STRATIGRAPHY, DEPOSITIONAL AND DIAGENETIC HISTORY OF THREE MIDDLE PENNSYLVANIAN CYCLOTHEMS (BREEZY HILL AND FORT SCOTT LIMESTONES), MIDCONTINENT NORTH AMERICA

by

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CERTIFICATE OF APPROVAL

PH.D. THESIS

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ABSTRACT

The upper Cherokee-lower Marmaton stratigraphic interval (Breezy Hill-Fort Scott Limestone interval) of the Midcontinent Middle Pennsylvanian includes three consecutive cyclothems, each consisting of an open marine shale and/or carbonate sequence overlain by a nearshore deltaic to nonmarine sequence.

The upper Cherokee Breezy Hill cyclothem represents a minor transgression of open marine carbonates (Breezy Hill Limestone) across nearshore deltaic sediments from Oklahoma into southeastern Kansas. As the sea withdrew southward, meteoric leaching, coal swamps, and a caliche/rhizolite horizon developed to the north.

Both the Lower and the Upper Fort Scott cyclothems of the lower Marmaton represent widespread rapid eustatic transgressions that deposited deep-water, offshore shales (Excello and Little Osage Shales, respectively) directly over shallow-water to nonmarine sediments. During slower regressions, both cyclothems developed a shallowing-upward sequence of carbonates, interrupted by a brief eustatic transgression or slowdown in deltaic sedimentation before the final withdrawal of the sea

resulted in shallow-water carbonate facies, coals, and subaerial exposure from Iowa and Illinois into southeastern Kansas.

Diagenetic trends within the limestones support the depositional interpretations. Thin, discontinuous transgressive limestones are overcompacted, showing little evidence for early marine or nonmarine cementation before burial by impermeable shales and eventual cementation in a deeper-burial environment. Regressive limestones contain evidence of early marine cement followed in turn by meteoric neomorphism, cementation, dissolution, and root horizons before deeper burial silica, ferroan calcite, and ferroan dolomite cementation.

Comparison of the extent of development of rhizoliths in each of these cyclothems suggests that early cementation of otherwise porous and permeable sediments hinders the later development of rhizoliths in the sediments. As a consequence, the development of a rhizolite horizon, which itself cements sediments, would most likely be a self-limiting process.

Pronounced thickenings, both in deep-water shales and in shallowing-upward sequences of overlying carbonates during the upper Cherokee-lower Marmaton interval suggest that an area along the Kansas-Oklahoma border (Kansas-Oklahoma Border Trend) was an active hinge line between the

Cherokee Platform to the north and the Arkoma Basin to the south.

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CHAPTER I

INTRODUCTION

Scope of Study

During Medial and Late Pennsylvanian time large areas of the North American Midcontinent experienced repeated inundations by an inland sea, which were recorded as cyclically repeating vertical sequences of lithologies termed cyclothems. The subject of this study is the Breezy Hill Limestone-Fort Scott Limestone interval, which includes portions of three cyclothemic sequences from the top of the Cherokee and the base of the Marmaton Groups of the Desmoinesian Stage (Middle Pennsylvanian Series) of the Western Interior Basin, Midcontinent North America (Fig. 1). This interval is readily traced from the Arkansas River in northeastern Oklahoma, through southeastern Kansas, west-central to north-central Missouri, into south-central and southwestern Iowa and to central Illinois (Fig. 2).

Previous nomenclature included four units within this interval (in ascending order, Figure 3): 1) Breezy Hill Limestone, 2) Mulky coal, 3) Excello Shale, and 4) Fort Scott Limestone. The first three units were part of the Cherokee Group while the Fort Scott Limestone was the basal

Figure 1. Middle Pennsylvanian Midcontinent stratigraphic column. Includes new nomenclature (this study) suggested to replace previous Fort Scott nomenclature and new upper Marmaton nomenclature from Heckel (manuscript in review). (Column modified from Heckel, *et al.*, 1979, p. 10).

MIDDLE PENNSYLVANIAN SEQUENCE IN KANSAS

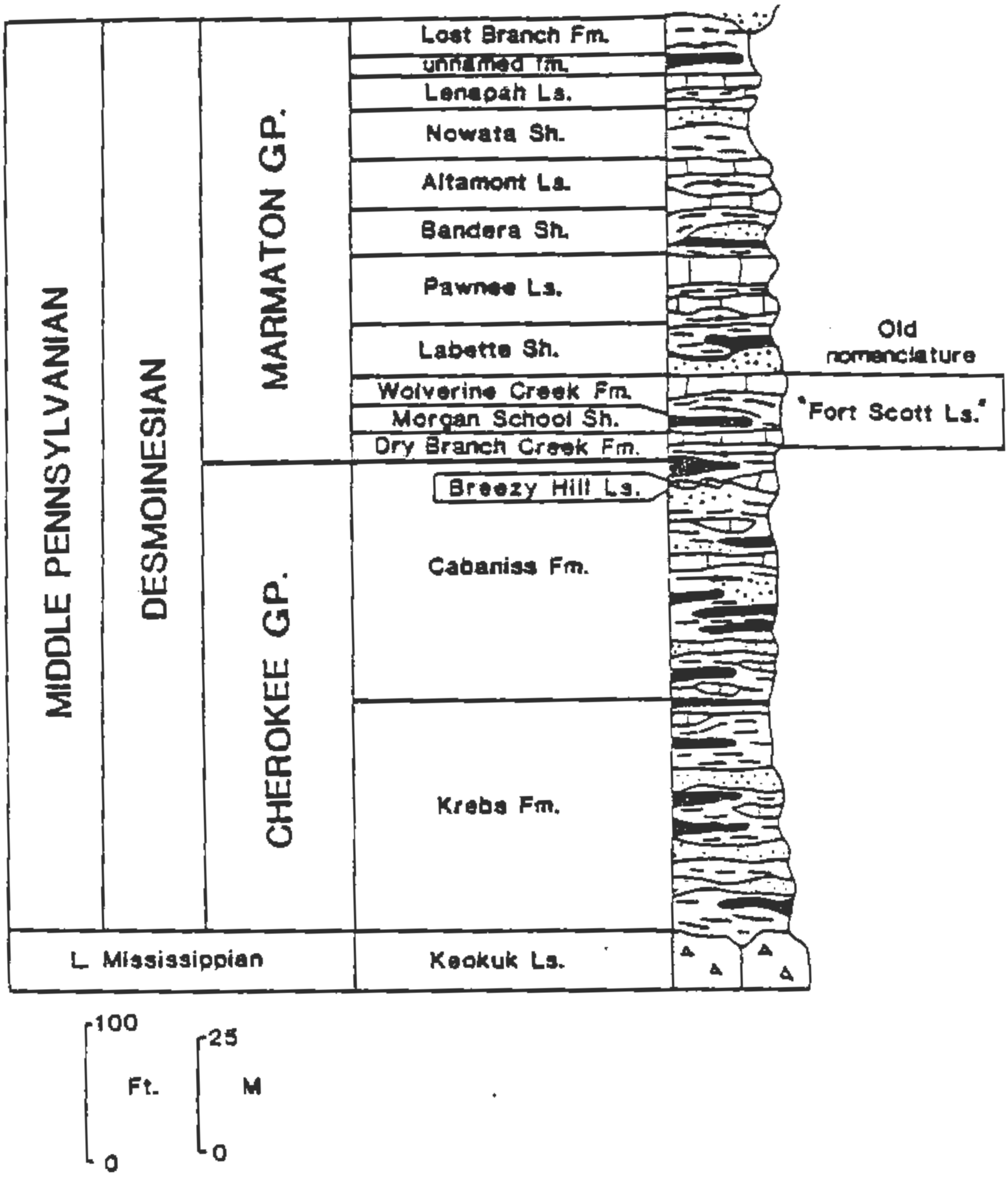


Figure 2. Location map of stratigraphic sections. Sections were measured for this study from outcrop (closed circles) or core (asterisk) or obtained from the literature (open circles). See Appendix A for exact section locations.

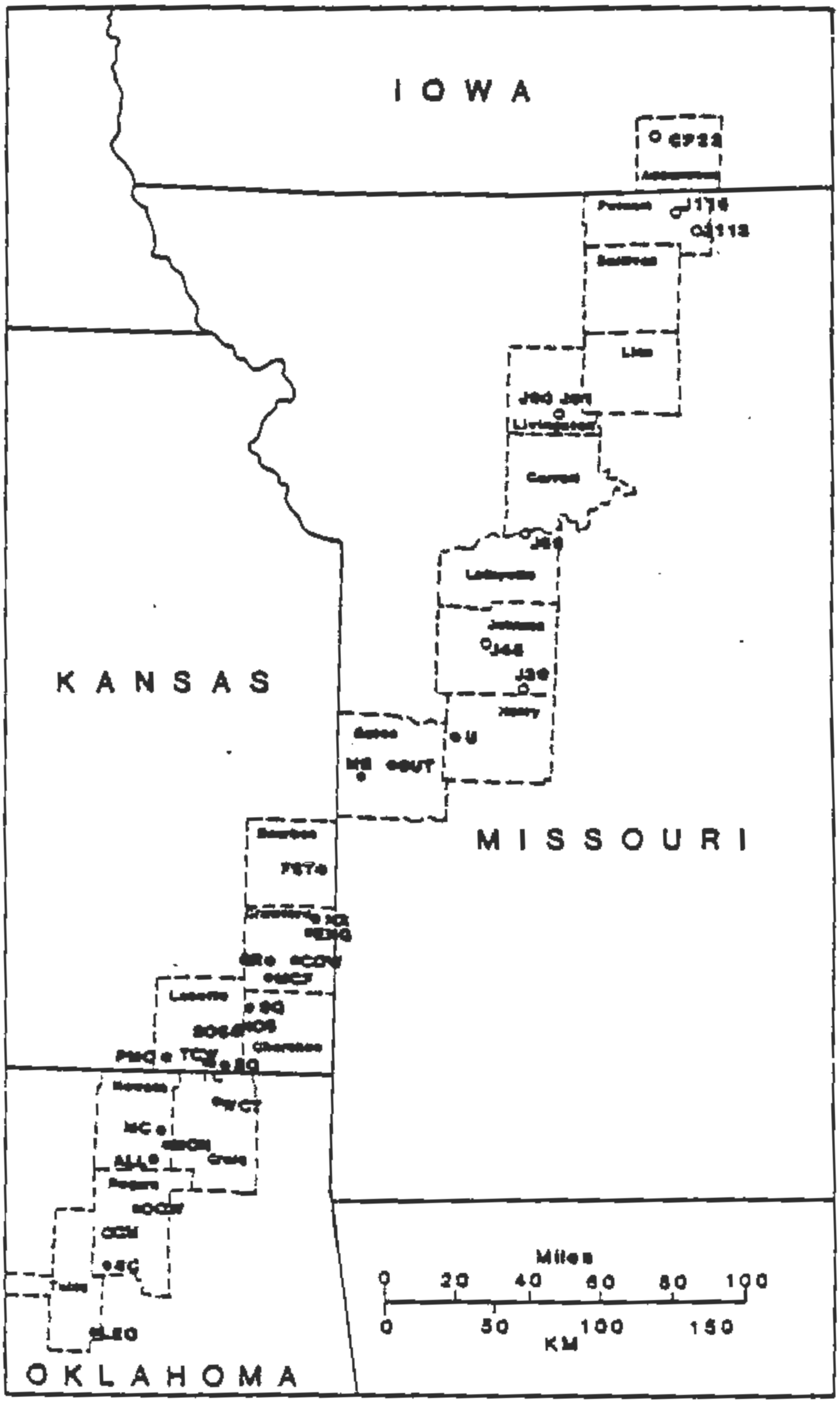
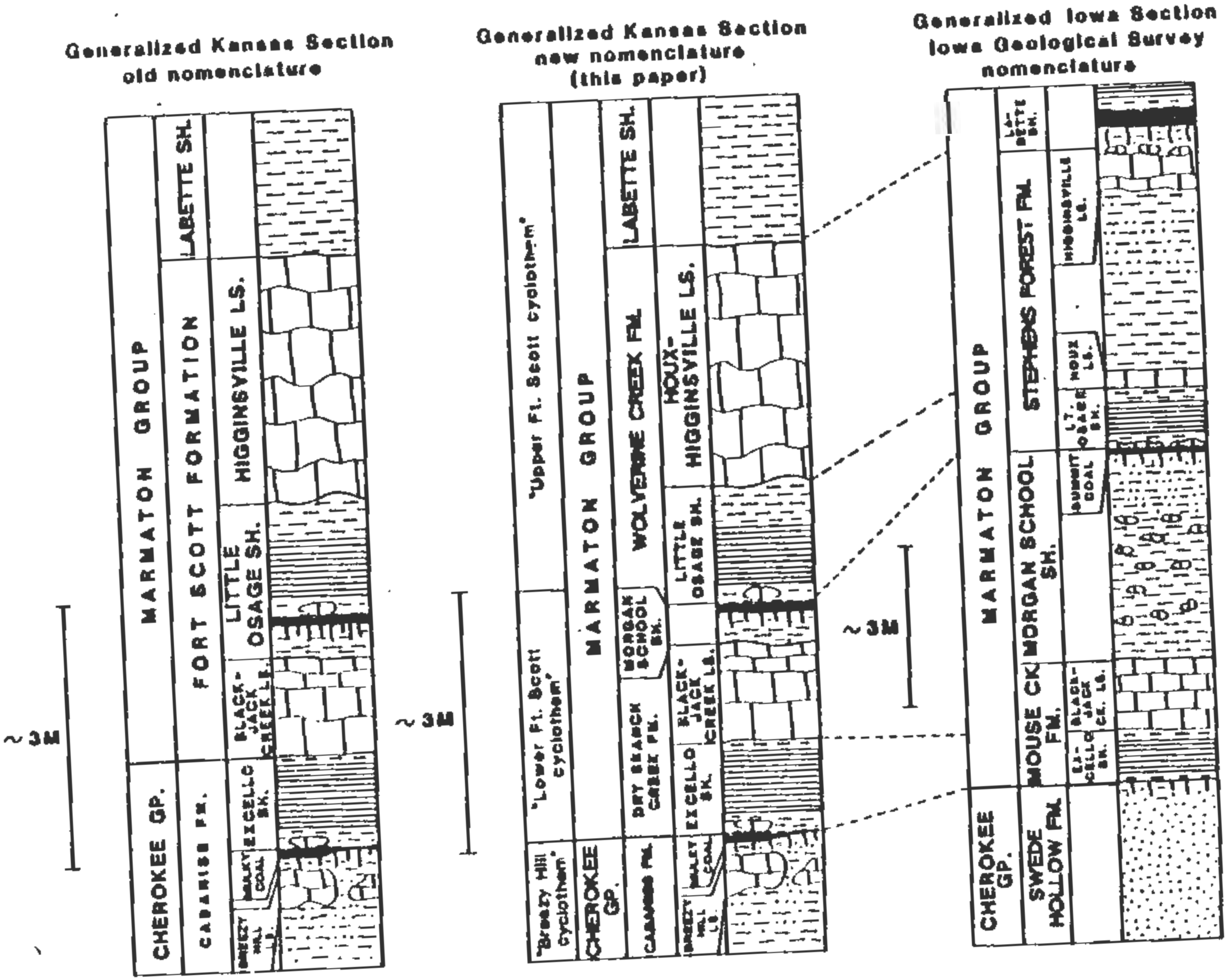

IOWA
Putnam
Sullivan
Linn
Livingston
Carroll
Lafayette
Johnson
J46
J39
Henry
Bates
MISSOURI
KANSAS
Bourbon
FS7
Crawford
Labette
Cherokee
Nowata
Craig
Rogers
OCM
Tulsa
OKLAHOMA
Miles
0
20
40
60
80
100
0
50
100
150
KM

Figure 3. Cabaniss Formation-Labette Shale interval nomenclature. Generalized stratigraphic columns show old and newly proposed Kansas (herein) and Iowa (Ravn *et al*., 1984) nomenclature.


Generalized Kansas Section
old nomenclature
Generalized Kansas Section
new nomenclature
(this paper)
Generalized Iowa Section
Iowa Geological Survey
nomenclature
~3M
~3M
~3M
MARMATON GROUP
FORT SCOTT FORMATION
LABETTE SH.
HIGGINSVILLE LS.
LITTLE OSAGE SH.
BLACK-JACK CREEK LS.
CHEROKEE GP.
CABANISS FM.
EXCELLO SH.
MULKY COAL
BREEZY HILL LS.
"Upper Ft. Scott cyclothem"
"Lower Ft. Scott cyclothem"
"Breezy Hill cyclothem"
MARMATON GROUP
CHEROKEE GP.
LABETTE SH.
WOLVERINE CREEK FM.
HOUX-HIGGINSVILLE LS.
LITTLE OSAGE SH.
MORGAN SCHOOL SH.
DRY BRANCH CREEK FM.
BLACK-JACK CREEK LS.
EXCELLO SH.
CABANISS FM.
MULKY COAL
BREEZY HILL LS.
MARMATON GROUP
CHEROKEE GP.
LA-BETTE SH.
STEPHENS FOREST FM.
HIGGINSVILLE LS.
HOUX LS.
LT. OSAGE SH.
MORGAN SCHOOL SH.
SUMMIT COAL
MOUSE CK FM.
BLACK-JACK CK. LS.
EX-CELLO SH.
SWEDE HOLLOW FM.

formation of the Marmaton Group.

This study introduces a revised nomenclature, which includes five units (Fig. 3) in ascending order: 1) Breezy Hill Limestone, 2) Mulky coal, 3) Dry Branch Creek Formation, 4) Morgan School Shale, and 5) Wolverine Creek Formation. The Dry Branch Creek Formation includes the Excello Shale at its base, and consequently the Cherokee-Marmaton boundary has been lowered to the base of the Dry Branch Creek Formation as Ravn _et al_. (1984) have done in Iowa, though using different formational names. Units of the Fort Scott Limestone have been incorporated within the Dry Branch Creek Formation, Morgan School Shale, and the Wolverine Creek Formation.

Portions of three cyclothemic sequences are recognizable within this interval. The Breezy Hill Limestone is the marine portion of the youngest cyclothem of the Cherokee Group, informally designated the Breezy Hill cyclothem in this study. It directly overlies the thick fluvial-deltaic sequence of the upper part of the Cabaniss Formation. The Breezy Hill cyclothem formed during a time of transition between the delta-dominated cyclothemic sequences of the Cherokee Group and the marine limestone- and shale-dominated cyclothemic sequences of the younger Middle and Upper Pennsylvanian groups. The overlying Dry Branch Creek Formation, Morgan School Shale, and Wolverine

Creek Formation contain units within the two oldest cyclothemic sequences of the Marmaton Group, the Lower and Upper Fort Scott cyclothems (Fig. 3).

Objectives

Application of the scientific method to the study of major ancient sedimentary sequences is often difficult. Ideally, such a study would begin with a catalog of observations of several ancient sedimentary sequences, where only one influencing factor such as tectonics, climate, biota, or sea level varied at a time. From these observations it would proceed inductively to a set of models relating the processes of sedimentation and diagenesis to the varying factor. These models could then be tested against similar sedimentary sequences. In reality many of the variables responsible for ancient sedimentary sequences fluctuated simultaneously and nonrepetitively. As a consequence, many ancient sedimentary sequences bear little resemblance to one another so that it is often impossible or tentative at best to isolate the effects of a single variable. The resulting complexity often frustrates the development of viable models of sedimentation and diagenesis.

The forty or more (P. H. Heckel, personal communication) cyclothemic sequences that constitute the Middle-Upper Pennsylvanian section in the Midcontinent outcrop belt were each deposited during a relatively brief period of time (on the order of 400,000 years; Heckel, 1980, 1984) and display distinct similarities, thus providing a potential exception to this complexity. During a typical cyclothem, rates of change in tectonics, topography, and biota were often slow enough that the major variable affecting sedimentation and diagenesis was sea level fluctuation. Models relating sea level fluctuation to the sedimentation and diagenesis occurring within individual Pennsylvanian cyclothems have been developed (Heckel, 1977, 1983). Within the time-frame of several consecutive cyclothems, it should be possible to test these models and in addition, to follow through time the effects of the more slowly fluctuating variables such as tectonics, topography, and biota.

This study includes an analysis of three of these cyclothemic sequences that succeed one another in the same area. The intent is: 1) to clarify the stratigraphic relationships between the units in the Breezy Hill Limestone-Wolverine Creek Formation interval, 2) to relate outcrop and petrographic observations to the depositional and diagenetic history of this interval, 3) to compare these observations with currently accepted models of Pennsylvanian cyclothemic sedimentation and diagenesis in relationship to sea level fluctuation, and 4) to reconcile any incongruities between observation and theory, by examining the effects of other variables, including climate, tectonics, and topography.

Methods of Study

The Breezy Hill Limestone-Wolverine Creek Formation interval was examined in the field from south of Tulsa, Oklahoma, northward into Henry County, Missouri. Stratigraphic sections (see Appendix A for exact locations and descriptions) were measured, and detailed sampling of the limestone and shale lithologies was made at many localities previously mentioned in the literature and at a number of localities new in this study. A core from Labette County, Kansas (Section PMC), was measured and sampled in detail. Published stratigraphic sections (see Appendix A for exact locations) and descriptions of this interval have been used as a supplement to extend the stratigraphic, depositional, and diagenetic interpretations into northern Missouri and southern Iowa. Approximately 545 gamma-ray and neutron well-logs were examined in order to trace the lateral continuity, facies variations, and thicknesses of units within the studied interval into the near subsurface (Appendix B).

Over three hundred thin-sections and 42 polished slabs were prepared from the limestones. All thin-sections were studied with a polarizing petrographic microscope. Many were stained with alizarin red-S and potassium ferricyanide using techniques described by Dickson (1965).

Limestone and shale members from four sections were collected in detail and processed for conodonts. Individual samples from other localities were also processed for conodonts to aid in stratigraphic correlation of units. Conodonts were identified to genus level to aid in stratigraphic correlation and to determine whether they followed the same distributional patterns described by Heckel and Baesemann (1975) and Swade (1982) (see Appendix C for conodont data).

Depositional Models

The Middle and Upper Pennsylvanian stratigraphic sequence in the Midcontinent is characterized by the alternation of widespread marine limestone units that typically contain a thin, laterally continuous shale unit, and widespread sandy shale units, locally containing coals and channel sandstones. Moore (1929) recognized the repetitive nature of these units, and attributed them to a periodic widespread submergence of the craton by shallow seas. Wanless and Weller (1932) applied the term "cyclothem" to these stratigraphic cycles in Illinois, Iowa, and Missouri. Moore (1936) used this term and introduced the additional term of "megacyclothem" for cycles of cyclothems that he recognized in Kansas.

Wanless and Shepard (1936) attributed the periodic submergence of the craton by marine water to eustatic sea level fluctuations resulting from the waxing and waning of Gondwanan glaciers in the southern hemisphere. Weller (1956) disputed this mechanism, attributing much of the apparent sea level fluctuation to local or regional cratonic diastrophism. The mechanism of local delta progradation and abandonment has also been applied to a number of cyclothems (D. Moore, 1959; Ferm, 1970). The extremely widespread extent of the marine limestones and the thin, laterally continuous shale units over hundreds of square kilometers of outcrop and subsurface; along with the short durations of the cyclothems, cannot be satisfactorily explained by either a slower acting cratonic diastrophism or the more areally localized delta progradation and abandonment.

A more specific depositional model used with some success in recent studies of Midcontinent Pennsylvanian "Kansas-type" cyclothems (Heckel, 1977, 1980; Mitchell, 1981; Price, 1981; Ravn, 1981; Parkinson, 1982) attributes the widespread marine limestone and shale units to eustatic marine inundations and withdrawals over much of the craton, while the sandy shale units containing coals and channel sandstones are attributed to more localized delta plain progradation and abandonment on the migrating margins of the fluctuating sea. Crowell (1978) has supported the mechanism of Wanless and Shepard (1936) for this model by documenting periods of glaciation on the Gondwanan Continent from Late Mississippian to Mid-Permian time.

The basic depositional model for the "Kansas cyclothem" (Heckel, 1977) consists of an ascending sequence of four positional members (Fig. 4): 1) outside shale, 2) middle limestone, 3) core shale, and 4) upper limestone.

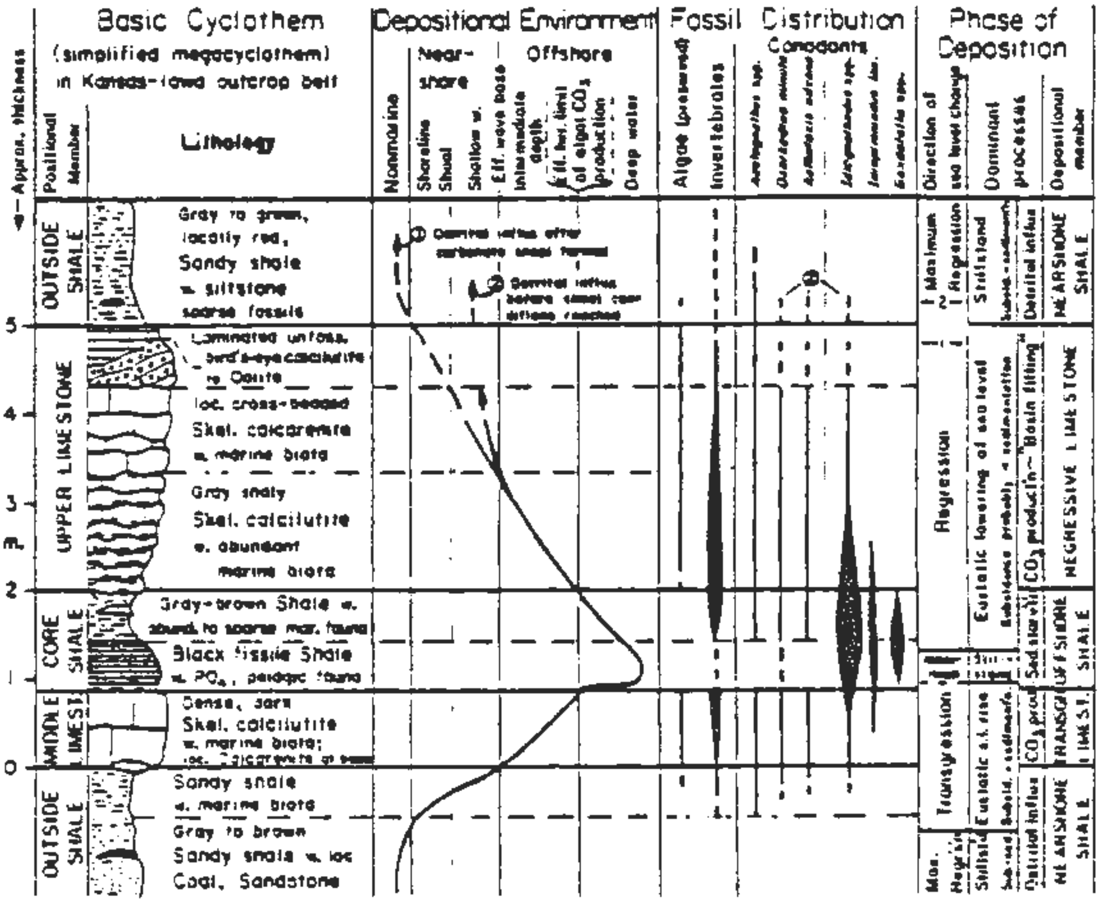
Outside Shale

The outside or "nearshore" shale consists of sandy shales. Highly variable in thickness, it often contains nonmarine coals, channel sandstones, caliche or soil horizons, and "fresh-water" or "underclay" limestones within the underclay of coals. Where marine, it may contain a low-diversity, low-abundance conodont and skeletal invertebrate biota reflecting fluctuating nearshore conditions and rapid sedimentation. The outside shale is interpreted as nonmarine to deltaic in origin, representing times of lowest sea level stand during maximum withdrawal of the epeiric sea.

Middle Limestone

The middle or "transgressive" limestone is often a thin to absent, dark, organic-rich, skeletal calcilutite containing a diverse marine biota. Rare shoal-water facies

Figure 4. Basic eustatic depositional model of "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
Approx. thickness
m.
0
1
2
3
4
5
Positional Member
Lithology
OUTSIDE SHALE
UPPER LIMESTONE
CORE SHALE
MIDDLE LIMEST.
Gray to green, locally red, Sandy shale w. siltstone sparse fossils
Laminated unfoss. bird's-eye calcilutite to Oolite
loc. cross-bedded Skel. calcarenite w. marine biota
Gray shaly Skel. calcilutite w. abundant marine biota
Gray-brown Shale w. abund. to sparse mar. fauna
Black fissile Shale w. PO4, pelagic fauna
Dense, dark Skel. calcilutite w. marine biota; loc. Calcarenite at base
Sandy shale w. marine biota
Gray to brown Sandy shale w. loc Coal, Sandstone
Depositional Environment
Nonmarine
Near-shore
Shoreline
Shoal
Shallow w.
Eff. wave base
Offshore
Intermediate depth
Eff. low. limit of algal CO3 production
Deep water
① Detrital influx after carbonate shoal formed
② Detrital influx before shoal conditions reached
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Phase of Deposition
Direction of sea level change
Dominant processes
Depositional member
1 Maximum 2 Regression
Max. Regr.
Regression
Transgression
Eustatic lowering of sea level
Subsidence probably + sedimentation
CO3 productn ~ Basin filling
Sed. starv.
Eustatic s.l. rise
Subsid. + sedimentn.
CO3 prod.
Siltstone
Subsid. + sediment.
Detrital influx
NEARSHORE SHALE
REGRESSIVE LIMESTONE
OFFSHORE SHALE
TRANSGR. LIMEST.

occur at its base. Deposition is interpreted to have occurred as marine water deepened rapidly, stranding shoreline clastics progressively farther away from the site of marine carbonate deposition.

Core Shale

The core or "offshore" shale is usually a thin but widespread and continuous, non-sandy shale. Consisting of dark gray shales with a variable benthic biota, it may grade vertically and laterally into a phosphatic black shale facies that lacks a benthic fauna but often contains an abundant and diverse conodont fauna. Most controversial of the cyclothemic members, the core shale has been interpreted as a shallow, marine swamp deposit developed where water circulation was restricted by an algal "flotant" (Zangerl and Richardson, 1963). This model does not adequately explain their great lateral continuity, central position between two marine limestones, abundant non-skeletal phosphorite, nor their conodont and invertebrate distributions. The "Kansas cyclothem" depositional model more adequately explains these features by suggesting that the core shale was deposited during times of highest sea level stand at maximum transgression (Heckel, 1977). This model suggests that the phosphatic black shale developed on an anoxic sea bottom beneath a thermocline, which restricted vertical water circulation and oxygen replenishment.

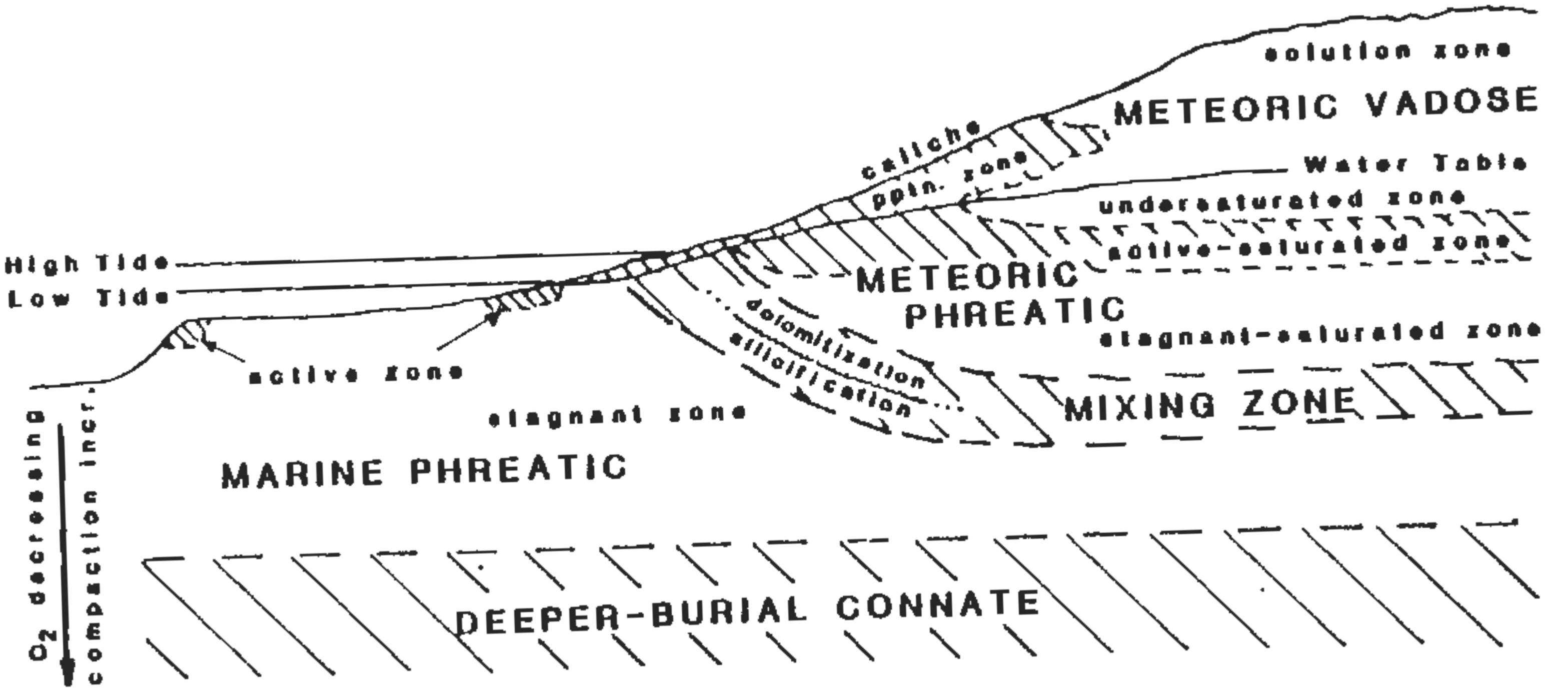
Upper Limestone

The upper or "regressive" limestone is variable in thickness, generally grading upward from an argillaceous calcilutite with shaly partings and a diverse marine biota deposited below wave base into progressively more restricted shoal-water and supratidal facies. Substantial carbonate buildups or mounds, often attributable to phylloid algae, developed locally in this member. The upper limestone is interpreted as being deposited during the slow withdrawal of marine water from the craton, which allowed the periodic influx of detrital sediment from the encroaching shoreline.

Major Diagenetic Environments

Recent models of diagenesis (Longman, 1980, 1981; Heckel, 1983) have divided the diagenetic realm into a number of diagenetic environments and subenvironments or zones based on three important factors: 1) the pore-water chemistries, whether marine, fresh water (meteoric), mixing zone, or deeper-burial connate and their degree of saturation with respect to certain ions and minerals such as calcite, dolomite, and silica; 2) whether the pore space is filled with water (phreatic) or contains both air and water (vadose); and 3) the degree of circulation of water between the pores, whether active or stagnant. Five of these environments, recognized from units in this study, will be described briefly (Fig. 5).

Figure 5. Major diagenetic environments in partly emergent carbonate terrain. Lined areas indicate zones of significant cementation (from Nollsch, 1983, Fig. 5, modified from Heckel, 1983, Fig. 2).


solution zone
METEORIC VADOSE
caliche
pptn. zone
Water Table
undersaturated zone
active-saturated zone
High Tide
Low Tide
METEORIC PHREATIC
dolomitization
silicification
stagnant-saturated zone
active zone
MIXING ZONE
stagnant zone
MARINE PHREATIC
DEEPER-BURIAL CONNATE
O_2 decreasing
compaction incr.

Marine Phreatic

In the marine phreatic environment all pores are filled with water of normal marine salinity. Longman (1980) has defined two zones within this environment based on the presence or absence of intergranular cements, which he attributes to the degree of water circulation within pores.

The active zone is generally located close to the sediment-water interface, especially on topographic highs, where waves, tides, or currents providing good circulation of water oversaturated with carbonate result in marine cements. Marine cements range from micrite fillings of microborings in skeletal grains to early fibrous rims of aragonite and high-Mg calcite.

The stagnant zone dominates the marine phreatic environment especially in the carbonate mud-rich sediments deposited below wave base. Little intergranular cementation occurs due to the insufficiency of circulation of pore-waters. Intragranular cementation does occur within the small pores and microborings in skeletal grains, resulting in micritized envelopes.

Mixing Zone

The mixing zone is the brackish-water interface between marine and meteoric water. It fluctuates slightly with tides but is affected more by factors that influence the hydraulic head of the meteoric water, such as seasonal changes in rainfall. Meteoric water in a confined aquifer with sufficient hydraulic head can flow a substantial distance seaward into the marine environment before it mixes with marine water, resulting in the displacement of the mixing zone and meteoric phreatic environments seaward. Cement types are gradational between the marine and meteoric phreatic environments. Silicification has been recognized from the marine end of this environment (Knauth, 1979), while dolomite forms where salinities are lower (Badiozamani, 1973).

Meteoric Phreatic

The meteoric phreatic environment lies below the terrestrial water table, where pores are filled with meteoric water. It is commonly divided into three zones on the basis of calcium carbonate saturation and degree of water circulation. Generally, water actively enters the meteoric phreatic environment from above, undersaturated with calcium carbonate, resulting in dissolution of aragonite grains to form molds in the undersaturated zone. If undersaturated enough, it dissolves calcite as well, resulting in vugs, collapse breccia, and ultimately karst features. With sufficient dissolution of carbonate material, the meteoric water becomes saturated with calcium carbonate. Where circulation of pore waters is sufficient in the active saturated zone of the meteoric phreatic environment, low-Mg calcite cement will precipitate as clear drusy dogtooth (scalenohedral) rims, blocky mosaics of crystals that tend to coarsen towards the center of voids, and as syntaxial overgrowths on echinoderm grains. Where circulation of pore waters is less active, in the stagnant saturated zone, little cementation takes place, and aragonite may neomorphically alter to calcite, preserving original aragonite fabrics. Within the meteoric phreatic environment potential situations exist, such as fresh-water swamps, where the depletion of oxygen due to organic decomposition would allow free ferroan iron to precipitate with calcite as blocky ferroan calcite cements.

Meteoric Vadose

The meteoric vadose environment lies above the terrestrial water table and experiences alternate wetting and drying of sediment, resulting in air-water interfaces within pores. In humid climates this environment is usually dominated by a solution zone where water undersaturated with calcium carbonate and enriched with soil carbon dioxide dissolves unstable grains, which enhances original porosity and ultimately results in karst features. The solution zone of the meteoric vadose environment would usually be indistinguishable from the undersaturated meteoric phreatic zone.

Meteoric water in the vadose environment may become saturated with calcium carbonate, which results in the precipitation of micrite and equant to bladed low-Mg calcite spar as meniscal and pendant cements. In drier climates strong surface evaporation can result in formation of caliche within soils. Some root systems that exist in the meteoric vadose and possibly the meteoric phreatic environments can directly or indirectly precipitate microcrystalline calcite creating a variety of rhizolithic fabrics (Klappa, 1980).

Deeper-Burial Connate

Increasing burial of sediments results in compactional features in uncemented calcarenites, such as overpacked grains with grain crushing, and increasing amounts of grain-to-grain contacts, pressure solution and stylolitization along their contacts. Pore-water chemistries change substantially as they become increasingly isolated from the sea- or fresh-water reservoirs. Clay conversions take up some ions, while releasing others, providing magnesium and silica for dolomite and chert cementation (McHargue and Price, 1982). Removal of magnesium by dolomite formation allows the precipitation of low-Mg calcite in blocky equant form. Depletion of oxygen by organic decomposition allows ferrous iron in the connate pore-waters to precipitate as ferroan calcite and dolomite spar. Aragonite and high-Mg calcite grains and cements may also slowly neomorphose to equant blocky spar, thus preserving original fabrics.

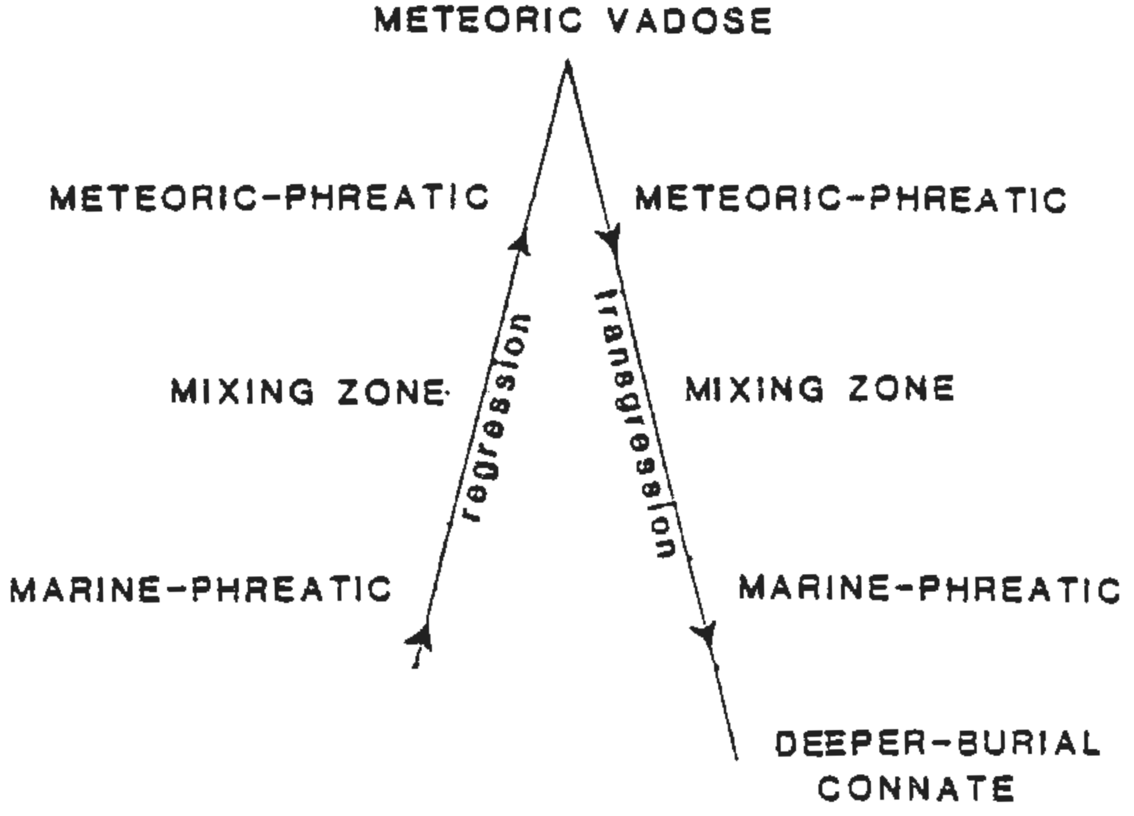
Diagenetic Model for Midcontinent Pennsylvanian Cyclothems

Heckel (1983) has developed a diagenetic model for Midcontinent Pennsylvanian cyclothems based on the hydrologic implications of the depositional model previously discussed. Eustatically controlled fluctuations in sea level that were responsible for the cyclic variation in deposited sediments were also responsible for the migration of diagenetic environments through these lithologies (Fig. 6).

Sediments of the transgressive and regressive limestones and the offshore shale were deposited in the marine phreatic diagenetic environment. Regression of marine waters resulted in the migration of first the mixing zone environment followed in sequence by the meteoric phreatic and the meteoric vadose environments through the sediments, as the nearshore shale was deposited. During the subsequent cyclothem, transgression of marine waters added overlying sediments to the sediment pile and resulted in the reverse migration of the same diagenetic environments back through the sediments (Fig. 6). Ultimately the addition of

Figure 6. Diagenetic model for Midcontinent Pennsylvanian cyclothems. Shows migration of diagenetic environments through sediments during regression and subsequent transgression of sea (from Nollsch, 1983).

MIGRATION OF DIAGENETIC ENVIRONMENTS



overlying sediments of low permeability resulted in barriers to the easy passage of subsequent marine and meteoric waters through the underlying sediment, and this brought about deeper-burial connate diagenesis.

Transgressive limestone sediments would typically begin in the stagnant marine phreatic environment where little early cementation occurred. Subsequent burial under a rather impermeable blanket of offshore shale sediment would also effectively prevent either cementation or dissolution of unstable grains by meteoric waters. Therefore transgressive limestones would usually pass directly into the deeper-burial connate environment resulting in overpacking of grains, slow neomorphism of unstable grains and late-stage ferroan calcite, ferroan dolomite, and silica cements.

Regressive limestone sediments typically pass from the marine phreatic environment, where early marine cement rims may form if circulation of pore-water is sufficient, through silica- and dolomite-forming mixing zone water. Subsequent meteoric diagenesis would result in pervasive blocky calcite cementation, neomorphism, and leaching of unstable grains. With sufficient subaerial exposure, karst, soil, and caliche features might also develop. Subsequent transgression would result in passage back through the meteoric phreatic and mixing zone environments and ultimately into the deeper-burial connate environment, where ferroan calcite, ferroan dolomite, and silica cements may form.

CHAPTER II

DEPOSITIONAL TOPOGRAPHY AND STRUCTURE

Introduction

Depositional topography or sea-floor relief profoundly affects the thickness and facies variations of both siliciclastic and carbonate sediments. Knowledge of the effects that depositional topography has upon sedimentation can therefore be used as a predictive tool. Where depositional topography, operative on sedimentation during an earlier time, has been recognized, it can be used to predict similar consequences during later sedimentation. In other cases, patterns of sedimentation suggestive of depositional topography can be used to predict and delineate the topography.

The abundance and brief duration of individual Pennsylvanian cyclothemic sequences provides an excellent opportunity to follow the evolution of particular topographic features and their effects on sedimentation through time. Schenk (1967), Neal (1969), Ravn (1981), Mitchell (1981), and Price (1981) have contributed to our understanding of Midcontinent depositional topography through studies of individual cyclothemic sequences. This study extends this knowledge by detailing the effects of depositional topography on three additional consecutive cyclothemic sequences.

Effects on Deposition

Pennsylvanian cyclothemic sequences include both carbonate and terrigeneous detrital units, which are affected in different ways by depositional topography.

Carbonate Sedimentation

Maximum carbonate productivity is dependent on the presence of the clear, warm, and shallow surface waters typical of tropical and subtropical latitudes. Reconstruction of Upper Pennsylvanian paleogeography (Heckel, 1980) suggests that the Midcontinent was located in tropical latitudes (Middle Pennsylvanian latitudes were probably slightly more equatorial). Therefore the epeiric sea over the Midcontinent had surface waters with ideal temperatures for maximum carbonate productivity. The two factors responsible for maximizing this productivity were the clarity or absence of terrigeneous detrital influx and the shallowness (within the photic zone) of the waters (Heckel, 1984). Both of these factors were influenced by topography.

Carbonate production is typically attenuated by the proximity of subaerially exposed highland and detrital-rich shoreline areas. Delta-lobe progradation will inhibit carbonate production, while abandoned delta-lobes may provide excellent platforms for carbonate production. Heckel and Cocke (1969) noted that many of the phylloid algal-mound complexes responsible for carbonate thickening in the Midcontinent were positioned between terrigenous detrital facies and the more open marine shelf-limestones. This influence can be delineated by examining the interfingering and relative thicknesses of carbonate and siliciclastic facies.

Since calcareous algae were probably responsible for most of the mud-size carbonate debris, productivity of carbonates was greater in shallow marine waters within the photic zone. At any given time during transgression and regression, sea-floor highs were more likely to be within the photic zone and might therefore be expected to accumulate more carbonate sediment; in contrast, seafloor lows and basins were more likely to be below the photic zone and in cooler waters, which inhibited carbonate production. However, once within the photic zone, the total accumulation of carbonates on any topographic surface would depend on the relative rates of sea-level change and subsidence of the seafloor (Heckel, 1984). Seafloor highs would have included structural features (anticlines and upthrown fault-blocks) and sediment-related features (differential compaction of previously deposited sediments; mud mounds; and delta platforms). Ravn (1981), Mitchell (1981), and Price (1981) have suggested that structural highs resulted in thick phylloid algal-mound development during Middle and Upper Pennsylvanian time. Harbaugh (1964) proposed offshore mud bars as topographic highs on which algal-mound development was initiated. Once begun, rapid algal growth kept pace with subsidence, maintaining the topographic high in shallow water, resulting in thick algal-mounds. Crowley (1966) suggested that the Upper Pennsylvanian Wyandotte algal-mounds developed atop an old delta-platform. Heckel and Cocke (1969) suggested that the stacking of many algal-mound complexes through time reflected the possibility that the greater compaction of the mud surrounding a previously well-cemented and compactionally resistant mound would maintain that site as a topographic high conducive to future mound growth. They also suggested that the alignments of the terminations of many of these mound complexes in southeastern Kansas suggested structural controls.

In addition to hosting carbonate mounds and algal limestone facies, topographic highs are more likely to develop thick deposits of shallow-water lithologies during transgressions and regressions. They are also more likely to have experienced subaerial exposure and to contain evidence of erosional activity and meteoric phreatic and vadose diagenesis.

Terrigenous Detrital Sedimentation

Two different depositional regimes dominated Pennsylvanian cyclothemic terrigenous detrital sedimentation. The "nearshore" shales predominately resulted from rapid deltaic to nonmarine deposition, whereas the "offshore" shales resulted from the slow settling of suspended fine-grained sediments from water too deep to sustain carbonate production.

The thickest deltaic deposits develop as lobes that prograde seaward from the strandline. Most Pennsylvanian Midcontinent deltaic systems developed over a gently sloping seafloor during low stands of sea level and often during the active seaward migration of the strandline. Such delta systems would tend to develop laterally widespread and relatively thin sedimentary sequences, which could be effectively barred or constricted by minor topographic relief. As a consequence, significant topographic highs might be expected to lack or have less terrigenous detrital cover and might also successfully bar the transport of terrigenous sediments into basins lacking their own sources.

Correlation can also be made between the development of coal-forming swamps and depositional topography. Detailed mapping of units within the interval of this study by

Wanless et al. (1963) suggested that most of the widespread coals, including the Mulky coal (coal No. 4 in Illinois) and the Summit coal (coal No. 5 in Illinois), developed on old subsiding delta-platforms. Neal (1969) reached the same conclusion for the Mulky coal in Missouri. Price (1981) on the other hand found that the Lexington and Mystic coals in the overlying Labette Shale accumulated their greatest thicknesses in topographic lows.

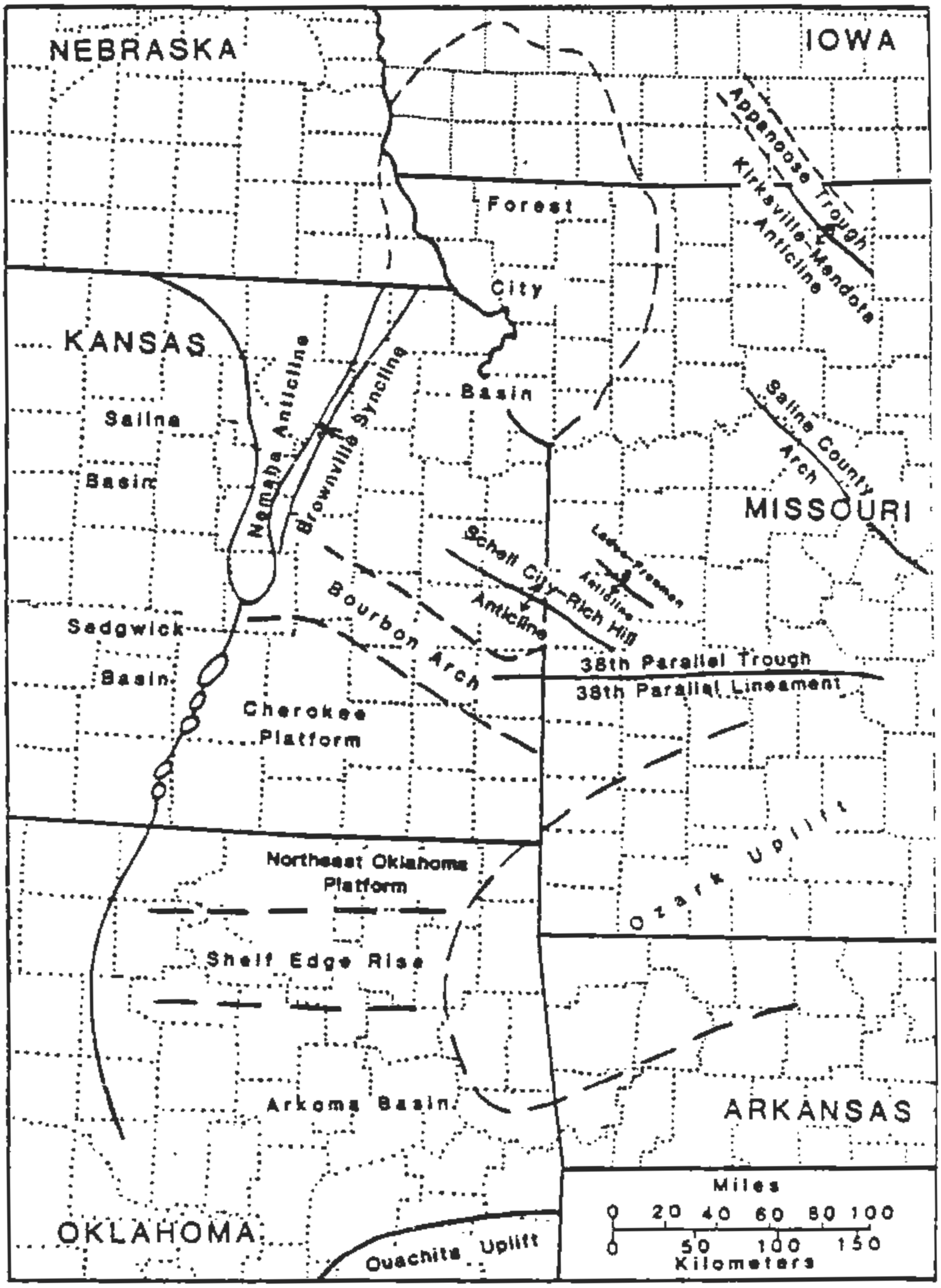
Deposition of the "offshore" shales typically began as a rapid transgression quickly covered the Midcontinent in deeper marine water. Therefore, the base of many "offshore" shales represents an approximate time line. As waters deepened and overall rates of sedimentation, including carbonate production, decreased; the slow deposition from suspension of fine-grained siliciclastics began to dominate the seafloor. Deeper water was also more likely to develop anoxic bottom conditions and a black shale facies and to maintain these conditions for a longer time. Consequently, topographic lows tended to have thick "offshore" shales and a thicker black shale facies within the "offshore" shale, whereas topographic highs tended to have thinner "offshore" shales and often lacked the black shale facies altogether. As a result, thickness variations of the "offshore" shale and especially its black shale facies may reflect not only duration of exposure to offshore conditions but also the variation in sea-floor topography.

