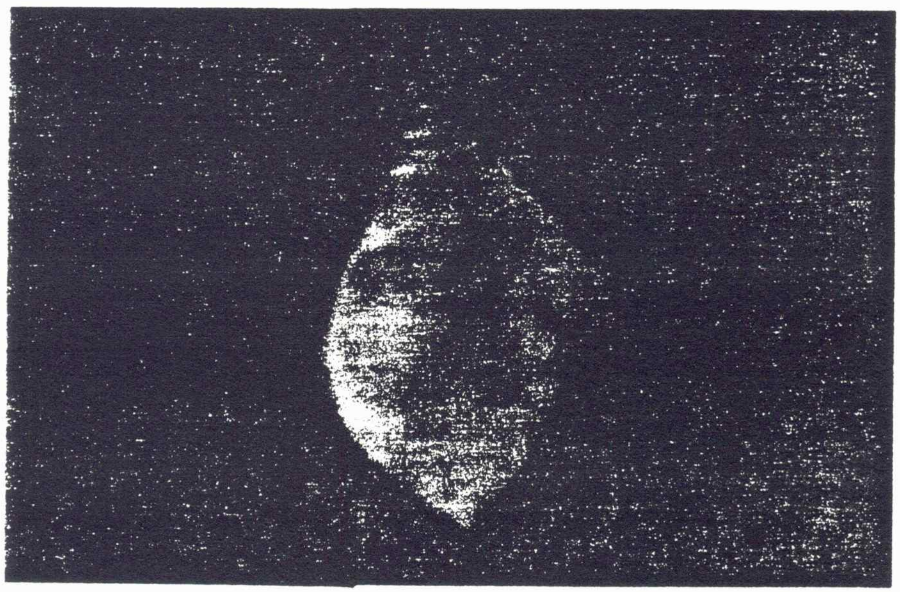
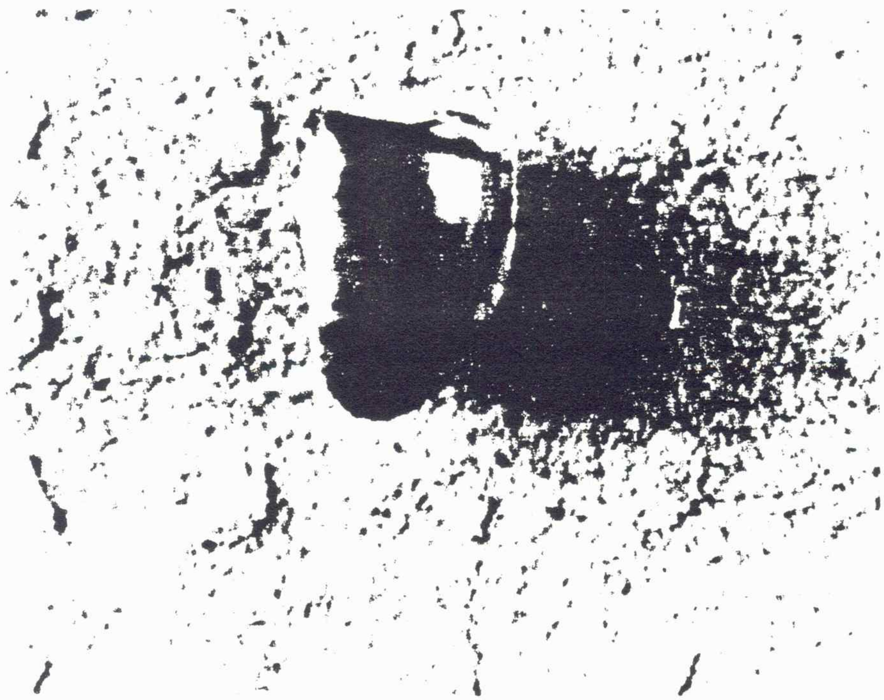


Figure 26. Pelecypod from the Dry Shale near Humboldt, Richardson County, Nebraska (location 6) (7 X).



Humboldt, Nebraska. They are present in the Dry Shale, but are not nearly as abundant as the juvenile goniatites which dominate this fauna. The pelecypods here are small, most are less than 1 inch long.

Plants (Fig.27)

Plant fossils were observed only in the Pillsbury Formation. Fossil wood was collected at location 3, near Nebraska City, Nebraska. A study of the palynoflora of these units might contribute to the understanding of their depositional environments. Financial considerations prevented such a study from contributing to this report. The Illinois Geological Survey graciously agreed to process material from the Dry Shale at location 6, near Humboldt, Nebraska for palynomorphs. Upon completion of this report, results of this study were not yet available.

Trace Fossils

Trace fossils were observed in the Grandhaven Limestone in southern Lyon County, Kansas, and in the Dry Shale near Humboldt, Nebraska (location 6). Those in the Grandhaven Limestone appear to represent feeding or locomotion traces (Fig.28), whereas those in the Dry Shale appear to represent dwelling structures (Fig.29). The traces in the Dry were not analyzed in situ at the outcrop. They were extracted from a washed bulk sample taken from this locality.

Figure 27. Plant fossil (wood) from the Pillsbury Formation near Nebraska City, Otoe County, Nebraska (location 3) (3 X).

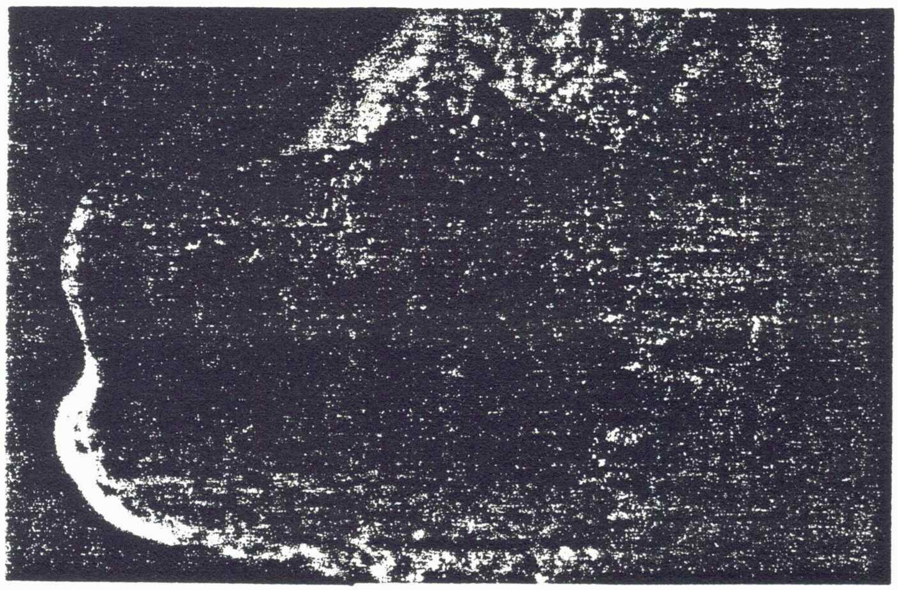


Figure 28. Trace fossils in the Grandhaven Limestone from Lyon County, Kansas (location 16).

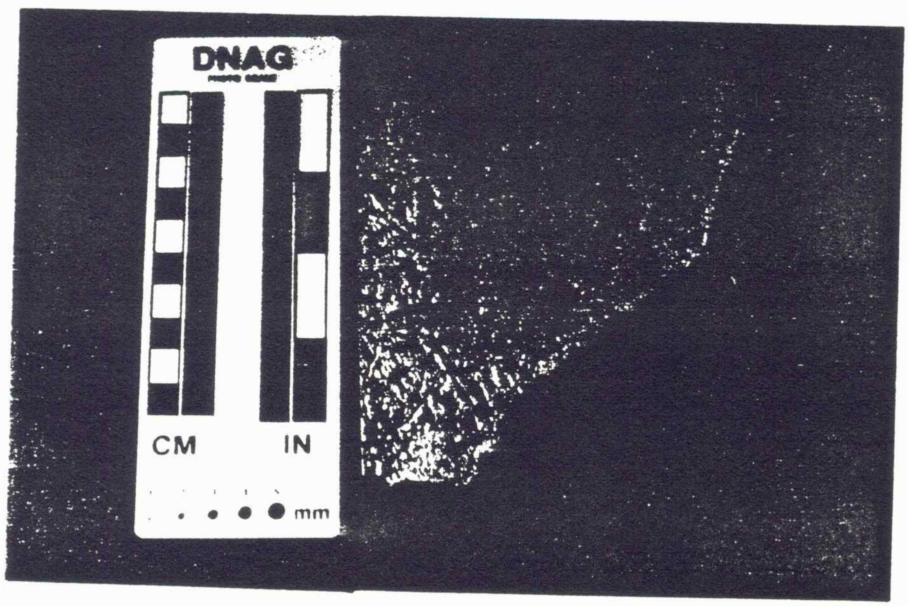
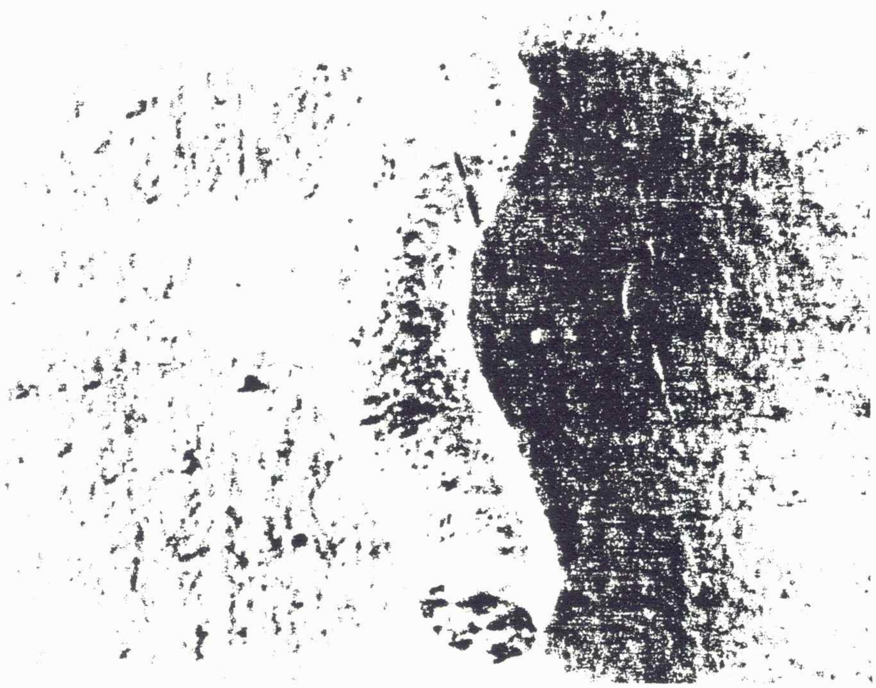

DNAG
CM
IN
mm

Figure 29. Trace fossil from the Dry Shale near Humboldt, Richardson County, Nebraska (location 6) (5 X).



Depositional Environments

Introduction

During Late Paleozoic time, the North American Midcontinent was repeatedly covered by epeiric seas. Eustatic rises and falls of sea level were responsible for the successive invasions and retreats of the sea. Water initially invaded the continent through a restricted area in southwest Texas, and spread in a northeast direction (figure 30) (Heckel, 1980). Within the study area of this report, conditions were more marine toward the south.

The most extensive Late Paleozoic transgressions took place during Missourian time, when water depth was as much as 600 feet. Transgressions during Virgilian time were not nearly so extensive, reaching a maximum water depth of approximately 150 feet (figure 31) (Heckel, 1986). The absence of black, fissile offshore shales from most Midcontinent Virgilian rocks can be attributed to the less extensive Virgil transgressions, as compared to those during Missourian time. Extensive transgressions also serve to prevent detrital influx into the basin, and allow well-developed regressive limestones to form. In the Virgilian, however, lack of extensive transgressions left the basin more susceptible to detrital influx. Thick regressive limestones are not as abundant as in the Missourian section.

