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DEPOSITIONAL AND DIAGENETIC STUDY OF THE LENAPAH LIMESTONE (MARMATON GROUP, LATE MIDDLE PENNSYLVANIAN), IN EASTERN KANSAS AND WESTERN MISSOURI

by

Helene Greenberg

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Geology
in the Graduate College of
the University of Iowa

May, 1986

Thesis supervisor: Professor Philip H. Heckel

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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Helene Greenberg

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Geology at the May, 1986 graduation.

Thesis committee: _____
Thesis supervisor

_____
Member

_____
Member

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ABSTRACT

The Lenapah Limestone (upper Marmaton Group, Desmoinesian, Middle Pennsylvanian) crops out in eastern Kansas, western Missouri and extends into the subsurface in southern Iowa. In its type area near the Kansas-Oklahoma border, the Lenapah comprises three members, in ascending order: 1) Norfleet Limestone, 2) Perry Farm Shale, 3) Idenbro Limestone.

Variable lithologies and poor exposure northward have resulted in miscorrelation with the newly proposed overlying Mound Valley Shale and Lost Branch Formation. The Norfleet thins northward and is laterally extensive, extending into Clarke County, Iowa, whereas the Idenbro Member pinches out in Linn County, Kansas.

Petrographically, the Norfleet consists of five facies: 1) skeletal calcarenite, 2) sandy skeletal calcarenite, 3) skeletal calcilutite, 4) algal-coated calcarenite, and 5) shale. The Perry Farm Shale can be divided into two facies: 1) shale with limestone nodules to the south, and 2) shale and sandstone facies to the north. The Idenbro consists of skeletal calcilutite overlain by a skeletal calcarenite.

Conodont abundance in the Lenapah is relatively low, compared to other Midcontinent cyclothems. It is dominated by the genera Neognathodus, Adetognathus, and Anchignathodus, with rare Idiognathodus, and it lacks the offshore genera, Gondolella and Idioprioniodus.

The Lenapah represents two intermediate to minor eustatic transgressive-regressive cycles. The offshore calcarenites, calcilutites and shale facies of the lower Norfleet, dominated by Neognathodus, were deposited during maximum transgression of the first cycle. The main calcarenitic ledge of the upper Norfleet, dominated by Adetognathus, represents the early regressive phase. The Perry Farm, which consists of deltaic and prodeltaic facies, represents the late regressive phase. Both facies of the Idenbro represent the second transgressive-regressive phase.

Diagenetically, the overcompacted offshore calcarenites of the lower Norfleet, display evidence of movement from the marine phreatic zone into the deeper burial connate environment. The loosely packed calcarenites of the upper Norfleet display leached aragonite grains, extensive echinoderm overgrowths, and nonferroan blocky calcite void-filling cement, suggesting movement from the marine phreatic into meteoric phreatic environment. The late stage ferroan carbonate cement indicates movement back into the deeper burial connate zone.

The lower and upper Idenbro units contain irregular void areas strongly affected by meteoric leaching, which reflects meteoric influence from the overlying regressive Mound Valley Formation.

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INTRODUCTION

The Midcontinent Pennsylvanian succession consists of alternating thin, laterally extensive limestone and shale units. Each limestone formation generally is 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 alterations of shale and limestone to a periodic transgression and regression of the sea resulting from glaciation in Gondwanaland. Heckel (1977,1980,1984) provided stratigraphic evidence that supports this hypothesis, and he developed a model for depositional interpretation of a Kansas cyclothem, which incorporates distribution of conodont genera. The basic cycle currently recognized has in ascending order: 1)thick, nearshore to non-marine "outside" shale; 2)thin, transgressive "middle" limestone, typically a skeletal calcilutite; 3)thin, non-sandy offshore "core" shale; commonly with a black phosphatic facies and abundant conodonts; 4)thick regressive "upper" limestone, typically a skeletal calcilutite grading upward into a skeletal calcarenite; and 5)thick, sandy nearshore shale, like unit one. Heckel (1977) suggested that the outside shale of a

cycle was deposited during the time of greatest regression, whereas the black phosphatic facies within the core shale (formed in anoxic bottom water below a circulation-restricting thermocline) was deposited during the time of greatest transgression (Figure 1).

This sequence characterizes a complete cycle in which all units were developed and preserved. Heckel (1984) suggested that the petrology and conodont faunas of corresponding units in a thinner, incomplete cycle should be reasonably similar to that of a complete cycle. Thus, one should be able to determine whether a limestone is transgressive or regressive by using the combination of petrographic criteria and conodont sequences. Several intervals in the Pennsylvanian sequence do not contain all units of a complete cycle, particularly those that lack the offshore black phosphatic shale unit. The Lenapah Formation, a part of the Marmaton Group, Desmoinesian (Late Middle Pennsylvanian) in age, and studied by Parkinson (1982) in the Kansas-Oklahoma border area, is one of these sequences that lacks the black phosphatic shale unit (Figure 2).

Figure 1. Basic eustatic depositional model of a "Kansas cyclothem". Shows positional members, depositional interpretation, and gross distribution of fossil groups (from Heckel, 1977, Fig. 2).

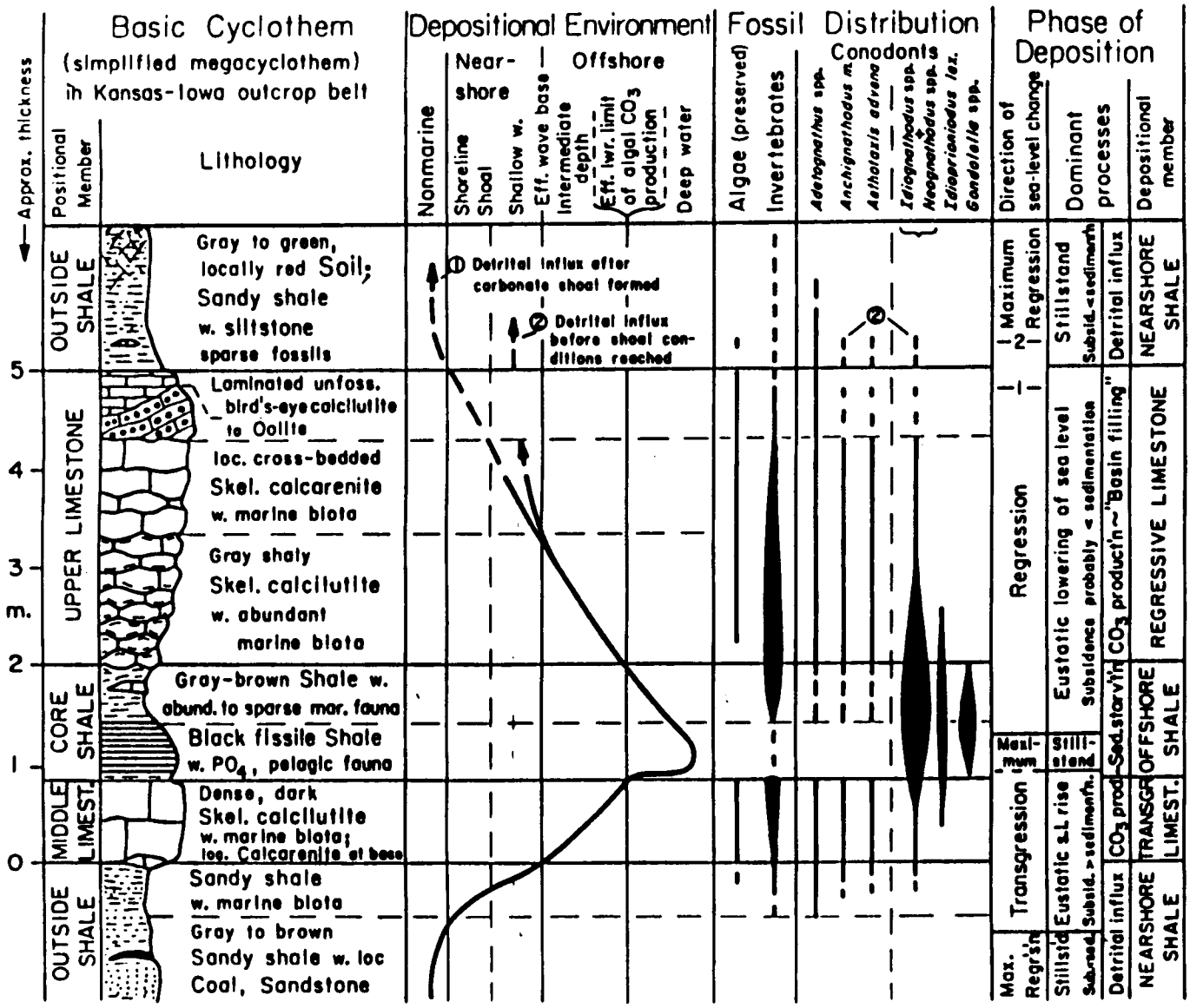
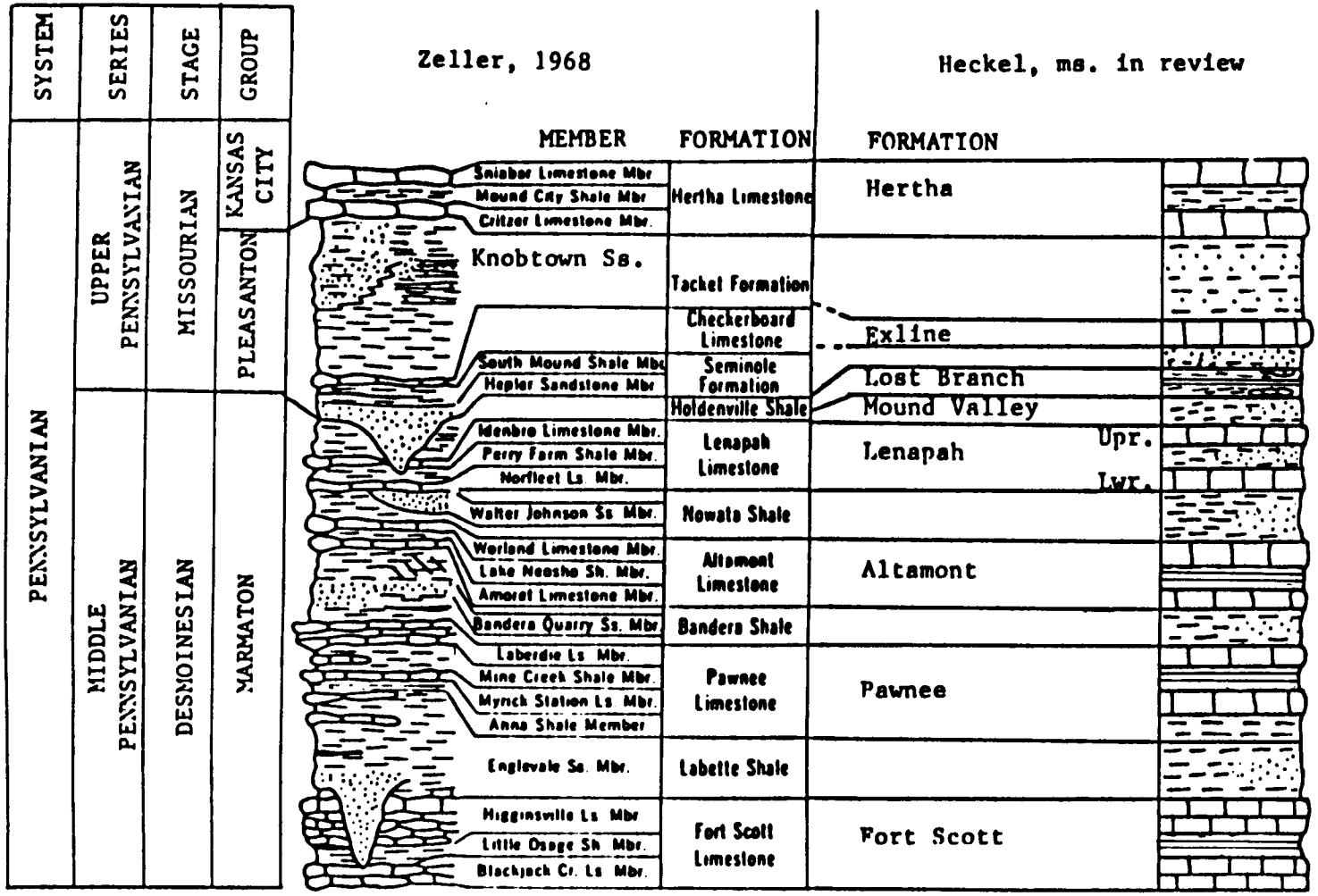

Basic Cyclothem
(simplified megacyclothem)
in Kansas-Iowa outcrop belt
Depositional Environment
Fossil Distribution
Phase of Deposition
Approx. thickness
m.
Positional Member
Lithology
Nonmarine
Near-shore
Offshore
Shoreline
Shoal
Shallow w.
Eff. wave base
Intermediate depth
Eff. lwr. limit of algal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

Figure 2. Middle Pennsylvanian Midcontinent stratigraphic column. Shows stratigraphic position of Lenapah Formation within upper part of Marmaton Group and suggested new nomenclature replacing old nomenclature (Zeller, 1968; Heckel, manuscript in review).


SYSTEM
SERIES
STAGE
GROUP
PENNSYLVANIAN
UPPER PENNSYLVANIAN
MIDDLE PENNSYLVANIAN
MISSOURIAN
DESMOINESIAN
KANSAS CITY
PLEASANTON
MARMATON
Zeller, 1968
MEMBER
FORMATION
Sniabar Limestone Mbr.
Mound City Shale Mbr.
Critzer Limestone Mbr.
Hertha Limestone
Knobtown Ss.
Tacket Formation
Checkerboard Limestone
South Mound Shale Mbr.
Hepler Sandstone Mbr.
Seminole Formation
Holdenville Shale
Idenbro Limestone Mbr.
Perry Farm Shale Mbr.
Norfleet Ls. Mbr.
Lenapah Limestone
Walter Johnson Ss. Mbr.
Nowata Shale
Worland Limestone Mbr.
Lake Neosho Sh. Mbr.
Amoret Limestone Mbr.
Altamont Limestone
Bandera Quarry Ss. Mbr.
Bandera Shale
Laberdie Ls. Mbr.
Mine Creek Shale Mbr.
Mynch Station Ls. Mbr.
Anna Shale Member
Pawnee Limestone
Englevale Ss. Mbr.
Labette Shale
Higginsville Ls. Mbr.
Little Osage Sh. Mbr.
Blackjack Cr. Ls. Mbr.
Fort Scott Limestone
Heckel, ms. in review
FORMATION
Hertha
Exline
Lost Branch
Mound Valley
Lenapah
Upr.
Lwr.
Altamont
Pawnee
Fort Scott

PURPOSE OF STUDY

The purpose of this investigation was: 1)to describe in detail the stratigraphy and petrology of the Lenapah Limestone north of Parkinson's (1982) study area, in eastern Kansas, western Missouri and in cores from northwestern Missouri and southern Iowa; 2)to determine the lateral extent of members of the formation, trying to correct miscorrelations, using both petrographic characteristics and conodont faunas; and 3)to determine the depositional and diagenetic environment of the formation, applying both depositional and diagenetic models of Heckel (1977, 1980, 1983) and Longman (1980).

METHOD OF STUDY

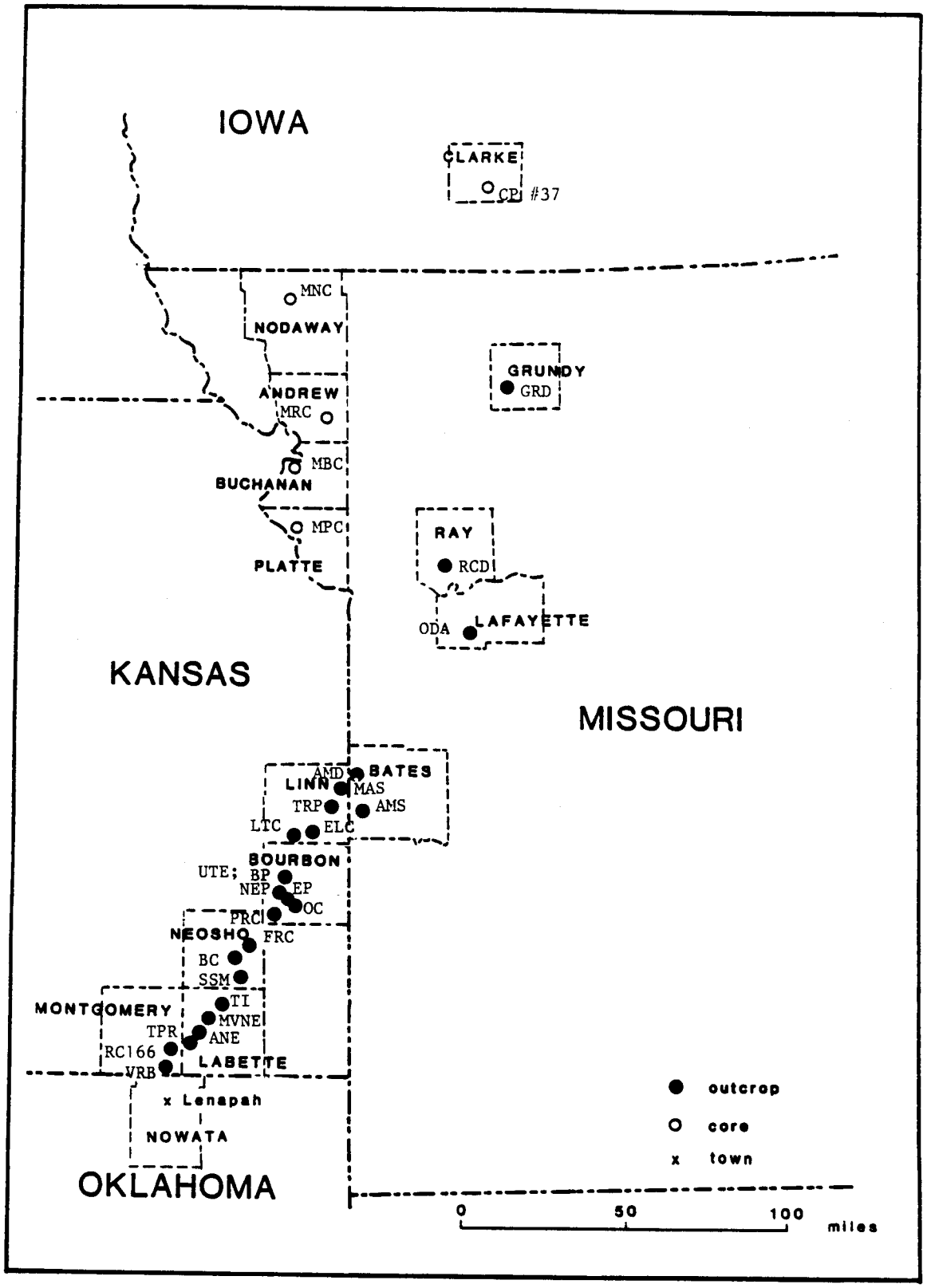
Field Methods

The first step of this study involved locating and studying good outcrop exposures of the Lenapah Formation in eastern Kansas and western Missouri. The field work concentrated on describing lithologies, fossils and lithologic contact relationships. Samples of the Lenapah Formation were collected from 24 locations (Figure 3) at one-foot intervals and/or at a change in lithology.

Laboratory Methods

From the collected limestone samples and cores, polished slabs were made and described to supplement field descriptions, and 60 thin section were prepared to closely examine the petrography of the Lenapah Formation. Some of the thin sections were first examined with the cathodoluminoscope to detect trends in cement stratigraphy, and then stained to differentiate chemical compositions of both skeletal grains and cements: The slides were first stained with alizarin red-S, to distinguish dolomite from calcite, and then stained with potassium ferricyanide to distinguish ferroan from non-ferroan calcite and dolomite.

Figure 3. Location map of stratigraphic sections. Sections were measured for this study from outcrop (closed circles) and from cores (open circles). See appendix on Stratigraphic Sections for exact section locations.


IOWA
CLARKE
CPJ #37
MNC
NODAWAY
GRUNDY
GRD
ANDREW
MRC
MBC
BUCHANAN
MPC
PLATTE
RAY
RCD
ODA
LAFAYETTE
KANSAS
MISSOURI
AMD
BATES
LINN
MAS
TRP
AMS
LTC
ELC
BOURBON
UTE; BP
NEP
EP
OC
FRC
NEOSHO
FRC
BC
SSM
MONTGOMERY
TI
MVNE
TPR
ANE
RC166
LABETTE
VRB
x Lenapah
NOWATA
OKLAHOMA
outcrop
core
x town
0
50
100
miles

Point counts of 20 thin sections were used to aid in estimating the percentages of skeletal debris, terrigenous impurities, and carbonate cements.

Limestone and shale members from all sections were processed for conodonts. Limestones were dissolved in 10% formic acid for approximately 24 hours. Non-black shales were oven-dried, disaggregated by immersion in Stoddard's Solvent for 24 hours followed by immersion in water for 24 hours. All residues were wet-sieved through 18(1mm), 120 (125 micron) and 230 (63 micron) mesh screens. Conodonts were then picked from the 120-mesh residues. Large residues were first processed with a magnetic separator, which separates a smaller non-magnetic fraction (including conodonts) from a larger magnetic fraction, and this reduces the amount of material to be subsequently picked for conodonts.

GEOLOGIC SETTING

During the Pennsylvanian the southern Midcontinent was a region of active tectonic elements that was being subjected to a major marine transgression. Pennsylvanian history of the region involved the development of a deep basin (Arkoma-Anadarko) south of a stable shelf, and its filling by westwardly prograding sediments (Moore, 1979).

Tectonic activity increased in the Midcontinent following Mississippian time. In Oklahoma the Arkoma and Anadarko Basins (Figure 4) were developing, possibly in response to continental suturing to the south resulting from the collision between the North American and South American-African plates (Kluth and Coney, 1981). In eastern Kansas the main structural features produced by the activity were the Nemaha Uplift and Bourbon Arch (Merriam, 1963).

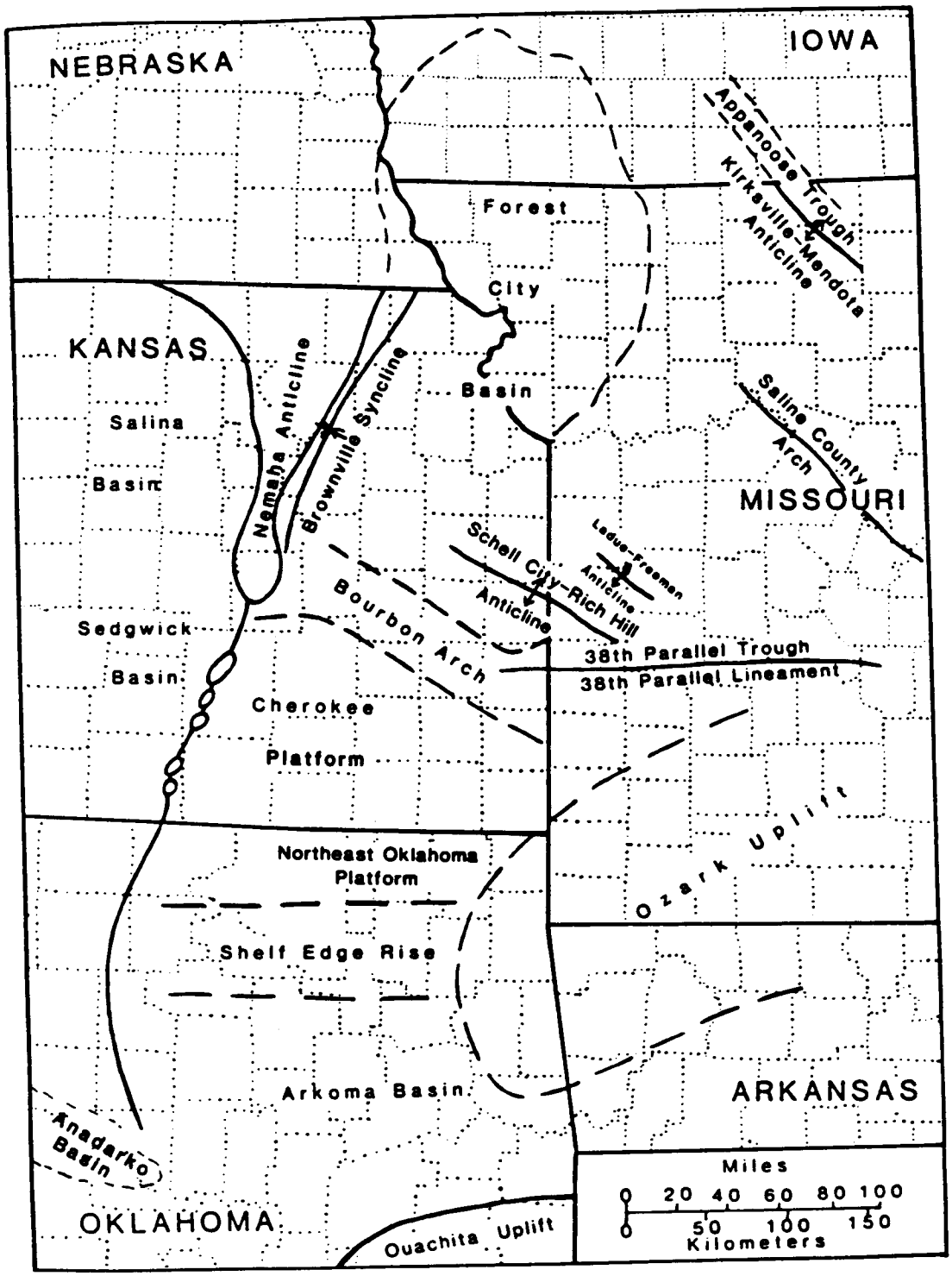
The Nemaha Uplift divided the Kansas area into two regions, the Salina Basin to the west and Forest City and Cherokee Basins to the east (Merriam, 1963). The Nemaha Uplift is generally steeper on its eastern flank than on the west, and is interpreted as an eastward-facing fault escarpment (Lee, 1943). The steep western boundary of the Forest City Basin created by the Nemaha Uplift produced an

asymmetrical profile with the deeper part of the basin adjacent to the uplift.

The Cherokee Basin, a shelf-like extension of the Arkoma Basin of Oklahoma, was separated from the Forest City Basin by the Bourbon Arch, a positive feature at various times during the Pennsylvanian, trending northwest to southeast through east-central Kansas and into Missouri (Merriam, 1963). The Ozark Dome forms the eastern boundary of the Cherokee Basin and the southeastern boundary of the Forest City Basin.

During the Pennsylvanian, the sea advanced northward from Oklahoma reworking the sediments from the newly uplifted source area. The Nemaha Uplift and Bourbon Arch were major influences on earlier Pennsylvanian sedimentation in Kansas, in that older Pennsylvanian deposits were confined to the basinal areas, with younger rocks overstepping one another on the positive areas (Merriam; 1963, Visher and others, 1971) (figure 4). Recently Price et al. (1985) suggested that the Bourbon Arch continued to exert subtle influence on later Pennsylvanian deposition.

Figure 4. Pennsylvanian Midcontinent structures. Includes structures known and suspected to have affected Pennsylvanian sedimentation (from Knight, 1984, Fig. 7).


NEBRASKA
IOWA
Appanoose Trough
Kirksville-Mendota Anticline
Forest City Basin
KANSAS
Salina Basin
Nemaha Anticline
Brownville Syncline
Saline County Arch
MISSOURI
Schell City-Rich Hill Anticline
Ledue-Freeman Anticline
Bourbon Arch
Sedgwick Basin
38th Parallel Trough
38th Parallel Lineament
Cherokee Platform
Ozark Uplift
Northeast Oklahoma Platform
Shelf Edge Rise
Arkoma Basin
ARKANSAS
Anadarko Basin
OKLAHOMA
Ouachita Uplift
Miles
0 20 40 60 80 100
0 50 100 150
Kilometers

STRATIGRAPHY

Previous Investigation

Jongmans (1936, fide Jewett, 1945, p.9) stated:

> "There is no geologic formation of which the detailed subdivision and correlation have been the subject of longer scrutinizing than the Carboniferous (Pennsylvanian and Mississippian) but at the same time agreement on the formation has been found more difficult to attain than on almost any other."

When dealing with early investigations and literature concerning the Pennsylvanian system, I found that no statement could be truer. The Lenapah Limestone, a very small unit within the Pennsylvanian has also been the subject of much confusion and miscorrelation. These next few pages will attempt to describe these early correlations, and the following sections hopefully will help to clarify the miscorrelations.

Jewett (1941) described the Marmaton Group (the upper portion of the Desmoinesian Stage) in Kansas as consisting of 250 feet of shale, sandstone and limestone beds with very minor amounts of coal. The Marmaton Group lies comformably above the Cherokee Group, which consists dominantly of shale, with a considerable amount of sandstone and minor amounts of coal, limestone and underclay. The upper

boundary of the Marmaton Group is a disconformity below the Missourian Stage (Figure 2), the base of which is marked by the Hepler Sandstone. This disconformity has been recognized northward from the Arbuckle Mountains into southeastern Kansas and as far north as Putnam County, Missouri. The Marmaton Group comprises eight formations of which the lowest unit is the Fort Scott Limestone (Figure 2) The remaining seven formations (as reported by Jewett in 1941) include in ascending order; Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, Nowata Shale, Lenapah Limestone, and Memorial Shale.

The Lenapah Limestone was originally named by Ohern (1910) from the town of Lenapah in Nowata County, Oklahoma. The next discovery of what was thought to be the Lenapah occurred in 1936 when Greene named the Sni Mills Limestone of Missouri, with a type section in eastern Jackson County. He believed this to be the upper limestone member of the Lenapah Formation. Therefore, the Sni Mills Limestone was actually the earliest term of member rank to be applied to any portion of the Lenapah.

In 1937, Moore described a type exposure for the Lenapah in Nowata County, Oklahoma, at Bell Spur, a short distance north of the town of Lenapah. A more detailed description will be included in the stratigraphy section.

In Kansas, early work on the Lenapah Limestone was conducted by Jewett (1941, 1945) who divided the formation into three members, in ascending order: 1) Norfleet Limestone, 2) Perry Farm Shale, and 3) Idenbro Limestone, and suggested that the upper member, the Idenbro, was the laterally persistent unit extending into western Missouri. Type sections for all these members are in Labette County near the Oklahoma border (Figure 3).

A report by Cline (1941) named the Cooper Creek Limestone of Iowa and correlated this with the Sni Mills Limestone of Missouri as both were thought to be the top member of the Lenapah (Figure 5).

Later, Cline and Greene (1950) correlated the Sni Mills Limestone of Missouri with the upper member of the Lenapah Formation in Kansas, the Idenbro, and suggested that the term Idenbro should be suppressed. However, Howe (1953) suggested that Cline and Greene (1950) had erroneously correlated the lower Norfleet Member with the upper member, the Sni Mills, in portions of Lafayette and Ray counties, Missouri.

Later reports (e.g., Zeller, 1968) describe the Lenapah of Kansas as two limestones separated by a shale that is locally thin or absent as a result of pre-Missourian erosion, and continued to suggest that the Idenbro is the laterally persistent member while the lower two members are

absent in some places. The Norfleet Limestone was described as a dark brownish-grey massive to bluish-grey slabby limestone, which resembles local facies of the Idenbro limestone in some northern outcrops; this statement probably explains why miscorrelations within the Lenapah were so plentiful.

Parkinson (1982) studied the Lenapah Formation of northeastern Oklahoma and southeastern Kansas and found that the Norfleet Limestone of Kansas is equivalent to the informally named Eleventh Street Limestone of the Tulsa, Oklahoma area, as both occupy the same stratigraphic position. Like Jewett, Parkinson also suggested that the Norfleet may not have developed at all north of Parsons, Kansas and that it is the Idenbro Member that extends into western Missouri and southern Iowa.

The formation directly overlying the Lenapah was referred to as the Memorial Shale by Jewett (1941) named from the Tulsa area by Dott (1936) but later recognized as equivalent to the Holdenville Shale by Oakes (1952). Present investigation of the units along the Desmoinesian-Missourian boundary by A.P. Bennison, P.H. Heckel, R.A. Peppers, and D.R. Boardman in Oklahoma has shown that the term Holdenville Shale is inappropriate as previously used from the Tulsa area northward. Heckel (1984) proposed that this term should be abandoned in northern Oklahoma, Kansas,

and Missouri in favor of a new term, the Lost Branch Formation (Figure 2).

The Lost Branch Formation is now recognized as the highest Desmoinesian unit and is defined as the marine shale and limestone above the Dawson Coal of Oklahoma and Kansas, above the Laredo Coal in Missouri, and below the terrestrial shale and sandstones like the Hepler and its equivalents.

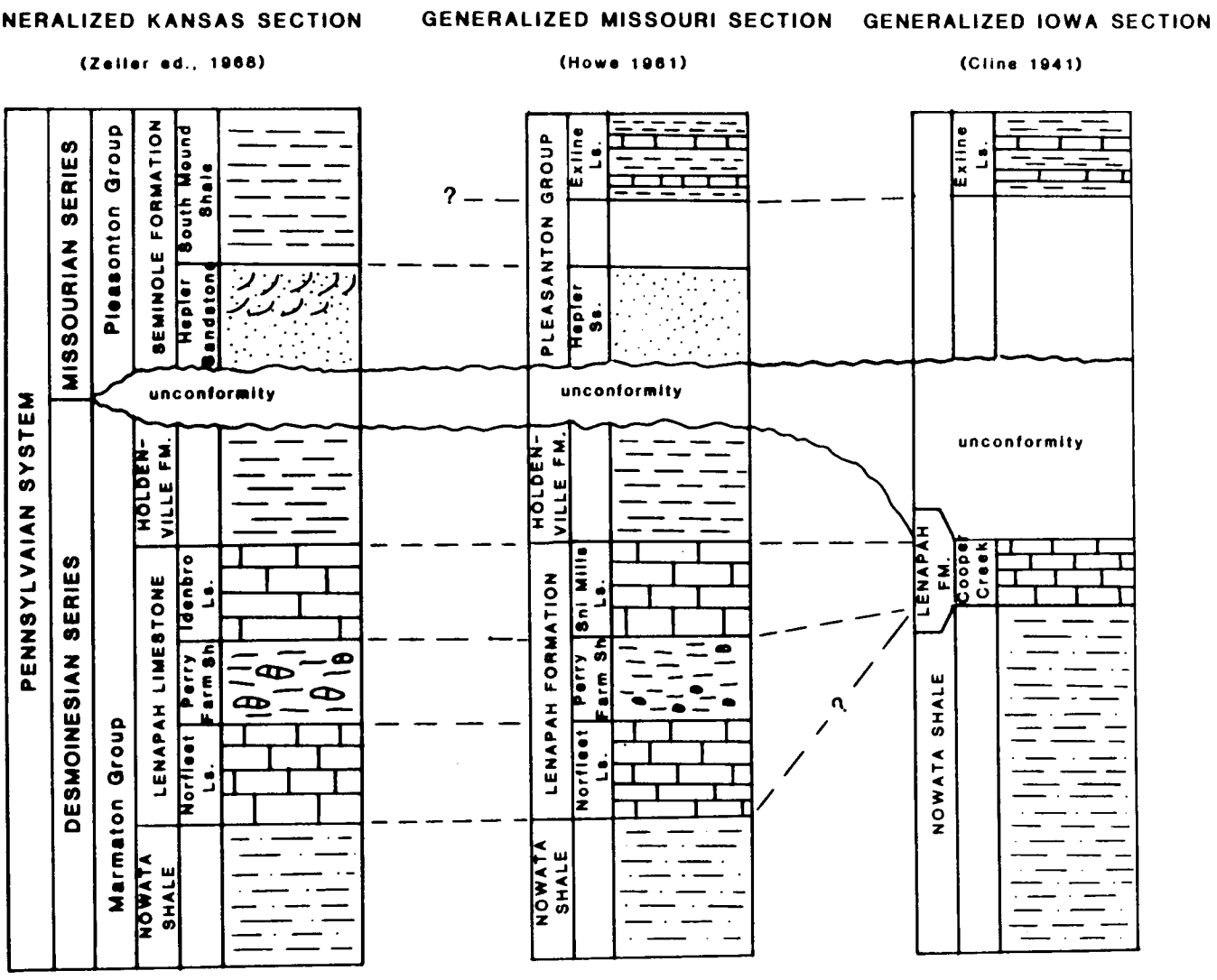
Those coals and their underclays and any other terrestrial strata overlying the Lenapah Limestone, but underlying the Lost Branch Formation have been proposed by Heckel (manuscript in review) to constitute a new unit, the Mound Valley Formation (Figure 2).

It is within these new formations (Mound Valley and Lost Branch) that many miscorrelations of the Lenapah were made. A description of the two units and a detailed explanation of the miscorrelations are included later within this section.

Revised Stratigraphy

The Lenapah Limestone outcrop belt of this study extends from Montgomery, through Labette, Neosho, Bourbon, and Linn counties of southeastern Kansas, and Bates, Lafayette, Ray and Grundy counties of western and northern Missouri (Figure 3). Cores from Platte, Buchanan, Andrew and Nodaway Counties, Missouri, and Clark County, Iowa were

Figure 5. Early correlations of Lenapah Formation in Kansas, Missouri and Iowa. Shows correlations of Idenbro Limestone of Kansas with Sni Mills Limestone of Missouri and with Cooper Creek Limestone of Iowa. It also shows Holdenville Shale, formerly Memorial Shale (Dott, 1936), above Lenapah Formation (Heckel, manuscript in review).


GENERALIZED KANSAS SECTION
(Zeller ed., 1968)
GENERALIZED MISSOURI SECTION
(Howe 1961)
GENERALIZED IOWA SECTION
(Cline 1941)
PENNSYLVAIAN SYSTEM
MISSOURIAN SERIES
DESMOINESIAN SERIES
Pleasonton Group
Marmaton Group
SEMINOLE FORMATION
Hepler Sandstone
South Mound Shale
LENAPAH LIMESTONE
Norfleet Ls.
Parry Farm Sh
Idenbro Ls.
HOLDEN-VILLE FM.
NOWATA SHALE
unconformity
PLEASANTON GROUP
Exline Ls.
Hepler Ss.
LENAPAH FORMATION
Norfleet Ls.
Parry Farm Sh
Sni Mills Ls.
HOLDEN-VILLE FM.
NOWATA SHALE
unconformity
Exline Ls.
unconformity
LENAPAH FM.
Cooper Creek
NOWATA SHALE
?
?

incorporated into the stratigraphic correlation. The rocks strike slightly east of north and dip westward approximately 20 feet per mile (Parkinson, 1982).

Along with the three members of the Lenapah, the underlying Nowata Shale and overlying newly proposed Mound Valley and Lost Branch formations shall be discussed in detail, because recognition of these units aided in identification and stratigraphic correlation of the Lenapah Limestone (See appendix for detailed lithologic sequences).

Problems of Fieldwork

The Lenapah Formation has proved to be an exceptionally difficult formation to trace both laterally and vertically in the field. Most of the type section of the Norfleet Limestone is nearly constantly under water, and the designated type section of the Idenbro by Jewett (1941) is not fully exposed. Jewett noted in his original definition (1941, p.340) that:

> This exposure probably does not include the entire thickness of the Idenbro Limestone, because some limestone has probably been eroded, but the full thickness is present below the soil above, and not far from the outcrop.

North of their type sections the very poorly exposed limestones exhibit great variability in lithology and thickness, making identifications of each member in some localities difficult if not impossible. In other

localities, the Lenapah Formation forms the bottom of creek beds, and field collection correlated inversely with the amount of precipitation in the area at the time of fieldwork.

Nowata Shale

Shale and sandstone lying between the Altamont and the Lenapah limestones were named Nowata Shale by Ohern (1910) from the town of Nowata in Nowata County, Oklahoma, where the type exposure is located. According to Moore (1937) the Nowata shale is 175 feet thick near Nowata, and 600 feet thick near Tulsa, Oklahoma.

At Coffeyville on the Kansas-Oklahoma line, the Nowata Shale is approximately 50 feet thick but thins very rapidly northward, where near Angola in Labette County, Kansas, the base of the Lenapah is nearly in contact with the Altamont Limestone. Farther north the Nowata Shale is thicker, and thicknesses of 20-30 feet have been measured in several places. Where well exposed, the Nowata Shale is both marine and non-marine consisting principally of yellow-grey, blocky clay shale and lenses of sandy shale and sandstone (Jewett, 1941). Within the Nowata Shale, the Walter Johnson Sandstone Member is a thin bedded to massive sandstone occurring locally in southeastern Kansas (Zeller, 1969).

The average thickness of the Nowata Shale in western and northern Missouri is between 10 and 15 feet (Howe, 1953). In Ray County, Missouri, Howe (1953) described the Nowata as 15 feet of shale with hematite nodules, and a calcareous clay and limonite zone near the base.

In Madison County Iowa, Hershey and others (1960) described three outcrops of the Nowata Shale, where 50 feet of greyish-brown sandstones, and red and green silty shales were observed, but they suggested that this may include part of the overlying Lenapah Formation as recognized in Missouri. Swade (1982) recognized 18 feet of section as the Nowata Shale in a core in Clark County, Iowa and divided it into two distinct units. The lower unit is a barren mudstone 4 feet thick grading upward from green to brick red and then to gray with maroon mottling and irregular carbonate nodules at the base. Ravn et al. (1984) recognized only this lower unit as the Nowata Shale and placed Swade's upper "Nowata" unit, 4 feet of gray, calcareous, silty, marine shale, overlain by 10 feet of reddish blocky mudstone in the Lenapah and overlying units.