Pennsylvanian Midcontinent Structures and Depositional Topography

Figure 7 illustrates Midcontinent structures previously recognized to have significantly affected Pennsylvanian sedimentation. The Midcontinent from northeastern Oklahoma through Iowa and Illinois is located on a platform-like extension of the large, stable, cratonic Canadian Shield. Throughout this generally flat area, mild flexures and fractures of the craton developed into basins and highlands with varying degrees of relief and permanence.

To the south of the study area in southeastern Oklahoma, the Ouachita Uplift developed along Precambriam zones of weakness during Middle Pennsylvanian time as South America collided with the southern margin of North America (Price, 1981). The Ozark Uplift existed during Desmoinesian time as a landmass of low relief to the southeast of the study area in southern Missouri, northeastern Oklahoma, and northern Arkansas (Wanless, 1975). Price (1981) identified the Ozark Uplift as the source area for the detrital monocrystalline quartz-rich Mine Creek Shale deltaic wedge, which developed during a minor regression within the middle Desmoinesian Pawnee Limestone of Missouri (Fig. 1). However, chert-bearing carbonates dominated exposures of the

Figure 7. Pennsylvanian Midcontinent structures. Structures known and suspected to have affected Pennsylvanian sedimentation. Sources for diagram: Forest City Basin (Lee, 1943; Merriam, 1963); Salina Basin, Sedgwick Basin, and Brownville Syncline (Merriam, 1963); Cherokee Platform (Moore, 1979); Bourbon Arch (Jewett, 1951); Nemaha Anticline (Merriam, 1963; Krumme, 1981); Northeast Oklahoma Platform, Ozark Uplift, Arkoma Basin, and Ouachita Uplift (Krumme, 1981); Appanoose Trough, 38th Parallel Trough, and Shelf Edge Rise (Price, 1981); 38th Parallel Lineament (Heyl, 1972); Kirksville-Mendota Anticline (Hinds and Green, 1915); Ladue-Freeman Anticline (Gentile, 1976); Schell City-Rich Hill Anticline (Gentile, 1976; Ravn, 1981); Saline County Arch (Searight and Searight, 1961).


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

Ozark Uplift during Pennsylvanian time, making this an unlikely source for abundant monocrystalline quartz-rich sediments.

Bordering the western limit of the study area, the Nemaha Anticline or Uplift extended from Omaha, Nebraska, south-southwesterly across Kansas toward Oklahoma City, Oklahoma. It was an asymmetrical anticline, having a steeper, locally faulted, east flank, which dipped into the adjacent Brownville Syncline and separated the Salina and Sedgwick Basins in central Kansas from the Forest City Basin and Cherokee Platform in eastern Kansas. Merriam (1963) recognized it as a major pre-Desmoinesian post-Mississippian element along which pre-Pennsylvanian strata are upturned, truncated, and overstepped by Pennsylvanian sediments along its flanks. Pennsylvanian beds overlie rocks as old as Precambrian on the crest, and during early Pennsylvanian time, granite was exposed as a low ridge or chain of hills, which shed arkosic sediments down the flanks into adjoining basins. Lee (1943) and Price (1981) thought it was active longer than this and was not completely covered until Missourian time in the Upper Pennsylvanian. Ravn (1981) also concluded from the predominance of shoreline carbonate facies in Nebraska that it affected Hertha Limestone deposition in the Upper Pennsylvanian.

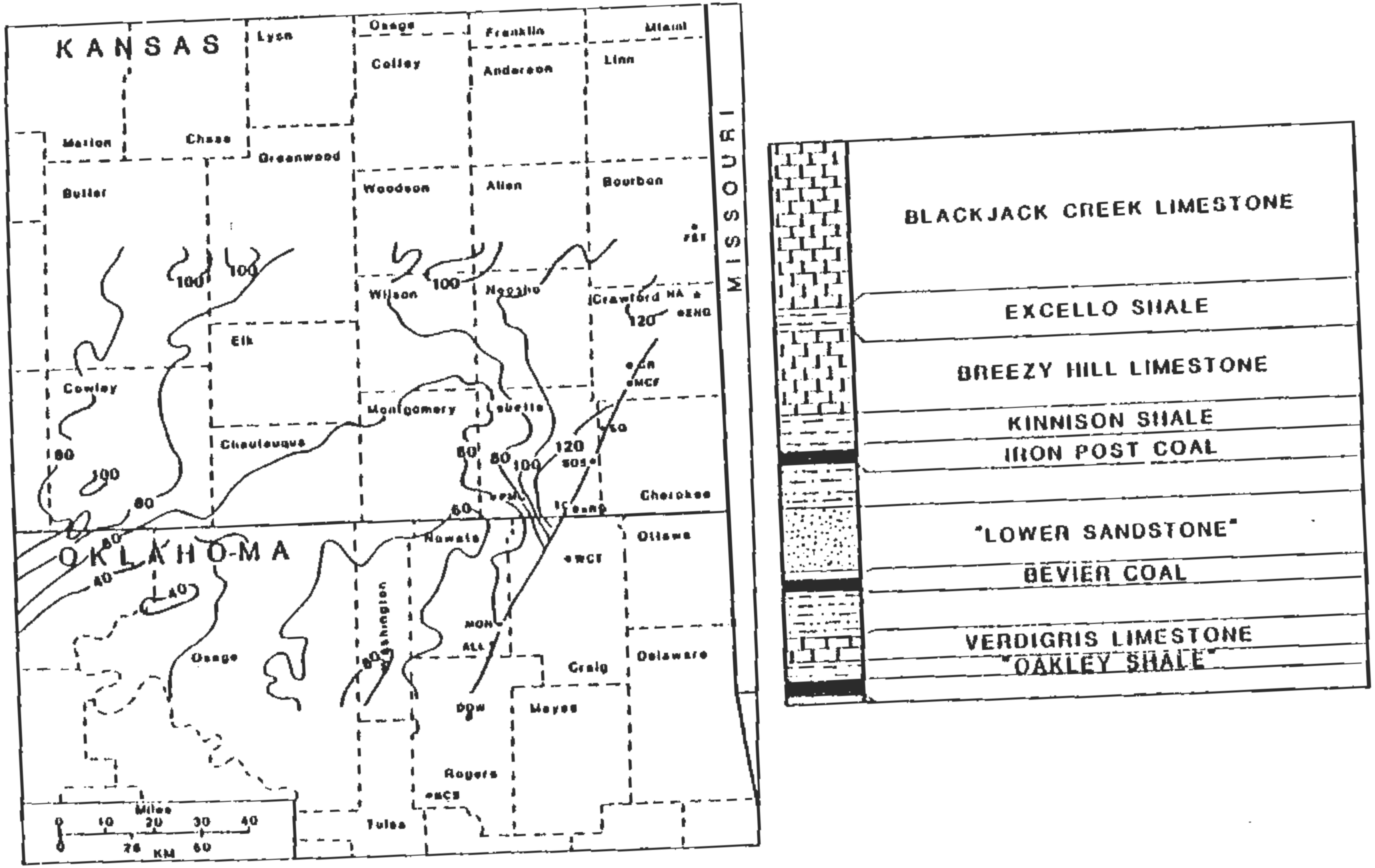
The Bourbon Arch trending northwest-southeast and crossing Bourbon, Allen, and Coffey Counties, Kansas, initially separated the Cherokee Platform to the south from the Forest City Basin to the north (Lee, 1943). Wanless (1975) recognized it as a remnant structure of the pre-Mississipian Chautauqua Arch, which was a westward extension of the Ozarks into southeastern Kansas. By Pennsylvanian time the southern portion of the Chautauqua Arch had been depressed to form the Cherokee Platform while the northern part, remaining positive, became the Bourbon Arch. The north side of the Bourbon Arch corresponds with the upthrown side of the Chesapeake Fault Zone, which cuts late Mississipian but not Pennsylvanian rocks (Merriam, 1963). Price (1981) recognized a genetic similarity and continuity between this upthrown block and an upthrown block farther south, which lay on the north side of an unnamed fault zone. He proposed the name "Bourbon Arch Complex" for this horst. Gentile (1968) suggested that the Bourbon Arch was inactive or did not affect upper Cherokee and lower Marmaton sedimentation. S. L. Denesen (personal communication), from extensive well-log study, concluded that the lower Cherokee (Krebs Formation) sediments lap onto the arch whereas upper Cherokee (Cabaniss Formation) sediments cover it. He also noted that there is no displacement of Cherokee strata across the arch, suggesting the lack of later structural displacements.

On the other hand, Price (1981) identified several effects of the Bourbon Arch on the middle Desmoinesian Pawnee Limestone: 1) an algal mound in the Pawnee Limestone developed along the arch, 2) the Anna Shale, a core shale in the Pawnee, thins over the arch, and 3) the arch also apparently prevented the influx from Missouri onto the Cherokee Platform of the regressive Mine Creek Shale clastic wedge. Schenk (1967) found evidence for the influence of the Bourbon Arch on carbonate deposition of the upper Desmoinesian Altamont Limestone. The transgressive member of the Altamont pinches out over the arch and the regressive member contains brecciated fabrics and osagia-grain calcarenites along the flanks of the arch and a phylloid algal-mound over the crest. Ravn (1981) noted major facies changes in the lower Missourian Hertha Limestone, which were related to complex structural features associated with the Bourbon Arch by Underwood (1984). Price (1981) noted that the southeastern Kansas phylloid algal-mound facies belt identified by Heckel and Cocke (1969) for Missourian rocks coincides with the geographic position of the Bourbon Arch Complex. McMillan (1956) has suggested that the Bourbon Arch continued to influence sedimentation as late as the upper Virgilian Stage of the Upper Pennsylvanian.

The Cherokee Platform (Moore, 1979; commonly designated a basin), a depositional shelf of the epeiric sea, was formed in early Pennsylvanian time by the mild downwarping of the Chautauqua Arch. Lower Pennsylvanian beds overlie Cambrian through Ordovician beds throughout most of the platform (Merriam, 1963). The Northeast Oklahoma Platform (Krumme, 1981) is an extension of the Cherokee Platform into northeastern Oklahoma. To simplify terminology, this study will refer to both platforms collectively as the Cherokee Platform. Based on the presence of another algal mound in the Pawnee Limestone, Price (1981) has identified the Shelf Edge Rise as a slight topographic high between the southern limit of the Cherokee Platform and the deep Arkoma Basin to the south. By late Missourian time, the Arkoma Basin was filled by deltaic clastics that had prograded from the south (Krumme, 1981; Price, 1981).

Substantial quantities of prodeltaic and "shoestring" sands prograding from the northeast (S. L. Denesen, personal communication) accumulated along the Kansas-Oklahoma border area prior to the deposition of units included in this study. Figure 8 illustrates an isopach map of part of this accumulation from the top of the "Oakley shale", at the base of the Verdigris Limestone in the middle of the Cabaniss Formation, upward to the base of the Excello Shale. Of particular interest to this study is the area of thinning in these clastics, including most of Osage, Washington, Nowata, and northwestern Craig Counties in Oklahoma and Chautauqua,

Figure 8. Isopach map of interval between top of "Oakley Shale" and base of Excello Shale. Includes stratigraphic column of units within interval. Northeast-southwest trending line indicates western limit of Cherokee outcrop with letters showing localities of measured sections from this study. Majority of sediments are prodeltaic shales and "shoestring" sands. Contour interval = 20 ft (modified from figure to be included in M.S. thesis by S. L. Denesen, Univ. of Iowa).



Top Oakley Sh.-Base Excello Sh. Isopach

Montgomery, and southwestern Labette Counties in Kansas. From this evidence, it is not clear whether this area of thinning represented a prior topographic high restricting the influx of fine-grained sediment from the delta or a topographic low representing an area basinward of the thick prodeltaic-wedge. However, it is clear that by the time the overlying limestones of the Breezy Hill-Houx-Higginsville Limestone interval began to be deposited, considerably less sediment had already accumulated in this area. It will be shown in subsequent sections that this area, designated the Kansas-Oklahoma Border Trend, probably represented the hingeline between the more rapidly subsiding Arkoma Basin to the south and the Cherokee Platform to the north.

Based on a thickening in the regressive Mine Creek Shale clastic wedge and the presence of a coal in Missouri, Price (1981) has identified a depression he named the 38th Parallel Trough, which parallels the north side of the well documented 38th Parallel Lineament. These structures are oriented east-west, cutting across the more commonly oriented northwest-southeast structures. The 38th Parallel Lineament intersects the Bourbon Arch, and though probably genetically different from it, their respective effects on sedimentation in eastern Kansas would be exceedingly difficult to differentiate.

In addition to the Bourbon Arch, a number of other northwest-southeast oriented structures affecting Pennsylvanian sedimentation have been identified. Neal (1969) recognized the effects of the Schell City-Rich Hill Anticline (of Gentile, 1976) in west-central Missouri on several units included in this study. It formed a partial barrier between the Morgan School Shale clastic wedge on the east side of the barrier and more continuous deposition of the Blackjack Creek Limestone on the west side. In addition, the Mulky coal and Excello Shale thin and the phosphatic black shale facies of the Excello Shale is absent over the crest; also the Blackjack Creek Limestone developed an oncolitic calcarenite facies on the flanks of the anticline. Ravn (1981) noted the effects on the lower Missourian Hertha Limestone of a probable extension of the Schell City-Rich Hill Anticline (misnamed Bates County Anticline) into northern Linn County, Kansas. The transgressive member in this vicinity is entirely calcarenitic; the core shale has typical core shale conodonts but lacks the hard fissile black facies; and the top of the regressive limestone contains oolitic calcarenite and birdseye calcilutite facies.

The Ladue-Freeman Anticline occurs just to the north and parallel to the Schell City-Rich Hill Anticline. Neal

(1969) identified a lagoonal facies in the Blackjack Creek Limestone over the crest of this anticline.

The Saline County Arch in central Missouri (Searight and Searight, 1961) was a northwest-southeast trending structural high in Middle Pennsylvanian time. Price (1981) noted a thinning in the Labette Shale over this structure. The Anna Shale also thins over the arch and is represented by only a thin pebbly phosphate horizon along both the Saline County Arch and the Kirksville-Mendota Anticline to the north.

The Lincoln Fold System in northeastern Missouri and south-central Iowa is a series of northwest-southeast trending anticlines and synclines (Bunker, 1981). Price (1981) noted that the Kirksville-Mendota Anticline, the westernmost anticline of this system, and the associated negative area to the east, the Appanoose Trough, affected sedimentation during Desmoinesian time.

CHAPTER III

STRATIGRAPHIC OVERVIEW

Historical Perspective

This study includes units from the Breezy Hill Limestone-Fort Scott Limestone interval (Fig. 3).

The name Breezy Hill Limestone was applied by Pierce and Courtier (1938) to the uppermost limestone of the Cherokee Group, from exposures in Crawford County, Kansas. Jewett (1945, Plate 1) misidentified the Breezy Hill of Oklahoma as the Blackjack Creek Limestone and the Blackjack Creek as the Higginsville Limestone, both of which are actually part of the overlying Fort Scott Limestone.

Overlying the Breezy Hill in Kansas and Missouri is the discontinuous Mulky coal bed, named by Broadhead (1874) from exposures in Lafayette County, Missouri.

The Excello Shale was named by Searight (1955) from an exposure in Macon County, Missouri. The uppermost unit of the Cherokee Group (Cabaniss Group in Oklahoma), it directly overlies the Breezy Hill Limestone in Oklahoma and portions of southeasternmost Kansas and overlies the Mulky coal in eastern Kansas and western Missouri. A marine shale with a black phosphatic facies, it is the most laterally persistent and uniform unit included in this study.

The Fort Scott Limestone is the basal formation of the Marmaton Group and everywhere directly overlies the Excello Shale (Fig. 3). It comprises two limestone members separated by a shale member.

Based on outcrops at Fort Scott in Bourbon County, Kansas, Swallow (1866) first applied the name "Fort Scott Limestone" to the upper limestone member (Higginsville Limestone) of what is now recognized as the Fort Scott Limestone. In the same publication, he applied the name "Fort Scott coal series" to about 100 feet of beds including the Higginsville Limestone and the overlying Labette Shale; the "Fort Scott marble" to a limestone in the Cherokee Shale; and "Fort Scott marble series" to a group of beds that included the Fort Scott marble.

Unaware that the name was preoccupied by an Ordovician formation in New York, Broadhead (1874) applied the name Oswego to beds now recognized as the Fort Scott Limestone, from exposures at Oswego, Labette County, Kansas.

McGee (1892) named a thin coal located in the shale between the two limestones, the Summit coal, from exposures in Macon County, Missouri.

Bennett (1896) included both limestones, the "Cement rock" (Blackjack Creek Limestone) and the overlying limestone, "the Lexington bottom rock" (Higginsville

Limestone) as part of the Fort Scott Limestone, but he also continued to use the name Oswego. He probably intended the type exposure to include a railway cut a short distance east of the Missouri Pacific Railway station in Fort Scott, Kansas.

Adams (1903), noting that the name Oswego was preoccupied, clearly established the name Fort Scott Limestone to include the two limestones and intervening shale and coal at Fort Scott, Kansas. But "Oswego" is still commonly used to designate the entire Breezy Hill-Fort Scott Limestone interval in the subsurface of Oklahoma.

Cline (1941) named three units in the Fort Scott Limestone after exposures in Johnson and Lafayette Counties in Missouri. The lower limestone he named the Blackjack Creek Limestone, and the upper limestone he named the Higginsville Limestone. He applied the name Houx Limestone to a thin limestone above the persistent black shale in the intervening shale unit. Jewett (1941) named the intervening shale, Little Osage Shale, after an exposure in Bourbon County, Kansas.

Jewett (1941) recognized that the type exposure chosen by Bennett (1896) was inadequate, probably since it did not include the entire Higginsville Limestone interval. He redesignated the type section as a quarry in the NE1/4, Sec. 19, T.25S., R.25E., northeast of Fort Scott, Kansas, assuming that it would remain well exposed. This quarry is not only presently inactive, but it has been partially destroyed as a result of road construction.

Houx-Higginsville Interval

The Houx-Higginsville interval in Missouri and Iowa (within the Wolverine Creek Formation of this study) has traditionally included three units named for exposures in Missouri (ascending order): 1) the Houx Limestone, a thin unit above the Little Osage Shale in Missouri and Iowa, was thought to pinch out southward into southeastern Kansas, 2) an intervening shale to sandstone unit, a portion of which is named the Flint Hill Sandstone, and 3) the widespread Higginsville Limestone, recognized from Oklahoma into Iowa and thought to occupy the entire Houx-Higginsville interval through most of Kansas and Oklahoma. Evidence to be presented in this study strongly suggests that the middle siliciclastic unit present in Missouri and Iowa represents a southerly prograding clastic wedge that splits the single limestone unit (Higginsville Limestone) present in Oklahoma and Kansas into the two limestone units (Houx and Higginsville Limestones) present in Missouri and Iowa.

Consequently, the single limestone that has traditionally been designated as the Higginsville Limestone in Oklahoma and Kansas is not the simple lateral equivalent to the type Higginsville Limestone in Missouri but is actually the lateral equivalent to both the Houx and Higginsville Limestones and the intervening clastic unit in Missouri and Iowa. Therefore, this study recommends "Houx-Higginsville Limestone" as a more appropriate and accurate name to replace the designation "Higginsville Limestone" for the single limestone unit present in Oklahoma and Kansas. Subsequent discussions of each of these units will be included together as parts of a general discussion of the Houx-Higginsville interval.

Cherokee-Marmaton Boundary

There has been a long debate concerning the appropriate boundary between the Cherokee and Marmaton Groups. In light of the recent redefinition of this boundary in Iowa by the Iowa Geological Survey (Ravn et al., 1984) and the present stratigraphic study of units on either side of the boundary from Oklahoma to Iowa, it seems timely to review the issue.

Based on a clear break in lithology between the Excello Shale and the Blackjack Creek Limestone, the base of the Marmaton Group was defined by Haworth (1898) and redefined by Moore (1936) as the base of the Fort Scott Limestone.

Weller (1932) recognized cyclothems in the Pennsylvanian strata of the Midcontinent, and he regarded them as equivalent in rank to formations. Moore (1936) believed that the boundaries between cyclothems were not always easily identified in the field, and he rejected them as the basic unit in classification of Pennsylvanian rock units. He believed lithologic and not genetic relationships should be used to name lithologic units, but he did recognize the usefulness of superimposing a genetic classification (cyclothem names) on the lithologic classification.

Jewett (1945) recognized the cyclic nature of the Fort Scott Limestone and underlying units. He included the Fort Scott Limestone and overlying coal and clastic deposits (Labette Shale) of the Marmaton Group and the immediately underlying coal and clastic deposits of the Cherokee Group, as part of a larger cycle of deposition, the Fort Scott megacyclothem. He also recognized that the Breezy Hill in Kansas corresponds cyclically to limestones found at the base of other Marmaton limestone formations. But miscorrelation of the Breezy Hill Limestone with a lower limestone in the Cherokee of Oklahoma led him to believe that the strata between the Breezy Hill and the Fort Scott in Oklahoma contained a number of additional cycles not recognized in Kansas. In spite of this, based on the genetic relationships he recognized between the Breezy Hill, Excello, and Blackjack Creek units, he discussed, but ultimately did not recommend changing, the Cherokee-Marmaton boundary (Jewett, 1945, p. 21).

For years the subsurface nomenclature of Oklahoma has informally used "Oswego" to designate the Breezy Hill-Higginsville interval (Jordan, 1957; Cole, 1967,1968; Michlik, 1981; Drexler, 1982), which thus included the Cherokee (designated the Cabaniss Group in most Oklahoma literature)-Marmaton boundary. Recognizing the prevailing opinion in Oklahoma, Krumme (1981) suggested enlarging the scope of the Fort Scott Limestone by establishing its base at the base of the Breezy Hill Limestone. The consequence of this change would be to effectively lower the Marmaton Group boundary to the base of the Breezy Hill Limestone.

Details of the Breezy Hill Limestone will be discussed later, but evidence strongly suggests that the Breezy Hill represents a minor but separate transgressive-regressive cycle of its own, apart from the major marine inundation represented by the Excello Shale-Blackjack Creek Limestone interval (Knight, 1983). This is particularly clear in Kansas where the marine Breezy Hill Limestone is separated from the Excello Shale by a nonmarine coal. Although the relationship in Oklahoma is not as clear, since the sea retreated only far enough to produce a marine shallow-water lithology but not a nonmarine lithology atop the Breezy Hill, it is inappropriate, based on genetic relationships, to include either the Breezy Hill Limestone of Oklahoma or Kansas as part of the Excello Shale-Blackjack Limestone interval.

This highlights the problem inherent in using genetically derived lithologic relationships to determine lithologic nomenclature. Those genetic relationships must be precisely and correctly understood before the naming of lithologic units can begin, and in geologic practice this is rarely the case. Naming of units usually precedes their thorough study, and in any event our understanding of genetic relationships is an evolutionary process. Consider the only recently recognized deep-water origin for the black phosphatic shale found in so many Pennsylvanian cyclothems.

The Iowa Geological Survey (Ravn _et al_., 1984) returned to the issue of the use of lithologic versus genetic relationships in determining lithologic boundaries by pointing out that genetic relationships have in fact been used repeatedly before. As they pointed out, it has been standard practice to recognize the depositional cyclicity of most Marmaton and younger Pennsylvanian units by dividing each cyclothem into two formations: 1) a marine formation generally consisting of the succession of transgressive limestone, deep-water marine shale, and regressive limestone deposited during a single inundation and withdrawal of the sea, and 2) a nonmarine or marginally marine clastic formation formed near maximum regression.

In Iowa the Fort Scott Limestone contains portions of two marine units separated by one nonmarine to marginally marine unit. Consequently, the Iowa Geological Survey, in line with the practice used in naming other cyclothems, no longer considers "Fort Scott" as an acceptable formational name. Ravn *et al.* (1984) propose three new formational subdivisions for the Excello Shale and the Fort Scott Limestone in Iowa (in ascending order): Mouse Creek Formation, Morgan School Shale, and Stephens Forest Formation (Fig. 3). The Mouse Creek Formation is a marine unit, which includes the Excello Shale and overlying Blackjack Creek Limestone. The Morgan School Shale is a nonmarine to marginally marine unit, which includes the nonmarine lower part of the Little Osage Shale and the Summit Coal. The Stephens Forest Formation is generally a marine unit, which includes the interval from the base of the upper marine part of the Little Osage Shale to the top of the overlying Higginsville Limestone. As a consequence of dividing the Little Osage Shale as previously defined, between two units, they propose retaining its name but restricting it to a member of the Stephens Forest Formation. With this redefinition, the Little Osage Shale would include only the marine interval between the top of the Summit coal and the base of the Houx Limestone. As a consequence of including the Excello Shale as the basal member of the Mouse Creek Formation, the Iowa Geological Survey proposes lowering the Cherokee-Marmaton boundary to the base of the Excello Shale.

This study confirms the finding of the Iowa Geological Survey that the Excello Shale and Blackjack Creek Limestone represent the marine facies of a single genetic unit. The Excello Shale is an extremely persistent and widespread unit that is easily recognizable in the field, making it an excellent boundary between major lithologic units. On the other hand the Breezy Hill Limestone is a highly variable unit becoming indistinct to nonexistent from Missouri to Iowa and is not a part of the Excello-Blackjack Creek genetic unit.

In line with the revision made by the Iowa Geological Survey, this study recommends lowering the boundary between the Cherokee-Marmaton Groups to the base of the Excello Shale but considers the base of the Breezy Hill Limestone, wherever it occurs, as an inappropriate boundary.

Excello-Fort Scott Nomenclature

By agreeing with the Iowa Geological Survey that the Cherokee-Marmaton boundary should be lowered to encompass the Excello Shale, it is necessary to reevaluate the nomenclature of the entire Excello-Fort Scott interval. The simplest solution would be to include the Excello Shale as the basal formation of the Marmaton Group and to continue to exclude it from the Fort Scott Limestone. A slightly more complex alternative would be to include the Excello Shale as the basal member of the Fort Scott Limestone.

Either solution is reasonable. However the evidence that this study has gathered from Oklahoma, Kansas, Missouri, and Iowa for the Excello-Labette Shale interval supports the conclusion of the Iowa Geological Survey that two marine-nonmarine depositional cycles are present. It is therefore agreed that the nomenclature should be revised to reflect the genetic groupings of the Excello-Labette Shale interval, just as it does for younger Pennsylvanian units.

The Iowa Geological Survey (Ravn et al., 1984) accomplished this revision by dropping "Fort Scott Limestone" as a formational name and replacing it by three new formational units (Fig. 3). There is no question that this revision accomplishes the goal of combining adjacent marine units within a cycle under one formational name and adjacent transitional to nonmarine units under another formational name. Whether the type sections and formational names choosen for these units in Iowa are appropriate for other areas is another question.

It is essential in choosing type sections and formational names for Pennsylvanian units that dominate the outcrop and subsurface in Oklahoma, Kansas, and Missouri, that they are acceptable to geologists in these states.

This is especially important if we propose to change already very familiar nomenclature to the unfamiliar.

The Excello-Fort Scott interval in Iowa was deposited closer to the northern shore of the Middle Pennsylvanian epeiric seaway; thus its lithologies there are not entirely representative of the much larger expanse of outcrop from Oklahoma through Missouri, which was deposited farther out on the marine platform. Additionally, due to the extensive blanket of glacial drift that covers much of Iowa, bedrock outcrops are rare. This is reflected in the incomplete and poorly exposed outcrops choosen by the Iowa Geological Survey as type sections, which were admittedly the best that could be found (Ravn et al., 1984). It is therefore doubful that the Iowa nomenclature will be acceptable to workers in other states.

This study agrees with the principles of revision and the basic divisions proposed by the Iowa Geological Survey. After extensive study of outcrops from Oklahoma through western Missouri, two alternative formational names and type sections are proposed as equivalents to and replacements for two of the Iowa names, Mouse Creek and Stephens Forest Formations (Fig. 3).

The name Dry Branch Creek Formation is proposed as an equivalent replacement for the Mouse Creek Formation. This name includes the interval from the base of the marine

Excello Shale to the top of the marine Blackjack Creek Limestone. The suggested type section (Sec. ENG) includes the cutbanks along Dry Branch Creek, by the bridge of an old railroad grade, 0.3 km. south of Englevale Cemetary, middle of the W line, NE1/4, Sec.25, T.28S., R.24E., Crawford County, Kansas.

The name Wolverine Creek Formation is proposed as an equivalent replacement for the Stephens Forest Formation. It includes the interval from the first marine beds overlying the Morgan School Shale to the base of the Labette Shale. Wolverine Creek is located north of Fort Scott, Bourbon County, Kansas, close to the quarry choosen by Jewett (1941) as the new type section for the Fort Scott Limestone. It is therefore suggested that this location, which has been partially destroyed, along with the original type section in Fort Scott be used as a composite type section for the Wolverine Creek Formation (Section FST). Named members include the Little Osage Shale (as redefined by the Iowa Geological Survey [Ravn et al., 1984]) and Houx-Higginsville Limestone (proposed replacement for Higginsville Limestone in Oklahoma and Kansas) in Oklahoma and Kansas and in addition, the Houx Limestone, an unnamed shale, which includes the Flint Hill Sandstone, and Higginsville Limestone in Missouri and Iowa.

The Morgan School Shale is an interval best developed in Missouri and Iowa, outside of the area studied in detail for this report. Therefore no attempt has been made in this report to locate a new type section or to rename it. It is suggested that a better exposed type section might be located in central Missouri where the Morgan School Shale has a thick representative shale, nodular limestone, underclay and coal succession.

Conclusions

As a consequence of this study, the following changes in stratigraphic nomenclature are proposed:

1 - In agreement with the Iowa Geological Survey, this study redefines the base of the Marmaton Group as the base of the Excello Shale.

2 - As a result of lowering the Cherokee-Marmaton boundary and in recognition of the marine-nonmarine depositional cycles represented by the Excello Shale-Labette Shale interval, "Fort Scott Limestone" has been dropped as a formational name, and replaced by three new formational units.

3 - The Iowa Geological Survey proposes the name Mouse Creek Formation for the marine interval that includes the Excello Shale and Blackjack Creek Limestones. This study suggests an alternative name, the Dry Branch

Creek Formation, from a better exposed outcrop in Kansas more typical of this interval.

4 - This study, in agreement with the Iowa Geological Survey, has redefined the Little Osage Shale to include only the marine gray to black shale interval between the base of the thin basal transgressive limestone of the upper Fort Scott marine inundation and the base of the Houx-Higginsville Limestone in Oklahoma and Kansas, and Houx Limestone, in Missouri and Iowa.

5 - This study, in agreement with the Iowa Geological Survey, will use the name Morgan School Shale for the transitional marine to nonmarine lithologies best developed in Missouri and Iowa between the Blackjack Creek Limestone and the Little Osage Shale. However, it is recommended that a better exposed type section for this interval may be located in Missouri.

6 - The Iowa Geological Survey proposes the name Stephens Forest Formation for the interval between the base of the Little Osage Shale (as redefined) and the top of the Higginsville Limestone. This study suggests an alternative name, the Wolverine Creek Formation, from a better exposed outcrop in Kansas more typical of this interval.

7 - The Higginsville Limestone of Oklahoma and Kansas, where it includes the horizon of the Houx Limestone,

should be referred to as the Houx-Higginsville Limestone.

CHAPTER IV

STRATIGRAPHY AND PETROLOGY

Introduction

Seven units included in this study will be discussed in detail: 1) Breezy Hill Limestone, 2) Mulky coal, 3) Excello Shale, 4) Blackjack Creek Limestone, 5) Morgan School Shale, 6) Little Osage Shale, and 7) Houx-Higginsville Limestone.

Correlation of units was made on the basis of twenty-three sections measured from outcrops, one core obtained from the Kansas Geological Survey, nine sections taken from previous work, and the lateral tracing of units along outcrop in the field and from well-logs in the subsurface (see Appendix A for details of stratigraphic sections). Generalized cross-sections were constructed to show the lateral stratigraphic and facies relationships of the units (Figures 9, 10, and 11).

These units include two shales that resemble each other and three limestones, which may appear similar in the field. The Excello Shale-Blackjack Creek Limestone interval often resembles the Little Osage Shale-Houx-Higginsville Limestone interval in northern Oklahoma and Kansas. In Oklahoma, the Breezy Hill Limestone-Excello

Figure 9. Stratigraphic cross-section and lithofacies of Breezy Hill Limestone. Datum is top of Excello Shale. Derived from Figure 12 and measured sections (Appendix A).

BREEZY HILL LIMESTONE LITHOFACIES CROSS-SECTION

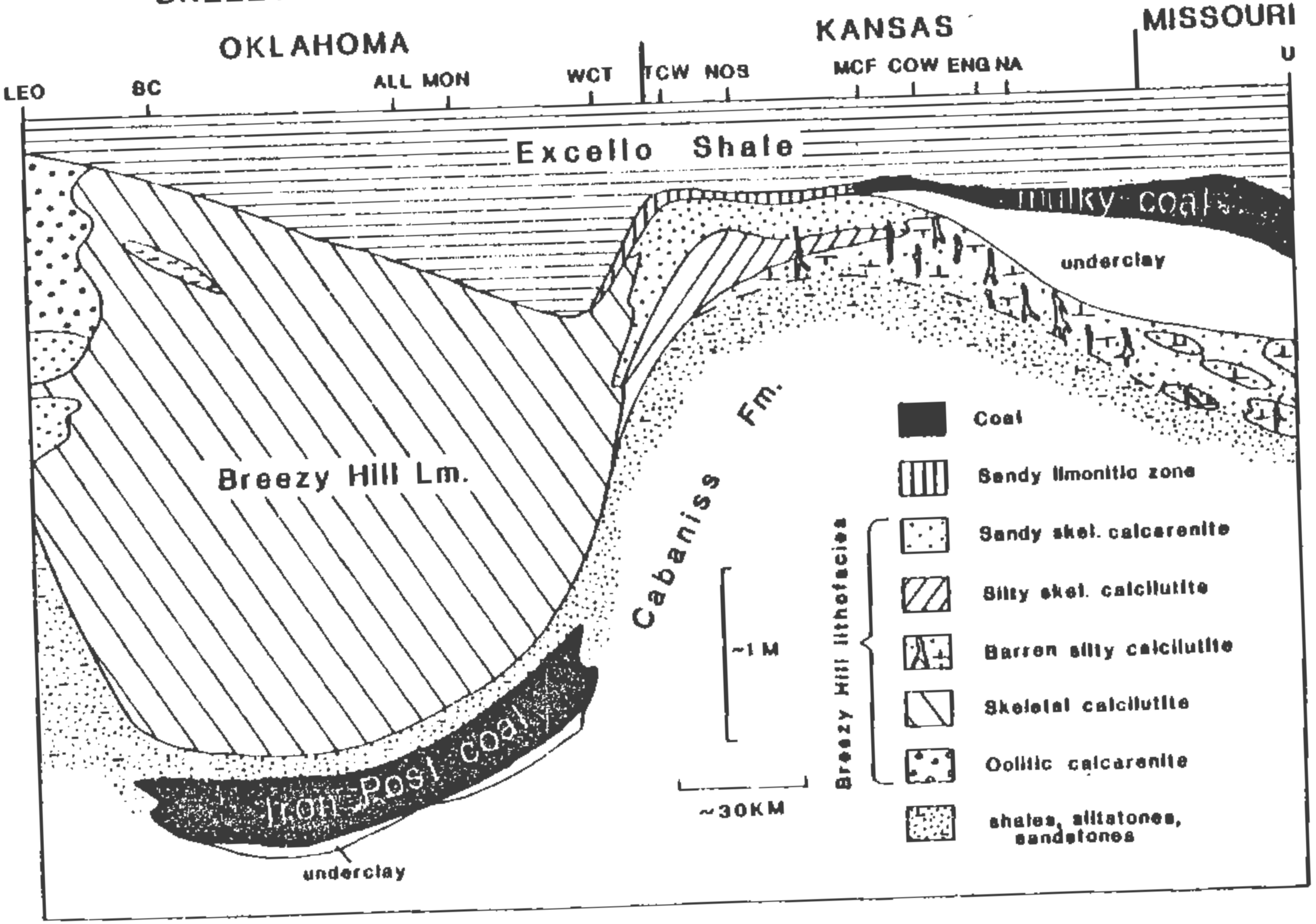


Figure 10. Stratigraphic cross-section of Dry Branch Creek Formation and Morgan School Shale. Includes lithofacies of Blackjack Creek Limestone, which north of Section U are generalized from Neal (1969) and Swade (1982). Datum is base of Excello Shale. Derived from Figure 19 and measured sections (Appendix A).

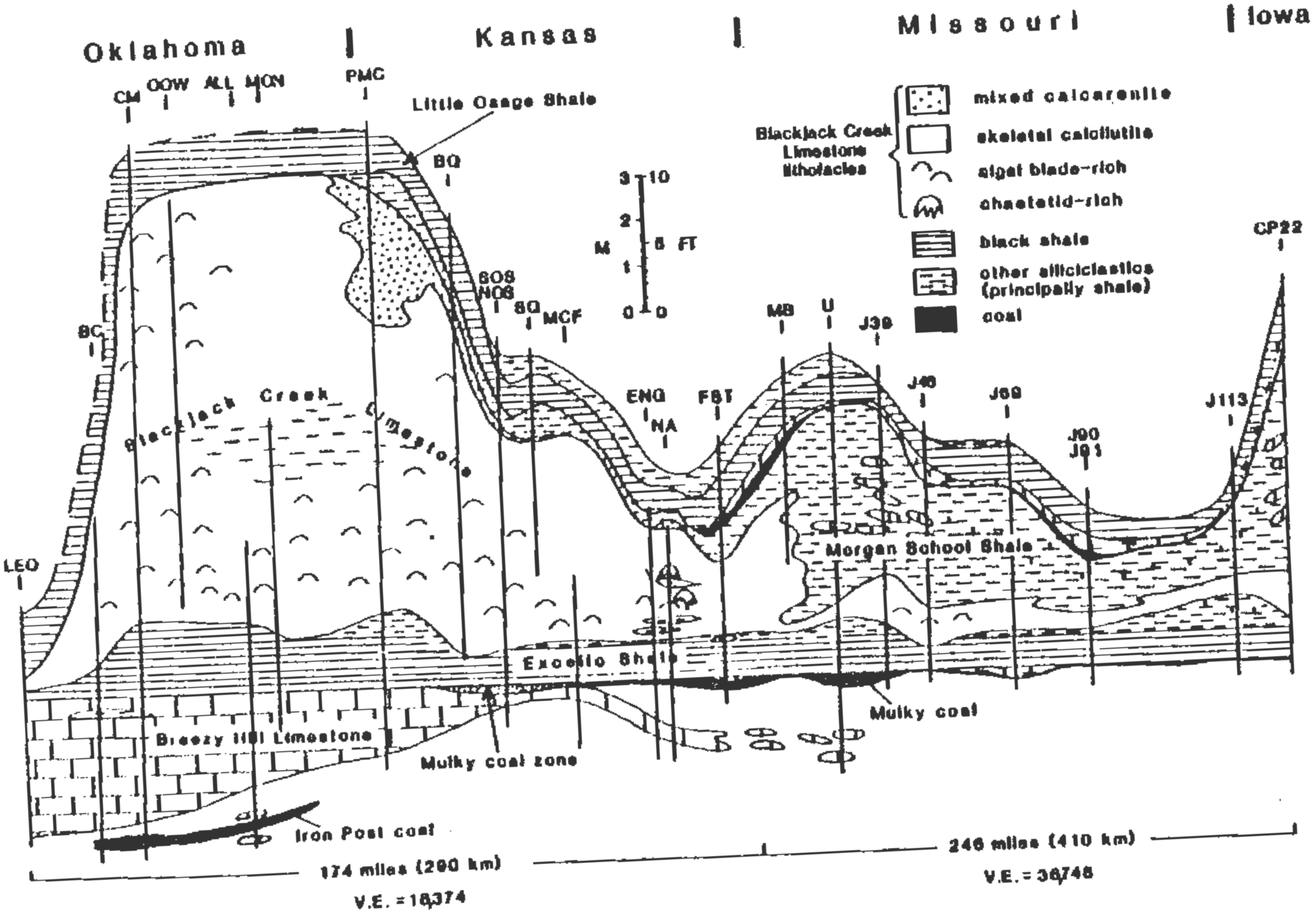
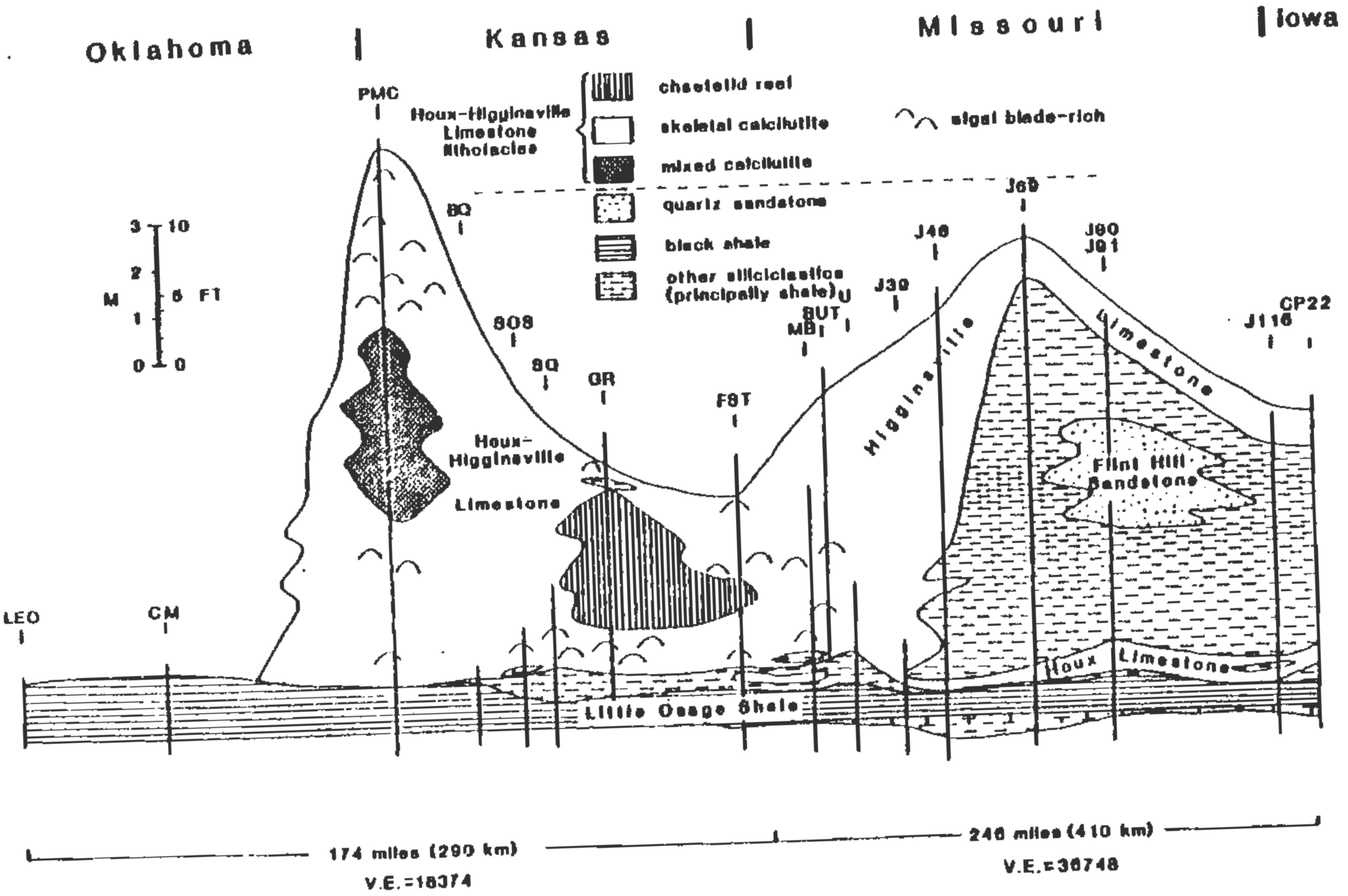

Oklahoma
Kansas
Missouri
Iowa
CM
OOW
ALL
MON
PMC
Little Osage Shale
BQ
SOS
NOS
SG
MCF
BC
LEO
Blackjack Creek Limestone
Blackjack Creek Limestone lithofacies
mixed calcarenite
skeletal calcilutite
algal blade-rich
chaetetid-rich
black shale
other siliciclastics (principally shale)
coal
3
2
1
0
M
10
5
0
FT
MB
U
J39
J46
J69
J90
J91
J113
CP22
ENG
NA
FST
Morgan School Shale
Excello Shale
Mulky coal
Mulky coal zone
Breezy Hill Limestone
Iron Post coal
174 miles (290 km)
V.E. = 18,374
246 miles (410 km)
V.E. = 36,746

Figure 11. Stratigraphic cross-section of Wolverine Creek Formation. Includes lithofacies for Houx-Higginsville Limestone, which north of Section U are generalized from preliminary work by Jeffries (1958) and Swade (1982). Datum is base of Little Osage Shale. Derived from Figure 22 and measured sections (Appendix A).


Oklahoma
Kansas
Missouri
Iowa
Houx-Higginsville Limestone lithofacies
chaetetid reef
skeletal calcilutite
mixed calcilutite
quartz sandstone
black shale
other siliciclastics (principally shale)
algal blade-rich
M
FT
3
2
1
0
10
5
0
PMC
SQ
SOS
SQ
GR
FST
MB
BUT
U
J30
J46
J69
J90
J91
J116
CP22
LEO
CM
Houx-Higginsville Limestone
Higginsville Limestone
Flint Hill Sandstone
Houx Limestone
Little Osage Shale
174 miles (290 km)
V.E.=18374
246 miles (410 km)
V.E.=36748

Shale interval often resembles the Blackjack Creek Limestone-Little Osage Shale interval. At many outcrops that contain only one of the shales and an overlying extensively eroded limestone, determining the correct interval based on lithology or location in the field may prove difficult. Swade (1982) found from conodont studies on cores in Iowa and outcrops in Kansas and Oklahoma that the black shale facies of the Excello Shale contains the conodont platform element of Gondolella sp. whereas the black shale facies of the Little Osage Shale consistently lacks this element. This study generally confirms his observation (see chapter on Conodonts), which thus provides an important tool in distinguishing these units where other evidence is inconclusive.

The three limestone units (Breezy Hill, Blackjack Creek, and Houx-Higginsville) are a significant part of this study. Observations of outcrop and well-log lithologic relationships, polished slabs, and thin-sections from each of these limestones have been made from western Henry County, Missouri, into southern Tulsa County, Oklahoma, to facilitate their classification into depositional facies and to describe the diagenetic features found within each depositional facies.

As a consequence of the limited lateral outcrop control and the large area under investigation, this study is restricted to a generalized analysis of depositional facies. Each carbonate unit is subdivided into a number of depositional facies for the purpose of understanding the broad biologic, hydrologic, topographic, and climatic controls influencing their sedimentation. These subdivisions are based mainly on syndepositional fabrics, which include the presence or absence of carbonate mud; nature of grain support; grain types, size, rounding, and coatings; and evidence of biogenic activity, diversity, and abundance of fossils. The names given to these depositional facies are intended only as descriptive names and make no attempt to precisely utilize a particular scheme of carbonate classification. However, unless otherwise stated, the carbonates within a particular depositional facies are classified using Dunham's (1962) nomenclature. The description of post-depositional features and fabrics included with each depositional facies emphasizes grain and mud-matrix preservation and cement types and their paragenetic sequence.

Breezy Hill Limestone

Definition

The Breezy Hill Limestone member of the Cabaniss Formation of the upper Cherokee Group (Zeller, 1968; member of Senora Formation of the Cabaniss Group in Oklahoma) was named by Pierce and Courtier (1938) for exposures at Breezy

Hill, just southwest of Mulberry, Kansas. They noted that on the west side of Breezy Hill, the limestone consists of less than a meter of impure unfossiliferous limestone whereas on the eastern flank of the hill, it thickens to a maximum of 2.4 m and contains marine fossils. Though unable to locate a 2.4 m thick section of Breezy Hill in this area (less than 1 m was observed), I observed the lithologic variation suggested by Pierce and Courtier. In the same report they state that where fossils are found in the Breezy Hill Limestone, they are entirely marine.

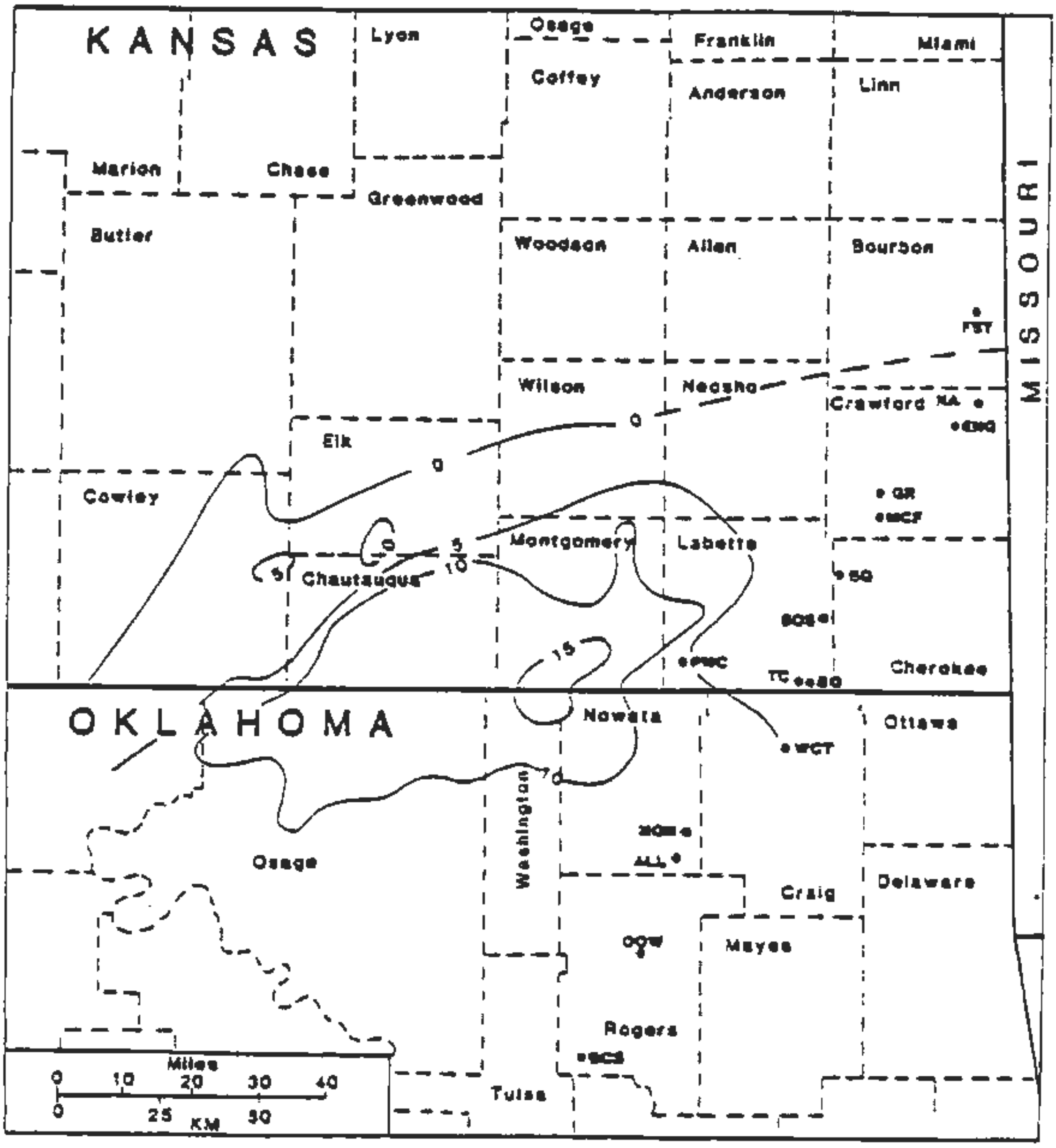
Description and Lateral Variations

Along the outcrop belt the Breezy Hill Limestone varies from about 3 m of marine skeletal calcilutite, directly below the Excello Shale in Oklahoma, to a thin nodular to massive bed of silty to sandy, barren calcilutite that is located within or at the base of the Mulky coal underclay in Kansas and is also tracable into Missouri and Illinois. In portions of both Kansas and Oklahoma it is capped by a skeletal or oolitic calcarenite. The Breezy Hill Limestone is divided into five distinct lithologic facies (Fig. 9), which reflect widely different origins of deposition: 1) barren silty calcilutite, 2) sandy skeletal calcarenite, 3) silty skeletal calcilutite, 4) skeletal calcilutite, and 5) oolitic calcarenite.

The Breezy Hill Limestone attains a maximum thickness of 5.4 m along a northeast-southwest trend in the subsurface, centered in southern Montgomery County, Kansas and northern Washington County, Oklahoma (Fig. 12). The thickness of the Breezy Hill Limestone along this trend is inversely related to the thickness of the underlying detrital clastics of the upper Cabaniss Formation (compare Figures 8 and 12). The overlying Blackjack Creek and Houx-Higginsville Limestones have similar thickening trends in this area, and collectively these trends will be referred to as the Kansas-Oklahoma Border Trend.

An anomalously thick section (about 6 m) of the Breezy Hill has long been recognized east of Turkey Creek at a defunct quarry just 1.2 km north of the Kansas-Oklahoma border (Pierce and Courtier, 1938). This study has not been able to determine with certainty whether this is the Breezy Hill or Blackjack Creek Limestone. This quarry (Section TC) is now filled with water and typically less than 3 m of limestone is still visible. The limestone grades from a skeletal calcilutite at water level into a crossbedded, intraclastic, almost coquinoid calcarenite, interbedded with finer grained calcarenite containing burrows filled with coarser skeletal debris. The upper contact is a sharp undulatory surface containing chert nodules overlain by 0.9 m of fissile black shale capped by 5-7 cm of yellow skeletal

Figure 12. Isopach map of Breezy Hill Limestone. Contour interval = 5 ft. Based on outcrop and well-log data (Appendix B).