Figure 30. Paleogeography of Upper Pennsylvanian Midcontinent sea during maximum transgression (Heckel, 1980).

UPPER PENNSYLVANIAN PALEOGEOGRAPHY, CENTRAL U.S.

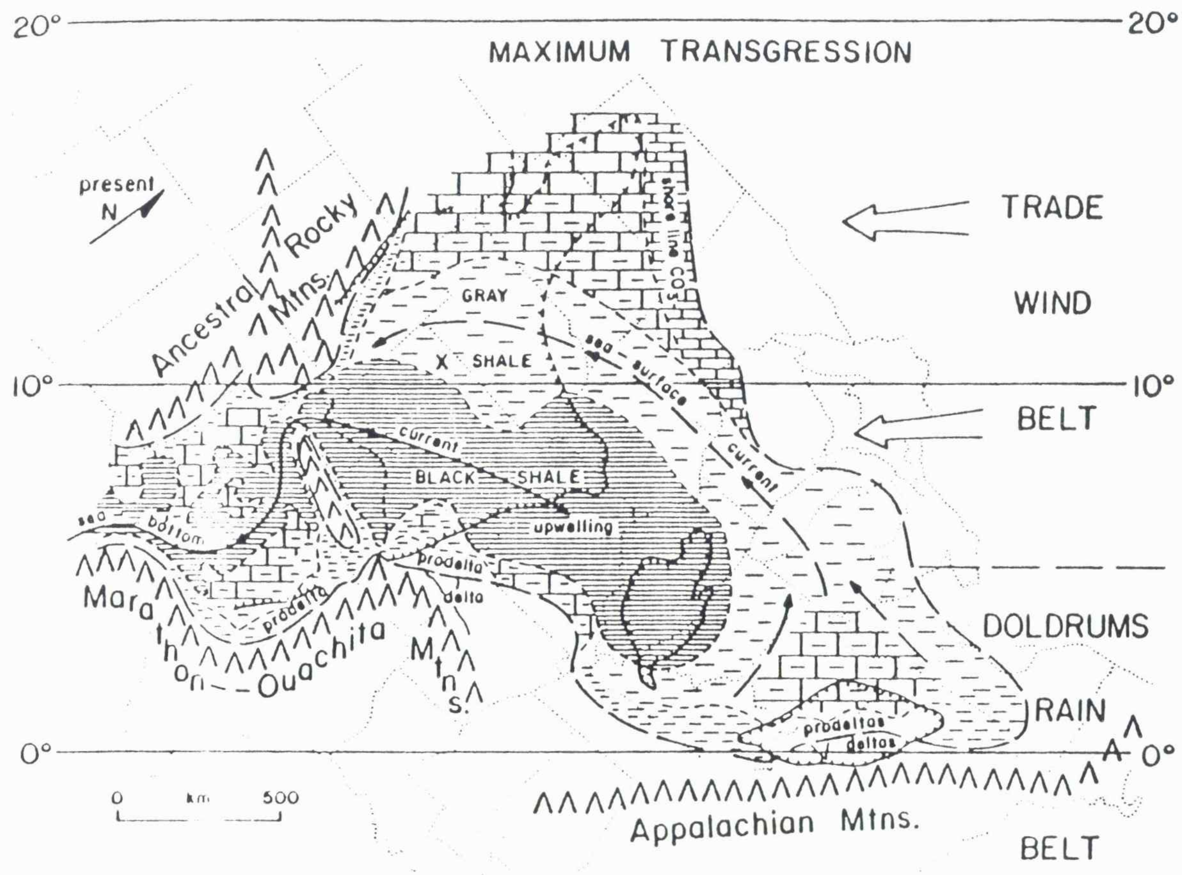
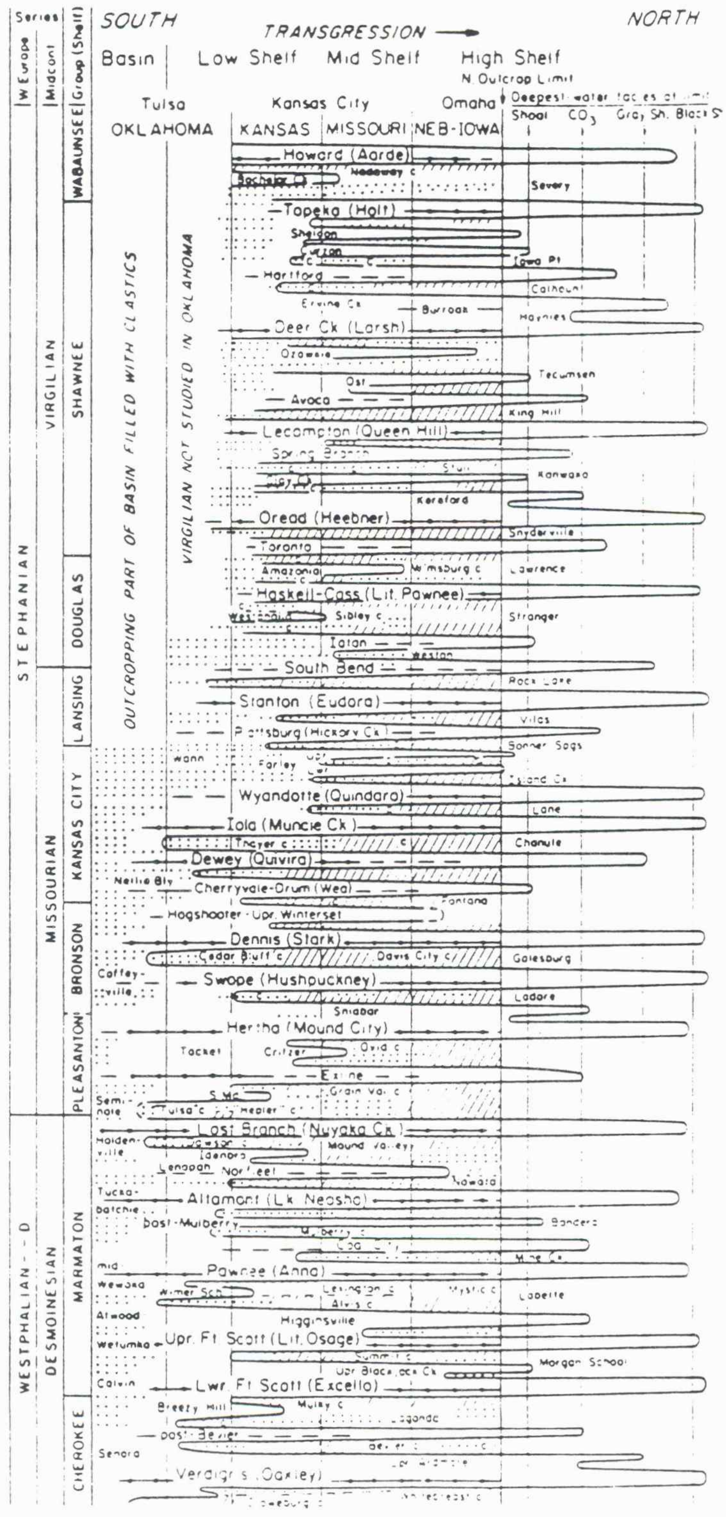


Figure 31. Sea level curve for Middle-Upper Pennsylvanian Midcontinent section (Heckel, 1986).



Series
W Europe
Midcont
Group (Shelf)
SOUTH
TRANSGRESSION
NORTH
Basin
Low Shelf
Mid Shelf
High Shelf
N. Outcrop Limit
Deepest water facies at limit
Shoal
CO_3
Gray Sh.
Tulsa
Kansas City
Omaha
OKLAHOMA
KANSAS
MISSOURI
NEB-IOWA
OUTCROPPING PART OF BASIN FILLED WITH CLASTICS
VIRGILIAN NOT STUDIED IN OKLAHOMA
WABAUNSEE
SHAWNEE
DOUGLAS
LANSING
KANSAS CITY
BRONSON
PLEASANTON
MARMATON
CHEROKEE
VIRGILIAN
MISSOURIAN
DESMOINESIAN
STEPHANIAN
WESTPHALIAN - - D
Howard (Aarde)
Severy
Topeka (Holt)
Sheldon
Iowa Pt
Hartford
Calhoun
Ervine Ck
Burroak
Haynes
Deer Ck (Larsh)
Ozawkie
Ost
Tecumseh
Avoca
King Hill
Lecompton (Queen Hill)
Spring Branch
Kanwaka
Kereford
Oread (Heebner)
Snyderville
Toronto
Amazonia
Lawrence
Haskell-Cass (Lit. Pawnee)
Sibley c
Stranger
Iatan
Weston
South Bend
Rock Lake
Stanton (Eudora)
Vilas
Plattsburg (Hickory Ck.)
Wann
Farley
Island Ck
Wyandotte (Quindaro)
Lane
Iola (Muncie Ck)
Thayer c
Chanute
Dewey (Quivira)
Nellie Bly
Cherryvale-Drum (Wea)
Fontana
Hogshooter - Upr. Winterset
Dennis (Stark)
Cedar Bluff c
Davis City c
Galesburg
Coffeyville
Swope (Hushpuckney)
Ladore
Sniabar
Hertha (Mound City)
Tacket
Critzer
Exline
Grain Valley c
Seminole
"Tulsa" c
Lost Branch (Nuyaka Ck.)
Holdenville
Mound Valley
Idenbro
Lenapah
Norfleet
Howard
Tuckabatchie
Altamont (Lk. Neosho)
post-Mulberry
Bandera
Mulberry c
Mine Ck.
Pawnee (Anna)
Wewoka
Lexington c
Labette
Atwood
Higginsville
Wetumka
Upr. Ft. Scott (Lit. Osage)
Summit c
Morgan School
Upr. Blackjack Ck
Calvin
Lwr. Ft. Scott (Excello)
Breezy Hill
Mulky c
Laganda
post-Bevier
Senora
Verdigris (Oakley)
Whitebreast c

Depositional Environments at Key Areas

Nebraska City, Nebraska (Fig.32-34)

The Pillsbury Formation is thick here (28 feet) and consists of alternating beds of shale, siltstone, and sandstone. Coal, pyrite nodules and plant fossils are also present. These are indicative of deposition in a nearshore environment, during a regression of an epeiric sea.

As sea level rose again, the Dover Limestone was deposited. The base of the Dover is a biomicrite that grades upward into a biosparite (grainstone). It is dominated by phylloid algae and algal-coated grains (Osagia?) (Fig.34). It was most likely deposited in a shallow-marine, high-energy environment. The Dover becomes less fossiliferous and more micritic toward its middle. The uppermost part of the Dover here, however, is dominated by fossil fragments and intraclasts, indicating deposition in a high-energy environment. No evidence of subaerial exposure was observed. The presence of diagenetic pyrite in the upper part of the Dover is evidence against subaerial exposure.

The Dover Limestone at Nebraska City, Nebraska, may represent a single rise and fall of sea level, or it may represent a transgressive limestone that was flooded out by detritus, before an offshore or regressive facies could develop. The top of the Dover exhibits

Figure 32. Stratigraphic section from Nebraska City, Otoe County, Nebraska (locations 1 and 2). Solid black symbol at top of Pillsbury Formation represents coal.