Lenapah Limestone

Definition

The type exposure of the Lenapah Limestone was measured by R.C. Moore (1937) in a quarry in the NW 1/4 NE 1/4

section 30, T28N, R16E, Nowata County, Oklahoma, at Bell Spur a short distance north of Lenapah, on the west side of (old) U.S. Highway 169. In ascending order the outcrop consists of: 1) 15 feet of limestone, light-grey, massive, with weathered surface showing irregular wavy laminae; 2) 1 foot of shale, blue-grey, calcareous containing abundant Marginifera; 3) 6 feet of limestone, light grey, weathered light yellowish brown, slabby somewhat nodular, some beds brecciated with fragments of very fine, dense, light bluish algal limestone, poorly fossiliferous, with Composita.

When Jewett (1941) revisited the type exposure it was partly filled with water, so a newer quarry section in the NE 1/4 SE 1/4 section 30, T28N, R16E, Nowata County, Oklahoma was described; in ascending order; 1) Limestone, 12 feet mottled grey and medium dark grey, massive but with nodular structure, no fossils observed; 2) Shale and limestone, 0.66 feet, greenish grey shale with medium dark grey nodular limestone in upper part, and Marginifera; 3) Limestone, 1.6 feet light grey massive with Osagia and brachiopods; 4) Shale, 0.2 feet, grey; 5) Limestone, 3 feet, light grey weathers tan and pitted, somewhat slabby. Jewett correlated units 1 and 2 with the Perry Farm Member (see below) and units 3 to 5 with the Idenbro.

Norfleet Limestone Member

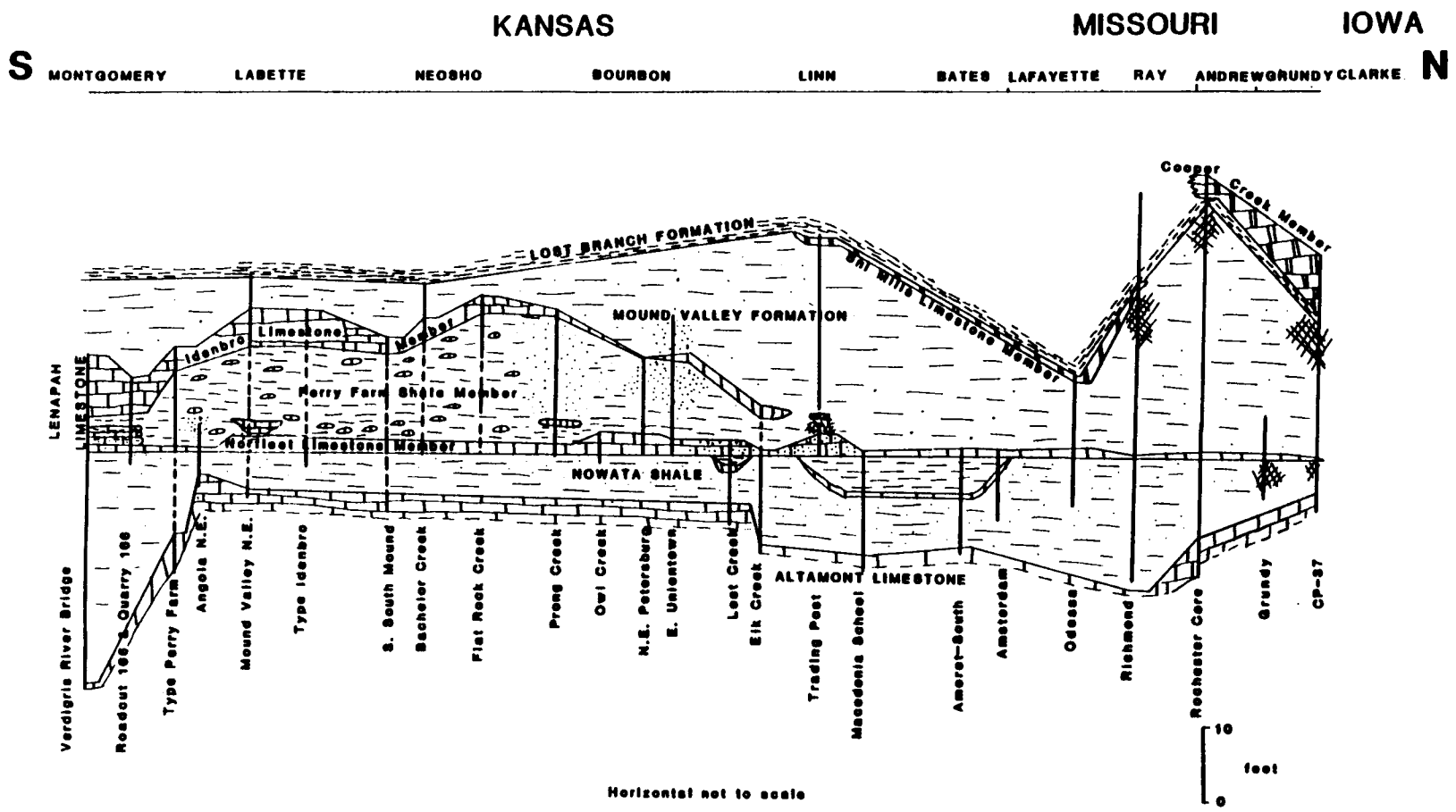
Definition

The Norfleet Member was defined by Jewett (1941) to include all limestone and shale beds below the "easily" identified nodular and locally fossiliferous Perry Farm Shale. The type exposure of the Norfleet Limestone Member is on the Ivy Norfleet farm along Pumpkin Creek north of the low water bridge in SE 1/4 section 35, T32S, R18E, on the northeast outskirts of Mound Valley (MVNE on Figure 3), Labette County, Kansas. This exposure was described as 5.0 feet of dark gray and black, platy shale overlain by 3.0 feet of limestone.

Lateral and Vertical Distribution

North of its type section, the Norfleet contains variable lithofacies of limestone and interbedded shales. The lithofacies may be subdivided into 3 generalized field lithotypes consisting of: 1) predominantly shale, capped by 0.5 to 1 foot of limestone and/or underlain by another 0.5 to 1.5 feet of limestone; 2) predominantly limestone, 2 to 4 feet of light grey-tan skeletal calcarenite and/or skeletal calcilutite; 3) sandy crinoidal to diverse skeletal limestone, 0.5 to 3 feet thick. The Norfleet ranges in thickness from approximately 0.5 feet in Missouri to 7 feet in Kansas, along the line of outcrop (Figure 6).

Figure 6. Generalized lithologic cross-section of Lenapah Limestone in study area. Datum is base of main ledge of Norfleet Limestone Member.


KANSAS
MISSOURI
IOWA
S
MONTGOMERY
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
LOST BRANCH FORMATION
Cooper Creek Member
Ohl Mills Limestone Member
MOUND VALLEY FORMATION
Idenbro Limestone Member
Perry Farm Shale Member
Merriott Limestone Member
NOWATA SHALE
ALTAMONT LIMESTONE
LENAPAH LIMESTONE
Verdigris River Bridge
Readout 166 Quarry
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prong Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
10
feet
0
Horizontal not to scale

In Neosho County the Norfleet could not be found, although at Bachelor Creek (BC), Jewett (1941) reported 6 feet of shaly nodular limestone as the Norfleet. On visiting this area it seems that either the Norfleet is now covered, or it is indistinguishable from the overlying Perry Farm Shale Member. North of Neosho County, in Bourbon County the 2 to 4 feet of skeletal calcarenite and skeletal calcilutite dominate the outcrops in that area. Near Owl Creek (OC) along highway K-39, a good exposure contains 3 feet of slabby skeletal calcilutite capped by a crinoidal calcarenite and underlain by a few inches of dark shale rich in conodonts. At the Prong Creek (PRC) section approximately 3 miles west of Owl Creek along K-39, the top of the skeletal calcarenite forms the creek bed and probably is equivalent to the top of the limestone at Owl Creek, but unfortunately the full thickness at this locality cannot be measured. In Linn County, the best exposure of the Norfleet is recognized at the Lost Creek (LTC) locality, which consists of in ascending order; 1) limestone 1.5 feet, the bottom containing algal-coated grains and skeletal calcarenite with productids, grading upward into a dark, dense calcilutite at the top; 2) 2-foot covered interval with a few inches of shale very rich in conodonts at top; 3) limestone, of the sandy crinoid-rich lithotype with red hematitic staining. At Trading Post (TRP), Linn County,

Kansas, the Norfleet is approximately 3 feet thick in the bed of the Marais des Cygnes River (at low water level), containing at the base a tan skeletal limestone grading upward into the sandy brachiopod-rich lithofacies slabby with dark red hematitic staining.

In Bates County, Missouri, approximately 2 miles south of Amoret, is a well exposed section (AMS) consisting of, in ascending order; 1) limestone, 0.5 feet dark, dense calcilutite; 2) shale, 5 feet of light to dark grey silty shale exceptionally abundant in conodonts in the upper portion; 3) limestone, 0.5 feet of dark skeletal calcarenite containing crinoid fragments, brachiopods and corals. A similar section was seen at Macedonia School 8 miles to the northwest across the border in Linn County, Kansas. Although two limestones characterize the Norfleet in Linn County, Kansas, and Bates County, Missouri, the base of the upper limestone has been used as the datum to construct the cross-section, because this horizon contains or directly overlies the zone of greatest abundance of conodonts and seems to be the northern equivalent of the Norfleet limestone as developed in Bourbon and Labette Counties, Kansas.

In Ray and Grundy Counties, Missouri, the Norfleet has thinned to approximately 0.5 to 1 foot of hard to nodular clayey light grey green crinoidal limestone. The same

lithology is seen in cores to the west in Platte, Buchanan Andrew and Nodaway counties.

D. L. Swade (pers. commun., 1984) reported the Norfleet from the core (CP37) in Clarke County, Iowa as a 0.1-foot bed of argillaceous limestone with invertebrate fossils and sparse conodonts, overlain by 2.25 feet of calcareous shale.

Perry Farm Shale Member

Definition

The name Perry Farm Shale was applied by Jewett (1941) to the middle member of the Lenapah Limestone. It is defined as the calcareous fossiliferous shale above the Norfleet Limestone and below the "easily" identified Idenbro Limestone. The type exposure is located along the south side of the east-west road in NW 1/4 NE 1/4 section 7, T34S, R18E, 1.4 miles west of Angola in Labette County, Kansas, and contains approximately 10 feet of grey shale with limestone nodules. This fossiliferous shale contains molluscs, corals and particularly the brachiopods Ambocoelia (now Crurithyris) and Marginifera.

Lateral and Vertical Distribution

South of the type section toward the Kansas-Oklahoma line, Parkinson (1982) recognized the Perry Farm as almost 10 feet of rubbly, wavey bedded, grey, very sparsely fossiliferous limestone. The Perry Farm Shale Member north

of its type section consists primarily of the shale with limestone nodules and a horizon now known to be equivalent (Sutton, 1985) consisting of silty shales and sandstones, originally referred to as the type "Hepler" Sandstone. Unfortunately, the name Hepler has been used to refer to as many as three stratigraphically different sandstone units, causing much confusion in the literature (Sutton, 1985). The Perry Farm Member ranges from 2.5 to 10 feet along the line of outcrop (Figure 6).

At the Bachelor Creek locality (BC) in Neosho County, the Perry Farm is easily identified by its characteristic shaley facies with limestone nodules, with approximately 5 feet of exposed outcrop, directly below the Idenbro and perhaps 7 feet more downstream (Jewett, 1941). Northward into Bourbon County, the Perry Farm is not as distinctive, and identification depends mainly on its stratigraphic position between the Norfleet and Idenbro Limestone. At the Prong Creek locality (PRC), the Perry Farm has graded into 2.5 feet of grey sandy shale, with beds of thin (0.1 foot) lenticular calcarenite, and grading upward into 12 feet of sandstone, which appears to be laterally continuous with type Hepler sandstone established by Jewett (1940), 2 miles to the southeast. At the Uniontown East (UTE) and Petersburg NE (NEP) localities, the Perry Farm stratigraphic equivalent is predominantly sandy shale from 7 to 10 feet

thick, capped by 3 feet of rippled, cross-bedded sandstone. In Linn County at the Elk Creek locality (ELC), 0.5 to 3 feet of a covered interval between two limestones probably is the Perry Farm equivalent, and shows a significant thinning of this member in these northern exposures.

The position of the conodont-rich horizon in the type sections for the Norfleet Limestone and Perry Farm Shale members suggests minor revision in terminology of part of the lower Lenapah in its type area. The thin nodular Norfleet at the Perry Farm type locality (TPR) constitutes the entire conodont-rich horizon, but at the Norfleet type locality (MVNE), only a thin limestone ledge, 0.5 feet below the upper 3 feet of limestone, contains the conodont-rich horizon. Thus in southern Kansas the upper 3 feet of limestone that had originally been defined as the upper Norfleet and the lower part of the shale that had originally been defined as Perry Farm by Jewett (1941) appear actually to be stratigraphically equivalent horizons (Figure 6). Therefore, if carbonate dominates the horizon it will now be referred to as the Norfleet Member, whereas if shale dominates, it shall be considered the Perry Farm Member. This means that in the Lenapah type area in Nowata County, Oklahoma, and adjacent Montgomery County, Kansas, only the thin (1 foot) green shale below the Idenbro is the Perry Farm, whereas the entire carbonate sequence below this

belongs to the Norfleet instead of the lower Perry Farm as classified by most previous workers.

Idenbro Limestone Member

Definition

The Idenbro Member was named by Jewett (1941) from Idenbro, a station on the Missouri, Kansas and Texas railroad about 4 miles southwest of Parsons, in Labette County, Kansas. It is defined as the limestone above the fossiliferous Perry Farm Shale. The type exposure is along drainage at SW 1/4 SW 1/4 section 2, T32S, R19E, and is approximately 3 feet thick (but could be up to 7 feet thick, according to Jewett). It is characterized by its wavy, irregular beds of light grey crystalline limestone. It is somewhat fossiliferous, with corals prominent and much algal material in the upper part (Jewett, 1941).

Lateral and Vertical Distribution

The Idenbro ranges from 1-7 feet along the line of outcrop and seems to pinch out northward in Linn County, Kansas (Figure 6).

At the roadcut west of the low water bridge over Pumpkin Creek near the type Norfleet (MVNE), a good exposure shows the Idenbro to be approximately 5 feet thick, consisting of a skeletal calcilutite near the base and grading upward into a productid-rich skeletal calcarenite;

both lithologies proved sparse in conodonts. In Neosho County, at three localities, South of South Mound (SSM), Bachelor Creek (BC) and Flat Rock Creek (FRC), the Idenbro ranges from 2-3 feet of grey, skeletal calcilutite grading upward into calcarenite, increasing in brachiopod and crinoid fragments towards the top. Directly below the main limestone ledge are hummocky, irregular, iron-rich grey calcilutitic nodules with brachiopod fragments. At the East of Uniontown (UTE) locality in Bourbon County, the Idenbro has thinned to approximately 1.5 feet of grey-buff shaly skeletal calcilutite. In Linn County at Elk Creek (ELC) is the northernmost locality where the Idenbro is recognized as a limestone facies, about 2 feet thick. The depositional sequence at the Trading Post locality (TRP) suggests that the Idenbro equivalent is a thin coal horizon. North of this area it appears that the Idenbro has completely pinched out, and thus the Norfleet Member is the more laterally persistent limestone of the Lenapah formation.

Mound Valley Formation

The unit above the Lenapah Formation but below the newly proposed Lost Branch Formation (Heckel, 1984), comprises the Dawson coal bed, its underclay and any equivalent detrital rocks. The unit has informally been referred to as the Mound Valley Formation, a term derived

from a section at the type locality of the Lost Branch just southwest of the town of Mound Valley, consisting of 2 feet of blocky mudstone and coal (Heckel, manuscript in review).

In areas where the Idenbro Member has pinched out, differentiating the Mound Valley from the Perry Farm equivalent would be impossible. Therefore Heckel (manuscript in review) suggests recognizing the Mound Valley Formation, in the area north of the Idenbro pinchout, from the top of the Norfleet Member up to the base of the Lost Branch Formation. This is because the entire sequence in these localities is dominated by blocky mudstone like the Mound Valley near Mound Valley, as opposed to the marine shale with limestone nodules characteristic of most of the Perry Farm Member.

Lost Branch Formation

The Lost Branch Formation is presently recognized as the highest Desmoinesian unit, originally named Memorial Shale by Dott (1936), then correlated with the Holdenville Shale of central Oklahoma and renamed in Kansas and western Missouri. The Lost Branch includes the marine units above the Dawson coal of Oklahoma and Kansas and the Laredo Coal in Missouri, up to the base of the unfossiliferous terrestrial deposits that include what has traditionally been regarded as "Hepler" Sandstone.

The type section of the Lost Branch Formation as designated by P. H. Heckel (manuscript in review) is an excellent exposure approximately 15 feet thick in a cutbank on the west side of Lost Branch, near the center NE 1/4 NE 1/4 NE 1/4 section 10, T33S, R18E, southwest of Mound Valley, Labette County, Kansas. Heckel describes the type section in ascending order as: 1) 0.3 feet of slightly micaceous and sandy, soft, dark grey shale; 2) 1.3 feet of fissile black shale with phosphate nodules and abundant conodonts; 3) 12 feet of grey shale with an abundant and diverse invertebrate fauna; 4) 1 foot of hard, calcareous very fine quartz sandstone to sandy skeletal calcarenite.

Within the Lost Branch Formation, as correlated along outcrop by Heckel, (1984), the widespread black phosphatic shale is the offshore deep-water unit, underlain by a local transgressive limestone and overlain by a local regressive limestone. Through the recognition of this new marine unit, based on work conducted by P.H. Heckel, A.P. Bennison, D.R. Boardman, and R.A. Peppers, the miscorrelations of the Lenapah Limestone have been uncovered and rectified.

The Sni Mills Limestone of Missouri was discovered to be actually the local transgressive limestone of the Lost Branch Formation and therefore not correlative with the Idenbro of Kansas, (Heckel, 1984). The Cooper Creek Limestone of Iowa was discovered to be the regressive

limestone of the Lost Branch and therefore not correlative with the Idenbro Member of the Lenapah Formation. In summary, nearly all the limestones in western Missouri and southern Iowa once thought to correlate with the Lenapah, actually correlate with the newly proposed Lost Branch Formation, which lies above the type Lenapah Formation; and the upper half of what was considered Nowata Shale in Iowa and part of Missouri belongs to the newly proposed Mound Valley Formation (Figure 7).

Stratigraphic Summary and Interpretations

1)The cross-section (Figure 6) from Labette County, Kansas to Grundy County, Missouri (and including the core from Clarke County, Iowa), shows that the entire Lenapah Formation has thinned greatly from approximately 15 feet to 0.5 foot or less of limestone.

2)The Idenbro Member pinches out in Linn County, Kansas; hence the Norfleet Member is the laterally persistent limestone into Missouri and Iowa, in contrast to what the early workers on the Lenapah had suggested.

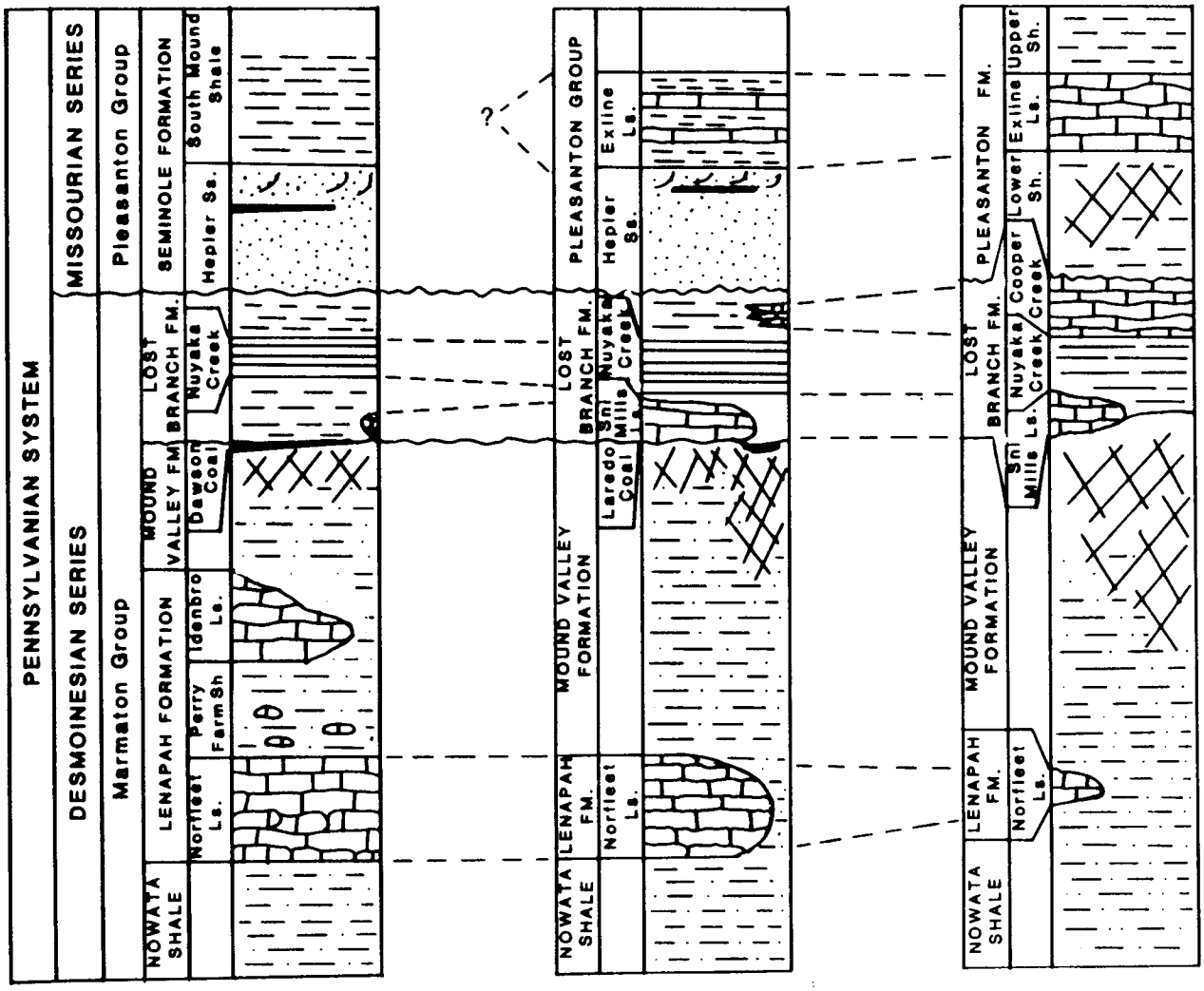
3)The upper limestone of the Norfleet and the lower portion of the type Perry Farm Shale may be stratigraphically equivalent horizons, and shall be called Norfleet where carbonate dominates and Perry Farm where shale dominates.

Figure 7. Generalized diagram of revised correlations and nomenclature of Lenapah and associated units. Based on combined effort of P.H. Heckel (manuscript in review), R.A. Peppers, D.R. Boardman, A.P. Bennison, and this study, (vertical not to scale).

GENERALIZED KANSAS SECTION

GENERALIZED MISSOURI SECTION

GENERALIZED IOWA SECTION



4)Because of the difficulty in differentiating the Perry Farm Shale from the Mound Valley Formation where there is no Idenbro, Heckel (manuscript in review) has suggested that north of the Idenbro pinchout, the term Mound Valley should refer to the entire sequence from Norfleet to Lost Branch (Figure 6).

PETROGRAPHY

Introduction

Petrographic examination of the Lenapah Formation allowed 8 lithofacies to be distinguished. The Norfleet Member is by far the most diverse, and can be divided into five lithofacies, each of which will be described and discussed. The elusive Perry Farm, comprising predominantly shale with flaggy limestone and sandstone within this study area will be described petrographically only where the carbonate lithology allows the construction of thin sections. Finally, the Idenbro Member is divisible into 2 units, an upper muddy calcarenite and lower calcilutite.

The staining of thin sections with alizarin red-S and potassium ferricyanide distinguished the light-pink color as nonferroan calcite and the blue color as ferroan carbonate on all photos.

The classification used for describing the different lithofacies will be predominantly that of Grabau (1904), but in some cases that of Dunham (1962) has been applied.

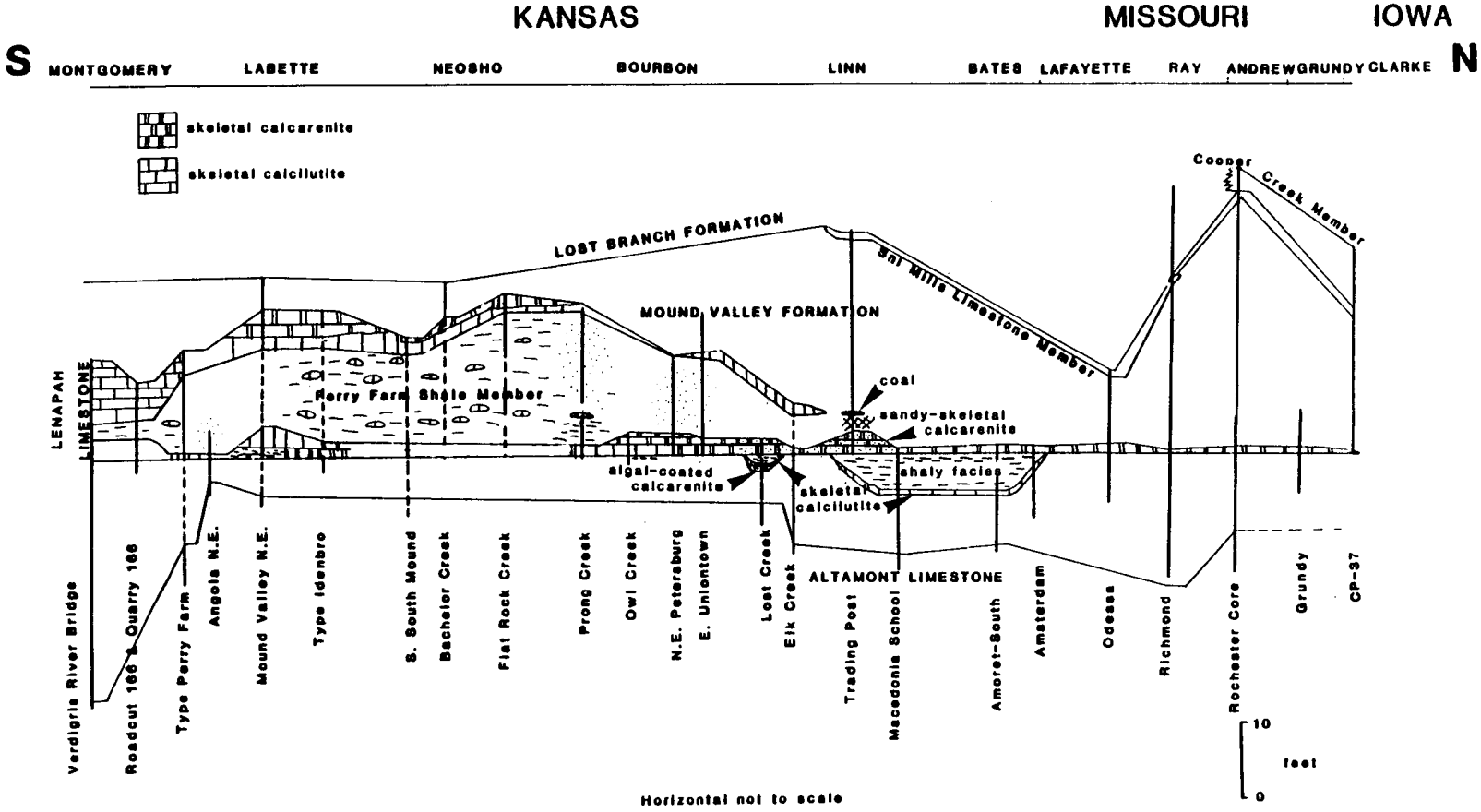
Norfleet Member

The five lithofacies of the Norfleet Member include: 1)skeletal calcarenite; 2)sandy skeletal calcarenite; 3)algal coated calcarenite; 4)skeletal calcilutite; and 5)shale. Facies distribution within the Norfleet is shown in Figure 8.

Skeletal Calcarenite

The skeletal calcarenite facies composes most of the Norfleet Limestone, and shows a high diversity of characteristics depending upon locality. In general, it is a well to poorly sorted, loosely packed to well compacted (Figure 9A,B), grainstone to fairly washed packstone. Skeletal grains constitute 50-70% of the rock, and display a diverse marine biota (Figure 10), consisting of: crinoids (15-30%), brachiopods (5-10%), several types of bryozoans (5-10%), corals (1-10%), molluscs (5-10%), foraminifers (5-20%), red algae (Archeolithophyllum) and dasyclad green algae (1-5%), trilobite fragments, ostracodes, brachiopod spines, and echinoid spines each constituting approximately 1% or less of the rock. The skeletal fragments are usually somewhat abraded (Figure 10B). In some cases the skeletal grains have been so badly abraded and micritized that identification of the shell is impossible. These fragments have been termed "abraded cryptocrystalline" shell material

Figure 8. Distribution of facies within the Lenapah Limestone and its three members.


KANSAS
MISSOURI
IOWA
S
MONTGOMERY
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
skeletal calcarenite
skeletal calciilutite
LOST BRANCH FORMATION
Cooper Creek Member
Sni Mills Limestone Member
MOUND VALLEY FORMATION
LENAPAH LIMESTONE
Perry Farm Shale Member
coal
sandy-skeletal calcarenite
shaly facies
algal-coated calcarenite
skeletal calciilutite
ALTAMONT LIMESTONE
Verdigris River Bridge
Roadcut 166
Quarry 166
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prong Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
10
feet
0
Horizontal not to scale

and constitute up to 11% of the rock in some of the calcarenites.

Dominance of skeletal types varies according to area. For example at the Uniontown East locality, east-central Kansas, foraminifers become the major constituent and constitute 25% of the rock (Figure 11A). In the outcrop at Amsterdam, Missouri (AMD), crinoid fragments dominate the skeletal material (Figure 11B), and point counting has shown that they constitute 35% of the total rock, whereas other skeletal fragments only make up 10-15%.

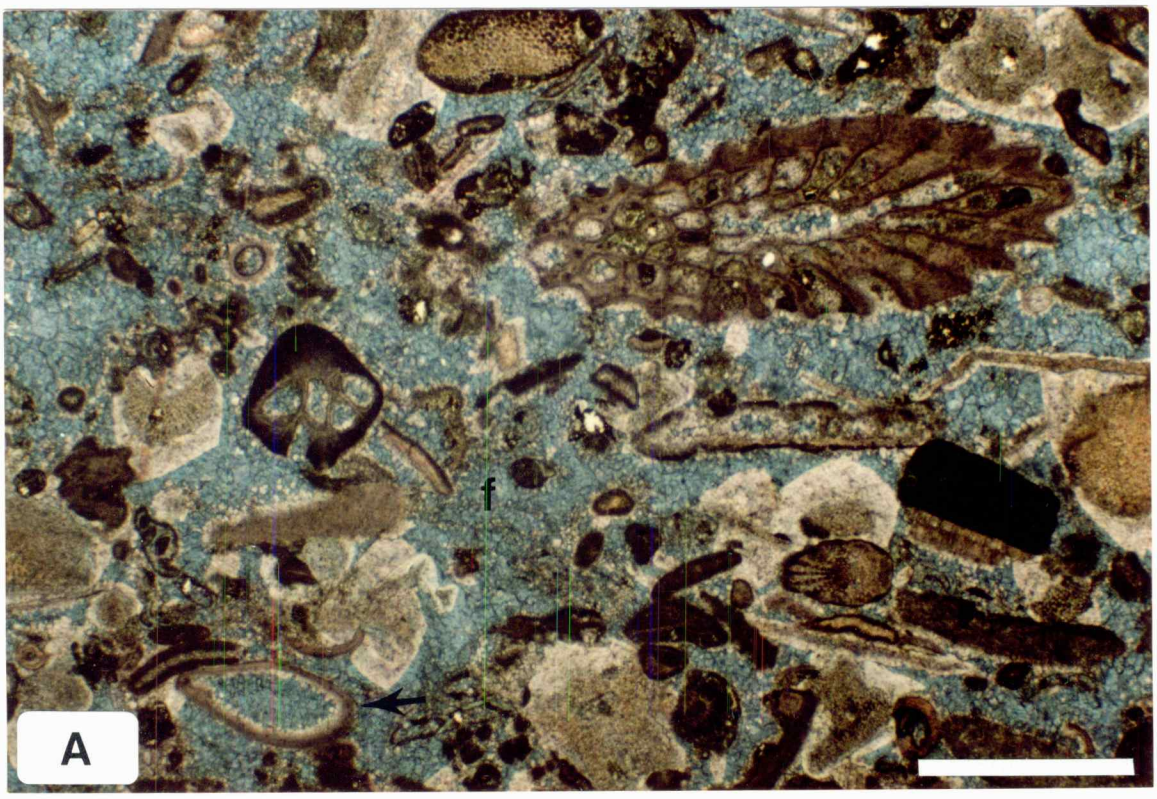
Terrigenous sediments, such as quartz silt (Figure 12A) and authigenic glauconite grains (Figure 11B), are present in small amounts (1-5%).

Original pore space in the skeletal calcarenite facies included intergranular and intragranular pores. The intergranular porosity (depending upon locality) may be filled predominantly by blocky calcite or blocky ferroan carbonate cements. The ferroan cements consist of small amounts of ferroan dolomite, and larger amounts of ferroan calcite; (for the remainder of this text, this cement shall be referred to as ferroan carbonate cement). Some cement includes patches of microspar (Figure 11A). Echinoderm overgrowths and early rims of bladed calcite surrounding some of the brachiopod shells also fill void areas. These void areas are first filled with blocky calcite cement

Figure 9. Skeletal calcarenite facies of Norfleet.

A) Loosely packed skeletal grainstone. Showing diverse marine fauna, signs of abrasion and local micritic coatings. Ostracode void fill shows isopachous rims of early calcite cement (arrow). Some intergranular void filling derived from syntaxial overgrowths (light) of echinoderm fragments, followed by ferroan carbonate cement (f). Section: Baptist Pasture, plane light, bar scale=1.0mm.

B) Overcompacted skeletal calcarenite with ragged grain boundaries. Note neomorphism of pelecypod shell to large sutured crystals of calcite. Note also fracture in pelecypod shell now filled with ferroan carbonate (arrow). Interparticle void space also filled with ferroan carbonate. Section: Type Perry Farm-ledge, plane light, bar scale=1.0mm.


f
A

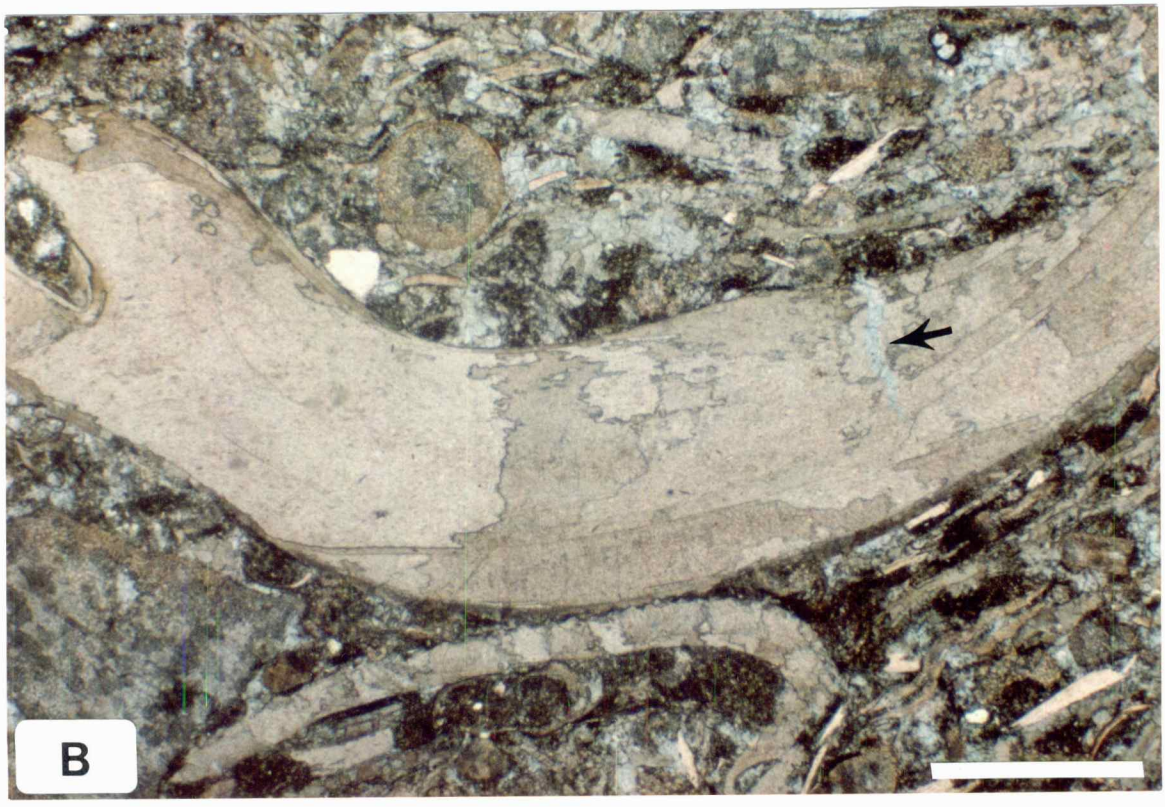

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Figure 10. Skeletal calcarenite facies of Norfleet.

A) Note diverse marine biota (trilobite, forams, ostracodes, brachiopod spines) and phosphatic grains (p) possibly conodonts. Section: Mound Valley North East-lower ledge, plane light, bar scale=0.5mm.

B) Diverse marine biota with most grains showing abrasion including Archeolithophyllum (a), and echinoderm fragments with syntaxial overgrowths (o) followed by ferroan carbonate cement. Note pelecypod shell with micritic coating, leached and now filled with blocky calcite cement (arrow). Section: Petersburg NE, plane light, bar scale=1.0mm.

A

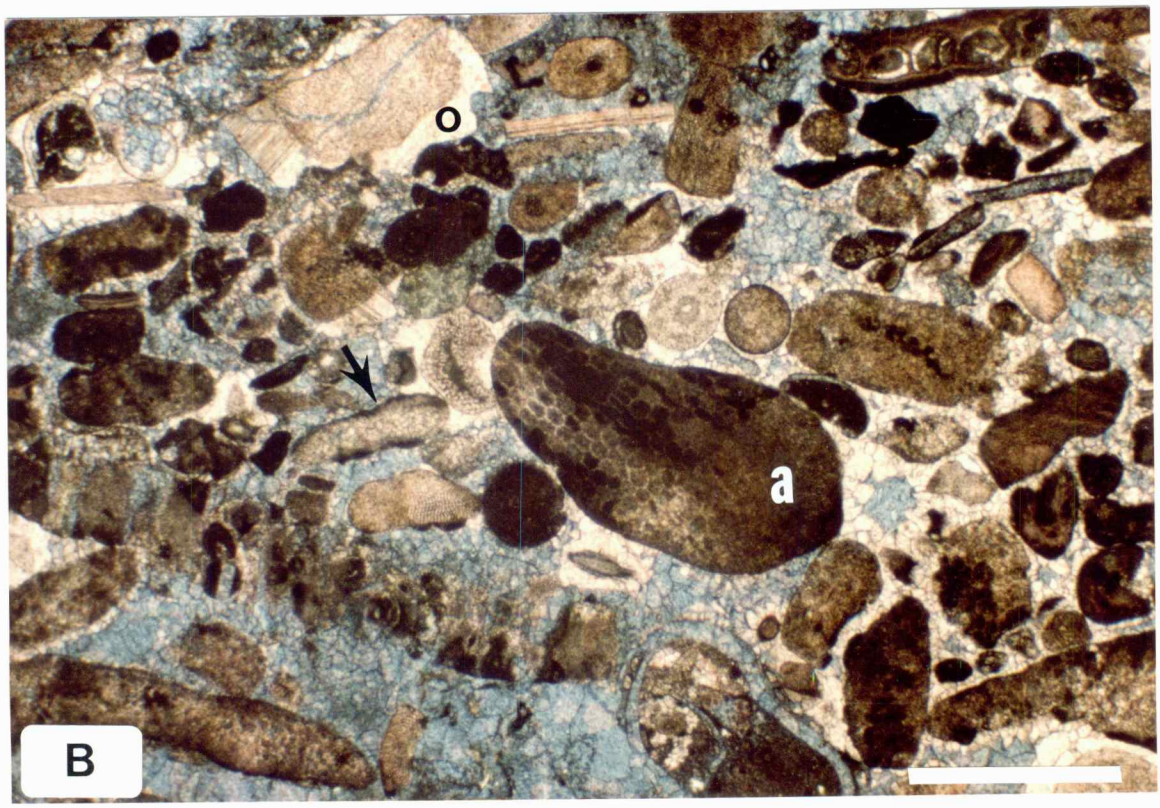
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Figure 11. Skeletal calcarenite facies of Norfleet.

A) Skeletal packstone composed of 25% foraminifers, both encrusting and free forms. Intragranular area is filled with subequal amounts of sparry calcite cement and microspar. Section: Uniontown East, plane light, bar scale=0.5mm.