BREEZY HILL LIMESTONE ISOPACH

calcilutite. Downsection along a creek to the west of the quarry are abundant fragments of black shale suggesting an underlying black shale, in which case the limestone would be the Blackjack Creek. But these may only be float derived from the black shale at the top of the quarry and transported into the creek.

An operational quarry less than a kilometer to the east (Section BQ) contains a limestone very similar to the one at Turkey Creek, but this limestone is underlain and overlain by fissile black shales and therefore is definitely the Blackjack Creek Limestone. Less than a kilometer to the west of Turkey Creek, along a road cut (Section TCW), the Breezy Hill can be easily identified as a massive bed of skeletal calcilutite to calcarenite less than 20 cm thick and overlain by 10 cm of limonitic friable sandstone.

The Breezy Hill Limestone is not 6 m thick anywhere else along outcrop (Fig. 12) and the subsurface trend does not suggest that such an outcrop thickness is likely to exist in southeastern Labette County. Therefore the only evidence suggesting that the limestone at Turkey Creek is the Breezy Hill is one *Gondolella* platform fragment recovered from the overlying black shale (along the rest of the outcrop *Gondolella* has been recovered from the Excello Shale, which overlies the Breezy Hill Limestone, but not from the Little Osage Shale, which overlies the Blackjack

Creek Limestone). This fragment may have resulted from sample contamination as it was not duplicated with subsequent washings. If this section is the Breezy Hill, then it represents a very localized mound capped by the sandy skeletal calcarenite facies.

Barren Silty Calcilutite Facies

Description

From the northernmost Breezy Hill outcrop examined, Section U in western Missouri, southward into portions of east-central Crawford County, Kansas, the entire Breezy Hill interval, averaging less than 0.5 m thick, consists of the barren silty calcilutite facies. On outcrop this facies ranges from a nodular (Section U) to a massive bed (Section NA) of orange-brown and gray mottled, barren, calcareous siltstone to silty, sandy carbonate [Dunham's (1962) nomenclature does not adequately describe this lithology]. It has a sharp but undulating contact with the overlying underclay of the Mulky coal and a gradational contact with the siltstones and sandstones of the underlying Cabaniss Formation. Southward in central Crawford County this facies is gradational with and overlain by the silty skeletal calcilutite facies. It thins and disappears in the same area where the overlying underclay-coal sequence thins to little more than a sandy limonitic zone (Fig. 9) with occasional wavy laminations of coaly plant fragments. Its southernmost observed occurrence is in the southwestern corner of Crawford County (Section COW). Where extensively weathered, it grades downward from a massive carbonate bed into a crumbly matrix of calcareous siltstone to sandstone containing nodules of carbonate (Fig. 13a). At some localities stringers of subvertical to subhorizontal orange-brown carbonate clearly disrupt the bedding at the top of the underlying Cabaniss Formation (Fig. 13b). The top of the Cabaniss Formation in southeastern Kansas is dominated by a barren, argillaceous, calcareous, dolomitic siltstone to sandstone containing subangular to subrounded quartz with subordinate amounts of muscovite, plagioclase, and irregularly shaped organic- and clay-rich patches. Cross-laminations are often preserved, with individual laminae separated by organics and small pyrite crystals. Intergranular porosity is filled by blocky ferroan calcite and lesser amounts of non-ferroan calcite, blocky ferroan dolomite, silica, limonite, and hematite.

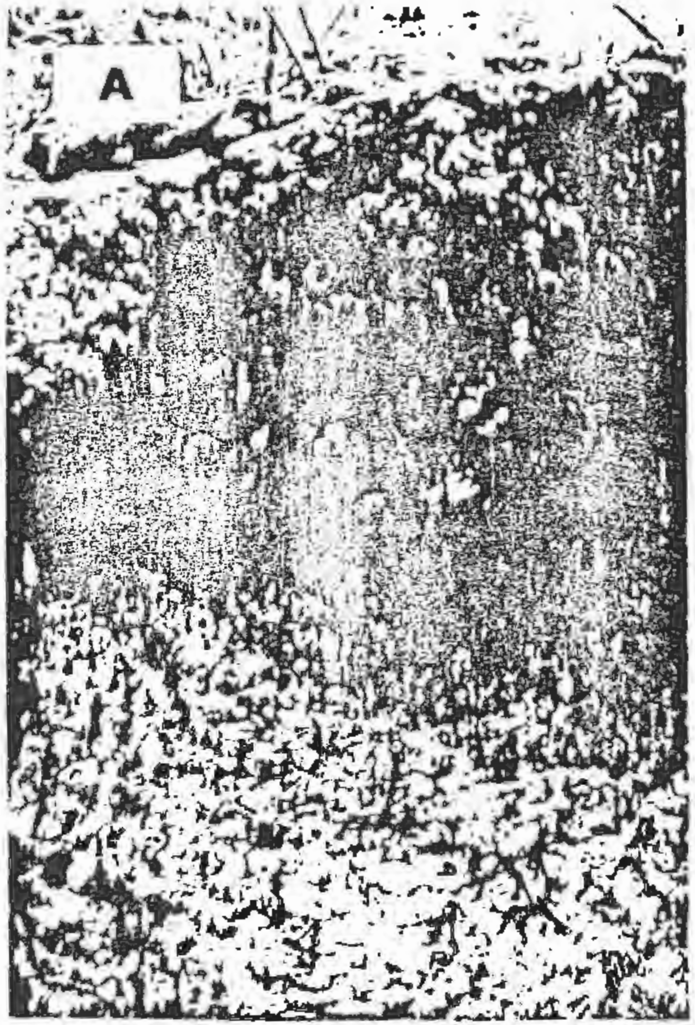
An unusual calcareous fabric modifies the top of the Cabaniss Formation and is responsible for the barren silty calcilutite facies of the Breezy Hill Limestone. Polished slabs from the base of this facies (Fig. 14) show discrete orange-brown and light to dark gray calcareous patches less than a centimeter in diameter in a cream to greenish-colored siltstone matrix. As these patches increase in number

Figure 13. Outcrops of barren silty calcilutite facies of Breezy Hill Limestone.

a) Massive carbonate bed at top grades downward into nodules of carbonate in siliciclastic matrix. Crumbly, nodular pattern in this facies results from differential weathering of well-cemented rhizocretions formed from plant roots within less well-cemented Cabaniss Formation siliciclastics.

b) Cross-bedding in siliciclastics at top of Cabaniss Formation disrupted by rhizocretions of a rooted-horizon that developed subsequent to deposition of overlying marine Breezy Hill Limestone.

Photographs from roadcuts in Crawford County, Kansas, along Highway 69, north of Arma (Section NA).


A

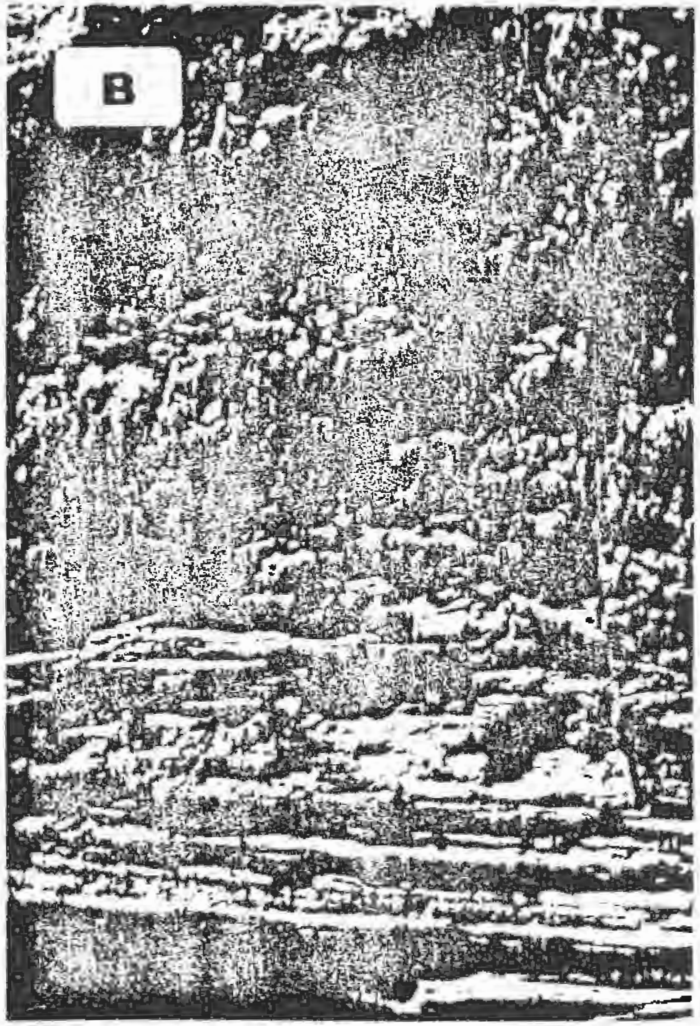
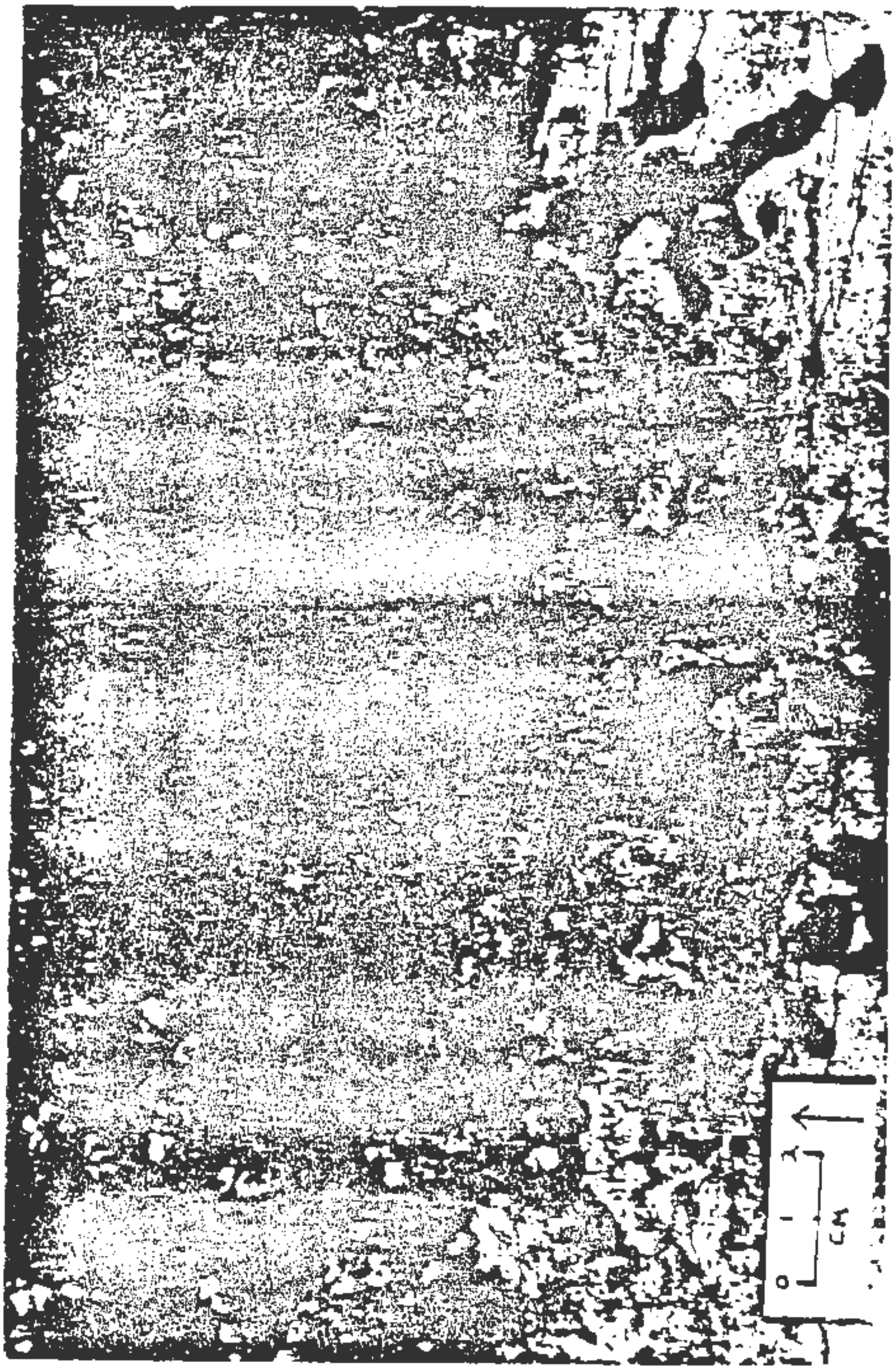

B

Figure 14. Polished slab of barren silty calcilutite facies. From outcrop shown in Figure 13b. Shows horizontal to vertical rhizocretions (dark) disrupting cross-bedding of underlying Cabaniss Formation siliciclastics (light).


0
1
2
CM

upward, they coalesce into horizontal to vertical stringers and larger more irregularly shaped masses.

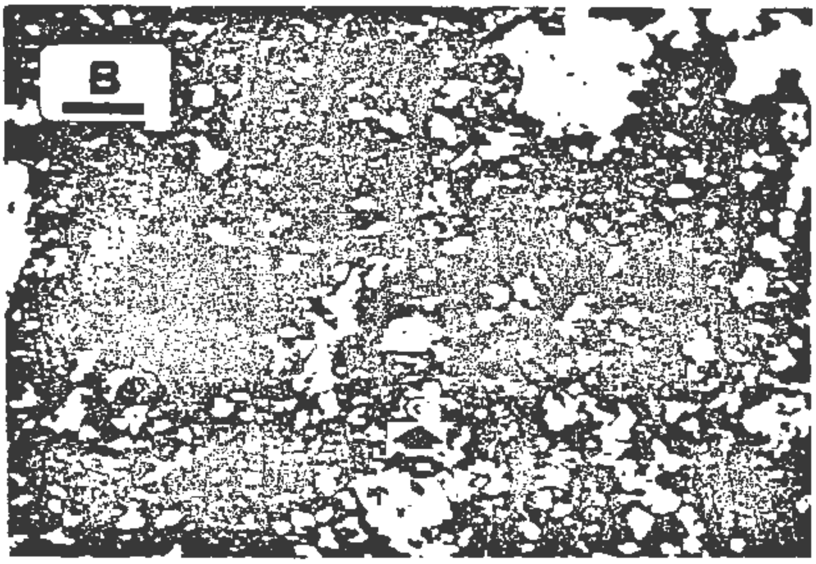
Petrographically these patches have been identified as rhizoliths containing rhizopatches, rhizosheaths, root casts, and desiccation fractures (see section on rhizoliths at the end of this chapter). In addition to the desiccation fractures genetically associated with rhizopatches, this facies contains fractures and solution vugs that also are associated with the overlying silty skeletal calcilutite and sandy skeletal calcarenite facies. These fractures have sharp to crumbly, circumgranular sides passing through and displacing or fragmenting both the siltstone matrix and the rhizopatches (Fig. 15a). Both types of fractures are most commonly filled by a microspar to blocky ferroan dolomite (often with undulose extinction) and ferroan calcite that incorporate disseminated quartz grains and clay. Geopetal ferroan dolomite microspar grading upward into spar, partially fills some fractures (Fig. 15a). In one case, blocky ferroan calcite spar completely fills one end of a fracture while the other end is filled by ferroan dolomite. Rare microcrystalline to macrocrystalline chert occurs as a final fracture fill. Tiny (2-4 microns in diameter) calcareous(?) ring- and horseshoe-shaped objects (Fig. 15b) are occasionally found in abundance, floating in the ferroan dolomite filling the fractures. They appear to be composed

Figure 15. Barren silty calcilutite facies of Breezy Hill Limestone.

a) Fracture filled with ferroan dolomite spar (fD) and geopetal cloudy dolomite spar and quartz grains (G). Matrix is nonferroan calcite. From silty skeletal calcilutite facies but found also in barren silty calcilutite and sandy skeletal calcarenite facies. (Plane-polarized light; COW10D1; Scale bar = 0.2 mm).

b) Some fractures in barren silty calcilutite facies contain problematic calcareous (?) ring- and horseshoe-shaped objects (P) in ferroan dolomite cement (Plane-polarized light; COW12DL; Scale bar = 0.04 mm).


A
fD
G


B

of a clear non-ferroan calcite without distinct crystal boundaries. Almost perfectly circular, and with a hollow center, these rings are often open-ended. Two or more are often linked together, sharing a common hollow center.

The barren silty calcilutite facies continues northeastward from Arma, Kansas, into western Missouri, becoming less massive, more nodular and discontinuous into Iowa and Illinois. In Illinois where it exists as a discontinuous nodular zone below the Summum (No.4) coal, it is part of the Carbondale Formation. Inden (1968) has identified stromatolite clasts, peloids, and intraclasts from the Breezy Hill in Missouri and Illinois, but this study will suggest alternative interpretations for these clasts, more in line with the rhizocretions identified herein.

Depositional and Diagenetic Interpretations

The barren silty calcilutite facies of the Breezy Hill Limestone, which occurs at the base of the Mulky coal underclay, is rather typical of similarly positioned units in other Pennsylvanian underclays that have been called "underclay" or "fresh-water" limestones. Norman (1957) interpreted the Breezy Hill in Illinois as lacustrine due to the presumed presence of Botryococcus braunI, an alga indicative of a fresh-water environment. Inden (1968) identified peloids, intraclasts, and stromatolites from the Breezy Hill and postulated a variety of marginal marine environments for their origins, from brackish-water lakes and lagoons to mudflats on a deltaic coastline.

Results from this study suggest that previous authors working on "underclay" limestones have often overlooked or misinterpreted critical features in making their depositional interpretations. Perhaps the most significant characteristic of this facies is its gradational relationship with the underlying terrigenous clastics of the Cabaniss Formation. Where best developed, its profile includes a massive bed of carbonate as a cap, which grades downward into a more crumbly, nodular, calcareous zone that is transitional with, and disrupts the bedding of the Cabaniss Formation. The development of this profile appears to have resulted from the displacive growth downward and outward of calcareous material at the expense of the siliciclastic host material.

The gradational nature of the barren silty calcilutite facies with the underlying sediments, the profile that it develops, and its internal fabrics are all very similar to the descriptive definition of caliche proposed by Esteban (1976). He recognized a complete caliche profile as including a vertically zoned series of sub-horizontal to horizontal carbonate deposits that grade downward into the original sediment. In descending order, a complete profile would include: 1) compact crust or hardpan, 2) platy or sheet-like zone, 3) nodular-crumbly zone, and 4) massive-chalky to transitional zone. The position and development of these carbonate deposits both vertically and laterally in a particular caliche profile is highly variable, but there is always a transition zone between the caliche and the host sediment with evidence of in-place alteration and replacement of the host sediment. Predominant caliche fabrics include clotted, peloidal micrite with microspar channels and cracks, rhizoliths, glaebules (pisoliths, ooliths, nodules, peloids), and poorly laminated micrite.

The intimate association of rhizoliths with this facies suggests the importance of plant roots in its formation. Klappa (1980) has coined the term "rhizolite" for a rock showing "structural, textural and fabric details determined largely by the activity, or former activity, of plant roots". The barren silty calcilutite facies probably represents a caliche/rhizolite horizon. The presence of rhizoliths in this facies and in the overlying silty skeletal calcilutite and sandy skeletal calcarenite facies suggests that a rooted-horizon developed both in the deltaic sediments of the Cabaniss Formation and in the north end of the marine carbonate sediments of the Breezy Hill Limestone subsequent to subaerial exposure. Therefore, the barren silty calcilutite facies primarily represents a rooted-horizon. It was initially produced by the diagenetic alteration of previously deposited sediment and therefore is not itself a depositional facies. The absence of fossils in the barren silty calcilutite facies is best explained by their absence at the top of the Cabaniss Formation from which it predominantly developed.

Fractures were responsible for breaking the calcareous patches into angular to rounded fragments. These fragments occasionally mimic peloids and intraclasts and may be the actual source of the peloids and intraclasts that Inden (1968) attributes to a marginal marine depositional environment. It is also possible that the textures he identified as stromatolites are actually the micritic and microspar laminae typical of a well developed caliche horizon, although this fabric was not observed in the present study.

Similar caliche or rhizolite horizons have been recognized from other Carboniferous rocks. Schutter (1983) identified a dark, micritic, ameboid, nodular limestone containing random cracks, pedotubules and a glaebular structure at Fithian, Illinois, as a caliche. Mitchell (1981) identified a rooted-horizon in the top of the Iola Limestone in Iowa and Nebraska. Watney (1980) documented rooted-horizons in Upper Pennsylvanian units of northwestern Kansas. Adams (1980) provided excellent documentation of a rhizolite profile in the Eyam Limestone of Derbyshire, England.

Summary

The barren silty calcilutite facies represents a rhizolite or caliche that developed in a nonmarine environment through the diagenetic activity of roots on the previously deposited marine Cabaniss Formation. This rooted-horizon also passed through the carbonate sediments of the overlying silty skeletal calcilutite and sandy skeletal calcarenite facies and probably developed only after their deposition.

Sandy Skeletal Calcarenite Facies

Description

The sandy skeletal calcarenite facies uniformly caps the Breezy Hill Limestone from northeastern Crawford County, Kansas, southward to the area of the Kansas-Oklahoma border (Fig. 9). South of the border, it becomes discontinuous and at the southernmost exposure examined (Section LEO), it is interbedded with the underlying skeletal calcilutite facies and overlying oolitic calcarenite facies. Generally it includes less than the top 0.2 m of the single massive bed that constitutes the Breezy Hill Limestone in southeastern

Kansas, but in a core close to the Kansas-Oklahoma border (Section PMC), it is interbedded with the sandy skeletal calcilutite facies through much of the 1.5 m Breezy Hill interval. Cross-bedding can occasionally be observed on weathered surfaces. It is directly overlain by the Mulky coal-underclay sequence at its northern exposures, but southward the Mulky coal-underclay interval thins to a limonitic, sandy horizon (Fig. 9) with only occasional coaly stringers.

This facies generally grades upward from silty, sandy skeletal packstones into loosely packed sandy skeletal grainstones. Very fine-grained subangular to subrounded quartz sand with subordinate amounts of muscovite, microcrystalline and macrocrystalline chert, and plagioclase constitute from less than 5% to over 95% of the grains. Skeletal grains include a diverse marine biota (in descending order of abundance): echinoderm, encrusting foraminifer, brachiopod, foraminifer, mollusk, ostracode, bryozoan, dasyclad green algae, coral, and phosphatic fragments. Skeletal fragments are often rounded, heavily micritized, and sorted (Fig. 16a). Micrite envelopes are generally rich in euhedral pyrite inclusions. Broken and abraded skeletal grains are often enclosed and overgrown by multiple layers of encrusting forams. Packing is generally very loose; little stylolitization has occurred.

Figure 16. Sandy skeletal calcarenite facies of Breezy Hill Limestone.

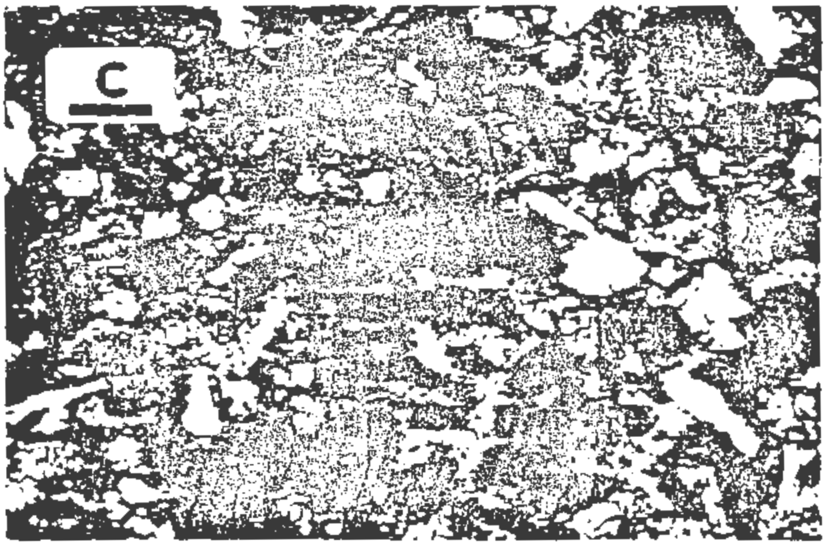
a) Rounded, heavily micritized skeletal (dark) and quartz (light) grains. Outer boundary of skeletal grain contains micritized rim grading inward into irregular-sided, nonferroan calcite spar (C), suggesting neomorphism of skeletal grain's unstable minerology. Sharp contact, with inner filling of clear blocky ferroan dolomite (fD) suggests partial dissolution and void-filling of grain's interior. Isopachous nonferroan calcite rims (Cr) surround grains. Final intergranular filling is blocky ferroan dolomite (fD) (Plane polarized light; COWTa; Scale bar = 0.2 mm).

b) Skeletal grain with sharp inner micritic rim and final fill of blocky ferroan dolomite (bfD). Another skeletal grain contains micritized rim grading inward into irregular-sided, nonferroan calcite spar (C). Nonferroan calcite overgrowths (O) on echinoderm ossicle (dark). Dominant intergranular cement is ferroan dolomite (fD) (Plane-polarized light; COWTa; Scale bar = 0.07 mm).

c) Loosely packed grainstone from north side of Kansas-Oklahoma Border Trend with intergranular, irregular-sided ferroan calcite cement (Plane-polarized light; PMC391; Scale bar = 0.13 mm).


A
fD
C
fD
Cr


B
bfD
O
fD
C


C

Muddy material decreases in abundance upward in the facies and consists of nonferroan and ferroan calcite micrite and microspar, with varying amounts of clays, organics, pyrite, and iron oxides.

Inter- and intragranular void-filling cements are found in a fairly consistent sequence from void-edge to void-center throughout this facies (though not all cement types are represented at all localities): 1) initial isopachous, scalenohedral, nonferroan calcite, 2) blocky nonferroan calcite, 3) blocky ferroan calcite and ferroan dolomite, and 4) silica. Ferroan calcite and ferroan dolomite are variable in their order of appearance.

The initial isopachous, scalenohedral, nonferroan calcite cement rims (Fig. 16a) are found locally (Section COW) only at the top of this facies. The blocky straight-sided nonferroan calcite cement occurs as syntaxial overgrowths on echinoderm fragments (Fig. 16b). Scalenohedral to blocky straight-sided ferroan calcite often follows, in optical continuity with the nonferroan calcite; it also occurs as a void-fill in the dissolved interiors of unstable grains. Smaller, irregular-sided, nonferroan and ferroan calcite spar crystals represent the dominant intergranular cement (Fig. 16c).

Irregular-sided, cloudy, nonferroan calcite occasionally preserves relict structure in unstable skeletal grains and often has a gradational boundary with the remaining micritized rim (Fig. 16a, b).

Microcrystalline and macrocrystalline silica occurs as a minor intergranular cement. It grows over the isopachous calcite rims at Section COW. Near the top of the Breezy Hill at Section TCW, silica partially to completely replaces all carbonate skeletal grains. Where replacement was total, no relict structure was preserved in any skeletal grains, but where replacement was restricted mainly to unstable mollusk grains, chalcedony has preserved relict structure.

Blocky ferroan dolomite can occur as the dominant cement between grains (Fig. 16b), but more commonly it is a final void-filling cement (Fig. 16a, b). Where it fills the interiors of unstable grains, it appears to be a void-filling cement (Fig. 16a, b), having a sharp contact with the remaining micritized envelope and with any earlier calcite spar filling the interior. Tiny incipient nonferroan and ferroan dolomite rhombs are occasionally found floating within silicified skeletal grains.

Root casts with thin rhizosheaths are found in this facies in Crawford County, Kansas, although in less abundance and without the development of the sediment-altering rhizopatches that occur in the lower facies. Fracturing and solution vugs with crumbly sides and filled with ferroan dolomite, and fragments of earlier calcite-cemented grains occur in Crawford County, Kansas (Section COW).

Depositional and Diagenetic Interpretations

The presence of a diverse marine biota including dasyclad green algae suggests that the sandy skeletal calcarenite facies was deposited in shallow, normal marine water. The cross-bedding, rounding, micritized rims, and osagia coatings of skeletal grains indicate deposition in an agitated shoaling environment. This environment also contributed siliciclastic grains either through reworking of the underlying Cabaniss sediments or by the contemporaneous influx of terrestrial sediments. The sandy skeletal calcarenite facies was probably deposited along a strandline between the more open shelf carbonate and more terrestrial siliciclastic environments.

The preservation of relict structure by silica in a few unstable mollusk grains suggests early silicification, probably during the initial regression of marine water, before leaching by meteoric water. Nonferroan dolomite rhombs may also have formed during this time. Isopachous rims of scalenohedral and blocky nonferroan calcite on loosely packed detrital grains suggests early cementation as the meteoric phreatic zone passed through the marine sediment during regression. Preservation of relict internal skeletal structures, along with micritic rims on unstable skeletal grains whose inner boundaries are gradational into cloudy nonferroan calcite spar suggest neomorphism in stagnant, saturated meteoric phreatic water. The leaching of other unstable skeletal grains, of early calcite cements, and the formation of solution vugs and fractures with crumbly sides suggests the passage of undersaturated meteoric water through partially lithified sediment. Root casts suggest that the sediment may have been situated above the meteoric water-table for a time. This facies contains fewer root casts and none of the rhizopatches found in the silty skeletal calcilutite and barren silty calcilutite facies below it. The sandy skeletal calcarenite facies was probably initially more permeable than the other finer grained facies. This greater initial permeability was more conducive to the circulation of early cement-forming meteoric phreatic water, which could have effectively cemented the sediments and probably have lessened the potential effects of the later-forming roots (see section on rhizoliths). Final ferroan and silica cements filled remaining voids within reducing meteoric phreatic or deeper-burial connate environments.

Summary

The sandy skeletal calcarenite facies reflects a shallow, agitated, shoal-water environment, which culminated

Breezy Hill deposition during regression of marine water from the shelf in southeastern Kansas. During initial regression, the sediments first passed through the mixing zone. Final withdrawal of marine water resulted in meteoric cementation and leaching and the development of a rooted-horizon. Ferroan cements may have begun to develop in oxygen-poor water of the meteoric phreatic zone and probably, together with silicification, continued into the deeper-burial connate zone.

Silty Skeletal Calcilutite Facies

Description

The silty skeletal calcilutite facies of the Breezy Hill Limestone, observed only in Kansas (Fig. 9), is gradational with the overlying sandy skeletal calcarenite and underlying barren silty calcilutite facies. It may also interfinger with the skeletal calcilutite facies that constitutes much of the Breezy Hill interval in Oklahoma, although this relationship has not been clearly documented.

The silty skeletal calcilutite facies is dominated by a silty to sandy skeletal wackestone grading upward into a skeletal packstone. Non-carbonate grains show the same mineralogical types and characteristics as the underlying barren silty calcilutite facies except for a gradual increase upward in grain size and rounding. Skeletal grains include a diverse marine biota of echinoderm, brachiopod, foraminifer, mollusk, ostracode, bryozoan, coral, and dasyclad green algal fragments that become more rounded, encrusted with foraminifers, and micritized upward. Substantial numbers of peloids occur in this facies close to the Kansas-Oklahoma border (Section PMC).

Detrital grains are supported by a matrix of nonferroan calcite and less abundant ferroan calcite and dolomite microspar and spar. Rhizopatches, rhizosheaths, and root casts are still present in this facies but appear to become less abundant or less distinct upward. Solution vugs and fractures are common and are often filled with partially cemented fragments of the overlying sandy skeletal calcarenite facies.

Depositional and Diagenetic Interpretations

Two mechanisms appear to be responsible for this facies. The first mechanism is depositional. The turbid water responsible for the Cabaniss Formation was replaced for a time by clearer water dominated by carbonate deposition. Water agitation gradually increased, winnowing away finer grained sediment, rounding larger grains, and eventually resulting in the deposition of the overlying sandy skeletal calcarenite facies.

The second mechanism is diagenetic. Roots that passed through the marine facies of the Breezy Hill and into the top of the Cabaniss Formation were responsible for the development of meteoric carbonate material (rhizoliths), which reduced packing by pushing detrital grains apart. These effects appear to have increased downward through the marine Breezy Hill interval and reached a maximum in the top of the Cabaniss Formation (see section on rhizoliths for detailed explanation of this mechanism).

Both the depositional and diagenetic environments had the potential for introducing carbonate material among detrital grains in this facies. Carbon and oxygen isotope studies might clarify the relative importance of marine detrital and meteoric diagenetic muds.

Summary

The silty skeletal calcilutite facies of the Breezy Hill Limestone represents a depositional transition from the deltaic and fluvial sedimentation of the Cabaniss Formation to marine carbonate production, in clearer water, followed by an increase in agitation, with deposition of the overlying sandy skeletal calcarenite facies. It also represents a diagenetic transition that reflects the increasing effects of a rooted-horizon downward through the Breezy Hill Limestone into the top of the Cabaniss Formation.

Skeletal Calcilutite Facies

Description

The skeletal calcilutite facies dominates the Breezy Hill Limestone interval south of the Kansas-Oklahoma border, attaining a maximum thickness on outcrop of around 3 m. At the southernmost section of the Breezy Hill studied, south of Tulsa, Oklahoma (Section LEO), it interfingers with the basal portion of the overlying sandy skeletal calcarenite and the oolitic calcarenite facies. It continues into the subsurface of west-central Oklahoma where the Breezy Hill Limestone consists of a thin, argillaceous, phylloid algal calcilutite with silicified, well preserved algal blades (Michlik, 1981).

Although it is predominantly a bedded skeletal wackestone, subordinate amounts of skeletal packstones and mudstones occur at the base and top of the facies. Where the base of the Breezy Hill was examined in Oklahoma (Section BC), it consists of a skeletal packstone with skeletal grains aligned parallel to bedding, grading upward into a skeletal wackestone and containing a rather diverse marine fauna of brachiopod, foraminifer, bryozoan, encrusting bryozoan, echinoderm, trilobite, and phosphatic skeletal fragments. Skeletal grains are typically broken but unabraded with only minor micritization of their rims. At this same locality, the top of the Breezy Hill Limestone, directly below the Excello Shale, is a single massive bed (0.38 m thick) of loosely packed packstone containing whole mollusk and brachiopod shells with spines merely broken or still in place, grading downward into a mudstone. This upper bed is separated from the lower Breezy Hill by a gray claystone to a black platy shale, less than 20 cm thick and containing a fauna of brachiopods, foraminifers, bryozoans, and ostracodes. A massive bed that appears to be a mirror image of the overlying carbonate bed occurs below the claystone and shale. Farther north (Section MON), the top of the Breezy Hill grades from a skeletal, bioturbated wackestone upward through a darker gray unabraded skeletal packstone directly into the overlying Excello black shale facies. This packstone is tightly compacted; some grains appear corroded and have grain-to-grain sutured contacts from pressure solution (Fig. 17a). The matrix is rich in organic material, iron oxides, clays, and silt-sized ferroan dolomite rhombs. The fauna consists of brachiopod, bryozoan, and phosphatic skeletal fragments, which are broken but display little abrasion and only minor micritization of their rims.

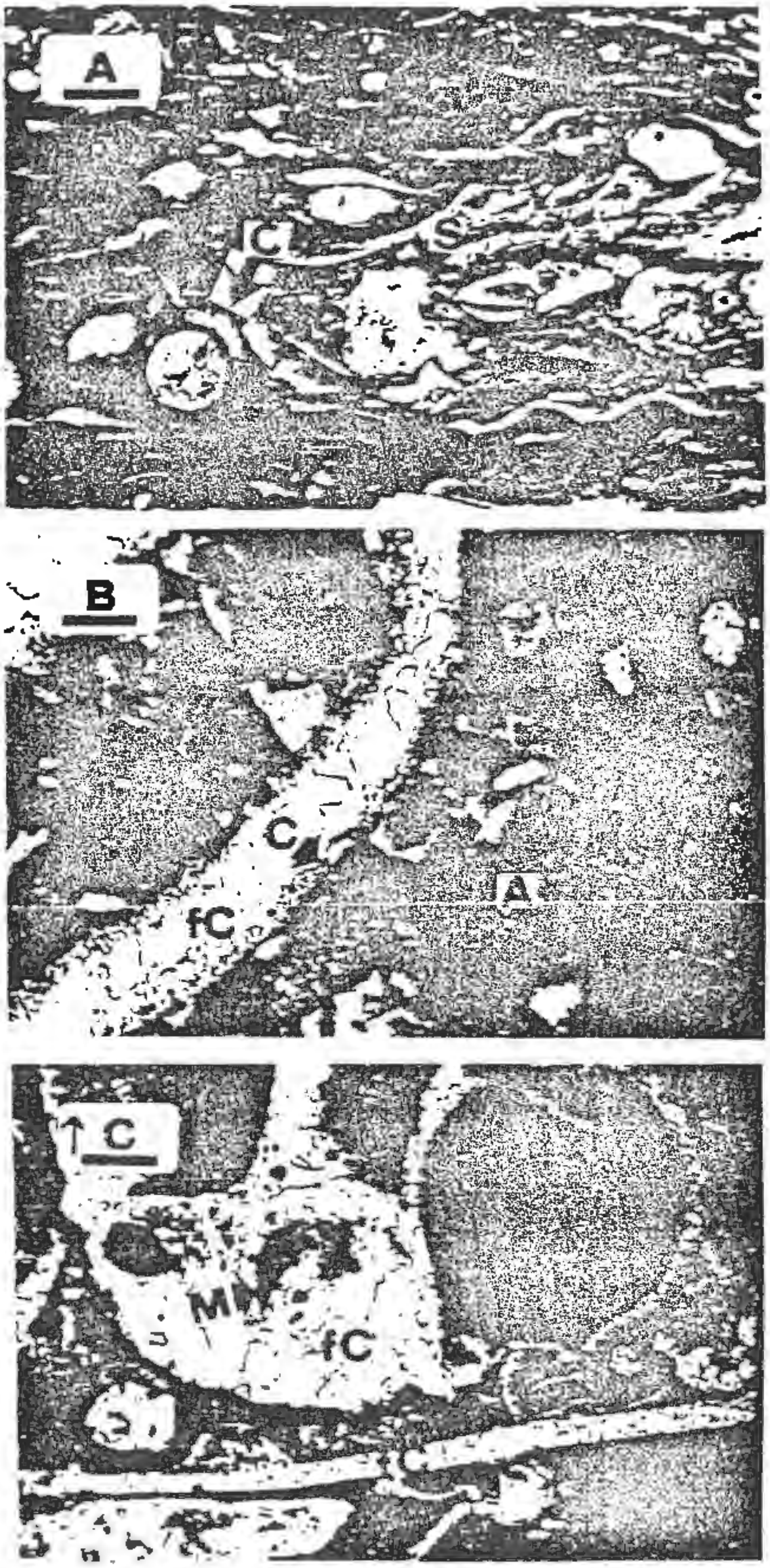
Middle portions of the facies, in addition to the fauna already noted, contain abundant sponge spicules, and phylloid algal blades including _Archaeolithophyllum_ sp. and _Anchicodium_ sp..

Figure 17. Skeletal calcilutite facies of Breezy Hill Limestone.

a) Overcompacted packstone transitional between underlying skeletal wackestones of Breezy Hill Limestone and overlying black shale facies of Excello Shale in Oklahoma. Grain-edges are corroded (C) and have sutured grain-to-grain contacts (S). Probably represents "transgressive" limestone member of Lower Fort Scott cyclothem in Oklahoma (Plane-polarized light; MON T; Scale bar = 0.5 mm).

b) Thallus of phylloid alga Archaeolithophyllum well preserved by nonferroan calcite (A) suggests neomorphism. Less well-preserved codiacean algal blade with blade-edge composed of cloudy irregular-sided nonferroan calcite (C) and center filled with clear blocky ferroan calcite (fC) suggests neomorphism of blade-edge and dissolution of blade-center before void-filling (Plane-polarized light; MON1D; Scale bar= 0.5 mm).

c) Mollusks, including gastropod, are filled by clear, blocky ferroan calcite spar (fC) and partially collapsed ceiling material or internal mud (M) (Plane-polarized light; BC T; Scale bar = 0.5 mm).


A
C
S
B
C
fC
A
↑C
M
fC

Rare, rounded, skeletal grain-rich intraclasts occur about 0.9 m from the top of the Breezy Hill at Section MON. One of these is partially coated with a broken rim containing multiple micritic laminations. Peloids, ranging from individual, loosely packed grains to a clotted or grumous texture are found towards the middle of the facies.

The matrix is typically micrite grading into irregular-shaped patches of microspar to spar and contains varying amounts of organics, clays, and silt-sized rhombs and patches of ferroan dolomite spar. The dolomite is most abundant within or close to argillaceous zones.

Unstable skeletal grains show varying degrees of preservation. Many foraminifer grains, probably originally composed of high magnesium calcite micrite have aggraded to microspar. The cellular structure of the hypothallus and the conceptacles along the blade-edges in a few Archaeolithophyllum blades are preserved by irregular-sided cloudy nonferroan calcite microspar to spar (Fig. 17b). Most mollusk fragments (Fig. 17c), sponge spicules, and some phylloid algal blades are filled with large, equant, clear ferroan calcite and ferroan dolomite spar, probably representing void-filling cements. Apparently, no major collapse of grain-rims occurred after the leaching of their interiors though minor collapse of wall-fragments into the void-space was observed (Fig. 17c). Where ferroan calcite and dolomite occur together, ferroan calcite generally precedes ferroan dolomite. Microcrystalline chert occurs as patches, apparently replacing matrix mud and foraminifer skeletons. Chalcedony replaces brachiopods, typically preserving their skeletal structure, and also occurs as an intragranular void-fill.

A typical primary void-filling sequence of cements includes: 1) isopachous rim of nonferroan calcite, 2) ferroan calcite and/or ferroan dolomite, and 3) final fill of blocky silica.

Depositional and Diagenetic Interpretations

The lack of abraded skeletal grains, the presence of interstitial carbonate mud and detrital clays, and the diverse marine fauna, including a variety of phylloid algae, suggests that the skeletal calcilutite facies was mostly deposited in a quiet, open marine environment within the photic zone, which replaced the turbid water responsible for the underlying Senora Formation (Cabaniss Formation in Kansas). The minor occurrence of rounded intraclasts in an otherwise quiet water lithology suggests occasional storm-related events. Continued shallowing resulted in the low diversity, low abundance mudstone to packstone (Section BC) and in the overlying calcarenites, from Oklahoma into Kansas. However, the top of the Breezy Hill at Section MON, consisting of an organic-rich, overcompacted packstone grading into the overlying deep water Excello black shale, resembles a transgressive limestone. In this area the platform bottom may have been sufficiently deep to allow continuous deposition of an open marine Breezy Hill lithology until the next transgression, which at first slowed carbonate mud production or accumulation and began to preserve organic detritus and eventually, with the full development of anoxic water, resulted in the deposition of the Excello black shale facies.

The occurrance of nonferroan calcite as void-filling cements and preserving skeletal structure in unstable grains, while other unstable grains are leached, suggests the presence of both saturated and undersaturated meteoric water within the sediments of the Breezy Hill Limestone in Oklahoma after deposition. No direct depositional or erosional evidence exists along the outcrop in Oklahoma, south of Section WCT, to confirm the presence of a non-marine environment in Oklahoma at the end of marine Breezy Hill deposition and before the transgression that deposited the deep-water Excello Shale. However, with sufficient hydraulic head it is possible for meteoric water within a confined aquifer to travel a substantial distance below the marine environment. This could produce meteoric or at least mixing zone cementation and perhaps also dissolve unstable skeletal grains. Final void-filling with ferroan calcite, ferroan dolomite, and silica probably occurred in the deeper-burial connate zone.

Summary

The skeletal calcilutite facies of the Breezy Hill Limestone was principally deposited in quiet, open marine water transgressing over the delta platform of the Senora Formation in Oklahoma. Subsequent regression was sufficient for an area of shoaling-water to develop in Tulsa County, Oklahoma, while farther north (Section MON), where the sea floor may have been slightly deeper, shallowing of the sea was not noticeably reflected in the deposited sediments. The subsequent transgression, which resulted eventually in the anoxic deep-water conditions responsible for the overlying Excello black shale, was first recorded in the dark gray, organic-rich, skeletal packstone at the top of the Breezy Hill Limestone in northeastern Oklahoma (Section MON).

Diagenetic evidence from the skeletal calcilutite facies, including nonferroan calcite cements and leaching of unstable grains north of Tulsa, Oklahoma, suggests the influence of meteoric water, although no direct depositional or erosional evidence for subaerial exposure is evident along the outcrop in this vicinity. Final ferroan void-filling cements and silica suggest the later effects of the deeper-burial connate zone.

Oolitic Calcarenite

Description

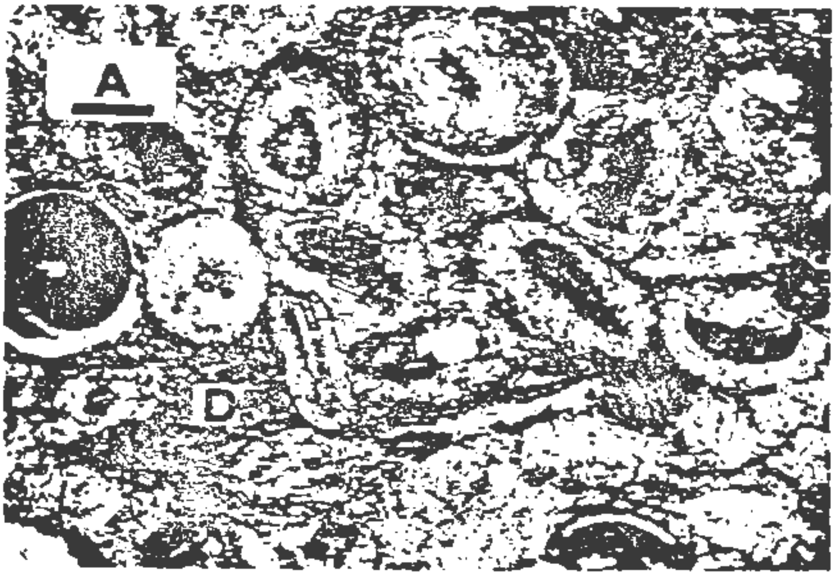
The oolitic calcarenite facies of the Breezy Hill Limestone is recognized from only one locality (Section LEO), near Leonard, south of Tulsa, Oklahoma. Here the oolitic calcarenite constitutes the upper meter of a 1.8 m thick Breezy Hill Limestone sequence. A crumbly, argillaceous, fossiliferous reentrant (less than 2 cm thick) separates it from the underlying interbedded sandy skeletal calcarenite and skeletal calcilutite facies.

The oolitic calcarenite facies is cross-bedded and grades upward from an oolitic packstone into an overcompacted oolitic grainstone containing compressed ooids with welded to stylolitized grain contacts (Fig. 18a). Ooids have nuclei composed of skeletal fragments and probable peloids. The cortex of these ooids is well preserved; cloudy, irregular-sided crystals of ferroan calcite cut across relic concentric layering (Fig. 18a). Abraded, non-micritized echinoderm, brachiopod, fusulinid, bryozoan, foraminifer, bivalve, gastropod, ostracode, and phosphatic skeletal fragments constitute from 1-2%, while quartz silt constitutes less than 1% of the remaining grains.

Figure 18. Oolitic calcarenite facies of Breezy Hill Limestone.

a) Overcompacted oolitic grainstone at top contains compressed ooids with welded to stylolitized grain contacts. Relict concentric laminations of ooids are preserved by blocky ferroan calcite. Intergranular spar is dominantly ferroan calcite but some pores are filled by limonite-stained rhombs of ferroan dolomite (D) (Plane-polarized light; LEO T; Scale bar = 0.25 mm).

b) Preservation of relict structure in mollusk fragment by blocky ferroan calcite (R) (Plane-polarized light; LEO4.5; Scale bar = 0.2 mm).


A
D


B

Early rim cements are absent. Irregular-edged crystals of non-cloudy ferroan calcite microspar to spar are the predominant intergranular cement. Unstable grains, principally mollusks, are broken and bent but not collapsed, and are replaced by blocky ferroan calcite, which occasionally preserves relict skeletal structure (Fig. 18b). Ferroan calcite also fills the micropores of echinoderms. Blocky ferroan dolomite, often with limonite-stained, corroded edges, occasionally acts as a final fill. Individual rhombs (0.02 mm) of ferroan dolomite are found floating within echinoderm grains, between grains, and in some places appear to be spilled between the grains (Fig. 18a).

Depositional and Diagenetic Interpretations

The oolitic calcarenite facies, interbedded with the skeletal calcilutite and sandy skeletal calcarenite facies and capping the Breezy Hill Limestone south of Tulsa, Oklahoma, represents a shallowing of the open marine water in which the skeletal calcilutite facies was deposited below wave-base. This more agitated shoal-water environment lay near the platform-edge, between the Arkoma Basin to the south and the platform to the north.

Their present composition of blocky ferroan calcite spar cutting across relict concentric laminations, suggests that the ooids were originally composed of an unstable minerology, probably aragonite. Overcompaction, the absence of early rim-cements, the preservation of internal relict structure in ooids and mollusks by ferroan calcite, and intergranular cementation by blocky ferroan calcite and ferroan dolomite suggest early passage of the sediment into the deeper-burial connate zone before either early marine or meteoric rim-cements, or meteoric leaching of ooids and mollusks had a chance to occur.

The depositional history of the south end of the Breezy Hill Limestone along the platform-edge is typical of a regressive limestone. However, the diagenetic history suggesting early movement into a deeper-burial environment before nonmarine diagenesis is more typical of a transgressive limestone. Actually, these two apparently contradictory interpretations are not mutually exclusive. They are explained quite well by a regression of the Breezy Hill sea sufficient to deposit a shallow-water marine facies but insufficient to develop marine cements or to expose it to meteoric leaching or cementation before the rapid transgression deposited the overlying impermeable Excello Shale. Consequently, the first significant diagenesis occurred in the deeper-burial connate environment. The Breezy Hill Limestone along the platform-edge incorporates features of both regressive and transgressive limestones and illustrates an important point about the distinction between depositional and diagenetic environments.

Summary

Depositionally the position of the oolitic calcarenite facies resembles that in a regressive limestone. It was formed in shallowing marine water, near the platform-edge, toward the end of Breezy Hill deposition. Diagenetically it resembles a transgressive limestone. The subsequent transgression responsible for the overlying impermeable Excello Shale occurred early enough, while the oolite facies was still in marine water, to preclude marine or meteoric cementation or leaching. Most of the diagenetic activity on the oolitic calcarenite facies thus occurred in the deeper-burial connate environment.

Breezy Hill Depositional and Diagenetic History

The Breezy Hill Limestone represents a minor transgressive-regressive pulse (the Breezy Hill cyclothem) of marine water over a portion of the delta-platform of the Cabaniss Formation (Senora Formation in Oklahoma) in northeastern Oklahoma and southeastern Kansas. The lack of early marine or meteoric cements or other evidence of early subaerial exposure within Cabaniss sediments in Kansas suggests that this transgression occurred before the complete withdrawal of the marine water that was already present over this delta-platform. For a time, the skeletal calcilutite facies was deposited below wave base in Oklahoma. The dominance of silty to sandy skeletal calcilutites and calcarenites along the outcrop of the marine Breezy Hill in Kansas suggests that it represented a principal Breezy Hill strand-line between marine and non-marine environments. Regression of the Breezy Hill sea resulted in the retreat of marine water from southeastern Kansas into Oklahoma, allowing the development of the diagenetic barren silty calcilutite facies in Kansas and Missouri. This facies represents a non-marine caliche and rooted-horizon (rhizolite) within marine Breezy Hill and Cabaniss sediments, preceding the swamps responsible for the overlying Mulky coal. In Oklahoma between the Arkoma Basin to the south and the Cherokee Platform to the north, regression resulted only in shallowing sufficient for the development of shoaling-water skeletal and oolitic calcarenites and restricted-water calcilutites. Farther north in Oklahoma, the platform-floor was apparently deep enough that minor regression had little effect on marine sedimentation. Regression of the sea into northeasternmost Oklahoma allowed a lens of meteoric water to pass through Breezy Hill sediment, resulting in fresh-water diagenesis from Kansas into Oklahoma, just short of Tulsa, but not into the southernmost sediments of the Breezy Hill studied, around Leonard, Oklahoma.

The overlying coal swamp that developed in Kansas may have been responsible for reducing conditions in the meteoric lens, resulting in early ferroan cementation. Other ferroan and silica cements may represent later deeper-burial diagenesis. Evidence within the Breezy Hill for the rapid, widespread transgression that followed includes the overcompacted packstone at the top of the skeletal calcilutite facies in Oklahoma and the passage of the southernmost oolitic Breezy Hill sediments directly into the deeper-burial connate environment without shallow marine or meteoric diagenesis.

Mulky Coal

Definition

The Mulky coal bed was named by Broadhead (1874) for outcrops along Mulky Creek in Lafayette County, Missouri. Searight et al. (1953) defined the Mulky Formation to include all the strata occurring above the Iron Post coal, a coal below the Breezy Hill, and found only in Oklahoma, and below the top of the Mulky coal, which is absent in Oklahoma. Since the Iron Post coal is absent in Kansas, this definition does not apply. As presently defined in Kansas (Zeller, 1968), the Mulky coal is a bed in the Cabaniss Formation and does not include the underclay. It is directly overlain by the Excello Shale. The Mulky coal bed is equivalent to the Summum (No.4) coal of Illinois.

Description and Lateral Variations

The Mulky coal is absent in Oklahoma and the southernmost part of the Kansas outcrop, but it is mined in northeastern Crawford and eastern Bourbon Counties, where the maximum thickness is about 0.5 m. Where the coal is present, the underclay ranges from 0.6 to 1.2 m thick, and persists even where the coal is absent (Howe, 1956). It commonly contains fossil root impressions and other plant material. This study has traced the "Mulky coal zone" as a thin limonitic, poorly cemented, sandy zone with thin stringers of coaly plant material as far south as northern Craig County, Oklahoma (Section WCT). The "Mulky coal zone" in the core in Labette County, Kansas (Section PMC), is represented by a dolomitic laminated sandstone 0.75 m thick above the Breezy Hill Limestone.

The Mulky coal persists across western Missouri, where it ranges from a smut in Bates County over the Schell City-Rich Hill Anticline to a 0.5-m-thick unit in western Henry County over the Ladue-Freeman Anticline (Gentile, 1976). It extends into Iowa, where it ranges from a smut to over 13 cm thick (Ravn _et al_., 1984).