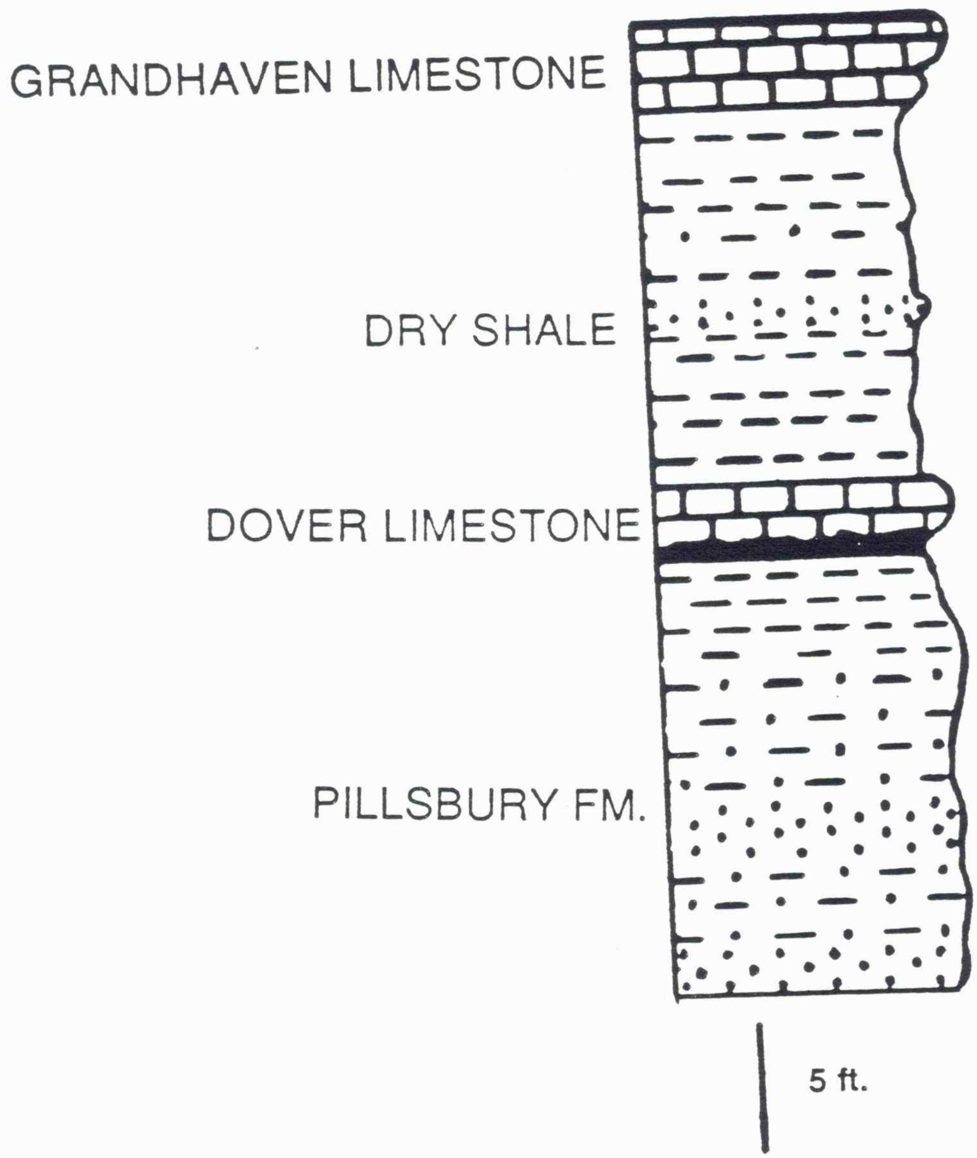

GRANDHAVEN LIMESTONE
DRY SHALE
DOVER LIMESTONE
PILLSBURY FM.
5 ft.

Figure 33. Outcrop at location 2, near Nebraska City, Otoe County, Nebraska. A = Pillsbury Formation, B = Dover Limestone, C = Dry Shale, D = Grandhaven Limestone.

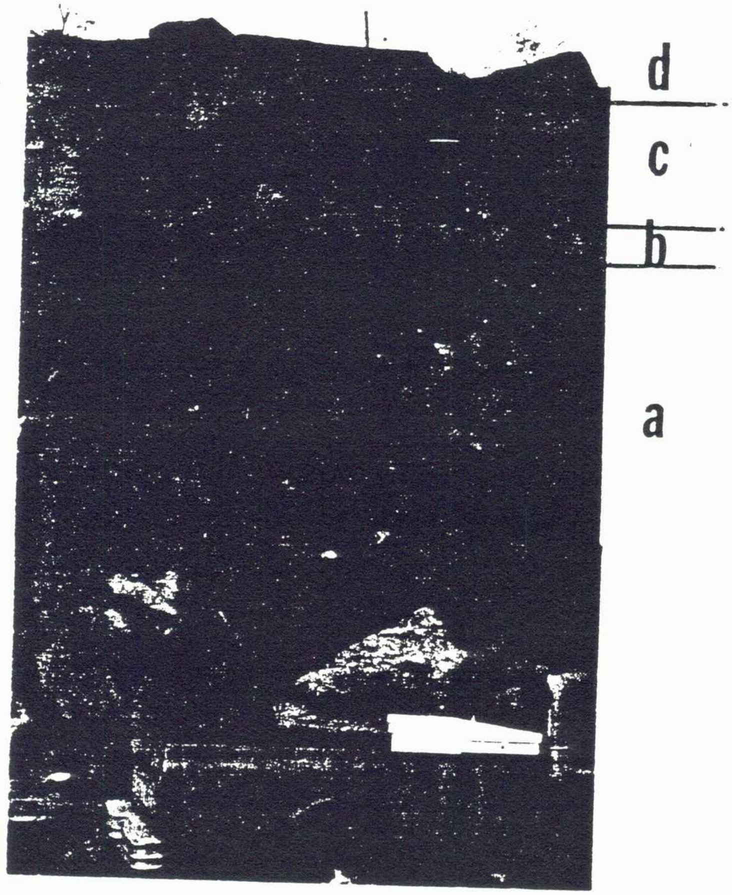
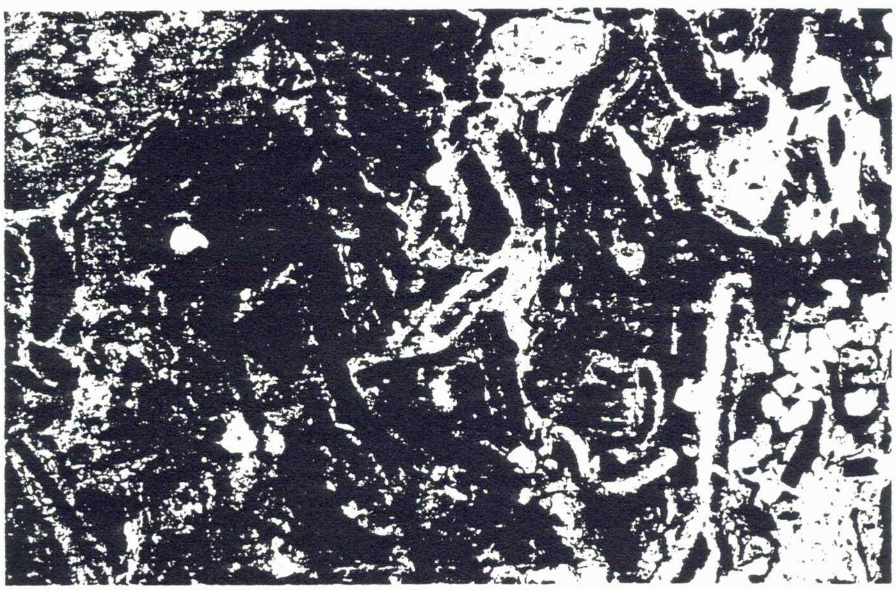

d
c
b
a

Figure 34. Photo negative print of thin section. Dover Limestone at Nebraska City, Otoe County, Nebraska (location 2). Note abundance of phylloid algae (8 X).



characteristics which could be explained by either scenario. Determining whether eustatic (allocyclic) change or detrital influx (autocyclic) was the controlling factor on carbonate deposition in the study area is difficult. Absence of an impermeable black shale in this sequence limits the applicability of Heckel's (1983) predictive diagenetic model for determining depositional environments.

The Dry Shale at Nebraska City, Nebraska is a thick (13 feet), grey, micaceous , predominantly shale and siltstone unit. There is a thin (5 inches) micaceous rich sandstone developed in this unit. No marine fossils were observed. By virtue of its vertical position in the cyclic sequence the Dry Shale should be an offshore shale, according to the Heckel depositional model. The evidence from Nebraska City, Nebraska, however, suggests that the Dry Shale was deposited in a nearshore, non-marine environment. It was deposited as relative sea level fell in the area, and carbonate deposition (Dover Limestone) ceased.

The Grandhaven Limestone is a thinly bedded intrabiosparite at its base. Several of the allochems are coated by algae. Toward the top, this unit becomes more massive and intraclasts are less abundant.

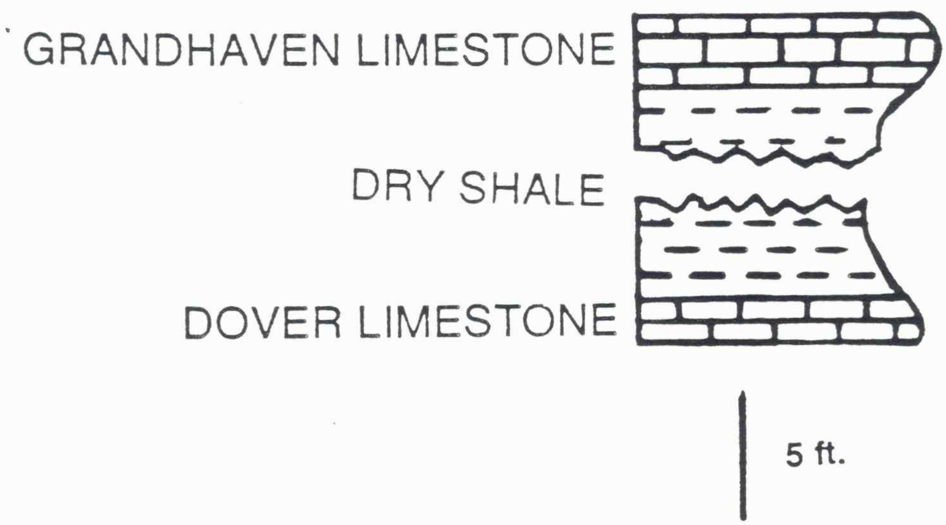
As with the Dover Limestone, it is difficult to determine whether the Grandhaven represents a single cycle of sea level rise and fall or a transgressive limestone that was flooded out by detrital influx. The more massive nature toward the top of this unit could represent deposition in a less muddy, more open marine environment than at the base. It could also be the result of some diagenetic process independent of depositional environment. No subaerial exposure features were observed in the Grandhaven here. Unfortunately, the unit which overlies the Grandhaven (Root Formation) is not exposed here. The nature of the base of this unit might supply some clues as to why carbonate deposition ceased (allocyclic vs. autocyclic).

Humboldt, Nebraska (Fig. 35)

The Dover Limestone is a thin (6 inches) coquinoid limestone. It was most likely deposited in a shallow marine, high-energy environment.

Only the base of the Dry shale is exposed here. The most striking feature of the Dry shale near Humboldt, Nebraska, is the abundance of juvenile goniatites. Location 6 (Fig.3) is the only exposure of the Dry Shale, in the study area, where these fossils were observed. A great deal of study has been devoted recently to juvenile ammonoid faunas in Late Paleozoic rocks of the Midcontinent by Boardman et al. (1984) and by Kammer et al., (1986). They proposed that faunas such as this represent mass-mortality events caused by

Figure 35. Composite stratigraphic section from Humboldt, Richardson County, Nebraska (locations 5 and 6).