B) Skeletal calcarenite composed dominantly of crinoidal fragments, most with syntaxial overgrowths (o). Note bladed calcite cement on brachiopods (b), authigenic glauconite fragment (arrow), and final ferroan carbonate filling (blue background). Section: Amsterdam, plane light, bar scale=1.0mm.

A

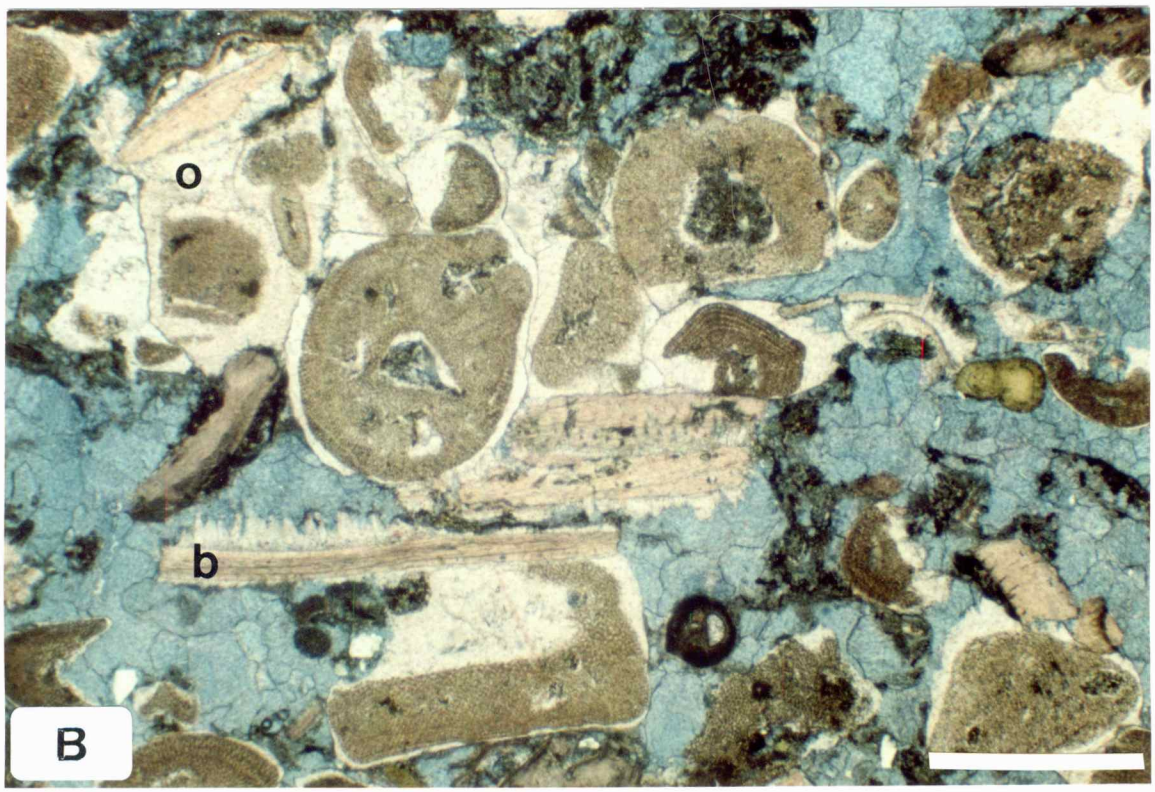
o
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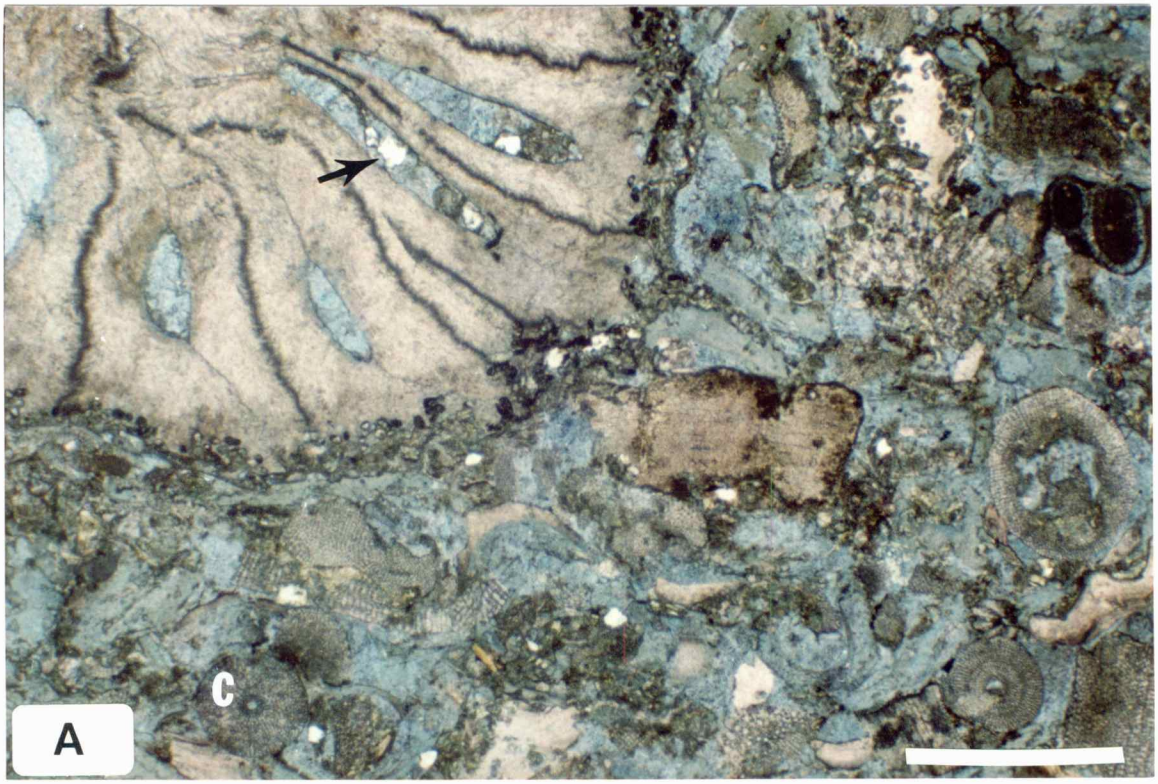
Figure 12. Skeletal calcarenite facies of Norfleet.

A) Note quartz sand grains (arrow) and lack of syntaxial overgrowths on echinoderm fragments (c). Section: Amoret-south, plane light, bar scale=1.0mm.

B) Replacement of pelecypod shell by ferroan carbonate (p), lack of syntaxial overgrowths on echinoderm fragments, and overall ragged appearence of grains due to partial replacement by ferroan carbonate and compaction. Section: Amoret-south, plane light, bar scale=0.5mm.


c
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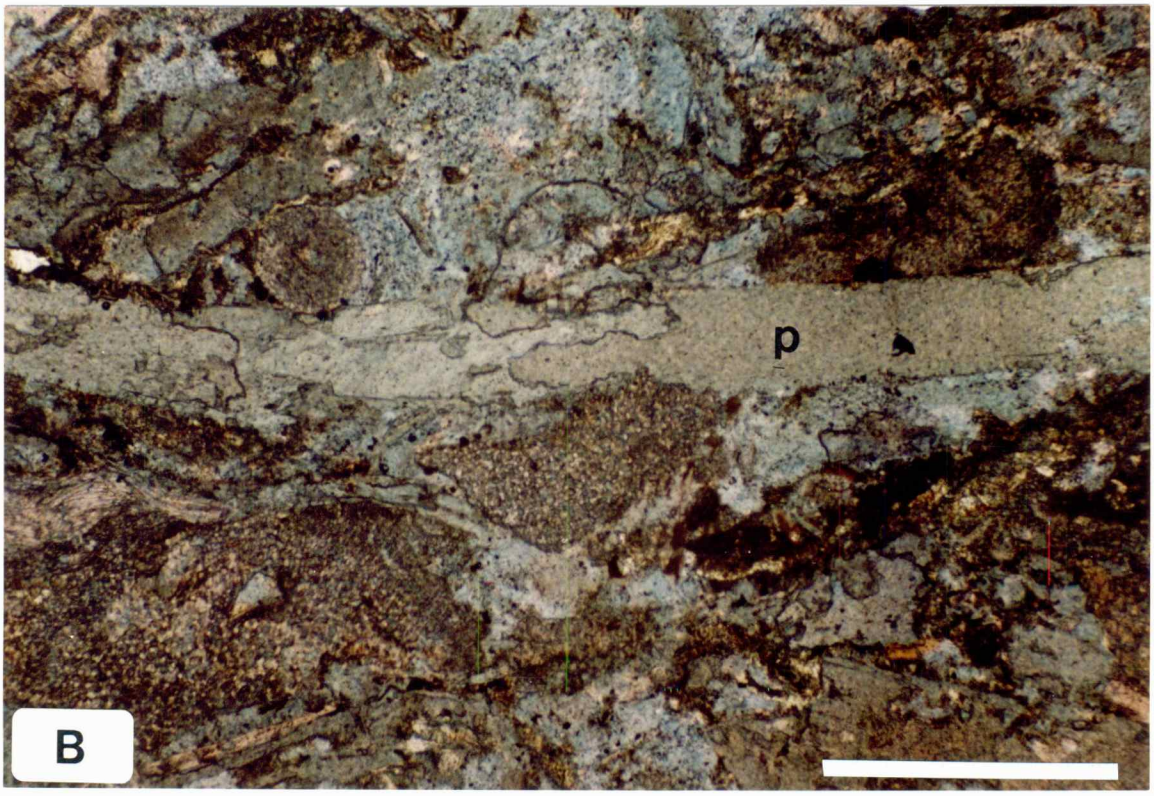

p
B

followed by ferroan carbonate cements filling the remainder of void space (Figure 9A, 10A, B, 11B).

Intragranular pores may be filled with calcite, ferroan carbonate or microspar, and quite often the shell voids show a sequence of infilling including: 1)bladed calcite; 2)blocky calcite; and 3)blocky ferroan carbonate; all increasing in size towards the center of the void.

Preservation of skeletal grains is varied depending upon original composition. Stable original calcite grains such as brachiopods, crinoids, trilobites, bryozoans, and ostracodes are usually found unaltered. The less stable original aragonite grains such as mollusc shells (both pelecypod and gastropod) contain micritic coatings and are commonly leached and then filled with blocky calcite (Figure 10B) or blocky ferroan carbonate. In some places (Perry Farm, Amoret-S), compaction is displayed by great reduction in original void space, and grain fractures, which are usually filled with ferroan carbonate (Figure 9B). Neomorphism of pelecypod fragments was also observed. Within these shells large lath-like calcite or ferroan carbonate crystals follow the contours of the original shell structure (Figure 9B, 12B). Also, at the Amoret-South locality replacement of most of the grains including crinoid fragments, by patches of microspar converted to ferroan carbonate gives this rock an overall ragged

appearance, which is partly due to overcompaction (Figure 12A,B). The echinoderm fragments are lacking any obvious overgrowths and the edges show slight dissolution.

Sandy Skeletal Calcarenite Facies

The sandy skeletal calcarenite facies, which occurs at the Lost Creek, Elk Creek and Trading Post localities of Linn County, Kansas, is a fairly well sorted, skeletal calcarenite much like the previously described facies, but with abundant quartz grains (Figure 13A,B).

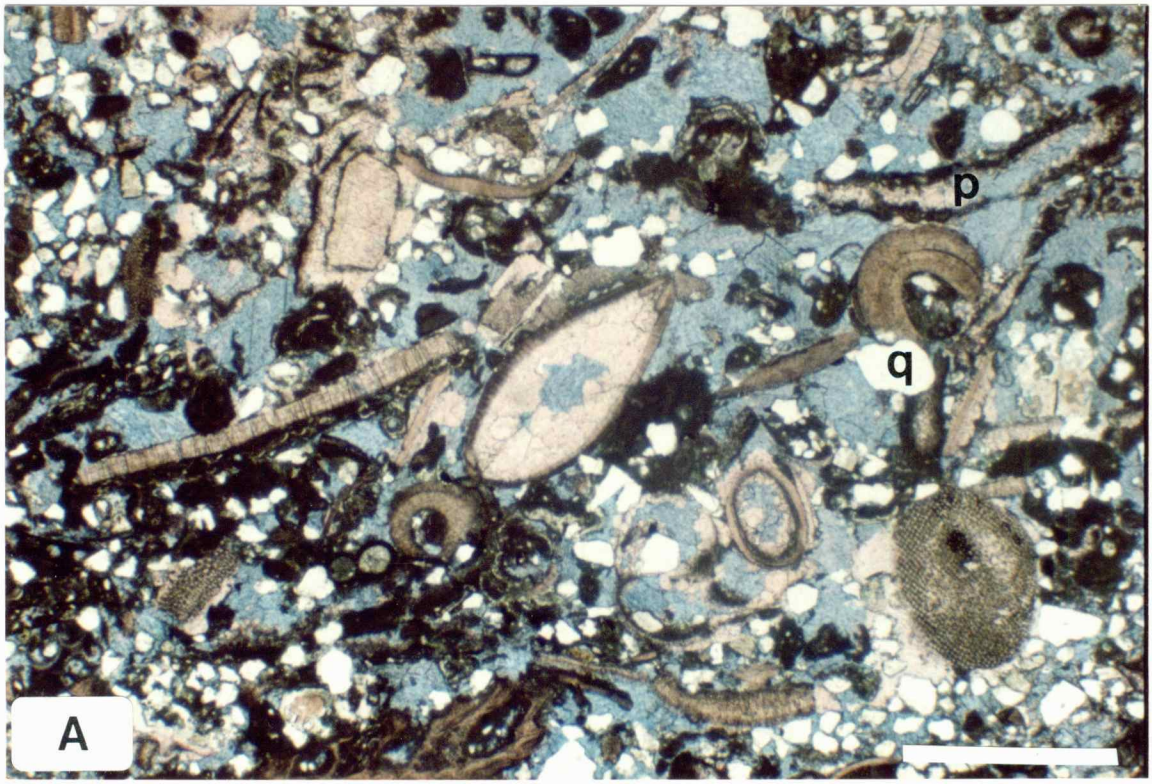
The skeletal fragments consist of a diverse normal marine fauna, but constitute only 20-30% of the entire rock. In order of abundance the fragments include crinoids (2-30%) predominantly at Elk Creek and Lost Creek (Figure 14A,B), brachiopods, both punctate and pseoudopunctate (5-10%) predominantly at Trading Post (Figure 15A,B), bryozoans (1-4%), foraminifers both encrusting and free (1-2%), brachiopod spines (2%), ostracodes, trilobites, and algae, both red Archeolithophyllum and green dasyclads, each constituting <1%, and abraded cryptocrystalline fragments (6%).

The distinctive feature of this facies is its high percentage of sand-sized, subangular to subrounded quartz grains, which constitute 30-50% of the rock matrix. Other detrital grains, including feldspar, chert and shale

Figure 13. Sandy skeletal calcarenite facies of Norfleet.

A) Sandy skeletal calcarenite with abundant quartz sand grains (q). Ostracode (arrow) beautifully displays early interior rims of bladed to blocky calcite cement, and later infilling by ferroan carbonate cement. Pelecypod shell (p) has been leached and filled with blocky calcite and blocky ferroan calcite cement. Also syntaxial overgrowths on crinoid fragments. Section: Trading Post L-L1, plane light, bar scale=1.0mm.

B) Pelecypod shell with micritic coating and encrusting forams surrounding it (p). Shell has been leached and filled with blocky calcite cement. Late stage fracture cutting across shell and underlying calcite-cemented debris is now filled with ferroan carbonate. Section: Trading Post L-L1, plane light, bar scale=1.0mm.


p
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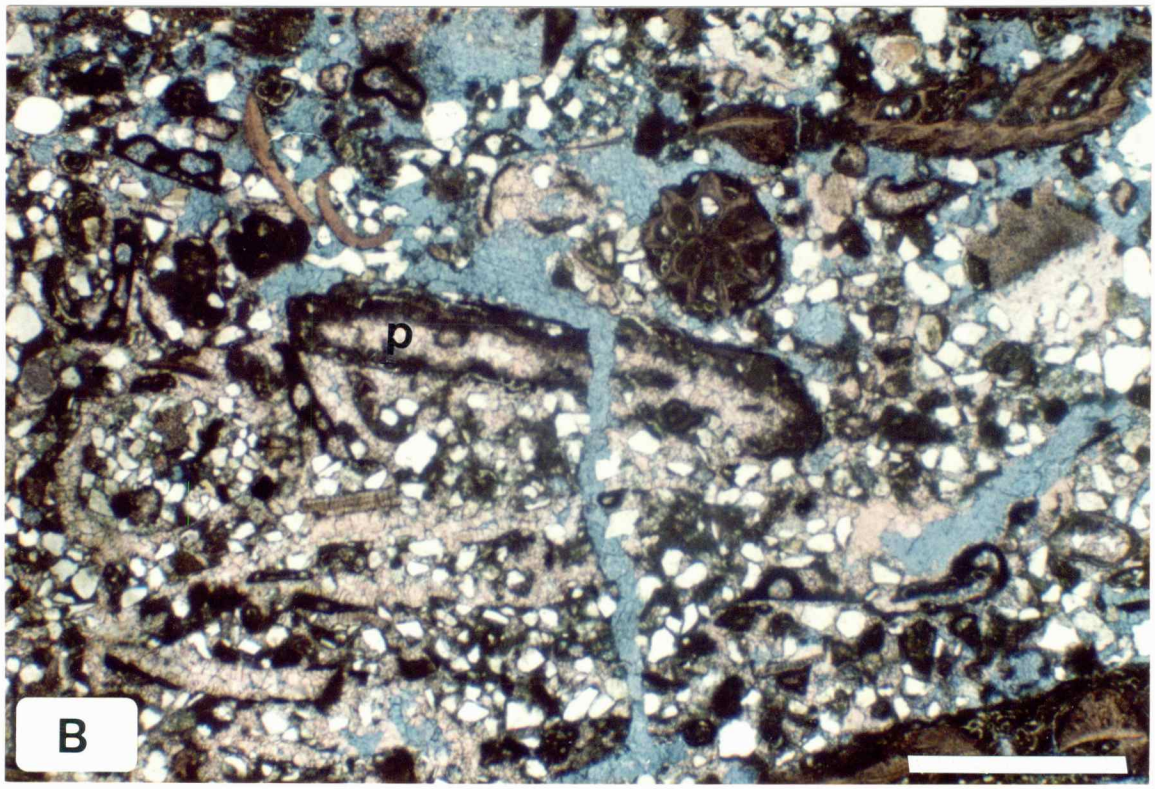
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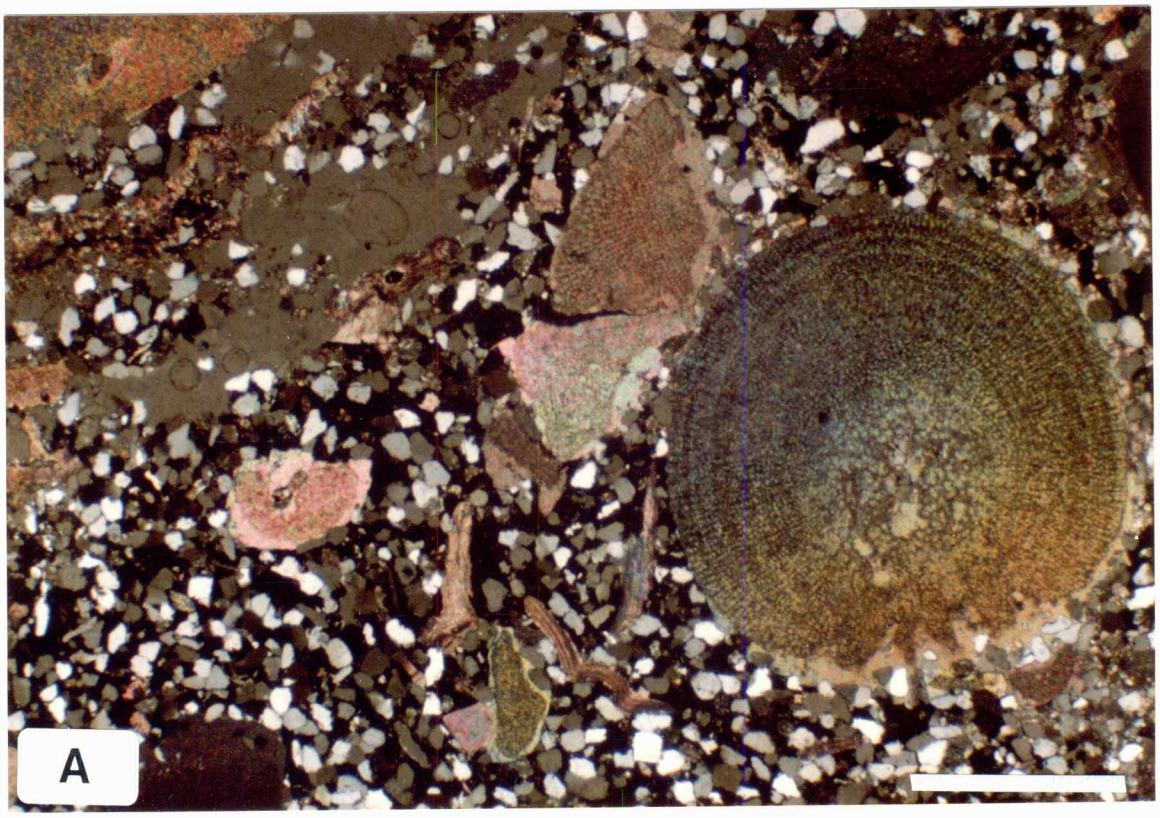
Figure 14. Sandy skeletal calcarenite of Norfleet.

A) Showing abundance of both sand-sized quartz grains and crinoidal fragments. Quartz grain boundaries show slight suturing, and crinoid fragments display syntaxial overgrowths. Section: Elk Creek-b, cross-polarized light, bar scale=1.0mm.

B) Crinoidal fragments showing large syntaxial overgrowths (o) of calcite. Also shows diverse marine fauna. Section: Lost Creek 5-u, cross-polarized light, bar scale=1.0mm.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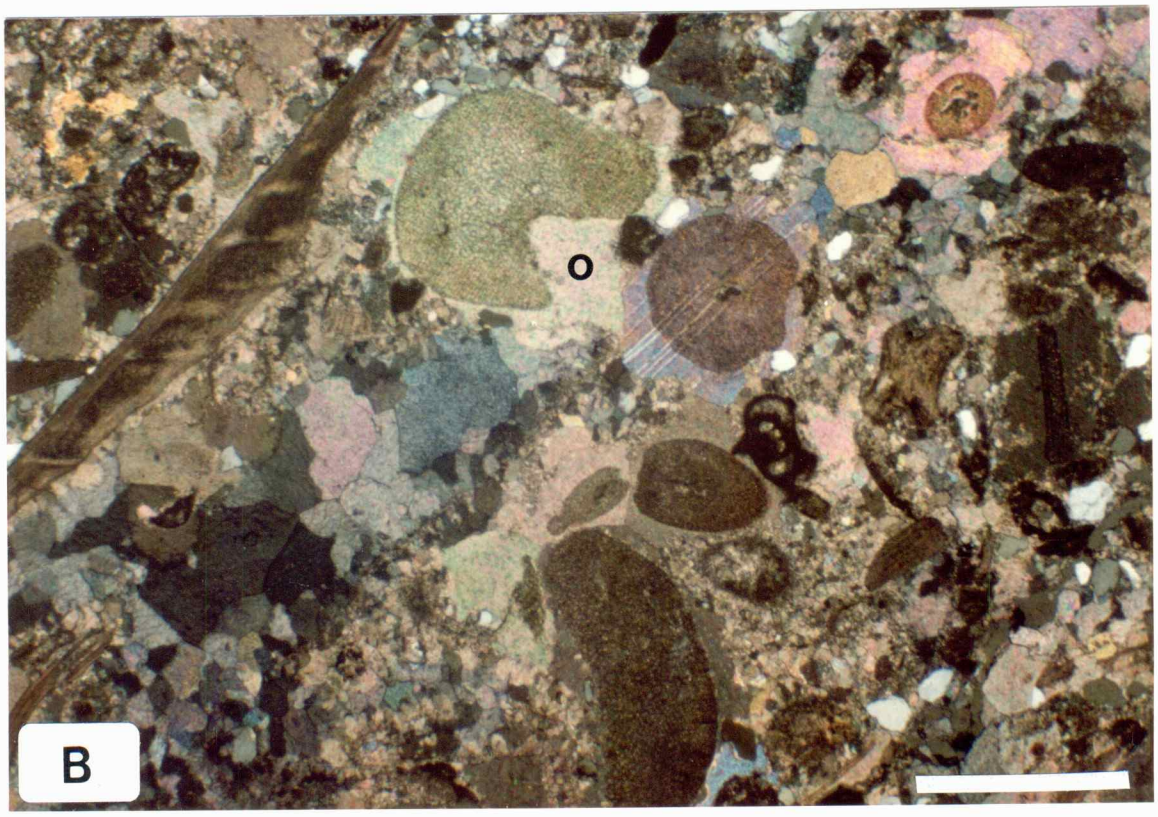
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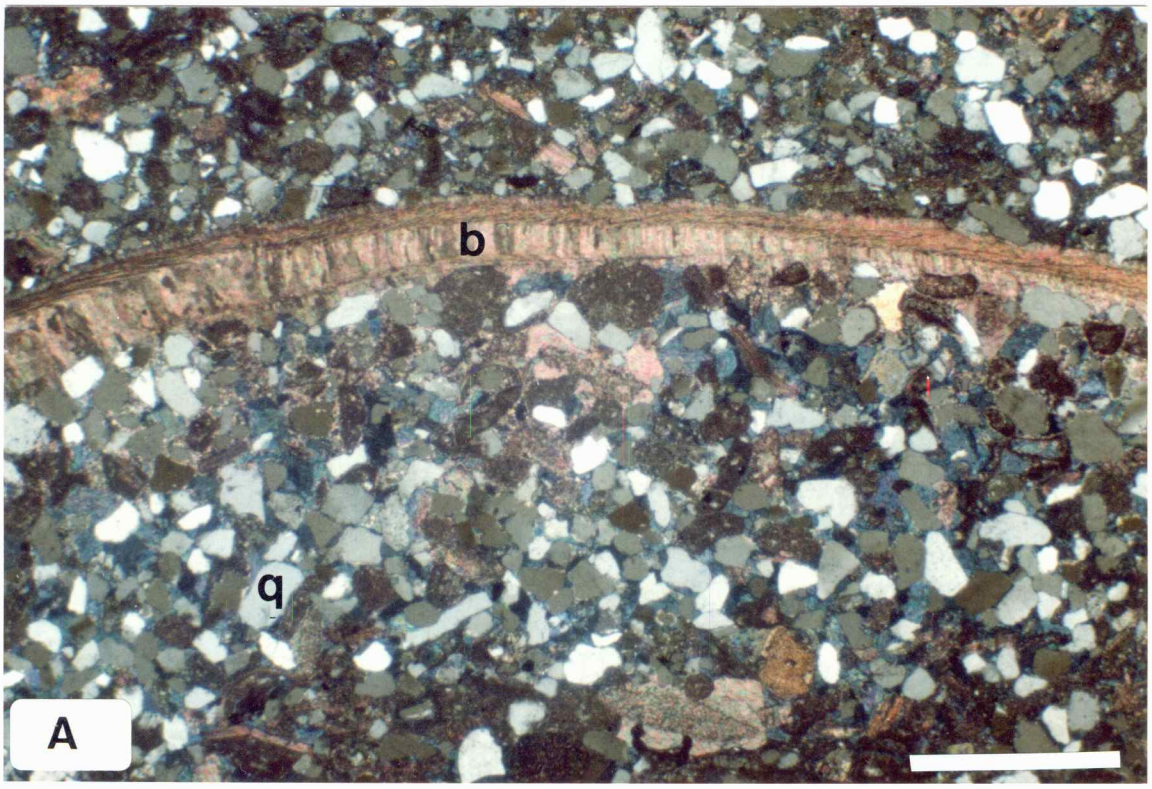
Figure 15. Sandy skeletal calcarenite facies of Norfleet.

A) Note abundance of detrital sand sized quartz grains (q), and large brachiopod shell (b). Early cement overgrowths on scattered echinoderm fragments and late stage ferroan carbonate in matrix. Section: Trading Post L-T1, polarized light, bar scale=1.0mm.

B) Note encrusting forams on brachiopod shell, with intragranular voids (arrow) of forams lined with isopachous rims of calcite followed by ferroan carbonate cements. Brachiopod shell shows bladed calcite cement along interior (b). Intergranular void space mostly filled with ferroan carbonate cement. Section: Trading Post L-L1, plane light, bar scale=0.5mm.


b
q
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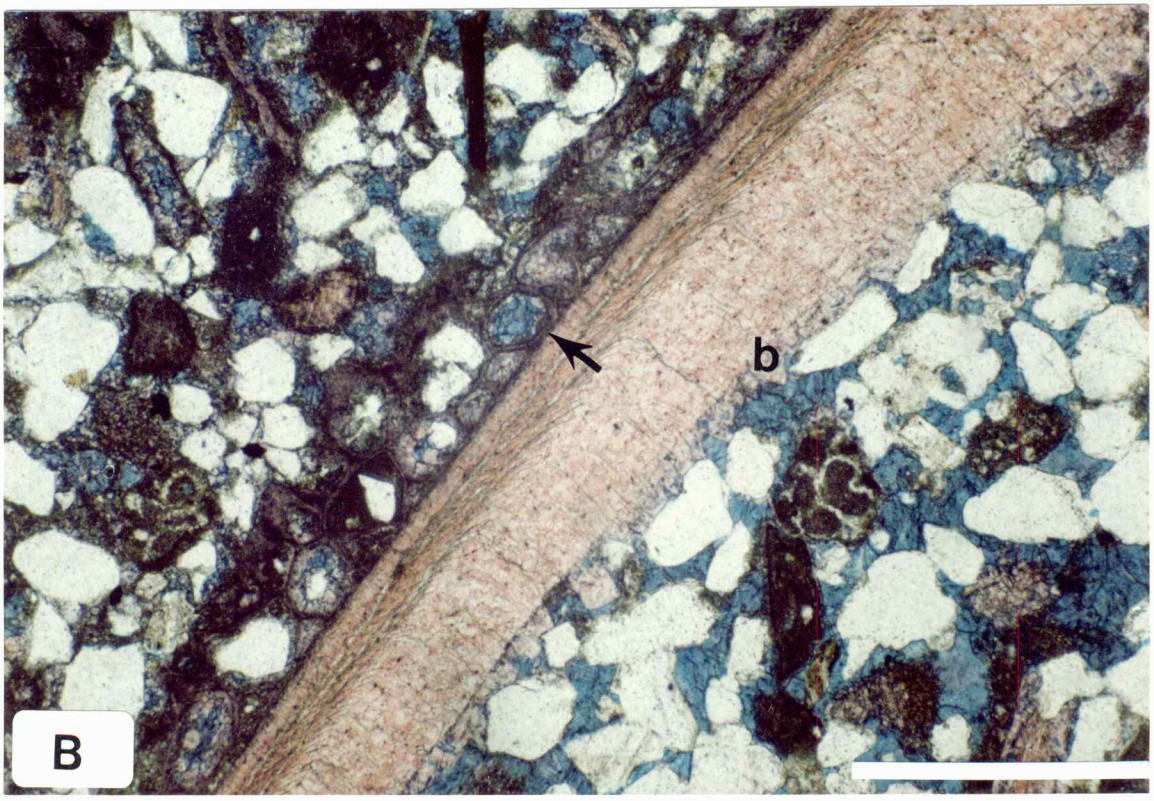
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particles, along with authigenic glauconite grains, are found scattered throughout this facies, totaling less than 1% of the rock.

Both intragranular (Figure 16) and intergranular porosity (Figure 13A,B, 15A,B) are filled with patches of blocky calcite (2%), and ferroan carbonate (12%). Microspar (30%) is found in the matrix. One intrashell void filling is beautifully displayed in an ostracode (Figure 13A), where it consists of rims of early bladed calcite followed by blocky calcite and ferroan carbonate, with all crystals increasing in size towards the center. Others are filled with a combination of micrite and silt particles.

The unstable mollusc fragments and dasyclad algae have been leached and replaced with blocky calcite (Figure 13A) and ferroan carbonate, while the more stable carbonate fragments (echinoderms, brachiopods) remain compositionally unchanged.

The rock has been slightly compacted as seen by the suturing of some quartz grain boundaries (Figure 14A). Micritic coatings, sometimes with the addition of encrusting forams (Figure 13B, 15B), surround many of the skeletal fragments. Early cement is displayed as bladed isopachous crystals around some brachiopod shells (Figure 15B), and all the crinoid fragments contain syntaxial overgrowths (Figure 13A, 14A,B, 16). Late-stage fractures cutting across shell

Figure 16. Sandy skeletal calcarenite of Norfleet with bryozoan. Shows intergranular and intragranular void space filled with different amounts of calcite cement, followed by ferroan carbonate cement both within bryozoan fragment and around other grains of rock. Section: Elk Creek-m, plane light, bar scale=1.0mm.

fragments (Figure 13B) are now filled with ferroan carbonate.

At the Trading Post locality, the amount of sand and microspar increase upward, while the amount of shell material and sparry cement decreases. At the Elk Creek and Lost Creek localities, the amount of sand decreases upward, while the amount and diversity of skeletal fragments and also of sparry calcite and ferroan carbonate cement increases, therefore making the rock more of a grainstone.

Algal-Coated Calcarenite

The basal limestone at the Lost Creek locality (LTC) in southern Linn County, Kansas, is the only locality where this facies is observed. It is a poorly sorted, moderately compacted, algal-coated skeletal calcarenite. The coated grains compose over 50% of the rock, and a wide variety of grain types occur as the nuclei for the algal coated grains. The skeletal grains reflect a diverse marine fauna, including brachiopods (5%), molluscs (5%), foraminifers (3%), dasyclad algae, and Archeolithophyllum, ostracodes, brachiopod spines, bryozoans, and crinoids, each at 1% or less (Figure 17A). Unidentified abraded cryptocrystalline fragments dominate the grains at approximately 15%.

The coatings found on most grains are composed dominantly of micrite (Figure 17A). Some coatings display

well preserved endolithic algal tubes (Figure 17B). Others have layers of encrusting forams (Figure 17A), and most incorporate silt-sized quartz particles. The coatings appear in some cases to be thicker on the tops of shells, but in other cases they are equal in thickness around the entire grain. The grains that do not have this coating usually contain a micritic envelope around the exterior of the grain.

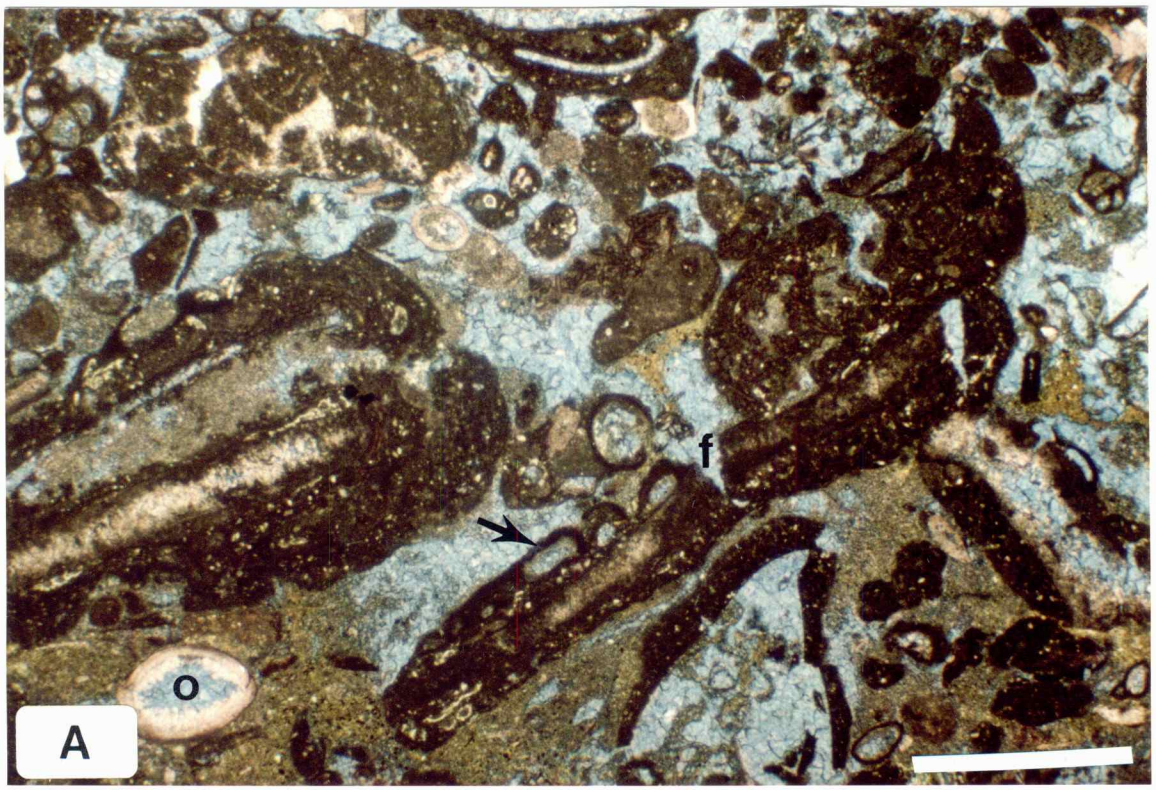
Unstable grains within this facies include originally aragonitic gastropods, bivalves and dasycladacean algae. Little relict structure was preserved, and identification was based primarily on their external grain shapes preserved by surrounding micritic envelopes and algal coatings. The stable brachiopod, crinoid, and ostracode fragments remain unaltered.

Original pore space within the algal-coated facies include both intergranular and intragranular pores. The intergranular pore space is filled predominantly by ferroan carbonate (revealed by staining), some patches of peloid microspar, and syntaxial overgrowths on crinoids (Figure 17A), while intragranular pore space may be filled with calcite, ferroan carbonate or microspar (Figure 17A,B). Molluscan grains are filled with blocky calcite along the edges and ferroan carbonate towards the center, with crystal size increasing toward the centers. The rock does show some

Figure 17. Algal coated calcarenite facies of Norfleet.

A) Note variety of grain types serving as nuclei for algal coatings, and in some areas encrusting forams (arrow). Also fractures (f) wedging downward, which suggests compaction. Late stage ferroan carbonate fills both intragranular and intergranular void spaces. Note interior of ostracode shell (o) with an isopachous rim of calcite followed by ferroan carbonate. Section: Lost Creek 3-b, plane light, bar scale=1.0mm.

B) Close-up of upper right of A, showing endolithic algal tubes (a) entwined with silt sized quartz particles. Bar scale=0.5mm.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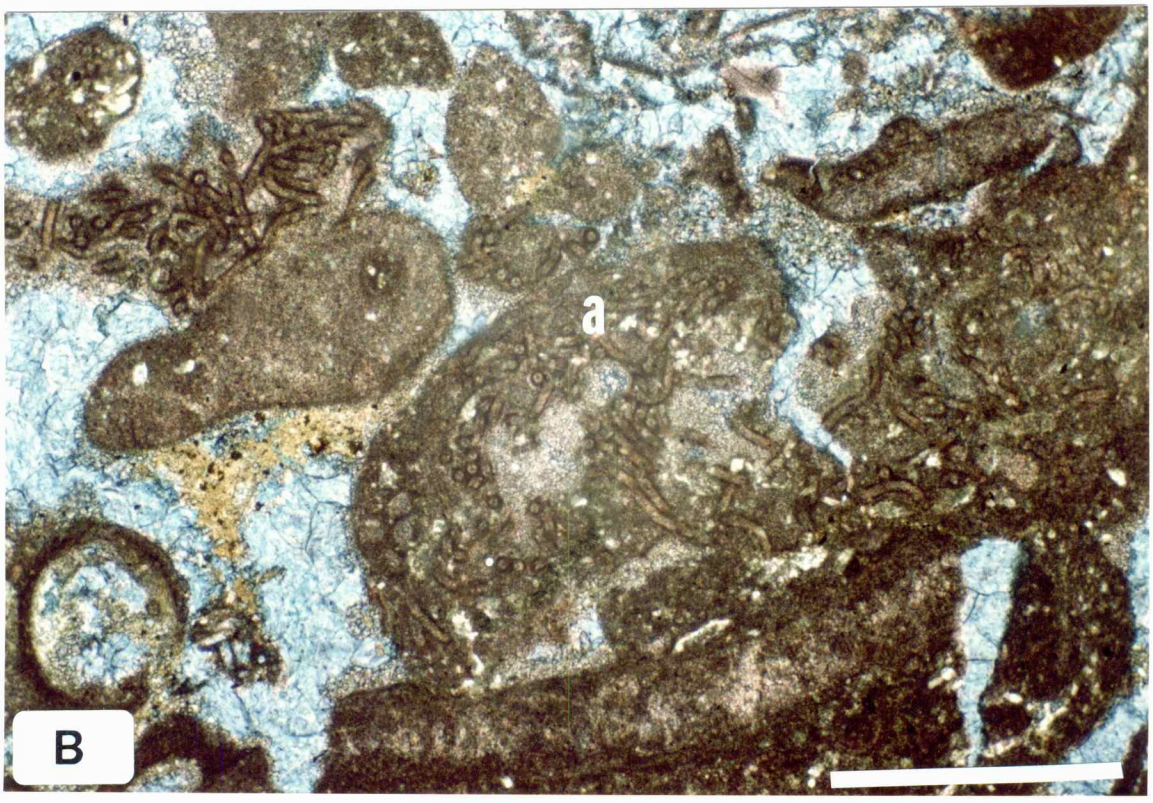
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signs of compaction as observed by the broken grains with fractures wedging downward (Figure 17A,B).