Mulky Coal Depositional History

The Mulky coal represents widespread terrestrial coal-swamp conditions developing after the retreat of the marine water responsible for deposition of the Breezy Hill Limestone. Sediments within the "Mulky coal zone" suggest that processes of subaerial weathering extended as far south as northern Craig County, Oklahoma, at the end of Breezy Hill Limestone deposition. This provides a possible source area for the meteoric water postulated to have affected Breezy Hill sediments further southward toward Tulsa in Oklahoma.

Excello Shale

Definition

Searight _et al_. (1953) defined the Excello Formation in Missouri to include all strata above the Mulky coal and below the Blackjack Creek Limestone of the Fort Scott Formation. A type section was designated by Searight (1955) as the highwall of an abandoned strip mine about 1.2 km west of Excello, Macon County, Missouri. In Oklahoma where the Mulky coal is absent, the lower boundary is the top of the marine Breezy Hill Limestone. This study includes the Excello Shale as the basal member of the Dry Branch Creek Formation at the base of the Marmaton Group.

Description and Lateral Variations

Three lithologic facies are recognized within the Excello Shale: 1) a very thin basal layer of pyritized skeletal material, 2) a thick middle zone of black, flakey to fissile shale containing abundant phosphatic nodules, and 3) a thin upper zone of dark to light gray fossiliferous shale to gray-blue to green to yellow claystone.

The basal layer generally consists of less than 10 cm of discontinuous silty shale dominated by pyritized brachiopods and bivalves. The least persistent of the three facies, it has been identified sporadically in Oklahoma (Cassidy, 1962), Kansas (Fort Scott type section), Missouri (Gentile, 1965; James, 1970), and in Iowa, where it occurs as a dark gray, slightly silty shale containing minor carbonaceous plant debris (Swade, 1982). This thin marine zone positioned above and transitional with the Breezy Hill in Oklahoma and in sharp contact with the underlying Mulky coal north of Oklahoma, was probably deposited during a period of rapid transgression and corresponds to the transgressive marine limestones better developed in younger Pennsylvanian cyclothems.

The thick middle zone consists of a black, fissile to flakey shale, which commonly is vertically jointed and weathers into rectangular blocks. It contains abundant, small (0.5 to 5 cm in diameter), rounded to flattened gray phosphatic nodules, which frequently nucleate around orbiculoid brachiopods and phosphatic skeletal material and weather from the shale, littering the outcrop. Occasional large (up to 0.6 m), dark gray, pyritized, calcitic concretions are also found in this facies. Its biota is generally restricted, but in addition to high abundances of conodonts (including _Gondolella_), it may include cephalopods, fish spines and scales, and phosphatic inarticulate brachiopods.

The black fissile shale grades upward into a thin (averaging less than 15 cm) upper facies of dark to light gray, bioturbated, fossiliferous shale, which contains occasional thin fossiliferous limestone nodules. Portions of this facies consist of a pliable gray, blue, green to yellow claystone (pliable clay generally lacking bedding).

The Excello Shale is amazingly persistent and is easily traced along the outcrop and in the subsurface from Oklahoma into Iowa and Illinois. Along the east side of the Kansas-Oklahoma Border Trend in northeastern Oklahoma, the Excello Shale, consisting principally of the black shale facies, attains its greatest thickness along outcrop, reaching over 1.6 m in Rogers County (Section CM). Farther south in Tulsa County it has thinned to less than 0.3 m. On the north side of the Kansas-Oklahoma Border Trend in northern Craig County, Oklahoma, and southernmost Labette

County, Kansas, the upper third of the black shale facies appears to have graded into a fossiliferous gray shale to gray-blue to yellow claystone. Just north of this area, in south-central Labette County, Kansas, the Excello Shale thins abruptly to 0.6 m (Section TCW) and most of the claystone is lost. Northward, the Excello maintains a thickness of about 0.9 m, dominated by the black shale facies through southeastern Kansas. It does not thin noticably over the Bourbon Arch, but across the border in the vicinity of the Schell City-Rich Hill Anticline in Bates County, Missouri, Gentile (1976, Section G22) reports that it thins to less than 0.3 m and that the black shale facies is lost. However, at Section U, which sits atop the Ladue-Freeman Anticline, the black shale facies is still 0.9 m thick and is overlain by 0.3 m of dark gray shale to green claystone.

Excello Shale Depositional History

The thin basal pyritized skeletal lithology of the Excello Shale and portions from the top of the Breezy Hill Limestone in northeastern Oklahoma represent the transgressive (middle) limestone of the Lower Fort Scott cyclothem.

The phosphatic black shale and the overlying gray shale to claystone are the most laterally continuous and extensive of any lithologies studied in the Breezy Hill-Wolverine

Creek interval. In addition, their general lack of coarse-grained terrigenous detritus, their stratigraphic position between two marine lithologies, and an abundant and diverse conodont fauna are typical characteristics of core shales of the "Kansas-cyclothem" model, suggesting that a continued rapid transgression of the sea pushed back the strandline and quickly covered a substantial area of the Midcontinent with deep marine water and anoxic bottom conditions. This resulted in the slow deposition of the black shale facies. The overlying fossiliferous gray shale and claystone facies represents a return to oxygenated bottom conditions and was probably deposited as the sea began to withdraw.

Based on the thickening of the Excello Shale and especially of its black shale facies, the Kansas-Oklahoma Border Trend apparently represented a topographic low that was subjected to a longer period of deep marine deposition under anoxic bottom conditions than was the area on the Cherokee Platform to the north. Based on the presence of a thick algal mound in the Oologah Limestone (upper Labette-Pawnee), Price (1981) identified the area of the Kansas-Oklahoma Border Trend as the "Shelf Edge Rise", a topographic high, during the deposition of the next younger post-Fort Scott (Pawnee) cyclothem. An alternative explanation for the presence of carbonate algal mounds in this area, compatible with its being a topographic low rather than a topographic high, will be laid out in later sections of this study. The thinning of the Excello Shale farther southward in Tulsa County suggests that either a topographic high existed there, perhaps similar to that postulated by Price (1981), or that perhaps this area was sufficiently basinward of siliciclastic sources to have experienced more extreme sediment starvation.

Evidence by Gentile (1976) for thinning of the Excello Shale and loss of its black shale facies over the Schell City-Rich Hill Anticline suggests that it was a topographic high at this time. On the other hand, the lack of thinning over the Bourbon Arch suggests that it did not affect sedimentation in this way in the area of studied exposures relative to the rest of the Cherokee Platform.

Blackjack Creek Limestone

Definition

Cline (1941) named the Blackjack Creek Limestone based on exposures along Blackjack Creek, 2.4 km southeast of Fayetteville, Missouri, without giving an exact type section. His composite section for this area (Cline, 1941, Section II, p.34) includes a basal bed of massive, gray limestone, 0.75 m thick, directly overlying the Excello Shale, which is labeled the "Blackjack Creek Limestone". Overlying this basal limestone and below the Summit coal and underclay, there is an unnamed calcareous, gray shale, 2.25 m thick, capped by 0.3 m of gray nodular limestone. Jeffries (1958) pointed out that these overlying calcareous shales and nodular limestones, which are quite well developed in much of Missouri and Iowa, were included by both Jewett (1941) and Unklesbay (1952) as part of the Blackjack Creek Limestone. Jeffries (1958) proposed including both the basal massive limestone bed and the overlying calcareous beds as part of the Blackjack Creek Limestone. Thus defined, the Blackjack Creek Limestone would include all calcareous beds from the top of the Excello Shale to the base of the underclay of the Summit coal. He designated a type section exposed in the north ditch of a gravel road along the south line of SW1/4, SE1/4, SW1/4, Sec. 14, T.47N., R.25W., Lafayette County, Missouri.

A review of the literature published since that time makes it evident that there is still confusion as to what constitutes the Blackjack Creek Limestone. Howe and Koenig (1961, p.90) in their report on the stratigraphic succession in Missouri, and Neal (1969), in his study on the Blackjack Creek Limestone in Missouri, use Jeffries' definition. The Iowa Geological Survey, on the other hand, restricts the Blackjack Creek to its original definition (Ravn et al., 1984). The overlying calcareous shale as well as the underclay and Summit coal is then part of the predominately nonmarine Morgan School Shale, which they named from Iowa.

In agreement with Cline's original definition and the current usage in Iowa, this study restricts the Blackjack Creek in Missouri and Iowa to the basal limestone bed. The name Morgan School Shale shall here be used to include the overlying calcareous shales, nodular limestones within the calcareous shales, the underclay, and the Summit coal (Fig. 3).

The Blackjack Creek Limestone has been correlated with the Hanover Limestone of Illinois (Hopkins and Simon, 1975).

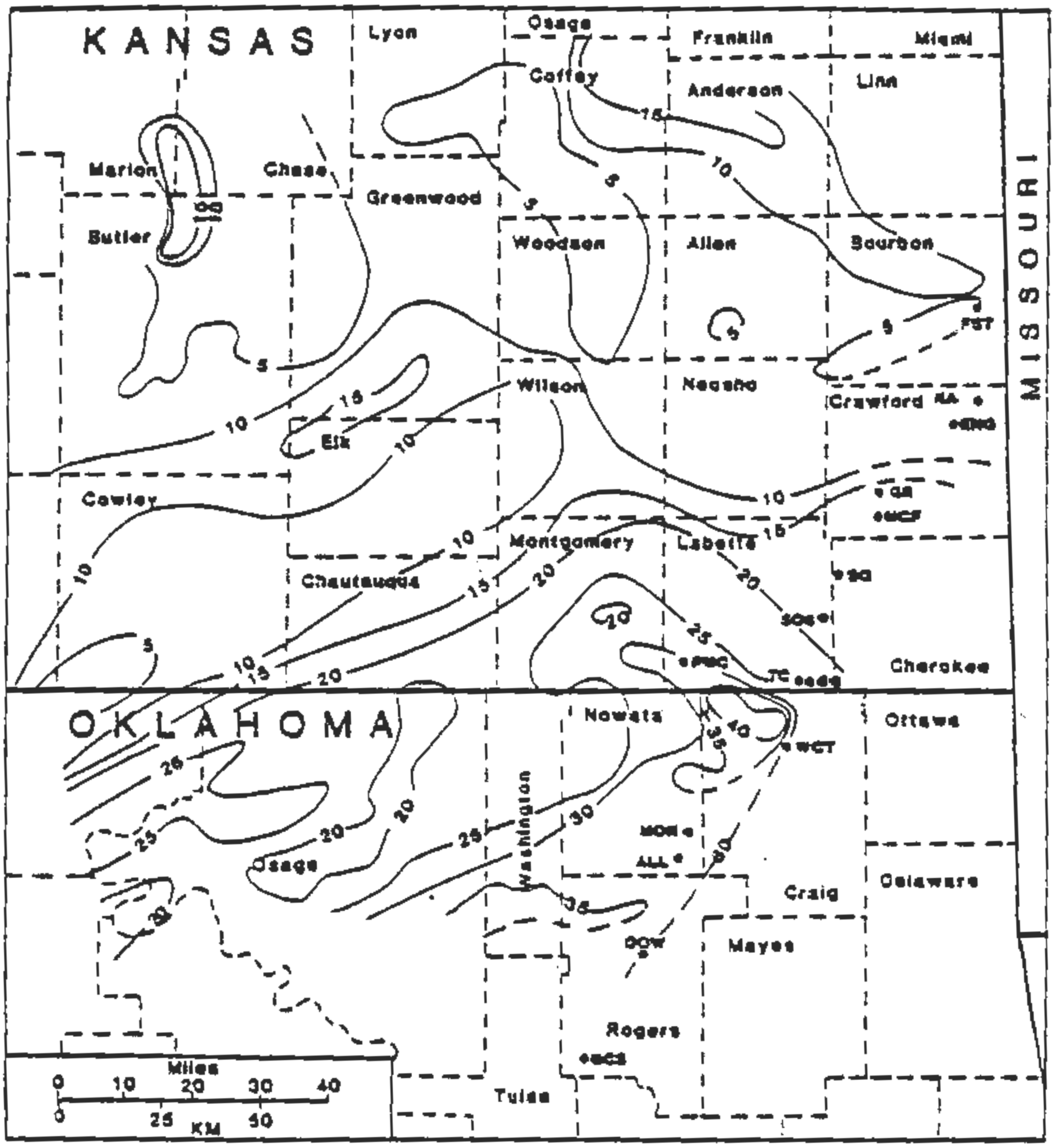
Description and Lateral Variations

Figure 10 represents a cross-section of the Dry Branch Creek Formation, which includes the Blackjack Creek Limestone. Field and laboratory examination of the Blackjack Creek Limestone was restricted for this study to the outcrop-belt exposed from western Henry County, Missouri (Section U), into southern Tulsa County, Oklahoma, plus one core in Labette County, Kansas. Stratigraphic and petrographic observations from this area have been integrated with those of other studies from the remainder of Missouri and Iowa.

From western Missouri into Oklahoma the Blackjack Creek Limestone directly overlies the Excello Shale and is principally a marine skeletal calcilutite ranging from less than 0.3 m to over 12 m thick. Along the northern half of the Kansas-Oklahoma Border Trend it can be divided into lower and upper purer limestone zones by an argillaceous middle zone up to 2 m thick. Through Kansas and into westernmost Missouri the middle zone becomes less distinct but may be represented by several laterally continuous shaly reentrants at exposures in Crawford County, Kansas. The upper zone is capped in some localities by a thin intraclastic, skeletal, peloidal packstone.

Figures 10 and 19 illustrate the thickening of the Blackjack Creek Limestone in both outcrop and subsurface from Bourbon County, Kansas, southward onto the northern flank of the Kansas-Oklahoma Border Trend centered in northwestern Craig County, Oklahoma. Another mound to the north appears centered near the four corners of Osage, Franklin, Coffey, and Anderson Counties, Kansas, on the northern flank of the Bourbon Arch. Well-log signatures (see Appendix B) of this Blackjack Creek Limestone mound suggest that a major contributor to its thickening is an argillaceous middle zone. If stratigraphically correlated with the corresponding outcrop lithologies across the border in Missouri, this argillaceous middle zone and the more calcareous zone above it would be part of the Morgan School Shale. However, since the Morgan School Shale has been defined from outcrop exposures in Missouri, not well-log

Figure 19. Blackjack Creek Limestone isopach map. Contour interval = 5 ft. Based on outcrop and well-log (Appendix B) data.



BLACKJACK CREEK LIMESTONE ISOPACH

signatures, this interval has been plotted as part of the Blackjack Creek Limestone in Figure 19. The Blackjack Creek thins and is less argillaceous along the Bourbon Arch (Fig. 10, Sections NA and FST), forming a "trough" between the argillaceous thickening just to the north and the one farther to the south. Another, more localized thickening of the Blackjack Creek occurs at the corners of Marion, Chase, and Butler Counties, directly on the southern extension of the Nemaha Uplift in Kansas (Fig. 19).

In Missouri, north of the Schell City-Rich Hill Anticline, the Blackjack Creek Limestone thins as the middle and upper zones in Kansas appear to grade into and interfinger with the calcareous shale and the overlying nodular limestone of the thick Morgan School Shale clastic wedge (Fig. 10). Jeffries (1958) reported that the Blackjack Creek Limestone (what he calls the lower Blackjack Creek) has an average thickness of 0.9 m along outcrop in Missouri, with a maximum thickness of slightly over 2.1 m in Vernon County, and a minimum thickness of slightly over 0.3 m in Johnson County.

Neal (1969) noted seven facies of the Blackjack Creek in Missouri. These facies range from mudstones to grainstones, but are dominated by burrowed wackestones (skeletal calcilutite facies of this study) with a diverse marine fauna. He noted that algal-rich calcilutites are developed locally over sites of Mulky coal thickening. Over the Schell City-Rich Hill Anticlinal structure, an oncolitic calcarenite facies developed.

O'Brien (1977) reported a thickness of 1.2 m for the Blackjack Creek in Iowa, which he divided into two units (Section CP37). Unit 1 is 0.9 m of burrowed, skeletal, wackestone grading in places to a skeletal packstone, with a diverse marine fauna. Unit 2, the overlying unit, is a barren brecciated mudstone 0.3 m thick, containing vertical anastomosing clay veins and irregular clay blotches. It is capped by a "clay matrix conglomerate" less than 3 cm thick, containing dark pyritic and carbonate pebbles, some of which are fossiliferous.

The thick, gray, calcareous shales and nodular limestones commonly found in the overlying Morgan School Shale of Iowa are absent in the core studied by O'Brien. It is probable that Unit 2, with its abundance of clay is a lateral facies equivalent of the Morgan School and represents a site where carbonate production was not completely overwhelmed by the clastic influx of the Morgan School.

The Blackjack Creek Limestone examined for this study from western Missouri into Oklahoma is divided into two lithologic facies (Fig. 10): 1) skeletal calcilutite and 2) mixed calcarenite.

Skeletal Calcilutite Facies

Description

The Blackjack Creek Limestone is dominated by the skeletal calcilutite facies from Oklahoma into western Missouri. The skeletal calcilutite facies varies from a skeletal mudstone (grains constitute less than 10% of the rock) to a skeletal wackestone containing minor thin skeletal packstone lenses. Where skeletal packstones constitute a more significant portion of the rock, they have been included as part of the mixed calcarenite facies. Dolostones and crystalline (recrystallized) limestones are included within this facies since the evidence to be presented suggests that they resulted from the diagenetic alteration of skeletal mudstones and wackestones.

Angular skeletal grains with poorly developed micritized rims include a diverse marine fauna of brachiopods, foraminifers, fusulinids, echinoderms, bryozoans, ostracodes, phylloid algae, sponge spicules, auloporid and chaetetid corals, and trilobites. Along the Kansas-Oklahoma Border Trend, the argillaceous middle zone has a slightly lower diversity, containing only sponge spicules, mollusks, foraminifers, fusulinids, echinoderms, and ostracodes. Biotic diversity and abundance also decrease toward the top of the skeletal calcilutite facies in places where it is not capped by the mixed packstone facies. At Section PMC on the north side of the Kansas-Oklahoma Border Trend, multiple coatings of encrusting foraminifers occur on phylloid algal blades to form "osagia" grains.

Phylloid algae are common (except in the basal foot) throughout the bottom third to half of the skeletal calcilutite facies from northern Crawford County, Kansas, into southern Rogers County, Oklahoma. Along the Kansas-Oklahoma Border Trend from central Craig and Nowata Counties southward into southern Rogers County, Oklahoma, they are also common in the upper third of the facies. Generally constituting less than half of the skeletal grains in a sample, they are typically broken into many smaller fragments. Consequently, spar-filled sheltered voids are rare. Using the descriptive terminology employed by Heckel and Cocke (1969) for phylloid algal carbonates, the majority of the algal-rich facies of the Blackjack Creek Limestone is best classified as an "algal calcilutite". Generally, the typical Pennsylvanian algal-mound complex contains an algal facies more dominated by spar-filled sheltered voids.

Other grains include peloids and intraclasts. Peloids may be quite abundant but are usually only distinguishable from the matrix as a grumulose texture in sheltered areas or where differential neomorphism has aggraded the crystal size of the matrix-mud more than that of the peloidal material.

Rounded to angular intraclasts, generally containing a diverse marine fauna, are rare but occur within the skeletal calcilutite facies along the Kansas-Oklahoma Border Trend and at the base of the Blackjack Creek Limestone at Section FST in Bourbon County, Kansas.

The matrix of the skeletal calcilutite facies is predominantly a nonferroan calcite microspar to spar with subordinate amounts of micrite, ferroan calcite microspar and spar, clays, ferroan dolomite, and silica. Disseminated and discontinuous wisps of clays (less than about 0.5 mm thick) occur in a thin basal argillaceous zone in contact with the underlying Excello Shale and more rarely as a thin zone at the top, in contact with the overlying Morgan School Shale. The argillaceous middle zone, best developed along the Kansas-Oklahoma Border Trend, contains disseminated clays and thin (several centimeters thick) clay- and fusulinid-rich seams. Thin clay- and fusulinid-rich seams also occur scattered throughout the skeletal calcilutite facies.

These argillaceous zones are often highly dolomitized with silt-sized rhombs and minor patches of blocky ferroan dolomite representing up to 90% of the carbonate matrix and often filling intragranular pores. Edges of skeletal grains and syntaxial overgrowths on echinoderm grains found within the more highly dolomitized matrices are usually ragged and embayed, suggesting their dissolution or replacement by ferroan dolomite.

These highly dolomitized zones are often weathered orange or yellow along the outcrop belt and contain a matrix rich in iron oxides (predominantly limonite) and silt-sized rhombs that stain pink with alizarin red and dissolve easily in dilute hydrochloric acid, suggesting that nonferroan calcite has replaced ferroan dolomite and in the process released iron to be oxidized (Fig. 20a). The contact between the pseudomorphosed ferroan dolomite zones and zones with unaltered ferroan dolomite is gradational; fresh surfaces taken several centimeters into the rock are not stained, suggesting that pseudomorphism of ferroan dolomite was governed by exposure of the outcrop to modern weathering processes.

Silicification of the matrix occurs predominantly in the highly dolomitized zones as disseminated euhedral quartz and microcrystalline silica. However, extreme silicification of the matrix in the forms of microcrystalline chert, chalcedony, and blocky silica occurred locally in the algal-rich facies along the Kansas-Oklahoma Border Trend.

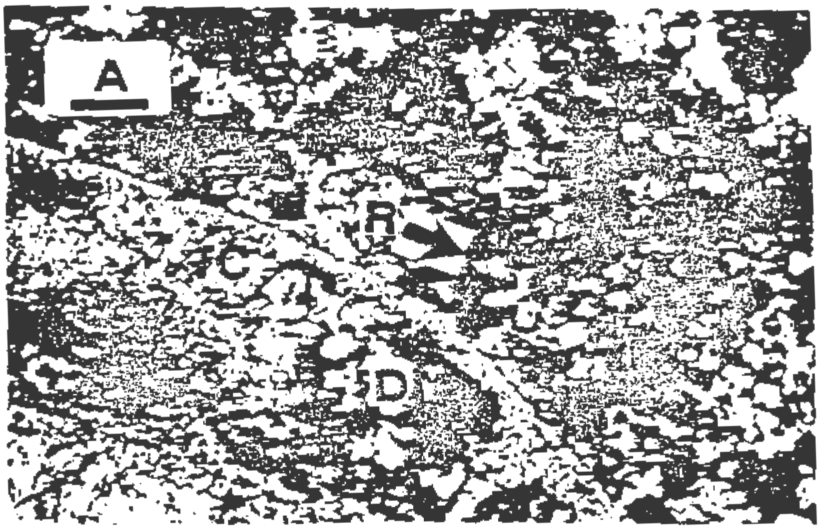
The skeletal calcilutite facies occupies the entire Blackjack Creek interval along the Bourbon Arch (Section FST). Here it consists of a unique variation that includes

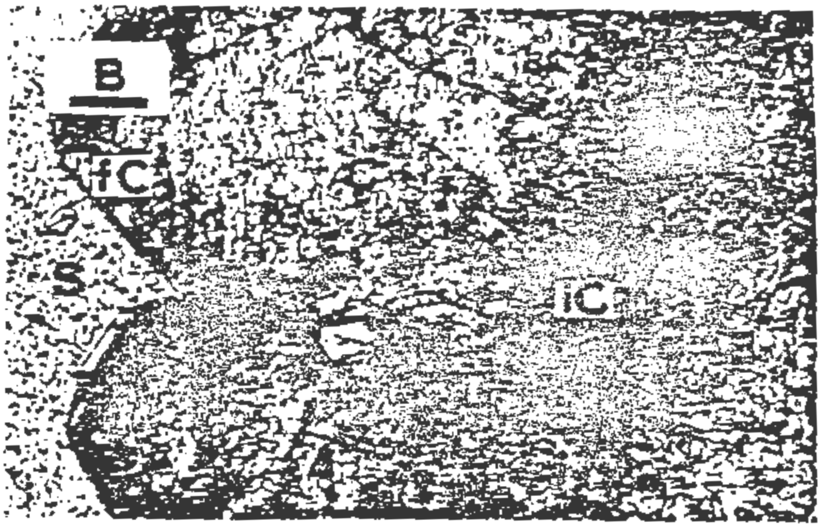
Figure 20. Skeletal calcilutite facies of Blackjack Creek Limestone.

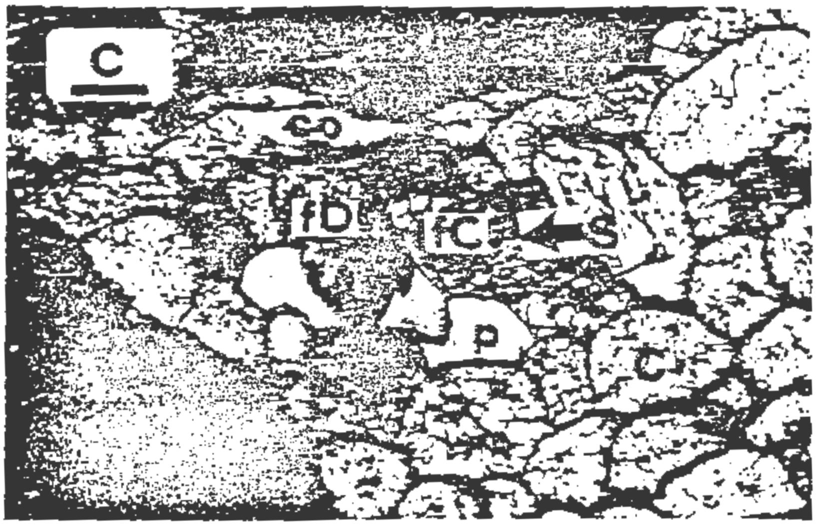
a) Upper Blackjack Creek Limestone close to overlying Little Osage Shale. Intragranular porosity of fusulinid is filled with blocky ferroan calcite (fC) and ferroan dolomite (fD). Matrix contains abundant rhombs (R), which stain pink and are coated by limonite suggesting that they are calcite pseudomorphs after ferroan dolomite (Plane-polarized light; MB1.5D; Scale bar = 0.05 mm).

b) Brachiopod shell (B) with geopetal fill (not visible in photograph) has void-filling cement sequence that includes initial inclusion-rich rim of nonferroan calcite (iC), which grades in optical continuity into clear nonferroan calcite (C) and finally into ferroan calcite (fC). Final fill is blocky megaquartz (S) (Plane-polarized light; OCW9U; Scale bar = 0.05 mm).

c) Bryozoan with various intragranular void-filling cements including initial thin scalenohedral rim of nonferroan calcite (S) and final fill of ferroan calcite (fC); also drusy fill of nonferroan calcite (C); fill of ferroan dolomite (fD) with corroded wall of zooecia (co); and probable plucked cements (p) (Plane-polarized light; PMC371; Scale bar = 0.2 mm).


A
R
C
D


B
fC
S
iC


C
co
fD
fC
S
p
C

a skeletal packstone at the base with abundant glauconite occurring as irregular to rounded peloids and intragranular pore-fillings. While silt-sized angular quartz grains (about 1%) occupy the lower half, a low-diversity mudstone containing abundant root casts that decrease in abundance downward is found at the top. Root casts are also found to the south (Section SOS).

Along much of the outcrop, originally unstable skeletal grains including mollusks, sponge spicules, and phylloid algal blades are replaced by structureless, clear, blocky nonferroan and ferroan calcite spar enclosing occasional collapsed micritic envelopes. The only preserved internal structure occurs in the mud-filled utricles along the edges of a few codiacean phylloid-algae and the thallus of an occasional *Archaeolithophyllum*. A few encrusting foraminifers from Section OOW are also recrystallized to blocky nonferroan calcite.

Spar cements occur as intragranular, sheltered, and fracture void-fill; as syntaxial overgrowths on echinoderm and occasional brachiopod fragments; and as void-fill of dissolved unstable grains. The void-filling paragenetic sequence of original intragranular and sheltered porosity commonly includes: 1) an initial isopachous rim of inclusion-rich, grading into inclusion-free, bladed nonferroan calcite (Fig. 20b), 2) a scalenohedral to blocky nonferroan calcite, often displaying a zoned transition into ferroan calcite, 3) blocky ferroan calcite and dolomite (Fig. 20c), and 4) blocky silica (Fig. 20b). The zoned transitions from nonferroan into ferroan calcite occur within single, optically continuous crystals as sharp euhedral boundaries between pink-stained (iron-poor) spar and more purple-stained (iron-rich) spar. Fractures and porosity created by dissolution of unstable grains invariably lack the inclusion-rich initial rim.

Evidence from the base of the skeletal calcilutite facies at Section PMC suggests that ferroan calcite and ferroan dolomite may be concurrently precipitating cements, with the dolomite preferentially precipitating closer to the clay-rich sediments. Here the base is in contact with the Excello Shale and the basal few centimeters grade upward from an argillaceous into a purer carbonate. Over this same interval, ferroan dolomite rhombs decrease in the matrix while void-filling spar in algal blades grades from predominately ferroan dolomite to ferroan calcite.

Depositional and Diagenetic Interpretations

The lack of abraded skeletal grains, the presence of interstitial carbonate mud and detrital clays, and the diverse marine fauna including phylloid algae suggest that the skeletal calcilutite facies was deposited in an open marine environment, below effective wave base but within the photic zone. The thin argillaceous basal zone represents a transition from the offshore deeper water responsible for the underlying Excello Shale into a more shallow-water carbonate-producing environment. The argillaceous, lower-diversity middle zone in Kansas and Oklahoma suggests that a widespread influx of clays effectively halted algal production during the middle of Blackjack Creek deposition in this area (see Morgan School Shale for further discussion of this zone). Although detrital influx appears to have decreased during later deposition, algal production never recovered except along the southern part of the Kansas-Oklahoma Border Trend (Fig. 10). The development of a thick sequence of algal-rich skeletal calcilutite along the Kansas-Oklahoma Border Trend suggests that it represented a phylloid algal-mound complex during much of Blackjack Creek deposition.

The thin clay- and fusulinid-rich seams located throughout the skeletal calcilutite facies have several possible explanations. They may represent storm surge events that transported terrestrial clastics offshore into normally clear, carbonate-producing water. They may be the consequence of land-based flooding temporarily increasing the clay content of rivers entering the sea. Or they may represent brief delta-lobe migration events.

The presence of detrital quartz-silt within the Blackjack Creek Limestone along the Bourbon Arch suggests that it may have been a topographic high with slightly higher energy conditions and proximity to a coarser detrital source. The root casts, concentrated at the top, indicate terrestrial conditions with land plant growth at the conclusion of Blackjack Creek deposition from Bourbon County, into southern Labette County, Kansas, possibly associated with deposition of the overlying Summit coal.

The initial inclusion-rich spar cement rims suggest possible original aragonitic or high-magnesium calcite cementation in marine phreatic or vadose water, though the present scalenohedral crystal form indicates calcitization in meteoric water. Leaching of most unstable grains suggests the passage of undersaturated meteoric phreatic/vadose water subsequent to the regression of marine water. Clear scalenohedral to blocky nonferroan calcite cementation and neomorphism of matrix-mud probably began prior to this as the sea retreated, and these processes continued subsequently as saturated meteoric phreatic waters passed back through the sediment.

The distinct zoning of calcite spar from nonferroan to ferroan suggests an episodic transition from oxidizing conditions to progressively more reducing conditions and/or an episodic increase in free iron abundance from chemical processes such as the deep-burial smectite to illite conversion (Mchargue and Price, 1982) and probably occurred during progressively deeper burial. The proximity of abundant late-stage ferroan dolomite and silica cements to clays below, within, and above the skeletal calcilutite facies suggests that deeper burial clay conversions released the necessary magnesium, iron, and silica (McHargue and Price, 1982). The proximity of clays is also important in determining which of the possibly concurrently precipitating cements, ferroan calcite or ferroan dolomite, will actually occur. Calcite pseudomorphs after dolomite were apparently produced late in the diagenetic history during exposure of the lithified sediments to modern subaerial weathering.

Summary

The deeper, anoxic marine water responsible for deposition of the Excello Shale shallowed sufficiently at the beginning of Blackjack Creek deposition to encourage proliferation of carbonate-producing organisms. Abundant phylloid algae developed into a phylloid algal-mound complex along the Kansas-Oklahoma Border Trend. Continued shallowing brought terrigenous detrital sources closer, resulting in clay-rich pulses either through storm and/or landward flood events or the more unlikely brief shifting of delta-lobes. During the middle of Blackjack Creek deposition, a temporary influx of clays effectively overwhelmed production of phylloid algae in Oklahoma and Kansas while replacing carbonate production with the siliciclastics of the Morgan School Shale in Missouri and Iowa. As the influx of clays decreased, a diverse marine fauna recovered, although phylloid algal production resumed only on the southern part of the Kansas-Oklahoma Border Trend. Final withdrawal of the sea resulted in the overlying shallow-water calcarenite facies, and a rooted-horizon along portions of the Kansan outcrop. Diagenetic patterns of the skeletal calcilutite confirms the subsequent passage of saturated and undersaturated meteoric waters through the sediment before late-stage deeper-burial ferroan carbonate and silica spar cementation and subsequent dedolomitization by subaerial weathering.

Mixed Calcarenite Facies

Description

The mixed calcarenite facies forms a generally thin (several centimeters) cap atop the skeletal calcilutite facies from northern Crawford County, Kansas (Section NA) to central Craig County, Oklahoma (Section WCT). South of Craig County, except for Section LEO in southern Tulsa County, the top of the Blackjack Creek Limestone was removed by modern erosion. The mixed calcarenite facies is composed of peloidal, skeletal, and intraclastic packstones and grainstones. Peloids are the most abundant grain type, and where they dominate, skeletal diversity is low. However, lenses or burrows of skeletal packstones and grainstones containing a diverse biota of rounded, moderately sorted, and micritized grains can be found at some localities. Mudstone to skeletal and peloidal wackestone and packstone intraclasts form a minor component at several localities. Much of the intergranular space in this facies is filled by a cloudy, irregular-sided calcite microspar to spar that may be neomorphosed carbonate mud.

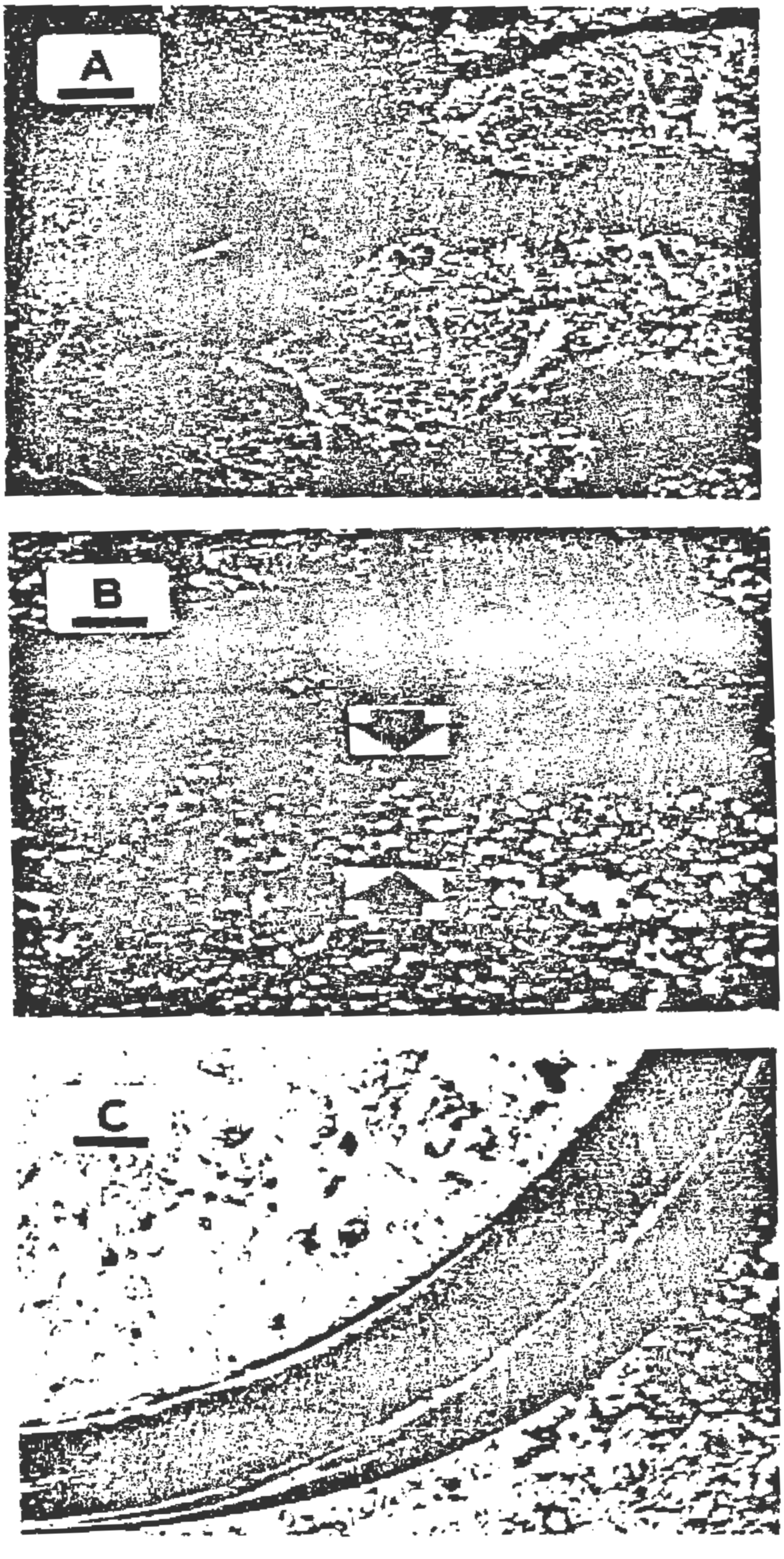
In Core PMC on the north end of the Kansas-Oklahoma Border Trend, the packstone facies has thickened to 3 m. It grades upward through a lithologic succession of skeletal, peloidal, intraclastic, and argillaceous peloidal packstones. The intraclastic packstone includes peloids, skeletal fragments of low diversity, and intraclasts in a matrix of calcite microspar and patches of ferroan dolomite. Intraclasts range in shape upward in the section from irregular and slightly rounded to flat-pebble with their long axes predominately oriented parallel to bedding. They often contain V-shaped cracks (Fig. 21a), are occasionally laminated, and more rarely contain small fenestrae. They are predominately composed of peloids, highly micritized foraminifers, and occasional ooids and ostracodes. Ooids consist of 2-3 concentric coatings and a peloidal nucleus. Peloids within intraclasts, especially

Figure 21. Mixed Calcarenite facies of Blackjack Creek Limestone.

a) Intraclastic packstone near top of Blackjack Creek Limestone on north side of Kansas-Oklahoma Border Trend. Intraclast (I) composed predominantly of highly micritized foraminifers (dark). Several V-shaped cracks (V) filled by blocky nonferroan calcite are visible in intraclasts suggesting subaerial exposure of sediments cohesive enough to be ripped-up, transported, and subsequently cemented by meteoric water (Plane-polarized light; PMC354.5; Scale bar = 1.2 mm).

b) Edge of peloidal packstone intraclast (bottom) in peloidal skeletal wackestone matrix (top). Intraclast edge contains zone with abundant dissolved peloids (white spheres between arrows) suggesting the presence of undersaturated mixing zone or meteoric water. Some peloidal voids are filled with nonferroan and ferroan calcite spar (Plane-polarized light; PMC353; Scale bar = 0.5 mm).

c) Completely silicified peloidal packstone containing well preserved bivalve from top of Blackjack Creek Limestone on northeast side of Kansas-Oklahoma Border Trend suggests early, probable mixing-zone, silicification before meteoric water had the opportunity to dissolve unstable aragonite of bivalve. A less likely possibility, considering the excellent preservation, is early neomorphism in stagnant meteoric water and later silicification in mixing zone or deeper-burial connate water (Plane-polarized light; BQBTc; Scale bar = 0.5 mm).


A
B
C

along their outer edges, are leached more extensively than those in the matrix, which results in secondary porosity of up to 10% (Fig. 21b). Others are replaced by/or leached and filled with nonferroan and blocky ferroan calcite.

Thirty kilometers east of Core PMC the packstone facies is thinner (Section BQ; 11 cm thick). Here it is cross-bedded, includes a basal shell hash and contains rounded quartz sand, skeletal fragments, plant fragments, a few scattered ooids, peloids, and carbonate mud intraclasts. It also drapes a hummocky surface with large dark gray chert nodules atop the skeletal calcilutite facies. The chert nodules are a silicified version of the overlying lithology, containing fractures filled with skeletal debris and preserving relict structure within unstable mollusk grains (Fig. 21c). Microcrystalline silica and chalcedony replacement of matrix and grains is also extensive at other localities.

Depositional and Diagenetic Interpretations

Most modern peloidal packstones are reported as forming in quiet water, subtidal lagoonal or shallow-water platform environments. Where abraded micritized skeletal fragments are present, it is clear that a more agitated, shoal-water subtidal to intertidal environment was also present.

Flat-pebble intraclasts at Section PMC, containing V-shaped cracks, fenestrae, laminations, and a very resticted biota suggest nearby intertidal to supratidal environments that were intermittently dessicated.

It is therefore probable that the skeletal and peloidal packstones with intraclasts deposited towards the end of Blackjack Creek time represent a shallowing of the deeper offshore water responsible for the underlying skeletal calcilutite facies. This shallowing allowed the brief development of a complex of subtidal to intertidal bars, tidal flats, and quiet-water lagoons throughout southeastern Kansas.

The preservation of relict structure in silicified mollusk grains suggests that silicification occurred early during regression, probably in the mixing zone, prior to their leaching by meteoric water. The presence of fractures within the chert nodules filled with skeletal debris certainly suggests very early silicification.

With the sea's continued regression, saturated meteoric water neomorphosed matrix mud to microspar and pseudospar, and filled many voids with blocky nonferroan calcite; while undersaturated meteoric water leached many peloids and the remaining unstable grains that had not been previously silicified. Enhanced leaching of the peloids from the rims of the intraclasts, but not from their interiors or those within the interstitial matrix, suggests a fresh-water influence on these grains, perhaps as the intraclasts were transported in tidal channels, even before final deposition. Subsequent reducing conditions were responsible for late-stage ferroan cements.

Summary

As the sea responsible for the underlying skeletal calcilutite facies continued to retreat, the calcarenite facies was deposited in nearshore subtidal to supratidal environments throughout southeastern Kansas and into northernmost Oklahoma. This shallow-water facies was best developed atop the phylloid algal-mound located along the Kansas-Oklahoma Border Trend. Early mixing zone silicification preceded the substantial neomorphism and leaching of unstable sediments and cementation of pore space that occurred as meteoric water replaced marine water in the sediment. Minor late-stage deeper-burial ferroan cementation also filled remaining pore space.

Blackjack Creek Limestone Depositional and Diagenetic History

The Blackjack Creek Limestone represents the upper (regressive) limestone of the Lower Fort Scott cyclothem, deposited as the deep marine water responsible for deposition of the black phosphatic and gray shale facies of the Excello Shale withdrew from the Midcontinent. Along much of the outcrop from Oklahoma into Iowa it can be divided into three distinct levels. The lower level, generally a skeletal calcilutite deposited in open marine water, below effective wave base, continues through Missouri and into Iowa. The middle level, an argillaceous carbonate zone, deposited as continued shallowing encouraged an increase in argillaceous influx in portions of Oklahoma and Kansas, grades into the siliciclastics of the lower Morgan School in Missouri and Iowa. The upper level, grading from open marine skeletal calcilutites into subtidal to supratidal packstones in Oklahoma and Kansas, is laterally equivalent to the vertical succession of nodular marine limestone, nearshore shale, and coal of the upper Morgan School in Missouri and Iowa.

During regression, widespread but minor marine cementation within the Blackjack Creek Limestone was followed by early silicification within the mixing zone along the Kansas-Oklahoma Border Trend. Final withdrawal of the sea resulted in much cementation and leaching within meteoric water before late-stage deeper-burial ferroan carbonate matrix replacement and void filling and silica void filling.

The Kansas-Oklahoma Border Trend developed a substantially thicker shallowing-upward sequence of carbonates than the Cherokee Platform did to the north, suggesting that it was exposed for a longer period of time to conditions optimum for carbonate production. This thickening in the Blackjack Creek Limestone, along with similar thickenings in the Breezy Hill and Houx-Higginsville Limestones and in the offshore Excello and Little Osage Shales stongly suggest that the Kansas-Oklahoma Border Trend was an area of active subsidence between the Arkoma Basin to the south and the Cherokee Platform to the north. However, a discussion of the full implication of these thickenings will be delayed until the higher units in the Breezy Hill-Wolverine Creek interval have been examined.

The quartz-silt and rooted lithologies along the Bourbon Arch and the shoal-water facies deposited over the Schell City-Rich Hill Anticline suggest that they were topographic highs during deposition of the Blackjack Creek Limestone. This would explain the loss of the argillaceous middle zone and thinning of the Blackjack Creek Limestone over these structures. As topographic highs, they effectively barred the southerly flow of Morgan School clastics into both southeastern Kansas and southwestern Missouri.

Morgan School Shale

Definition

The Iowa Geological Survey (Ravn et al., 1984) has proposed the name Morgan School Shale for the nonmarine to marginal marine clastic unit overlying the Blackjack Creek Limestone and underlying the first recognizable marine unit (Little Osage Shale) marking the base of the Wolverine Creek Formation (Stephens Forest Formation of Iowa Geological Survey, Figure 3). The designated type section is located at the center of the east line of NW1/4, Sec. 18, T.2N., R.2W., Lucas County, Iowa. The name was derived from the former site of Morgan School approximately one mile to the southeast. The Summit Coal is the only named member, and if present, it occurs at the top of the formation.

Description and Lateral Variations

In Iowa the Morgan School is a laterally variable unit, ranging from a thickness of 6 m in Wayne County to less than 0.3 m in Clarke County (Ravn et al., 1984). Usually consisting of a single clastic sequence that coarsens upward from shale to siltstone, it commonly contains nodules of calcilutite in the middle and upper portions and is capped by an underclay-coal or carbonaceous smut, the Summit coal.

Swade (1982) studied the conodont distribution of Core CP22 in northern Appanoose County, Iowa, and found that most of the Morgan School Shale contains a sparse fauna of low diversity (from 80 elements/kg at the base to less than 10 elements/kg of Idiognathodus elements in the overlying shales). But near the top, within both the shale and carbonate nodules, is a zone with an unusual increase in both conodont abundance (over 100 elements/kg) and diversity. This unusual fauna is more typical of the open marine fauna of the underlying Blackjack Creek Limestone. It suggests a brief partial return from the marginal marine, probably deltaic, sedimentation typical in most of the Morgan School, to the more open marine conditions typical of the Blackjack Creek Limestone, before final retreat of the sea and deposition of the Summit coal.

The Morgan School Shale in Missouri is very similar to that in Iowa. Nevertheless, Jeffries (1958) noted that locally the shale-nodular limestone lithology is lacking, with the underclay of the Summit coal resting directly on the lower Blackjack Creek Limestone. The underclay and coal are also absent in some areas. He identified three areas where the Morgan School thickens from less than 1.5 m to over 3 m. Two of the areas are centered in Jackson, Cass, and Johnson Counties, north of the Schell City-Rich Hill and Ladue-Freeman Anticlines. The other is centered just northeast of the Saline County Arch in Chariton and Randolph Counties. Neal (1969) identified these same locations as areas where the nodular limestone becomes more bedded in character, the Mulky coal is thickest, and the algal calcilutite facies of the Blackjack Creek is best developed.

At Section U in Henry County, Missouri, atop the Ladue-Freeman Anticline, the Morgan School is well developed. Here it consists of about 4 m of gray shale containing a fauna of brachiopods and a 0.6 m thick zone of silty limestone nodules about 1.5 m above its base, containing a restricted fauna of brachiopods, ostracodes, and sponge spicules. No underclay or coal is present at this location.

At Section MB in Bates County, Missouri, just south of the Schell City-Rich Hill Anticline, the shale is much thinner (0.6 m) and the Summit coal and underclay are present. Above the Summit coal, about 20 cm of orange to gray claystone is capped by an argillaceous, nodular to thin-bedded brachiopod-rich limestone. This brachiopod-rich limestone corresponds to a nodular limestone located just below the black facies of the Little Osage Shale at Urich and probably should not be considered as part of the Morgan School. Most likely it represents a thin marine, transgressive limestone comparable to the one found locally below the Excello Shale. It will therefore be included as a basal lithology of the Little Osage Shale.

The Summit coal can be traced southward into central Bourbon County, Kansas, and may be represented by the presence of plant debris atop the Blackjack Creek Limestone at Section BQ near the Kansas-Oklahoma border. Throughout most of this area, the Morgan School includes only a thin (less than 0.3 m) blue to light gray claystone with orange, rusty, plate-like partings, a monospecific snail fauna and a sharp contact with the overlying dark gray to black shales of the Little Osage Shale.

Morgan School Shale Depositional History

The depositional sequence of the Blackjack Creek-Morgan School interval in Iowa and Missouri from open marine, to restricted, to slightly less restricted, and finally to restricted and nonmarine lithologies is similar to the sequence previously described for the Blackjack Creek Limestone in Oklahoma. Together with the probable correlation between the shaly zone within the Blackjack Creek Limestone in Oklahoma and Kansas and the lower shaly portion of the Morgan School in Iowa and Missouri, these observations suggest that the regression of the sea responsible for deposition of the lower Blackjack Creek Limestone allowed a very widespread influx of clastics across the Midcontinent in the middle of Blackjack Creek deposition. Subsequently, the clastic influx was slowed or halted, possibly by a period of drier climate or a short resumption of eustatic transgression. This allowed the resumption of algal proliferation within the Blackjack Creek

Limestone in Oklahoma and deposition of the nodular marine limestone facies within the Morgan School Shale in Missouri and Iowa. Nearshore to nonmarine lithologies were deposited at the top of the Morgan School from Iowa to Kansas and at the top of the Blackjack Creek Limestone from Kansas into Oklahoma as the sea finally retreated from the Midcontinent. Jeffries (1958) reached essentially the same conclusion for the Blackjack Creek Limestone-Morgan School Shale interval in Missouri.

The substantial thinning, noted by Jeffries (1958), of one lobe of the Morgan School Shale just north of the Saline County Arch and the other two lobes just north of the Schell City-Rich Hill and Ladue-Freeman Anticlines suggest that these may have been northwest-southeast trending positive structures at that time. As positive structures, they acted as effective barriers to the transportation of the Morgan School clastics onto the Cherokee Platform and protected the area of Blackjack Creek Limestone deposition just to the south in western Missouri and Kansas from significant clastic influx.

Little Osage Shale

Definition

Jewett (1941) applied the name Little Osage Shale to the shales, coal bed, and limestone beds in the interval between the Blackjack Creek Limestone and the Higginsville

Limestone. His designated type section was in the northeast part of the SE1/4, Sec.2, T.24S., R.25E., Bourbon County, Kansas, on the south valley wall of the Little Osage River, but has since been removed by strip mining. As defined, the Little Osage included six distinct nonmarine to marine units: 1) a lowermost gray shale; 2) the Summit coal bed; 3) a thin dark gray shale with fossiliferous limestone nodules; 4) a black, fissile, marine shale; 5) the Houx Limestone (based on his correlation between the Houx Limestone of Missouri and a thin discontinous limestone bed present in Bourbon County, Kansas); and 6) an uppermost gray calcareous shale.

The Iowa Geological Survey (Ravn *et al.*, 1984) restricts the Little Osage Shale to the strata overlying the Morgan School Shale (which contains the Summit coal where present) and underlying the Houx Limestone. This includes only units 3) and 4) of Jewett's original definition.

This study uses the revision proposed by the Iowa Geological Survey with one additional clarification: where the Houx is not a separate bed, it is considered to be present as the base of the overlying Houx-Higginsville Limestone, which had previously been considered to represent only the Higginsville Limestone (see later section).

Description and Lateral Variations

The Little Osage Shale, as defined in this study, includes (in ascending order): 1) a thin rather persistent unit of light to dark gray, fossiliferous marine shale containing interbedded, less persistent, thin, nodular to bedded, fossiliferous calcilutite and with a gradational upper contact, 2) a thicker black, fissile shale containing phosphatic nodules, and 3) an overlying dark to light gray fossiliferous, marine shale to gray-blue to yellow marine claystone.

The basal unit of the Little Osage generally grades upward from a light to dark gray calcareous shale into the overlying black shale. In places, a thin-bedded to nodular fossiliferous calcilutite appears within the shale or occupies the entire basal unit from Crawford County, Kansas, into Iowa, and it appears to be best developed where the underlying Summit coal is present (Fig. 10). Along the Bourbon Arch (Section FST) this unit consists of about 7 cm of dark gray shale containing nodules of an overcompacted, dark gray skeletal packstone. Skeletal grains include brachiopod, encrusting foraminifer, dasyclad algae, mollusk, and phosphatic fragments, which appear to be almost totally replaced by iron oxides. O'Brien (1977) reported a 0.9 m interval in Clarke County, Iowa (CP37), grading upward from a gray silty shale with carbonaceous fragments, broken brachiopods, and mollusks into lenticular interbedded dark gray shale and mostly non-abraded skeletal packstone. Swade

(1982) reported a thinner (15 cm) interval in Appanoose County (Section CP22) that includes calcilutites and calcarenites. This limey horizon corresponds with the transgressive limestone unit, which is generally better developed in the younger Pennsylvanian cyclothems of Kansas.

South of Bourbon County, Kansas, the Summit coal is absent but a claystone, probably equivalent to the underclay of the Summit coal, remains. Here the overlying basal shale unit of the Little Osage is less calcareous, and its contact with the underlying claystone is more arbitrary.

The black fissile shale is the most laterally persistent unit of the Little Osage and is recognized along outcrop from south of Tulsa, Oklahoma into Iowa. Like the Excello Shale, its signature on gamma-neutron well-logs allows it to be easily recognized in the subsurface. In Oklahoma south of southern Nowata and northern Rogers Counties, where the overlying resistent Higginsville Limestone thins and disappears, the less resistent Little Osage Shale is difficult to find exposed, and where present, it is gradational with the overlying Labette Shale.

The black shale of the Little Osage is very similar to the black shale of the Excello, averaging about 1 m. in northeastern Oklahoma and thinning abruptly to around 0.6 m. just north of the northern edge of the Kansas-Oklahoma Border Trend. It is platy or flakey to fissile and contains abundant, small phosphatic nodules. The fauna is restricted to nonbenthic organisms including abundant conodonts (Appendix C). The conodont platform element of Gondolella, which is commonly found in the Excello Shale, has not been clearly identified from the Little Osage Shale (see also Swade, 1982).