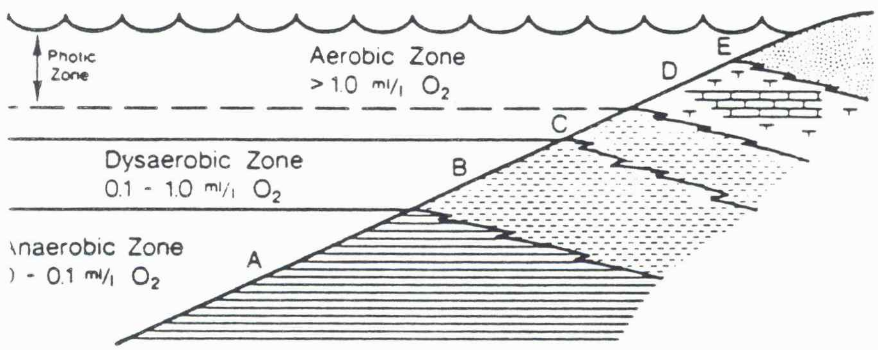
GRANDHAVEN LIMESTONE
DRY SHALE
DOVER LIMESTONE
5 ft.

fluctuations in the dysaerobic zone of the water column (figure 36). Apparently, adult forms were able to escape the rising anoxic and near-anoxic waters. No adult forms were observed in this exposure of the Dry shale.

Dysaerobic conditions usually develop in deeper parts (150 feet) of the water column. Boardman et al. (1984) demonstrated that dysaerobic faunas are usually associated with offshore shales of the Heckel depositional model. All other exposures of the Dry Shale in this study area lack evidence of dysaerobic conditions. The paleogeographic evidence does not support an offshore depositional environment for the Dry Shale here, but rather a nearshore one.

There are two possible explanations for the development of dysaerobic conditions in a nearshore environment. One is the presence of a topographic basin near Humboldt, Nebraska, that resulted in deep water conditions close to shore during transgressions. The other is the development of a restricted bay or estuary in which dysaerobic conditions could develop. Devera et al. (1987) have employed the latter scenario to explain the occurrence of juvenile ammonoid faunas from some Lower Pennsylvanian rocks in the Illinois basin. Either scenario could explain the data presently available from the Dry Shale near Humboldt, Nebraska.

Figure 36. Bio- and lithofacies in an oxygen-deficient basin. Juvenile goniatite faunas are common in Dysaerobic (B) environments (Kammer et al., 1986).


Photic Zone
Aerobic Zone
> 1.0 ml/l O2
Dysaerobic Zone
0.1 - 1.0 ml/l O2
Anaerobic Zone
0 - 0.1 ml/l O2
A
B
C
D
E

Location 5 is close to the ammonoid rich exposure of the Dry Shale at location 6 (Fig.3). At locality 6 only the base of the Dry Shale is exposed. At location 5 only the top of the Dry Shale is exposed. Figure 35 is a composite stratigraphic section from both localities. The top of the Dry shale (location 5) is a red, unfossiliferous shale. This represents detrital influx and possible subaerial exposure.

The Grandhaven Limestone at location 5 is a massive biomicrite. It is overlain by a shale (Friedrich Shale, Root Formation) which contains abundant marine fossils (brachiopods, bryozoans, crinoids). The Grandhaven Limestone here is thus a transgressive limestone deposited in a normal marine environment.

Wabaunsee County, Kansas (Fig. 37)

The Pillsbury Formation in Wabaunsee County, Kansas is predominantly siltstones and shales. No fossils were observed in this unit. Its depositional environment, similar to that at Nebraska City, Nebraska, is nearshore and non-marine. It was most likely deposited during the regression of an epeiric sea.

In Wabaunsee County, Kansas, the Dover consists of four different lithologies (in ascending order): a basal fusulinid rich limestone, massive algal limestone, marine shale, and an upper limestone (Fig.38). As relative sea level rose, Pillsbury deposition ended and

Figure 37. Stratigraphic section from Wabaunsee County, Kansas (locations 7 and 8).

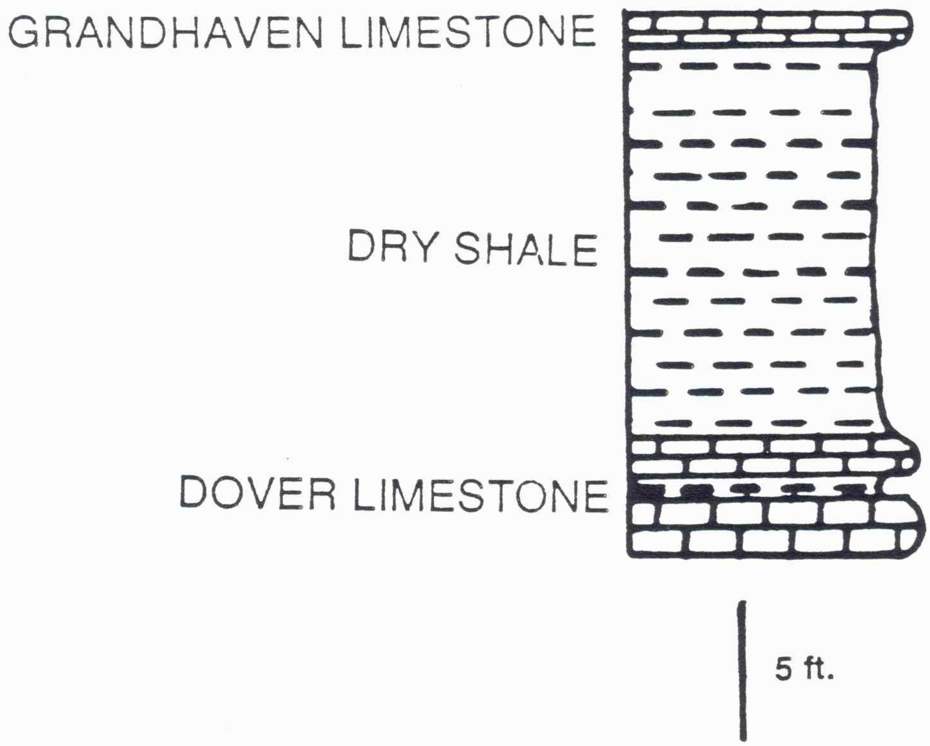
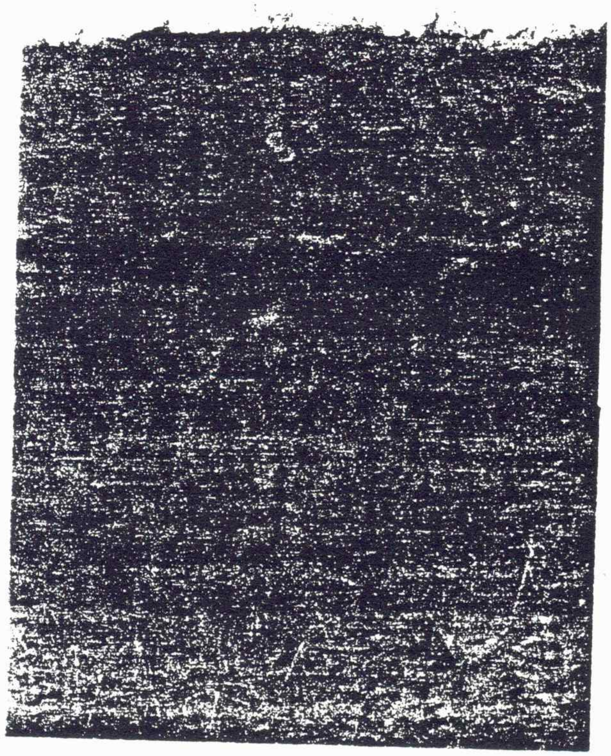

GRANDHAVEN LIMESTONE
DRY SHALE
DOVER LIMESTONE
5 ft.

Figure 38. Dover Limestone from Wabaunsee County, Kansas (location 7). Note: figures 38 and 10 are identical.



deposition of the Dover limestone began. The basal fusulinid-rich limestone (Fig.39) was deposited in a shallow, high-energy, marine environment. This basal unit grades upward into a sparsely fossiliferous micrite, indicating lower energy conditions than at the base.

The basal fusulinid rich limestone is directly overlain by a massive algal limestone (Fig.40). This was deposited in a shallow marine (within the photic zone) environment, free of detrital influx. . This massive bed becomes less algal, and other bioclasts become more abundant, toward the top. This may represent higher energy conditions at the top of this bed, than at its algal-rich base.

The massive algal limestone is overlain by a marine shale. The fauna of this shale includes bryozoans (fenestrates and rhomboporoids), productoid brachiopods, and crinoid columnals. The fenestrates in particular seem fragile and must have been deposited in a low-energy (deep-water?) environment. This shale is light olive grey. Although no black shale facies develops here, this unit may be a shallower water analogue of an offshore shale in the Heckel depositional model.

Directly overlying the marine shale is the upper limestone bed of the Dover Limestone. It is a biomicrite which becomes more fossiliferous toward its

Figure 39. Photo negative print of thin section. Basal fusulinid-rich Dover Limestone, Wabaunsee County, Kansas (location 7) (8 X).

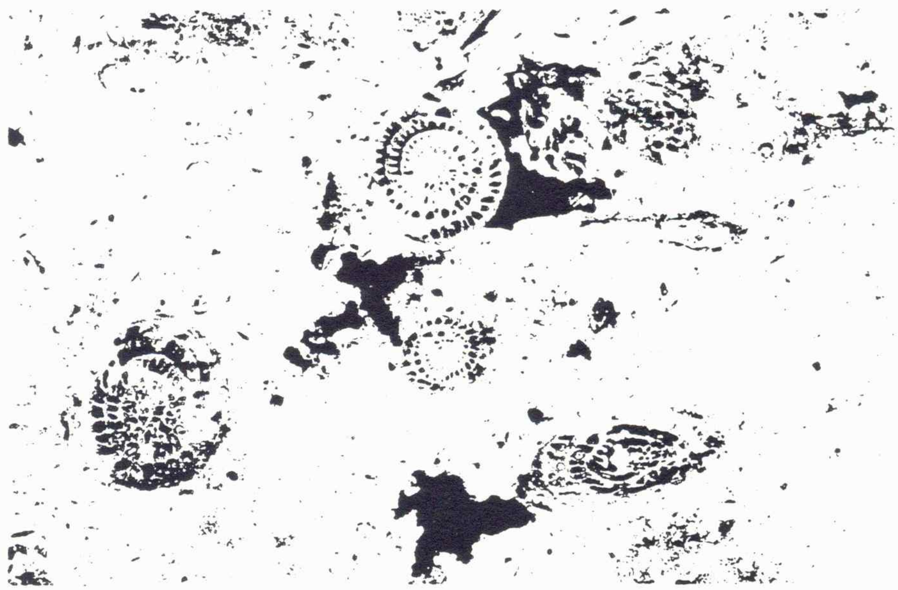
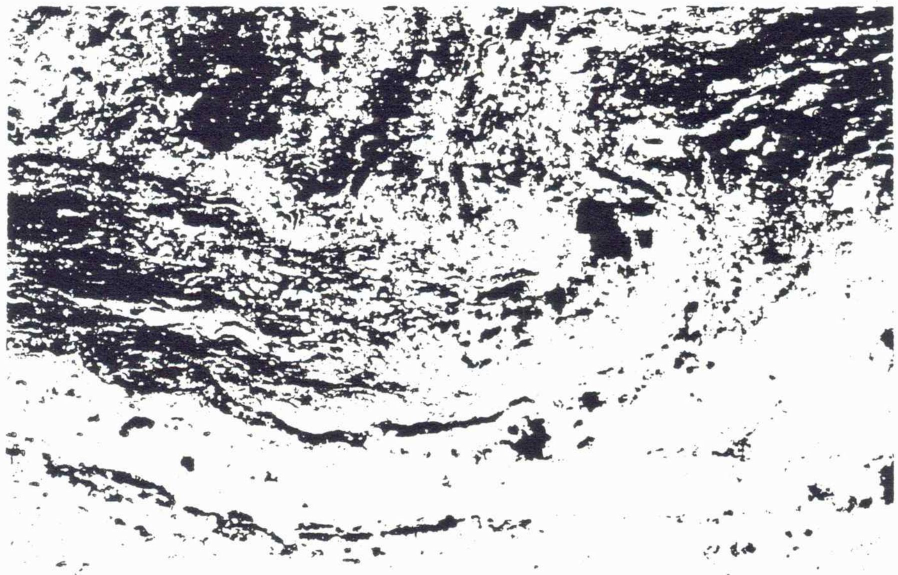


Figure 40. Photo negative print of thin section. Massive algal limestone, Wabaunsee County, Kansas (location 7) (3 X).



top (Fig.41). Algal-coated grains are present toward the top. This may represent deposition during a regression after maximum depth was reached during deposition of the marine shale. This would then be a regressive limestone.