Upward in this facies, the percentage of dasycladacean and Archeolithophyllum algae increases. Also the size of skeletal grains and the amount of interstitial blocky ferroan carbonate cement decrease as the amount of matrix and skeletal fragments increases as the entire facies grades into the overlying sparse skeletal calcilutite, which is described in detail in the next section.

Skeletal Calcilutite

The skeletal calcilutite facies is constitutes the entire Norfleet at the Grundy County locality (GRD), and in CP37 core in Iowa; the top bed of type Norfleet (MVNE), top of lower bed at Lost Creek (LTC), base of main ledge at Owl Creek (OC), and entire lower bed at Amoret-South (AMS) localites. This facies is a sparsely fossiliferous skeletal wackestone, supported predominantly by lime mud or microspar with little or no spar cement (Figure 18A). Although the skeletal fragments present in this facies are much less abundant than the other facies, ranging from 20-50%, the biota is just as diverse. The fauna includes; crinoids (5-10%), brachiopods (3-8%), bryozoans (5%), brachiopod spines (1%), foraminifers (1%), trilobite fragments (1%), ostracodes (1%), and mollusc fragments (<1%). A

distinguishing feature of this facies is presence of many small (.5mm) elongate and circular shapes made up of ferroan carbonate. It is believed they were originally sponge spicules, possibly composed of silica, now replaced with ferroan carbonate (Figure 18B). At the Grundy County, Missouri, locality, some of the trilobite fragments, bryozoan and brachiopod grains are ferroan calcite (Figure 18A).

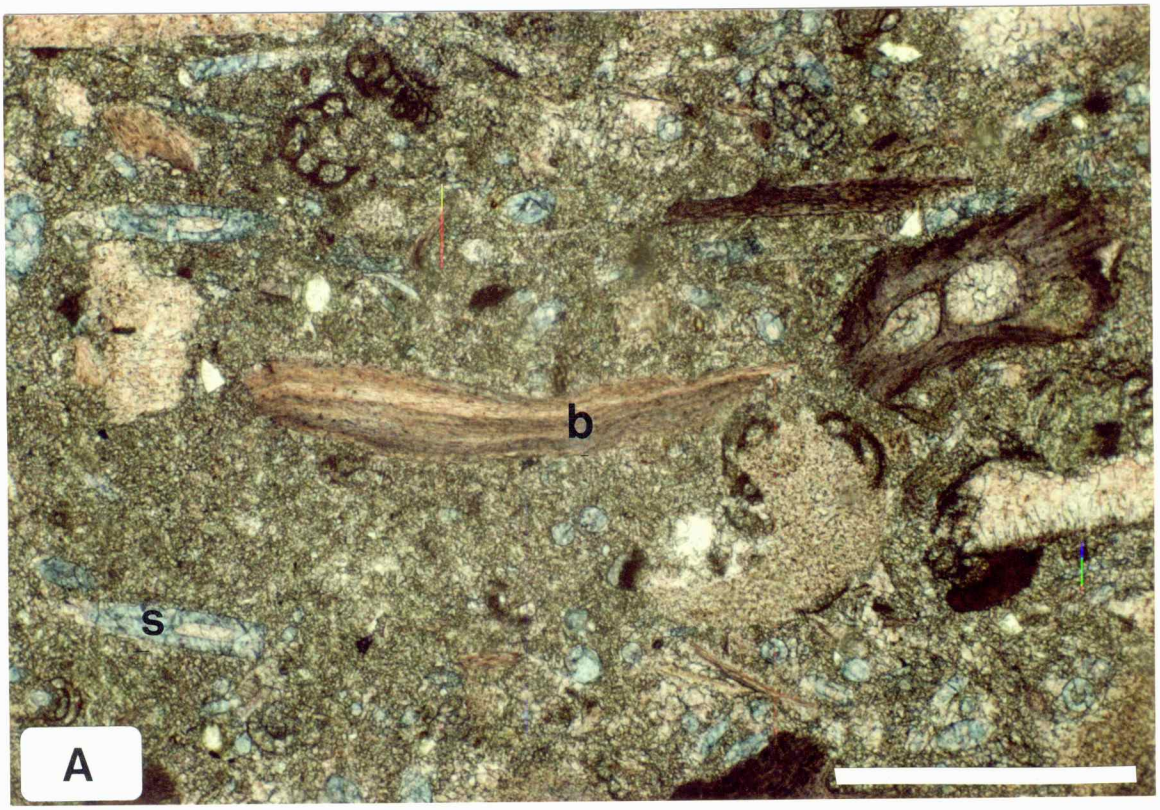
The matrix is predominantly microspar with much carbonate silt (Figure 19) and ranges from 50-80% of the rock. The fine nature of the matrix makes it hard to distinguish much in the way of diagenetic patterns, but compaction is observed by stylolites (Figure 18B), and it is thought that the original matrix was micrite with carbonate silt grains now largely converted to microspar. Some brachiopod shells display thin early isopachous rims of bladed calcite (Figure 19). Some voids have been filled with blocky calcite and blocky carbonate cements (Figure 18A,B, 19).

Skeletal fragments decrease upward in the upper portion of the basal limestone at Lost Creek. In contrast, skeletal grains and spar cement increase upward in the main ledge at the Owl Creek locality of eastern Kansas, where it grades into skeletal calcarenite.

Figure 18. Skeletal calcilutite facies of Norfleet.

A) Mud supported, sparsely fossiliferous skeletal calcilutite. Ferroan calcite composes both brachiopod shell (b) and bryozoan fragment. Also note leached sponge spicules (s) now filled with ferroan carbonate. Section: Grundy-L, plane light, bar scale=0.5mm.

B) Showing elongate and circular forms thought to be sponge spicules now replaced by sparry ferroan carbonate (s). Also showing a stylolite resulting from compaction (arrow). Section: Mound Valley North East Nf-t, plane light, bar scale=0.5mm.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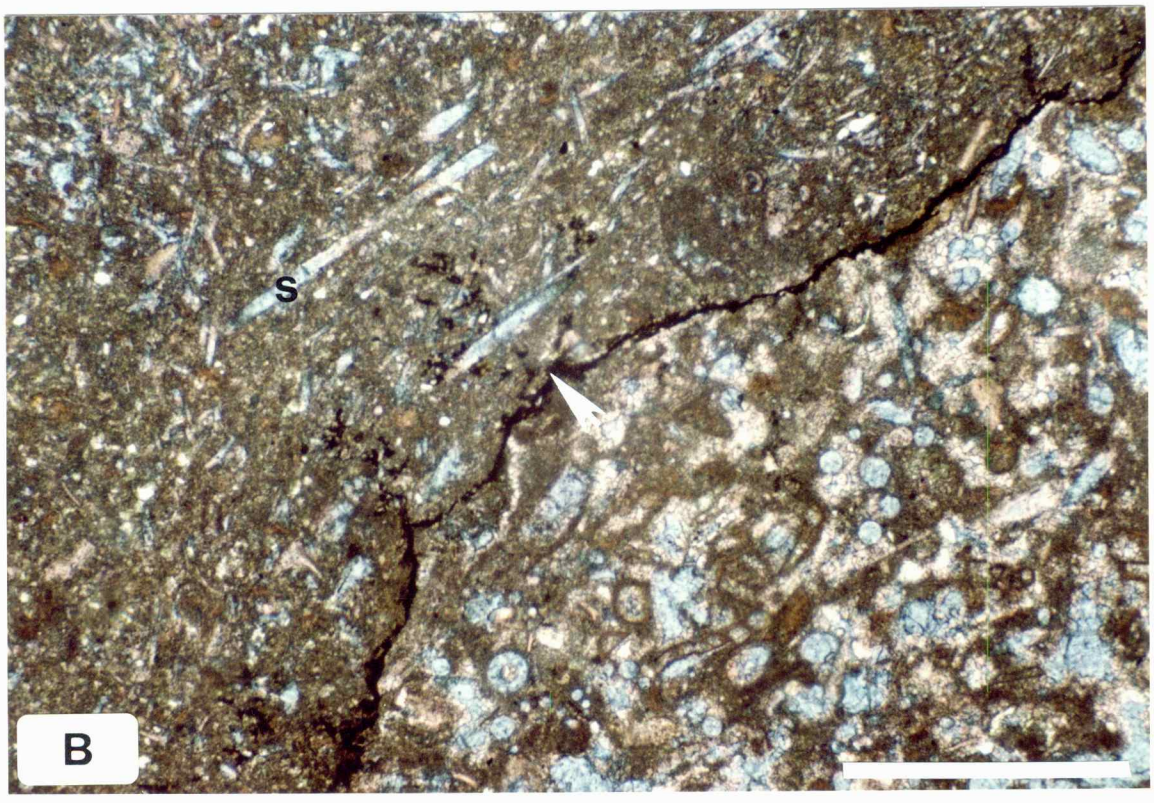
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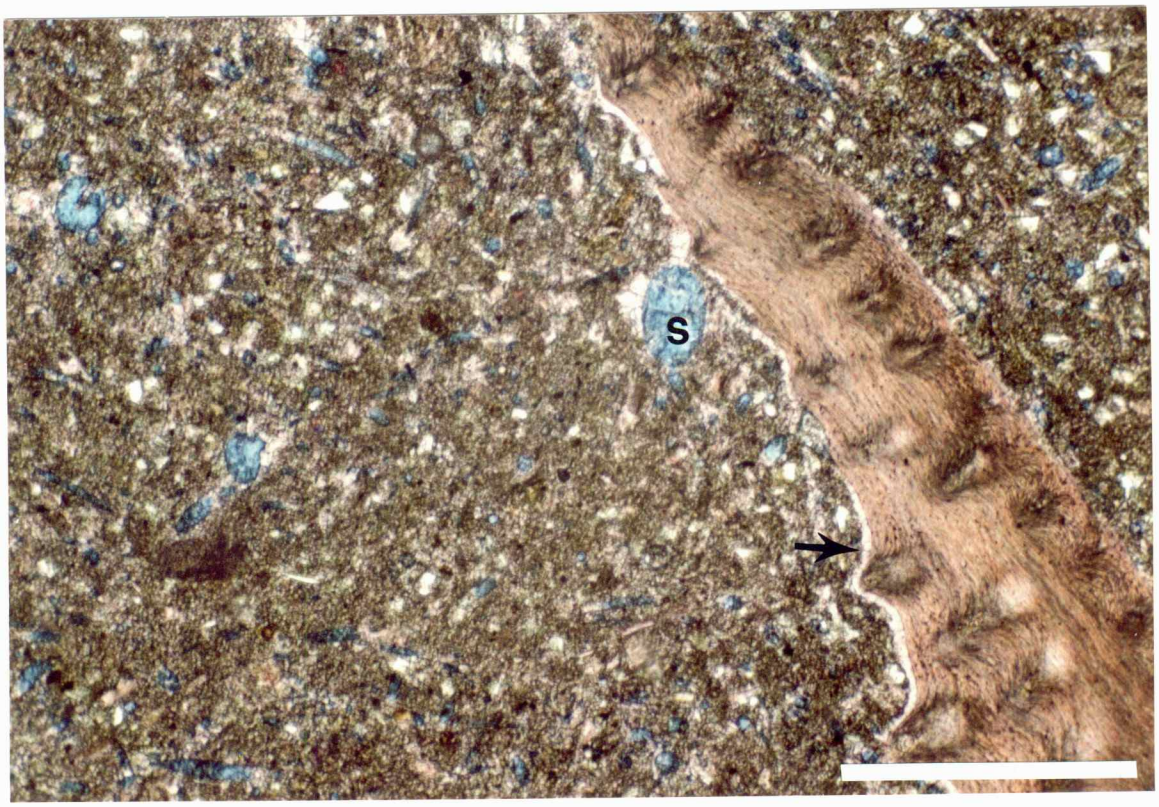
Figure 19. Skeletal calcilutite facies of Norfleet. Isopachous rims of calcite cement surrounding edges of pseudopunctate brachiopod shell (arrow). Note matrix composed predominantly of microspar with carbonate silt grains (cloudy white), scattered quartz silt grains (clear white), and leached sponge spicules now filled with ferroan carbonate (s). Section: Lost Creek 3-u, plane light, bar scale=0.5mm.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Shale Facies

The grey shale facies of the Norfleet, found at the type Idenbro (TI), and below the main limestone ledges at Owl Creek, Lost Creek, and Amoret-south localities, contains an abundance of marine carbonate shells observed after disaggregation in Stoddard's Solvent. The biota includes an abundance of brachiopod shells, crinoid fragments and conodonts, with lesser amounts of bryozoan and coral fragments. Much unidentifiable shell material is present.

Prong Creek Locality

At the Prong Creek locality (PRC) in southwestern Bourbon County, a thin (0.1 foot) ledge of micrite-coated calcarenite occurs 2 feet above the main ledge of the Norfleet in the Perry Farm Shale (Figure 20). This calcarenite is somewhat different from any of the other lithologies in that petrographic analysis shows that there is a greater amount of skeletal grains, particularly pelecypods, and many grains display a thin micritic coating not common in the other localites. There is more compaction, and the intragranular void space is filled with microspar or finely crystalline clear spar unlike the other facies, in which void space is usually filled with coarser blocky calcite or blocky ferroan carbonate cement. Even though it occurs 2 feet above the base of the Perry Farm

Shale, this lenticular bed is grouped with the lithofacies of the Norfleet Member, because its lithology is closer to that of the Norfleet calcarenites than to the carbonates in the Perry Farm Shale.

Perry Farm Shale Member

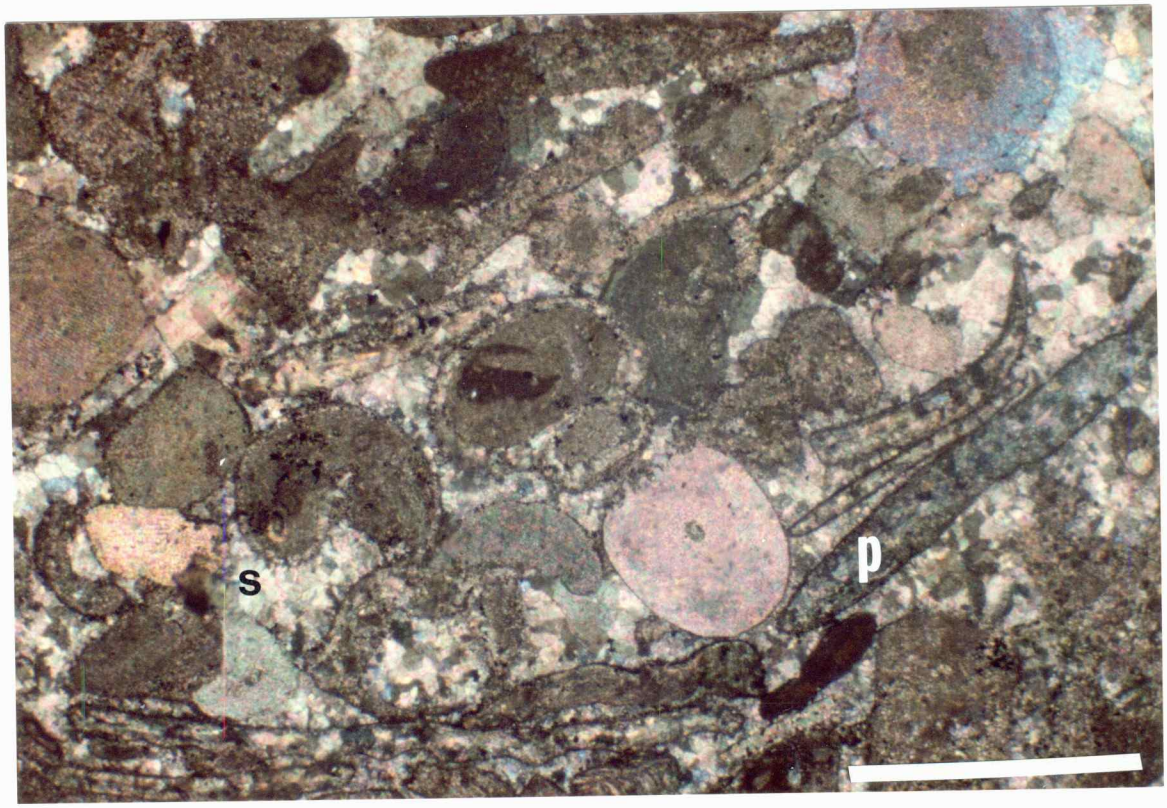
The Perry Farm Shale Member of the Lenapah Limestone comprises two lithofacies: 1) a silty shale containing many flaggy limestone beds and nodules in southern Kansas (Labette and Neosho counties); 2) sandy shale with thick lenses of fine-grained sandstone, in Bourbon County, Kansas (Figure 8).

Silty Shale with Limestone Nodules

The greenish-grey silty shale of the southern facies is best exposed at the type Perry Farm and Bachelor Creek localities. It appears devoid of obvious fossil material, although closer examination of the sediment after disaggregation in Stoddard's solvent, reveals small amounts of calcareous debris, including extremely small gastropod, brachiopod and crinoid fragments.

The abundant limestone nodules scattered throughout the shale facies consist of a dense calcilutite (Figure 21). Fossil debris is visible and may actually constitute 5-10% of the nodule, although particles are so fragmented and extremely fine-grained that identification is difficult.

Figure 20. Micrite-coated skeletal calcarenite in lenticular bed 2 feet above main ledge of Norfleet.
Shows neomorphosed pelecypod grains (p), and void space filled with microspar to fine clear spar (s). Section: Prong Creek 3-t, cross-polarized light, bar scale=0.5mm.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Material identified consists of fragmented pieces of pelecypods, gastropods, foraminifers, and sponge spicules ranging from 50-200 microns in length.

The matrix is composed of micrite with some clotted portions, and patches of microspar to fine spar with crystal diameters reaching up to 50 microns in size. Detrital silt grains consisting of subangular to subrounded quartz, along with bits of shale are also present within the matrix.

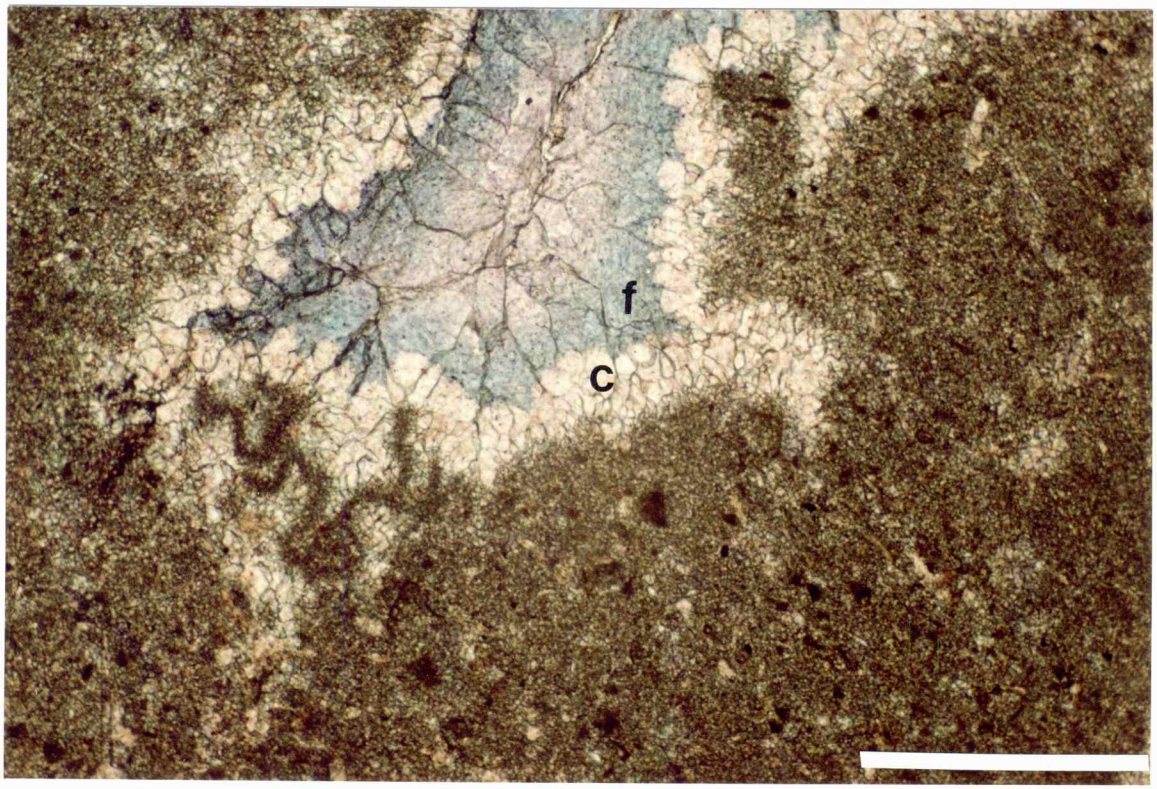
Small irregular lens-like areas within the rock contain high concentrations of broken shell material, silt grains, shale particles and tiny sparry calcite grains, but without micrite.

The most commonly observed diagenetic feature is the conversion of micrite to microspar, and the leaching and subsequent infilling of some of the pelecypod, gastropod, and sponge spicule fragments with blocky calcite and blocky ferroan carbonate. Large irregular spar patches in the rock consist of a rim of blocky calcite followed by ferroan calcite cement (Figure 21).

Sandstone Facies

Northward, the Perry Farm lacks the limey nodular inclusions, but contains buff-grey micaceous fine-grained sandstone, which is well exposed at the Prong Creek and Uniontown East localities. These sandstones were analysed

Figure 21. Limestone nodule in Perry Farm Shale. Showing dense, micritic matrix with tiny shell fragments and silt-sized quartz grains. Irregular spar area is filled with rim of blocky calcite (c), followed by ferroan carbonate (f). Section: Bachelor Creek-nodule, plane light, bar scale=0.5mm.


f
c

in detail by Sutton (1985) as "Hepler" sandstone horizons A and B.

Idenbro Limestone Member

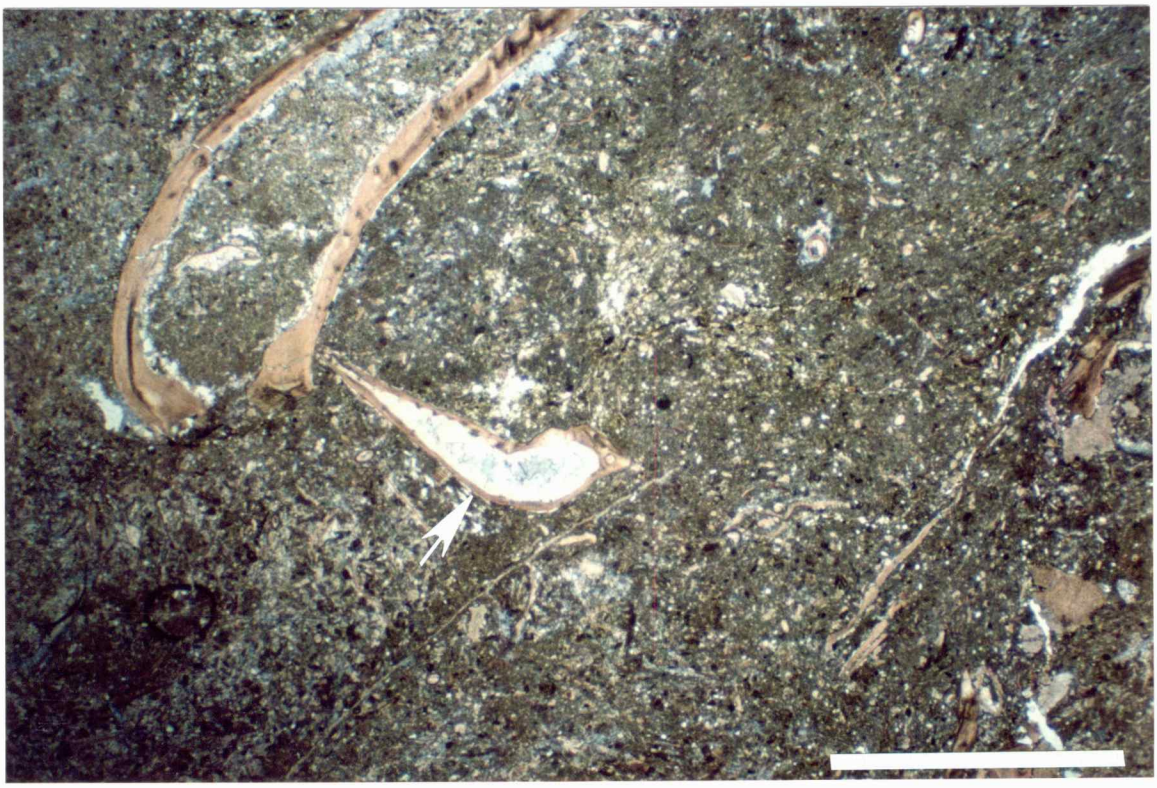
The Idenbro limestone in southeastern Kansas is divisible into two facies, a lower skeletal calcilutite, and an upper muddy skeletal calcarenite (Figure 8).

Skeletal Calcilutite Facies

The skeletal calcilutite found at Mound Valley, Bachelor Creek, Uniontown East, and Elk Creek, is a skeletal wackestone (Figure 22). Compared to similar facies in the Norfleet Member, the skeletal grains are much less abundant and compose only 15-25% of the rock. The skeletal grains, nonetheless are representative of a fairly diverse fauna. The biota includes: brachiopods (5-10%), foraminifers, both encrusting and free living (1-5%), crinoid fragments (0-7%), brachiopod spines (2%), bryozoans (<1-2%), sponge spicules (1%), molluscs, both pelecypods and gastropods (1%), trilobite fragments (1%), ostracodes (<1%), and dasyclad algae (1%).

The matrix composes 65 to 75% of the rock and consists predominantly of micrite, microspar, and incorporated shale particles. At the Bachelor Creek and Elk Creek localities, angular to subangular silt-sized detrital quartz grains constitute 5 to 10% of the matrix (Figure 23B).

Figure 22. Skeletal calcilutite facies of Idenbro. Skeletal wackestone with brachiopod filled with bladed calcite and ferroan carbonate cement (arrow). Section: Bachelor Creek-b, plane light, bar scale=4.0mm.



The spar in this calcilutite usually forms isopachous calcite rims in skeletal grains and fills in both shells and large irregular void areas with bladed calcite, blocky calcite, or blocky ferroan carbonate cement (Figure 22, 23A,B)

The most obvious diagenetic features are the conversion of micrite to microspar, and the leaching and subsequent filling with sparry cement of originally aragonite grains such as gastropods, pelecypods and algal blades (Figure 23A,B). At the Mound Valley North East locality, the matrix contains 10 to 15% of these irregular voids that probably were enlarged after leaching of aragonite grains, before being filled with calcite spar (Figure 23A). At the Uniontown East locality, similar irregular voids are now filled with blocky ferroan carbonate cement (Figure 23B). Compaction was occurring as the interior of the grains were being leached as shown by an ostracode below the fractured mud matrix in Figure 23B.

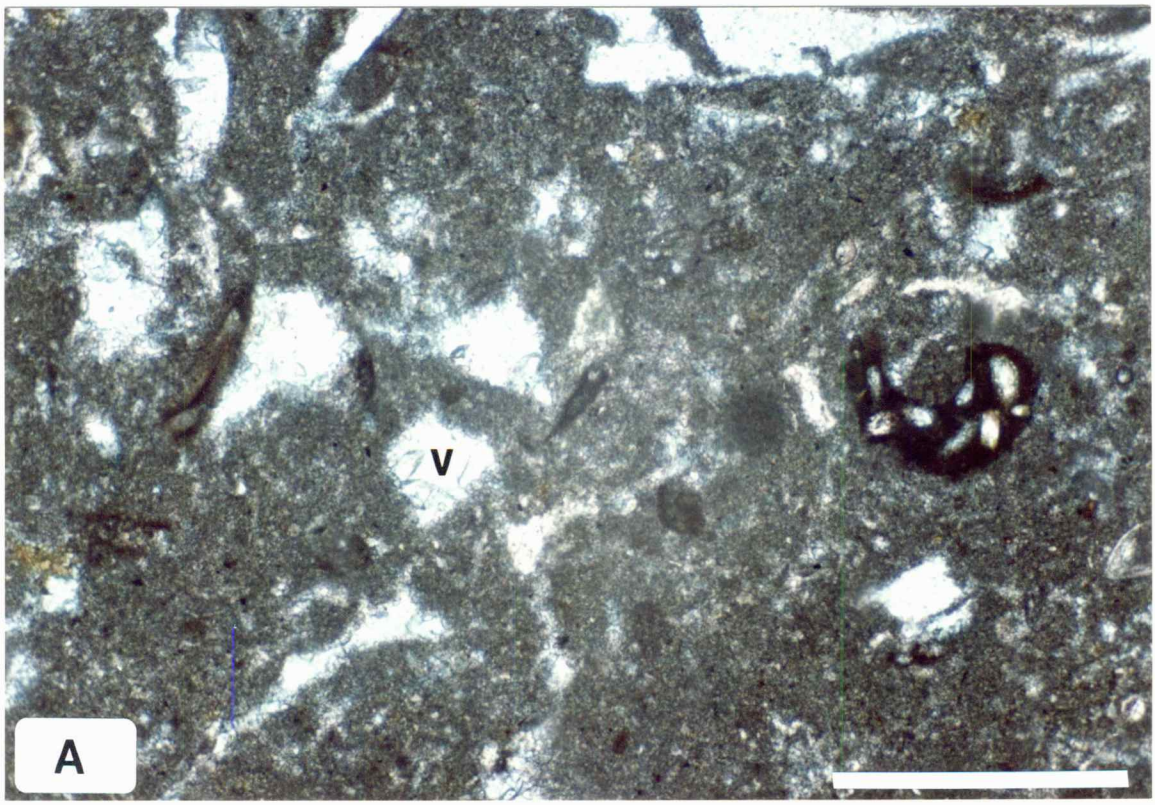
At the South of South Mound locality, parts of the matrix and some of the intragranular void spaces are now replaced or filled with silica (Figure 24).

This calcilutitic facies is last seen northward at the Elk Creek locality in Linn County, Kansas, where skeletal material is also fairly scarce. North of this locality the Idenbro limestone has not been identified, now that the Sni

Figure 23. Skeletal calcilutite facies of Idenbro.

A) Skeletal calcilutite with irregular voids probably formed from meteoric leaching of algal blades and aragonitic shells. Voids are now filled with dogtooth calcite and blocky calcite cement (v). Section: Mound Valley Id-b, plane light, bar scale0.5mm.

B) Similar calcilutite showing irregular voids (v) which may have been areas of algal blades or aragonitic shells enlarged and connected by continued leaching from meteroic water. Some compaction is shown by crushed ostracode shell (c), which happened after leaching and lithification of remaining matrix. Note sand grains in matrix (arrow). Section: Uniontown East, plane light, bar scale=0.5mm.


V
A

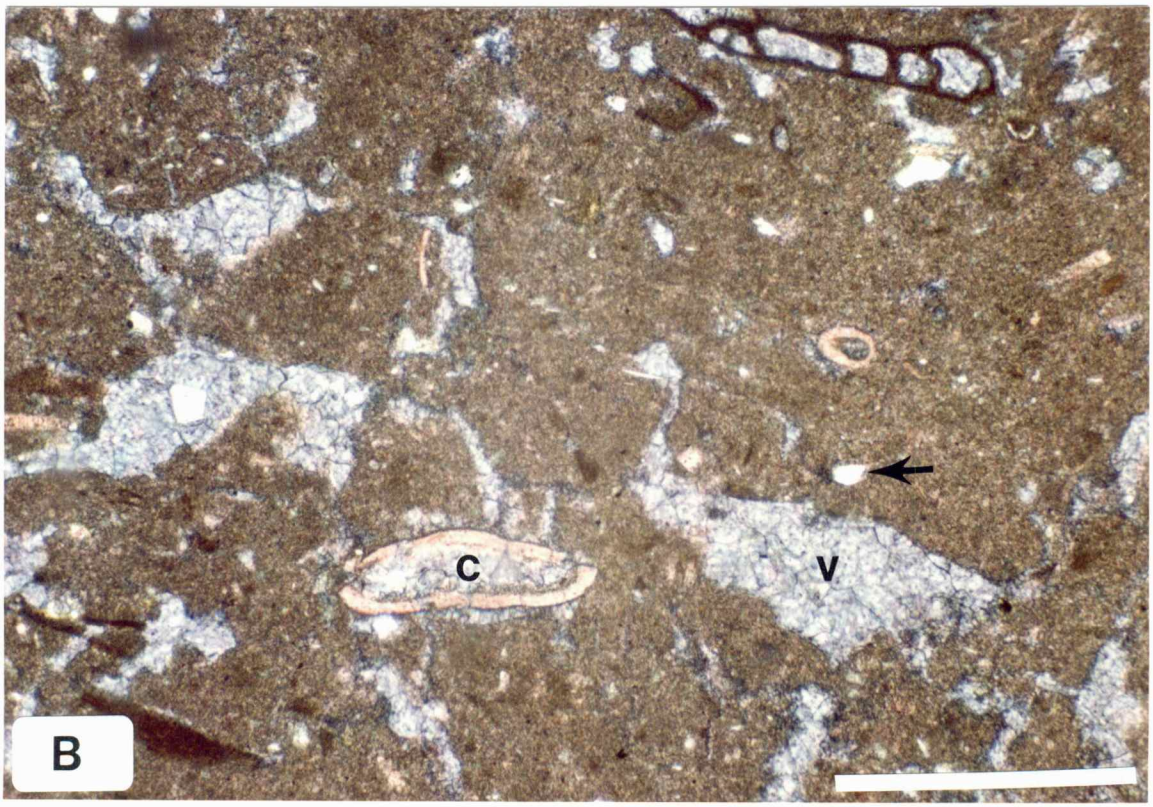
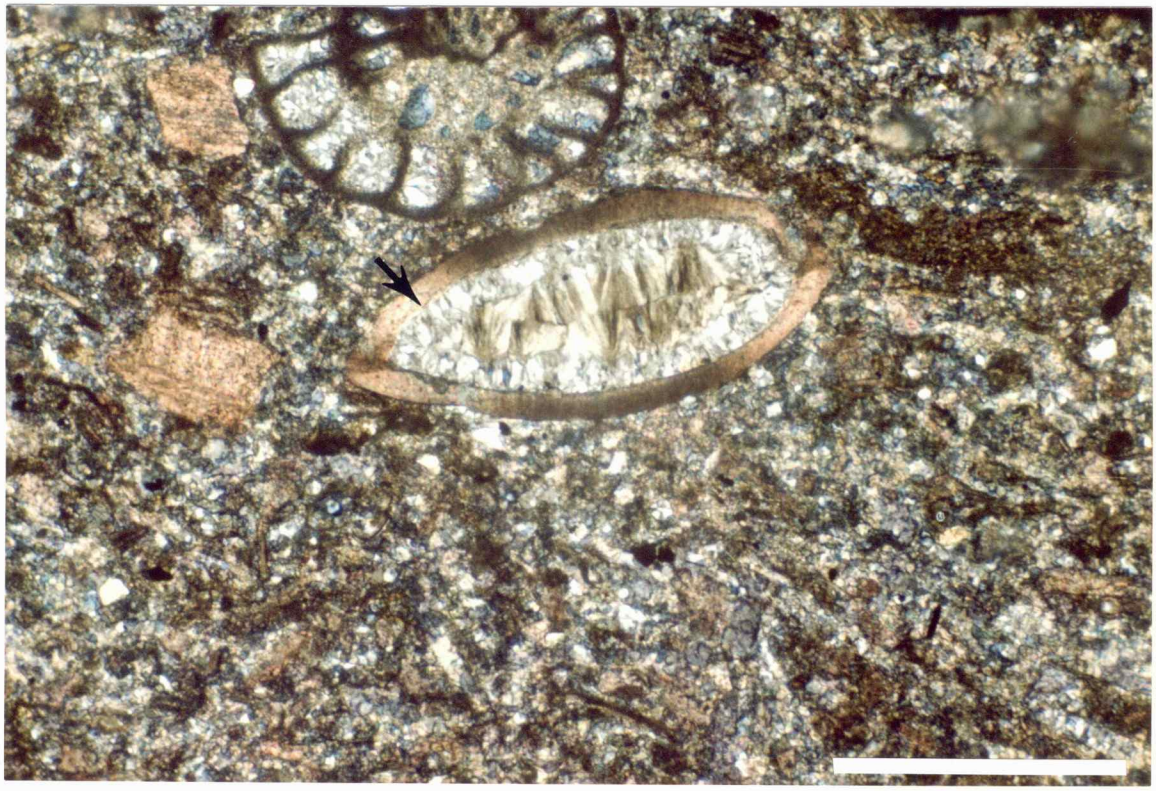

C
V
B

Figure 24. Skeletal calcilutite facies of Idenbro. Shows ostracode with internal void space now filled with silica (arrow). Silica also fills void spaces in foram and matrix. Section: South of South Mound-b, cross-polorized light, bar scale=0.5mm.



Mills Limestone is known to belong to the overlying Lost Branch Formation. The Idenbro apparently pinches out between Elk Creek and Trading Post, where a coal bed and underclay above the Norfleet is thought to be its equivalent.

Muddy Skeletal Calcarenite Facies

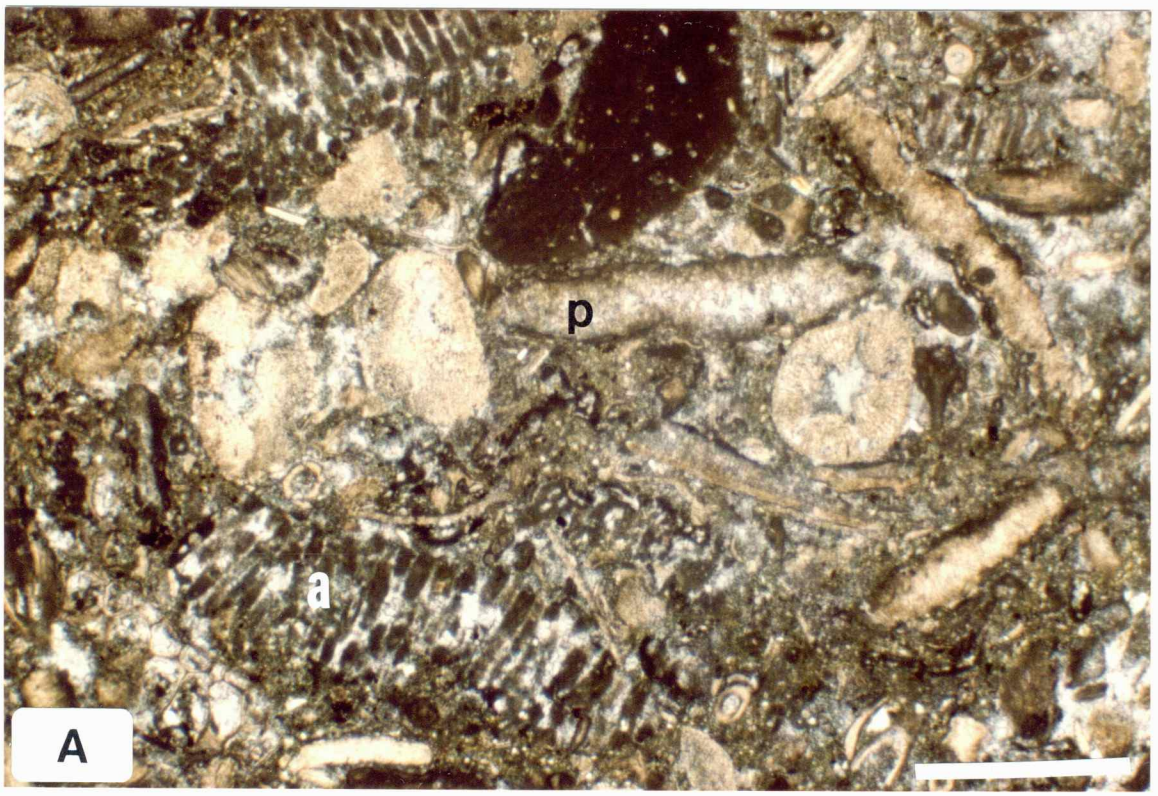
The upper facies of the Idenbro Member, is found in only a few localities (Mound Valley North-East, Bachelor Creek, Flat Rock Creek) in southeastern Kansas. It is distinguished from the lower facies by its greater amount of skeletal grains and spar cement and resultant decrease in matrix. This rock is a poorly sorted, moderately to poorly washed skeletal packstone with subequal amounts of micrite and spar cement in the matrix (Figure 25A,B).

The skeletal grains represent the same biota as in the lower unit, but the overall percentage of grains increases to approximately 35 to 50%. The biota includes brachiopod spines (2-4%), dasyclad green algae (2%), brachiopods (5-10%), bryozoans (3-6%), foraminifers (7-10%), crinoid fragments (5%), molluscs, both gastropods and pelecypods (3%), ostracodes (1%), echinoderm spines (<1%), sponge spicules (2%), and unidentifiable shell material (5%). At the Mound valley North East locality, large brachiopod spines compose a high percentage of the skeletal grains (Figure 26A).

Figure 25. Muddy skeletal calcarenite facies of Idenbro.

A) Diverse fauna found in packstone facies of the upper Idenbro. Note micritic coating and encrusting forams around pelecypod shell (p). Also note that dasyclad algae (a) and pelecypod shell have been leached and later filled with blocky calcite cement. Section Flat Rock Creek-m, plane light, bar scale=1.0mm.