Calcareous shale, grading upward from dark to light gray, generally overlies the black shale facies of the Little Osage Shale from Kansas into Iowa. Often, in southeastern Kansas, where the Houx Limestone is undifferentiated, the gray calcareous shale grades upward into a gray-blue, green, orange, or yellow claystone just below the Houx-Higginsville Limestone. The shale and claystone lithology thins southward into the Kansas-Oklahoma Border Trend by an amount equal to the thickening that occurs in the underlying black shale facies (Fig. 11). This change thus maintains the overall thickness of the Little Osage Shale from the Cherokee Platform into the border trend, which suggests that the upper gray shale is the lateral facies equivalent to the upper part of the black shale facies to the south. As the black shale grades into the overlying gray shale and claystone, a diverse benthic fauna of brachiopods, echinoderms, and bryozoans appear, and the abundance of a deep offshore fauna of conodonts actually increases at some localities (see conodont chapter).

Little Osage Shale Depositional History

The basal calcareous shale to fossiliferous calcilutite lithology of the Little Osage Shale is similar to the similarly positioned lithology in the Excello Shale and represents the transgressive limestone of the Upper Fort Scott cyclothem. The continued rapid transgression of this sea covered the Midcontinent as far north as Iowa with deep marine water and resulted in the slow sedimentation of the middle black shale facies on an anoxic bottom. This facies and the overlying fossiliferous gray shale and claystone, which represents the return to an oxygenated but still relatively deep, sediment-starved bottom (based on conodont fauna and abundance), are the core ("offshore") shale of the Upper Fort Scott cyclothem.

The maintenance of the overall thickness and conodont fauna of the Little Osage Shale over both the Cherokee Platform and the Kansas-Oklahoma Border Trend suggests appproximately equal exposure times of both to offshore deep-water sedimentation. However, thickening of its black shale facies along the Kansas-Oklahoma Border Trend suggests that this area experienced anoxic bottom conditions for a longer period of time than did the Cherokee Platform to the north, probably as the result of being topographically lower than the Cherokee Platform. The maintenance of this area as a topographic low relative to the Cherokee Platform, in spite of a thicker accumulation of regressive limestones (Breezy Hill and Blackjack Creek), implies a greater rate of subsidence along the Kansas-Oklahoma Border Trend, just as do similar relations between the Excello Shale and Blackjack Creek Limestone.

Houx-Higginsville Interval

Definitions

Along the outcrop in Oklahoma, Kansas, and westernmost Missouri, the Houx-Higginsville interval includes only the Houx-Higginsville Limestone. However, north of Bates and Henry Counties, Missouri, and into Iowa, it includes three units (in ascending order): 1) Houx Limestone, 2) a shale to sandstone unit, a portion of which is named the Flint Hill Sandstone in Missouri, and 3) the Higginsville Limestone.

The Houx Limestone, which is a distinct limestone unit from western Missouri into Iowa, but undifferentiated along outcrop in Oklahoma and Kansas, was named by Cline (1941). He designated as the type section, but left undescribed, exposures on the Houx ranch, NE1/4, Sec.15, T.46N., R.27W., Johnson County, Missouri. Jeffries (1958) gave as a more specific type section the exposures in the hillside and road ditch north of the private road leading to the farm house in the NE1/4, NE1/4, Sec.15, T.46N., R.27W., Johnson County, Missouri. He pointed out that although the Houx is easily recognized northward from the type area, to the south where it is thin and shaly, and its position is only a short distance below the Higginsville Limestone, it may be confused with other thin unnamed limestones at the base of the Higginsville. He suggested that the Houx and the unnamed limestones may be distinguished by their stratigraphic sequence. The Houx is directly overlain by noncalcareous, gray, platy shales, whereas the higher limestones, where present, are overlain by calcareous, gray, platy shales containing irregular green-gray markings.

Unklesbay (1952) named the Flint Hill Sandstone for a clastic sequence between the Houx and Higginsville Limestones in northern Missouri, dominated by siltstone and sandstone. The type section consists of exposures near the Flint Hill School in the W1/2, SW1/4, Sec.11, T.50N., R.13W., Boone County, Missouri. The upper boundary was not the base of the Higginsville but a well marked contact between thin- to medium-bedded siltstone and sandstone below and poorly bedded shale or clay above. The basal contact of the Flint Hill Sandstone is gradational with the underlying shales above the Houx Limestone.

The name Higginsville Limestone was proposed by Cline (1941) for the upper limestone bed to which the name "Fort Scott Limestone" was first applied by Swallow (1866). He did not designate a specific type section but said it was well exposed east of Higginsville, Lafayette County, Missouri and referred the reader to Hinds (1912, pp.242,243). Jeffries (1958) found no good exposures east of Higginsville so he designated as type section an exposure about 6.6 km southwest of Higginsville in a small drainage ditch just north of a gravel road near the center of the NW1/4, SW1/4, SE1/4, Sec.15, T.49N., R.26W., Lafayette County, Missouri.

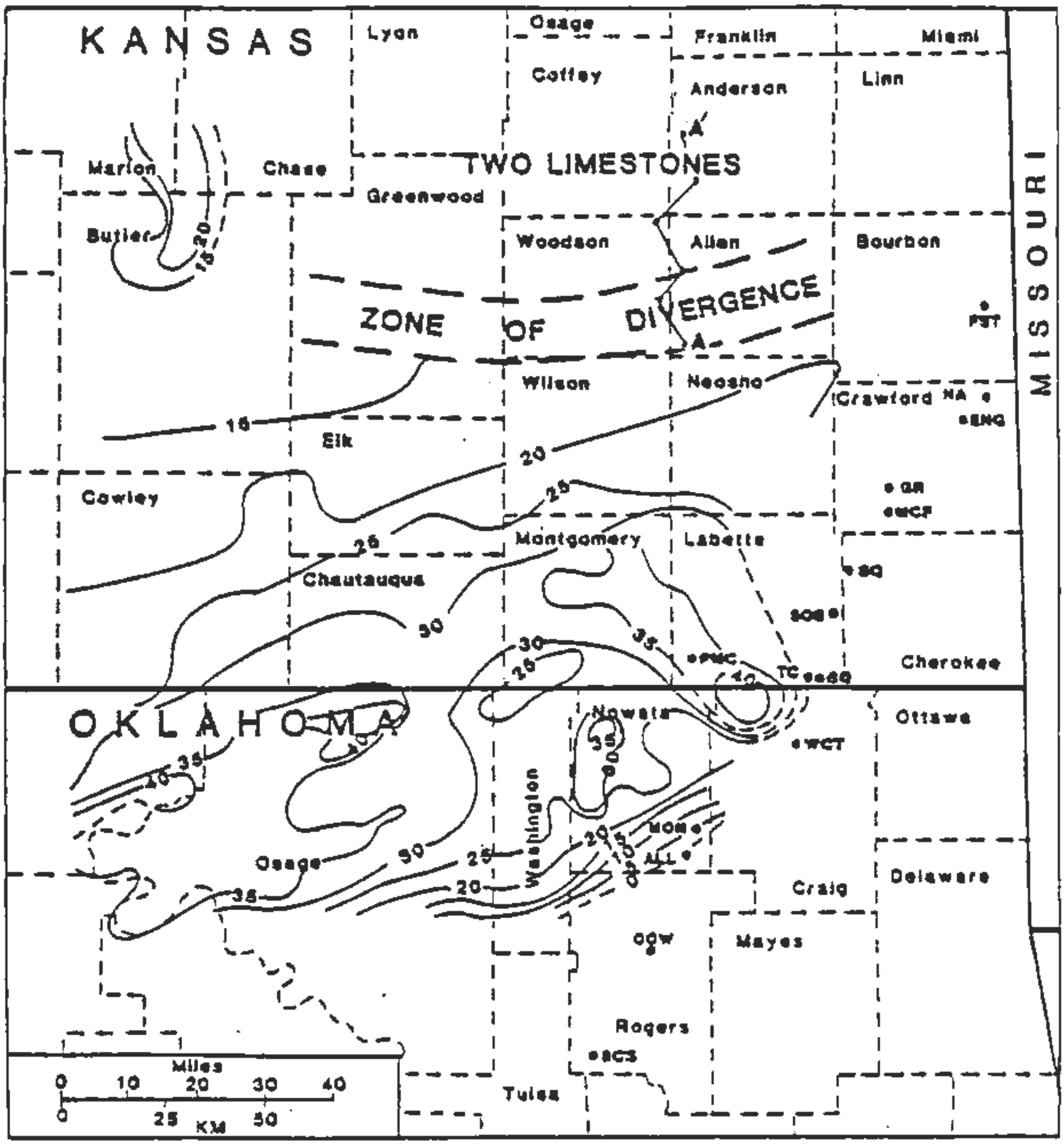
Outcrop and subsurface evidence to be presented in this section suggest that the separate Houx and Higginsville (including the type Higginsville) Limestones and intervening siliciclastic unit present through much of Missouri and Iowa are the lateral facies equivalents of the limestone unit traditionally called "Higginsville" in northeastern Oklahoma, southeastern Kansas, and westernmost Missouri. Consequently, the "Higginsville" Limestone of Oklahoma, Kansas, and westernmost Missouri is not equivalent solely to the type Higginsville Limestone in Missouri, but to the Houx and overlying detrital strata as well. Therefore, the hypenated name "Houx-Higginsville Limestone" is proposed for the single limestone unit that appears between the Little Osage and Labette Shales along outcrop from Oklahoma into westernmost Missouri.

Description and Lateral Variations

Figure 11 presents a cross-section of the Wolverine Creek Formation, which includes the Houx-Higginsville interval. This interval along outcrop from Oklahoma northward into southern Johnson County in western Missouri averages less than 4.5 m thick and contains only the Houx-Higginsville Limestone. Section PMC, a core from southern Labette County, Kansas, was the southernmost complete section of the Houx-Higginsville examined for this study, because of poor exposure of this limestone in the dip slope held up by the thick underlying Blackjack Creek Limestone. In the vicinity of this core, in southeastern Kansas and northeastern Oklahoma, as especially well shown by subsurface well logs, the Higginsville Limestone shows a thickening or mounding along the Kansas-Oklahoma Border Trend, and it thins to nothing over a very short distance on the southeastern flank of the trend (Fig. 22). As a consequence, the Houx-Higginsville is absent along outcrop south of southeastern Nowata County, Oklahoma.

Along the Kansas-Oklahoma Border Trend itself, the Houx-Higginsville and Blackjack Creek Limestones contain several more localized areas of thickening that correspond. The most obvious of these is in the northwestern corner of Craig County, Oklahoma (compare Figures 19 and 22). The Houx-Higginsville also thickens locally at the corners of Marion, Chase, and Butler Counties, Kansas, directly on the southern extension of the Nemaha Uplift, a location where a thickening also is present in the Blackjack Creek Limestone.

Figure 22. Houx-Higginsville Limestone isopach map. Area between heavy dashed lines illustrates zone of divergence where Houx-Higginsville Limestone in the south is split by a siliciclastic wedge into two limestones (Houx and Higginsville) to the north. Line A-A' represents position of stratigraphic cross-section illustrated in Figure 23. Contour interval = 5 ft. Based on outcrop and well-log data (Appendix B).



HOUX-HIGGINSVILLE LIMESTONE ISOPACH

Since the Houx-Higginsville Limestone presents an erosionally resistant bench overlain by up to 66 m of overlying shale, usually less than 2 m of its original thickness is exposed beneath slumped shale along the outcrop in Oklahoma and Kansas. Generally a skeletal to algal calcilutite, it weathers to thin, wavy beds containing algal blades, distinctive large crinoid columnals, and chaetetid heads. The basal beds have usually weathered to a distinct yellow color due to the presence of abundant ferroan dolomite. An extensive chaetetid biohermal facies is developed within the Houx-Higginsville Limestone in southeastern Kansas. Between it and the mounding southward along the Kansas-Oklahoma Border Trend, a low-diversity mudstone to packstone facies developed in the middle of the Houx-Higginsville Limestone (Section PMC). North of central Labette County, Kansas, and into western Missouri, a rather persistent shaly reentrant several centimeters thick occurs less than 0.3 m from the base of the Houx-Higginsville Limestone. It separates the overlying wavy thin-bedded calcilutites from a basal, thin nodular to bedded, dolomitic calcilutite containing brachiopods, encrusting foraminifers, crinoids, ostracodes, and phosphatic skeletal grains. Jewett (1945) thought that this basal calcilutite at the type section of the Fort Scott Limestone in Bourbon County, Kansas, was the Houx Limestone, but Jeffries (1958) believed it to be just an unnamed basal bed of the Higginsville Limestone (Houx-Higginsville Limestone of this study). It has not been possible to trace this basal bed into the Houx Limestone in the vicinity of its type section, so its exact relationship to the Houx remains unclear.

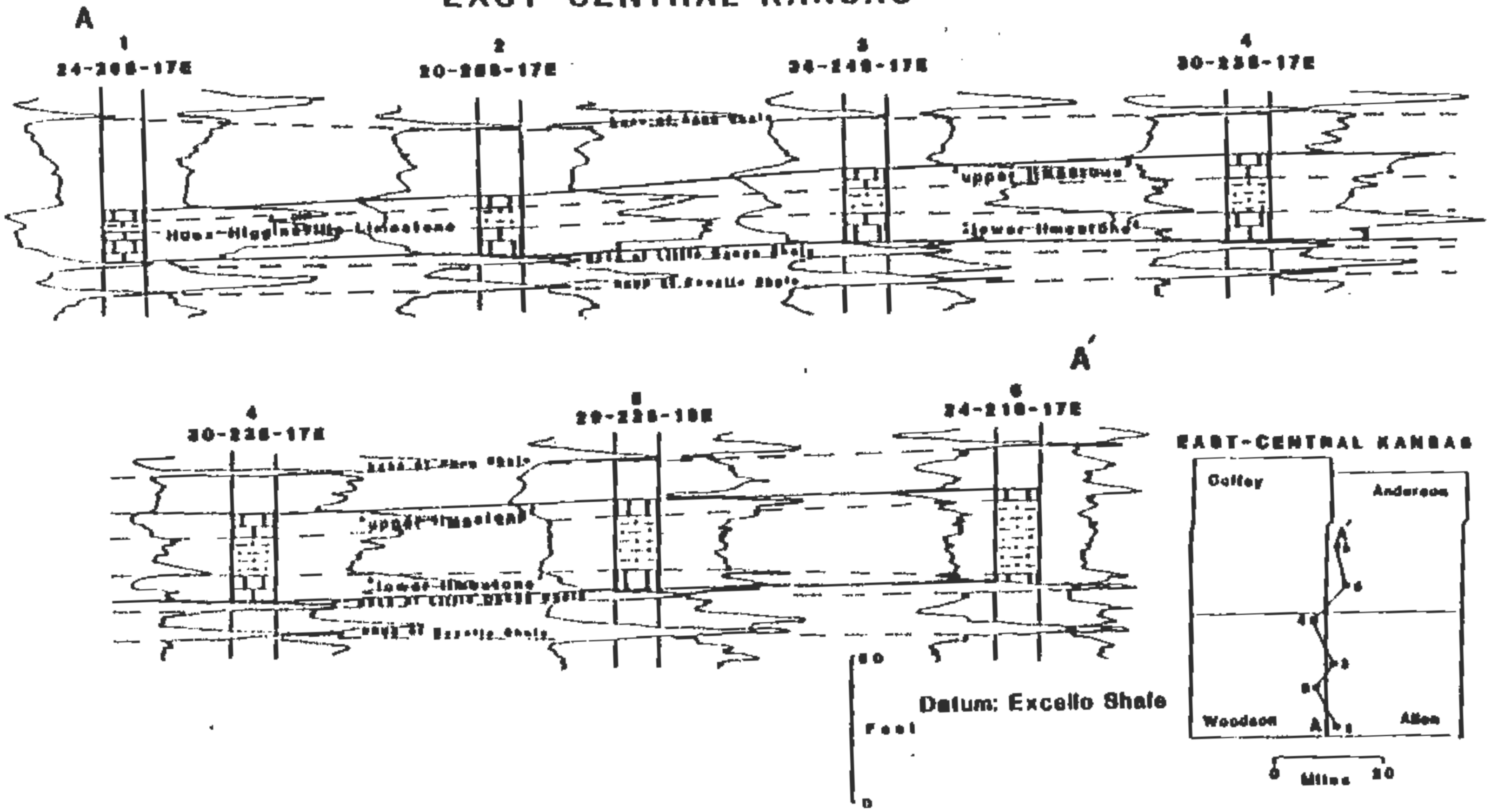
North of Bates and Henry Counties, in central Johnson County, Missouri, the Houx Limestone appears as a distinct thin limestone bed separated from the overlying Higginsville Limestone by a clastic wedge. Absent in Bates and Henry Counties, the clastic wedge thickens northward to over 6 m north of the Ladue-Freeman Anticline in northern Johnson County. As this wedge thickens, the Houx Limestone remains a thin unit at its base, while the Higginsville Limestone climbs and thins over the wedge (from 6 m in Bates County to less than 1.5 m in northern Johnson County). A published cross-section by Wanless _et_ _al_. (1963, fig. 2) shows this wedge splitting the Houx-Higginsville Limestone as presently recognized in southeastern Kansas and westernmost Missouri into the separate Houx and Higginsville Limestones further north.

Well-log data available for this study, from adjacent counties across the border in Kansas, confirm these relationships. Figure 22 is an isopach map for the first limestone unit above the typical gamma-ray signature of the radioactive black Little Osage Shale. This limestone unit can be traced directly to the Houx-Higginsville Limestone along its outcrop from Bourbon County, Kansas, into Oklahoma. North of the Bourbon Arch, northward from southern Allen, Woodson, and Greenwood Counties, it is split into two thin limestone units by a siliciclastic wedge, which progressively thickens to the north. Figure 23 demonstrates the stratigraphic relationship between the Houx-Higginsville Limestone and these two limestones from Allen and Woodson Counties and into Anderson County, in east-central Kansas. What is clearly the Houx-Higginsville Limestone in southern Allen County is split northward, north of the Bourbon Arch, by a thickening clastic unit into "lower" and "upper" limestone units. The "lower limestone" thins northward and is lost on the well-logs.

There is a strong similarity between the stratigraphy of these two limestone units in the subsurface of Kansas and those of the Houx and Higginsville Limestones across the border in Missouri. This similarity suggests that the Houx of Missouri is a lateral equivalent to the "lower limestone" that appears in the subsurface of Allen and Anderson Counties in Kansas. Therefore it is also laterally equivalent to the basal Houx-Higginsville Limestone from Bates and Henry Counties, Missouri, southward into Kansas and Oklahoma. The type Higginsville of Missouri, north of Bates and Henry Counties, would then be the lateral

Figure 23. Subsurface correlation of Houx-Higginsville interval. South of Woodson and Allen Counties in east-central Kansas the well-log signature of the Houx-Higginsville Limestone interval shows a single limestone (lower limestone) above the radioactive Little Osage Shale. Northward this single limestone is split by a clastic wedge into "lower" and "upper" limestones. Figure 22 is an isopach map of the single limestone south of Woodson and Allen Counties and shows the zone of divergence into two limestones north of these counties. This study suggests that where the Houx-Higginsville Limestone has been split into two limestones in east-central Kansas, the "lower" limestone may correlate with the Houx Limestone and the upper limestone may correlate with the Higginsville Limestone in Missouri. This figure also shows the excellent lateral control provided by the Excello and Little Osage Shales (Datum: Excello Shale).

HOUX-HIGGINSVILLE LIMESTONE CORRELATION
EAST-CENTRAL KANSAS



equivalent to the "upper limestone" in the subsurface across the border in Kansas and to the upper part of the Houx-Higginsville Limestone along the outcrop from Bates and Henry Counties in Missouri, southward into Kansas and Oklahoma. The separating clastic wedge, well developed northward from Johnson County, Missouri, would then be the lateral stratigraphic equivalent to some middle portion of the Houx-Higginsville developed southward. This would explain the several thin limestone units developed directly below the Houx-Higginsville in Kansas as an interfingering between carbonate production to the south and clastic influx to the north.

As the Higginsville Limestone thins and rises over the clastic wedge from Johnson County into northern Missouri, it consists of interbedded sublithographic and shaly nodular limestones with osagia grains dominating the upper portions (Jeffries, 1958). Looff (1969) reported a calcarenite facies in the Higginsville in Howard, Randolph, and Boone Counties, Missouri, just north of the Saline County Arch, which contains micritic intraclasts, osagia grains, skeletal fragments, and superficial ooids displaying faint concentric and well-developed radial structure. Through most of Missouri less than a meter separates the top of the Higginsville from an overlying coal.

In Appanoose County, Iowa (Core CP22), the Higginsville Limestone is approximately 1.4 m thick. The lower part is a light brown and green-gray, slightly argillaceous skeletal calcilutite, lenticularly interbedded with green clay partings and becomes more thickly bedded and fossiliferous upward. This grades into the middle part, which is massive, but contains vertically anastomosing clay partings and carbonaceous root impressions. The middle part grades upward into fractured limestone beds and nodules in a matrix of medium green, silty mudstone having a gradational contact with the overlying Labette Shale (Swade, 1982).

Closer to the northeast side of the Forest City Basin in Clarke County, Iowa, O'Brien (1977) reported a 2.7 m thick Higginsville interval dominated by calcareous mudstone, which he divided into two units. The lower unit is 1.2 m thick and grades upward from interbedded fossiliferous, green mudstone and skeletal lime wackestone layers containing whole brachiopods, clams, and large horizontal burrows, into an oncolite-bearing lime wackestone and packstone with a diverse fauna of abraded skeletal grains, and finally into a less fossiliferous, less diverse lime wackestone without oncolites. The upper unit, capping the Higginsville, is generally a barren lime mudstone and calcareous shale containing only rare brachiopods and horizontal burrows with an upper portion containing many vertical anastomosing quartz-bearing clay seams and dark mottling, which grades into rubbly limestone fragments in a clay matrix. Here the overlying Labette Shale consists of a cross-bedded conglomeratic sandstone unconformably resting on the Higginsville Limestone.

The Houx is well developed in north-central Missouri, averaging 0.6 m in thickness and attaining a maximum thickness of 0.9 m in Randolph, Howard, and Boone Counties, where chaetetid colonies are abundant. It also contains fusulinids, brachiopods, crinoids, mollusks, trilobites, and bryozoans (Jeffries, 1958). In Boone, Howard, Macon, Chariton, and Linn Counties, the Houx becomes more shaly and is divided by a dark gray, fossiliferous shaly parting (Jeffries, 1958), which suggests additional interfingering between the clastic wedge and the carbonate producing environment of the Houx.

In Iowa the Houx is generally about 10 cm thick but in Appanoose County it increases to about 0.3 m. It includes light to dark gray fossiliferous shales; burrowed brachiopod-bearing green mudstones; and light medium gray, slightly argillaceous, bioturbated, skeletal calcilutites. The upper and lower contacts are often gradational.

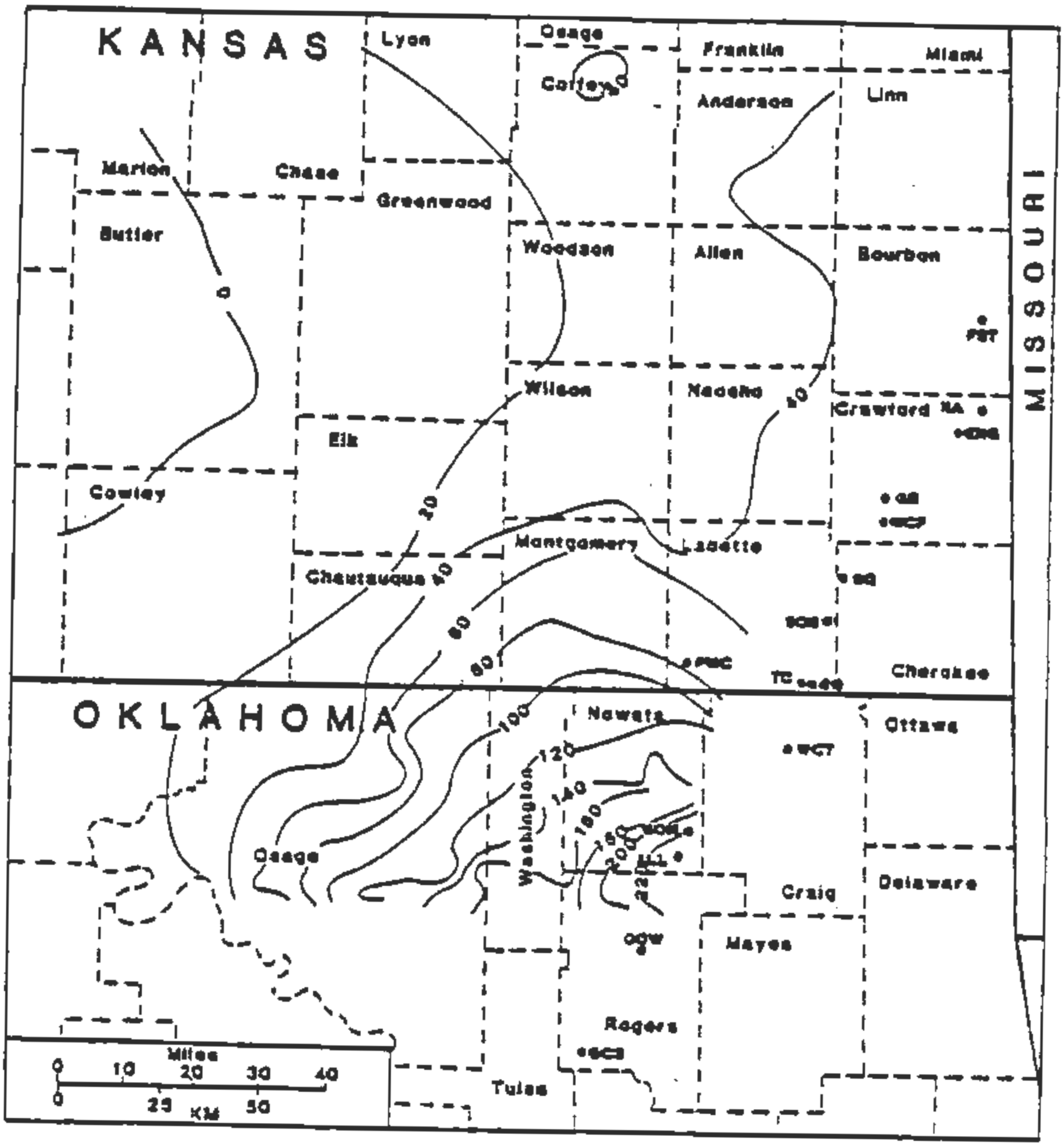
The interval between the Houx and the overlying Higginsville Limestone is only developed north of southern Johnson County, Missouri. Much of this interval is occupied by gray, noncalcareous, platy shales, often containing abundant clay-ironstone nodules, red to reddish brown shales with irregular green spots, and in northern Missouri a widespread sandstone, siltstone, and shale unit, the Flint Hill Sandstone (Jeffries, 1958). Jeffries (1958) noted that the upper part of this interval often contains mudstones suggestive of underclays and that a carbonaceous smut was observed at the contact with the overlying Higginsville Limestone in Putnam County, Missouri.

The Flint Hill Sandstone consists of a coarsening-upward sequence of interbedded shale, siltstone, and sandstone beds. The sandstones are unfossiliferous, and the shales contain only a few Pecten-like bivalves. Individual beds thicken upwards from 1 cm to 0.6 m. Ripple marks are mostly asymmetrical, and cross-bedding is rare. The Flint Hill Sandstone is a uniform blanket sanndstone and does not channel into the underlying strata (Jeffries, 1958; Siever, 1957).

In Iowa the clastic interval between the Houx and Higginsville Limestones is about 4.5 m thick in cores and consists of a single coarsening-upward sequence of thinly interbedded to cross-laminated shale, siltstone, and minor sandstone (Swade; 1982; Ravn et al., 1984). Landis and Van Eck (1965) report a thin mudstone with a coal smut at the top of this interval along the outcrop.

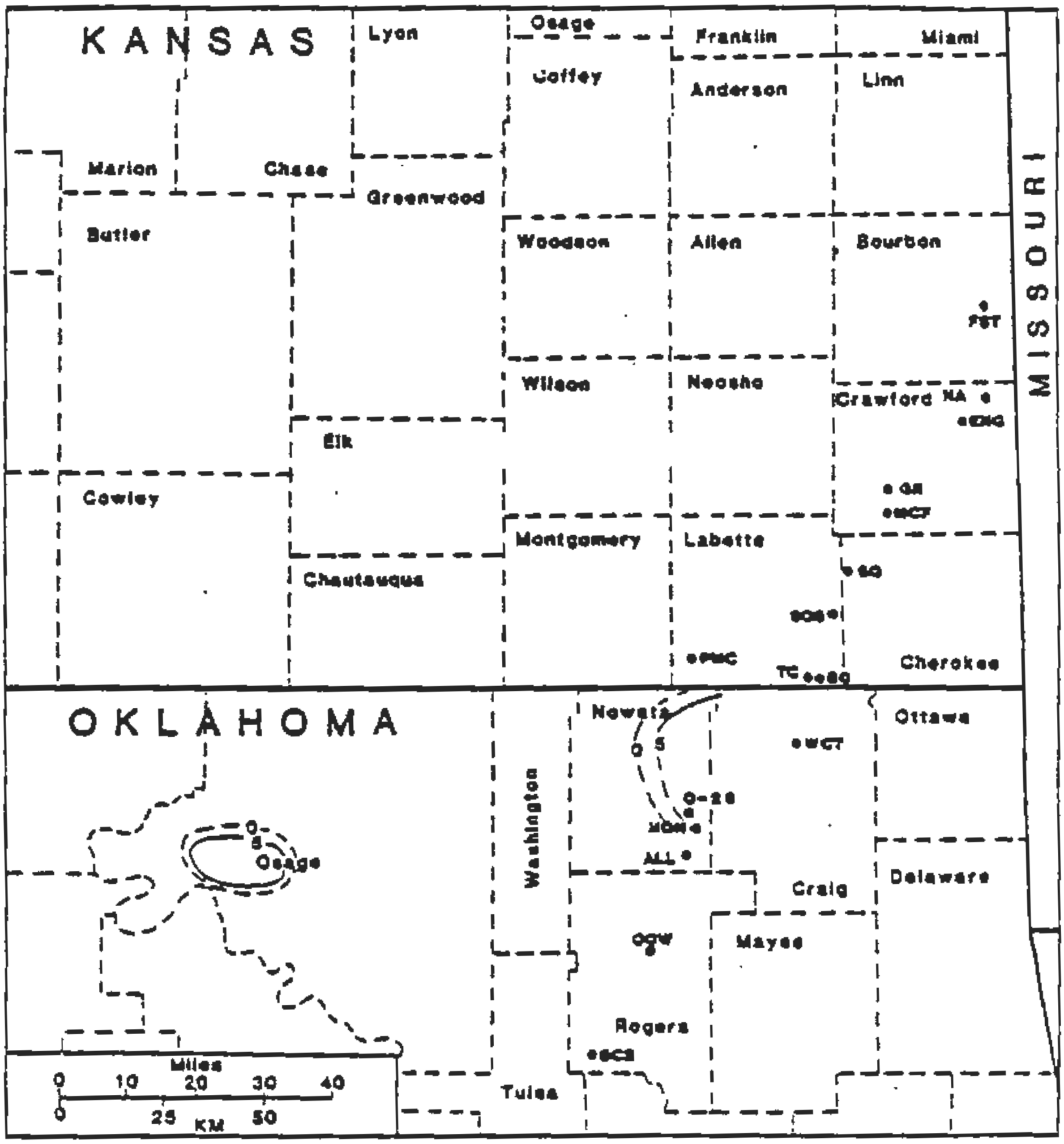
Several limestones that occur in the Labette Shale above the Houx-Higginsville Limestone in Oklahoma may be depositionally related to the Upper Fort Scott cyclothem. In northeastern Oklahoma near the outcrop belt, the Labette Shale has a wedge-shaped geometry centered over the Kansas-Oklahoma Border Trend and thinning to the northwest (Fig. 24). Price (1981) identified several limestones within this interval. The Childers School Limestone occurs sporadically just below the Anna Shale from Oklahoma to Missouri. He interpreted it as the basal transgressive limestone of the Pawnee Formation. The Wimer School Limestone, a massive dark gray to yellow-brown marine limestone in the Labette Shale, occurs in northern Nowata County, in an area and stratigraphic location [exact stratigraphic level could not be determined from the information provided in Price (1981)] that may correspond with a limestone-thickening that developed in the subsurface of Nowata County (Figure 25). P. H. Heckel (personal communication) has identified an algal limestone, about 3 m. thick, within the Labette Shale, along Oklahoma Highway 28 (NW1/4, SE1/4, Sec. 21, T.26N., R.17E.), in southeastern Nowata County, informally called the "O-28 Limestone". This limestone does occur in the same area and at the same stratigraphic level along outcrop as the

Figure 24. Labette Shale isolith map. Thickness of noncarbonate lithologies between base of Houx-Higginsville Limestone and base of Anna Shale in overlying Pawnee Limestone. In addition, in the north where the Houx-Higginsville Limestone has divided into "lower" and "upper" limestones, it includes the siliciclastic interval between them. Contour interval = 5 ft. Based on well-log data (Appendix B).



LABETTE SHALE ISOLITH

Figure 25. Isopach map of limestone interval below Pawnee but above Houx-Higginsville Limestone in Oklahoma. Contour interval = 5 ft. Based on well-log data (Appendix B).


KANSAS
Lyon
Osage
Franklin
Miami
Coffey
Anderson
Linn
Marion
Chase
Greenwood
Butler
Woodson
Allen
Bourbon
FST
MISSOURI
Wilson
Neosho
Crawford
NA
Elk
GR
WCT
Cowley
Montgomery
Labette
SQ
Chautauqua
PMC
TC
Cherokee
OKLAHOMA
Nowata
0
5
WCT
Ottawa
Washington
0-26
MON
ALL
0
5
Osage
Craig
Delaware
OGW
Mayes
Rogers
Miles
0
10
20
30
40
0
25
KM
50
Tulsa

subsurface limestone horizon illustrated in Figure 25, yet its stratigraphic relation with the Wimer School is currently uncertain. The subsurface "O-28 Limestone" in Oklahoma also occurs at about the same stratigraphic level between the distinct radioactive signatures of the underlying Little Osage and the overlying Anna Shales as does the "upper limestone" in the subsurface of east-central Kansas identified earlier as the equivalent of the type Higginsville Limestone in Missouri. The Sageeyah Limestone, below the Childers School in Rogers County, Oklahoma, consists of up to 21 m of massive algal limestone. North of Rogers County it thins and interfingers with the Labette Shale. Price (1981) and Heckel (1984) interpreted the Sageeyah Limestone as an algal mound that developed during a low stand of sea level as deltaic clastics of the upper Labette Shale prograded from the north.

Of the three limestone units present in the Houx-Higginsville interval below the Labette Shale, only the Houx-Higginsville Limestone from northeastern Oklahoma, southeastern Kansas, and westernmost Missouri was examined in petrographic detail for this study. Based on outcrop and core specimens, the Houx-Higginsville Limestone is divided into three facies (Fig. 11): 1) skeletal calcilutite, 2) chaetetid reef, and 3) mixed calcilutite.

Skeletal Calcilutite Facies

Description

The Houx-Higginsville Limestone is dominated by the skeletal calcilutite facies along the outcrop examined for this study from northeasternmost Oklahoma into western Missouri. In the core (Section PMC) from southwestern Labette County, Kansas, it is split in half by the mixed calcilutite facies. Locally, in Kansas, toward the middle of the skeletal calcilutite facies, the chaetetid reef facies is developed.

The skeletal calcilutite facies consists mainly of skeletal wackestones containing a high diversity of marine organisms. Mudstones and packstones containing a similar fauna occur as minor lenses within the skeletal wackestone. Thin skeletal packstones are also found occasionally at the base and top of the Houx-Higginsville Limestone. Skeletal grains found in the packstones from the top of the Houx-Higginsville are often slightly abraded. From the Bourbon Arch (Section FST) to the north side of the Schell City-Rich Hill Anticline (Section BUT), rounded to angular intraclasts occur in the middle of the skeletal calcilutite facies.

Although phylloid algae are found above the basal foot throughout much of the facies, they tend to dominate its lower and upper portions and are less common in the middle.

At some localities in southeastern Kansas (Sections PMC, GR), they are found at the very top of the limestone, where a rather sharp transition occurs into the overlying Labette Shale. As in the algal calcilutites in the underlying Blackjack Creek Limestone, algal blades generally constitute less than half of the skeletal grains, are often broken into smaller fragments, and only rarely are they responsible for spar-filled sheltered voids.

Although neomorphism of carbonate mud into microspar and spar in the Houx-Higginsville Limestone was more thorough, the matrix of the skeletal calcilutite facies is very similar to the matrix of the corresponding skeletal calcilutite facies in the Blackjack Creek Limestone. Although no argillaceous-rich middle zone, as found in the Blackjack Creek Limestone, was discovered in the Houx-Higginsville, clay- and fusulinid-rich seams do occur through much of the facies. The basal foot and the top are often clay-rich and highly dolomitized, containing silt-sized rhombs and blocky spar of ferroan dolomite.

The top of the skeletal calcilutite facies along the Bourbon Arch (Section FST) contains a biota of lower diversity dominated by ostracodes, fusulinids, and foraminifers. It is also highly dissected by fractures and solution vugs and, like the Blackjack Creek Limestone, contains root casts (see section on rhizoliths). Solution vugs have generally curvilinear crumbly sides and a geopetal fill of loosely packed, angular to rounded wall fragments and clay, enclosed by cloudy ferroan dolomite and a final void-fill of clear ferroan calcite and dolomite (Fig. 26a). Lower in the Houx-Higginsville Limestone at the same section, sheetlike voids of indeterminate origin contain an initial incomplete rim of cloudy nonferroan calcite, which is blanketed by a thin layer of micritic material displaying possible meniscal contacts and a final fill of clear ferroan calcite (Fig. 26b).

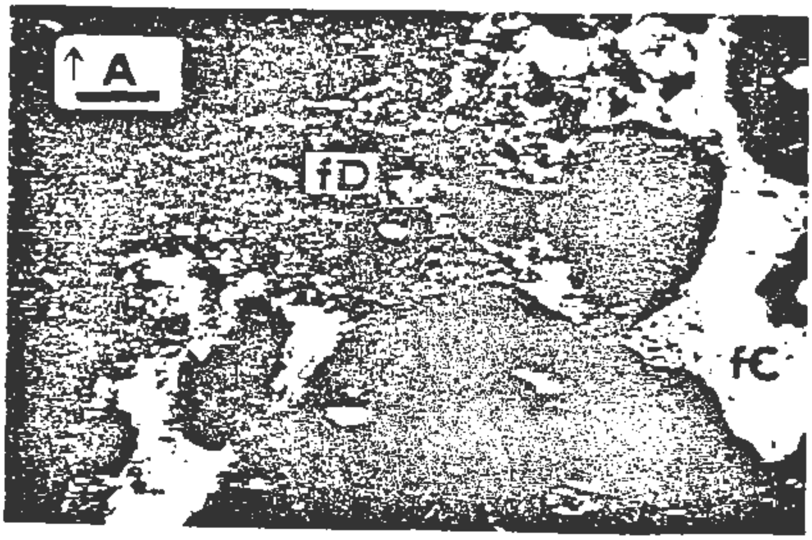
Preservation of the internal structure of unstable phylloid algal and mollusk grains is more pervasive and widespread in the Houx-Higginsville than it is in the Blackjack Creek Limestone and occurs extensively from the Kansas-Oklahoma border into western Missouri. In many cases the perithallus and hypothallus of the red phylloid algae Archaeolithophyllum (Fig. 26c) and the utricles in Anchicodium are well preserved. Generally the outer portions of the blades have better preservation, consisting of cloudy nonferroan calcite microspar to spar with relict structure and a ragged inner boundary in contact with a final, probable void-filling of clear blocky ferroan calcite and dolomite. Some micitic envelopes on unstable grains have collapsed and are surrounded by clear blocky spar.

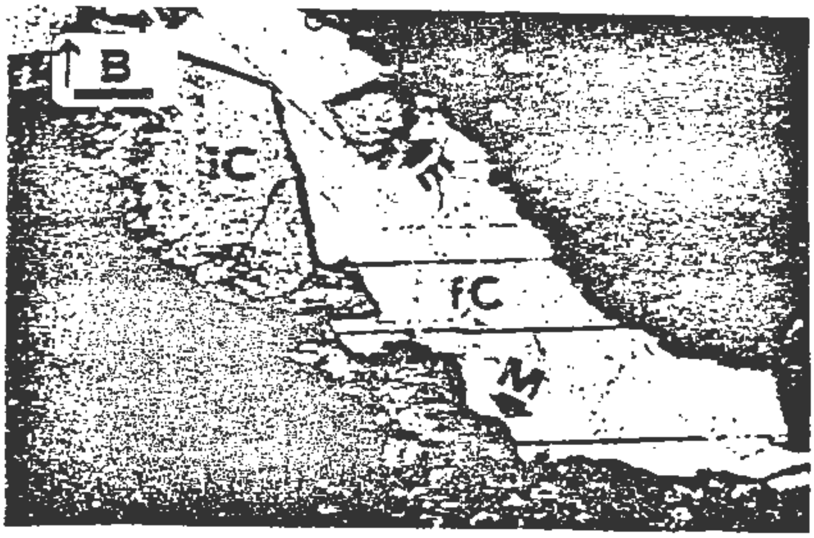
Figure 26. Skeletal calcilutite facies of Houx-Higginsville Limestone.

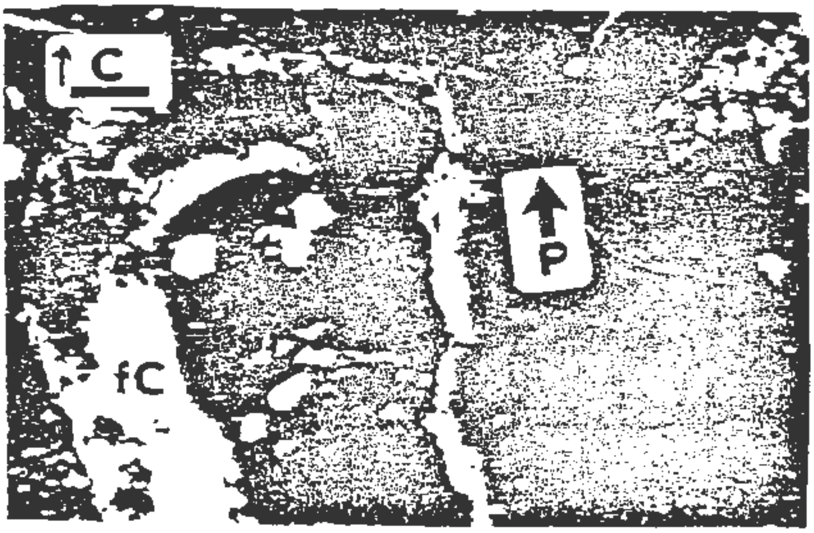
a) Solution vug from top of Houx-Higginsville Limestone along Bourbon Arch is filled with loosely packed rounded to angular wall fragments in a clay-rich matrix, suggesting that in place rounding resulted from dissolution, probably in undersaturated meteoric water. Late-stage fill of remaining voids within the solution-vug consists of clear ferroan calcite (fC) and cloudy ferroan dolomite (fD) (Plane-polarized light; FSTHTb; Scale bar = 1.2 mm).

b) Fenestral void of indeterminate origin contains initial cloudy, blocky nonferroan calcite cement (iC) followed by a fine layer of micrite (M) blanketing the initial cement and void-walls; note its meniscal coating (m) next to wall of nonferroan calcite spar fragment, which may be attached to wall, out of plane of thin section, or may have subsequently broken free. Final fill was blocky ferroan calcite (fC). The initial cloudy calcite cement lacks the morphology characteristic of early marine cements and perhaps represents calcite cement made cloudy by its concurrent precipitation with the settling or precipitation of mud-size carbonate. Subsequent possible meniscal coating suggests meteoric vadose precipitation (Plane-polarized light; FSQH4AD; Scale bar = 0.2 mm).

c) Partial preservation of red algal blade (cellular structure preserved) by nonferroan calcite microspar (P) probably occurred in stagnant meteoric phreatic water. Subsequent passage through undersaturated meteoric water dissolved remaining unneomorphosed part of blade; subsequent voids were filled with blocky ferroan calcite (fC) in reducing environment (Plane-polarized light; Ba8D; Scale bar = 0.5 mm).


A
fD
fC


B
fC
E
fC
M


C
P
fC

The typical void-filling sequence of original intragranular and sheltered porosity includes (Fig. 27a): 1) an initial bladed, isopachous rim of cloudy nonferroan calcite, 2) blocky nonferroan calcite occasionally displaying the same zoning into ferroan calcite found in the Blackjack Creek Limestone, 3) blocky ferroan calcite and dolomite, and 4) an occasional final fill of blocky silica.

Although the ordering of ferroan calcite and ferroan dolomite is often indeterminate, their relationship in Figure 27b suggests ferroan calcite preceeded ferroan dolomite. Ferroan calcite void-fill within the center of a partially dissolved unstable grain is cut by a fracture filled with ferroan dolomite. The dolomite becomes discontinuous, occurring as small blebs through the ferroan calcite. Although the fracture and its fill of dolomite occurred subsequent to the initial ferroan calcite cementation, additional ferroan calcite overgrowth filled in part of the fracture before the later dolomite filled the remaining part of the fracture in this area.

Silicification occurs as a minor but ubiquitous replacement of skeletal grains by microcrystalline silica and chalcedony, where its timing is generally indeterminate, and as a late-stage void-fill by blocky silica. It also occurs as discrete brown chert nodules concentrated in the upper half of the facies. Within some nodules, silicified

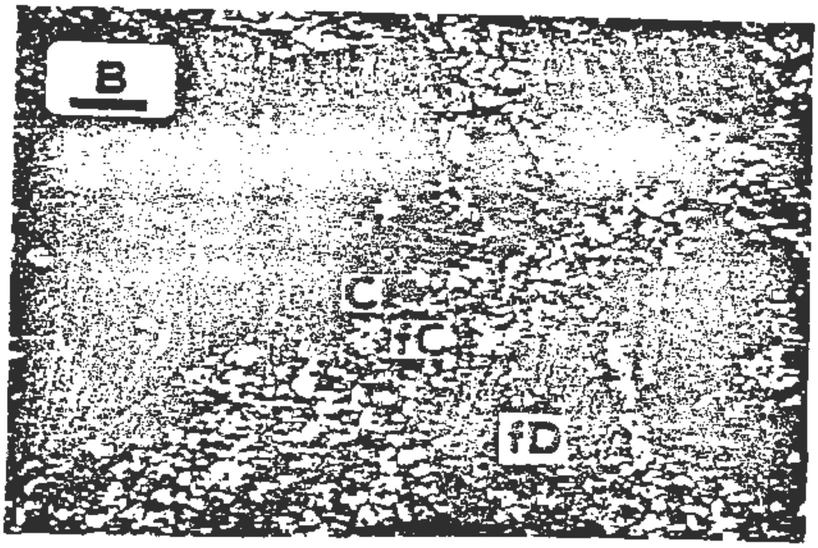
Figure 27. Other diagenetic cements in skeletal calcilutite facies of Houx-Higginsville Limestone.

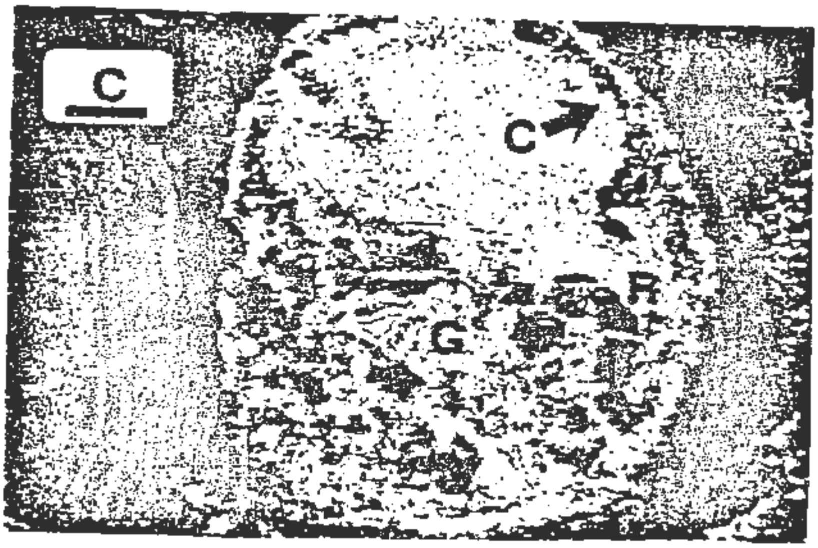
a) Geopetal void-filling sequence inside brachiopod (B) includes initial rim of inclusion-rich, bladed nonferroan calcite (iC) probably representing recrystallization of early marine cement in meteoric phreatic water; and blocky nonferroan calcite (nC); subsequently, this cement was offset by breakage of brachiopod shell and overgrown by ferroan calcite (fC) in optical continuity. Final fill was blocky silica (S) (Plane-polarized light; BaQH4U; Scale bar = 0.2 mm).

b) Unstable grain with outer wall partially preserved by nonferroan calcite (C) in stagnant meteoric phreatic water; remaining interior was dissolved in undersaturated meteoric water and filled by ferroan calcite (fC) in reducing water, either meteoric or connate. Fracture (vertical) filled with ferroan dolomite (fD) cuts unstable grain, where dolomite becomes discontinuous, occurring as small blebs through ferroan calcite within grain (Plane-polarized light; BaQ10D; Scale bar = 0.2 mm).

c) Silicified brachiopod within chert nodule in middle of Houx-Higginsville Limestone along Bourbon Arch is surrounded by completely silicified matrix. Interior of brachiopod is filled with silica that poikilotopically encloses isopachous rim of bladed nonferroan calcite (C) and extends into relict geopetal fill (G) containing individual rhombs (R) of ferroan dolomite.


A
nC
fC
S


B
C
fC
fD


C
C
R
G

relict geopetal fill may poikilotopically enclose individual ferroan dolomite rhombs and isopachous rims of bladed nonferroan calcite (Fig. 27c), suggesting that the silica developed later than at least the rims; the relationship with the dolomite rhombs is enigmatic.

Depositional and Diagenetic Interpretations

The presence of a diverse biota, abundant phylloid algae, and carbonate mud suggest that the skeletal calcilutite facies of the Houx-Higginsville Limestone was probably deposited in the clear water of an open marine environment, generally below effective wave base, but within the photic zone. Except for the development of the mixed calcilutite facies in the vicinity of the Kansas-Oklahoma Border Trend during the middle of Houx-Higginsville deposition, the open marine environment continued almost to the end. A slight increase in water agitation from the Bourbon Arch to the north side of the Schell City-Rich Hill Anticline during the middle of Houx-Higginsville deposition was probably responsible for the increased presence of angular to rounded intraclasts there. An increase in water agitation may also have been responsible for the abraded skeletal packstones found near the top at some localities. Even in the vicinity of the Kansas-Oklahoma Border Trend (Section PMC), where a thick mound developed, a rather sharp transition occurred at the end of Houx-Higginsville deposition from the clear open marine water responsible for the algal-rich calcilutite at this locality into the turbid water responsible for the overlying detrital clastics of the Labette Shale. Without outcrop or core control, it is difficult to determine the cause of the sudden thinning of the Houx-Higginsville Limestone southeast of this mound in the same area where the Labette Shale is thickest. It is possible that the southeast flank of the mound represented a transitional boundary between contemporaneous carbonate- and terrigenous clastic-depositing environments. If so, then interfingering of these sediments would be expected. However, this was observed neither in the well-logs, where it would be difficult to detect, nor in the core from Section PMC on the north side of the mound. The more likely possibility is that the build-up of the Houx-Higginsville Limestone along the Kansas-Oklahoma Border Trend, which thinned to the southeast into the Arkoma Basin, was nearly completed before significant deposition of the Labette Shale had begun. Probably only toward the end of Houx-Higginsville deposition did the Labette Shale, prograding from the southeast (Fig. 24), suddenly end the clear open marine water responsible for the skeletal calcilutite facies over the Kansas-Oklahoma Border Trend before more shallow-water lithologies developed.

The similarity between the cement sequence within the Blackjack Creek and Houx-Higginsville Limestones suggests the same basic sequence of diagenetic events (with some minor variations) from marine into saturated and undersaturated meteoric phreatic and vadose environments before deeper-burial cementation. The pervasive aggrading of carbonate mud into microspar and spar and the significant preservation of internal structure within the outer edges of unstable algal and mollusk grains suggests that significantly more neomorphism occurred in the Higginsville, probably in stagnant meteoric water saturated with calcium carbonate, before the passage of active undersaturated meteoric water dissolved the still remaining unstable minerologies. Railsback (1984) reported similar trends of neomorphism and dissolution from the regressive Winterset Limestone of the Upper Pennsylvanian Dennis Formation.

Several lines of evidence confirm the presence of subaerial exposure along the Bourbon Arch after Houx-Higginsville sediments were deposited and cemented by meteoric phreatic water. Abundant fractures, solution vugs, and root casts are found only at the top of the unit. The dissolution-rounding of broken wall fragments in undersaturated meteoric water and the partial infilling with clays, possibly from early soil formation or the initial overlying sediments of the Labette Shale, resulted before reducing meteoric phreatic or deeper-burial connate water cemented the fractures with ferroan cements. Watney (1980) attributed similar features to subaerial weathering at the top of regressive limestones in the Upper Pennsylvanian in the subsurface of northwestern Kansas. The presence of micrite forming a caliche-like meniscal lining along previously precipitated nonferroan calcite cement within the Houx-Higginsville in the same area also suggests subaerial exposure subsequent to meteoric phreatic cementation but before deeper-burial cementation. The concentration of these distinctive vadose features across the Bourbon Arch indicate that it was a topographic high at the conclusion of Houx-Higginsville Limestone deposition.

Summary

By the end of deposition of the underlying Little Osage Shale, the return of oxygenated bottom conditions encouraged the proliferation of the carbonate-producing organisms responsible for the skeletal calcilutite facies of the Houx-Higginsville Limestone. These conditions were temporarilly interrupted during the middle of its deposition along the Kansas-Oklahoma Border Trend as the mixed calcilutite facies was deposited. During this time, a chaetetid bioherm developed farther to the north in Kansas, and slightly more agitated conditions may have prevailed along the topographic highs of the Bourbon Arch and the Schell City-Rich Hill Anticline. As shallowing continued, a brief period of greater agitation developed along portions of the outcrop before inundation by a thick clastic wedge, probably from the southeast, effectively ended carbonate production toward the south.