The Dry Shale is thick (13 feet) and unfossiliferous here (Fig.42). The depositional environment of this unit is nearshore and non-marine, as at Nebraska City, Nebraska. The basal Grandhaven Limestone (Fig.43) here is a biosparite. It was deposited during a relative rise in sea level. Whether this rise was of allocyclic (eustatic) or autocyclic origin is unclear. The Grandhaven grades upward into a calcarenite. It is overlain by a calcareous, micaceous, shale that grades upward into a sandstone which indicates deposition during a regression. Mudge and Burton (1959) maintain that there is only one limestone bed in the Grandhaven in Wabaunsee County, Kansas. This is not the case to the south, in Lyon County, Kansas, where the Grandhaven is composed of two limestone beds, separated by a shale.

Lyon County Kansas(figure 44)

No exposures of the Pillsbury Formation or the Dover Limestone were located in Lyon County, Kansas. The Dry Shale here is similar to its counterpart in Wabaunsee County, Kansas (Fig.45). It is, for the most part, a non-marine shale deposited in a nearshore

Figure 41. Photo negative print of thin section. Upper Dover Limestone, Wabaunsee County (location 7) (3 X).

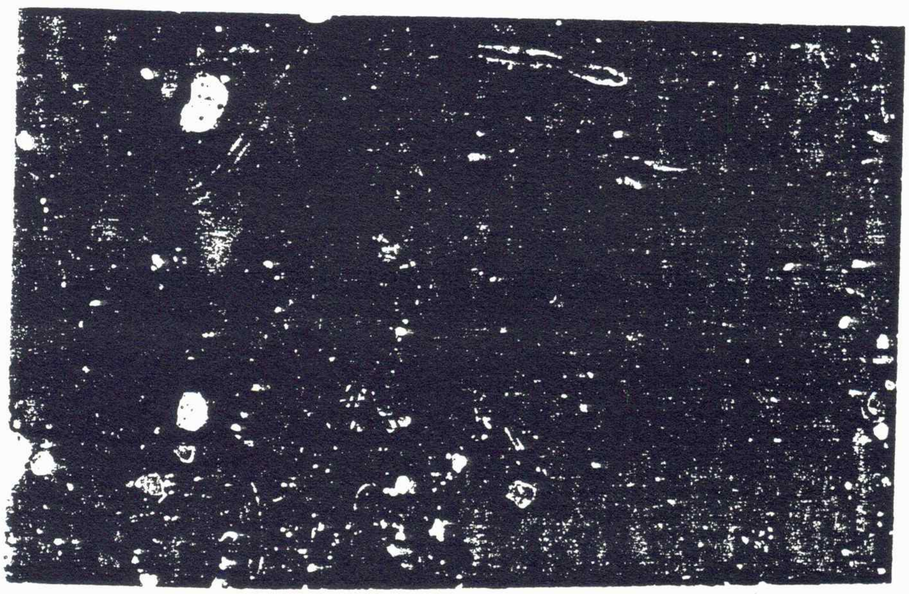


Figure 42. Exposure of the Dry Shale, Wabaunsee County, Kansas (location 7). Hat for scale. Note: figures 45 and 11 are identical.

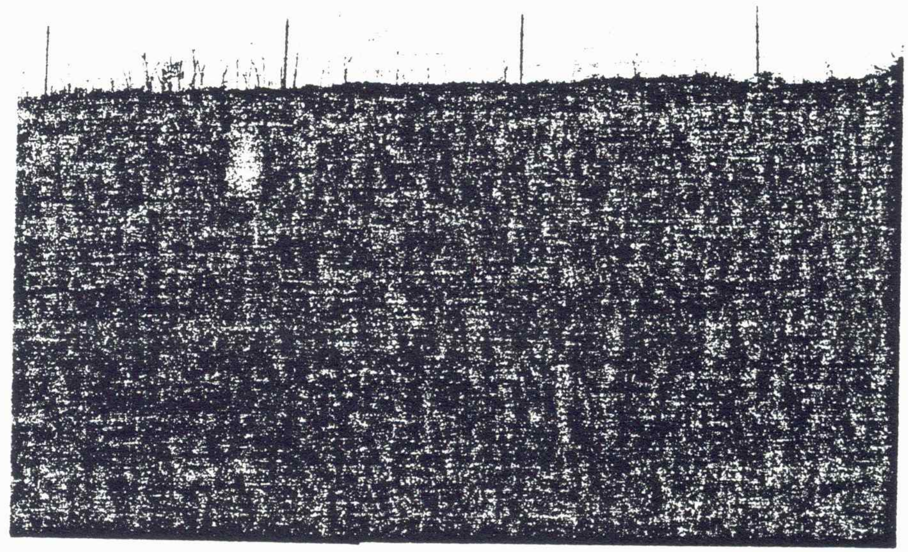


Figure 43. Exposure of the Grandhaven Limestone, Wabaunsee County, Nebraska (location 7). Hat for scale.

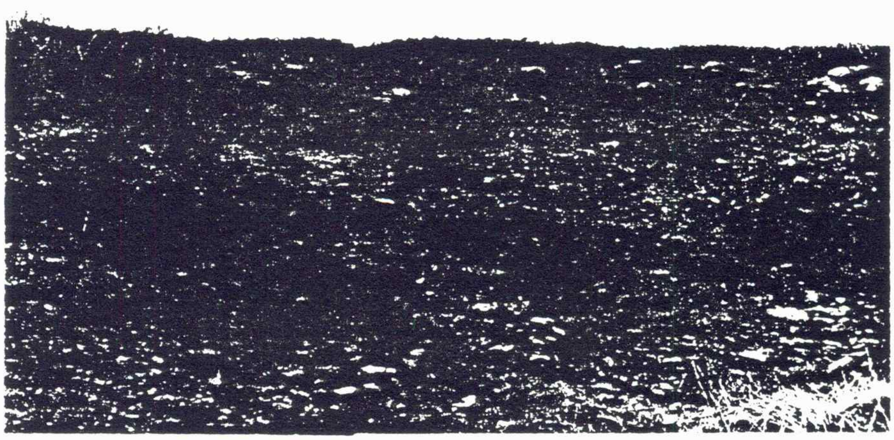


Figure 44. Composite stratigraphic section from Lyon County, Kansas.

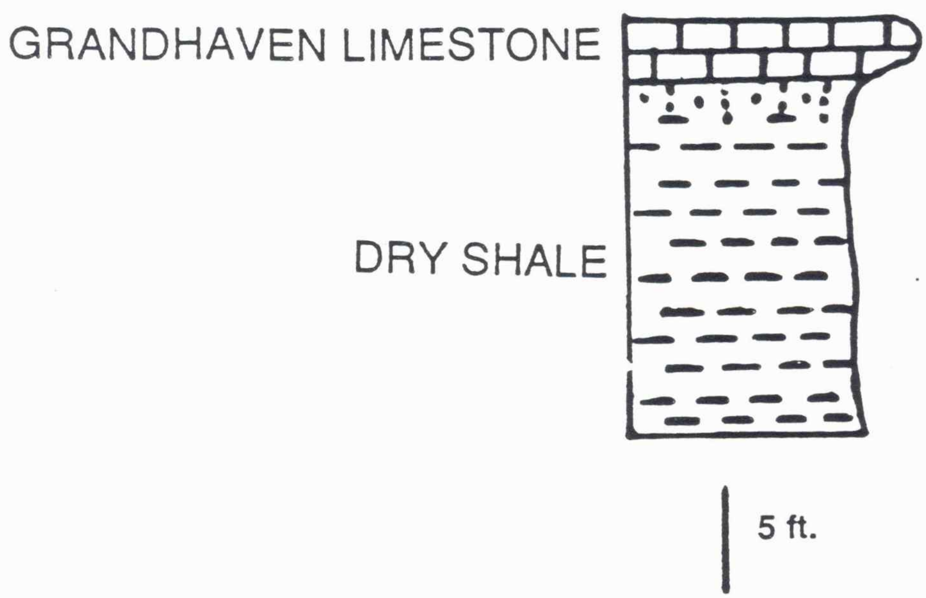
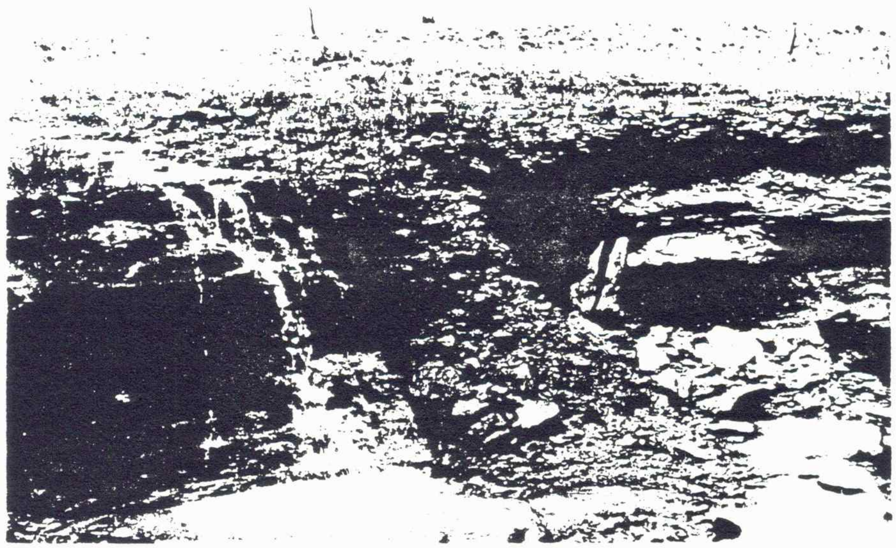

GRANDHAVEN LIMESTONE
DRY SHALE
5 ft.

Figure 45. Outcrop at location 9, Lyon County, Kansas (hat for scale). Grandhaven Limestone is at the top of the ledge, ovelying the Dry shale.



environment. In southern Lyon County, Kansas, (locations 15 and 16) chonetoid brachiopods are present in the Dry Shale. Tasch (1953) alluded to a "limestone-stringer" within this unit that contained chonetoid brachiopods. Although no "limestone-stringer" was observed here, these chonetids might represent what Tasch (1953) described. Development of the chonetoid community could be the result of a eustatic rise in sea level , a cessation in detrital influx (both resulting in more marine conditions), or these organisms may have been suited to living in a nearshore environment. It is uncertain as to which (if any) was responsible for their presence.

The top of the Dry Shale here is commonly a sandstone. This is a non-marine unit, deposited during a regression. At the Lyon County Fishing Lake (location 12) crinoid columnals and fusulinids are present within the sandy top of the Dry Shale. These fossils appear to have been weathered and may have been reworked from older sedimentary rocks.

The Grandhaven Limestone in Lyon County consists of two limestone beds separated by a shale. The limestone beds vary considerably with respect to their lithology, thickness, and fossil content. Determining the stratigraphic position of an outcrop is difficult. This study relied heavily on previously published measured sections and geologic maps (especially O'Connor, 1953).

The base of the Grandhaven is comprised of two different lithologies. In some parts of Lyon County, Kansas, it is a biomicrite (Fig. 46), in others it is a calcareous sandstone (Fig.14). These could represent different environments along the depositional strike of a single stratigraphic unit, but are more likely two different, locally developed, stratigraphic units. The biomicrite was most likely deposited under normal marine conditions, whereas the calcareous sandstone was deposited in a shallow, high energy environment.

The shale within the Grandhaven is locally thick (16 feet). The majority of it is covered by vegetation. Despite this it is reasonable to infer, because of its thickness, that it is not an offshore shale but was instead deposited in a nearshore environment (Heckel, 1980).