B) Poorly sorted packstone showing leaching of aragonitic shells (g), which have later been filled with blocky calcite cement and followed in some places by ferroan carbonate cement. Section: Flat Rock Creek-u, plane light, bar scale=0.5mm.


p
a
A

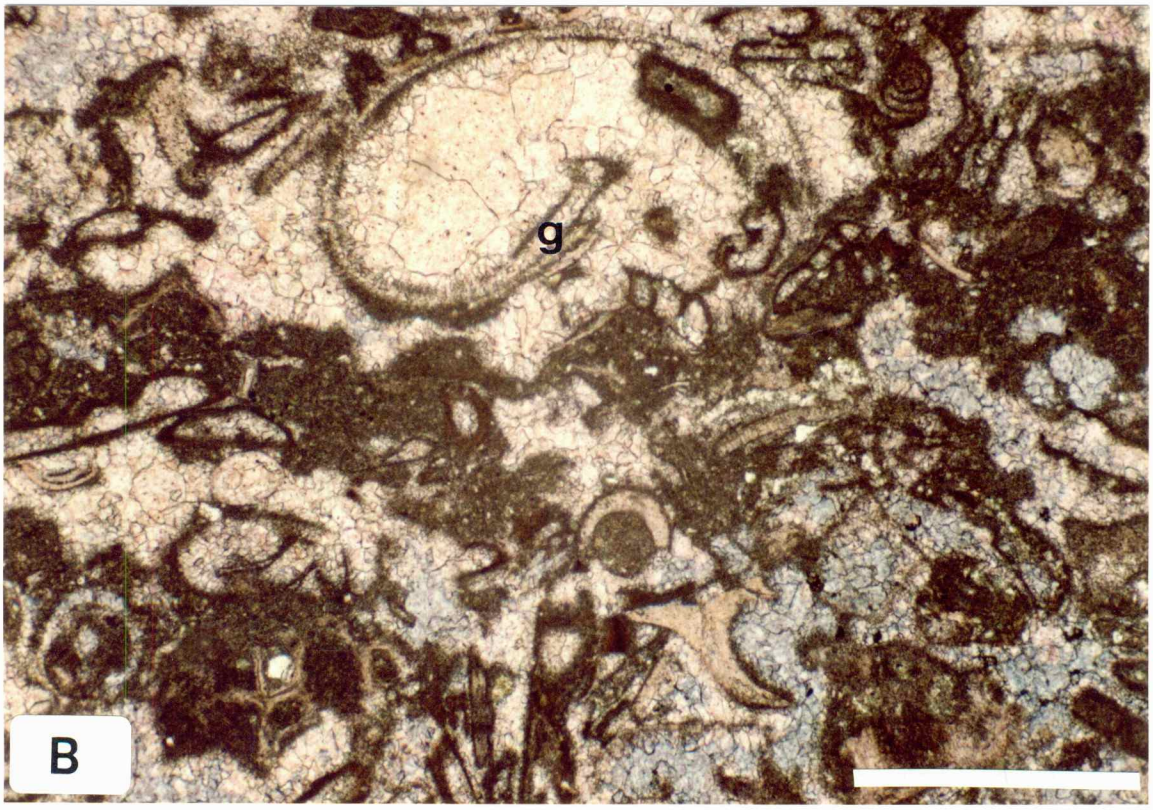
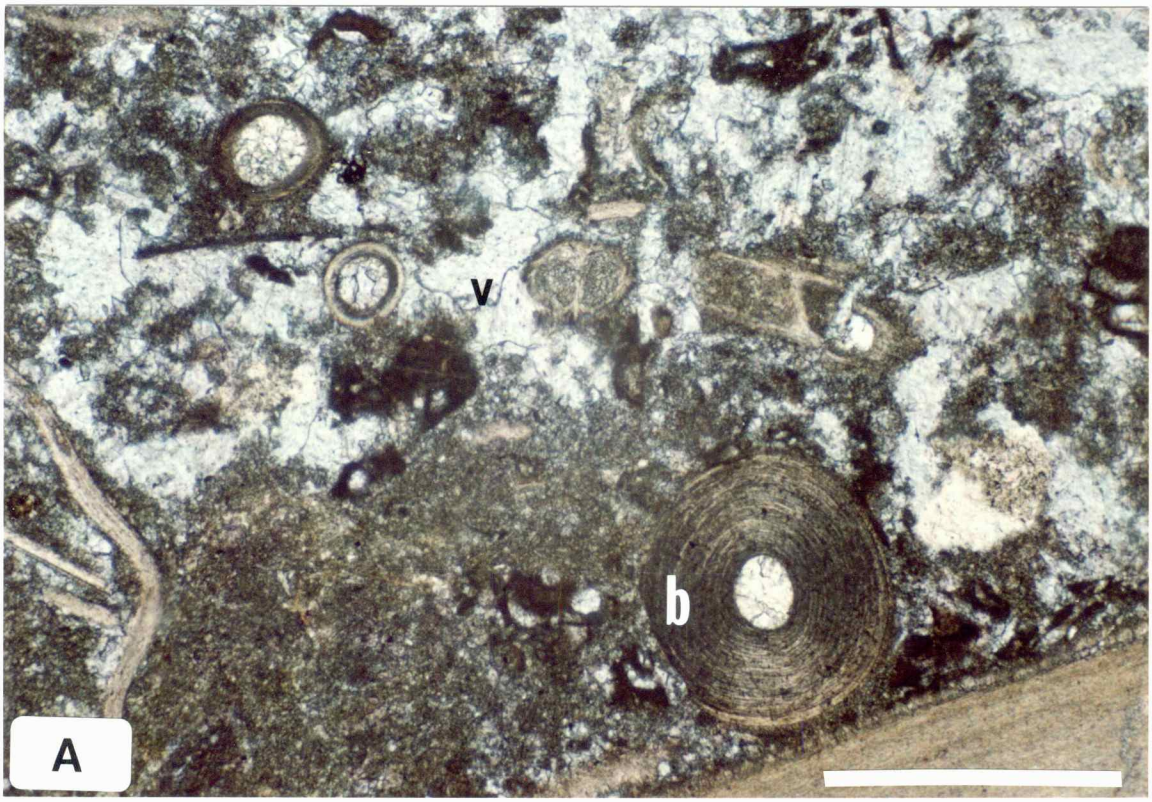
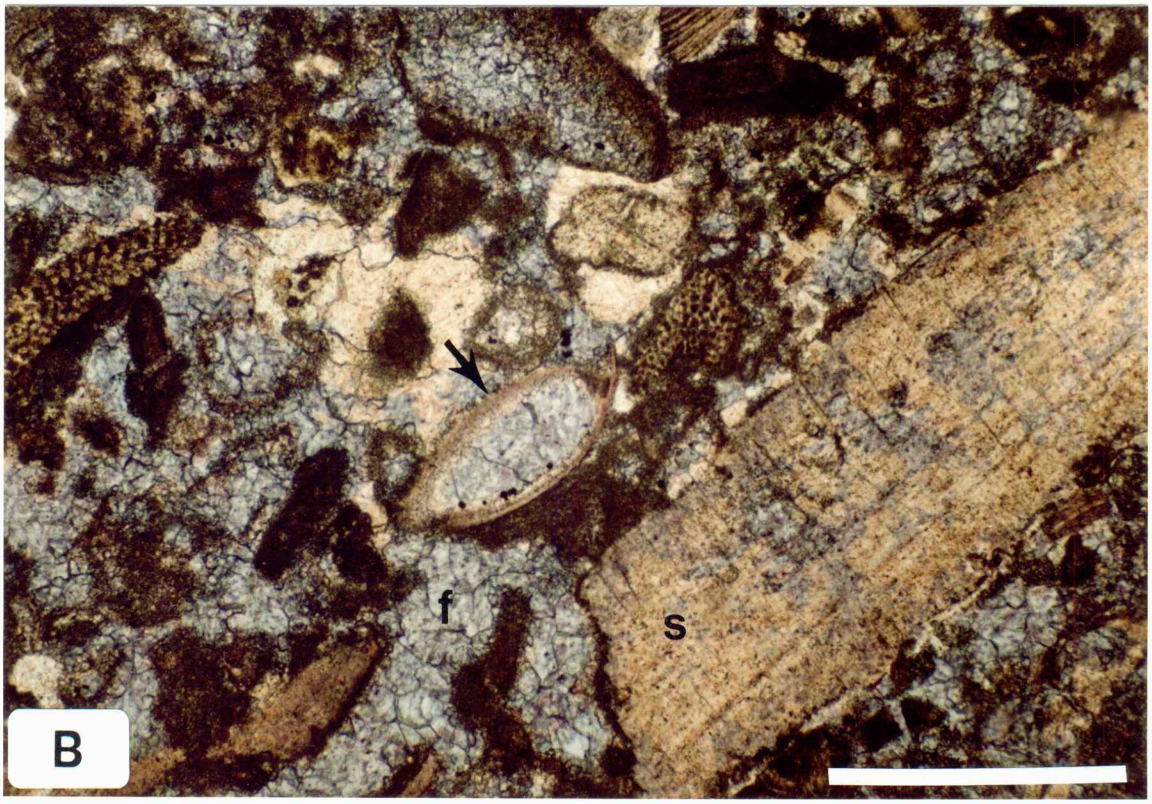

g
B

Figure 26. Muddy skeletal calcarenite facies of Idenbro.

A) Upper unit of Idenbro showing large brachiopod spines (b). Leaching has caused much of the void area now filled with blocky calcite cement (v). Section: Mound Valley Id-t, plane light, bar scale=0.5mm.

B) Ostracode grain showing isopachous rims of bladed calcite (arrow) followed by blocky ferroan carbonate. Note partly leached shells (s) and other void areas now filled with ferroan carbonate. Section: Bachelor Creek-t, plane light, bar scale=0.5mm.


v
b
A


f
s
B

Terrigenous detrial grains were not seen in this upper unit, although Parkinson (1982) reported abundant quartz at the top of this facies at a locality just to the southwest of the Mound Valley North East locality.

When compared to the calcarenitic facies of the Norfleet Member, a greater amount of leaching of originally aragonitic grains and also of surrounding matrix is observed. This probably relates to the fact that the Idenbro is overlain by a blocky mudstone thereby indicating an increased amount of subaerial exposure. Both intragranular and intergranular void space is filled with isopachous rims of calcite and generally followed by blocky ferroan carbonate (Figure 25B, 26A,B). The conversion of micrite to microspar is also observed.

CONODONTS

Introduction

Recent studies have been documenting the lateral and vertical distributional trends of conodonts within the Middle Pennsylvanian cyclothemic sequences of the midcontinent. Workers have been able to use this distribution in sedimentary rocks as an aid in interpreting paleoenvironments. As Merrill (1972) has written,

> "Those in the Pennsylvanian include some of the most complex examples, perhaps the most striking ones, and ones that have been useful for operational paleoecological interpretations over the past decade".

Based on the pelagic model of Seddon and Sweet (1971) an environmental interpretation of conodont distribution in Upper Pennsylvanian cyclothems of eastern Kansas was developed by Heckel and Baesemann (1975). This was further developed and modified for the upper Desmoinesian by Swade (1982, 1985). Both studies suggested that the pattern of conodont distribution reflects the transgressive-regressive depositional setting associated with each cyclothem.

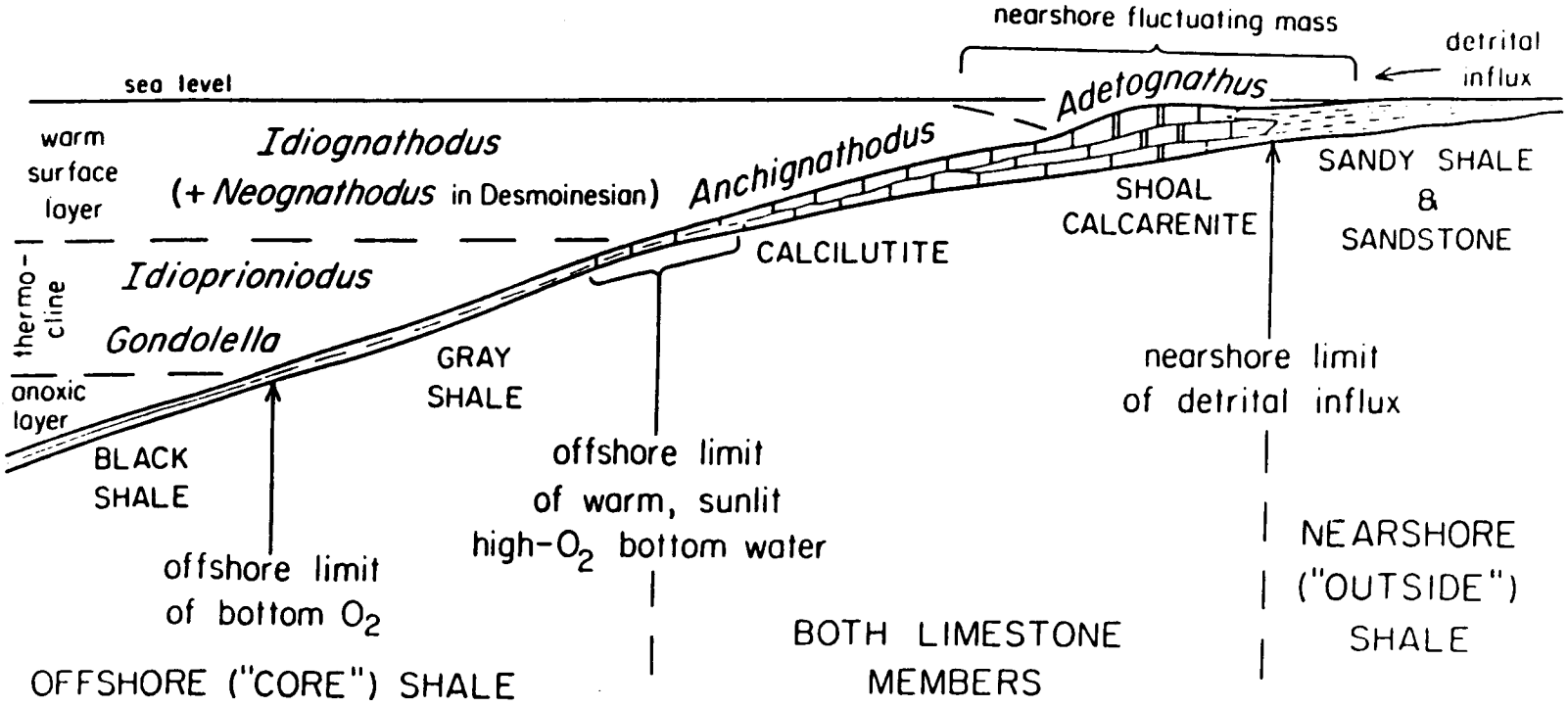
In the shallow-water facies, the conodont Adetognathus is present and exhibits a distribution pattern compatible with life in nearshore water bodies characterized by

fluctuating environmental conditions, particularly the brackish salinities that result from fresh-water influx.

Idioprioniodus and Gondolella were offshore conodonts adapted to colder, less oxygenated waters, and are characteristic of the deep-water facies. Conodonts characteristic of shallow to intermediate water depths include Idiognathodus, Neognathodus and Anchignathodus (which is equivalent to Ozarkodina of Heckel and Baesemann, 1975, and Hindeodus of Sweet, 1977). Idiognathodus and Neognathodus were offshore surface-dwelling conodonts adapted to warm, well oxygenated waters. Idiognathodus dominated in the onshore area, whereas Neognathodus became relatively more abundant offshore, but both genera are widely distributed (Swade, 1985). Anchignathodus seems restricted to carbonate lithotopes representing oxygenated conditions in the photic zone, but is found in calcareous shale indicating some tolerance for more turbid waters (Swade, 1985) (Figure 27).

Examination of the conodont distribution and application of Heckel and Baesemann's (1975) and Swade's (1985) paleoenvironmental interpretations to the Lenapah Limestone in northeastern Kansas and western Missouri has proved to be an important tool in aiding understanding of its stratigraphy and depositional environment.

Figure 27. Generalized diagram showing suggested living areas of certain conodont genera relative to environments responsible for a typical midcontinent cyclothem (from Heckel, 1985).


nearshore fluctuating mass
detrital influx
sea level
Adetognathus
warm surface layer
Idiognathodus
(+ Neognathodus in Desmoinesian)
Anchignathodus
SHOAL CALCARENITE
SANDY SHALE & SANDSTONE
CALCILUTITE
thermo-cline
Idioprioniodus
Gondolella
anoxic layer
GRAY SHALE
nearshore limit of detrital influx
BLACK SHALE
offshore limit of warm, sunlit high-O_2 bottom water
offshore limit of bottom O_2
NEARSHORE ("OUTSIDE") SHALE
BOTH LIMESTONE MEMBERS
OFFSHORE ("CORE") SHALE

Limestone and shale samples from the Lenapah Formation were collected in detail from 24 different sections in northeastern Kansas and western Missouri. The abundance and diversity figures generated by this investigation are based on the presence of platform elements only, as these are generally well preserved and easily identified. Identifications were based on the recognition of the platform elements of each genus using descriptions of Baesemann (1973), Merrill (1975) and Swade (1985).

Observations

From the Lenapah Formation, four major conodont genera were identified: Neognathodus, Adetognathus, Anchignathodus and Idiognathodus (Figure 28), whereas Gondolella and Idioprioniodus, which are present in many other cyclothems, are conspicuously absent. Maximum conodont abundance occurs in the lower portion of the Norfleet Member, and decreases in abundance upward through the sequence into the upper Norfleet, the Perry Farm Shale and the Idenbro Limestone (Figure 29).

Neognathodus

Within the Lenapah Formation, Neognathodus (Figure 28:7-24) is the most abundant and thus most useful conodont genus. Because of this importance, it has been identified to the species level, including: N. dilatus (Figure

28:7-9), N. roundyi (Figure 28:10,11), N. medexultimus, intermediate forms, (Figure 28:12-19) and a new species (Figure 28:20-24) which Parkinson (1982) had recognized as new in the Lenapah in northern Oklahoma and southern Kansas.

Neognathodids are abundant in the lower portion of the Norfleet Member. Both the dark limestone ledges and the dark shale lithofacies of the Norfleet are prolific neognathodid producers. Moving upward through the sequence, the upper portion of the Norfleet and the Idenbro limestones contain neognathidids, but in much less abundance than the lower portion of the Norfleet Limestone. Moving laterally from southern Kansas into southern Iowa, the Neognathodus fauna disappears (Figure 30).

Adetognathus

Adetognathus (Figure 28:3,5) is the second most abundant genus within the Lenapah Formation. Even though adetognathids are less abundant than neognathids, they are found throughout the entire Norfleet and Idenbro Members. No specimens, however, were recovered from the Perry Farm Member. The 0.1 foot of calcilutite belonging to the Norfleet Member in the core from Clarke County, Iowa (Swade, 1985, p.36) contains Adetognathus as its dominant conodont genus (Figure 31).

Figure 28. Conodont platform elements recovered from the Lenapah Formation. All figures are x40.

1: Idiognathodus sp. 6 of SWADE, 1985. Upper view of SUI 52841, form Loc. Ang.N.E. bot. Ls.

2: Idiognathodus sp. 5 of SWADE, 1985. Upper view of SUI 52842, from Loc. TrP bot. Ls.-Lr-1.

3,5: Adetognathus gigantus (GRUNNELL, 1933).
3, upper view of SUI 52843, from Loc. Lt. Ck. 5-u.
5, upper view of SUI 52845, from Loc. RMO-6.

4: Anchignathodus minutus (ELLISON, 1941). Upper view of SUI 52844, from Loc. Verd.R.B.-Nf.

6: Idiognathodus sp. 1 of SWADE, 1985. Upper view of SUI 52846, from Loc. TrP bot. Ls. Lr-1.

7-9: Neognathodus dilatus (STAUFFER & PLUMMER, 1932).
7, upper view of SUI 52847, from Loc. Lt.Ck. 5-b.
8, upper view of SUI 52848, from Loc. MVNE leg. bel. type Nf.
9, upper view of SUI 52849, from Loc. Verd.R.B.-Nf.

10,11: Neognathodus roundyi (GUNNELL, 1931).
10, upper view of SUI 52850, from Loc. Amt-S sh. 3-4" bel. Ls.
11, upper view of SUI 52851, from Loc. Lt. Ck. 5-u.

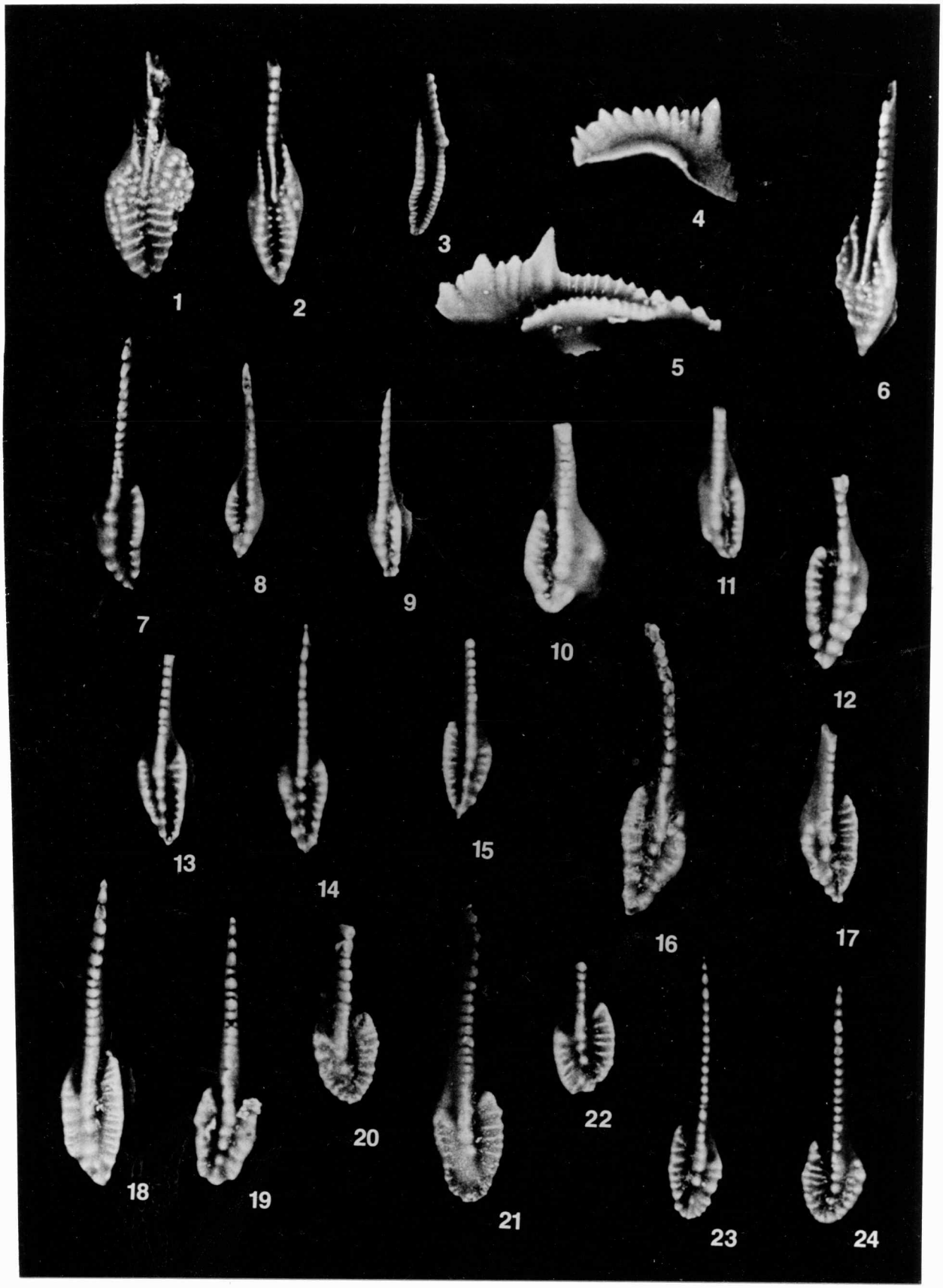
12-18: Neognathodus medexultimus MERRILL, 1972.
(=N. medadultimus MERRILL, 1972)
12, upper view of SUI 52852, from Loc. Amt-S top of top Ls.
13, upper view of SUI 52853, from Loc. Lt. Ck. 5-u.
14, upper view of SUI 52854, from Loc. Lt. Ck. 5-m.
15, upper view of SUI 52855, from Loc. Amt-S top of top Ls.
16, upper view of SUI 52856, from Loc. Amt-S top of top Ls.
17, upper view of SUI 52857, from Loc. Amt-S top of top Ls.
18, upper view of SUI 52858, from Loc.

Verd.R.B.-Nf.

19: Neognathodus sp. Upper view of SUI 52859, from Loc. Type Id. bot. Ls.

20, 22-24: Neognathodus n. sp. of PARKINSON, 1982.
20, upper view of SUI 52860, from Loc. New 169 Lp-Lr.
22, upper view of SUI 52862, from Loc. New 169 Lp-Lr.
23, upper view of SUI 52863, from Loc. Type Id. bot. Ls.
24, upper view of SUI 52864, from Loc. Type Id. bot. Ls.

21: Neognathodus cf. N. n.sp. of PARKINSON, 1982. Upper view of SUI 52861, from Loc. Type Id. bot. Ls.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24

Figure 29. Actual weights of conodont samples. Numbers indicate grams processed for conodonts when other than 500 grams for limestones, and 1000 grams for shales (both left blank).

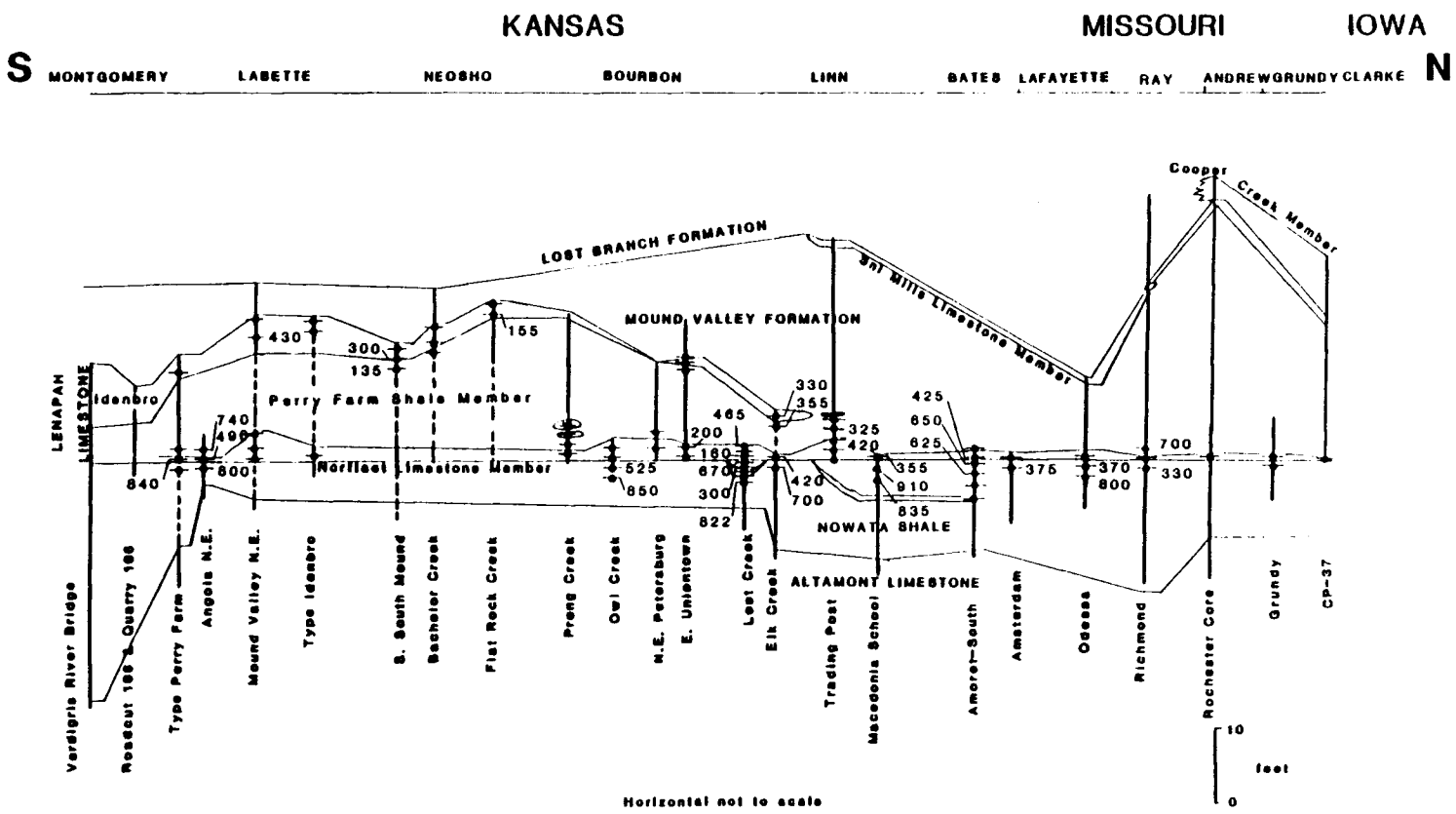
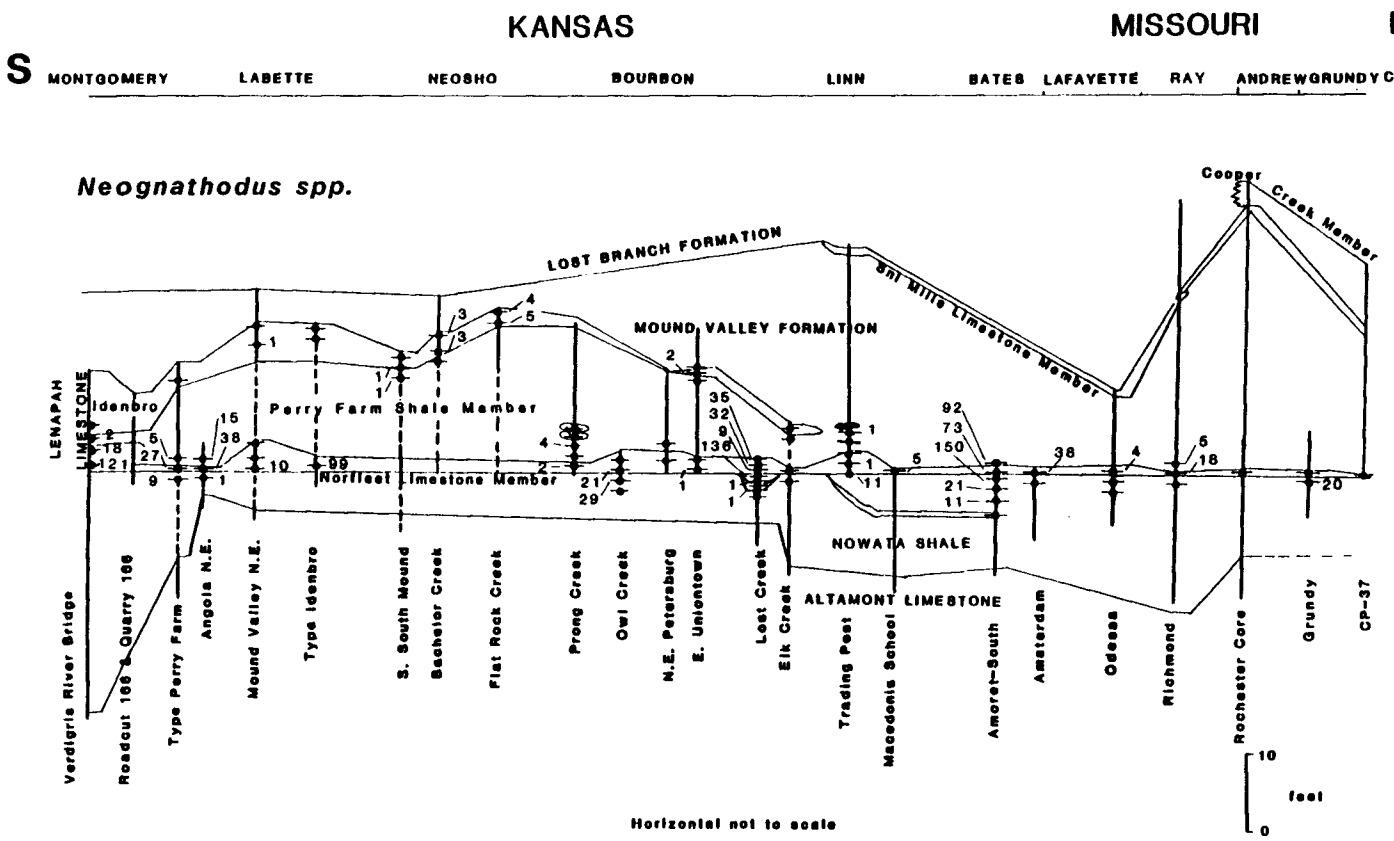

KANSAS
MISSOURI
IOWA
S
MONTGOMERY
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
LOST BRANCH FORMATION
MOUND VALLEY FORMATION
Jat Mills Limestone Member
Cooper Creek Member
LENAPAH LIMESTONE
Idenbro
Perry Farm Shale Member
Norfleet Limestone Member
NOWATA SHALE
ALTAMONT LIMESTONE
Verdigris River Bridge
Roseout 166 Quarry 166
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prong Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
430
300
135
155
740
490
800
840
525
850
330
355
465
200
160
670
300
822
420
700
325
420
355
910
835
425
650
625
375
370
800
700
330
10
feet
0
Horizontal not to scale

Figure 30. Distribution of Neognathodus in Lenapah Formation. Processed samples indicated by dots with lines; numbers indicate number of Neognathodus platform elements recovered.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MISSOURI
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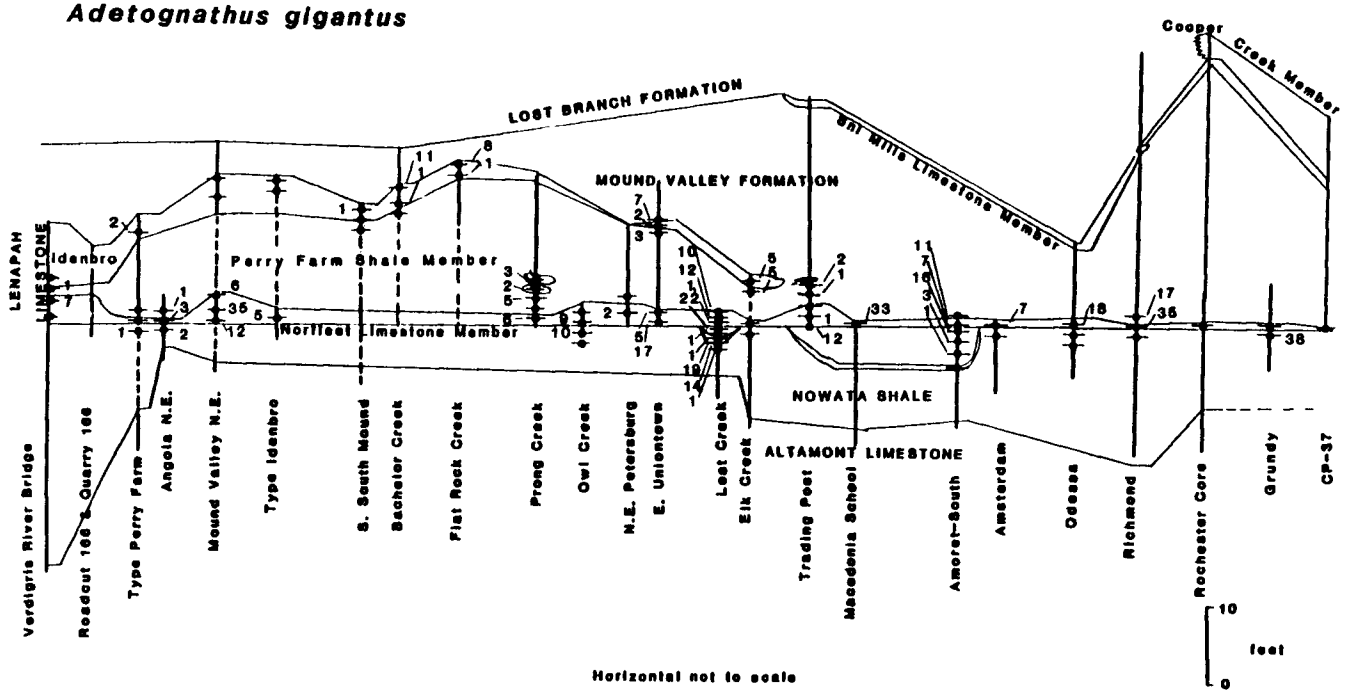
MONTGOMERY
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
Neognathodus spp.
LOST BRANCH FORMATION
Bnl Mills Limestone Member
Cooper Creek Member
MOUND VALLEY FORMATION
LENAPAH LIMESTONE
Idenbro
Perry Farm Shale Member
Northeast limestone Member
NOWATA SHALE
ALTAMONT LIMESTONE
Verdigris River Bridge
Roadcut 166 & Quarry 166
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prong Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
10
feet
0
Horizontal not to scale

Figure 31. Distribution of Adetognathus in Lenapah Formation. Processed samples indicated by dots with lines; numbers indicate number of Adetognathus platform elements recovered.

KANSAS MISSOURI IOWA

S MONTGOMERY LABETTE NEOSHO BOURBON LINN BATES LAFAYETTE RAY ANDREW GRUNDY CLARKE N

Adetognathus gigantus



Anchignathodus

Anchignathodus (Figure 28:4) is the next most abundant conodont genus in the Lenapah and has been found scattered throughout the Norfleet and Idenbro Members (Figure 32). Wherever present, it is usually associated with Neognathodus and/or Adetognathus.

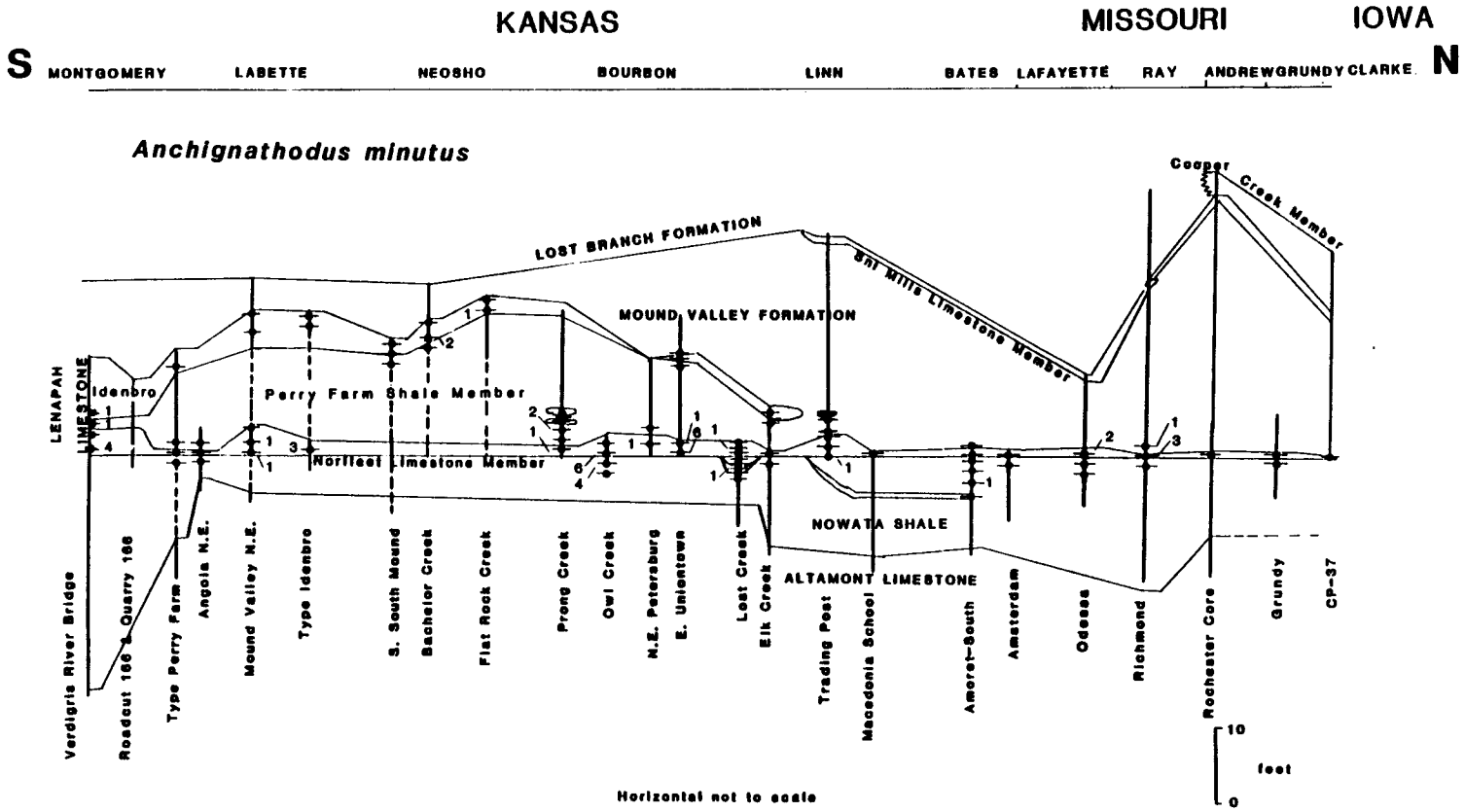
Idiognathodus

Idiognathodus (Figure 28:1,2,6) is the least abundant conodont genus of those recovered and identified from the Lenapah Formation. Ten specimens were found in the Norfleet Limestone at Angola NE, 2 specimens were retrieved from the type Norfleet, 1 from the Idenbro Member at the East of Uniontown locality and 5 in total from the Trading Post section (Figure 33).