Chaetetid Reef Facies

Description

Chaetetids are common in the Houx-Higginsville Limestone and developed, especially in the middle of the unit, into extensive bioherms. In Crawford County, Kansas, a complete section of Houx-Higginsville Limestone (Section GR) exposes a chaetetid bioherm complex, which can be traced at least 23 kilometers northeastward. The lower part of the Houx-Higginsville Limestone at this locality is the skeletal calcilutite facies, a gray, even-bedded, skeletal wackestone with phylloid algae and wavy, fusulinid-rich shale partings. The middle two-thirds consist of a massive fusulinid-rich wackestone to packstone with fusulinid-rich partings and local chaetetid boundstones, up to 3 m across and 2.4 m thick, containing chaetetids and attached auloporoid and horn corals. The shaly partings tend to drape over the chaetetid heads, and along with displaced angular chaetetid fragments and fusulinids, fill in the hollows around those heads still in upright growth positions. Fractures that break both the chaetetid heads and the nonferroan calcite spar filling their skeletal porosity contain a geopetal fill of chaetetid fragments, fusulinids, echinoderms, and cloudy ferroan dolomite. Clear ferroan dolomite fills the tops of the fractures (Fig. 28a). The top of the Houx-Higginsville at this locality consists of a 0.45 m thick massive bed of algal, skeletal calcilutite. This top bed lacks chaetetids and is separated from the lower chaetetid-bearing unit by a 5-20 cm thick draping of gray shale devoid of conodonts (P. H. Heckel, personal communication) and containing limestone nodules.

An unusually wide range of preservation occurs in fusulinids found within the chaetetid bioherm (Section GR). Fusulinids with their microcrystalline skeletal structure intact are found alongside fusulinid-shaped voids filled with clear, blocky nonferroan and ferroan calcite or mosaics of ferroan dolomite spar (Fig. 28b). Figure 28c illustrates a fusulinid-void containing a clear, zoned, euhedral ferroan calcite poikilotopically enclosed by a mosaic of ferroan dolomite crystals. Both ferroan cements poikilotopically enclose etched fragments of what was probably an early nonferroan calcite spar within the original fusulinid or the fusulinid-void. In other cases blocky nonferroan and ferroan calcite spar (Fig. 28d) and microcrystalline silica

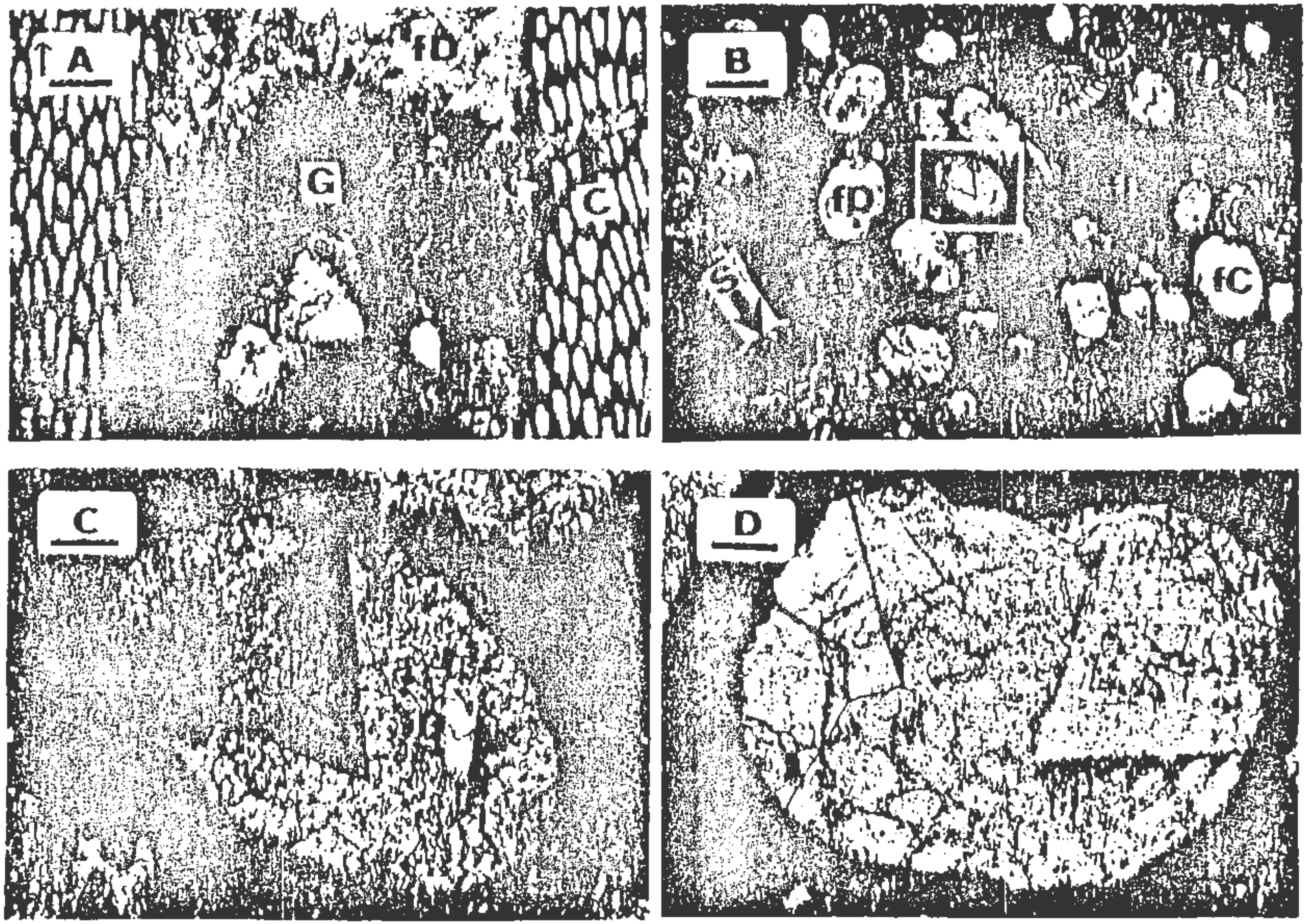
Figure 28. Chaetetid reef facies of Houx-Higginsville Limestone.

a) Fractures through chaetetid head cut and displace skeletal structure filled with nonferroan calcite (C) suggesting that fracturing followed meteoric cementation of skeletal voids. The larger fracture has a loosely packed geopetal fill of echinoderm and fusulinid fragments in a matrix of cloudy ferroan dolomite (G) and a final fill of clear ferroan dolomite above (fD), suggesting that fracture preceded lithification of the surrounding sediment (Plane-polarized light; GRSWG#13; Scale bar = 1.2 mm.).

b) Fusulinid wackestone from around chaetetid bioherms in southeastern Kansas displays an unusually wide range of grain preservation. Less than half the fusulinids preserve their original micritic walls (dark); others appear to have been dissolved, probably in undersaturated meteoric water and subsequently filled with ferroan dolomite (fD) or ferroan calcite mosaic spar (see Figure 28c for enlargement of fusulinid-void filled by both ferroan calcite and dolomite); still others are replaced by large crystals of nonferroan to ferroan calcite (fC) or microcrystalline silica (S), which preserves relict structure (Plane-polarized light; GRMM9; Scale bar = 1.2 mm).

c) Enlargement of box in Figure 28b shows a fusulinid-void with three cement minerologies. Etched crystals of nonferroan calcite (C) probably represent meteoric cement within this fusulinid, which was subsequently partially dissolved in undersaturated meteoric water. These calcite crystals are now poikilotopically enclosed by a later euhedral, zoned ferroan calcite crystal (fC) and by ferroan dolomite (fD), which fills remainder of void (Plane-polarized light; GRMM9; Scale bar = 0.2 mm).

d) Preservation of relict structure in fusulinid by large crystal of blocky ferroan calcite. Note euhedral growth of ferroan calcite crystal from right, which does not preserve relict structure but is in optical continuity with crystal that does and appears to have displaced residual relict material to its borders (Plane-polarized light; GRMM9; scale bar = 0.2 mm).



A
fD
G
C
B
fD
S
fC
C
D

(Fig. 28a), but never ferroan dolomite, contain faint, inclusion-rich relics of the original fusulinid walls.

Depositional and Diagenetic Interpretations

Chaetetids are thought to have thrived in warm, shallow, clear seas analogous to those in which modern reef corals live (Hill, 1948). As indicated by the presence of phylloid algae in its substrate, the chaetetid reef facies developed along an area that had already entered the photic zone and probably was a consequence of the continued shallowing of the Houx-Higginsville sea. The development of large chaetetid heads provided a more solid substrate for the colonization by attaching auloporoid and horn corals. The presence of shale partings containing angular chaetetid fragments and abundant fusulinids and draping the chaetetids suggest that occasional storm events surged through the reefs and transported fine-grained siliciclastics from the coast. A layer of conodont-free shale overlying the coral bioherm suggests that the corals were finally suffocated by detritus from a major storm or from the shifting of a delta-lobe across the area.

The range of preservation of fusulinids within the chaetetid reef facies suggests that their initial mineralogic composition varied. John Groves (personal communication) has suggested that whereas many fusulinids were initially composed of calcite, others may have been composed of aragonite and these were dissolved, neomorphosed, or replaced.

The passage of the chaetetid reef facies through the mixing zone resulted in the preservation of some unstable fusulinids by silica. Subsequently, as the facies passed through saturated meteoric water, nonferroan calcite cements preserved relict structure in unstable fusulinids and filled the voids left by others as well as the intragranular porosity in chaetetids. The dissolution and etching of other fusulinids and nonferroan calcite cements suggest the subsequent passage of undersaturated meteoric water. Fractures that break earlier formed nonferroan calcite cements but contain a geopetal fill cemented by late-stage ferroan dolomite may have also been a consequence of dissolution and subsequent brecciation by undersaturated meteoric water. The preservation of relict structure in fusulinids by ferroan calcite suggest that either they passed through reducing water early (for which there is no other evidence, such as an overlying coal swamp) before being hit by the undersaturated meteoric water, or perhaps that they were stable enough to survive the undersaturated water and only subsequently were slowly neomorphosed by ferroan calcite in the deeper-burial connate zone. Ferroan dolomite often poikilotopically encloses ferroan calcite and fills fusulinid-voids and chaetetid fractures indicating it is a later cement that probably formed with deeper burial.

Mixed Calcilutite Facies

Description

The mixed calcilutite facies, which occupies the middle 4.3 m of the Houx-Higginsville Limestone in Core PMC, is gradational below and above with the skeletal calcilutite facies. Due to the generally incomplete sections of the Houx-Higginsville Limestone available along the outcrop, it has not been possible to trace this facies northward through Kansas, though it may be the lateral equivalent to some portion of the chaetetid reef facies found to the north.

The underlying skeletal calcilutite facies grades upward with decreasing biotic diversity into the mixed calcilutite facies. The mixed calcilutite facies includes a vertical succession of: 1) basal low-diversity mudstone, 2) calcisphere and peloidal wackestone, 3) layered sequence containing breccias to intraclastic packstones, and 4) a top of laminated peloidal wackestones to packstones.

The basal mudstones are bioturbated and composed of peloids (less than 1%) and a sparse low-diversity fauna (less than 1%) including ostracodes, foraminifers, brachiopods, and gastropods in a clay-free microspar matrix. Peloids have diffuse edges with the microspar matrix. Gastropod fragments appear recrystallized to microspar and spar but lack preserved relict internal structures.

The calcisphere and peloidal wackestones are composed of abundant structureless peloids and wall-less spheres (0.02-0.05 mm in diameter) filled with single crystals of nonferroan calcite in a microspar matrix. Although a diverse fauna of skeletal fragments is concentrated in a lens or burrow near the top, the majority of this unit contains a biota of low diversity.

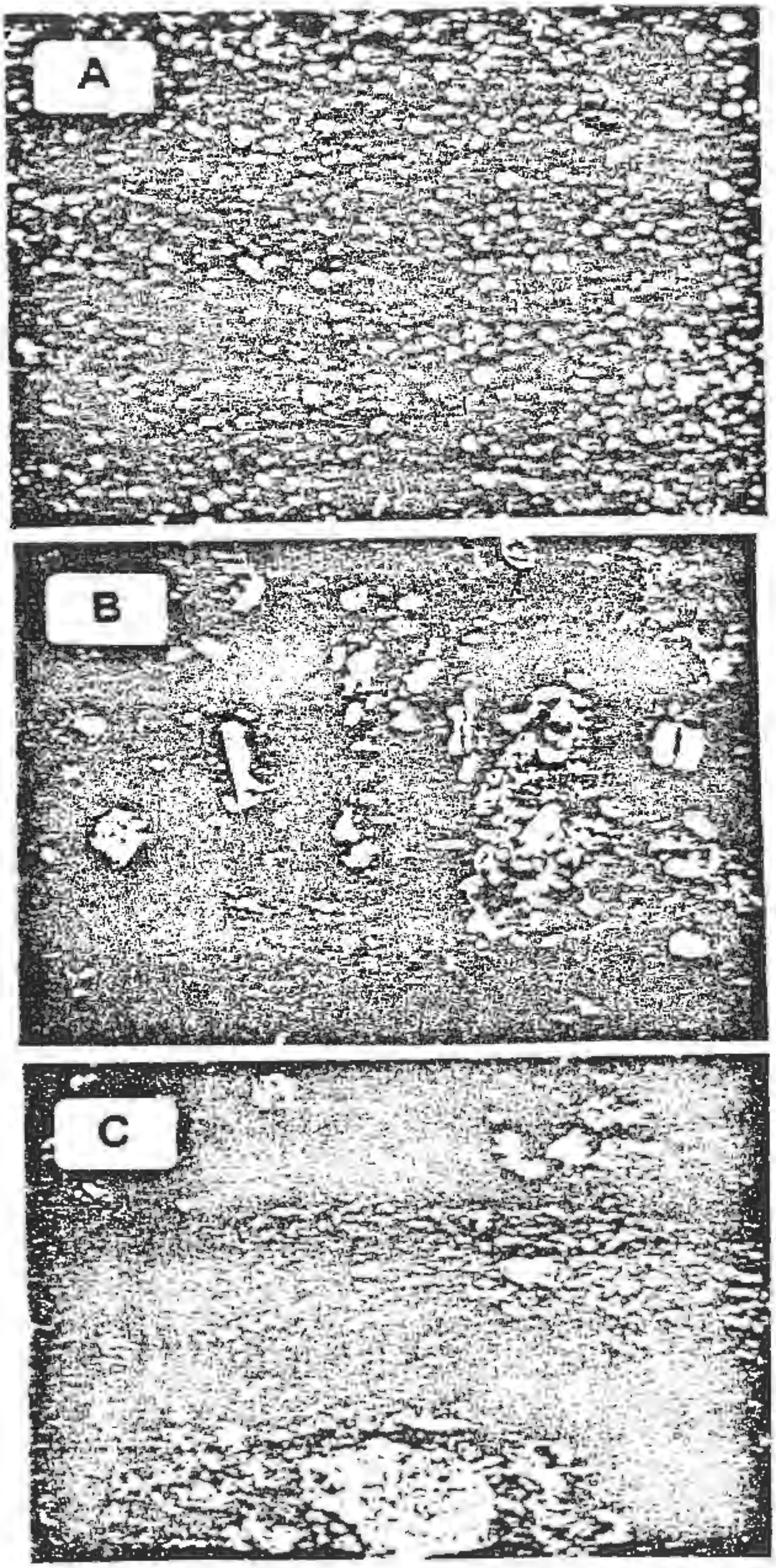
The layered sequence includes rounded to angular intraclasts in grain-to-grain contact grading downward into an in-place breccia. Intraclasts include wackestones to packstones filled with calcispheres (Fig. 29a), calcite blebs (Fig. 29b), and occasional echinoderm fragments. Calcite blebs are more irregularly oval to elongate than are the calcispheres, but are still very well-rounded. The blebs are filled by a single crystal of nonferroan calcite and occasional rhombs of nonferroan dolomite. A few calcite blebs and calcispheres contain internal relict structures that are generally indeterminate, although one appears to have been a foraminifer. Calcispheres and calcite blebs within some intraclasts are well-sorted and layered (Fig. 29c). Below the brecciated zone is a single layer of matrix-supported angular chert intraclasts composed of microcrystalline quartz enclosing scattered dolomite rhombs

Figure 29. Mixed calcilutite facies of Houx-Higginsville Limestone. Located along north side of Kansas-Oklahoma Border Trend.

a) Close-up of intraclast composed of calcisphere packstone in unit 3. Calcispheres are wall-less and mostly filled with nonferroan calcite; a few contain nonferroan dolomite rhombs (Plane-polarized light; PMC325; Scale bar = 0.2 mm).

b) Rounded intraclast containing calcite blebs in unit 3. These problematic grains are well-rounded and filled with nonferroan calcite, which only rarely preserves relict structure of possible foraminifers (Plane-polarized light; PMC325; Scale bar = 1.2 mm).

c) Rip-up clast composed of sorted, laminated calcite bleb, calcisphere wackestone to packstone in unit 3 (Plane-polarized light; PMC325; Scale bar = 1.2 mm).


A
B
C

and orange-brown relics of calcispheres. In addition to intraclasts, the calcite microspar matrix includes calcispheres, calcite blebs, and echinoderm, brachiopod, bryozoan, ostracode, and foraminifer fragments.

The top of the mixed calcilutite facies is composed of laminated low diversity peloidal wackestones to packstones containing, in addition to abundant peloids, a few calcispheres, brachiopods, foraminifers, and echinoderms concentrated in a burrow or lens. The microspar matrix contains a few patches of ferroan dolomite.

Depositional and Diagenetic Interpretations

The depositional and diagenetic interpretation of this facies depends to some extent on the origin of the numerous calcispheres and calcite blebs found within portions of the facies. Calcispheres have been found in limestones of Devonian, Mississippian (Flugel, 1982), and Pennsylvanian age and have been variously regarded as dasycladacean algal spores and as foraminifers. Recent Acetabulariae bear reproductive cysts remarkably similar to fossil calcispheres. Both recent Acetabulariae and many fossil calcispheres are associated with shallow, often back-reef environments of restricted circulation (Stanton, 1967; Rupp, 1967). The origin of the calcite blebs is more enigmatic. It is tempting to consider them as unstable skeletal, possibly molluskan or algal grains, although generally the voids left by these grains in other parts of the Houx-Higginsville are filled by a mosaic of calcite crystals rather than a single crystal.

The range in diversity of the biota and the presence of abundant peloids and calcispheres suggest a range of environments from more open to more restricted within close proximity to one another. Mud-supported to grain-supported lithologies containing angular to rounded intraclasts and skeletal grains suggest a similar range in depositional energies. This wide variation in depositional conditions suggests that the mixed calcilutite facies was deposited in very shallow subtidal to intertidal environments where minor fluctuations in water depth or migration of environments would be reflected in major lithologic changes. The occasional nonferroan dolomite rhombs may have precipitated in the more restricted higher salinity end of these environments or in later mixing-zone water.

Temporary shallowing of the more open marine water responsible for the surrounding skeletal calcilutite facies, due either to eustatic sea level drop, tectonic uplift, or progradation of a carbonate, perhaps reefal buildup to the north, resulted in the overlying mixed calcilutite facies before a return to more open marine conditions. The deposition of this shallow-water facies along the

Kansas-Oklahoma Border Trend to the south, of intraclasts farther north along the topographic highs of the Bourbon Arch and Schell City-Rich Hill Anticline, and the temporary development of a clastic wedge even farther north into Iowa suggests a regional sea level drop as the most likely causative agent. If this restricted facies is the lateral facies equivalent to the chaetetid reef facies located within the middle of the skeletal calcilutite facies farther north in Kansas, it may represent a back-reef facies developed between the thick carbonate buildup along the Kansas-Oklahoma Border Trend to the south and the reef to the north.

At some point, whether during the period of shallowing or later at the end of Houx-Higginsville deposition, meteoric water entered the sediment, resulting in neomorphism, leaching and void-filling cementation. Eventual deeper-burial resulted in the minor occurrence of ferroan cements.

Summary

The mixed calcilutite facies represents a temporary restriction of the open marine sea responsible for the skeletal calcilutite facies and may possibly represent back-reef facies of the chaetetid bioherm developed to the north in Kansas.

Houx-Higginsville Limestone
Depositional and Diagenetic
History

The Houx Limestone in Iowa and Missouri is the lateral equivalent to the lower part of the Houx-Higginsville in Kansas and Oklahoma. The clastic unit containing coal smuts, between the Houx and Higginsville Limestones in Missouri and Iowa, is the lateral equivalent to the middle of the Houx-Higginsville Limestone in Kansas and Oklahoma, probably corresponding to the shallow-water and biohermal lithologies developed in the middle of the Houx-Higginsville in southeastern Kansas and along the Kansas-Oklahoma Border Trend. The Higginsville Limestone in Iowa and Missouri north of central Johnson County is the lateral equivalent to only the upper part of the Houx-Higginsville Limestone in Kansas and Oklahoma. Therefore the Higginsville Limestone of Oklahoma, Kansas, and westernmost Missouri, as previously termed, is more properly called the Houx-Higginsville Limestone, as proposed earlier in this study.

Regional shallowing of the anoxic marine water responsible for the black facies of the Little Osage Shale from Iowa to Oklahoma, resulted in more open circulation and the beginning of Houx-Higginsville Limestone deposition from Oklahoma into western Missouri and of its lateral equivalent, the Houx Limestone, northward into Iowa.

Continued shallowing allowed the development of a siliciclastic wedge containing coals, from Iowa into west-central Missouri and east-central Kansas, which prograded toward the south but was probably effectively barred from moving farther south by the topographic highs of the Bourbon Arch and Schell City-Rich Hill and Ladue-Freeman Anticlines. This wedge temporarily halted carbonate production north of these structures in Kansas, Missouri, and Iowa, splitting the single carbonate unit (Houx-Higginsville Limestone) of southeastern Kansas and Oklahoma into the "lower" limestone (Houx) and "upper" limestone (Higginsville) units to the north. During this time, in western Missouri and southeastern Kansas, shallowing encouraged the development of slightly greater water agitation along the Schell City-Rich Hill Anticline and Bourbon Arch where intraclasts formed and of a chaetetid bioherm complex in southeastern Kansas. Farther south in the vicinity of the Kansas-Oklahoma Border Trend, it resulted in shallow-water, probably lagoonal to shoreline facies, perhaps partly restricted by the bioherm complex to the north. Subsequently, a minor transgression or a temporary halt to the regression coupled with a drier climate and continued subsidence allowed more open marine carbonate facies to redevelop in the Houx-Higginsville Limestone from Oklahoma into western Missouri and of the generally shallow-water carbonate facies of the Higginsville Limestone from Missouri into Iowa. As the sea withdrew from Iowa into Missouri, carbonate production from Oklahoma to Kansas was finally overwhelmed by clastics of the Labette Shale.

The Labette Shale probably represents a clastic wedge prograding from the southeast, as the sea depositing the Little Osage Shale, Houx-Higginsville, Higginsville, and Houx Limestones retreated from the north. The abundance of sediments prograding across Craig, Nowata, and Rogers Counties in Oklahoma suffocated Houx-Higginsville carbonate production, while later deltaic abandonments in Rogers County allowed renewed carbonate production to deposit the Sageeyah, "O-28", and Wimer School Limestones. The much thinner Labette Shale in Missouri, Iowa, and the subsurface of east-central Kansas suggest that carbonate production may have continued unabated there for a longer period of time. It is possible that the upper Higginsville Limestone in these states is the lateral equivalent to some part of the Labette Shale and possibly some part of the Sageeyah, "O-28", and Wimer School Limestones in Oklahoma.

The presence of a coal a short distance above the top of the Higginsville Limestone in the north and the pervasive neomorphism, cementation, and leaching of the Houx-Higginsville Limestone by meteoric water in Kansas and western Missouri indicate that the sea withdrew from this large area, possibly causing the end of carbonate deposition before much influx of Labette clastics.

Based on Heckel's (1977) depositional model, from Oklahoma into western Missouri the Houx-Higginsville Limestone represents the upper or "regressive" limestone of the Upper Fort Scott cyclothem. Farther north in Missouri and Iowa the development of the clastic wedge that splits the Houx-Higginsville of Oklahoma and Kansas into the Houx Limestone, Flint Hill Sandstone, and Higginsville Limestone of Missouri and Iowa complicates the depositional model resulting in a compound cycle more similar to that described by Moore (1936). The Houx Limestone would represent the upper limestone while the Higginsville in northern Missouri and Iowa would represent a "super" limestone separated from the Houx by temporary progradation of an outside shale as suggested by Swade (1982).

CHAPTER V

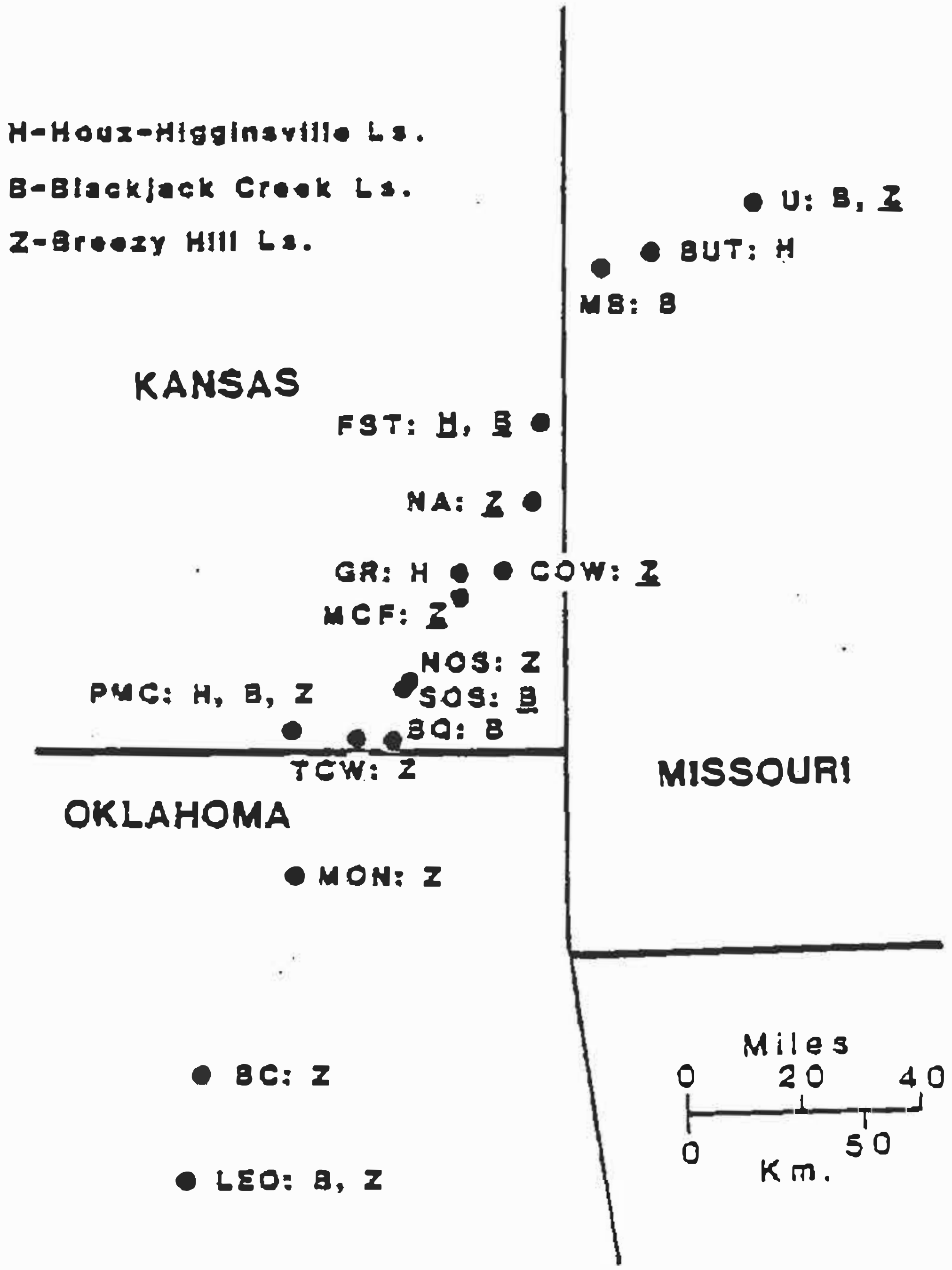
RHIZOLITHS

Rhizoliths (Klappa, 1980, p. 615) are the "accumulation and/or cementation around, cementation within, or replacement of, higher plant roots by mineral matter". Klappa (1980) has described several petrographic characteristics of rhizoliths. Root casts consist of the sediment and/or cement that fills the voids left by the decay of roots. Rhizocretions consist of the pedodiagenetic accumulation of mineral matter, ranging from cryptocrystalline to sparry calcite, around roots.

The tops of each of the Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones contain both root casts and rhizocretions in similar areas of southeastern Kansas and western Missouri (Fig. 30). The rhizocretions found in these limestones range from "rhizosheaths" (defined herein as cryptocrystalline carbonate precipitated as thin sheaths around root casts), found in all three limestones, to "rhizopatches" (carbonate material precipitated as extensive patches), found only in the Breezy Hill Limestone.

Rhizosheaths consisting of thin micritic, grain-excluding sheaths around root casts are perhaps the most

Figure 30. Map illustrating locations of rhizoliths. Illustrates locations where tops of Breezy Hill (Z), Blackjack Creek (B), and Houx-Higginsville (H) Limestones were petrographically examined. Units in which rhizoliths were identified are underlined.


H-Houx-Higginsville Ls.
B-Blackjack Creek Ls.
Z-Breezy Hill Ls.
KANSAS
MISSOURI
OKLAHOMA
U: B, Z
BUT: H
MS: B
FST: H, B
NA: Z
GR: H
COW: Z
MCF: Z
NOS: Z
SOS: B
PMC: H, B, Z
BQ: B
TCW: Z
MON: Z
BC: Z
LEO: B, Z
Miles
0
20
40
0
50
Km.

characteristic and identifiable evidence for the prior passage of plant roots through a sediment (Harrison and Steinen, 1978; Klappa, 1980; Wieder and Yaalon, 1982). Typical rhizosheaths found in the limestones of this study consist of micritic nonferroan calcite sheaths 0.05-0.5 mm thick enclosing root casts, and though passing through a grain-rich sediment, are almost to completely grain-free (Fig. 31). Klappa (1980) suggests that these sheaths may be a consequence of the etching and subsequent reprecipitation of the surrounding carbonate grains by root hairs. In the case of the barren silty calcilutite facies in the Breezy Hill Limestone, which lacks carbonate grains, the direct etching of carbonate grains could not have occurred. However, dissolution may have occurred in the overlying silty skeletal calcilutite or sandy skeletal calcarenite facies where there is some evidence for etching of early meteoric phreatic cements.

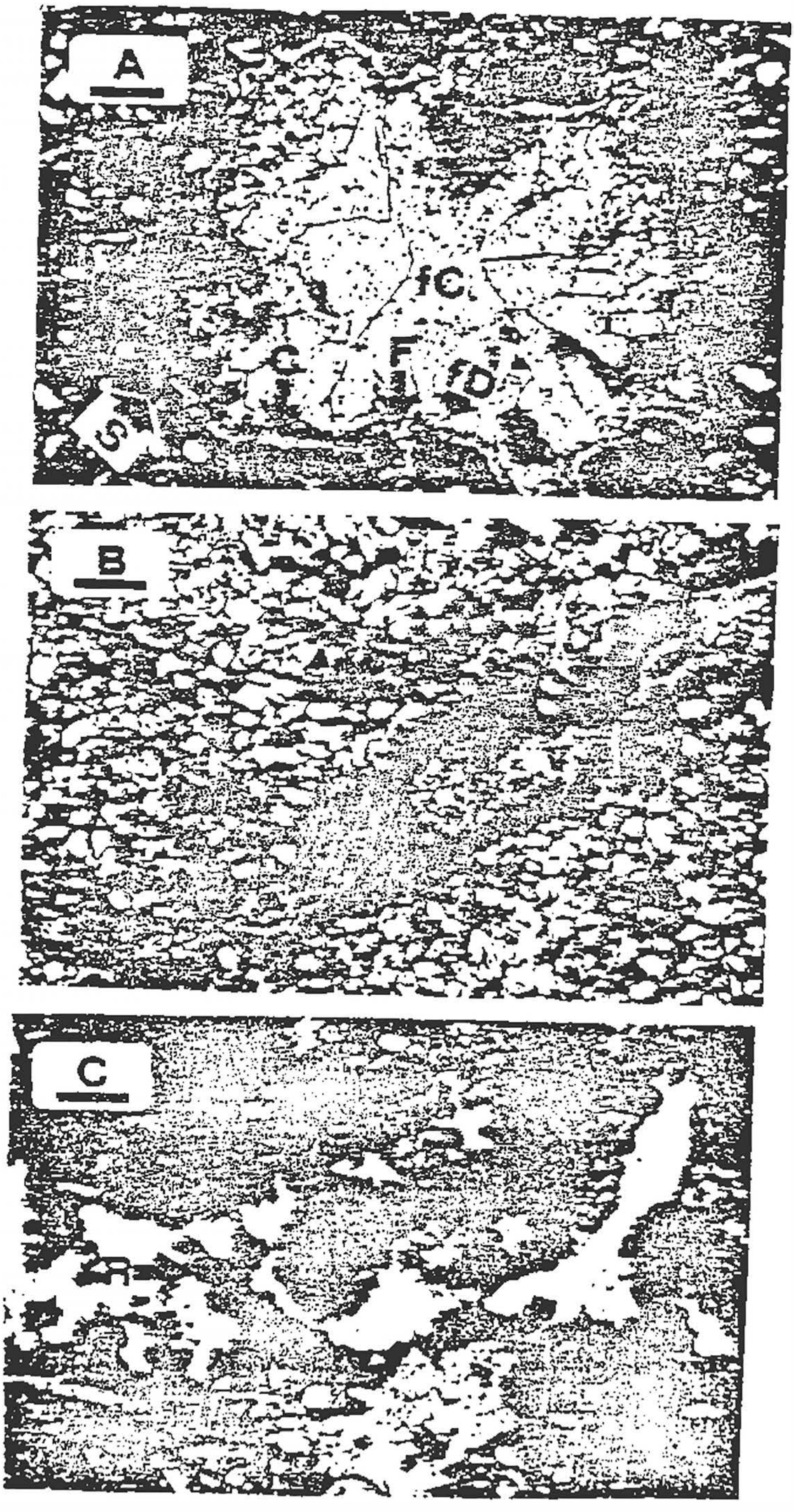
Calcareous rhizopatches are found only in association with the barren silty calcilutite facies of the Breezy Hill Limestone. This facies appears to represent a major diagenetic alteration of the siliciclastic sediments of the underlying Cabaniss Formation, predominantly through the activity of plant roots (see section on barren silty calcilutite facies of the Breezy Hill Limestone). Rhizopatches in this facies grade upward through coalescence

Figure 31. Rhizosheaths.

a) Transverse cut through rhizosheath and root cast in barren silty calcilutite facies of Breezy Hill Limestone. Rhizosheath is micritic grain-excluding sheath (S). Root cast includes several cements; initial isopachous rim of inclusion-rich, flat-terminated, nonferroan calcite spar (C) is broken by fracture filled with blocky ferroan dolomite (F); rhombic ferroan dolomite (fD) also forms incomplete rim around nonferroan calcite spar; final fill is blocky ferroan calcite (fC) and pyrite (black balls) (Plane-polarized light; COW2D; Scale bar = 0.2 mm).

b) Longitudinal cut through rhizosheath (black) and root cast (crystals) in barren silty calcilutite facies from Breezy Hill Limestone. Root cast contains same cement sequence as example above (Plane-polarized light; COW2D; Scale bar = 0.2 mm).

c) Longitudinal cut through rhizosheath and root cast from top of Blackjack Creek Limestone. Rhizosheath has partially collapsed (R) into root tubule void before cementation by ferroan calcite (Plane-polarized light; SOS7; Scale bar = 0.5 mm).


A
fC
C
F
fD
S
B
C

from discrete patches several millimeters in diameter at the base of the facies into horizontal to vertical stringers and larger more irregular and highly fractured patches (Fig. 14). Often containing root casts, they consist of detrital grains cemented by nonferroan to ferroan micritic to sparry calcite with minor amounts of ferroan dolomite (Fig. 32a, b). The carbonate material within a patch generally grades inward from an intergranular microspar to spar cement between touching grains to an organic- and iron oxide-rich microspar to spar cement matrix, which supports and increasingly separates the grains and grades into micritic rhizosheaths in the vicinity of enclosed root casts. Individual rhizopatches appear to have developed from the gradual concentration of calcareous material at a central point or axis, which may have represented the prior location of a root. The gradual filling of pore space between originally uncemented detrital grains subsequently pushed them apart (Fig. 32c). As a consequence, calcareous material between grains decreases outward from the center, grading from a calcareous matrix-supported center to a grain-supported periphery.

Wieder and Yaalon (1982) describe the growth of carbonate material surrounding roots in terms of three distinct layers around the channels that contained the roots: 1) an inner micritic layer without skeletal

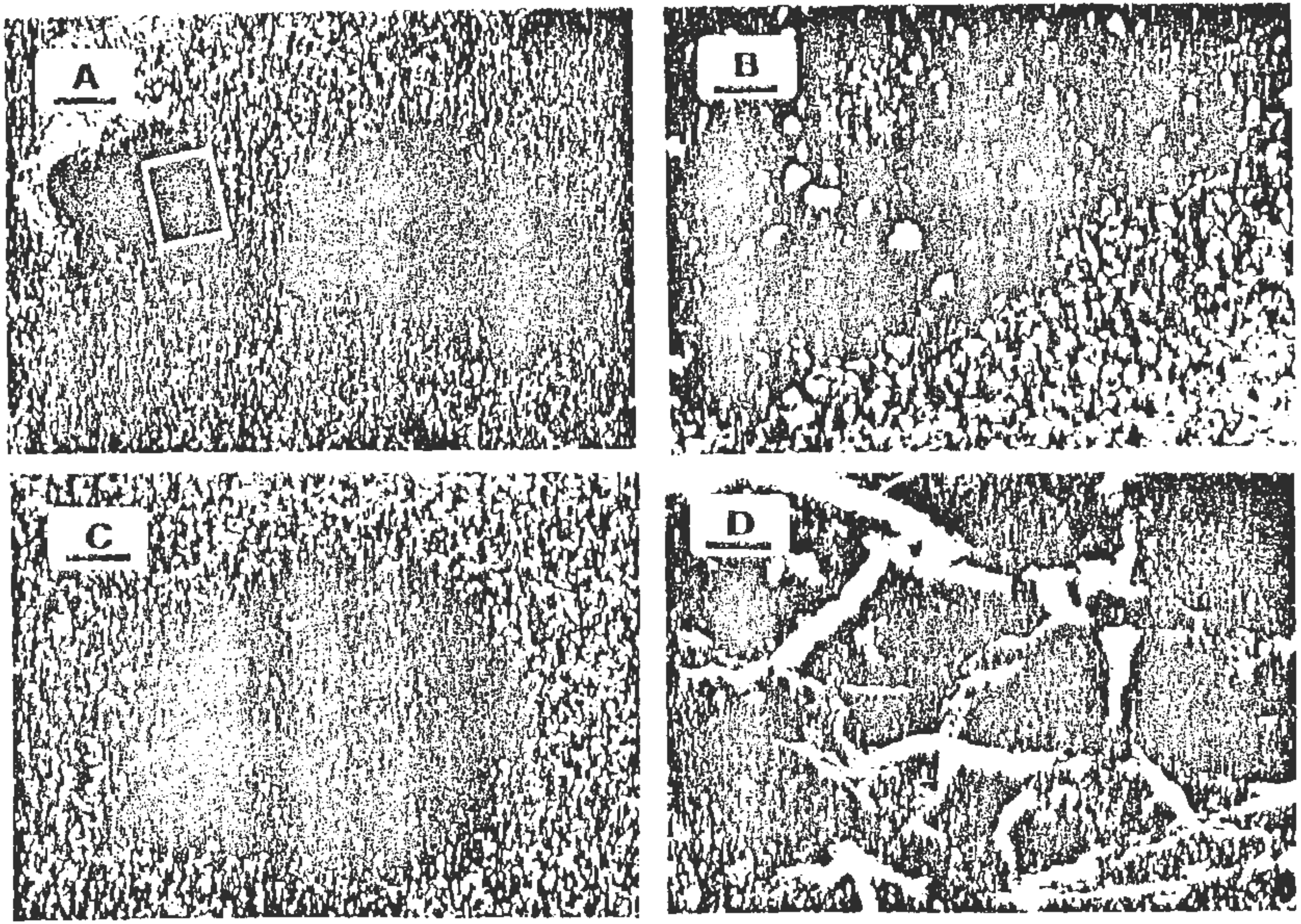
Figure 32. Rhizopatches.

a) Rhizopatches developed at base of barren silty calcilutite facies of Breezy Hill Limestone within sediments of Cabaniss Formation. White grains are quartz. Box indicates area for Figure 32b (Plane-polarized light; BONE; Scale bar = 1.2 mm).

b) Enlargement of box in Figure 32a. Shows close-up of rhizopatch (dark) with root cast (R) in argillaceous siltstone to very fine-grained sandstone (light) typical of top of the Cabaniss Formation in southeastern Kansas. Root cast has initial bladed nonferroan and final blocky ferroan calcite fill. Patch (dark) is composed of nonferroan and ferroan calcite microspar and spar. Note decrease in abundance of quartz grains (light grains) within patch (Plane-polarized light; BONE; Scale bar = 0.2 mm).

c) Incipient development of spherical nonferroan calcite rhizopatch from central point. Dark halo is probably organic-rich (Plane-polarized light; NALagT; Scale bar = 0.5 mm).

d) Well developed, fractured rhizopatch (occupies entire photograph) contains patches of concentrated organics (dark). Note that radiation and bifurcation of fractures has broken larger patch into smaller, individual glaebules. Many fractures have double-ended terminations suggesting desiccation of patch Plane-polarized light; NAEzH; Scale bar = 0.5 mm).


A
B
C
D

inclusions, 2) a transition layer of micrite and microsparite, and 3) a sparry layer including skeletal grains. By replacing skeletal with siliciclastic grains, this is an apt description of the rhizopatches and rhizosheaths found in the Breezy Hill rhizolith facies.

It is probable that rhizopatches developed around central points or axes that were originally roots, and in many cases they represent the extension of rhizosheaths into the enclosing matrix material. The spar-filled, branching tubules of these patches were probably originally the tracks of roots. The smaller rhizopatches that often lack preserved root casts were probably developing at distal root ends tiny enough that they left no significant void subsequent to their decay. Roots normally excrete CO2 and H+ ions, which should increase the acidity of the surrounding sediment and result in the dissolution rather than precipitation of carbonates. Klappa (1980) describes the various mechanisms previously suggested to explain the precipitation of calcium carbonate in spite of this conjectural acidity. Either the living roots themselves, the process of their dying, or the products of other living organisms associated with the roots, such as bacteria and fungi, are capable of directly precipitating calcium carbonate or producing an alkaline environment conducive to its precipitation. The roots themselves and or the cells left by the roots when they decay, acted as conduits for saturated carbonate fluids, which then precipitate outward into the pores of the surrounding grains, resulting in thin rhizosheaths that eventually developed into more extensive rhizopatches. Upon the death of the roots, the hollow tubules were eventually filled with cements to form the root casts.

Fractures occur within or as circumgranular cracks around the patches, breaking apart the less well cemented clay- and quartz-rich interpatch areas, eventually resulting in a fragmentation of the patches into rounded fragments or glaebules (Fig. 32d). Many fractures radiate and bifurcate from within and terminate along the periphery of the patch. Double-ended terminations suggesting the pull-apart fractures found within desiccated mud are common. Many of these fractures probably resulted from the expansion of the carbonate and clay mud-rich areas during growth and their subsequent contraction during drying.

Root casts found in these limestones consist of spar-filled, branching rhizosheaths oriented horizontally to vertically. Transverse sections show them to be ameboid to polygonal in shape, typically 1-2 mm in diameter, and containing a concentric sequence of interior void-fill (Fig. 31a). The interior wall of the surrounding rhizosheath represents the outer perimeter of the root cast. It is occasionally lined by an isopachous rim (about 8 microns thick) of one or more layers (each 1-2 microns thick) of clear nonferroan calcite showing no distinct crystalline boundaries (Fig. 33a). More commonly the interior wall of the rhizosheath is lined by an isopachous rim of inclusion-free to inclusion-rich bladed to flat-terminated nonferroan calcite (Fig. 31a, b). The most common final void-fill found in root casts from all three limestones is blocky ferroan calcite, but this may alternate with/or be substituted by blocky ferroan dolomite. Microcrystalline chert is occasionally found and invariably fills the center of the void, following all other cements.

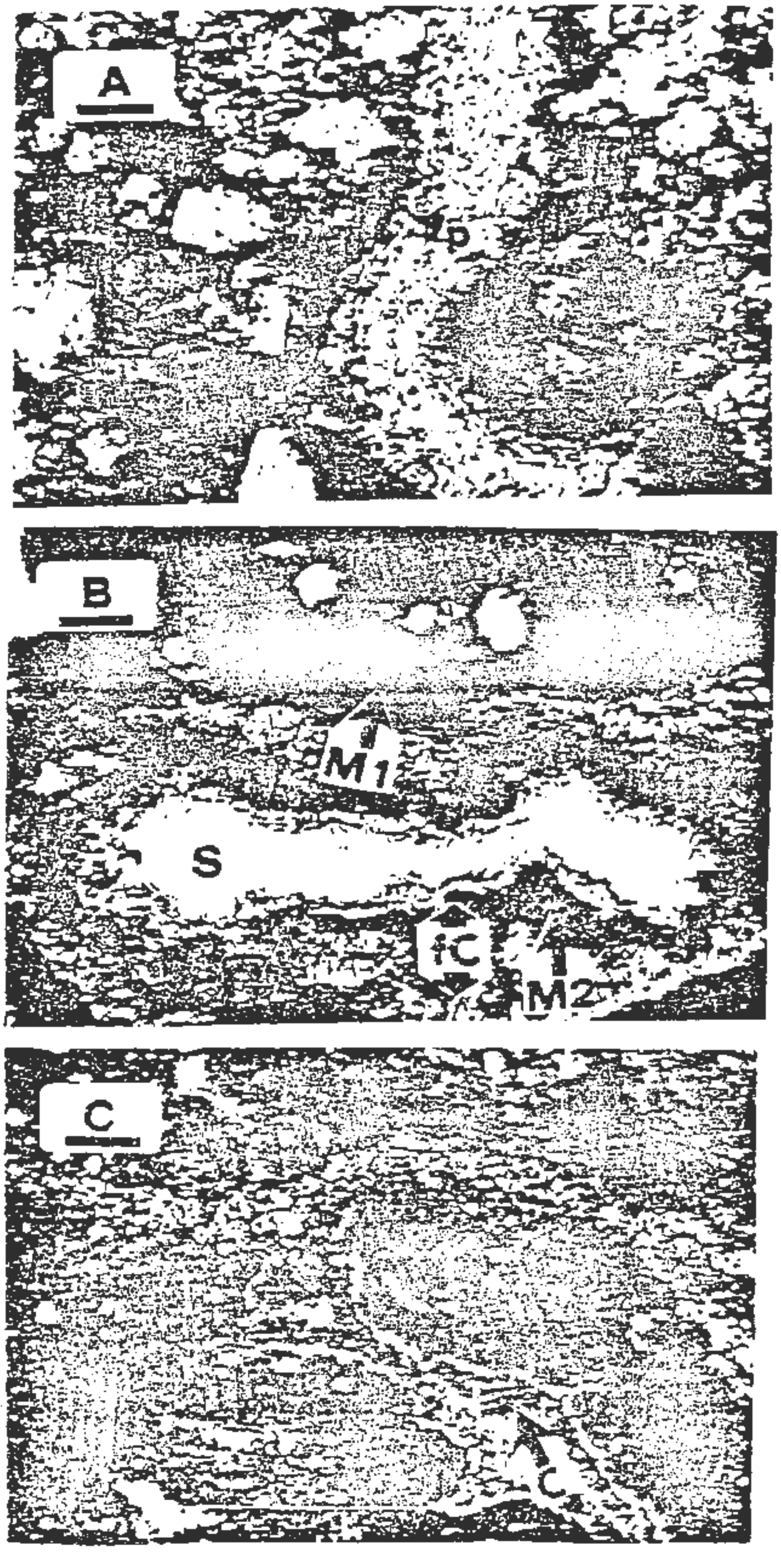
Cement-filled tubules, whose origin is more problematic, are also found in these limestones. They may contain several generations of micritic rhizosheath-like layers (Fig. 33b) separated by spar cements, including ferroan calcite. They may also lack the outer rhizosheath, containing only an inner micritic layer, which follows an initial concentric layer of spar (Fig. 33c). Subsequent void-filling cements include nonferroan and ferroan calcite. Where ferroan dolomite or microcrystalline silica occur, they are always the final void-fill. If these cement-filled tubules represent root casts with inner rhizosheaths, they suggest the possibility that successive generations of roots may have used the same indurated root

Figure 33. Root casts.

a) Longitudinal cut through rhizosheath and root cast in barren silty calcilutite facies from Breezy Hill Limestone. Root cast consists of several thin, discontinuous isopachous layers of clear nonferroan calcite (p) and final fill of blocky ferroan calcite. Light-colored grains are detrital quartz (Plane-polarized light; COW2D; Scale bar = 0.05 mm).

b) Problematic rhizosheaths and root cast from top of Blackjack Creek Limestone. Outer micritic border (M1) encloses initial isopachous rim of bladed ferroan calcite (fC) and second micrite-rich (M2) and bladed ferroan calcite (fC) layer. Final fill is microcrystalline silica (S) (Plane-polarized light; SOST; Scale bar = 0.2 mm).

c) Problematic rhizosheath and root cast from base of Breezy Hill Limestone. Lacks distinct outer rhizosheath. Initial layer of ferroan calcite is followed by layer of loosely compacted micrite to microspar (C) in nonferroan calcite spar suggesting an inner rhizosheath. Final fill including fracture that cuts the above cements is ferroan dolomite (Plane-polarized light; NABzH; Scale bar = 0.2 mm).


A
P
B
M1
S
fC
M2
C

tubules as passageways, resulting in more than one generation or at least a later generation of rhizosheath. The common occurrence of a layer of ferroan calcite spar between two generations of rhizosheaths (Fig. 33b) would then indicate the early presence of reducing, iron-rich water in a root-forming environment before passage into the deeper-burial connate environment.

A comparison of the effects resulting from the passage of plant roots through the Cabaniss Formation and Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones suggests the importance of early cementation on the development of rhizolithic features. The tops of each regressive limestone show evidence for early marine to meteoric lithification through neomorphism and cementation of their sediments, much of which may have occurred prior to the development of a rooted-horizon. The subsequent passage of plant roots through these semi-lithified sediments resulted in minor development of rhizosheaths and root casts but not in the major sediment-altering rhizopatches. On the other hand, the top of the Cabaniss Formation shows little evidence for early marine or nonmarine lithification. It was probably blanketed by a fairly impermeable layer of mud-rich Breezy Hill sediments that prevented the penetration and cementation by active marine or meteoric water and also lacked the initial carbonate mud required for neomorphic lithification (see Breezy Hill depositional and diagenetic history). The subsequent passage of plant roots through these slightly lithified sediments resulted in extensive rhizopatch development and in their profound alteration. This suggests that early cementation of otherwise porous and permeable sediments hinders the later development of rhizopatches, which makes ample sense considering that the mechanism proposed earlier for their development depended on the displacment of the previously deposited sediment by the precipitation of carbonate material between grains. Sediments that were already partially lithified could not be easily displaced, leaving little room for the precipitation of additional carbonate material.

An important consequence of this hypothesis is that the development of a rhizolite horizon would most likely be a self-limiting process. As the roots produce carbonate material that fills pores, constricts pore-throats, and lithifies the sediment, their continued effectiveness in altering the host sediment would be reduced. Eventually a fairly impermeable barrier would be formed, restricting the further alteration of the underlying sediment. The development of these low permeability, low porosity barriers could have important implications for the migration of fluids including oil.

CHAPTER VI

CONODONT DISTRIBUTION

Recent work (Price, 1981; Parkinson, 1982; Swade, 1982) has documented both the vertical and lateral distributional trends of conodonts within Middle Pennsylvanian cyclothemic sequences of the Midcontinent. Specifically, Swade (1982) documented these trends and developed a model of conodont paleoecology for much of the Upper Desmoinesian in Iowa, which includes the Dry Branch Creek Formation, Morgan School Shale, and Wolverine Creek Formation of this study (designated respectively, Mouse Creek Formation, Morgan School Shale, and Stephens Forest Formation in his study).

Consequently, this study has examined both the vertical and lateral distributional trends of conodonts within the Dry Branch Creek Formation, Morgan School Shale, and Wolverine Creek Formation, in addition to the Breezy Hill Limestone, from northeastern Oklahoma into western Missouri, in order to test both the vertical and lateral integrity of his model. This is only a generalized study of the gross distributional trends of distinctive conodont elements and is not intended as an exhausive taxonomic study.

Methods

Limestone and shale samples from the Breezy Hill Limestone-Wolverine Creek Formation interval were collected in detail from five different sections from northeastern Oklahoma into westernmost Missouri (Sections LEO, SOS and NOS combined, FST, and U; Fig. 2).

Limestones were dissolved in 10 percent formic acid for approximately 24 hours. Non-black shales were oven-dried, disaggregated by immersion in Stoddards Solvent for 24 hours, and finally immersed in water for 24 hours. Organic-rich black shales were placed in commercially available sodium hypochlorite (bleach), which was decanted and replaced repeatedly for up to 2 years to complete disaggregation. All residues were wet-sieved through 18 (1 mm), 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 nonmagnetic fraction (including conodonts) from a larger magnetic fraction and thus aids in the subsequent picking of the conodonts.

Detailed conodont data are presented in Appendix C. Since the weight of samples varied, generally between 250 to 500 grams, both the number of conodonts per sample and the extrapolated number of conodonts per kilogram are given for each identified form. To avoid the overcounting of conodont elements, only those that appeared to be more than half complete were included in the counts.