The upper Grandhaven Limestone bed is only locally developed. It is a fusulinid-rich biomicrite (Fig.47). Many of the bioclasts are algal-coated. This indicates deposition in a normal marine, high-energy environment.

General Depositional Model

Throughout the study area the Pillsbury Formation was deposited under nearshore, non-marine conditions (Fig.48). The Pillsbury is a regressive deposit that

Figure 46. Photo negative print of thin section. Basal Grandhaven Limestone from Lyon County, Kansas (location 11) (4 X).

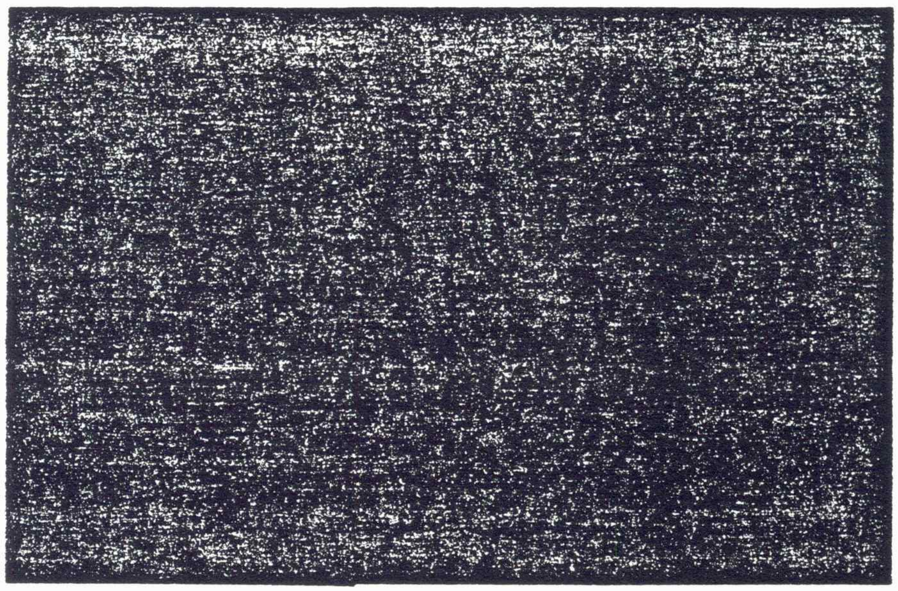
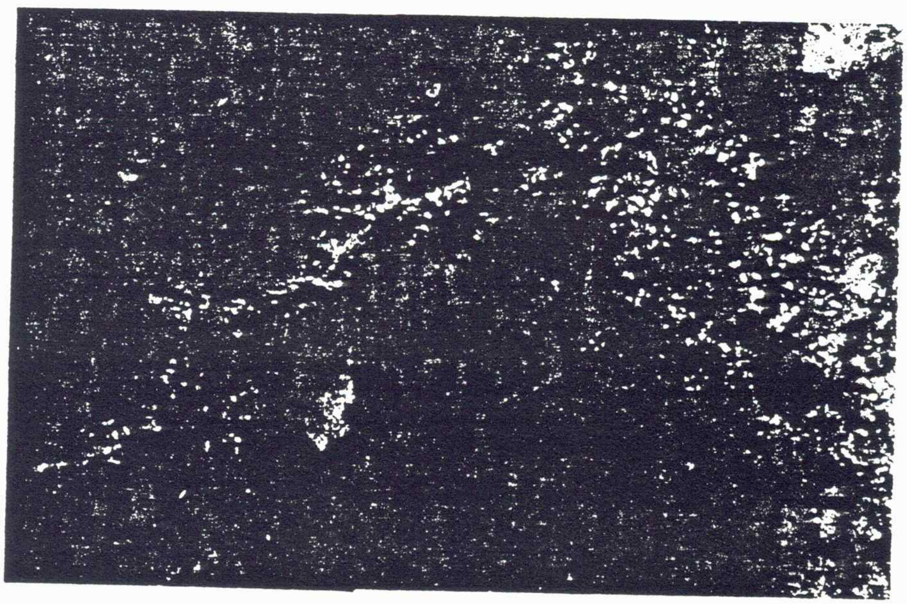
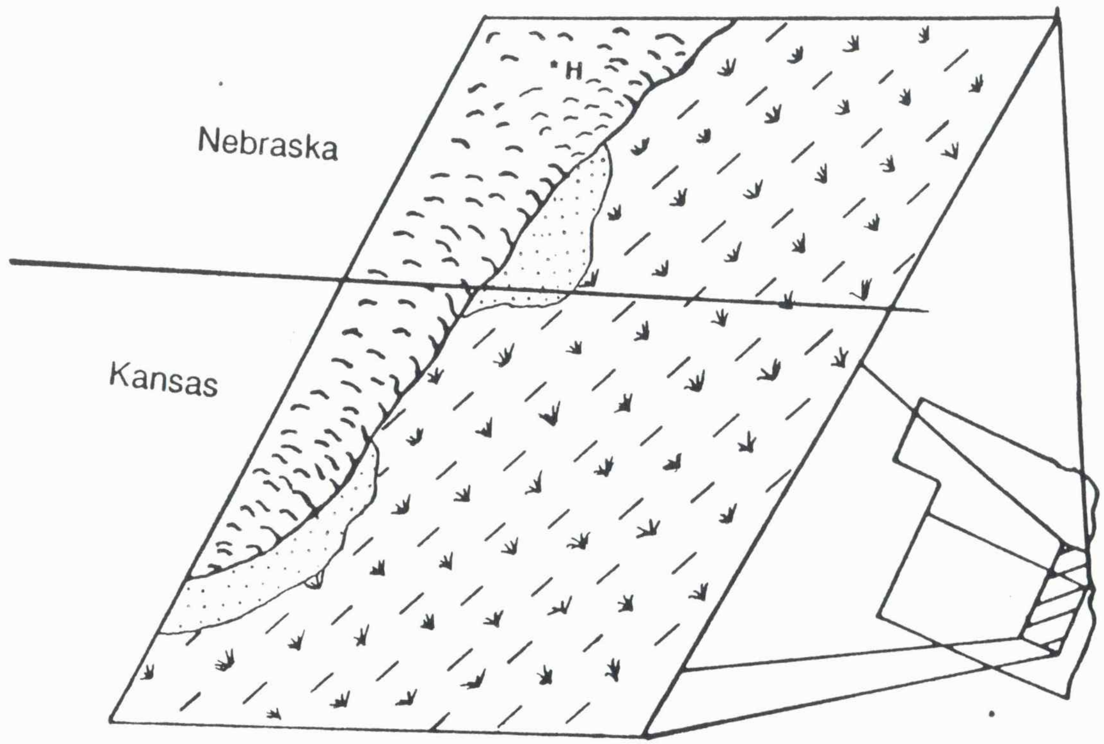


Figure 47. Photo negative print of thin section. Upper Grandhaven Limestone, Lyon County, Kansas (location 12) (4 X).



3-3

Figure 48. Schematic diagram of possible facies relationships within the study area during deposition of the Pillsbury Formation. Upper left of diagram is the land mass. *H denotes the location of Humboldt, Nebraska. Dotted pattern represents nearshore, sandy environment. Dash-and-frond pattern represents deposition of nearshore, non-marine shales.



Nebraska
Kansas
H

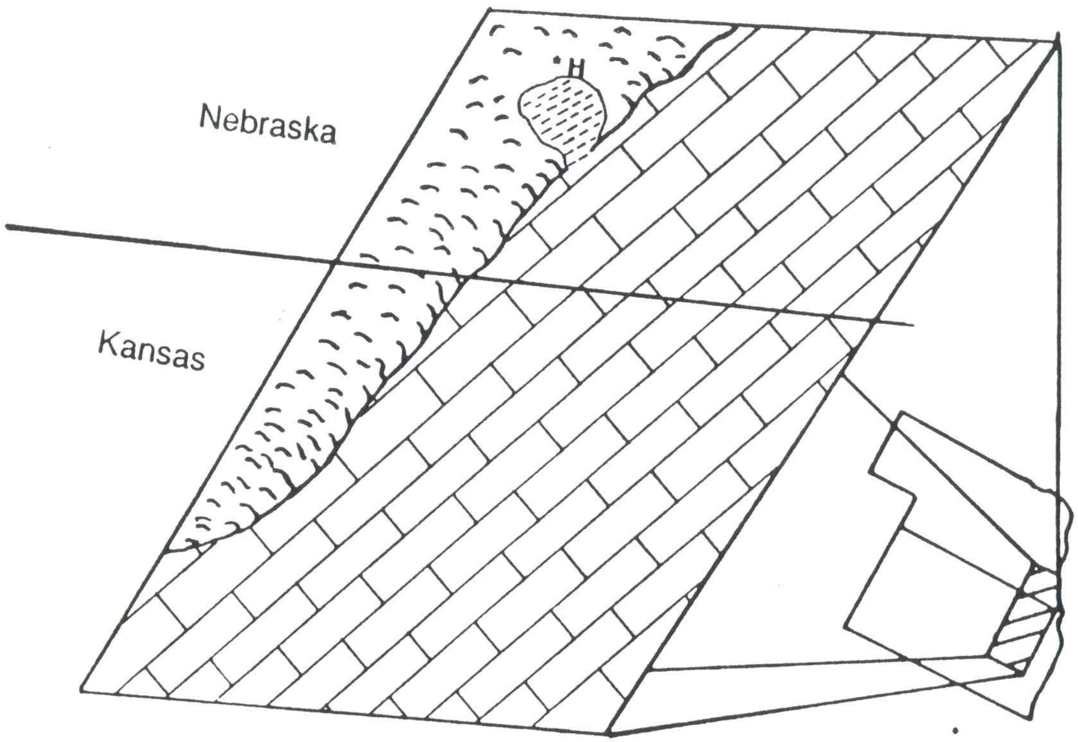
formed during a eustatic fall in sea level.

As eustatic sea level rose again, deposition of the Dover Limestone was initiated (Fig.49). Near Humboldt, Nebraska, dysaerobic conditions developed either in a bay or topographic basin, and the basal Dry Shale, with a well-developed juvenile goniatite fauna, was deposited. Near Nebraska City, Nebraska, the Dover Limestone is composed of only one limestone bed, the base of which was deposited during this transgression. In Wabaunsee County, Kansas, however, the Dover is composed of two limestone beds separated by a shale. The lower limestone and the shale may be analogues of transgressive limestones and offshore shales, respectively. Both were deposited during this transgression.

Sea level eventually began to fall again. Shallow water, higher energy conditions are recorded in the top of the Dover Limestone near Nebraska City, Nebraska. Here, the Dover Limestone was deposited by a single rise and fall of sea level. It does not appear to be a transgressive limestone that was flooded out by detrital influx, as was proposed by Shields (1987a, 1987b). The Dry Shale was deposited in a nearshore environment as sea level continued to fall (Fig.50).