Lateral and Vertical Trends

Merrill (1972) studied abundant representatives of the genus Neognathodus from the Pottsville and Allegheny groups in eastern Ohio. Six species, based largely on numbers of nodes or rows of nodes along the side of the parapet, were placed in biostratigraphic order order from oldest to youngest, in ascending order: N. bothrops, N. medadultimus, N. medexultimus, N. roundyi, and N. dilatus. Merrill believed this genus to be extremely time sensitive and thus useful for vertical and lateral zonation within the

Figure 32. Distribution of Anchignathodus in Lenapah Formation. Processed samples indicated by dots with lines; numbers indicate number of Anchignathodus platform elements recovered.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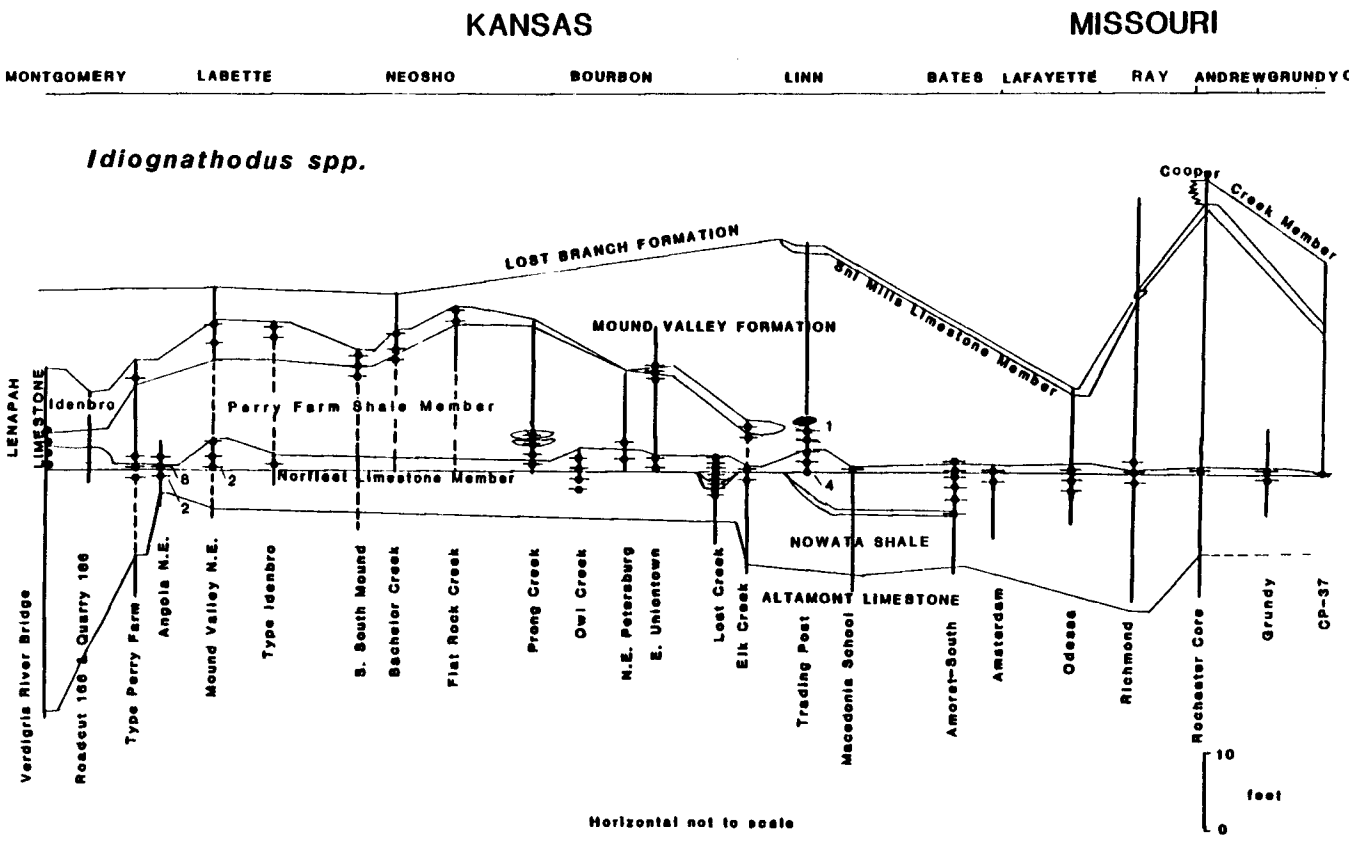
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
Anchignathodus minutus
LOST BRANCH FORMATION
Bethany Falls Limestone Member
Cooper Creek Member
MOUND VALLEY FORMATION
Dennis Limestone Member
LENAPAH LIMESTONE
Idenbro
Perry Farm Shale Member
Nettleton Limestone Member
NOWATA SHALE
ALTAMONT LIMESTONE
Verdigris River Bridge
Roadcut 166 & Quarry 166
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prong Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
10
feet
0
Horizontal not to scale

Figure 33. Distribution of Idiognathodus in Lenapah Formation. Processed samples indicated by dots with lines; numbers indicate number of Idiognathodus platform elements recovered.


KANSAS
MISSOURI
IOWA
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MONTGOMERY
LABETTE
NEOSHO
BOURBON
LINN
BATES
LAFAYETTE
RAY
ANDREW
GRUNDY
CLARKE
N
Idiognathodus spp.
LOST BRANCH FORMATION
Cooper Creek Member
Bird Mills Limestone Member
MOUND VALLEY FORMATION
LENAPAH LIMESTONE
Idenbro
Perry Farm Shale Member
Nortleet Limestone Member
NOWATA SHALE
ALTAMONT LIMESTONE
Verdigris River Bridge
Roadcut 166
Quarry 166
Type Perry Farm
Angola N.E.
Mound Valley N.E.
Type Idenbro
S. South Mound
Bachelor Creek
Flat Rock Creek
Prang Creek
Owl Creek
N.E. Petersburg
E. Uniontown
Lost Creek
Elk Creek
Trading Post
Macedonia School
Amoret-South
Amsterdam
Odessa
Richmond
Rochester Core
Grundy
CP-37
10
feet
0
Horizontal not to scale

Appalachian region. Merrill also suggested that the recognition of the same species elsewhere could provide interregional correlation for Desmoinesian and slightly older rocks. Using Merrill's information, the neognathidids of the Lenapah were arranged in a similar fashion. Although the Lenapah does not contain N. bassleri or N. bothrops, the new species with many nodes was used as the analog of N. bassleri and N. bothrops. Also, because much confusion exists in the literature concerning the difference between N. medexultimus and N. medadultimus, G. Klapper (personal communication, 1985) suggested combining both with all intermediate forms into the species N. medexultimus for statistical purposes. The interesting aspect of Merrill's study in relation to the Lenapah Limestone, is that most of Merrill's (1972) biostratigraphically useful species occur in this one small marine horizon of late Desmoinesian age; therefore doubt may be cast on the amount of time differentiation possible using these species of this genus in the Lenapah of southeastern Kansas.

Summary

1) Maximum conodont abundance occurs in the lower portion of the main ledge of the Norfleet Member or in associated shale, and is dominated by the genus Neognathodus. Abundances generally are less than those reported from core horizons of other, major Desmoinesian cyclothems by Swade (1985).

2) Conodont abundance decreases upward in the upper Norfleet and entire Idenbro Member when compared to the abundance in the lower Norfleet Member.

3) Conodonts are relatively scarce in the Perry Farm Shale Member and its equivalent detrital facies.

4) In the more northern exposures and cores of Lenapah, in northern Missouri and Iowa, Adetognathus is the dominant genus, thereby replacing Neognathodus, which is usually dominant southward.

5) The three genera found to be dominant in the Lenapah Limestone are Neognathodus, Adetognathus, and Anchignathodus, making this a rather unique fauna for a Midcontinent Pennsylvanian marine horizon, because Idiognathodus strongly dominates the faunas of nearly all others.

6) Idiognathodus, the ubiquitious genus in most Pennsylvanian cyclothems, is found only in very low numbers in scattered localities of the Lenapah Limestone. The identified species of Idiognathodus appear intermediate between those species characteristic of the underlying Altamont and overlying Lost Branch Formations (see Swade, 1985).

7) Idioprioniodus and Gondolella are conspiciously absent from the entire Lenapah Formation.

DEPOSITIONAL ENVIRONMENTS

Introduction

The preceding descriptions of stratigraphy, sedimentological, and petrographical characteristics of facies, and conodont abundance and diversity of the Lenapah Limestone and adjacent units can be used to reconstruct the depositional environments using principles of epeiric deposition summarized by Irwin (1965) and Heckel (1972). This will allow the Lenapah Limestone and adjacent units to be related to Heckel's (1980) eustatic depositional model for Middle and Upper Pennsylvanian cyclothems.

Norfleet Limestone Member

The abundance and diversity of biota, including "stenohaline" forms such as echinoderms in all facies of the Norfleet Member indicate deposition in an open marine environment.

The lower shaly portion of the Norfleet Member contains the maximum conodont abundance and diversity for the entire Lenapah Formation. In combination with the stenohaline organisms present, it is reasonable to interpret this shaly horizon as an offshore shale deposited below effective wave base, across an area relatively starved of sediment influx.

The skeletal calcarenite ledges found within the shaly zone may have been deposited in relatively deep water, possibly below the photic zone, and thereby may have been too deep for the proliferation of algae or production of lime mud. The skeletal calcilutite ledges found above and locally equivalent to the shaly zones indicate a quiet environment sufficiently calm to allow fine material to settle out of suspension. Due to the diversity of fauna present here as well, deposition probably occurred below effective wave base. Algae is conspicuously absent from the calcilutite facies and may be explained by decrease in light penetration caused either by depths of water below the photic zone or high turbidity. The presence of glauconite peloids in some of these limestone ledges provide evidence for slow offshore deposition of this horizon, as glauconite is typically found associated with marine transgressions, during episodes of reduced influx of sediment (McRae, 1972).

The skeletal calcarenite of the upper Norfleet displays increasing amounts of algal grains, micrite envelopes and completely micritized grains, when compared to the lower calcarenite and calcilutite ledges. All these features suggest depositon in clear water within the photic zone. The fragmented, abraded, well-sorted nature of the grains, along with intergranular sparry cement, indicate deposition in shallow water above effective wave base where water

turbulence was high and winnowing of fine mud occurred. The decrease in diversity and abundance of conodonts, represented predominantly by Adetognathus towards the top of this upper limestone ledge, supports a more nearshore environment compared to the calcarenites and calcilutites below. Thus, the main part of the Norfleet Member above the conodont-rich horizon displays a shallowing-upward sequence.

The ledge below the conodont-rich shale at Lost Creek shows a well-washed algal-coated calcarenite at the base, deposited above effective wave base, and a diverse skeletal calcilutite at the top, deposited below effective wave base. Thus this shows a deepening-upward sequence expected in a transgressive limestone, the converse of the depositional sequence of the main ledge of the upper Norfleet above the conodont-rich shale. At the Amoret-South locality, the lower limestone contains a higher abundance of detrital quartz grains suggesting it was closer to the eastern Linn County detrital source (see below) than the limestone in a similar position at the Lost Creek locality.

The sandy skeletal limestone facies of eastern Linn County also was deposited in an open marine environment as indicated by the abundance of stenohaline organisms, especially crinoidal fragments. The subdominance of Adetognathus suggests a relatively shallow water environment. The presence of micritzed grains suggests

deposition in clear water within the photic zone. The sparry cement that infills void areas in these sandy calcarenites, suggests some agitation near effective wave base, allowing winnowing of the fine mud. The high percentage of terrigenous quartz grains probably reflects nearness to a source of detritus that was reworked in a marine environment (for example, transgression over a small delta and reworking it as shoals and bars).

Perry Farm Shale Member

The low amount of marine biota in both the greenish-grey shale and the calcilutitic limestone nodules of the Perry Farm suggests deposition in a restricted environment. The presence of sparse gastropods, forams, and sponge spicules, in conjunction with absence of corals, bryozoans, and echinoderm fragments, suggests deposition in a restricted nearshore environment where fluctuating salinities, temperature, and turbidity are commonplace, and circulation, which controls nutrient replenishment, is reduced. The micritic matrix of the limestone nodules indicates that they as well as the shale were deposited in quiet water when periodic waning of detrital influx allowed some carbonate production.

The irregular lenticular zones of shell hash within some nodules may have resulted from a combination of

periodic winnowing and bioturbation during and after storm wash, and slower deposition between periodic fine detrital influx.

The paucity of conodonts throughout the Perry Farm facies also indicates a marginal marine, nearshore environment, where a high rate of clastic influx both caused unfavorable conditions for the conodont animal and diluted the conodonts that may have been there.

Northward, at Uniontown East and N.E. Petersburg localities in western Bourbon County, the sandy facies of the Perry Farm coarsens upward and displays ripple marks near the top. This reflects detrital influx caused by a small prograding delta that was affected by waves and currents at the top, and indicates a shallowing-upward sequence.

Idenbro Limestone Member

The lower calcilutite facies of the Idenbro Member contains a diverse marine biota and indicates deposition in an open marine environment. The abundance of micrite indicates deposition in quiet water below wave base, although the presence of algal voids indicates an environment still within the photic zone. The low abundance of skeletal grains, especially crinoid and bryozoan fragments, as compared to other facies, may be due to high

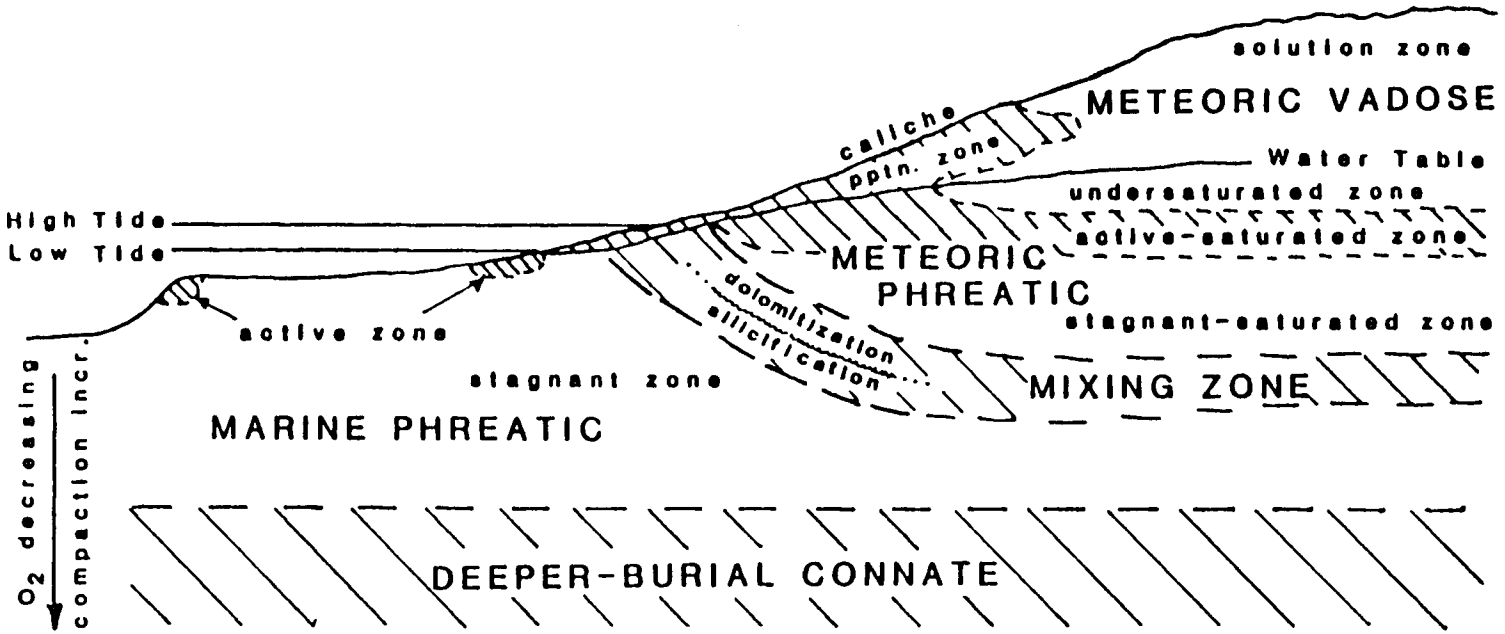
turbidity which is not conducive to filter feeders. Also, the abundance of mud may have produced a substrate too soft to allow prolific growth of epifaunal organisms. The low abundance of conodonts in the Idenbro Member, relative to the Norfleet Member, supports more turbid, shallower waters. This is further suggested by the dominance of the shallow-water conodont Adetognathus.

The upper muddy calcarenite facies of the Idenbro Member displays increase in both abundance of skeletal grains and sparry intergranular cement relative to the lower facies. This suggests deposition in water closer to effective wave base where more mud was winnowed, and more organisms may have thrived because of creation of areas with firmer substrates.

INTERPRETATION OF DIAGENESIS IN THE LENAPAH LIMESTONE

Longman (1980) described four major near-surface diagenetic environments that produce characteristic diagenetic textures: 1) marine phreatic, in which early fibrous rim cements may precipitate under local conditions of supersaturation; 2) mixing zone, in which bladed cements form; 3) meteoric phreatic, in which aragonite is commonly leached when water is undersaturated, and blocky calcite is precipitated when water becomes saturated, and 4) meteoric vadose, in which caliche and other soils form. Heckel (1983) described a fifth, deeper-burial connate environment, where compaction eliminates much void space, causing overcompacted calcarenite with stylolitized grain boundaries, and where oxygen is low, resulting in ferroan cements (Figure 34). These major diagenetic environments are further subdivided on the basis of inferred water circulation through the pores and the degree of pore water saturation with respect to calcium carbonate.

Figure 34. Common carbonate diagenetic environments in a partially emergent carbonate terrain. Lined zones represent areas of significant carbonate cement precipitation. Modified from Heckel (1983).


solution zone
METEORIC VADOSE
caliche ppin. zone
Water Table
undersaturated zone
active-saturated zone
High Tide
Low Tide
METEORIC PHREATIC
stagnant-saturated zone
active zone
dolomitization
silicification
stagnant zone
MIXING ZONE
MARINE PHREATIC
O2 decreasing
compaction incr.
DEEPER-BURIAL CONNATE

Diagenetic Model for Pennsylvanian Cyclothems

Using these five major diagenetic environments, Heckel (1983) proposed a diagenetic model to explain diagenetic patterns resulting from eustatic transgressions and regressions in Midcontinent Pennsylvanian cyclothems (Figure 35).

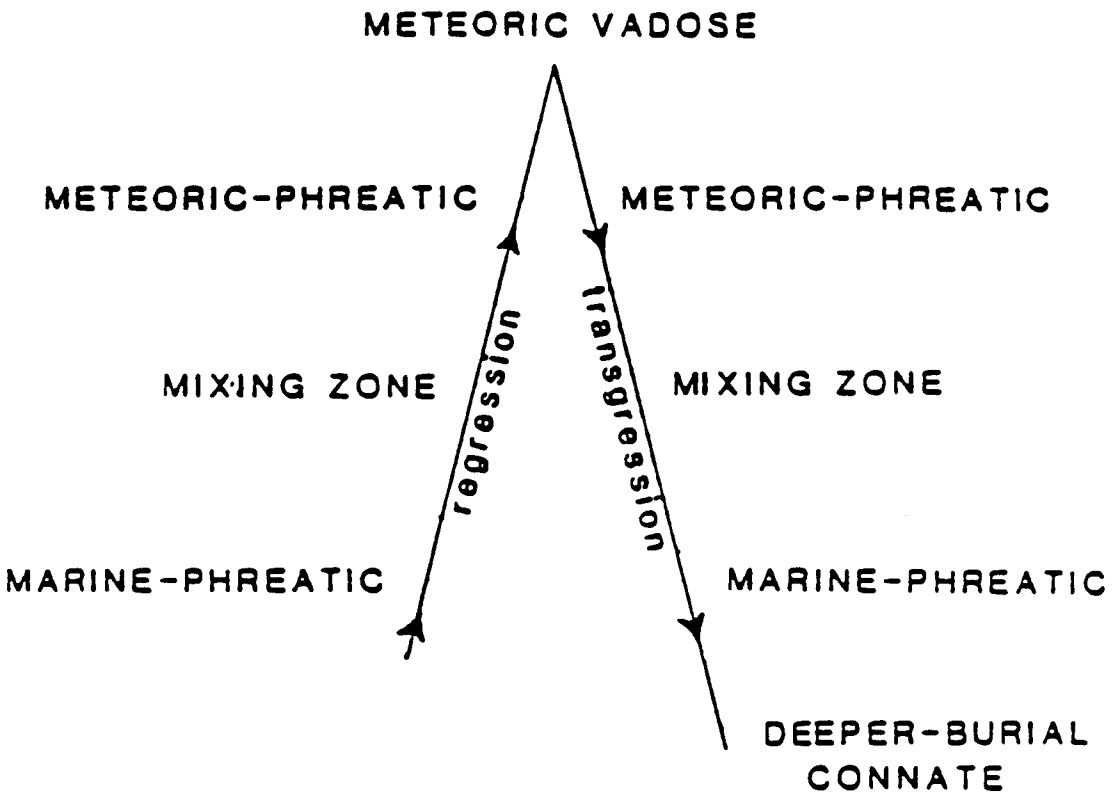
All marine rocks in the sequence (transgressive limestones, offshore shales, regressive limestones) were deposited in the marine phreatic environment. The nearshore shales may have been deposited in the nearshore marine phreatic or brackish to fresh waters of transitional and terrestrial environments.

The model predicts that transgressive limestones and offshore "core shales" should show pervasive overpacking of grains in calcarenites, neomorphism of originally aragonite grains, and ferroan calcite and dolomite cements. These characteristics indicate movement from the marine phreatic environment of deposition and diagenesis into a low-oxygen deeper burial connate zone without much effect of the meteoric environments.

In contrast, regressive limestones may show early marine cement rims formed in shallowing warm marine water, followed after emergence by large-scale leaching of original aragonite grains in undersaturated meteoric water (with

Figure 35. Migration of diagenetic environments in a eustatic cyclothemic sequence. Subsequent transgression and deposition of the overlying cyclothem reverses the migration of diagenetic environments. Modified from Nollsch (1983, Figure 6).

MIGRATION OF DIAGENETIC ENVIRONMENTS



subsequent collapse of micrite envelopes) eventually followed by pervasive blocky calcite cementation as the water became saturated. These characteristics indicate replacement of the depositional marine phreatic water by meteoric phreatic water after subaerial exposure at the top of the limestone. Later transgression resulted in reversal of the diagenetic environments back through the marine phreatic and eventually into the low-oxygen deeper burial connate environment, where the remaining voids were filled by ferroan calcite and dolomite cements.

In this model, meteoric waters usually are prevented from penetrating the transgressive limestone during regression by the offshore shale, which acts as an impermeable "seal".

Diagenetic Facies

Upper Norfleet Skeletal Calcarenite

The upper skeletal calcarenite and the sandy skeletal calcarenite facies of the Norfleet were deposited in the marine phreatic environment where skeletal grains were abraded and micritized. Some traces of drusy fibrous rims, and loose packing of grains with little to no grain-to-grain contact (Figure 9A) suggests that minimal compaction took place before cementation, and that initial cementation took place early, possibly within the saturated marine phreatic

zone. The overall lack of preserved original structure in green algae and molluscan grains suggests that these grains were originally aragonite, and were leached by undersaturated meteoric water during early regression. Bladed calcite rims on brachiopod fragments and on the interior of ostracode shells, syntaxial overgrowths on crinoid grains (Figure 11B), and other non-ferroan blocky calcite, all of which fills areas of original void space, probably precipitated in the still oxygenated, lower part of the meteoric environment as it became saturated later during regression as Railsback (1983) suggested in the younger Winterset Limestone. Filling of early formed molds also probably took place at this time.

Further filling of remaining molds and intergranular space with blocky non-ferroan calcite probably continued during movement of the saturated meteoric phreatic environment back through the limestone caused by the following transgressions that produced the overlying Idenbro Member and Lost Branch Formation. The final voids were filled by blocky ferroan carbonate (Figure 9A, 10A,B 11B), which may have formed anywhere from the mixing zone to the deeper burial connate environment after oxygen became depleted.

Lower Norfleet Calcarenitic Ledges

The deeper-water calcarenitic ledges scattered within the shale-rich horizon in the lower Norfleet contain invertebrate grains with little noticeable grain abrasion and lack of algal structures. The grains are overcompacted with much grain-to-grain contact (Figure 9B), grain welding, and grain fractures, all suggesting that this facies underwent much more intense compaction relative to the upper skeletal calcarenite facies. The lack of cemented original void space and absence of any noticeable echinoderm overgrowths (Figure 9B) suggests rapid transgression and movement into somewhat deeper water of the marine phreatic environment where little or no cementation took place. Original aragonitic grains such as mollusc fragments are both altered to large lath-like calcite crystals (Figure 9B) and replaced by ferroan carbonate (Figure 12B), depending upon locality, and show good retention of relict fabrics, indicating slow, delicately balanced processes in the "stagnant" marine phreatic zone, below the level of active circulation.

The blocky ferroan carbonate cement filling the small interstitial areas of the compacted matrix (Figure 9B) indicates a low-oxygen, deeper burial connate environment. This diagenetic sequence suggests movement from the marine phreatic environment directly into the deeper burial connate

zone as the sea transgressed, without penetration of the meteoric water that affected the upper Norfleet; perhaps the shale around the calcarenite ledges in the lower Norfleet protected them from meteoric penetration.

Norfleet Algal-Coated Calcarenite

The shallow-water algal-coated calcarenite facies of the Norfleet at Lost Creek was initially deposited in the marine phreatic environment where the grains were micritized, surrounded by algal coatings and encrusted by forams. The grains display some fracturing and grain-to-grain contacts (Figure 17A,B) in thin section, but when compared to the lower calcarenitic ledges (Figure 9B), compaction is not nearly as severe.

Isopachous rims of clear calcite along the interior of ostracode shells and small echinoderm overgrowths (Figure 17A) are present but much less abundant when compared to the upper regressive calcarenite facies, suggesting possibly a slight influence from the saturated meteoric environment. On the other hand it is possible that this precipitation may have resulted in the deeper burial environment where loss of magnesium allowed magnesium-free calcite to form. The remaining void space was filled by ferroan carbonate cement (Figure 17) and indicates precipitation under low-oxygen conditions in the deeper burial connate environment.

Therefore, this facies also moved directly from the marine phreatic environment into the deeper burial connate zone during the following transgressive phase, or at most was affected only a short time by impingement of saturated meteoric water.

Norfleet Calcilutite Facies

The calcilutite facies of the Norfleet was first deposited in the marine phreatic environment. Stylolitization (Figure 18B) and lack of any recognizable pellets within the matrix suggest that this facies underwent substantial compaction before lithification. The dark color of these calcilutites suggests minimal oxidation of organic matter before cementation. The thin fibrous rims surrounding some of the brachiopod fragments (Figure 19) and the small amount of blocky calcite filling interstital voids may possibly have been precipitated as a result of some saturated meteoric water filtering through from the overlying regressive Perry Farm Shale, but more likely formed in the deeper burial environment where loss of magnesium (possibly caused by the adsorption by clays) allowed magnesium-free calcite to form. The sponge spicules, which probably originally were unstable opaline silica, have all been replaced by ferroan carbonate (Figure 18B, 19). The dense nature and dark color of the rock, and

final small voids filled with ferroan carbonate all suggest compaction under conditions of decreasing oxygen as the sediment moved directly into the deeper connate zone prior to any significant cementation.

Lower Idenbro Calcilutite

The lower skeletal calcilutite facies of the Idenbro Member was originally deposited in the marine phreatic environment. The matrix lacks any recognizable pellets (Figure 26A,B), suggesting compaction before cementation. The light color of these rocks, (in contrast with the dark color of the Norfleet calcilutites) indicates that the diagenetic envrionment remained oxidizing during cementation.

At the South of South Mound locality, both chert and chalcedony fill original voids in skeletal grains and matrix (Figure 24), and replaced skeletal grains with good retention of relict structures. Precipitation of chert is interpreted as occurring in the mixing zone (Knauth, 1979), which passed through the Idenbro both during regression and again during the subsequent transgression.

The leaching of algal blades and aragonite shells and subsequent solution enlargement in the lower Idenbro created irregular void space (Figure 23A,B) and suggests penetration by the undersaturated meteoric phreatic environment. This

probably occurred during formation of the overlying regressive Mound Valley Formation, which contains a well developed paleosol overlain by a coal horizon, and indicating much subaerial exposure.

Crushed ostracode shells associated with the algal voids suggests that some more compaction occurred after leaching. The irregular voids were filled by bladed dogtooth calcite (Figure 23A) or ferroan carbonate cement (Figure 23B) depending upon locality. These cements may have developed as a result of movement back through the saturated meteoric phreatic environment into the deeper burial connate zone during the transgression that formed the overlying Lost Branch Formation.

Upper Idenbro Muddy Calcarenite Facies

The muddy calcarenite facies of the upper Idenbro was initially deposited in the marine phreatic environment where micrite envelopes developed. The slight fibrous rims and loosely packed grains (Figure 25B) all suggest early cementation in the marine phreatic environment.

The leaching of originally aragonitic grains such as dasyclad algae, phylloid algal blades, mollusc grains and also the void spaces towards the top of this facies (Figure 25A,B, 26B) suggest penetration by the undersaturated meteoric environment during early regression. The

percentage of leaching in this facies is much greater when compared to the regressive Norfleet calcarenite. This probably relates to the much greater regression inferred by paleosol formation throughout the overlying regressive Mound Valley Shale, which had a major effect on both this upper facies and the underlying calcilutite facies of the Idenbro.

The blocky calcite cement both within original void spaces and filling the leached aragonite grains may have begun precipitating as the meteoric water became saturated during regression and continued as the saturated meteoric environment moved back through the rock during the transgressive phase of the Lost Branch cycle. The blocky ferroan carbonate cement precipitated within the remaining void space much later in the low-oxygen connate environment.

Summary of Diagenetic Patterns

The facies in the lower Norfleet show little or no evidence of meteoric influence before compaction and predominantly late cementation in the deeper burial connate environment. This is consistent with both associated marine shale in the Norfleet and the overlying Perry Farm Shale to the south, which is associated with only a minor regression.

The upper Norfleet towards the north shows meteoric cements consistent with the overlying nearer-shore Perry Farm sandy, perhaps deltaic facies.

The entire Idenbro shows more widespread meteoric leaching and cementation consistent with major regression and soil formation developed in the overlying Mound Valley Shale over the entire study area.

DEPOSITIONAL HISTORY

The preceding interpretations of depositional environments and diagenetic history can be intergrated with the stratigraphy to provide the following depositional history.

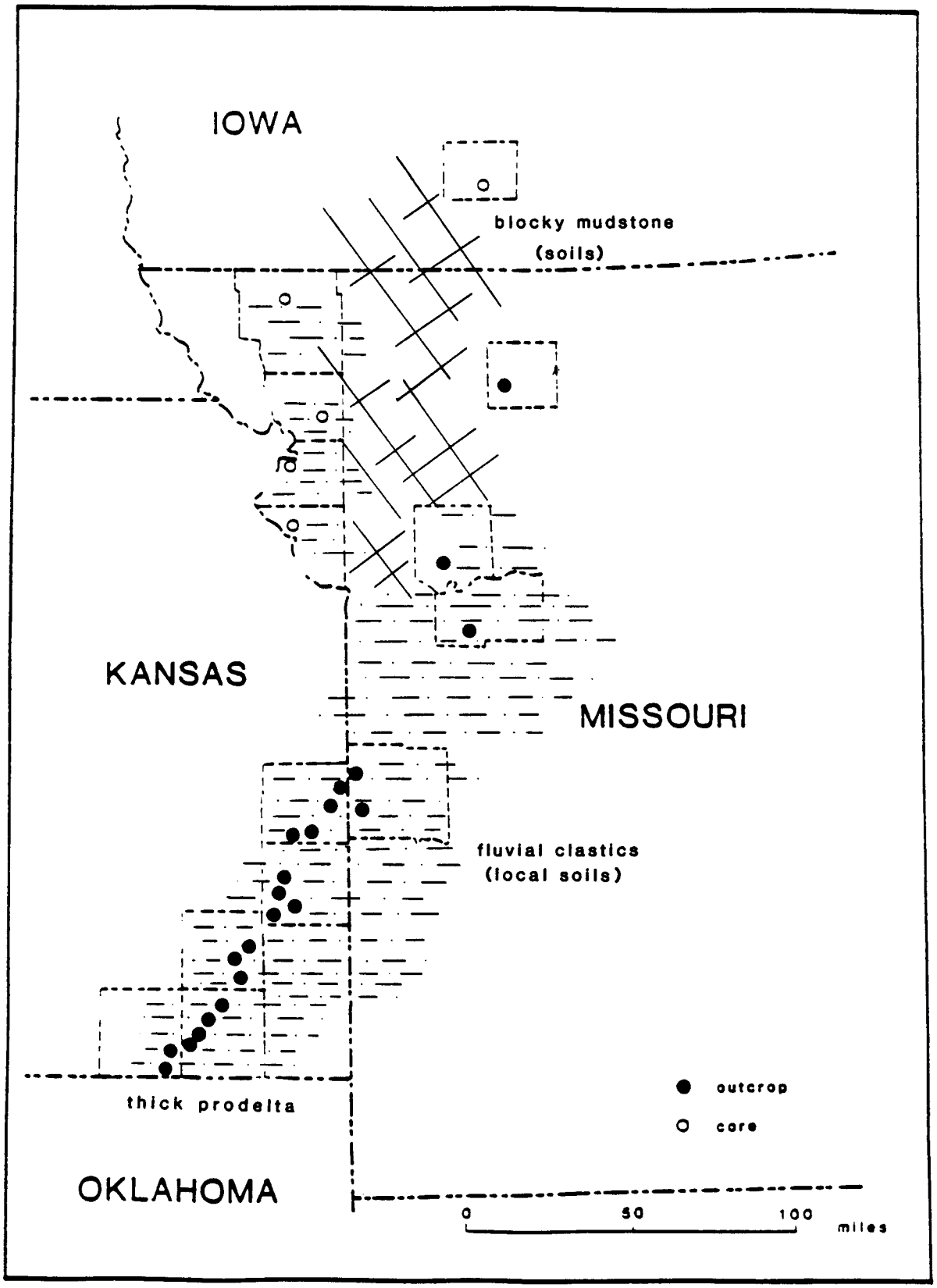
Regressive Phase--Nowata Shale

The Nowata Shale records a thick, probable prodeltaic to deltaic sequence in northern Oklahoma (Figure 36) that prograded southwestward in response to the regression closing the underlying Altamont cycle. In Kansas and Missouri, where the Nowata is thinner, it consists mainly of fluvial deposits. Eventually soil formation produced blocky mudstones, locally in Kansas and Missouri and widespread northward throughout Iowa, prior to deposition of the overlying Lenapah Limestone.

Transgressive Phase--Basal Norfleet Limestone Member (Ks), Entire Norfleet Northward

The earliest indication of transgression over the nearshore to terrestrial Nowata shale is recorded by the thin algal-coated calcarenite at Lost Creek, which is overlain by the skeletal calcilutite. Elsewhere, early

Figure 36. Generalized distribution of Nowata Shale facies during pre-transgressive phase of deposition. Standard lithologic symbols are used.


IOWA
blocky mudstone
(soils)
KANSAS
MISSOURI
fluvial clastics
(local soils)
thick prodelta
OKLAHOMA
outcrop
core
0
50
100
miles

transgression allowed marine organisms to colonize the surface of the Nowata, but brought little sediment.

The conodont-rich shaly zone overlying the initial local limestone unit, along with local conodont-rich limestones on the Nowata surface (type Perry Farm, type Idenbro) record maximum transgression and greatest depths of water within the Lenapah Formation (Figure 37). Reworking of the sandy facies on top of the Nowata near the Oklahoma border produced the conodont-rich sandy limestone there. The absence of Idioprioniodus and Gondolella, two genera present in deeper water facies in other cyclothems (Swade, 1985), along with scattered Adethoganthus suggests water depths that remained too shallow for the development of a thermocline and quasi-estuarine circulation that resulted in deposition of the characteristic black phosphatic shale in other, more major cyclothems. In spite of this relatively shallow water depth, sediment starvation extended across most of Kansas, and carbonate production migrated a considerable distance from Oklahoma northward across the shelf into northern Missouri and southern Iowa, marking this as at least an intermediate transgressive phase (Heckel, 1986). The thin Norfleet in northern Missouri and southern Iowa represents the maximum transgressive phase, although the progrssive replacement of Neognathodus by Adetognathus in northern Missouri culminating in the totally Adetognathus

fauna in Clarke County, Iowa, suggests deposition in very shallow water at the limit of transgression.

The deposition of the various different lithofacies of both the lower and upper portions of the Norfleet were dependent on the interaction of the relatively shallow depth of water with subtle paleotopography. The shaly facies may have formed either behind barriers that created a low-energy environment, or in paleotopographic lows where water depth was below effective wave base.

Early Regressive Phase--(Upper Norfleet Member in Kansas)

The main limestone ledge of the upper portion of the Norfleet represents the early regressive phase (Figure 38) and may have developed from the combined effect of local paleotopographic highs on the sea floor (Heckel, 1984) and a slow drop of sea level that allowed continued carbonate production migrating along the flanks of these subtle highs. Upward decrease of Neognathodus relative to Adetognathus in this upper limestone ledge supports shallowing of water depths. The sandy skeletal facies probably reflects reworking of detrital influx that may have started as early as Nowata deposition.

Figure 37. Generalized distribution of lower portion of Norfleet Member deposited during early and maximum transgression. Standard lithologic symbols are used.