Identification

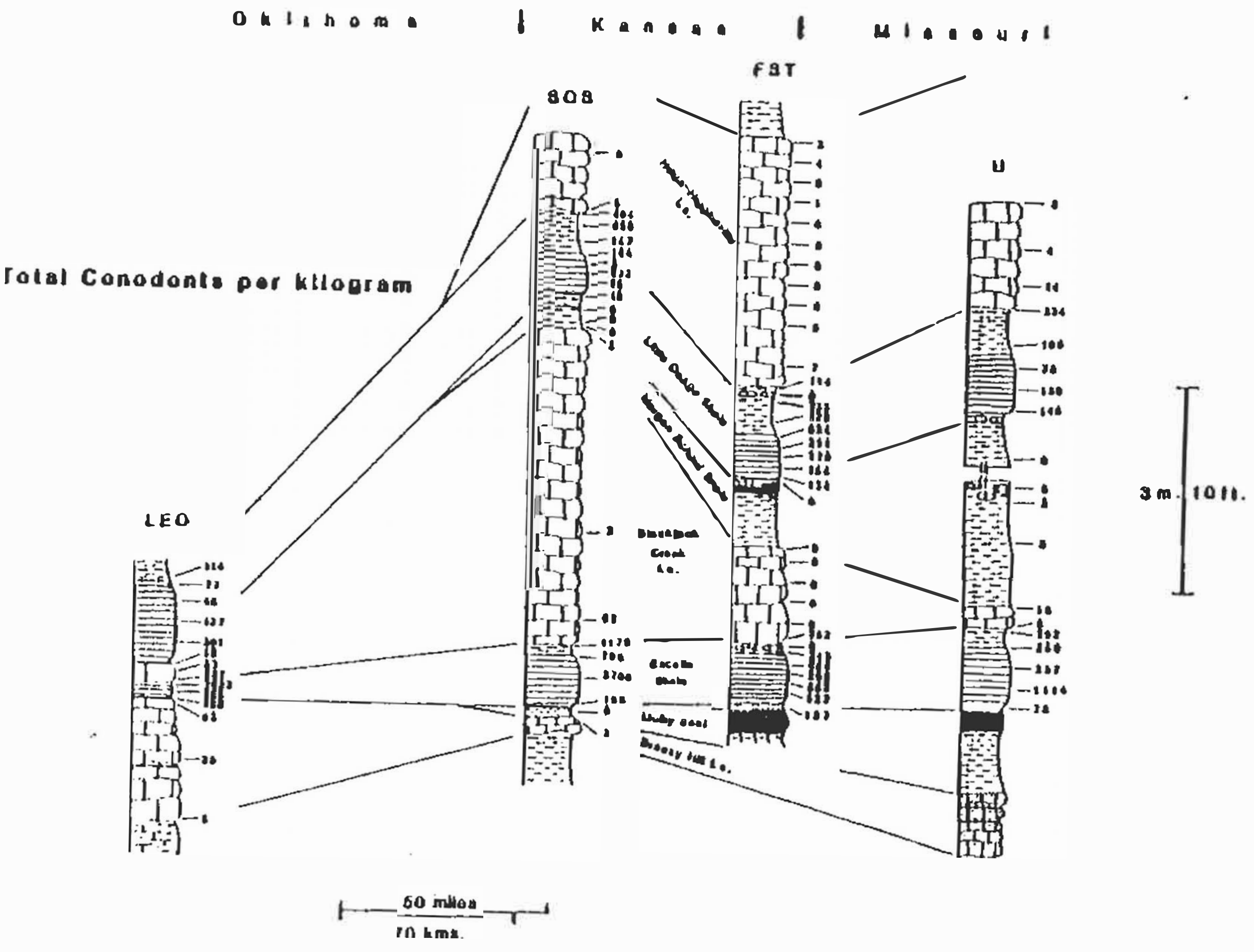
Conodont taxa identified in this study include those recognized and discussed by Baesemann (1973), Merrill and Merrill (1974), Merrill (1975), and Swade (1982).

Conodonts representing six different genera have been identified and placed in the following categories: 1) Adetognathus spp., 2) Anchignathodus minutus (=Ozarkodina minuta of some previous authors), 3) Gondolella spp., 4) Idiognathodus spp., 5) Idioprioniodus spp., and 6) Neognathodus spp. Only platform elements were included in abundance counts of Adetognathus, Anchignathodus, Gondolella, Idiognathodus, and Neognathodus. However, all elements of Idioprioniodus were included in abundance counts.

Vertical and Lateral Distribution

As previously reported for Desmoinesian (Swade, 1982) and Missourian (Heckel and Baesemann, 1975) cyclothems, maximum conodont abundance within the Breezy Hill Limestone-Wolverine Creek Formation interval occurs within the marine Excello and Little Osage Shales, the core shales of the Lower and Upper Fort Scott cyclothems, and decreases in both directions away from these shales (Fig. 34). Within

Figure 34. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing total abundance of combined conodont taxa. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.

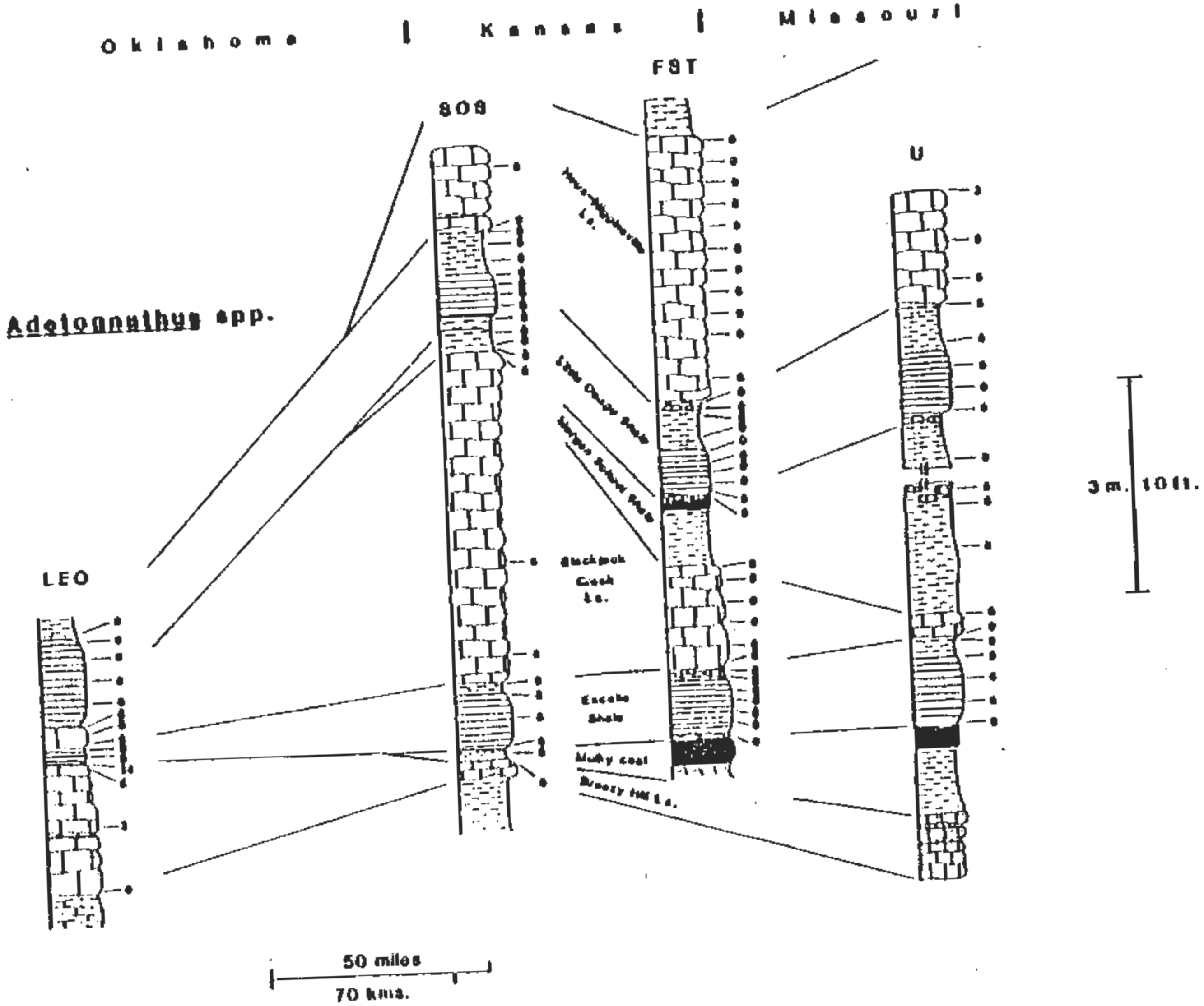

Oklahoma
Kansas
Missouri
Total Conodonts per kilogram
SOS
FST
U
LEO
Higginsville Ls.
Little Osage Shale
Blackjack Creek Ls.
Excello Shale
Mulky coal
Breezy Hill Ls.
3 m.
10 ft.
50 miles
70 kms.

the Excello Shale, maximum conodont abundance (almost 3000/kilogram at Section LEO) occurs consistently within the black shale facies. However, within the Little Osage Shale, maximum conodont abundance is generally less than in the Excello Shale (a maximum of 850/kilogram at Section SOS) and may occur within the overlying gray shale facies.

Adetognathus was recognized only from the southernmost section (Section LEO), where it occurs within the Breezy Hill Limestone, increasing slightly in abundance upward into an orange calcareous siltstone at the base of the Excello Shale, and from the northernmost section (Section U), where it occurs at the eroded top of the Houx-Higginsville Limestone (Fig. 35). Both of these lithologies are interpreted as shallow-water deposits. This is consistent with the finding of Swade (1982) that Adetognathus exhibits a distributional pattern compatible with a mode of life in a nearshore water mass, characterized by fluctuating environmental conditions.

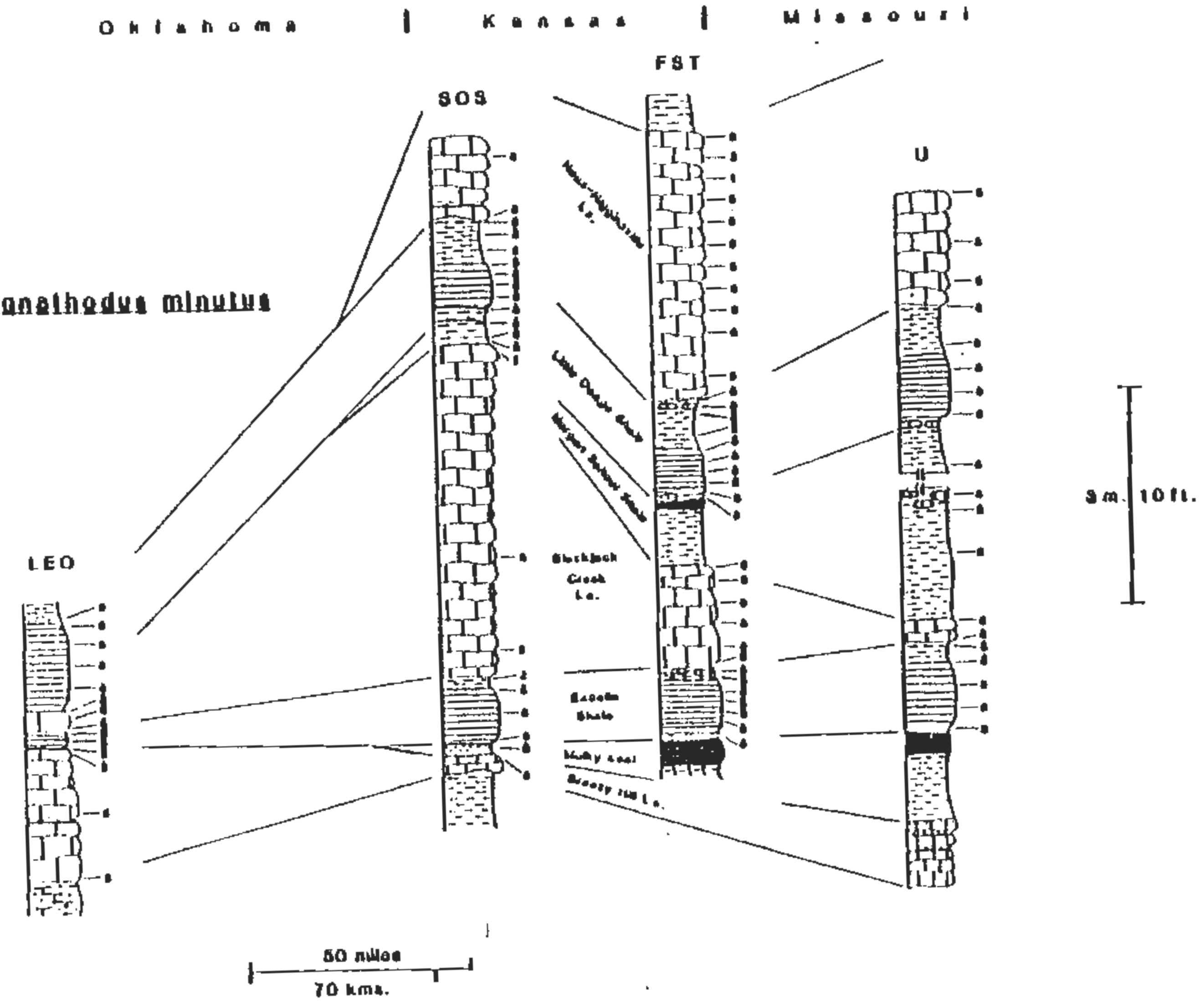
Anchignathodus minutus occurs within the shallow-water, marine Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones and occasionally within the deep-water gray shales overlying the black shale facies of the Excello and Little Osage Shales, but never within the black shale facies themselves (Fig. 36). Swade (1982) found Anchignathodus minutus within the Blackjack Creek, Houx, and Higginsville

Figure 35. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for Adetognathus spp.. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.



Adetognathus spp.

Figure 36. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for *Anchignathodus minutus*. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.



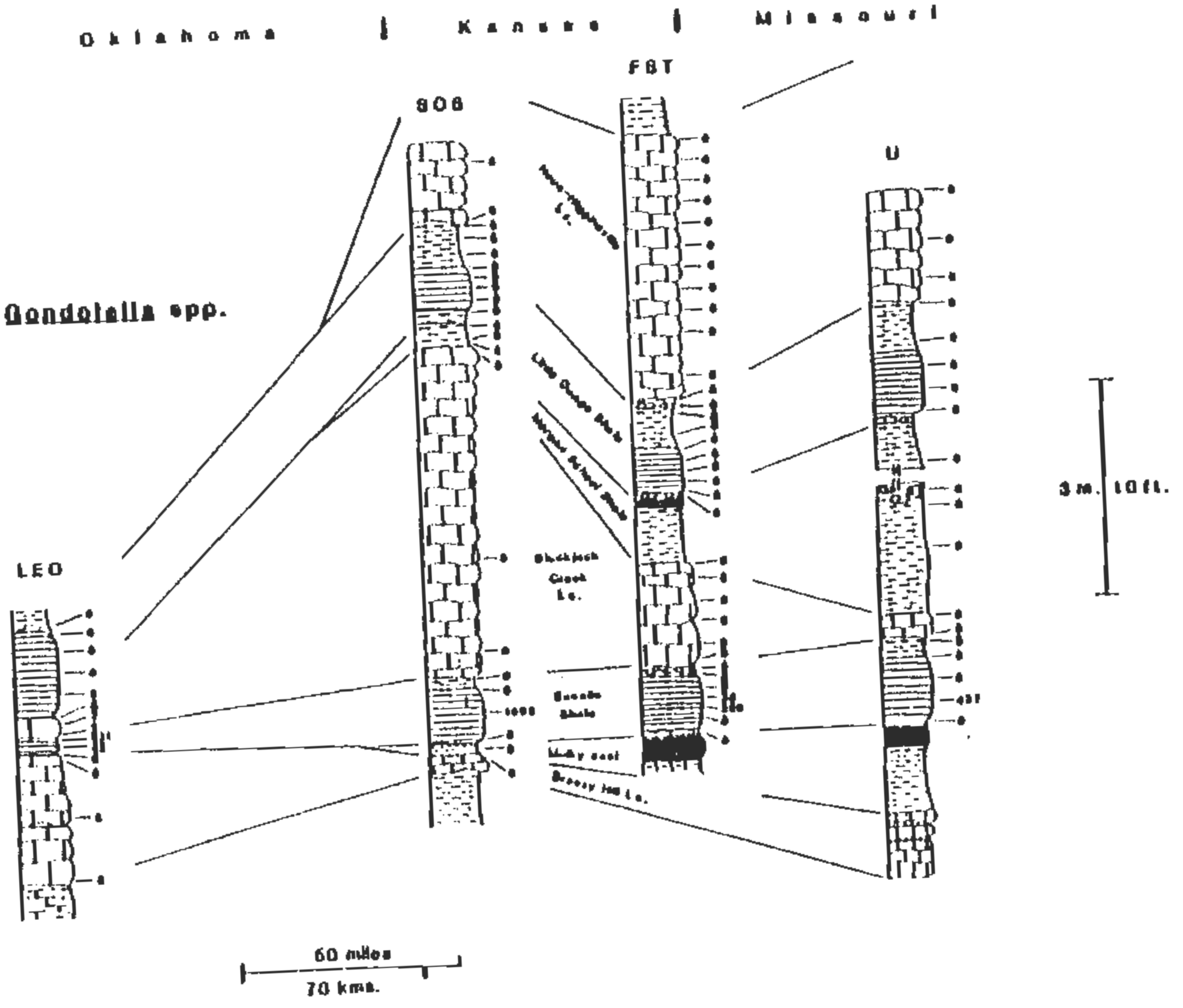
Anchignathodus minutus

Limestones of Iowa but not within the gray shale overlying the black shale facies of either the Excello or Little Osage Shales. He suggested that it was strongly restricted to carbonate lithologies representing oxygenated conditions within the photic zone; however, its rare presence within the gray shale of the Excello and Little Osage Shales implies a tolerance for a deeper, but still oxygenated bottom.

Gondolella was recognized almost exclusively from the Excello Shale, where it occurs abundantly in a thin, central zone within the black shale facies (Fig. 37). One *Gondolella* fragment was recovered from Section TC near the Kansas-Oklahoma border, in the center of a black phosphatic shale overlying a thick limestone previously identified as the Breezy Hill Limestone (Inden, 1968). This would put the *Gondolella* fragment in the Excello Shale, as expected. However, based on the field evidence of this study (see stratigraphy and petrography of Breezy Hill Limestone), the previous identification of this limestone as Breezy Hill is equivocal. It may actually be the Blackjack Creek Limestone, in which case *Gondolella* does occur rarely in the Little Osage Shale.

Of particular interest is the recovery of *Gondolella* from the thin Blackjack Creek Limestone at Leonard, near the edge of the Cherokee Platform. Swade (1982) has reported

Figure 37. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for *Gondolella* spp.. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.


Oklahoma
Kansas
Missouri
FBT
SOB
U
LEO
Gondolella spp.
Higginsville Ls.
Little Osage Shale
Morgan School Shale
Blackjack Creek Ls.
Excello Shale
Mulky coal
Breezy Hill Ls.
1000
437
3 m.
10 ft.
60 miles
70 kms.

scarce small elements of Gondolella in marginally marine detrital units separating upper and super limestones and in a conodont-rich, nodular carbonate zone in the Morgan School Shale. Otherwise, it is always found within core shales, including the Excello, but not the Little Osage. He has interpreted Gondolella as an offshore, deep-dwelling pelagic conodont. By considering that it was restricted to a particular deep, cold-water mass that became involved in upwelling only within certain cyclothems, he was able to explain its absence in the offshore Little Osage Shale. He attributed its presence in nearer-shore marine detrital units to transport while settling in upwelling currents. If his interpretations for the paleoecology of Gondolella are correct, then its presence in the Blackjack Creek Limestone near the edge of the Cherokee Platform suggests several possible explanations. The thin Blackjack Creek Limestone present there may represent allochthonus carbonate debris transported down the slope of the Cherokee Platform into the Arkoma Basin to the south. Or perhaps Gondolella elements were transported by the upwelling current during settling into the more shallow-water of the platform where the Blackjack Creek Limestone was accumulating.

Both Idiognathodus spp. (Fig. 38) and Neognathodus spp. (Fig. 39) have similar distributions in the Breezy Hill Limestone-Wolverine Creek Formation interval. They are

Figure 38. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for <u>Idiognathodus</u> spp.. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.

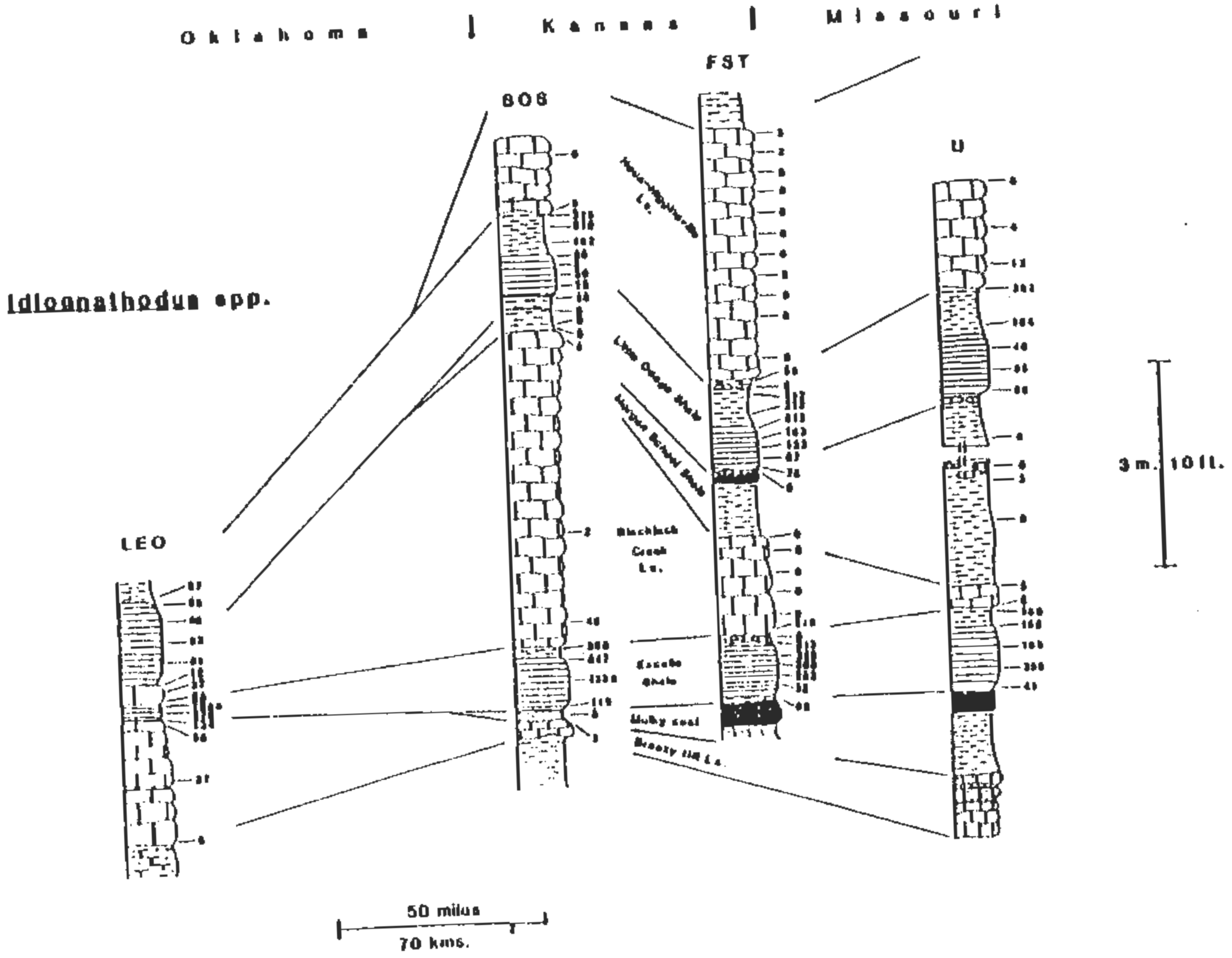
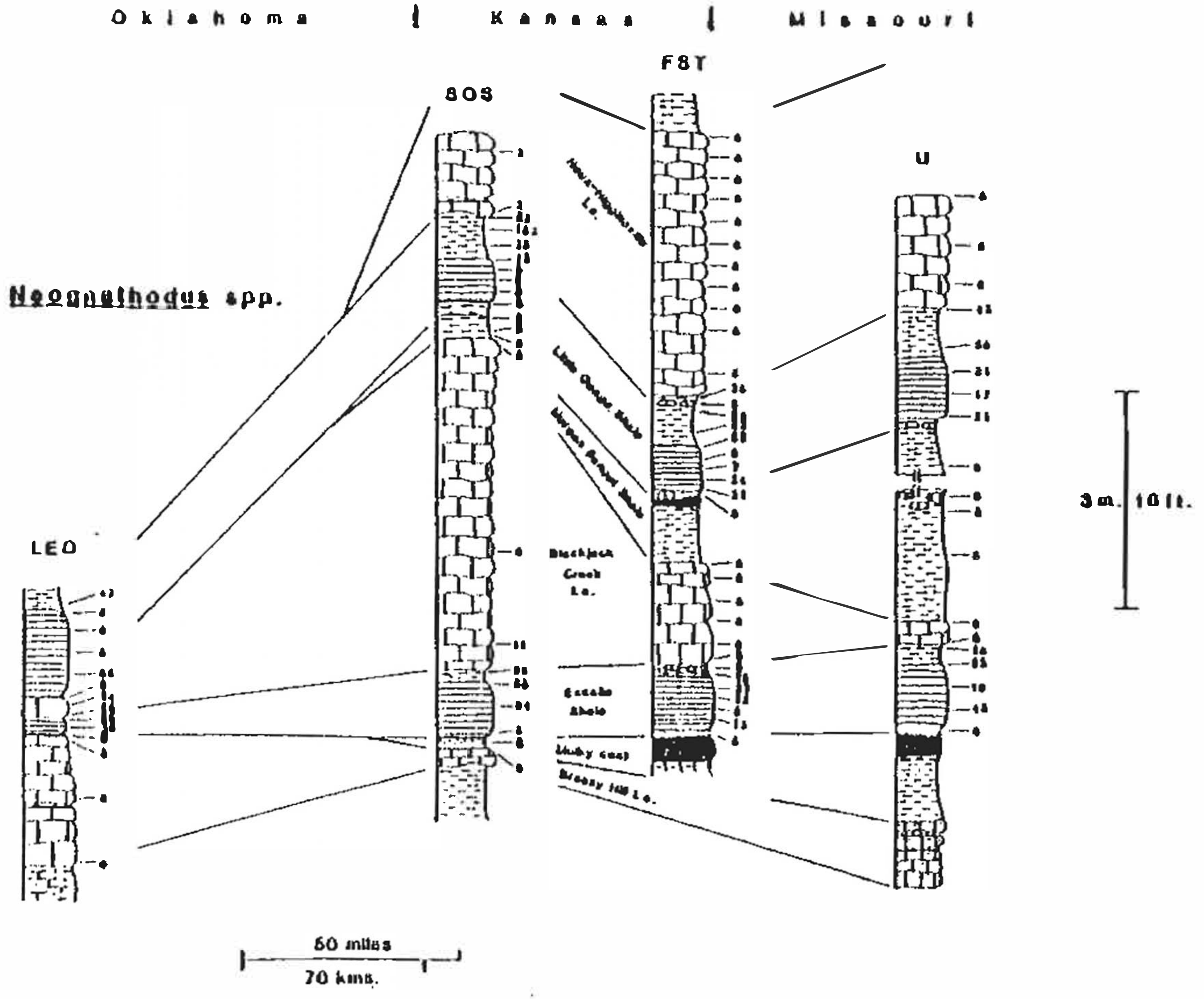

Oklahoma
Kansas
Missouri
FST
BOS
U
LEO
Idiognathodus spp.
Higginsville Ls.
Little Osage Shale
Morgan School Shale
Blackjack Creek Ls.
Excello Shale
Mulky coal
Breezy Hill Ls.
3 m. 10 ft.
50 miles
70 kms.

Figure 39. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for Neognathodus spp.. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.


Oklahoma
Kansas
Missouri
Neognathodus spp.
SOS
FST
U
LEO
Houx-Higginsville Ls.
Little Osage Shale
Morgan School Shale
Blackjack Creek Ls.
Excello Shale
Mulky coal
Breezy Hill Ls.
3m. 10 ft.
50 miles
70 kms.

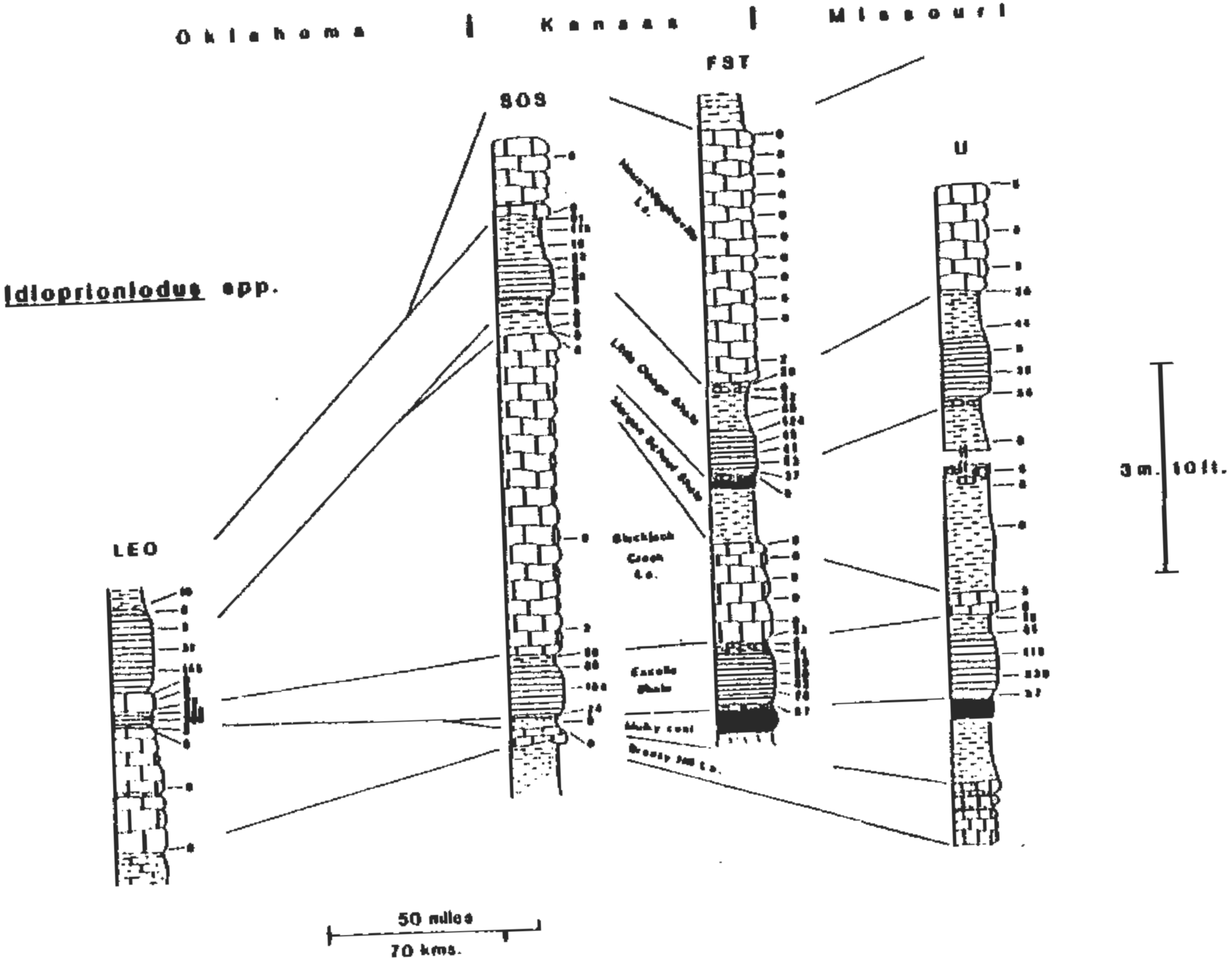
ubiquitous in the marine lithologies and exhibit maximum abundance within the core shales. These distributional trends are similar to those reported by Heckel and Baesemann (1975) and Swade (1982). They are thought to have been offshore surface-dwelling conodonts adapted to warm, well oxygenated water (Swade, 1982).

Idioprioniodus spp. are concentrated within the Excello and Little Osage core shales, but they are also present within the Blackjack Creek and Houx-Higginsville regressive limestones, concentrating near their contact with the underlying core shales (Fig. 40). This distribution is similar to that reported by Heckel and Baesemann (1975) and Swade (1982), who suggested that like Gondolella, Idioprioniodus was pelagic, inhabiting cool deep offshore waters.

Summary

This study has examined the conodont distribution of major taxa in the Breezy Hill Limestone, which is not present in Iowa. In addition, it confirms and extends the findings of Swade (1982) on conodont distributional patterns in the Dry Branch Creek Formation, Morgan School Shale, and Wolverine Creek Formation equivalents from Iowa, into western Missouri, southeastern Kansas, and northeastern Oklahoma. To summarize:

Figure 40. Cross-section of Breezy Hill-Houx-Higginsville Limestone interval showing abundance and distribution data for *Idioprioniodus* spp.. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.


Oklahoma
Kansas
Missouri
Idioprioniodus spp.
SOS
FST
U
LEO
Higginsville Ls.
Little Osage Shale
Morgan School Shale
Blackjack Creek Ls.
Excello Shale
Mulky coal
Breezy Hill Ls.
3 m.
10 ft.
50 miles
70 kms.

1 - Maximum conodont abundance occurs within the Excello and Little Osage Shales, interpreted as offshore, core shales of the Lower and Upper Fort Scott cyclothems.

2 - Completely absent from the black shale facies of the Excello and Little Osage Shales, *Adetognathus* spp. occurs only in lithologies interpreted as shallow-water deposits.

3 - *Anchignathodus minutus* was not as stongly restricted to carbonate lithologies as reported by Swade (1982). It is also found in the gray shale of the Excello and Little Osage Shales, suggesting a slight tolerance for a deeper, but still oxygenated bottom.

4 - *Gondolella* spp. occur within a thin zone within the black shale facies of the Excello but was not found in shale unequivocally identified as the Little Osage. *Gondolella* was also found in the overlying Blackjack Creek Limestone near the southern margin of the Cherokee Platform, suggesting either the allochthonus transport of carbonates into the deeper water of the Arkoma Basin or of the conodonts into the more shallow water on the platform.

5 - *Idiognathodus* spp. and *Neognathodus* spp. have similar distributional trends, occurring ubiquitously in marine lithologies and exhibiting maximum abundance within the Excello and Little Osage Shales.

6 - <u>Idioprioniodus</u> spp. concentrate in the Excello and Little Osage Shales but also occur near the base of the Blackjack Creek and Houx-Higginsville regressive limestones.

7 - The presence of <u>Idiognathodus</u>, <u>Idioprioniodus</u>, and <u>Neognathodus</u> within the anoxic black shale facies of the Excello and Little Osage Shales, and in addition, of <u>Gondolella</u> within the black shale facies of the Excello Shale, support the pelagic mode of life postulated for these taxa by Heckel and Baesemann (1975) and Swade (1982).

CHAPTER VII

DISCUSSION

Stratigraphy

Breezy Hill Limestone

From Oklahoma into southeastern Kansas the Breezy Hill Limestone exists as a marine lithologic unit between the underlying Cabaniss Formation and the overlying Mulky coal (Fig. 41a) or Excello Shale where the Mulky coal is absent. In this position most would probably agree that its sediments succeeded the sediments of the Cabaniss Formation in time and preceeded those of the Mulky coal or Excello Shale. However from southeastern Kansas northward into Illinois, lower portions and finally the entire interval take on very different characteristics. No longer a depositional lithologic unit at all, the evidence strongly suggests that the lower portions, and northward, the entire Breezy Hill interval represent a diagenetic lithologic unit (rhizolite/caliche), which resulted from the alteration of previously deposited sediments (Fig. 41b).

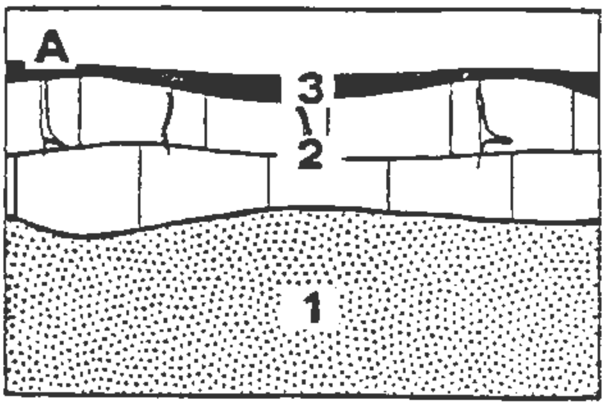
In southeastern Kansas where this diagenetic lithology developed within the marine sediments at the base of the Breezy Hill Limestone and at the top of the Cabaniss

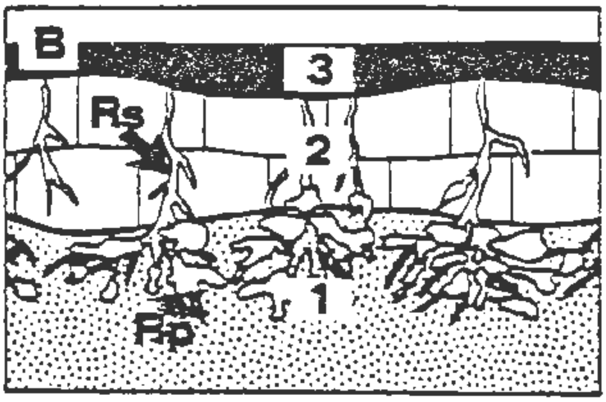
Figure 41. Development of facies in Breezy Hill Limestone rhizolite-horizon. Series of cartoons illustrate development of rhizolite-horizon (small brick pattern) within previously deposited Cabaniss Formation sediments (sand pattern) and marine Breezy Hill Limestone sediments (large brick pattern), probably near the time of Mulky coal (black) deposition. Numbers down center column indicate relative timing of sedimentary and diagenetic deposits as interpreted from this study: 1(oldest) to 3(youngest).

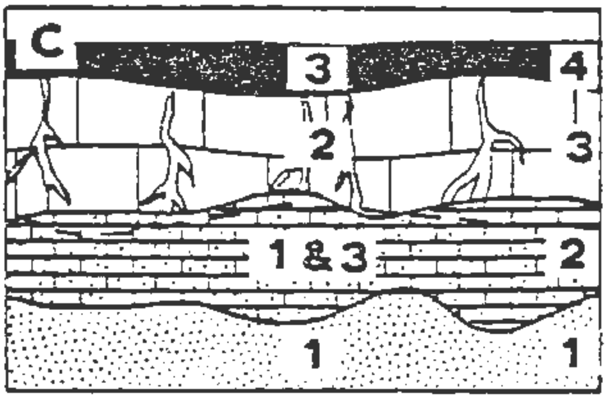
a) Law of Superposition suggests initial deposition of Cabaniss Formation (1) followed by Breezy Hill Limestone (2) and finally Mulky coal (3). Note incipient development of root system into top of Breezy Hill shortly before or during development of overlying coal swamp.

b) As root system passed through earlier lithified Breezy Hill sediments, rhizosheaths Rs) developed, resulting in only minor alteration to sediments; initial passage of root system into lightly lithified Cabaniss sediments resulted in incipient development of major sediment-altering rhizopatches (Rp). If examined at this point in their development, rhizopatches would probably be correctly interpreted as developing subsequent to marine Breezy Hill sediments.

c) Completed development of rhizolite-horizon resulted in stratigraphic inversion with well lithified younger unit (small brick pattern) located below older Breezy Hill Limestone. Rhizolite-horizon includes earlier deposited sediment of Cabaniss age (1, middle column) but consists of material and shows a texture predominately developed during time of Mulky coal deposition (3, middle column). Right column indicates previous ordering of depositional events based on misinterpretation of rhizolite-horizon as depositional unit.


A
3
2
1


B
3
Rs
2
1
Fp


C
3
4
2
3
1 & 3
2
1
1

Formation, stratigraphic position is turned upside down. Although the rhizolite-horizon is stratigraphically below much of the marine lithology of the Breezy Hill, it developed subsequently, probably during the time of soil formation prior to development of the overlying coal swamp (Fig. 41c). Yet previous workers, interpreting the entire Breezy Hill Limestone interval as a depositional lithology have also interpreted its depositional history accordingly. Using Steno's Law of Superposition, they suggested that the deposition of Cabaniss sediments was followed by an unusual type of restricted marine to nonmarine sedimentation before more open marine and finally nonmarine coal deposition occurred (Fig. 41c). In point of fact, the Law of Superposition itself, as commonly taught, does not distinguish between depositional and diagenetic sedimentary strata, although they have very different origins:

> Law of Superposition - A general law upon which all geologic chronology is based. In any sequence of sedimentary strata (or of extrusive igneous rocks) that has not been overturned, the youngest stratum is at the top and the oldest at the base; i.e., each bed is younger that (sic) the bed beneath, but older than the bed above it.
>
> Bates and Jackson [1980:354]

Our rapidly expanding recognition of these diagenetic strata (rhizolites and caliche) in the geologic record requires a refinement to the way we teach and interpret the Law of Superposition: "sedimentary strata" refer only to units whose predominant, identifying characteristics are depositional, not diagenetic.

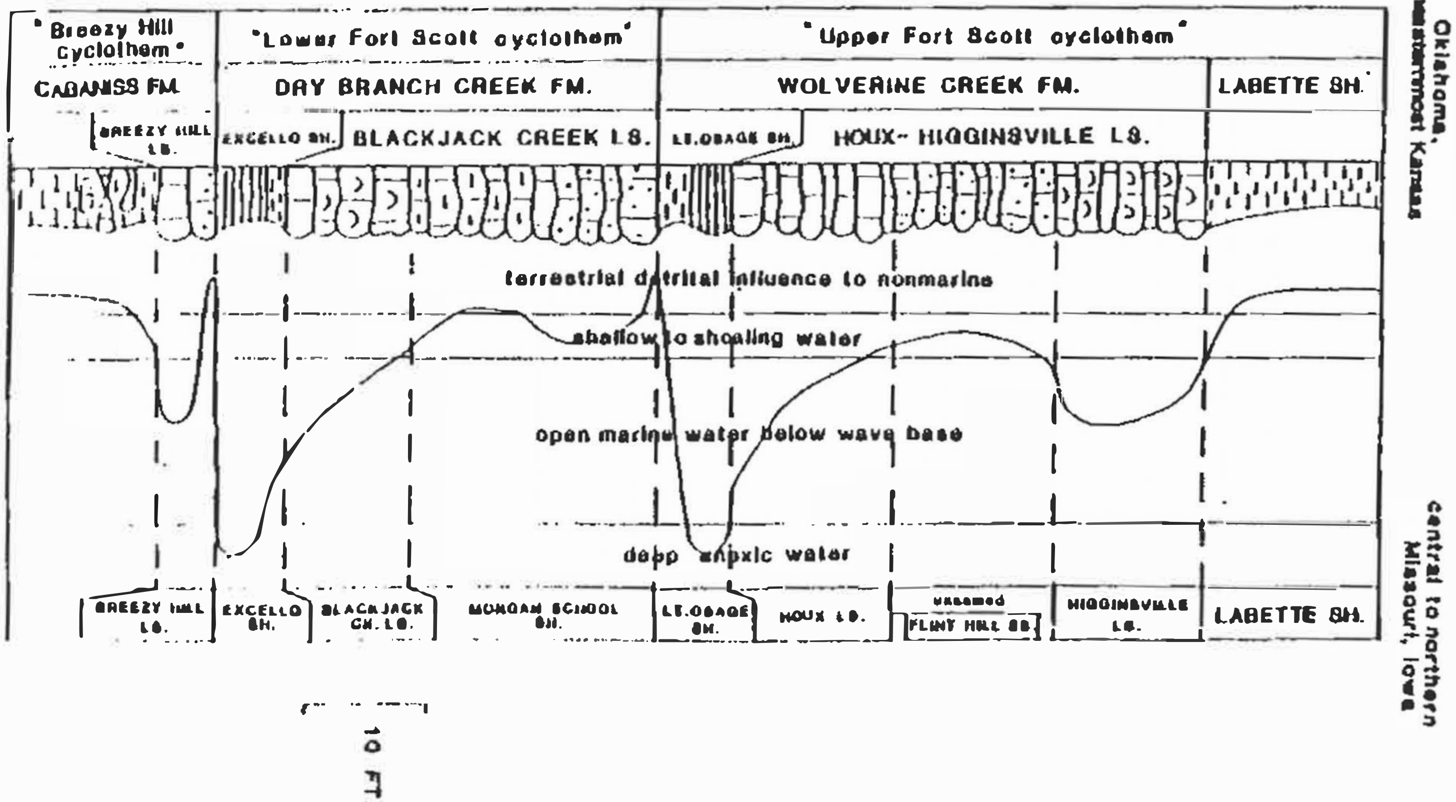
Excello and Little Osage Shales

Examination of conodonts from the Excello and Little Osage Shale intervals from northeastern Oklahoma into western Missouri confirms the finding by Swade (1981): Gondolella sp. is restricted to the Excello Shale interval and may be used as a supplement with other stratigraphic data to distinguish between the Dry Branch Creek and Wolverine Creek Formations.

Dry Branch Creek Formation

Figure 42 illustrates the interpreted stratigraphic relationships between members of the Dry Branch Creek Formation in southeasternmost Kansas and in central to northern Missouri and Iowa. Based on stratigraphic position between the approximate time lines represented by the Excello and Little Osage Shales and on depositional evidence, the entire thin marine Blackjack Creek Limestone interval through Missouri and Iowa is equivalent to only the lower third of the open marine portion of the Blackjack Creek farther south in Kansas and Oklahoma. The overlying transitional marine to nonmarine Morgan School Shale, dominating the Excello-Little Osage interval in Missouri and

Figure 42. Stratigraphic relationships and interpreted depositional history of Breezy Hill and Lower and Upper Fort Scott cyclothems illustrated in terms of a sea level curve. Stratigraphic column based on lithologies in Core PMC.


"Breezy Hill cyclothem"
"Lower Fort Scott cyclothem"
"Upper Fort Scott cyclothem"
CABANISS FM.
DRY BRANCH CREEK FM.
WOLVERINE CREEK FM.
LABETTE SH.
BREEZY HILL LS.
EXCELLO SH.
BLACKJACK CREEK LS.
LT. OSAGE SH.
HOUX- HIGGINSVILLE LS.
terrestrial detrital influence to nonmarine
shallow to shoaling water
open marine water below wave base
deep anoxic water
BREEZY HILL LS.
EXCELLO SH.
BLACKJACK CK. LS.
MORGAN SCHOOL SH.
LT. OSAGE SH.
HOUX LS.
unnamed
FLINT HILL SS.
HIGGINSVILLE LS.
LABETTE SH.
Oklahoma, southeasternmost Kansas
central to northern Missouri, Iowa
10 FT.

Iowa, is equivalent to the remaining upper two-thirds of the Blackjack Creek Limestone in Kansas and Oklahoma, where it consists of argillaceous, more turbid marine lithologies in the middle and slightly more open, but shoaling marine facies at the top. This represents an expected southward transition from shoreline to shallow marine facies during a more regressive phase of deposition.

Wolverine Creek Formation

Based on stratigraphic position between the underlying Little Osage Shale and overlying Labette Shale, on similarities between interpreted subsurface lithologies in east-central Kansas and outcrop lithologies in western Missouri, and on depositional characteristics, Figure 42 illustrates the interpreted stratigraphic relationships between members of the Wolverine Creek Formation in southeasternmost Kansas and in central to northern Missouri and Iowa. The open marine Houx Limestone, present from central Missouri into Iowa, is the lateral equivalent to the lower third, open marine portion of the Houx-Higginsville Limestone in Kansas. The siliciclastics between the Houx and Higginsville Limestones from central Missouri into Iowa, portions of which are called the Flint Hill Sandstone, are probably the lateral equivalent to the more shallow to shoaling-water facies developed through the middle of the Houx-Higginsville in Kansas. The open marine Higginsville

Limestone, which constitutes less than the top quarter of the Wolverine Creek Formation through much of Missouri and Iowa, is the lateral equivalent to the more open marine limestone dominating the top of the Houx-Higginsville in Kansas.

Depositional History

Figure 42 summarizes the depositional history of the interval between the upper Cabaniss Formation and the lower Labette Shale. Three clearly delineated cyclothemic sequences are represented in this interval: the Breezy Hill, Lower Fort Scott, and Upper Fort Scott cyclothems.

Breezy Hill Cyclothem

The Breezy Hill cyclothem includes the interval between the nearshore deltaic siliciclastics within the Cabaniss Formation and the base of the Excello Shale or the top of the Mulky coal, where present (Figs. 3, 42). The least developed of the three cyclothems, it lacks a distinct transgressive lithology and even at maximum transgression its deepest water facies occurs within the Breezy Hill Limestone only from west-central into northeastern Oklahoma. Nowhere has the core shale lithology, so typical of the "Kansas cyclothem", been identified.

The maximum northward extent of the Breezy Hill sea is marked by a shoaling marine facies in Crawford County in southeastern Kansas. As indicated by the nonmarine "Mulky coal zone", Mulky coal, and the caliche/rhizolite facies of the Breezy Hill Limestone, the sea retreated as far south as northern Craig County, Oklahoma, before the onset of the next transgression that was responsible for the Lower Fort Scott cyclothem.

In relationship to many of the other widespread eustatic transgressions of the Pennsylvanian, the transgression that culminated in the open marine Breezy Hill Limestone in Oklahoma had a very limited areal extent, and currently cannot be correlated with a similar event in other parts of the world. Therefore, the major argument in favor of eustasy as a causative agent is lacking and sudsidence, coupled with a slowdown in deltaic sedimentation, cannot be ruled out. In fact, a case can be made for the latter of these two causes. As will be argued shortly, the Kansas-Oklahoma Border Trend, where the open marine facies of the Breezy Hill Limestone is thickest, was a subsiding hingeline between the Arkoma Basin to the south and the Cherokee Platform to the north. With a slowdown in deltaic sedimentation, whether due to climatic conditions or delta-lobe abandonment, this area could have developed a thick shallowing-upward carbonate sequence that would have prograded southward toward the basin, giving the appearance of a eustatic oscillation in sea level. Both the presence of the extensive caliche/rhizolite profile that developed subsequent to the marine Breezy Hill Limestone in Kansas and the lack of a thick overlying outside shale argue for the slowdown of deltaic sedimentation as the likely mechanism responsible for the Breezy Hill cyclothem.

Lower Fort Scott Cyclothem

The Lower Fort Scott cyclothem includes the interval between the base of the marine Excello Shale (or the top of the Breezy Hill Limestone at a few localities in Oklahoma) and the base of the marine Little Osage Shale (Figs. 3, 42). The thin, discontinuous, pyritized skeletal lithology at the base of the Excello Shale north of the Kansas-Oklahoma border, the dense skeletal packstone at the top of the Breezy Hill Limestone in Nowata County, Oklahoma, and perhaps the overcompacted oolitic calcarenite containing diagenetic features of a transgressive limestone at the top of the Breezy Hill Limestone in Tulsa County, Oklahoma, are interpreted as the middle (transgressive) limestone of the Lower Fort Scott cyclothem. This transgression was very widespread, culminating in the overlying core shale represented by the phosphatic black shale, gray shale, and claystone of the Excello Shale from at least west-central Oklahoma into Iowa and Illinois. The great lateral extent of this transgression argues strongly for a eustatic event.

With regression, the Blackjack Creek Limestone and its equivalents were deposited from Illinois into Oklahoma. As the sea retreated farther south, an influx of siliciclastics ended carbonate production north of several topographic highs in east-central Kansas and western Missouri, depositing the lower part of the Morgan School Shale and producing an argillaceous-rich lithology within the Blackjack Creek Limestone in portions of Kansas and Oklahoma. However, the return to a less argillaceous lithology within the BlackjackCreek Limestone in Kansas and Oklahoma and a more open marine carbonate-rich lithology within the Morgan School Shale in Missouri and Iowa (Fig. 42) indicate a brief but widespread return to less turbid conditions. The widespread nature of the slowdown in siliciclastic influx argues against the generally more areally restricted effects of delta-lobe abandonment and most likely resulted from a drier climate or a minor eustatic transgression. The presence of rhizoliths in the top of the Blackjack Creek Limestone only as far south as Labette County, Kansas, indicates that the sea finally retreated at least this far south before the onset of the next transgression.

Upper Fort Scott Cyclothem

The Upper Fort Scott cyclothem includes the interval from the base of the Little Osage Shale and into the Labette

Shale (Figs. 3, 42). It represents a very widespread cyclothem with characteristics remarkably like those of the Lower Fort Scott cyclothem. The thin rather persistent fossiliferous marine shale and interbedded, less persistent fossiliferous calcilutite at the base of the Little Osage Shale represent the middle (transgressive) unit of the "Kansas cyclothem". The widespread and laterally continuous phosphatic black shale, gray shale, and claystone of the Little Osage Shale were deposited during and just after maximum transgression and represent the core shale. The widespread nature of this transgression argues for a eustatic event.

The Houx-Higginsville Limestone from Oklahoma into western Missouri and the Houx Limestone northward into Iowa were initially deposited as the sea shallowed. As regression continued, an influx of siliciclastics, including the Flint Hill Sandstone, north of several topographic highs in east-central Kansas and western Missouri, ended deposition of the Houx Limestone. During this time, carbonate production continued uninterrupted in southeastern Kansas as a chaetetid bioherm, and nearer the Kansas-Oklahoma border, as a shallow-water lithology that developed within the Houx-Higginsville Limestone. Subsequently, a minor but widespread eustatic transgression or a temporary halt to the regression coupled with a drier climate and continued subsidence allowed more open marine carbonates to redevelop within the Houx-Higginsville Limestone from Oklahoma into western Missouri and allowed the Higginsville Limestone to replace siliciclastic deposition from Missouri into Iowa. The presence of rhizoliths and solution vugs in the top of the Houx-Higginsville Limestone in Bourbon County, Kansas, are an indicator that the sea retreated at least this far south before the onset of Labette Shale sedimentation.