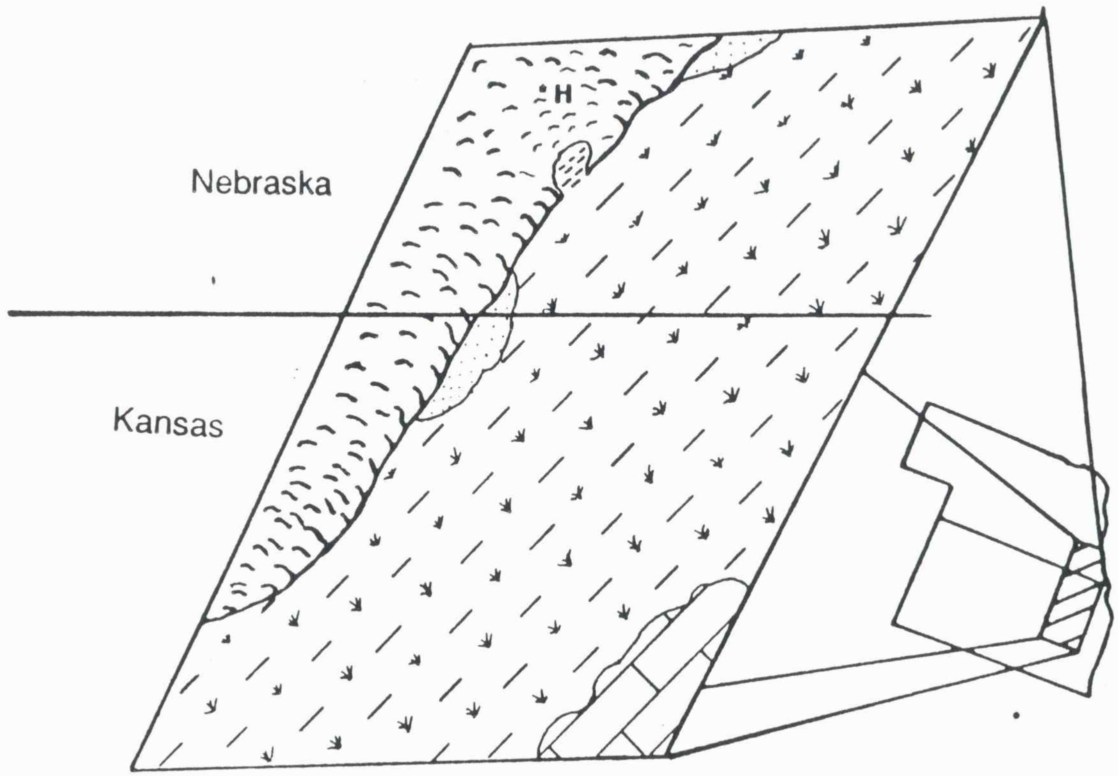
Near Humboldt, Nebraska, this regression is recorded by the red, unfossiliferous shale at the top of

Figure 49. Schematic diagram of possible facies relationships within the study area during deposition of the Dover Limestone and of the Dry Shale near Humboldt, Nebraska (*H). Block pattern represents marine carbonate depostion (Dover Limestone). Dashed pattern represents deposition of the Dry Shale near Humboldt (location of juvenile goniatite fauna).



Nebraska
H
Kansas

Figure 50. Schematic diagram of possible facies relationships within the study area during deposition of the Dry Shale. Carbonate depostion in the southeast represents a regressive limestone phase of the Dover Limestone.



Nebraska
H
Kansas

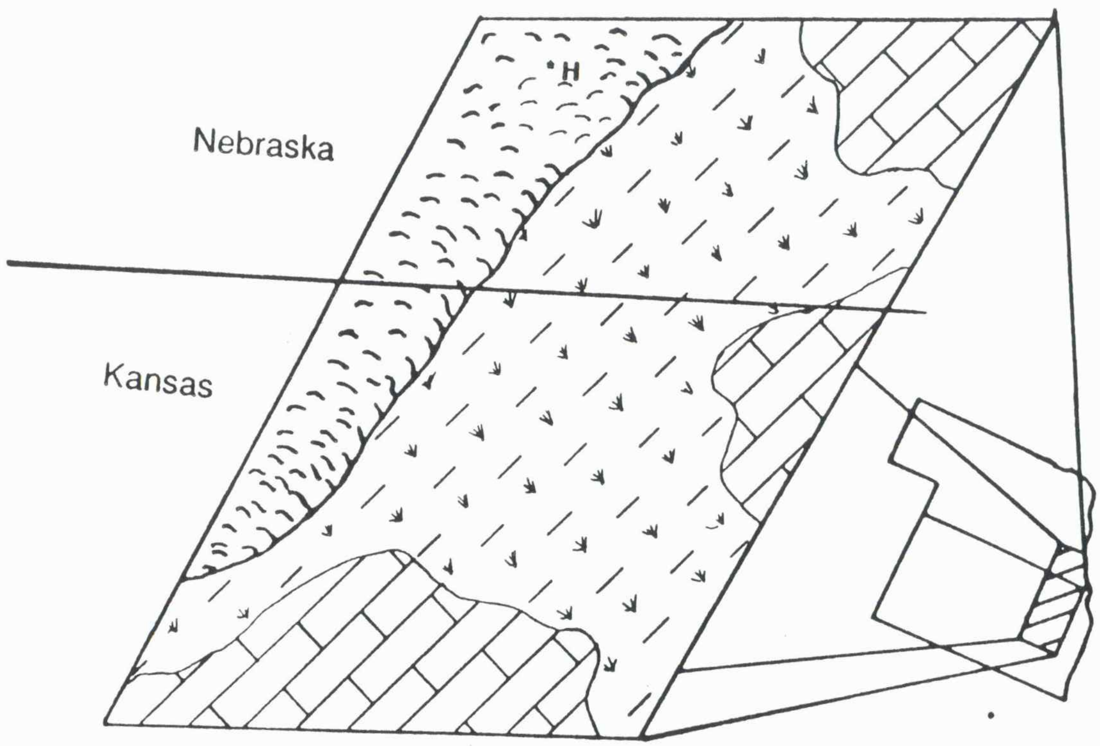
the Dry Shale. This unit records detrital influx (into the bay or topographic basin) and possible subaerial exposure. In Wabaunsee County, Kansas, the upper limestone bed in the Dover Limestone is a regressive limestone. As regression continued here, the Dry Shale was deposited.

As relative sea level rose once again (Fig.51), deposition of the Grandhaven Limestone began. The Grandhaven is a variable unit which is composed of different lithologies that are separate, geographically restricted stratigraphic units. The Grandhaven Limestones in the northern (Nebraska) and southern (Kansas) parts of the study area are not equivalent stratigraphic units (Condra, 1949). This lithologic variability suggests that the Grandhaven was not deposited by a single, widespread eustatic (allocyclic) rise of sea level. It appears instead that varying rates of detrital influx (autocyclic) at different places in the study area had a greater influence on sedimentation than eustatic changes in sea level.

Unanswered Questions

Several aspects of the depositional environments are, at this time, difficult to explain. Whether single limestone beds represent cycles of relative sea level rise <u>and</u> fall or were deposited as sea level rose <u>or</u> fell (the transgressive and regressive limestones of the Heckel depositional model) is uncertain. Shields

Figure 51. Schematic diagram of possible facies relationships within the study during deposition of the Grandhaven Limestone. Note the geographic restriction of carbonate deposition.


Nebraska
Kansas
H

(1987a, 1987b) suggested that the Dover and Grandhaven limestones were both transgressive limestones and that detrital influx inhibited the formation of regressive limestones. This claim may have been premature, as some evidence does exist, especially in the Dover, that single limestone beds record cycles of sea level rise and fall. Moore (1936, 1950, 1964) maintained that each limestone bed represented a sea level rise and fall. Many factors besides depositional environment can affect the lithology of carbonates and it is difficult to determine whether allocyclic or autocyclic factors were the dominant control on carbonate sedimentation.

Muscovite mica is present in all four lithologic units. It is especially abundant in the Dry Shale and Pillsbury Formation. Although a provenance study is not within the scope of this report, it would be interesting to know the origin of the muscovite. It would certainly add some insight to the paleogeography of the Midcontinent during Virgilian time.

The depositional environment of the Dry Shale near Humboldt, Nebraska, is also problematic. This unit has a well-developed juvenile goniatite fauna which is indicative of dysaerobic water conditions. In the Late Paleozoic Midcontinent seas dysaerobic conditions developed offshore, in water depths of approximately 150 feet (Boardman et al., 1984). Evidence from other localities indicates that the Dry Sshale was deposited in a nearshore environment and that an offshore depositional environment would be inconsistent with the paleogeography of the area. Development of geographically restricted, nearshore, dysaerobic conditions can be explained by at least two scenarios. One is that this area was a topographic basin in which deeper water conditions developed close to the paleoshoreline. The other is that this area was a shallow water bay and dysaerobic conditions developed because it was a stagnant water body. Devera et al. (1987) described a similar situation in the Lower Pennsylvanian of the Illinois Basin.

Juvenile ammonoids from the Dry Shale in an area to the south of the study area have been described by Tasch (1953). It appears that Tasch concentrated his study on the paleontology of this unit, paying little heed to unfossiliferous exposures of the Dry shale. He thus gave the impression that juvenile ammonoids are common along the depositional strike of this unit. This may not be the case. His fossiliferous localities could be geographically restricted, much like the localities near Humboldt, Nebraska discussed in this report (location 6). If this interpretation of Tasch's (1953) study is correct, it would seem far more plausible that there would be a series of shallow water bays along the paleoshoreline than a series of topographic basins with deeper water. The presence of structural features near

Humboldt, Nebraska, however, does not allow complete rejection of the topographic, deeper water basin scenario.

Conclusions

1. The Pillsbury Formation was deposited in a nearshore, shallow water, non-marine environment.

2. The Dover Limestone was deposited in a normal marine environment. At Nebraska City, Nebraska, it is a single bed of limestone that appears to represent a single rise and fall of sea level. In Wabaunsee County, Kansas, this unit includes two limestone beds separated by a shale. The lithologies here appear to be analogues of Heckel's (1980) transgressive limestone, offshore shale, and regressive limestone (in ascending order). Eustatic (allocyclic) processes were more influential in the deposition of this unit than were autocyclic processes such as detrital influx.

3. The Dry Shale was deposited in a nearshore, shallow water, dominantly non-marine environment. Near Humboldt, Nebraska the Dry shale contains a well-developed juvenile ammonoid fauna, indicative of dysaerobic conditions. These dysaerobic conditions were geographically restricted and probably occurred in shallow water bays. The possibility of dysaerobic conditions in a deeper water, nearshore, topographic basin near Humboldt, Nebraska cannot be ruled out, however.

4. The Grandhaven Limestone is composed of various geographically restricted lithologies. It was deposited

in a shallow marine environment that was subjected to detrital influx. Unlike the situation with the Dover Limestone, autocyclic processes were dominant over allocyclic (eustatic) ones in the deposition of the Grandhaven Limestone.

5. Deviation from the Heckel depositional model by this Virgilian cyclic sequence is due to the more extensive transgressions recorded in the Missourian rocks upon which Heckel based his model. The less extensive nature of the Virgilian transgressions inhibited formation of offshore shales and left the basin more prone to detrital influx.

6. Determining whether autocyclic or allocyclic conditions were dominant factors controlling deposition of carbonates, determining the origin of muscovite mica in these rocks, and determining whether the Dry Shale near Humboldt, Nebraska, was deposited under deep or shallow water dysaerobic conditions are all problems concerning the depositional environments of this cyclic sequence that cannot be answered with complete certainty at this point.

7. Exposures of these units are few and far between. Stratigraphic correlation from outcrop to outcrop is challenging at best. This must be kept under consideration with respect to the conclusions of this study. It is suggested that future studies of Virgilian

rocks in this area utilize as much subsurface data as is possible.

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Appendix

Measured Sections

Location #1

Western Brick and Supply Co. quarry, 1.5 miles south of Nebraska City, SW1/4 SE1/4 SW1/4 sec. 10, T8N, R14E, Otoe Co., NE (section also in Burchett and Reed (1967).