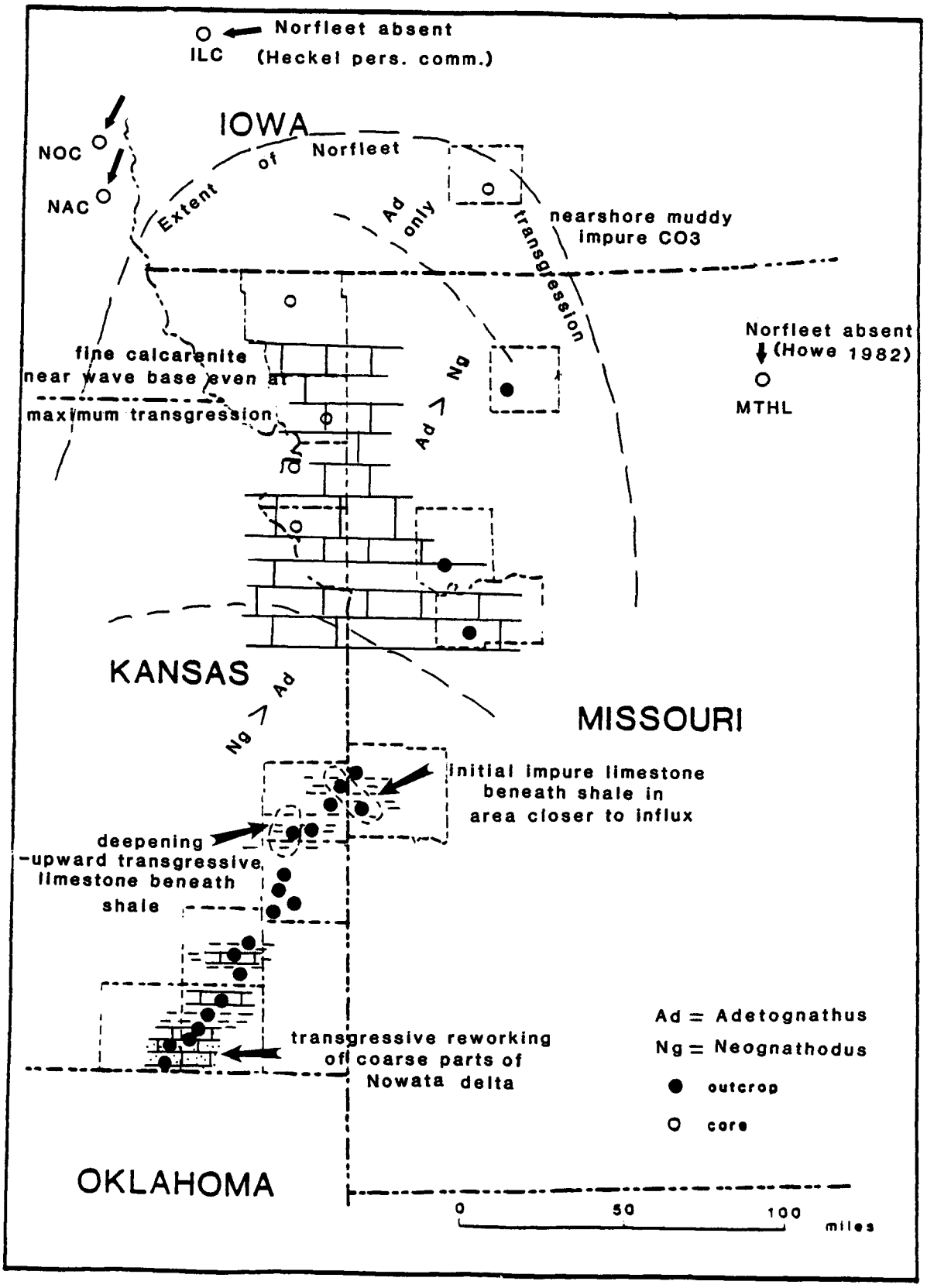
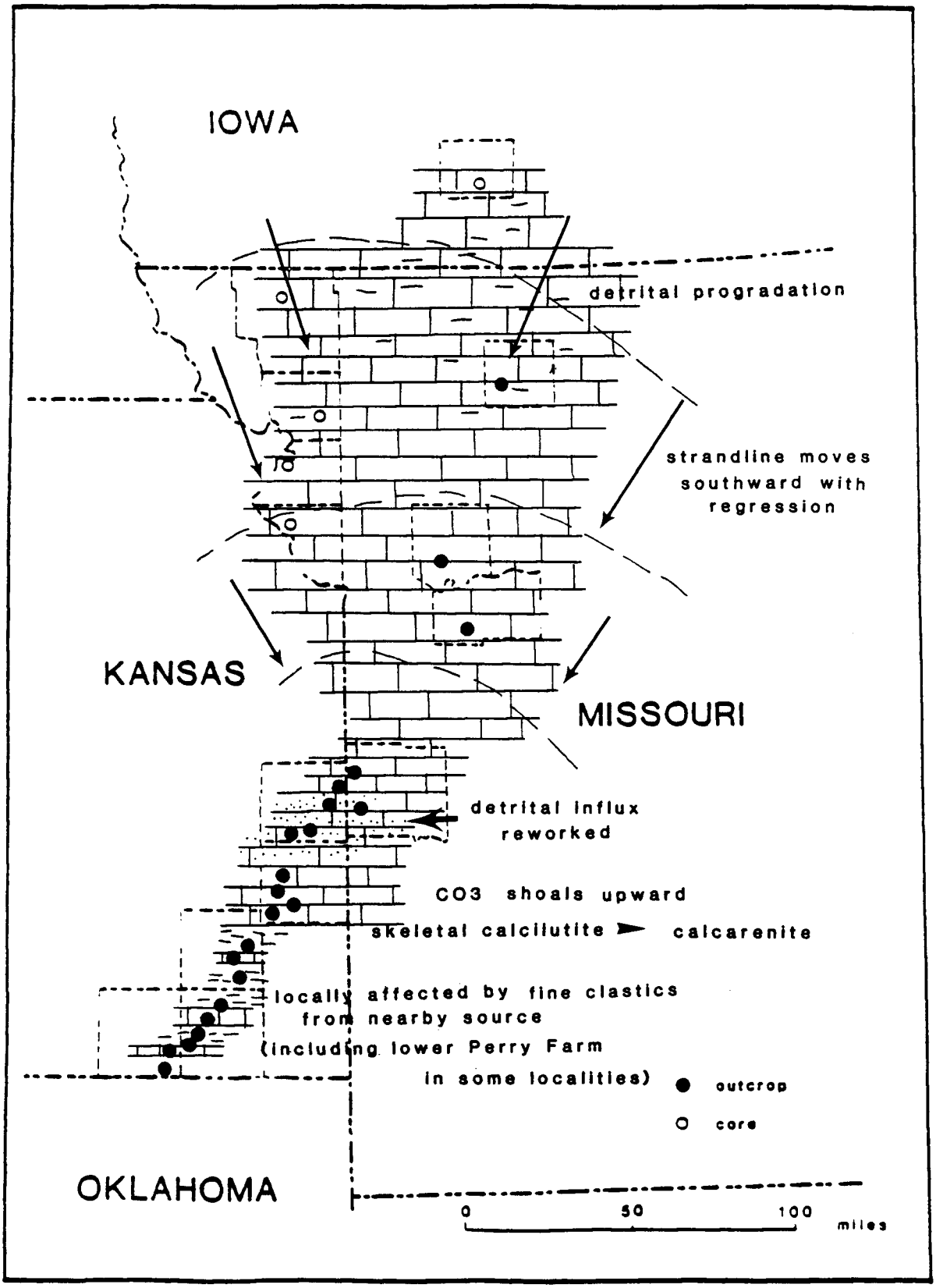

Norfleet absent
ILC (Heckel pers. comm.)
IOWA
NOC
NAC
Extent of Norfleet
Ad only
transgression
nearshore muddy impure CO3
Norfleet absent
(Howe 1982)
MTHL
fine calcarenite near wave base even at maximum transgression
Ad
Ng
KANSAS
MISSOURI
initial impure limestone beneath shale in area closer to influx
deepening-upward transgressive limestone beneath shale
transgressive reworking of coarse parts of Nowata delta
Ad = Adetognathus
Ng = Neognathodus
outcrop
core
OKLAHOMA
0
50
100
miles

Figure 38. Generalized distribution of upper portion of Norfleet during early regressive phase. Standard Lithologic symbols are used.


IOWA
detrital progradation
strandline moves
southward with
regression
KANSAS
MISSOURI
detrital influx
reworked
CO3 shoals upward
skeletal calcilutite
calcarenite
locally affected by fine clastics
from nearby source
(including lower Perry Farm
in some localities)
outcrop
core
OKLAHOMA
0
50
100
miles

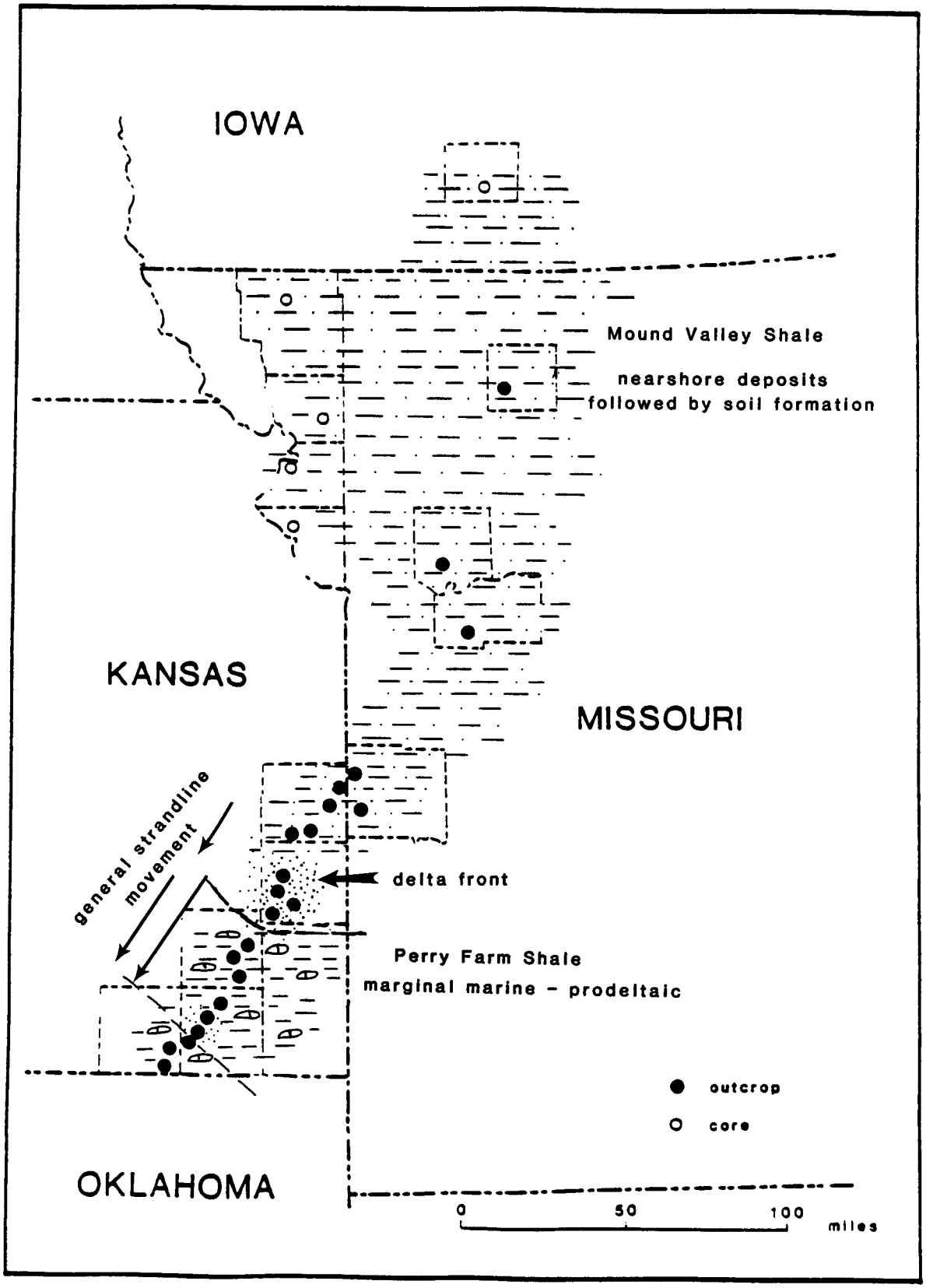
Late Regressive Phase--Perry Farm Member

The Perry Farm Member (and equivalent Mound Valley Shale to the north) were deposited as the sea withdrew across the Midcontinent. High rate of detrital influx affected the entire study area (Figure 39) as strandline moved southward toward Oklahoma. It was during this time that meteoric water associated with the Perry Farm delta affected the underlying upper part of the Norfleet Member in the more northern area.

The Mound Valley Shale of the north represents prograding detrital influx along the retreating paleoshoreline. The Perry Farm in the southern portion was also deposited during this sea level drop, although a closer detrital source brought Perry Farm clastics earlier to parts of southern Kansas, which perhaps were lower areas between highs where Norfleet carbonate production persisted longer (Figure 38). The alternation of environments in the Perry Farm between carbonate production and periodically increasing influx allowed carbonate flags to develop as Underwood (1984) suggested for the younger Bourbon Flags.

Parkinson (1982) recognized a thin grey-green shale overlying the upper "Perry Farm Carbonate" facies (now considered upper Norfleet) in southern Kansas and northern most Oklahoma to have soil characteristics in its clay mineralogy. This material was probably derived from

Figure 39. Generalized distribution of Perry Farm Shale Member and lower Mound Valley Shale (to north) during maximum regression within Lenapah Formation. Standard lithologic symbols are used.


IOWA
Mound Valley Shale
nearshore deposits
followed by soil formation
KANSAS
MISSOURI
general strandline movement
delta front
Perry Farm Shale
marginal marine - prodeltaic
outcrop
core
OKLAHOMA
0
50
100
miles

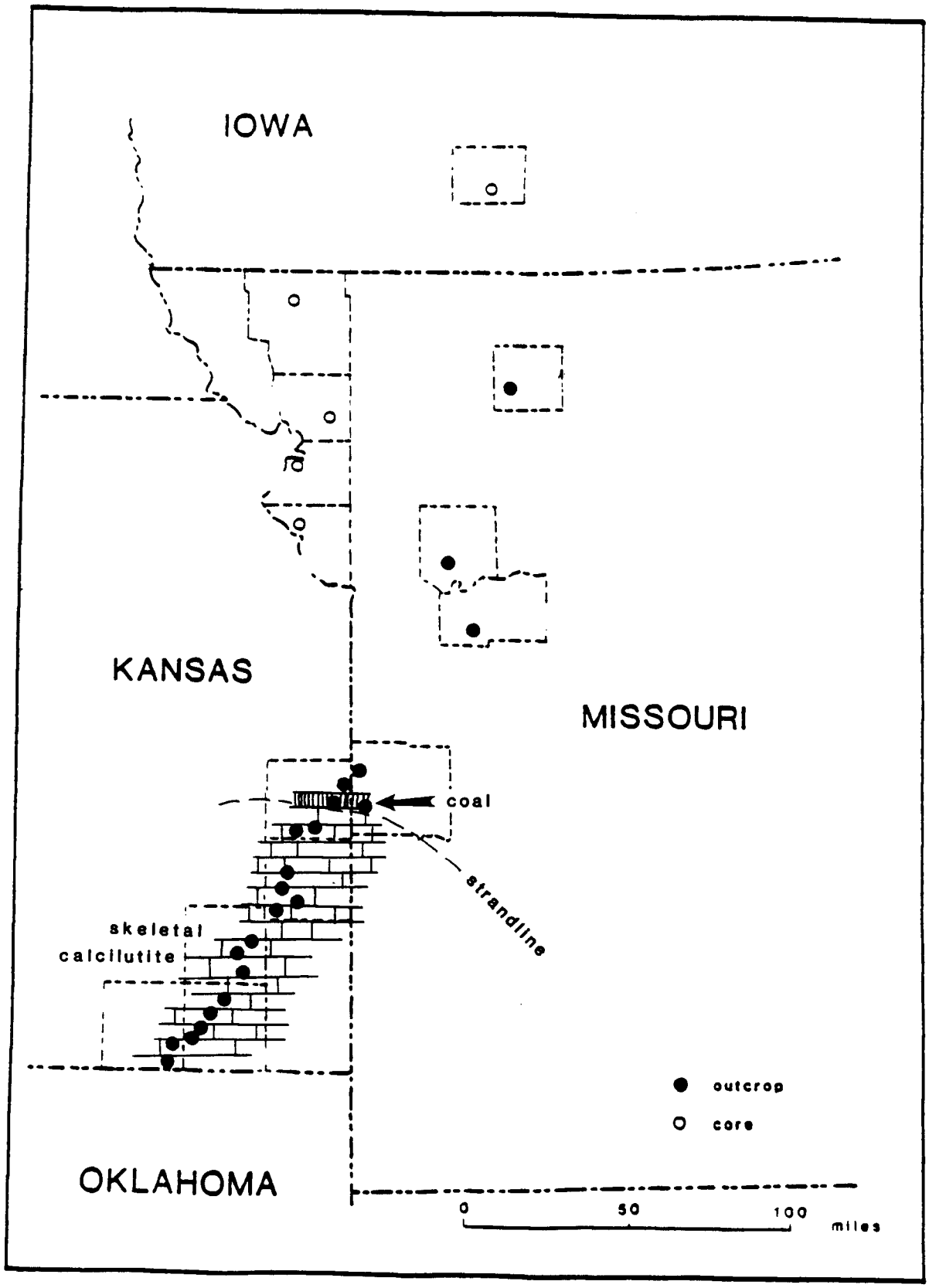
subaerially exposed Perry Farm Shale to the north. This would represent the point of maximum regression at the top of the Perry Farm Member across the area.

Second Transgressive-Regressive Phase--Idenbro Limestone Member

The next marine inundation during Lenapah deposition occurred at the base of the Idenbro Member, where carbonate production once again migrated northward over the regressive Perry Farm Shale (Figure 40). This transgressive phase did not extend as far north as the Norfleet Member. Carbonate production extended at least to southern Linn County, Kansas (Elk Creek). The lower calcilutite facies represents deposition in water below effective wave base, and the sparse conodont fauna suggests that water depth within this cycle remained quite shallow. The farthest northward extent of marine waters may be reflected by the coal horizon in east-central Linn County at the Trading-Post locality, which perhaps was deposited in a swamp that formed just landward of the maximum position of shoreline during this cycle.

The upper muddy skeletal calcarenite records the beginning of the next regressive phase (Figure 41). This facies was deposited nearer to effective wave base in shallowing water. The continued retreat of shoreline resulted in deposition of the silty shale of the terrestrial Mound Valley Shale, which ended carbonate production across

Figure 40. Generalized distribution of lower calcilutite portion of Idenbro Member deposited during second transgressive phase. Standard symbols are used.


IOWA
KANSAS
MISSOURI
OKLAHOMA
coal
strandline
skeletal
calcilutite
outcrop
core
0
50
100
miles

the northern midcontinent. The upper Mound Valley over Oklahoma, Kansas, and much of Missouri consists of a blocky mudstone soil horizon overlain in many places by coal in the southern region. It was this regressive phase and resulting widespread subaerial exposure that probably caused the pervasive leaching and subsequent deposition of sparry cement in the upper Idenbro.

Depositional Summary

The Nowata Shale ("outside shale") records detrial influx during maximum regression before deposition of the overlying Lenapah Formation (Figure 42). The Lenapah Formation, unlike many formations in the Middle and Upper Pennsylvanian, which have been interpreted to be a single transgressive-regressive carbonate deposit, represents two moderate to minor eustatic sea level fluctuations. The lower portion of the Norfleet Member records a fairly rapid though relatively shallow transgressive phase and includes both local transgressive limestone and more widespread conodont-rich ("core") shale. As the sea more slowly regressed, the upper regressive, main ledge of the Norfleet Limestone was deposited, followed in shallower waters by the regressive nearshore Perry Farm Shale Member as an "outside shale", which has a small delta in east-central Kansas and some evidence of paleosol development in its clay mineralogy in southern Kansas.

Figure 41. Generalized distribution of upper calcarenitic portion of Idenbro Member deposited during early part of second regressive phase. Standard lithologic symbols are used.

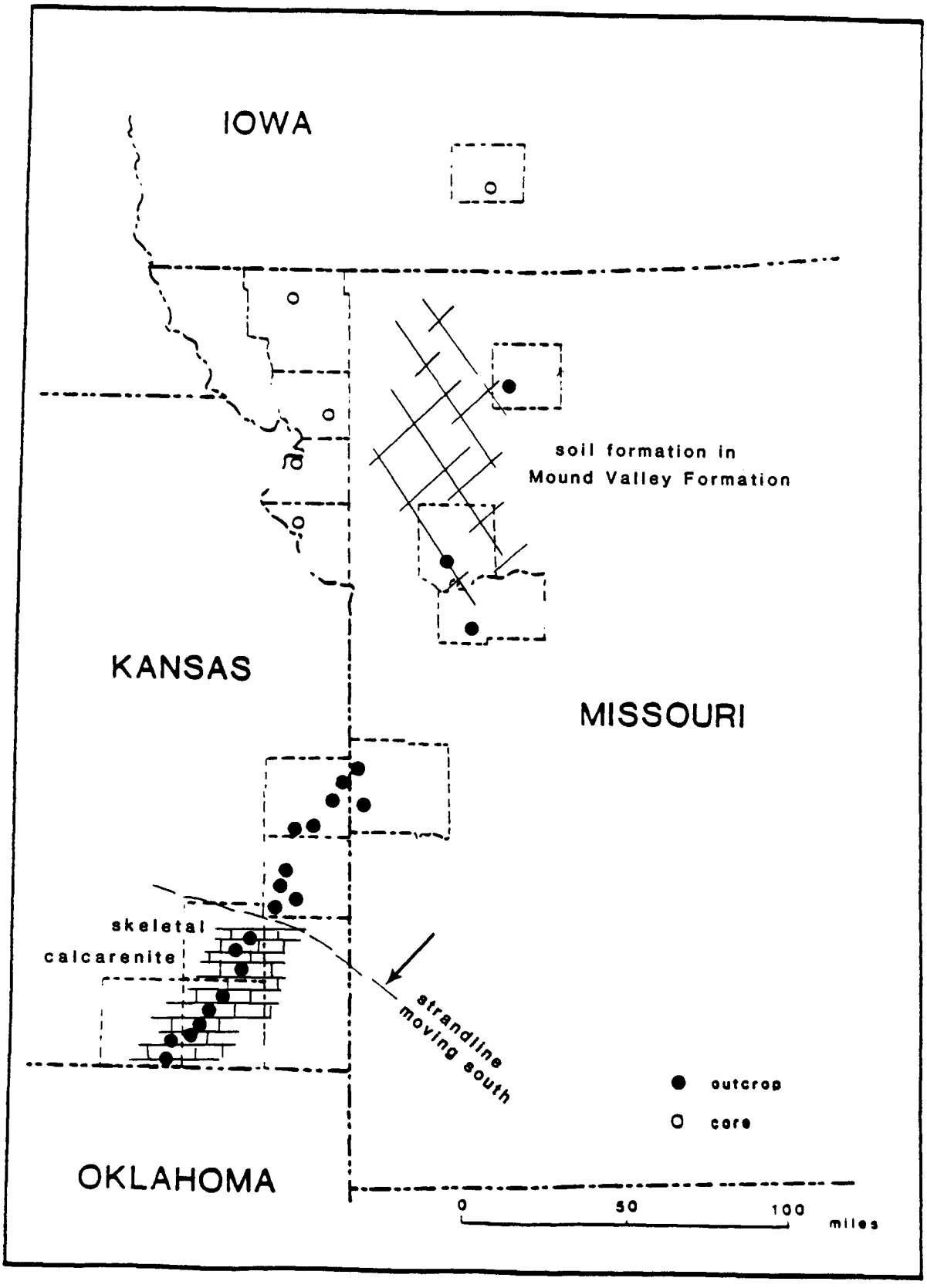
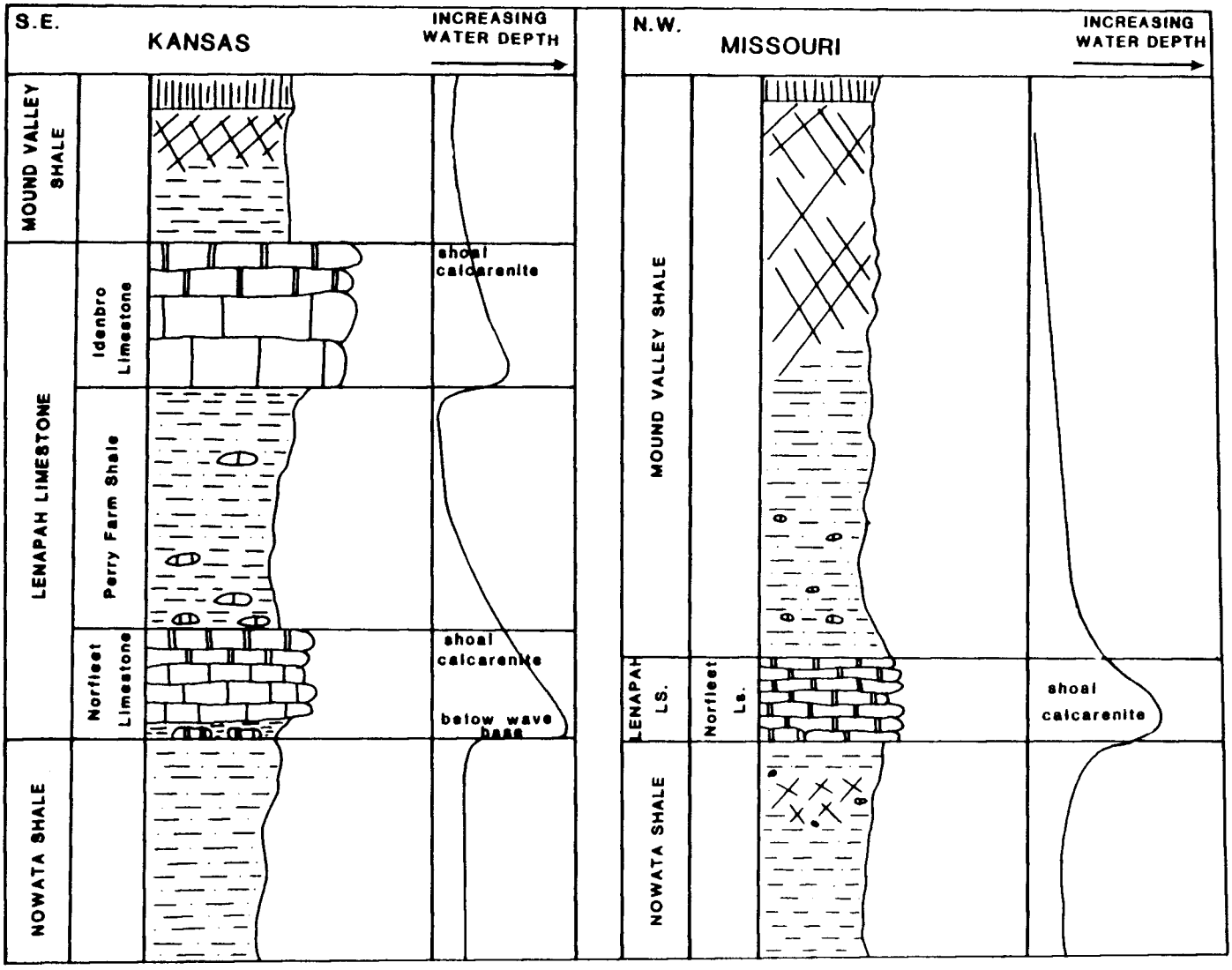

IOWA
soil formation in
Mound Valley Formation
KANSAS
MISSOURI
skeletal
calcarenite
strandline
moving south
outcrop
core
OKLAHOMA
0
50
100
miles

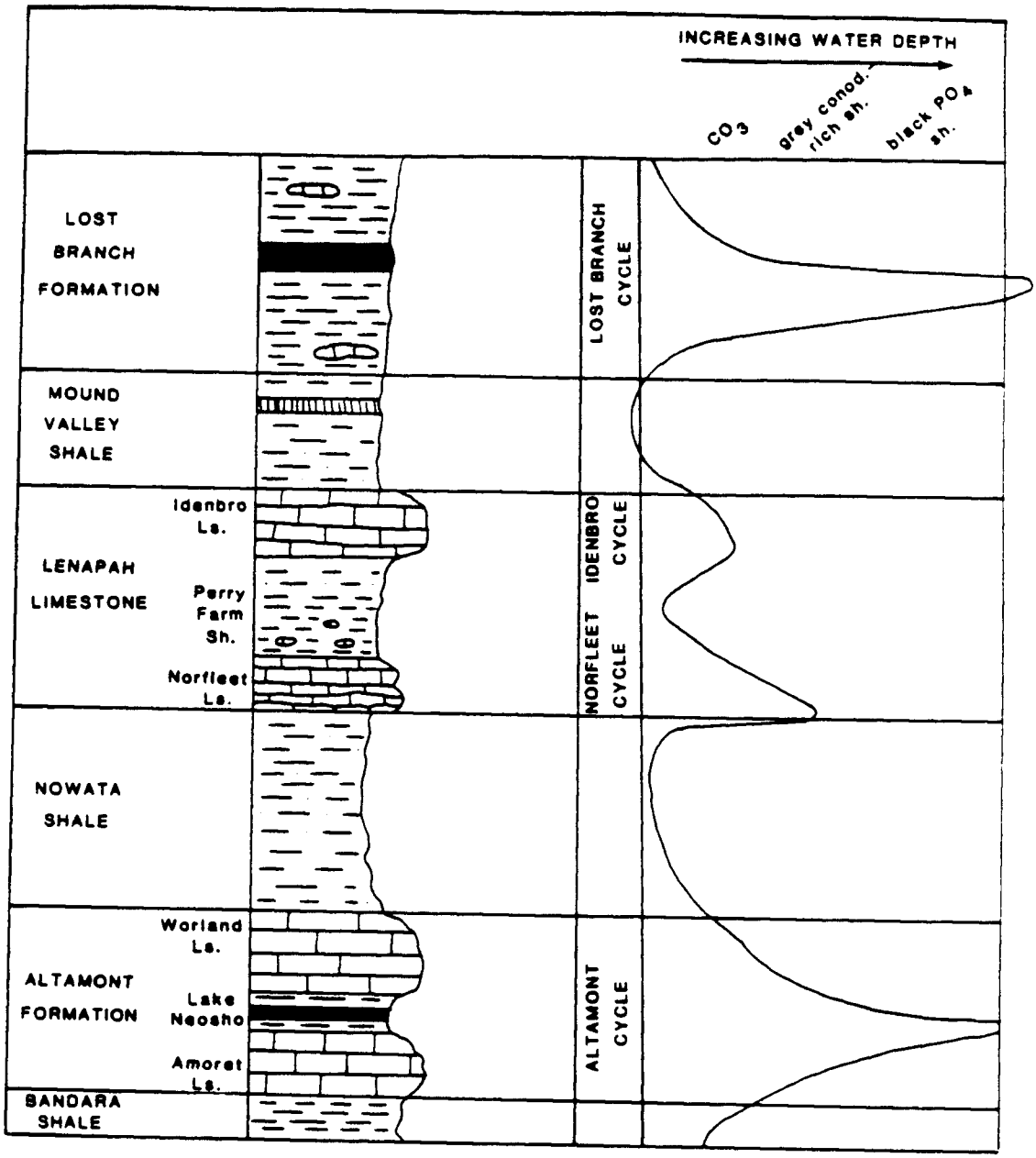
Figure 42. Generalized sea-level curve for Lenapah Limestone. Note two transgressive-regressive sequences in Lenapah in eastern Kansas, and only one extending into western Missouri. Standard lithologic symbols are used.


S.E.
KANSAS
INCREASING WATER DEPTH
MOUND VALLEY SHALE
LENAPAH LIMESTONE
Idenbro Limestone
Perry Farm Shale
Norfleet Limestone
NOWATA SHALE
shoal calcarenite
shoal calcarenite
below wave base
N.W.
MISSOURI
INCREASING WATER DEPTH
MOUND VALLEY SHALE
LENAPAH LS.
Norfleet Ls.
NOWATA SHALE
shoal calcarenite

The entire Idenbro Member records a minor second transgressive-regressive phase for the upper Lenapah Formation. The overlying mainly terrestrial Mound Valley Formation is the second and main "outside shale", which displays the eventual development of a widespread paleosol as the sea regressed a substantial distance into central Oklahoma, before the onset of the rapid transgression of the overlying Lost Branch Formation (Heckel, ms. in prep.).

Thus, the Lenapah formation represents two less widespread transgressive-regressive cycles. These are classified as intermediate (Norfleet) and minor (Idenbro) by Heckel (1986) and occurred after the depostion of the major Altamont Branch cycle (Figure 43).

Figure 43. Generalized diagram of succession of transgressive-regressive sequences in eastern Kansas and western Missouri. Shows intermediate Norfleet cycle and minor Idenbro cycle between more major Altamont and "Lost Branch" cycles. Standard lithological symbols are used.


INCREASING WATER DEPTH
CO3
grey conod. rich sh.
black PO4 sh.
LOST BRANCH FORMATION
MOUND VALLEY SHALE
LENAPAH LIMESTONE
Idenbro Ls.
Perry Farm Sh.
Norfleet Ls.
NOWATA SHALE
ALTAMONT FORMATION
Worland Ls.
Lake Neosho
Amoret Ls.
BANDARA SHALE
LOST BRANCH CYCLE
IDENBRO CYCLE
NORFLEET CYCLE
ALTAMONT CYCLE

CONCLUSIONS

1) The Norfleet Limestone Member (lower Lenapah) is now shown to be the laterally persistent limestone across northwestern Missouri into cores in southern Iowa, where it pinches out south of the outcrop, whereas the Idenbro Limestone (upper Lenapah) appears to pinch out northward in Linn County, Kansas.

2) When compared to other Midcontinent Pennsylvanian cyclothems, the Lenapah Limestone has relatively low abundance of conodonts.

a) The conodonts that are present (in order of abundance) include: Neognathodus, Adetognathus, Anchignathodus and Idiognathodus.

b) Unlike most other Pennsylvanian marine cycles, where it dominates, Idiognathodus is quite subordinate throughout the Lenapah.

c) Neognathodus dominates the Norfleet to the south and Adetognathus dominates it to the north.

d) The two genera associated with deeper water deposition, Idioprioniodus and Gondolella, are both conspicuously absent from the Lenapah Formation.

3) The Lenapah contains two eustatic transgressive-regressive cycles, corresponding fairly closely to the two limestone members, separated by the regressive Perry Farm Shale. Both cycles lack the offshore black phosphatic "core shale" characteristic of many of the other Pennsylvanian cyclothems.

a) The first early transgressive phase is represented by the algal-coated calcarenite of the lower Norfleet, which grades upward into a deeper-water skeletal calcilutite in Linn County, Kansas.

b) The deepest portion of either transgressive-regressive phase is represented by the offshore calcarenites, calcilutites and shale facies of the lower portion of the Norfleet Member, dominated by the genus Neognathodus.

c) The early regressive phase of the first cycle is represented in the upper Norfleet by the skeletal calcarenite and sandy skeletal calcarenite facies, which show an upward decrease in conodont abundance, dominated by Adetognathus.

d) The regressive Perry Farm Member of eastern Kansas displays sandstone-dominated deltaic facies to the north in eastern Kansas and offshore prodeltaic silty shale with carbonate nodules to the south in southeastern Kansas.

e) The calcilutite facies of the lower Idenbro and the muddy skeletal calcarenite facies of the upper Idenbro represent the second transgressive-regressive phase.

4) Diagenetic facies are readily interpreted in light of the depositional interpretation.

a) The overcompacted lower Norfleet calcarenites display diagenetic patterns consistent with movement directly from the marine phreatic environment into the deeper burial connate zone, without evidence of meteoric influence.

b) The loosely packed calcarenite of the upper Norfleet displays leaching of aragonitic grains and filling of molds and interstitial voids particularly by echinoderm overgrowths, which suggest penetration by the meteoric phreatic environment first undersaturated, then saturated. This was followed by movement into the deeper burial environment where final ferroan cements were deposited.

c) Both the lower and upper Idenbro units show irregular void areas strongly affected by meteoric leaching, which reflects the overlying major regressive Mound Valley Shale, which is characterized by a paleosol and coal horizon over much of its extent.

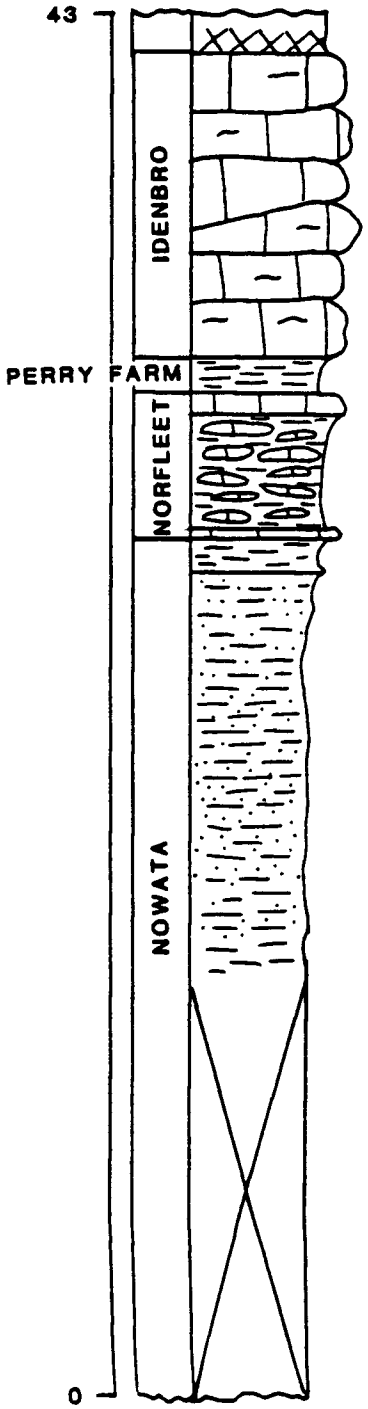
APPENDIX A

STRATIGRAPHIC SECTIONS

VERDIGRIS RIVER BRIDGE (VRB)

NE NW Sec18 T35S R17W Montgomery Co.

KANSAS



8 feet grey skeletal calcilutite with algal blades.

1 foot green shale.

6 inches wavy limestone ledge.

4 feet shale with limestone nodules.

2 inches limestone ledge with crinoids.

1 foot shale.

10 feet sandy shale with argillaceous sandstone.

20 feet shale, mostly covered. Contact covered.

ROAD CUT 166 (RC166)

SW NW Sec33 T34S R17E

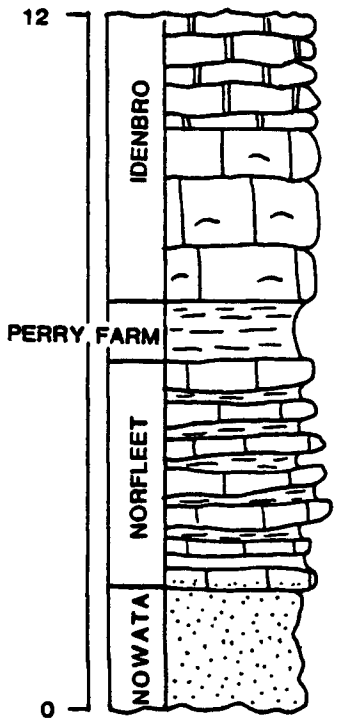
and

QUARRY 166

NW SW Sec32 T34S R17E

Montgomery Co.

KANSAS



2 feet medium-bedded skeletal calcarenite.

3 feet thick-bedded calcilutite, with algal blades.

1 foot green shale.

4 feet rubbly calcilutite slumped to rubble with shale partings.

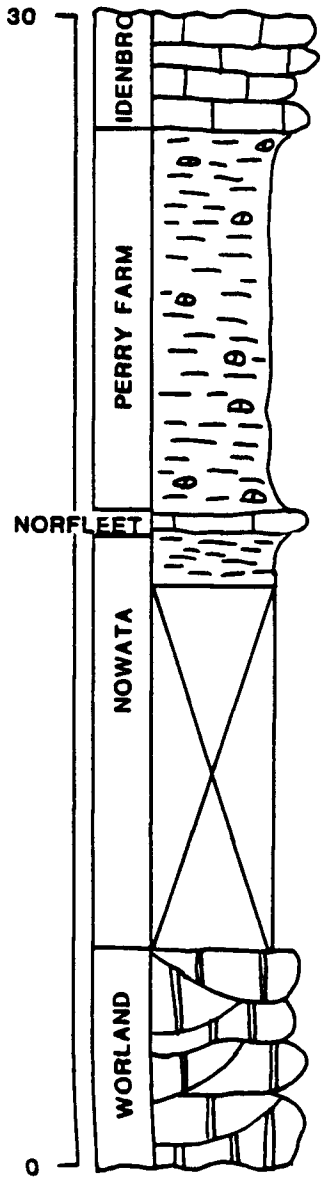
sandy limestone at base

2 feet calcareous sandstone with marine fossils.
Contact covered.

TYPE PERRY FARM (TPR)

NE NW Sec7 T34S R18E Labette Co.

KANSAS



3 feet light dove-grey, irregular bedding, skeletal calcarenite. Contact covered.

10 feet grey fossiliferous shale, limestone nodules. Some portions covered.

6 inches dark grey, dense nodular skeletal calcilutite.

1 foot grey shale.

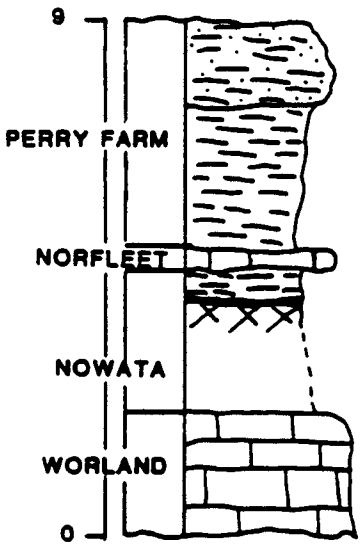
10 feet covered interval.

5 feet light grey, wavy, cross-bedded, skeletal calcarenite. Contact covered.

ANGOLA N.E. (ANE)

SE SE Sec34 T33S R18E Labette Co.

KANSAS



1.5 feet tan siltstone.

2.75 feet grey shale, dark grey at base.

.25 feet dark impure limestone.

6 inches dark grey shale with coal at base.

2 feet covered interval with underclay at top.

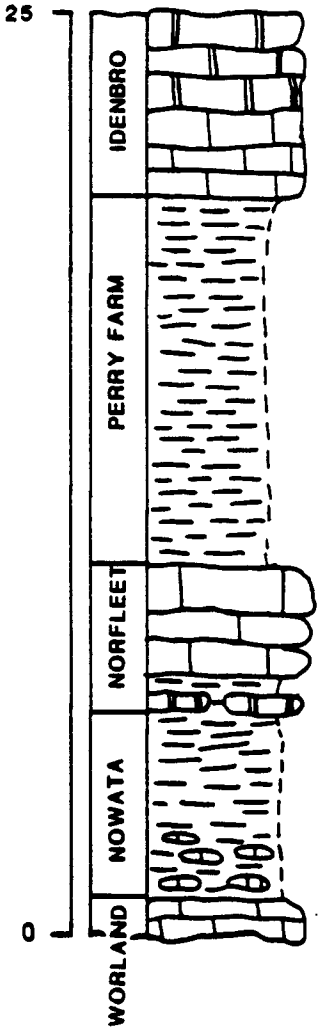
2 feet grey skeletal calcilutite in creek.

Contact covered by creek.

MOUND VALLEY NORTH-EAST (MVNE)

E Sec35 T32S R18E Labette Co.

KANSAS



2 feet light -grey to tan skeletal calcarenite with large productids.

3 feet light-grey calcilutite with brachiopods. Grains increasing towards top of section.

Jewett '41 reports 10 feet grey shale partly covered. Presently not exposed.

3 feet dove-grey massive calcilutite.

6 inches dark shale.
6 inches dark calcarenitic limestone nodules.

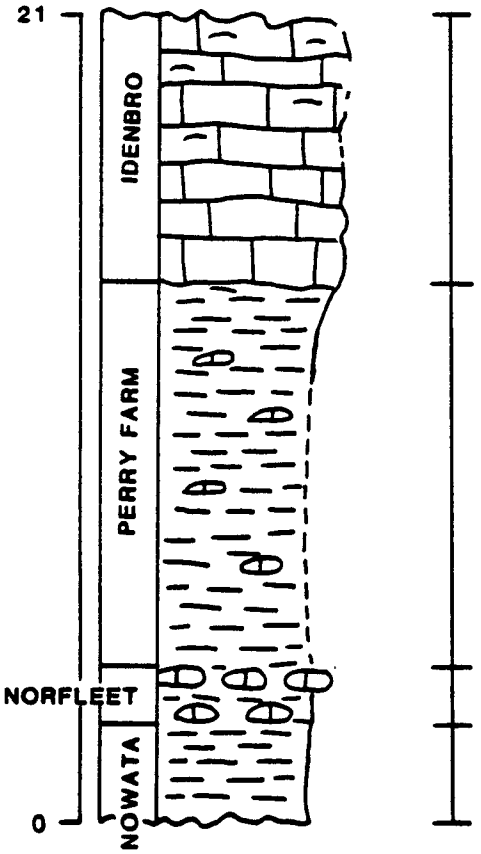
Jewett '41 reports 5 feet black shale with dark limestone nodules in lower part.

Jewett '41 reports 1 foot light-grey limestone.

TYPE IDENBRO (TI)

SW SW Sec2 T32S R19E Labette Co.

KANSAS



Jewett '41, reports 7 feet of Idenbro, presently not exposed. 3 feet grey skeletal calcilutite, nodular with algal remains.

Jewett '41, reports 10 feet grey shale with nodules, presently not exposed.

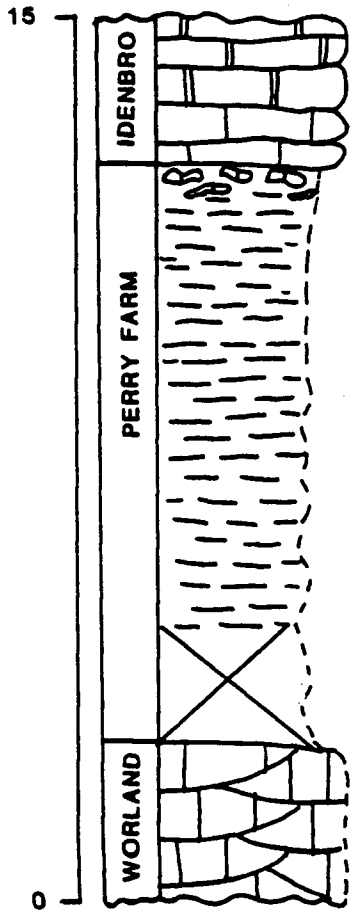
2 feet calcareous limestone nodules, grey shale. Contact gradational.

2 feet grey calcareous shale. Contact covered.

SOUTH of SOUTH MOUND (SSM)

SE SE Sec22 T30S R20E Neosho Co.

KANSAS



2.5 feet light grey calcarenite, crinoids, brachiopods, algae present increasing in abundance towards top. Contact gradational.

6 inches hummocky, irregular iron rich, grey calcilutitic nodules with brachiopods.

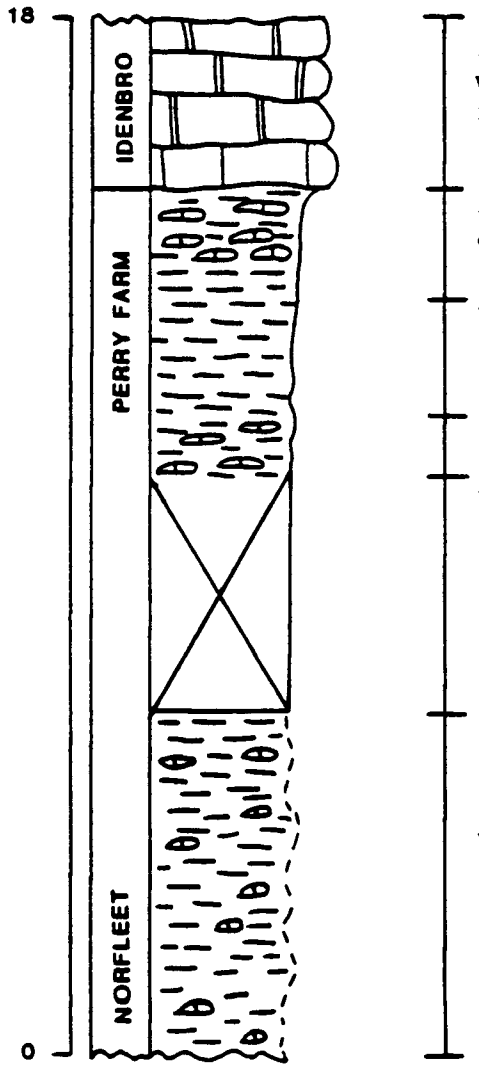
Jewett '45 reports 10 feet of shale with limestone nodules. Presently not exposed.

Jewett '45 reports 2.5 feet of light grey limestone containing thin lenses of flint. Presently not exposed.

BACHELOR CREEK (BC)

S SW Sec28 T29S R20E Neosho Co.

KANSAS



3 feet grey, skeletal calcarenite with pelecypods and large productids, irregular bedding.

2 feet grey shale with light grey dense calcareous nodules.

2 feet slightly micaceous shale.

1 foot shale with nodular limestone. Contact covered.

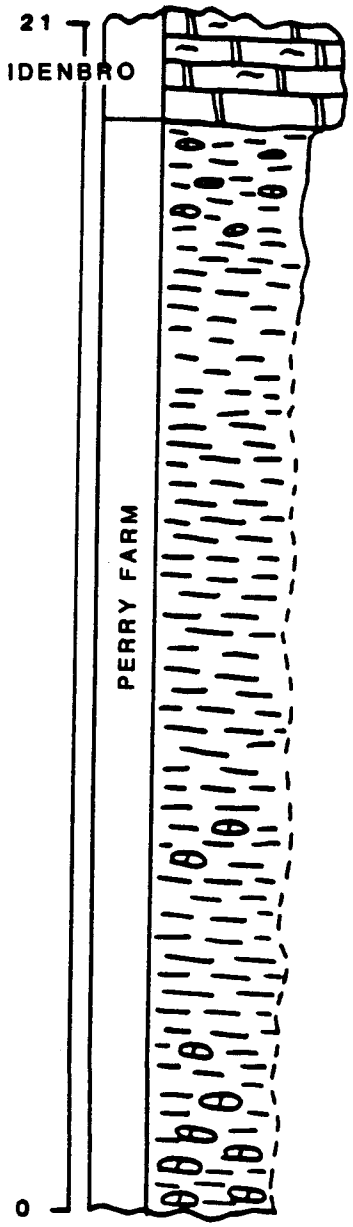
4 feet covered interval.

Jewett '45 reports 6 feet of Norfleet consisting of limey shale with dark grey nodular limestone.

FLAT ROCK CREEK (FRC)

SW Sec29 T28S R21E Neosho Co.

KANSAS



2 feet dove-grey, hummocky, skeletal calcarenite with algal blades.

3.5 feet yellow shale with small limestone nodules.

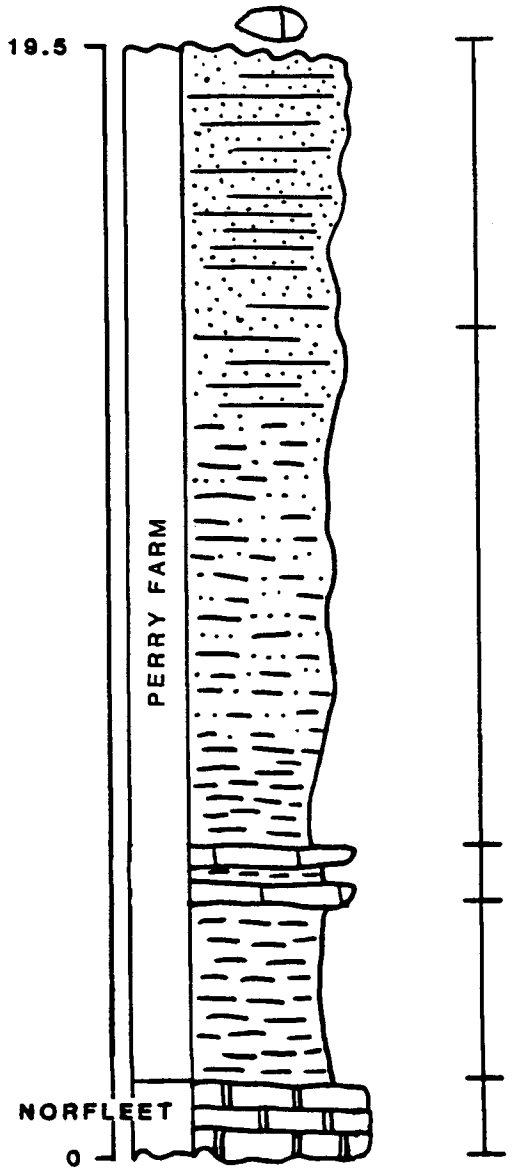
Jewett '45 reports 5.5 feet yellow-micaceous, slightly silty shale.

Jewett '45 reports 10 feet yellow micaceous shale with numerous limestone nodules in the lower part.

PRONG CREEK (PRC)

NL Sec10 T27S R22E Bourbon Co.

KANSAS



Idenbro skeletal calcilutite in float.

6 feet thin bedded fine grained sandstone.
Contact gradational.

5 feet grey silty shale.

3 feet grey shale getting silty upward.

1 foot coated- skeletal calcarenite, with few inches of clay shale in middle.

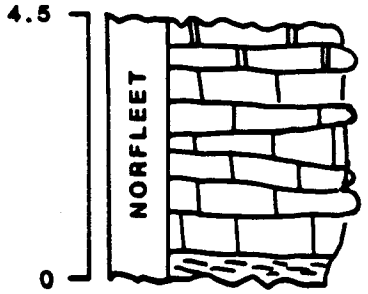
2.5 feet grey clay shle.
Contact sharp.

1 foot skeletal calcarenite, forming top of creek bed.
Water level 1983.

OWL CREEK (OC)

SE Sec6 T27S R23E BOURBON Co.

KANSAS



6 inches crinoidal calcarenite.

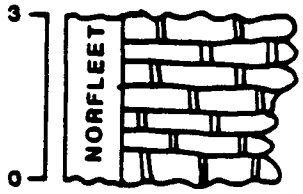
3.5 feet grey skeletal calcilutite with brachiopods, very slabby. Contact sharp.

6 inches dark grey shale. Contact covered.

EAST of PETERSBURG (EP)

W Sec13 T26S R22W Bourbon Co.

KANSAS

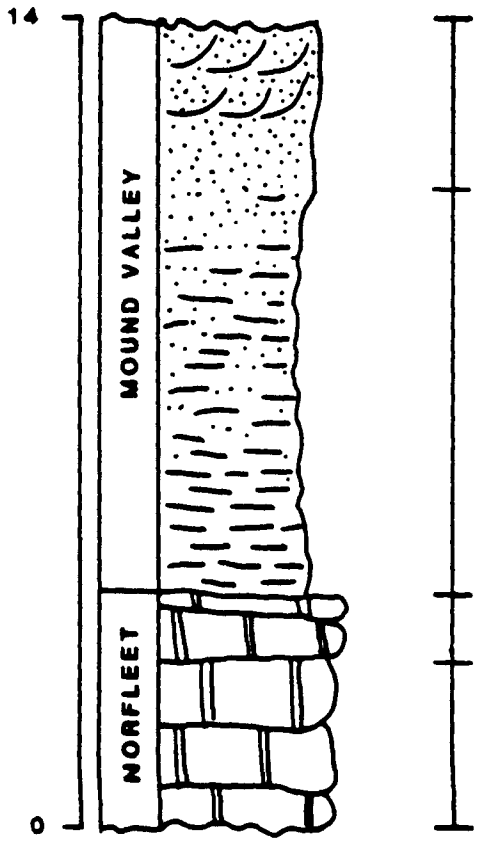


3 feet bluish-grey skeletal calcarenite.
Contact covered.

N.E. PETERSBURG (NEP)

SE Sec11 T26S R22E Bourbon Co.

KANSAS



3 feet sandstone with ripples.
Contact gradational.

7 feet grey shale, with increasing sand towards top.

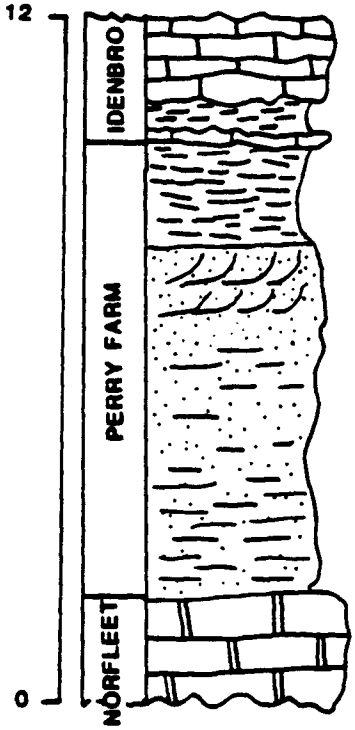
1 foot thin bedded calcarenite.

2 feet massive, grainy calcarenite.
Contact covered.

EAST of UNIONTOWN (UTE)

SL Sec23 T25S R22E Bourbon Co.

KANSAS



1.5 feet greenish-grey crumbly skeletal calcilutite.

6 inches grey shale.
3 inches crumbly sandy limestone with brachiopods.
2 feet grey shale.
2 feet fine-medium grained sandstone, with ripple laminae and some large scale cross stratification.

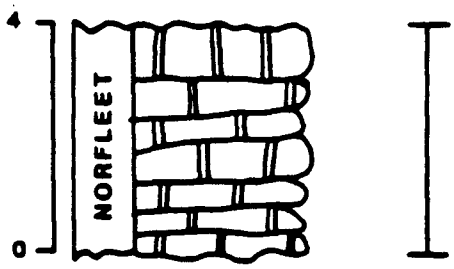
4 feet siltsone, grey, interbedded with shale.

2 feet grey skeletal calcarenite, massive.
Contact covered.

BAPTIST PASTURE (BP)

NW Sec26 T25S R22E Bourbon Co.

KANSAS

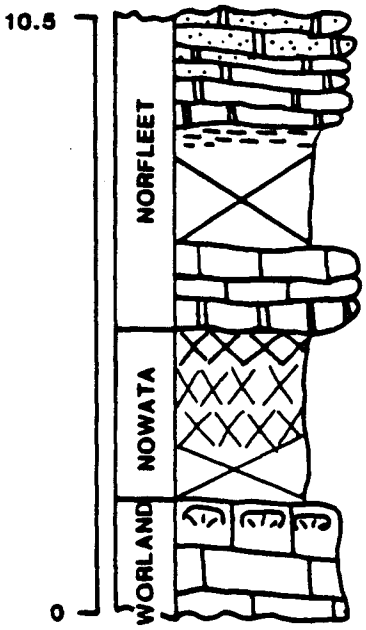


4 feet slabby brownish-grey, crinoidal, grainy, skeletal calcarenite.
Contact covered.

LOST CREEK (LTC)

SE NE Sec15 T23S R23E Linn Co.

KANSAS



2 feet sandy skeletal calcarenite with abundant crinoid fragments.

1-3 inches dark shale rich in conodonts.
2 feet covered interval.

1.5 feet limestone, calcilutite at top; skeletal calcarenite with productids middle; algal coated grains at bottom.

2 feet green blocky mudstone.

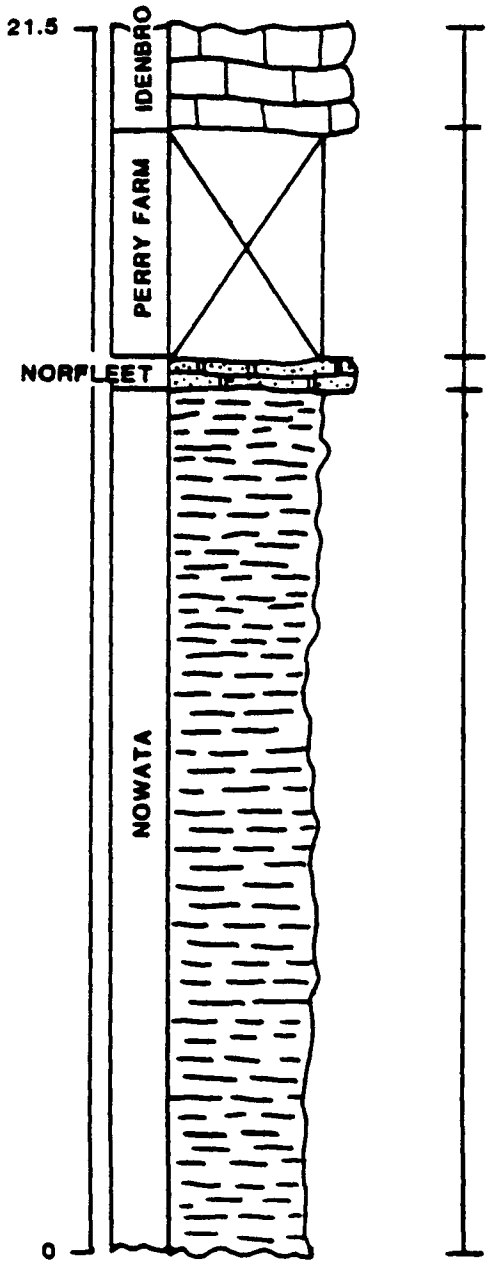
1 foot covered interval.

2 feet skeletal calcilutite with chaetited heads in creek bed.
Contact covered by creek.

ELK CREEK (ELC)

NE Sec7 T23S R24E Linn Co.

KANSAS



2 feet light-grey skeletal calcilutite.

4 feet covered interval.

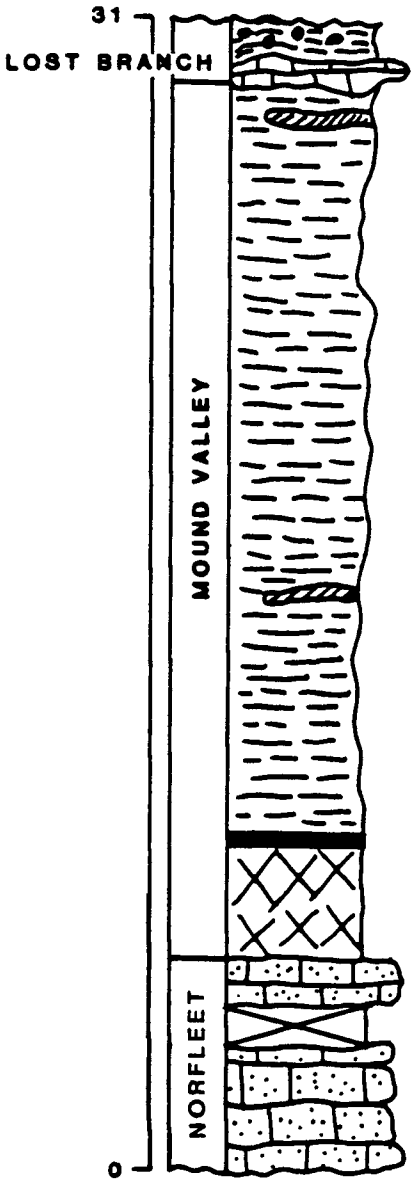
6 inches very sandy crinoidal calcarenite. Contact sharp.

15 feet green-grey silty shale. Contact covered by creek.

TRADING POST (TRP)

near cen. Sec5 T21S R25E Linn Co.

KANSAS



1 foot hard black, laminated shale with phosphate nodules.
1 foot hard dark lenticular skeletal calcilutite with brachiopods, argil aceous towards top.

20 feet shale with iron-stone horizons.

3 inches coal.

3 feet mudstone.

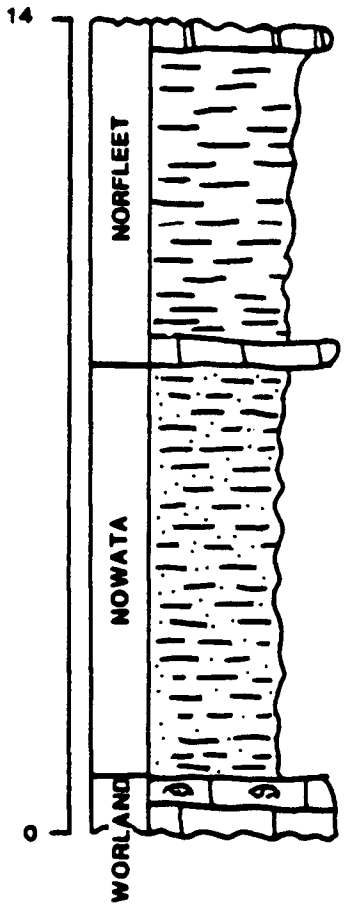
1.5 feet sandy limestone with brachiopods, slabby.
1 foot covered interval.

3 feet sandy , slabby limestone with brachiopods, more of a skeletal calcilutite towards bottom.
Contact covered by creek.

AMORET - SOUTH (AMS)

SW Sec33 T40N R33W Bates Co.

MISSOURI



6 inches dark skeletal calcarenite, with crinoids, corals and brachiopods.

5 feet grey shale.

6 inches dark, dense calcilutite.

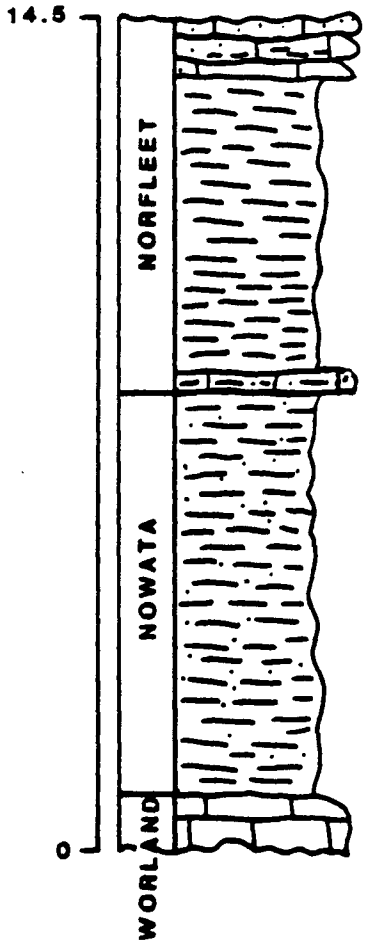
7 feet grey siltstone.

1 foot grey calcilutite in creek bed. Contact covered by creek.

MACEDONIA SCHOOL (MAS)

con. EL Sec9 T20S R25E Linn Co.

KANSAS



1 foot grey, crumbly, sandy, limestone, contains large productids. Contact sharp.

5 feet light grey fossiliferous shale.

6 inches dark silty limestone with brachiopods.

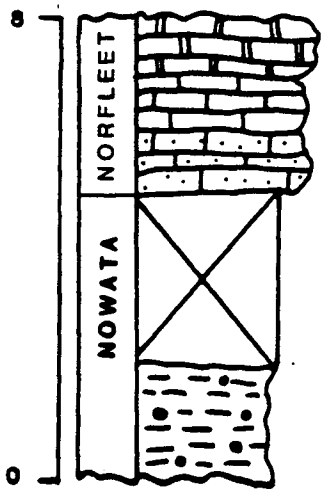
7 feet grey, sandy, fossiliferous shale.

1 foot grey calcilutite in creek bed. Contact covered by creek.

AMSTERDAM (AMD)

N of SW Sec21 T41N R33W Bates Co.

MISSOURI



1 foot grey coarse grained, crinoidal calcarenite.
1 foot grey silty calcilutite.

1 foot buff colored sandy limestone.

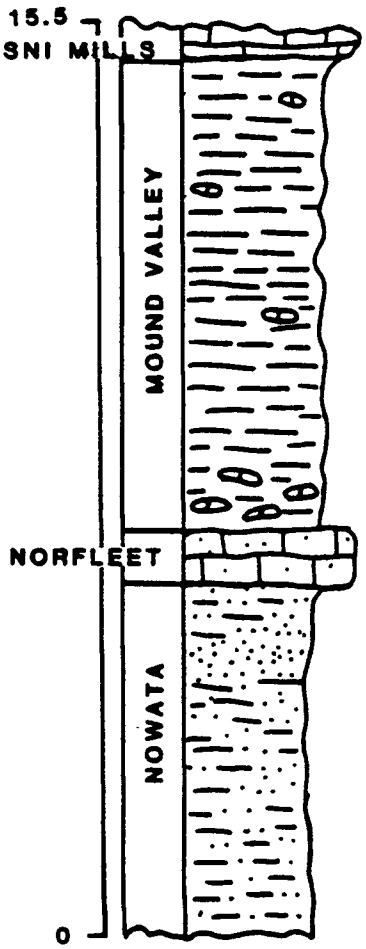
2 feet covered interval.

2 feet buff colored shale with iron nodules. Contact covered.

ODESSA (ODA)

SE SE NW Sec22 T49N R27W Lafayette Co.

MISSOURI



6 inches light to medium grey, with red veins, skeletal calcilutite.

8 feet olive green shale, dense light colored limestone nodules abundant at base and scattered throughtout shale.

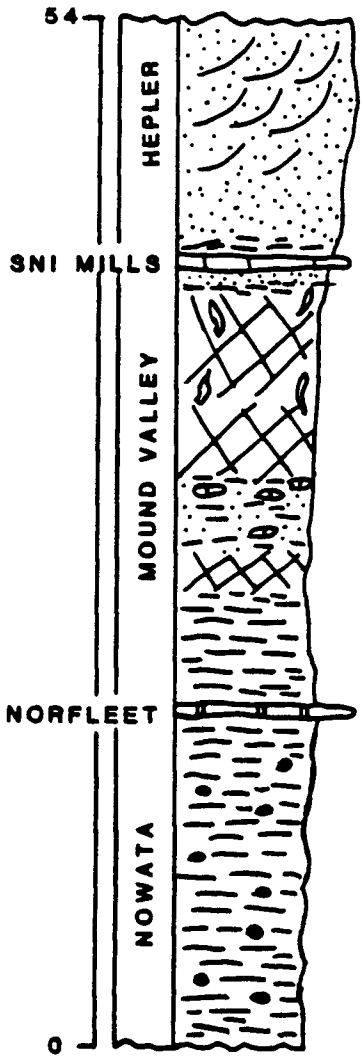
1 foot greenish-grey to brown sandy, skeletal calarenite, with abundant crinoids and Composita.

6 feet greenish-grey interbedded siltsones, shales and sandstones. Contact covered.

RICHMOND (RCD)

NW SW Sec24 T52N R28W Richmond Co.

MISSOURI



12 feet fine-grained sandstone, cross-bedded with ripple laminae.

6 inches black shale, carbonaceous, phosphatic nodules, weathers to brittle chips.

6 inches grey limestone
2 inches sandstone.
6 inches medium grey shale.

10 feet maroon and green underclay with root impressions.

3 feet siltstone with impure limestone concretions.

3 feet olive green clay.

6 feet greenish-grey shale with impure limestone layers. At base shale thinly laminated.

6 inches greenish-grey calcarenite with abundant crinoid fragments, some admixed clay and glauconite, occurring as a single ledge.

2 feet grey shale.

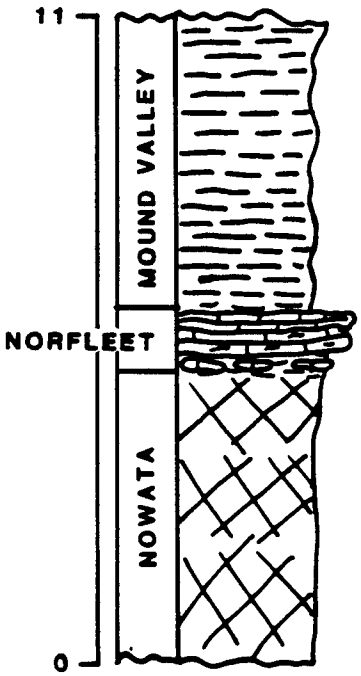
13 feet shale with hematitic nodules.

1 foot olive green shale.
Contact covered.

GRUNDY (GRD)

S SE NW Sec33 T62N R25W Grundy Co.

MISSOURI



5 feet grey shale.

8 inches argillaceous limestone, abundant crinoid debris, with scattered corals and brachiopods.

3 inches medium grey dense, lenticular masses, algal laminae and crinoids.

1 inch argillaceous limestone or calcareous shale, detrital shell material, small calcareous concretions.

5 feet underclay-like, clay. Contact covered.

APPENDIX B

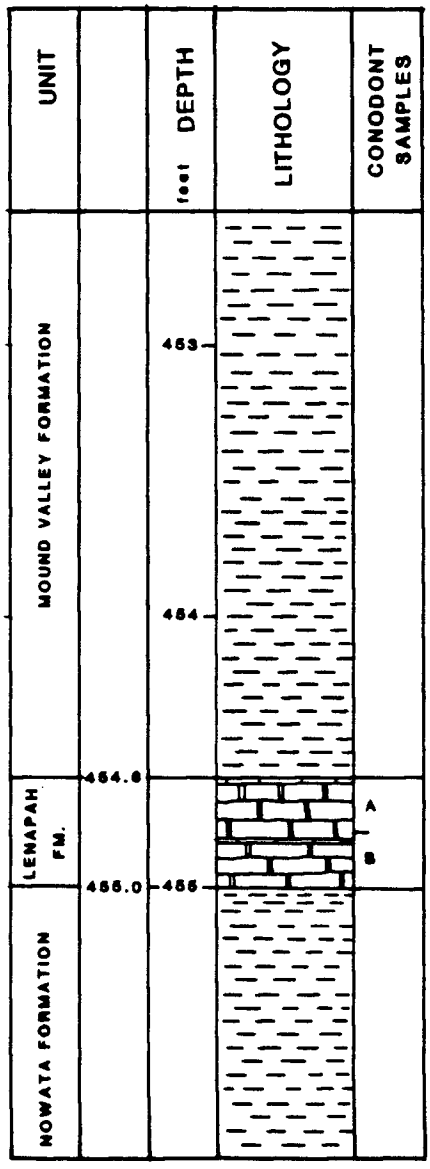
CORE DESCRIPTIONS

MPC

PLATTE CO., MISSOURI

NE SE sec. 9 T53N R36W

(after description by B. Netzler as modified by P.H. Heckel)



NAME: MPC-Missouri Platte Core

LOCATION: NE SE sec.9 T53N R36W

DESCRIPTION:

446.5-454.6: grey shale;

454.6-454.62: dark green clayey calcilutite with crinoid grains;

454.62-454.85: dark grey-green coarse grained crinoidal rich calcarenite;

454.85-454.86: dark grey-black limey calcilutite;

454.86-455.0: grey-dark green coarse grained crinoidal rich calcarenite;

455.0-468.0: grey shale;

CONODONT SAMPLES:

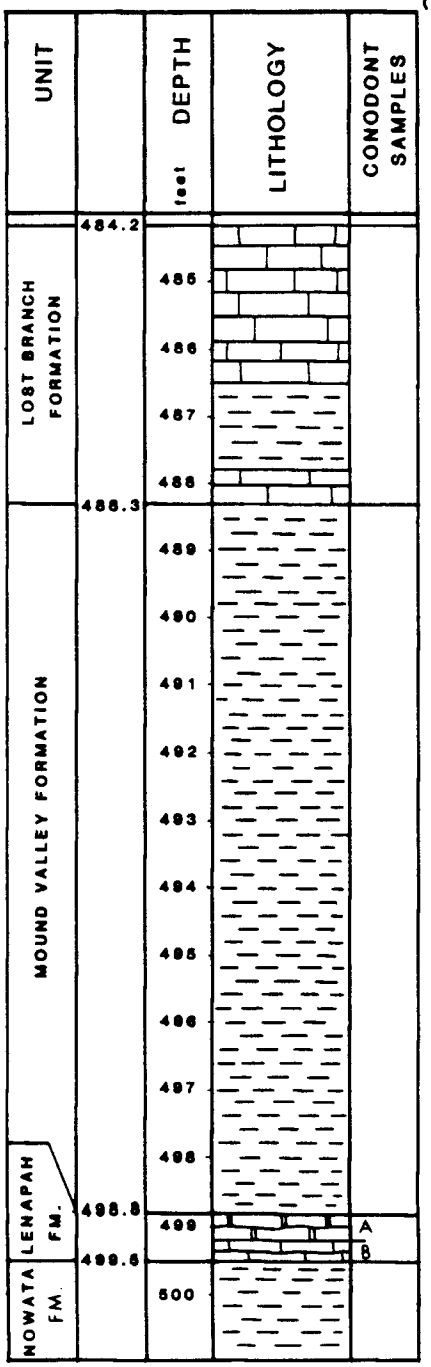
Sample A: 454.6-454.8 8 *Adetognathus* platforms, 3 *Neognathodus* platforms, 1 *Anchignathodus* platform;

Sample B: 454.8-455.0 4 *Adetognathus* platforms, 3 *Neognathodus* platforms;

MBC

BUCHANAN CO., MISSOURI
NW NW sec.33 T57N R36W

(after description by B. Netzler as modified by P.H. Heckel)



NAME: MBC-Missouri Buchanan Core

LOCATION: NW NW sec.33 T57N R36W

DESCRIPTION:

484.2-486.5: nodular limestone;

486.5-487.8: grey shale;

487.8-488.3: undulating nodular limestone with silt beds;

488.3-498.8: calcareous shale with small fossils;

498.8-499.2: grey-dark green coarse grained crinoidal calcarenite, with some shaly layers;

499.2-499.5: light grey skeletal calcilutite, skeletal grains predominantly crinoidal;

499.5-503.7: shale with small red mottling;

CONODONT SAMPLES:

Sample A: 498.85-499.2 20 *Adetognathus* platforms, 7 *Neognathodus* platforms;

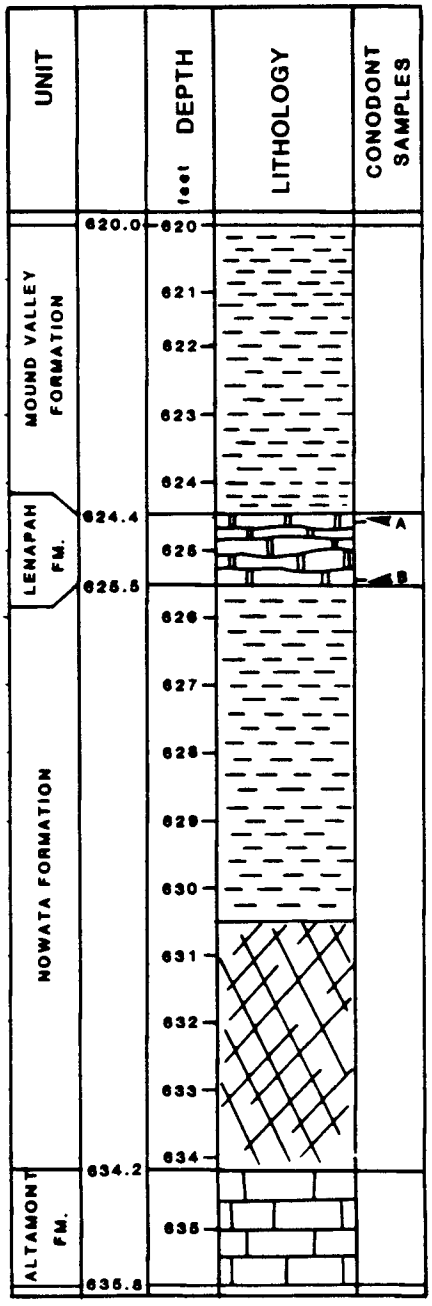
Sample B: 499.2-499.5 10 *Adetognathus* platforms, 17 *Neognathodus* platforms, 1 *Anchignathodus* platform, 3 elements

MRC

ANDREW CO., MISSOURI

SE SE sec.4 T59N R34W

(after description by B. Netzler and K. Deason as modified by P.H. Heckel)



NAME: MRC-Missouri Rochester Core:

LOCATION: SE SE sec.4 T59N R34W

DESCRIPTION:

620.0-624.4: grey shale with reddish spots;

624.4-625.5: skeletal calcarenite, light grey with spar cement, echinoderm and small grey clay or glauconite grains;

625.5-630.5: varigated gray to reddish shale;

630.5-634.2: grey blocky mudstone;

634.2-635.8: oolitic skeletal clacarenite with fusulinids;

CONODONT SAMPLES:

Sample A: 624.4-624.6 27 *Adetognathus* platforms, 4 *Neognathodus* platforms, 2 *Anchignathodus* platforms, 6 elements;

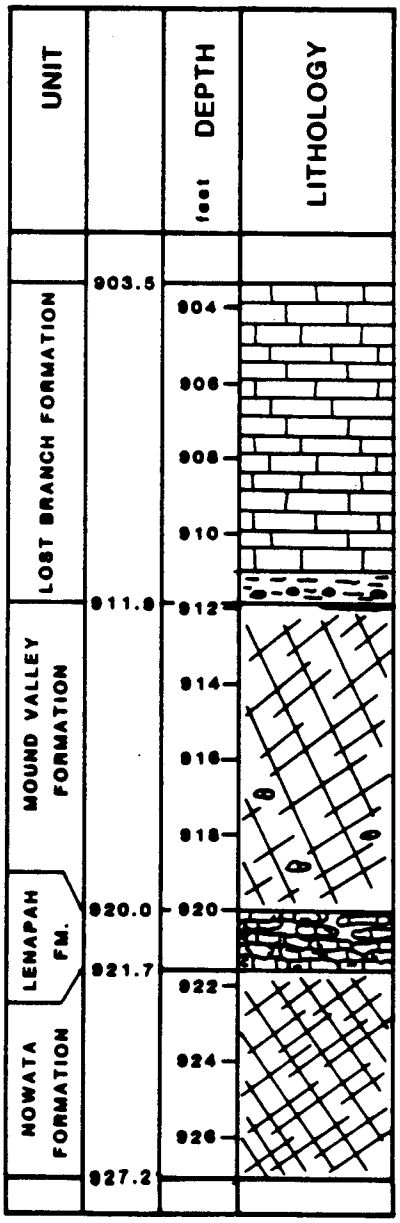
Sample B: 625.4-625.5 39 *Adetognathus* platforms

MNC

NODAWAY CO., MISSOURI

NW SE sec.10 T65N R36W

(after description by K. Deason as modified by P.H. Heckel)



NAME: MNC-Missouri Nodaway Core

LOCATION: NW SE sec.10 T65N R36W

DESCRIPTION:

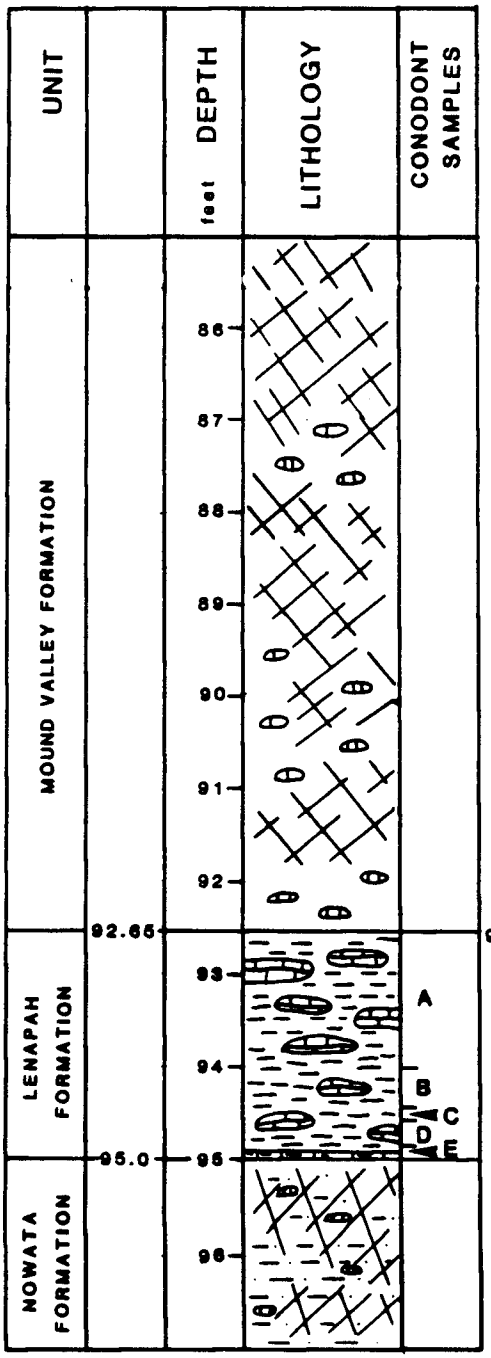
903.5-911.0:	Cooper Creek Limestone Member;
911.0-911.9:	shale with phosphatic nodules;
911.9:	coal smut;
911.9-920.0:	rubbly, blocky mudstone with limestone nodules;
920.0-921.7:	brecciated, nodular skeletal calcilutite in green mudstone matrix;
921.7-927.2:	grey blocky mudstone with reddish-stain;

CP #37

CLARKE CO., IOWA

NE SE NE sec.2 T72N R26W

(after description by D. Lipsius-Swade, 1984)



NAME: CP 37-Clarke County Core

LOCATION: NE SE NE sec.2 T72N R26W

DESCRIPTION:

80.9-92.65: reddish blocky mudstone with buff calcilutitic nodules; laminations in lower part grade upward to a very irregular maroon mudstone, possibly a soil horizon indicated by presence of caliche at 89.1 feet;

92.65-94.90: grey-green calcareous shale with common limestone nodules;

94.90-95.0: limestone with shale partings and abundant fossil material;

95.0-99.0: slightly silty, blocky mudstone with common limestone lenses;

CONODONT SAMPLES:

Sample A: 92.65-94.0 No conodonts,

Sample B: 94.0-94.4 1 Adetognathus platform,

Sample C: 94.4-94.65 No conodonts,

Sample D: 94.65-94.85 4 Adetognathus platforms,

1 Anchignathodus platform,

Sample E: 94.85-95.0 1 Adetognathus platform,

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