Rock Unit	Description	Thickness (inches)
Stotler Formation		
Grandhaven Limestone Member		
13	Limestone, grey(5n5) fresh, brownish weathered, fossils, limonite vugs (?), irregular base	12
Dry Shale Member		
12	Siltstones and shales, micaceous, somewhat fissile	70
11	Shale, grey(6N6), micaceous, fissile, pyrite nodules, irregular base	27
10	Sandstone, calcareous, micaceous, three 2 inch beds seperated by stringers of micaceous shale, irregular base	6
9	Shale, dark(4N4), micaceous, becomes darker and less massive toward top	16
8	Slumped/bench	39
Dover Limestone Member		
7	Limestone, grey(4N4), fossils (molluscs, crinoids, bryozoans, brachiopods, irregular contact at base	15
Pillsbury Formation		
6	Shale, with increasingly sandy layers and darkness (organic content) toward top, micaceous	195
5	Shale (coal?), dark(2N2), organic rich,	

micaceous, plant fossils(?)...............6

4 Alternating layers of sandstone (very fine grained,micaceous, calcareous) and shale (grey, laminated, micaceous, most abundant in mid-unit), calcarenite lens at top..............................41

3 Sandstone, light olive brown (5Y 5/6)fine grained, micaceous..................................5

2 Shale, dark with light brown laminations, micaceous....................(measured) 14

1 Slumped material..............................207

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base of pit

Location #2

Roadcut 1.75 miles south of Nebraska City, SW1/4 SW1/4 SE1/4 sec. 10, T8N, R14E Otoe Co., NE, under new bridge being constructed.

Rock Unit	Description	Thickness (inches)
Stotler Formation		
Grandhaven Limestone Member		
16	Limestone, dusky yellow (5 Y 6/4), fossils (bryozoans), massive	19
15	Limestone, medium grey (5N5), thinly bedded, limonite casts, fossils (brachiopods)	20
Dry Shale Member		
14	Shale, medium light grey (6N6), well bedded micaceous, red staining along some partings	42
13	Siltstone, light olive grey (5 Y 5/2), finely laminated, micaceous	7
12	Shale, medium light grey (6N6), laminated in places, micaceous	38
11	Limestone, medium light grey (6N6), micaceous, three seperate beds	5
10	Shale, medium grey (5N5), finely laminated (light laminations)	5
9	Shale, light grey (7N7), slightly bedded (fissile), micaceous, calcareous	44
8	Shale, light olive grey (5 Y 5/2), micaceous, limonite staining(??)	24
Dover Limestone Member		
7	Limestone, calcarenite, brown, weathers medium dark grey (4N4), fossils (brachiopods, bryozoans, crinoids), irregular base	28

Pillsbury Formation

6 Shale, greyish black (2N2), coal (??)..........2

5 Alternating layers of shale (grey),
siltstone (grey, some calcareous),
and sandstone (fine grained, some
calcarenite, grey and brown), micaceous
throughout.............................183

4 Sandstone, light olive brown (5 Y 5/6), fine
grained, micaceous......................21

3 Siltstone, medium grey (5N5), micaceous........2

2 Sandstone, light olive brown (5 Y 5/6),
fine grained, micaceous......(measured)..15

1 Slumped material.............................170

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present road level

Location #3

Nebco clay pit, 2 miles south of Nebraska City, NW1/4 NW1/4 NW1/4 sec. 15, T8N, R14E, Otoe Co., NE.

Rock Unit	Description	Thickness (inches)
Pillsbury Formation		
7	Shale, light olive grey (5y 5/2) colored, non-laminated micaceous, fossils (molluscs)...	138
6	Shale, dark grey(4N4), laminations, micaceous, with silty layers...	6
5	Sandstone, light olive grey(5y 5/2), very fine grained...	41
4	Shale, dark grey (4N4), laminated, pyrite nodules, micaceous...	99
3	Calcarenite, with shale at base (dark, fissile, micaceous), irregular base (soft sediment deformation??)...	24
2	Shale, dark grey (4N4), slightly fissile, micaceous...	36
1	Slumped material...	243

Location #4

Roadcut 0.75 miles southwest of Humboldt, NE1/4 SE1/4 SE1/4 Sec.4, T2N, R13E, Richardson Co., NE.

Rock Unit	Description	Thickness (inches)
Root Formation		
3	Limestone, light olive grey (5 Y 5/2), cross bedding present, slumped and may not be in situ	18
2	Shale, dark yellowish orange (10 YR 6/6), mostly slumped	47
Stotler Formation Grandhaven Limestone Member		
1	Limestone, dusky yellow (5 Y 6/4), thinly bedded, fossils (brachiopods, bryozoa)	9

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present road level

Location #5

Roadcut 6.5 miles south of Humboldt, W1/2 SW1/4 NW1/4 Sec. 10, T1N, R13E, Richardson Co., NE.

Rock Unit	Description	Thickness (inches)
Root Formation		
6	Limestone, medium grey (5N5), fossils (brachiopods)	5
5	Shale, medium dark grey (4N4), somewhat fissile, calcareous	15
4	Shale, red	57
3	Shale, brown	12
Stotler Formation		
Grandhaven Limestone Member		
2	Limestone, moderate yellowish brown (10 YR 5/4), cavities, limonite infilling of vugs, fossils (brachiopods, bryozoans, molluscs)	27
Dry Shale Member		
1	Shale, brown, reddish toward top, slumped and covered	80 (measured)

Location #6

Roadcut on Highway 8, 6.75 miles south (Highway 105) and 2.5 miles west (Highway 8) of Humboldt, SE1/4 SW1/4 NE1/4 sec. 18, T1N, R13E, Richardson Co., NE.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Dry Shale Member		
2	Shale, yellow grey(5Y 7/2), limonitic concretions and fossils (juvenile ammonoids, nautiloids, gastropods, and pelecypods)	70
Dover Limestone Member		
1	Limestone, medium grey(5N5), fossils (brachiopods, nautiloids and fossil fragments)	6

Location #7

Roaducut 3.5 miles south of Maple Hill, SW1/4 SW1/4 NW1/4 sec.6, T12S, R13E, Wabaunsee County, Kansas.

Rock Unit	Description	Thickness (inches)
Stotler Formation		
Grandhaven Limestone Member		
7	Limestone, mottled, weathers into small blocks	14
Dry Shale Member		
6	Shale, light olive grey, (5 Y 6/1), micaceous, fossils (?)	124
5	Shale, medium light grey (6N6), finely laminated, micaceous toward the top	69
Dover Limestone Member		
4	Limestone, light olive brown (5 Y 5/6), thinly bedded with beds becoming thicker towards the top, fossil fragments	16
3	Shale, light olive grey (5 Y 6/1), micaceous, calcareous, clayey, fossils (brachiopods)	11
2	Limestone, mottled (brownish-grey), fossils (crinoids, fusulinids)	24
1	Covered by vegetation	266

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level of bridge on road

Location #8

Roadcut of exit 341 of I-70 4 miles southeast of Maple Hill, SW1/4 SE1/4 SW1/4 sec. 30, T11S, R13E, Wabaunsee Co., Kansas.

Rock Unit	Description	Thickness (inches)
Root Formation		
13	Sandstone, calcareous, dusky yellow (5 Y 6/4) but mottled, thinly bedded, ledge former	12
12	Shale, clayey, calcareous	20
Stotler Formation		
Grandhaven Limestone Member		
11	Limestone, brown and red patches, thinly bedded	17
Dry Shale Member		
10	Shale, light olive grey (5 Y 5/2), fissile, micaceous, some calcareous layers present	138
9	Shale, dark grey (3N3) to medium dark grey (4N4), lighter color towards top, fissile	49
Dover Limestone Member		
8	Limestone, medium light grey (6N6), thinly bedded, fossil fragments	30
7	Shale, grey (mottled), calcareous	6
6	Limestone, brown (mottled), massive, variable thickness, fossils (crinoids, fusulinids)	29
5	Limestone, light olive grey (5 Y 6/1), thinly bedded, fossils (fusulinids abundant)	12
4	Siltstone, light olive grey (5 Y 6/1), micaceous, sandy layers in parts	70
Pillsbury Formation		

3 Sandstone, moderate yellowish brown (10 YR 5/4), micaceous, very thinly bedded....................................15

2 Alternating beds of shale, siltstone, and sandstone, many different colors, micaceous throughout.........(measured).276

1 Slumped material..............................207

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level of road cutting under I-70.

Location #9

Pond spillway at the intersection of Highway 56 and Kansas Turnpike, 3.5 miles northwest of Miller, SW1/4 SW1/4 SE1/4 sec. 13, T16S, R12E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Formation		
Grandhaven Limestone Member		
5	Limestone, dusky yellow (5 Y 6/4), thinly bedded, thickness varies..........	35
Dry Shale Member		
4	Sandstone, light olive brown (5Y 5/6), with orange speckles (limonite?), fine grained, calcarous................................	30
3	Lens of limestone, light grey (7N7), massive..................................	16max.
2	Sandstone, light olive brown (5 Y 5/6), micaceous, limonite concretions..........	25
1	Shale, medium grey (5N5), calcareous (some interbedded calcarenite), fissile........	29 (meas.)

level of pool at base of waterfall

Location #10

Roadcut 4 miles south of Admire, SW1/4 SW1/4 SE1/4 sec. 34, T16S, R12E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation Grandhaven Limestone Member		
2	Limestone, light olive grey (5 Y 5/2), thinly bedded at base, massive at top, irregular basal contact..................	33
Dry Shale Member		
1	Siltstone, light olive brown (5 Y 5/6), micaceous; becoming more massive, sandier, and having more concretions toward the top; concretions are calcareous...................(measured).	83

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level of ditch along road

Location #11

Roadcut 6 miles southeast of Admire, SE1/4 SW1/4 SW1/4 Sec.2, T17S, R12E, Lyon Co., Ks.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Grandhaven Limestone Member		
3	Limestone, light grey (7N7) and mottled fresh, weathers brown, thinly bedded, more massive toward top	25
Dry Shale Member		
2	Sandstone, dark yellowish orange (10 YR 6/6), very fine grained, micaceous, calcareous, concretions present, badly weathered (measured)	7
1	Slumped material	50

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present road level

Location #12

Exposure at Lyon County fishing lake, SW1/4 NE1/4 NE1/4 sec.34, T17S, R12E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Grandhaven Limestone Member		
4	Limestone, light grey, massive, fossils (crinoids, fusulinids (?))	8
3	Bench, everything covered	199
2	Limestone, light olive grey (5 Y 5/2), patches of grey also, thinly bedded, fossils (brachiopods)	19
Dry Shale Member		
1	Siltstone, yellowish grey (5 Y 7/2), calcareous, micaceous, somewhat fissile, becomes sandier and more massive toward the top, concretions in upper part of unit	(measured) 60

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present lake level

Location #13

Roadcut 7.5 miles northeast of Emporia,E1/2 NE1/4 SE1/4 Sec.24, T18S, R11E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Grandhaven Limestone Member		
1	Limestone, greyish orange (10 YR 7/4), fossils abundant, massive................	15

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road level

Location #14

Roadcut 3.75 miles south of Emporia, W1/2 NW1/4 sec.33, T19S, R11E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Grandhaven Limestone Member		
4	Limestone, dusky yellow (5 Y 6/4), with light grey (7N7) patches, fossils (crinoids)	15
Dry Shale Member		
3	Slumped and overgrown by vegetation	186
2	Shale, medium grey (5N5), slightly micaceous, calcareous at base only, becomes more fissile toward top (measured)	174
1	Slumped material with blocks of limestone in float	75

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present level of Dry Creek

Location #15

Roadcut 4.5 miles south of Olpe, NW1/4 NE1/4 NE1/4 Sec.27, T21S, R11E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Formation		
Grandhaven Limestone Member		
3	Limestone, dusky yellow (5 Y 6/4), calcarenite, micaceous, contact with underlying unit is covered	33
Dry Shale Member		
2	Siltstone, light olive brown (5 Y 5/6), very micaceous (measured)	54
1	Slumped material	65

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road level

Location #16

Roadcut 5 miles south of Olpe, N1/2 NW1/4 NW1/4 sec.28, T21S, R11E, Lyon Co., KS.

Rock Unit	Description	Thickness (inches)
Stotler Limestone Formation		
Grandhaven Limestone Member		
4	Limestone, perhaps not in situ, fossils (brachiopods, burrows(?))	4
Dry Shale Member		
3	Shale, brown, with some calcareous layers toward top	93
2	Hard layer, calcareous, very dusky red (10 R 2/2)	1
1	Shale, medium grey (5N5), slightly fissile, micaceous, calcareous (measured)	75

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level of ditch along road