Summary

The widespread extent of maximum transgression in both the Lower and Upper Fort Scott cyclothems argue for a eustatic event. However, neither cyclothem contains only the simple upper (regressive) limestone of the "Kansas cyclothem" model. Within their regressive lithologies both cyclothems developed a widespread shallow-water carbonate and/or siliciclastic-rich lithology and subsequently resumed production of a more open marine or more argillaceous-free carbonate before the final withdrawal of their respective seas. In formulating his concept of megacyclothems, Moore (1936, 1949) recognized that the higher lithologies of numerous cyclothems include two limestones separated by a nearshore to nonmarine unit. He called the lower of the two limestones, the "upper" limestone, and the upper of the two, the "super" limestone. Subsequently, Heckel and Baesemann

(1975) and Heckel (1977) regarded the super limestone as part of the upper limestone, owing its separate identity to a fortuitous intervening shale. However, Swade (1982) suggested that five of the six cyclothems he had identified within the Marmaton contain super limestones, and this study confirms that the sixth (the Lower Fort Scott cyclothem) contains one as well, strongly suggesting that more than coincidence is involved. It is proposed that some basic mechanism, either connected directly to glacial eustatic events or indirectly to variations in climate, is responsible for consistently producing these super limestones within the Middle Pennsylvanian Marmaton Group and perhaps into the Upper Pennsylvanian as well.

Diagenesis

The diagenetic model proposed by Heckel (1983) for Midcontinent Pennsylvanian cyclothems details the diagenetic characteristics of both the middle (transgressive) and upper (regressive) limestones of the typical "Kansas cyclothem" (Chapter I). Having examined the diagenesis of the limestones within three consecutive cyclothems, it is appropriate to review their compatibility with his model.

The Breezy Hill cyclothem lacks a distinct transgressive limestone. On the other hand, along most of the outcrop in Oklahoma its regressive limestone is well developed and contains a sequence of diagenetic events compatible with the Heckel model. Of particular interest is the meteoric caliche/rhizolite, probably developed near maximum regression within the marine siliciclastics of the Cabaniss Formation and within the marine carbonates at the north end of the Breezy Hill Limestone. This represents perhaps the best development of mainly terrestrial diagenetic carbonate identified from a Midcontinent Pennsylvanian cyclothem. Such horizons may provide the best diagenetic evidence for the extent and possibly the duration of the withdrawal of the sea from the craton.

The depositional and diagenetic history of the Breezy Hill Limestone along the platform-edge in Oklahoma is more complex. Here the top of the Breezy Hill Limestone incorporates depositional features of a regressive limestone and diagenetic features of a transgressive limestone, probably as a consequence of a rapid transgression that abruptly terminated the deposition of the regressive facies. The point is that transgressive depositional and diagenetic facies are distinct from one another, as are regressive depositional and diagenetic facies. Since the diagenesis of a sediment always follows or at most is concurrent with deposition, they need not always occur together.

Both the Lower and Upper Fort Scott cyclothems contain a transgressive lithology that is thin and discontinuous and

[redacted]

is dominated by calcareous shale. However, at several localities both cyclothems include a better developed transgressive limestone. In Nowata County, Oklahoma (Section MON), the top of the Breezy Hill Limestone consists of a packstone that is interpreted as the transgressive limestone of the Lower Fort Scott cyclothem. Its overcompaction, preservation of organic material, and the presence of ferroan dolomite are all diagenetic characteristics predicted by the Heckel model for transgressive limestones. In a similar fashion, a lithology interpreted as the transgressive limestone of the Upper Fort Scott cyclothem in Bourbon County, Kansas (Section FST), consists of an overcompacted, organic-rich skeletal packstone.

The Lower and Upper Fort Scott cyclothems each contain a well-developed regressive limestone and consistently exhibit the sequence of diagenetic events predicted by the Heckel model. This sequence begins with occasional early marine and mixing zone cementation followed in order by meteoric phreatic neomorphism and cementation, meteoric leaching, and the rather ubiquitous late-stage deeper-burial connate diagenesis. In particular, minor nonferroan dolomite rhombs and nodular cherts, which probably formed in the mixing zone, occur principally along the north side of the Kansas-Oklahoma Border Trend; solution vugs, which are perhaps the strongest evidence for meteoric leaching, occur along the Bourbon Arch; and most late-stage silica and ferroan dolomite cements occur in proximity to argillaceous-rich lithologies, confirming the finding of McHargue and Price (1982).

Depositional Structure and Topography

Evidence presented in this study suggests the possible presence of the following structures during the deposition of the Breezy Hill and Lower and Upper Fort Scott cyclothems: 1) Saline County Arch, 2) Ladue-Freeman Anticline, 3) Schell City-Rich Hill Anticline, 4) Bourbon Arch, 5) Nemaha Anticline, and 6) Kansas-Oklahoma Border Trend.

Saline County Arch

Only the thinning of a lobe in the Morgan School Shale southward against this structure suggests that it was a topographic high during the Lower Fort Scott cyclothem.

Ladue-Freeman and Schell City-Rich Hill Anticlines

The Morgan School Shale, within the Lower Fort Scott cyclothem, and the siliciclastic interval between the Houx and Higginsville Limestones, within the Upper Fort Scott cyclothem, are outside shales deposited during relatively low stands of sea level. Their significant thinning southward across the Ladue-Freeman and Schell City-Rich Hill Anticlines suggest that these structures were topographic highs and effectively barred the southward migration of siliciclastics. Additional evidence confirming the Schell City-Rich Hill Anticline as a topographic high are the thinning of the Excello Shale and the loss of its deep-water black shale facies over the anticline and the presence of a shoal-water facies at the top of the Blackjack Creek Limestone and of rounded to angular intraclasts within the middle of the Houx-Higginsville Limestone over the anticline during a time of lower sea-level.

Bourbon Arch

The black shale facies of neither the Excello or Little Osage Shales appear to thin over the arch along outcrop, suggesting that it had little effect on deep-marine sedimentation. However, the Morgan School Shale and the siliciclastic interval that splits the Houx-Higginsville Limestone in the subsurface appear to thin dramatically southward across the extension of the Bourbon Arch in the subsurface of east-central Kansas. In addition, the presence of quartz-silt and rooted lithologies in the Blackjack Creek Limestone, of rounded to angular intraclasts within the middle of the Houx-Higginsville Limestone during a time of lower sea level, and of a rooted and highly leached lithology at the top of the Houx-Higginsville over the arch suggest it had a significant effect on shallow-water sedimentation and subaerial diagenesis during lower Marmaton deposition.

Nemaha Anticline

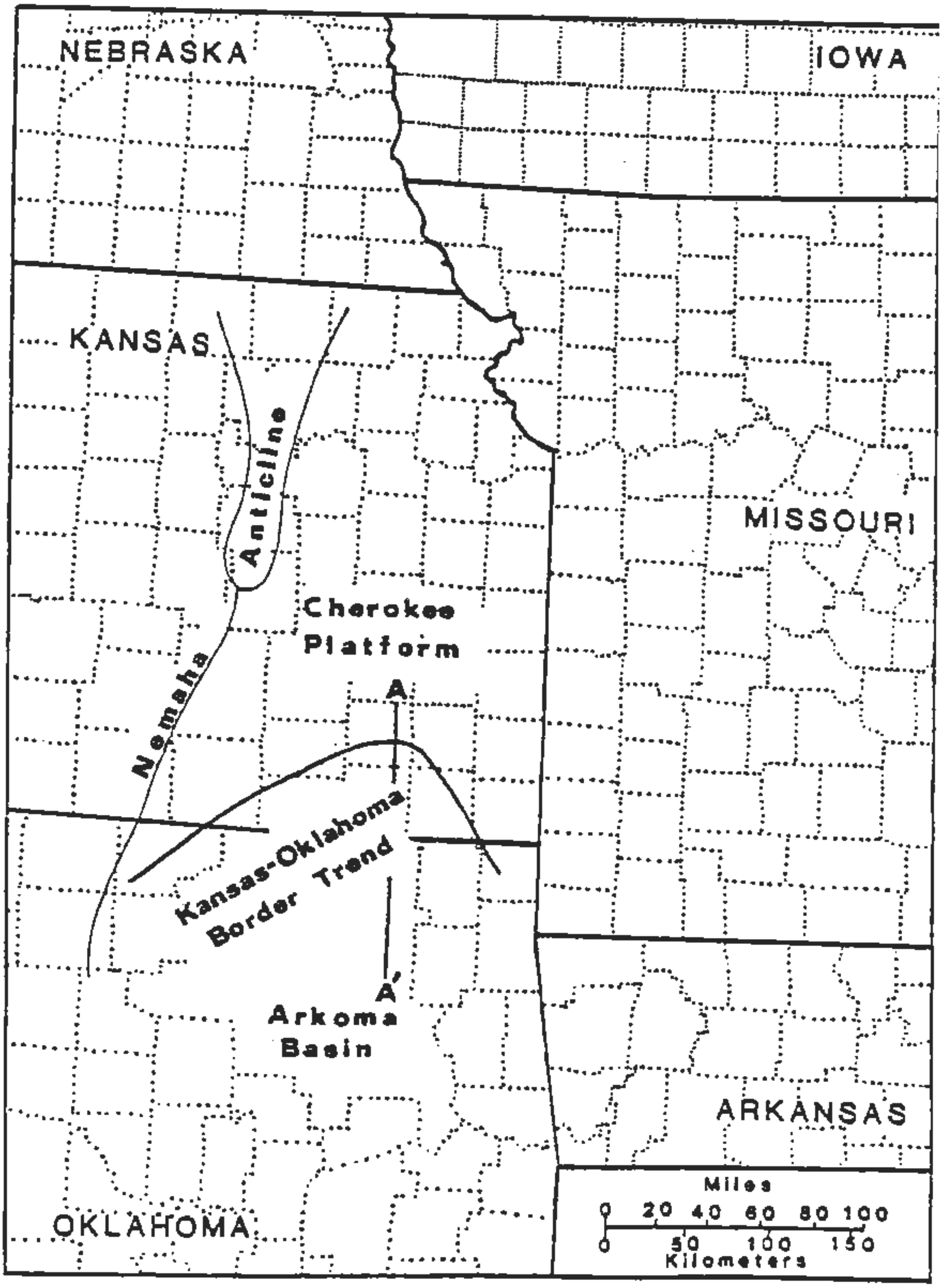
The knob-like thickening of both the Blackjack Creek and the Houx-Higginsville Limestones in the subsurface directly over the same area of the Nemaha Anticline in Marion, Butler, and Chase Counties, Kansas, suggest that portions of the anticline still maintained significant relief over the Cherokee Platform to the east during deposition of the Lower and Upper Fort Scott cyclothems. It is interesting to speculate that these knob-like thickenings represent localized algal mounds or shallow-water facies such as oolite shoals.

Kansas-Oklahoma Border Trend

Occurring between the Cherokee Platform to the north and the Arkoma Basin to the south (Fig. 43), the Kansas-Oklahoma Border Trend includes most of Osage, Washington, Nowata, and northwestern Craig Counties in Oklahoma, and Chautauqua, Montgomery, and western Labette Counties in Kansas.

The Kansas-Oklahoma Border Trend significantly affected sedimentation from at least upper Cherokee into lower Marmaton deposition. During deposition of the upper

Figure 43. Kansas-Oklahoma Border Trend. Interpreted as the hingeline between Cherokee Platform to the north and Arkoma Basin to the south. Line A-A' indicates approximate position of idealized cross-section shown in Figure 44.


NEBRASKA
IOWA
KANSAS
MISSOURI
Nemaha Anticline
Cherokee Platform
A
Kansas-Oklahoma Border Trend
A'
Arkoma Basin
ARKANSAS
OKLAHOMA
Miles
0 20 40 60 80 100
0 50 100 150
Kilometers

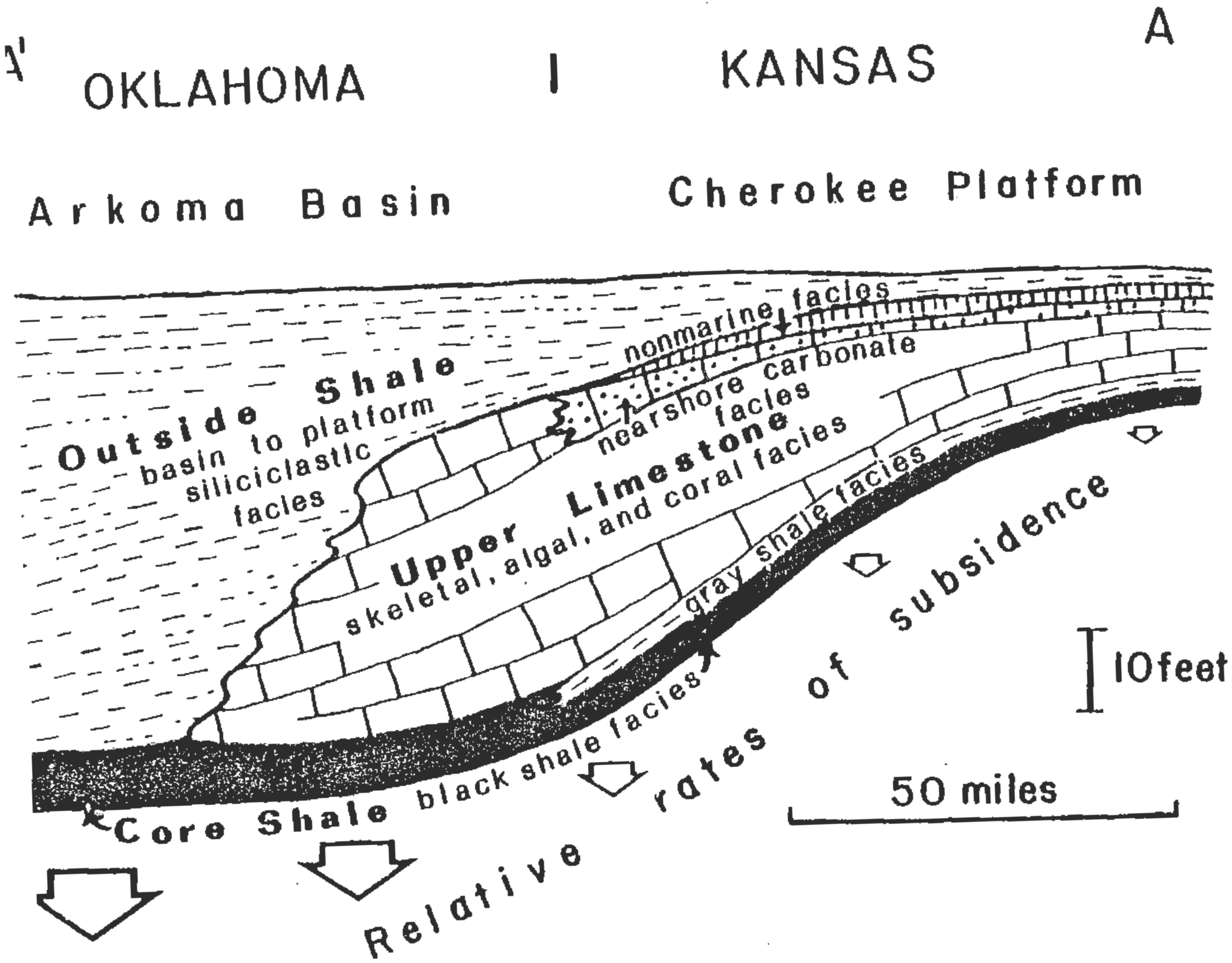
Cherokee, while the Cherokee Platform was dominated by nearshore deltaic sedimentation, a distinct area of thinning occurred along the Kansas-Oklahoma Border Trend (Fig. 8). However, during the later deposition of the Breezy Hill and the Lower and Upper Fort Scott cyclothems, substantial thickening occurred in both core (offshore) shales and in regressive limestones over the trend. The Breezy Hill (Fig. 12), Blackjack Creek (Fig. 19), and the Houx-Higginsville (Fig. 22) Limestones, each representing a shallowing-upward sequence, thicken along the trend and thin to the southeast. The black shale facies of both the Excello (Fig. 10) and the Little Osage (Fig. 11) Shales, representing deep-water, sediment-starved deposition on an anoxic bottom, are thicker along the trend, thinning by almost fifty percent onto the Cherokee Platform to the north. And finally, during the regression that ended the Upper Fort Scott cyclothem, the nearshore Labette Shale thickened markedly over the trend (Fig. 24).

Based primarily on the development of an algal mound in the Pawnee Limestone, the area along the south side of the Kansas-Oklahoma Border Trend had previously been considered by Price (1981) as a topographic high ("Shelf Edge Rise", Fig. 7). In light of the thickening of the Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones along the trend, it is tempting to speculate that it was also a topographic high during upper Cherokee and lower Marmaton deposition. However, the substantial thickening that occurred in the black shale facies of both core shales between these limestones along the trend, suggest that it actually represented a subsiding hingeline between the more rapidly subsiding Arkoma Basin to the south and the relatively stable Cherokee Platform to the north (Fig. 43).

This conclusion is based on the interpretation that the core shales of Midcontinent Pennsylvanian cyclothems are deposited in deep sediment-starved areas and that the black shale facies of the core shale was deposited below a thermocline in even deeper oxygen-starved water than was the overlying fossiliferous gray shale and claystone facies. Although other factors, such as the rates of influx of fine-grained sediments from coastal margins or the winnowing of sediments by deep-marine currents, may play some part, under sediment-starved conditions, the relative thicknesses of the core shales primarily should reflect the duration of sedimentation in deep-marine water. Therefore, assuming other factors are constant, if a core shale maintains its thickness between two areas then both areas experienced equal durations of deep-marine sedimentation. In addition, if the black shale facies within that core shale is thicker over one of the two areas and thins over the other by being replaced by the fossiliferous gray shale and claystone facies, then the area with the thicker black shale was at an even greater depth during deposition of the core shale and remained below the thermocline for a longer time as the sea shallowed. From the Kansas-Oklahoma Border Trend onto the Cherokee Platform, the black shale facies and the gray shale and claystone facies in the Little Osage Shale have precisely this relationship. Although the Little Osage Shale maintains its overall thickness, the gray shale and claystone facies thickens northward over the Cherokee Platform by an amount equal to the thinning that occurs in the black shale facies, suggesting that the Kansas-Oklahoma Border Trend was topographically lower than the Cherokee Platform. The black shale facies of the Excello Shale also thins northward over the Cherokee Platform, but the evidence for a shallower platform is not as conclusive since its gray shale and claystone facies is also thinner.

Figure 44 represents an idealized cross-section illustrating the depositional facies expected during a typical cyclothem along the Cherokee Platform, across the hingeline, and into the Arkoma Basin. In addition to the thickenings in the core shales, the persistence of the Kansas-Oklahoma Border Trend as a hingeline during upper Cherokee and lower Marmaton sedimentation explains a number of observations made by this study. The thinning of upper Cherokee deltaic sediments over the hingeline (Fig. 8)

Figure 44. Idealized cross-section of regressive part of cyclothem across Kansas-Oklahoma Border Trend. Illustrates representative depositional facies of a well-developed cyclothem between the Arkoma Basin and the Cherokee Platform (early Marmaton). Due to various other effects, not all cyclothems developed all of these facies.


A'
OKLAHOMA
KANSAS
A
Arkoma Basin
Cherokee Platform
nonmarine facies
nearshore carbonate facies
Outside Shale
basin to platform siliciclastic facies
Upper Limestone
skeletal, algal, and coral facies
gray shale facies
black shale facies
Core Shale
Relative rates of subsidence
10feet
50 miles

suggests that it may have been located basinward of the major nearshore depositional events occurring in this area as the shoreline sat farther to the north and east in Kansas and Missouri.

In addition, recourse to a topographic high would not be necessary to explain the substantial accumulations of shallowing-upward carbonate sequences along the Kansas-Oklahoma Border Trend. During regression, as the sea retreated toward the Arkoma Basin, carbonates would begin to accumulate over the Cherokee Platform and eventually onto the hingeline. Since the hingeline was already deeper than the platform and was subsiding more rapidly, it maintained its position within the open marine photic zone longer and received a thicker accumulation of algal-rich carbonates. In the case of the Breezy Hill and Blackjack Creek Limestones, the sea apparently retreated to the vicinity of the Kansas-Oklahoma border before halting, possibly going no farther because subsidence to the south was rapid enough to keep this area below sea level. Eventually, with the strand-line in the vicinity of the Kansas-Oklahoma border, carbonate production outstripped subsidence along the hingeline and thick deposits of shallow-water to shoaling facies capped the limestones. To the southeast, in deeper parts of the rapidly subsiding basin, carbonate production was never well established, explaining the dramatic thinning of the limestones in this direction. As noted by Bennison (1984) and confirmed by this study, the south flank of the Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones migrated farther north with each successive cyclothem. This migration of regressive limestones northward suggests that the hingeline itself was migrating northward over time.

By the end of Houx-Higginsvile deposition, before shallow-water or shoaling carbonate facies had the opportunity to develop, a thick sequence of Labette siliciclastics had prograded far enough into the basin to cover the Houx-Higginsville Limestone.

CHAPTER VIII

SUMMARY OF CONCLUSIONS

1-The Middle Pennsylvanian upper Cherokee-lower Marmaton stratigraphic interval of the Midcontinent includes three consecutive cyclothems, each consisting of an open marine shale and/or carbonate sequence overlain by a nearshore deltaic to nonmarine sequence. Eustatic fluctuations in sea level and/or fluctuations in terrigenous clastic influx over the Midcontinent are proposed as the major processes that produced these alternating sequences of transgressive-regressive carbonate and siliciclastic sediments. This supports the eustatic model of Pennsylvanian sedimentation of Heckel (1980).

2-Influx of siliciclastics was widespread within and toward the end of some regressions, but was only feebly developed during other regressive events, suggesting that variations in climate may have controlled the overall role of terrigenous clastics in the development of the cyclothems.

3-This study further documents the widespread lateral continuity in the subsurface, lack of coarse-grained terrigenous detritus, stratigraphic position between two marine lithologies, and conodont and invertebrate distributions of the phosphatic black shale facies of the Excello and Little Osage Shales, all of which suggest that they were deposited in deep marine water, probably during the maximum transgression of their respective cyclothems, as indicated by Heckel (1980, 1984).

4-The upper Cherokee Breezy Hill cyclothem represents the development of an open marine carbonate (Breezy Hill Limestone) across nearshore deltaic sediments from Oklahoma into southeastern Kansas. Although the role of eustatic transgression in the development of this cyclothem is uncertain, the extensive caliche/rhizolite profile and the lack of a thick overlying deltaic sequence argue for the influence of a more arid period that allowed open marine carbonates to replace deltaic sedimentation along the subsiding hingeline of the Cherokee Platform. As the sea withdrew southward into northeastern Oklahoma, meteoric cementation and leaching, coal swamps, and a caliche/rhizolite developed to the north.

5-The lower Marmaton Lower Fort Scott cyclothem represents a widespread rapid eustatic transgression that deposited a deep-water shale (Excello Shale) directly over shallow-water to nonmarine sediments. During the subsequent slower regression, thick open marine phylloid algal carbonates accumulated (Blackjack Creek Limestone).

Eventually, from Iowa into Missouri, carbonate production was replaced by deltaic sedimentation (Morgan School Shale), which extended into Kansas and Oklahoma as an argillaceous zone of lower diversity within the Blackjack Creek Limestone. A brief eustatic transgression or a widespread, possibly climatically controlled, slowdown in deltaic sedimentation resulted in the resumption of algal proliferation in the Blackjack Creek Limestone in Kansas and Oklahoma, while a marine carbonate-rich zone developed within the Morgan School Shale in Missouri and Iowa. Final withdrawal of the sea resulted in shallow-water carbonate facies, coals, and subaerial exposure and fresh-water diagenesis in the upper Blackjack Creek Limestone from Iowa into northeastern Oklahoma.

6-The Upper Fort Scott cyclothem represents a widespread rapid eustatic transgression that deposited the deep-water Little Osage Shale directly over shallow-water to nonmarine sediments. During the subsequent slower regression, an open marine carbonate accumulated from Oklahoma into Iowa (lower Houx-Higginsville Limestone from Oklahoma into western Missouri; Houx Limestone in Missouri and Iowa). Eventually, with continued shallowing, it was replaced by peritidal facies and a chaetetid bioherm within the Houx-Higginsville Limestone in Kansas and by a siliciclastic wedge (including the Flint Hill Sandstone) from Iowa into western Missouri.

During a minor but widespread eustatic transgression or a temporary halt to the regression coupled with a drier climate and continued subsidence, open marine carbonates redeveloped to the south within the Houx-Higginsville Limestone while the clastic wedge to the north was replaced by another marine carbonate, the type Higginsville Limestone in Missouri. The sea finally retreated into Kansas as carbonate production farther south was overwhelmed by deltaic sedimentation (Labette Shale).

7-The regressive carbonate interval of the Upper Fort Scott cyclothem in Oklahoma, Kansas, and western Missouri, traditionally designated the Higginsville Limestone, is not the simple lateral equivalent to the type Higginsville Limestone in Missouri. Because it appears from subsurface data to be the lateral equivalent of the entire Houx-Higginsville interval in Missouri and Iowa, the more appropriate hypenated name "Houx-Higginsville Limestone" is recommended where the intervening siliciclastic unit is absent.

8-As the upper Cherokee Excello Shale and the basal Marmaton Blackjack Creek Limestone are marine lithologies of a single cyclothem, it is recommended, in agreement with the Iowa Geological Survey, that they be included as members of a single unit. The name "Dry Branch Creek Formation" is proposed from a well exposed section in Crawford County, Kansas. As a consequence of combining both Cherokee and Marmaton lithologies into one unit, it is proposed that the base of the Marmaton Group be redefined as the base of the laterally continuous and widespread Excello Shale.

9-In agreement with the Iowa Geological Survey, it is recommended that the Little Osage Shale be redefined to include only the marine interval between the base of the thin basal transgressive limestone of the Upper Fort Scott cyclothem and the base of the Houx Limestone in Missouri and Iowa or the Houx-Higginsville Limestone in Oklahoma and Kansas.

10-In agreement with the Iowa Geological Survey, it is recommended that the transitional marine to nonmarine detrital lithologies between the Blackjack Creek Limestone and the Little Osage Shale (as newly defined) be given formational status. The name Morgan School Shale, recommended by the Iowa Geological Survey, is used, although a better exposed type section for this interval may be located in Missouri.

11-As the interval between the base of the Little Osage Shale and the top of the Higginsville Limestone (Houx-Higginsville Limestone in Oklahoma and Kansas) is dominated by marine lithologies of a single marine inundation, it is recommended, in agreement with the Iowa Geological Survey, that they be included as members of a single unit. The name "Wolverine Creek Formation" is proposed for well exposed sections in Bourbon County, Kansas.

12-As a consequence of the above recommended changes, "Fort Scott Limestone" should be dropped as a formational name.

13-Distributions of major conodont taxa in the Breezy Hill and Lower and Upper Fort Scott cyclothems tend to confirm earlier findings in Middle and Upper Pennsylvanian cyclothems (e.g. Swade, 1982; Heckel and Baesemann, 1975):

a) Maximum conodont abundance occurs within the offshore, core shales of the Lower and Upper Fort Scott cyclothems (Excello and Little Osage Shales, respectively).

b) *Adetognathus* spp. occurs only in lithologies interpreted as shallow-water.

c) *Anchignathodus* *minutus* was not as strongly restricted to carbonate lithologies as reported by Swade (1982), occurring also in the gray shale facies of the Excello and Little Osage Shales and suggesting a slight tolerance for a deeper, but still oxygenated bottom.

d) *Gondolella* spp. occur within the Lower Fort Scott cyclothem, concentrating within a thin zone within the black shale facies of the Excello Shale and in lesser abundance within the overlying Blackjack Creek Limestone near the southern margin of the Cherokee Platform, but are not found unequivocally in any units of the Upper Fort Scott cyclothem.

e) *Idiognathodus* spp. and *Neognathodus* spp. have similar distributional trends, occurring ubiquitously in marine lithologies and exhibiting maximum abundance within the Excello and Little Osage Shales.

f) *Idioprioniodus* spp. concentrate in the Excello and Little Osage Shales but also occur near the base of the Blackjack Creek and Houx-Higginsville regressive limestones.

g) The presence of *Gondolella*, *Idiognathodus*, *Idioprioniodus*, and *Neognathodus* within the anoxic black shale facies of the core shales support a pelagic mode of life.

14-Most of the Breezy Hill Limestone interval from southeastern Kansas northward represents a caliche/rhizolite that developed primarily as a response to plant roots that passed through previously deposited sediments.

15-Evidence from the siliciclastic top of the Cabaniss Formation and the carbonate tops of the Breezy Hill, Blackjack Creek, and Houx-Higginsville Limestones suggests that early cementation of otherwise porous and permeable sediments hinders the later development of rhizolites.

16-Diagenetic trends within the limestones support the depositional interpretations and generally follow the model of Heckel (1983). Thin, discontinuous transgressive limestones are overcompacted, showing little evidence for early marine or nonmarine cementation before burial by impermeable shales and deeper-burial cementation. Regressive limestones contain evidence of early marine cement followed in turn by meteoric neomorphism, cementation, dissolution, and root-horizons before deeper-burial silica, ferroan calcite, and ferroan dolomite cementation.

17-Based on their control over nearshore deltaic sedimentation and on the depositional and diagenetic evidence found within regressive carbonates, the Saline County and Bourbon Arches and the Ladue-Freeman and Schell City-Rich Hill Anticlines were topographic highs during the upper Cherokee-lower Marmaton interval.

18-Pronounced thickenings in deep-water shales and in shallowing-upward sequences of carbonates during this upper Cherokee-lower Marmaton interval suggest that an area near the Kansas-Oklahoma border (Kansas-Oklahoma Border Trend) was an active hingeline between the Arkoma Basin to the south and the Cherokee Platform to the north. The zone of thinning of the carbonates on the basinal side of the hingeline migrated northward with each successive cyclothem, suggesting that the south edge of the hingeline was migrating northward during upper Cherokee-lower Marmaton deposition.

APPENDIX A

STRATIGRAPHIC SECTIONS

Stratigraphic Section LEO

Cut bank along south side of Arkansas River, SW1/4, SW1/4, Sec. 21, T.17N., R.14E., Tulsa Co., Oklahoma.

Marmaton Group
    Labette Shale
        5. Shale, silty with thin sandstones.
            (6 ft. 0 in.)

    Wolverine Creek Formation
        Little Osage Shale Member
        4. Shale, black, fissile with phosphatic nodules, grades into overlying gray shale.
            (4 ft. 0 in.)

    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
        3. Limestone, skeletal calcilutite with thin irregular beds.
            (1 ft. 0 in.)

        Excello Shale Member
        2. Shale, base a sandy orange-brown calcareous siltstone, middle is black flakey shale, top is same as bottom with calcareous nodules.
            (0 ft. 9 in.)

Cabaniss Group
    Senora Formation
        Breezy Hill Limestone
        1. Limestone, basal 1 ft. is sparsely fossiliferous calcilutite, above this brachiopods and bryozoans appear; thin shaly reentrant about 2.7 ft. above base; above this cross-bedded skeletal, grading into, oolitic calcarenite; base is gradational with greenish, calcareous, laminated siltstone.
            (10 ft. 0 in.)

Stratigraphic Section BC

South cut bank of Bird Creek below Highway 266 bridge, NW1/4, Sec. 19, T.20N., R.15E., Rogers Co., Oklahoma.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            5. Calcilutite, light gray skeletal to algal wackestone; poorly exposed; top eroded. (10 ft. 6 in.)

        Excello Shale Member
            4. Shale, black, fissile with phosphatic nodules. (2 ft. 0 in.)

Cabaniss Group
    Senora Formation
        Breezy Hill Limestone Member
            3. Limestone, skeletal calcilutite, massive 1 ft. 3 in. upper unit with top containing large intact productids, spines inplace, separated from lower 8 ft. by 3-8 in. reentrant of gray claystone to black platy shale; top of limestone below reentrant identical to top above it; algal blade-rich zone about 4 ft. up; sharp base. (9 ft. 8 in.)

        Kinnison Shale
            2. Shale, dark gray at base to brown at top. (0 ft. 4 in.)

        Iron Post coal
            1. Coal. (1 ft. 0 in.)

Stratigraphic Section OOW

Wall of active quarry on north side of county road. SW1/4, SE1/4, Sec. 33, T.23N., R.16E., Rogers Co., Oklahoma.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member

1. Calcilutite, top 10 ft. algal blade-rich, below this is 5 ft. sublithographic zone with tiny brachiopods and occasional fusulinid partings grading below into 3 ft. zone of fusulinid- and clay-rich partings; this zone gradational with lower algal blade-rich zone; top eroded; base is covered but was told black shale is present.
(approx. 30 ft.)

Stratigraphic Section ALL

Along N-S county road just south of old iron bridge, along both sides of road, SW1/4, NW1/4, Sec. 21, T.25N., R.17E., Nowata Co., Oklahoma.

Marmaton Group
  Dry Branch Creek Formation
    Blackjack Creek Limestone
      6. Calcilutite, algal blades near base; top eroded.
        (approx. 6 ft.)

    Excello Shale Member
      5. Shale, black, fissile, with phosphatic nodules, base and top covered.
        (approx. 5 ft.)

Cherokee Group
  Cabaniss Formation
    Breezy Hill Limestone Member
      4. Calcilutite, poorly exposed, base and top covered.
        (approx. 7 ft.)

    Kinnison Shale Member
      3. Claystone, blue and yellow to reddish limey siltstone with brachiopods near base, poorly exposed, upper contact covered.
        (approx. 2 ft.)

    Iron Post coal
      2. Coal, no underclay.
        (1 ft. 4 in.)

    unnamed unit
      1. Siltstone, sandy with irregular lenses of brachiopod-rich limey siltstone (reddish colored) near top, plant fragments near base, poorly exposed down into creek.
        (approx. 4 ft.)

Stratigraphic Section MON

Composite section of: wall of old strip pit on south side of Highway 60, NE1/4, NE1/4, Sec. 36, T.26N., R.17E., and quarry on south side of Highway 60, NE1/4, NE1/4, Sec. 34, T.26N., R.17E., both in Nowata Co., Oklahoma.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member

4. Calcilutite, bottom 10 ft. abundant algal blades; about 10 ft. up several fusulinid- and shaly-rich partings, each several inches thick; upper 5-10 ft. is weathered orange-gray, less fossiliferous, very few algal blades, but contains hudge brachiopods and occasional chert nodules; top foot is more fossiliferous with bryozoans, fusulinids, and brachiopods; top eroded. (approx. 15 ft.)

        Excello Shale Member

3. Shale, gray, flakey, with occasional thin gray limey lenses. (1 ft. 0 in.)

2. Shale, black, fissile, with phosphatic nodules; base containing abundant shells is gradational with underlying limestone. (4 ft. 0 in.)

Cabaniss Group
    Senora Formation
        Breezy Hill Limestone Member

1. Calcilutite, gray, dense, uneven bedding or fracture surfaces, contains fusulinids, base covered, strip pit probably mined for underlying Iron Post coal. (approx. 5 ft.)

Stratigraphic Section MC

North-south road along creek just south of Martin Cemetary, SW1/4, NW1/4, Sec. 2, T.26N., R.17E., Nowata Co., Oklahoma.

Marmaton Group
    Labette Shale

4. Shale, gray to brown with concretionary brown rubble eroding from top.
(10-15 ft.)

3. Shale, dark gray, (no nodules).
(6-8 in.)

2. Claystone, brown.
(1-2 in.)

Wolverine Creek Formation
    Houx-Higginsville Limestone Member

1. Calcilutite, fossiliferous, abundant algal blades, base covered in creek.
(approx. 2 ft.)

Stratigraphic Section WCT

In a gas pipe trench along side of county road (now filled in), NW1/4, Sec. 25, T.28N., R.19E., Craig County, Oklahoma.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member

11. Calcilutite, light gray, orange-brown weathering, wavy bedded, fossiliferous with algal blades, brachiopods, top eroded. (approx. 1 ft.)

Little Osage Shale Member

10. Shale, interbedded shale to claystone, basal 1-2 ins. light to dark gray claystone gradational with black shale below, overlain by 1 in. rusty, platy-like shale which is overlain by interbedded dark gray to black shale and yellow to gray-blue claystone. (2 ft. 10 in.)

9. Shale, black, fissile to irregular chunks at top, phosphatic nodules, sharp base. (2 ft. 8 in.)

8. Claystone, gray-blue to yellow. (0 ft. 6 in.)

Dry Branch Creek Formation
    Blackjack Creek Limestone Member

7. Calcilutite, light to medium gray-blue on fresh surface, fossiliferous with brachiopods, crinoids, top contains shell hash of large brachiopods and bryozoans, measured over a long distance so thickness is uncertain. (approx. 28 ft.)

Excello Shale Member

6. Claystone, gray-blue to yellow, laminated, about 2 in. up there is 2 in. zone of dark gray to black laminated shale overlying a thin nodular calcilutite, sharp base. (2 ft. 10 in.)

5. Shale, black, fissile to chunky, phosphatic nodules, sharp contacts. (3 ft. 8 in.)

Cabaniss Group
    Senora Formation
        "Mulky coal zone"
            4. Sandy, orange, unconsolidated.
                (0 ft. 6 in.)

        Breezy Hill Limestone Member
            3. Calcilutite, gray, crinoids, brachiopods, and fusulinids, massive, sharp base.
                (3 ft. 4 in.)

        Kinnison Shale Member
            2. Claystone, gray-blue, laminated, two 2 in. thick layers of dark gray to black fissile shale 4 in. from base.
                (4 ft. 0 in.)

            1. Limestone, dark gray, base covered.
                (0 ft. 4 in.)

Stratigraphic Section TC

Old quarry wall south of county road, in pasture field, NE1/4, NW1/4, Sec. 1, T.35S., R.20E., Labette County, Kansas.

Marmaton Group
  Dry Branch Creek Formation
    Blackjack Creek Limestone Member (?)
      4. Calcilutite, weathers yellow as 2-3 in. foss. slabs at top of quarry.
(2-3 in.)

    Excello Shale Member (?)
      3. Claystone, green to orange, sharp contacts.
(approx. 6 in.)

      2. Shale, black, fissile with phosphatic nodules; one Gondolella fragment recovered; sharp but wavy basal contact.
(3 ft. 0 in.)

Cherokee Group
  Cabaniss Formation
    Breezy Hill Limestone Member (?)
      1. Limestone, calcarenite at top grading into calcilutite at base, which is partially underwater; calcarenite is crossbedded with interbedded intraclastic calcirudites and finer grained calcarenites with burrow fillings of coarser grains, abundant fossiliferous chert nodules; following this downsection along nearby creek sandstones, shales, and thin limestone beds rich in large brachiopods are present, however, it was impossible to locate another inplace black shale.
(greater than 6 ft. 6 in.)

Stratigraphic Section TCW

Along road cut and ditch of E-W county road, NW1/4, Sec. 1, T.35S., R.20E., Labette Co., Kansas.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            5. Calcilutite, light gray, brachiopods, crinoid stems, thin irregular beds, top eroded.
                (approx. 8 ft.)

        Excello Shale Member
            4. Shale, black, fissile, phosphatic nodules, sharp base, top 6 in. covered.
                (2 ft. 1 in.)

Cherokee Group
    Cabaniss Formation
        "Mulky coal zone"
            3. Sandstone, brown, very oxidized layer, base covered.
                (approx. 4 in.)

        Breezy Hill Limestone Member
            2. Calcilutite, massive, grades from calcarenite at top to calcilutite, abundant shell fragments, base covered.
                (approx. 8 in.)

        Lagonda Sandstone
            1. Siltstone, calcareous,brown to gray-green, thinly laminated with irregular calcareous bed partially covered 4.8 ft. from top, base covered.
                (approx. 12 ft.)

Stratigraphic Section PMC

Core from SW1/4, Sec. 19, T.34S., R.18E., Labette Co., Kansas, drilled in 1925 by Pittsburg and Midway Coal Mining Co. (309-393 ft in core). Core stored at Kansas Geological Survey, Lawrence, Kansas.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member

12. Limestone, light to medium gray phylloid algal wackestone, gradational contact with overlying gray-brown shale.
(12 ft. 0 in.)

11. Limestone, light to medium gray peloid, calcisphere, intraclast mudstone to packestone, top laminated, middle brecciated.
(14 ft. 0 in.)

10. Limestone, light gray mudstone to wackestone, diverse marine fauna, shaly fusulinid-rich partings 1-3 cm. thick, abundant fractures in bottom half.
(12 ft. 0 in.)

Little Osage Shale Member

9. Shale, black, fissile, phosphatic nodules, gradational contacts.
(3 ft. 0 in.)

8. Shale, gray, calcareous near base.
(2 ft. 6 in.)

Dry Branch Creek Formation
    Blackjack Creek Limestone Member

7. Limestone, light gray intraclast, peloid wackestone to packstone, shaly partings near top and base.
(11 ft. 0 in.)

6. Dolostone, dark gray, argillaceous, fusulinid-rich shaly partings, diverse marine fauna.
(7 ft. 6 in.)

5. Limestone, light gray phylloid algal wackestone, shaly partings.
(11 ft. 6 in.)

Excello Shale Member

4. Shale, dark gray, fossiliferous, gradational contacts.
(1 ft. 6 in.)

3. Shale, black, fissile, phosphatic nodules, sharp base.
(4 ft. 6 in.)

Cherokee Group
Cabaniss Formation
Breezy Hill Limestone Member

2. Sandstone, very fine to fine grained, sparsely fossiliferous, laminated, argillaceous, dolomitic, gradational base.
(2 ft. 6 in.)

1. Limestone, light gray, sandy packstone to grainstone, diverse marine fauna, base gradational with shale containing fossiliferous lenses.
(2 ft. 0 in.)

Stratigraphic Section BQ

Quarry floor, walls, and small upper section cleared of surficial material, NE1/4, NW1/4, Sec. 6, T.35S., R.21E., Labette Co., Kansas.

Marmaton Group
  Wolverine Creek Formation
    Houx-Higginsville Limestone Member
      7. Limestone, orange-yellow calcilutite, brachiopods, crinoids, algal blades, loose at top of outcrop.
(0 ft. 3 in.)

    Little Osage Shale Member
      6. Claystone, gray-green or blue, may not be in place.
(approx. 8 in.)

      5. Shale, black, fissile to crumbly, grades into dark gray shale at base.
(3 ft. 9 in.)

      4. Claystone, dark gray, gradational with underlying unit.
(2-3 ins.)

  Morgan School Shale
      3. Claystone, gray-green, grading upward to orange and into overlying unit; many coaly plant fragments near base, which is sharp but has undulatory contact with calcarenite below.
(1 ft. 0 in.)

  Dry Branch Creek Formation
    Blackjack Creek Limestone Member
      2. Limestone, calcilutite grading into thin cross-bedded calcarenite with chert nodules and plant fragments filling depressions in an undulatory surface near the top; chert nodules contain peloids, fusulinids, and mollusks; fractures in chert nodules filled with skeletal debris; several feet of pale purple, sparsely fossiliferous (contains large brachiopods) calcilutite below hummoky surface; abundant algal blades appear about 2.5 ft. below the top; lower 8-10 ft. contains algal blades and numerous shaly

partings with black chert nodules and thin shell hash.

(25 ft. 0 in.)

Excello Shale Member

1. Shale, black, chunky, not very fissile, phosphatic nodules, grading upward into dark gray, fossiliferous, laminated calcilutite, base covered.

(approx. 1 ft.)

Stratigraphic Section SOS

Along road cut on Highway 59 just south of Oswego, E center, Sec. 21, T.33S., R.21E., Labette Co., Kansas.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member

8. Limestone, light gray calcilutite, thin, wavy bedded, brachiopods, crinoids, algal blades; sharp, slightly wavy base; about 0.8 ft. above base is 1 in. thick shale reentrant.
(3 ft. 6 in.)

Little Osage Shale Member

7. Shale, dark gray, crumbly at base and gradational contact with black shale; grades upward into lighter orange-brown and gray-green claystones containing wispy laminations of dark gray shale.
(2 ft. 2 in.)

6. Shale, black, fissile to blocky chunks, phosphatic nodules.
(2 ft. 0 in.)

5. Shale, dark gray, crumbly, gradational contacts.
(0 ft. 6 in.)

Morgan School Shale

4. Claystone, blue or light gray, sharp base.
(0 ft 10 in.)

Dry Branch Creek Formation
    Blackjack Creek Limestone Member

3. Limestone, calcilutite, weathers orange to gray, thin, wavy bedded, some giant crinoid stems, brachiopods, algal blades, fusulinids become more abundant towards top; top several inches contains irregular lenses of calcarenite with root casts; top 1/2 in. is a yellow crumbly clay with a cap of dark red-brown rust-like scales or plates; base is covered.
(approx. 15 ft.)

Excello Shale Member

2. Shale, black, poorly exposed. (thickness uncertain)

Cherokee Group

Cabaniss Formation

1. Sandstone, brown, thinly laminated to medium bedded, poorly exposed in creek bed, several feet overlying this exposure are covered. (up to 10 ft.)

Stratigraphic Section NOS

Road cut near west side of city park on north side of Oswego, SE1/4, NE1/4, Sec. 16, T.33S., R.21E., Labette Co., Kansas.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            7. Limestone, orange to gray weathering calcilutite, brachiopods; top eroded.
                (approx. 1 ft.)

        Excello Shale Member
            6. Claystone, dark gray at base grading upward into light orange and into gray at top; lower contact is gradational.
                (0 ft. 6 in.)

            5. Shale, black, chunky, phosphatic nodules; sharp base.
                (2 ft. 6 in.)

Cherokee Group
    Cabaniss Formation
        "Mulky coal zone"
            4. Sandy clay, orange, contacts sharp.
                (0 ft. 6 in.)

        Breezy Hill Limestone
            3. Limestone, orange to gray mottling, bed massive to nodular, more fossiliferous towards top.
                (0 ft 8 in.)

        Lagonda Sandstone
            2. Claystone, yellow, poorly exposed.
                (approx 4 ft.)

            1. Sandstone, brown, in road ditch on west side, poorly exposed.
                (several feet)

Stratigraphic Section SQ

Quarry north of Sherman, W center, NE1/4, Sec. 13, T.32S., R.21E., Cherokee Co., Kansas.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member
            6. Limestone, light gray on quarry face, abundant algal blades, crinoid stems, brachiopods, sharp base.
(approx. 6 ft.)

        Little Osage Shale Member
            5. Shale, basal 1.1 ft. dark gray crumbly shale grades into black shale below, upper 1.3 ft gray blue to orange claystone grades into shale below.
(2 ft. 5 in.)

            4. Shale, black, fissile to blocky chunks, phosphatic nodules.
(2 ft. 0 in.)

            3. Shale, dark gray, gradational contacts.
(2-3 ins.)

    Morgan School Shale
            2. Claystone, gray-blue at base with orange rusty plate-like partings throughout.
(approx. 2 ft. 3 in.)

    Dry Branch Creek Formation
        Blackjack Creek Limestone
            1. Limestone, gray calcilutite, fusulinids, algal blades, wavy shaly laminations.
(approx. 9 ft.)

Stratigraphic Section MCF

From east side to quarry on west side of county road, SE1/4, Sec. 36, T.30S., R.22E., Crawford County, Kansas.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            5. Limestone, calcilutite, basal ft. or so weathers yellow-orange, upper part more light gray, algal blades, crinoids, brachiopods, chaetetids; wavy bedding, laminations noticed on weathered surface near top; sharp basal contact.
(approx. 5 ft.)

        Excello Shale Member
            4. Shale, black and fissile in center, black to gray-blue to yellow 6 in. section at top; bottom covered; poorly exposed.
(2 ft. 11 in.)

Cherokee Group
    Cabaniss Formation
        "Mulky coal zone"
            3. Sand, friable orange zone with plant fossils, gradational base.
(several inches)

        Breezy Hill Limestone Member
            2. Limestone, orange weathering fossiliferous calcilutite to calcarenite at top; base is covered.
(1 to 3 ft.)

        Lagonda Sandstone
            1. Sandstone and shales, orange to yellow.
(over 20 ft.)

Stratigraphic Section GR

Quarry at SE1/4, Sec. 12, T.30S., R.22E., Crawford County, Kansas.

Marmaton Group

Labette Shale

3. Shale, gray, silty, thinly laminated, grading into yellow-orange towards top, sharp but irregular basal contact, no coal present. (23 ft.)

Wolverine Creek Formation

Houx-Higginsville Limestone Member

2. Limestone, gray , lower 2/3 of quarry face is gray massive calcilutite between wavy darker gray laminations containing fusulinids which form packstones, filling in around large chaetetid heads, some areas between heads contain brecciated calcilutite and chaetetid fragments; occasional solitary rugosa and auloporid corals around chaetetid heads; algal blades concentrated in bottom third of quarry face; top 1 1/2 ft. is a massive unit with sharp base and a top weathering orange to dark brown, containing brachiopods and algal blades, its base is separated from the lower chaetetid limestone by 2-8 inches of gray shale wrapping over the chaetetid heads and containing limestone nodules. (16 ft. 6 in.)

Little Osage Shale Member

1. Shale, black, fissile, contains phosphate nodules, contact with overlying limestone and base are covered. (approx. 1 ft.)

Stratigraphic Section COW

Along creek south of county road, NE1/4, NW1/4, Sec. 5, T.30S., R.24E., Crawford County, Kansas.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            6. Limestone, fossiliferous calcilutite, wavy bedded, weathers orange; giant crinoid stems, chaetetids , brachiopods; top eroded, base covered.
(approx. 3 ft.)

        Excello Shale Member
            5. Shale, black, fissile, phosphatic nodules.
(approx. 3 ft.)

Cherokee Group
    Cabaniss Formation
        Mulky coal Member
            4. Coal, large petrified tree stump in creek may be from this horizon.
(0 ft. 1 in.)

            3. Claystone, blue-gray, rusty plate-like layer at top.
(approx 2 ft.)

        Breezy Hill Limestone Member
            2. Limestone, orange silty to sandy calcilutite grades upward into sandy fossiliferous calcarenite, top exposed in creek bed contains irregular potholed surface; becomes more nodular, less fossiliferous downward; gradational base.
(approx. 2 ft.)

        Lagonda Sandstone Member
            1. Siltstone, calcareous, orange to light gray, base covered.
(approx. 3 ft.)

Stratigraphic Section ENG

Along creek by bridge of old railroad grade, NW1/4, NE1/4, Sec. 25, T.28S., R.24E., Crawford Co., Kansas.

Marmaton Group
    Wolverine Creek Formation
        Little Osage Shale Member
            7. Shale, black, poorly exposed, top eroded.
(0 ft. 6 in.)

    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            6. Limestone, basal 0.75 ft. gray massive, sparsely fossiliferous, conchoidal fracture; overlain by 0.25 ft. gray calcareous claystone with irregular lenses of calcilutite and orange mottling, sharp smooth contacts; overlain by 1.2 ft. of calcilutite much like the lower part with sharp, flat base; this is overlain by a gray wavy, thinnly bedded calcilutite separated from the unit below by a basal inch of silty limestone; contains chaetetids, algal blades, fusulinids, and crinoids.
(approx. 8 ft. 2 in.)

        Excello Shale Member
            5. Shale, black, with phosphatic nodules.
(2 ft. 10 in.)

Cherokee Group
    Cabaniss Formation
        Mulky coal member
            4. Coal.
(0 ft. 6 in.)

            3. Claystone.
(2 ft. 3 in.)

        Breezy Hill Limestone Member
            2. Limestone, massive, sandy unit.
(0 ft. 9 in.)

        Lagonda Sandstone Member
            1. Sandstone and siltstone, interbedded.
(3-4 ft.)

Stratigraphic Section NA

Roadcut along U.S. Highway 69, SW1/4, NW1/4, SW1/4, Sec. 5, T.28S., R.25E., Crawford Co., Kansas.

Marmaton Group
    Dry Branch Creek Formation
        Blackjack Creek Limestone Member

6. Limestone, calcilutite, basal 1.25 ft. has a distinct upper contact from vuggy to smooth, with an intervening orange to gray claystone 1-2 ins. thick separating it from the overlying wavy bedded more fossiliferous calcilutite with chaetetids, brachiopods, fusulinids; another wavy-bedded silty layer up to 3 in. thick is located 3 ft. above the lower one and drapping over chaetetid heads; top contains a thin packstone with root casts; top eroded.
(9 ft. 6 in.)

        Excello Shale Member

5. Shale, black, fissile to blocky, phosphatic nodules; top 1 in. is gray claystone.
(3 ft. 2 in.)

Cherokee Group
    Cabaniss Formation
        Mulky coal member

4. Coal.
(0 ft. 8 in.)

3. Claystone, mottled gray, black, and orange; black coaly seams near top; poorly exposed, but sharp base.
(2 ft. 3 in.)

        Breezy Hill Limestone Member

2. Limestone, barren orange and gray massive to nodular at base, gradational base.
(1 ft. 6 in.)

        Lagonda Sandstone

1. Sandstone, silty, greenish gray and red mottling, 2 in. thick bed of more indurated limestone occurs 2 in. below top, base covered.
(greater than 4 ft.)

Stratigraphic Section FST

Composite section includes original type section along cut on south side of railroad, NE1/4, NW1/4, Sec. 30, T.25S., R.25.e., and new type section designated by Jewett (1943) in a quarry north of Fort Scott, NE1/4, NW1/4, Sec. 19, T.25S., R.25E., Bourbon Co., Kansas. Road construction has partially destroyed this exposure.

Marmaton Group

Labette Shale

15. Shale, dark gray, beds of coal, top eroded. (approx. 50 ft. thick)

Wolverine Creek Formation

Houx-Higginsville Limestone Member

14. Limestone, light gray wackestone, diverse marine fauna includes phylloid algae and chaetetids, abundant ferroan dolomite near base, occasional chert nodules, top is rooted and brecciated with less diverse fauna. (approx. 12 ft.)

Little Osage Shale Member

13. Shale, dark gray, flaky, orange lenses towards top, sharp contact at base, grades into limestone above. (0 ft. 6 in.)

12. Limestone, gray to orange, marine fauna, has been called Houx Limestone by Jewett (1945) but Jeffries (1958) disagrees. (0 ft. 5 in.)

11. Shale, dark gray. (0 ft. 10 in.)

10. Shale, black, fissile, phosphatic nodules, gradational contacts. (2 ft. 9 in.)

9. Shale, dark gray, wavy black and orange laminations, limestone nodules with marine fauna. (0 ft. 3 in.)

Morgan School Shale

Summit coal Member

8. Coal, sharp base.
(0 ft. 4 in.)

7. Shale, clayey, light gray at base to dark gray at top with plant fragments and orange-red horizontal laminations.
(2 ft. 6 in.)

Dry Branch Creek Formation

Blackjack Creek Limestone Member

6. Limestone, light gray, wackestone, diverse marine fauna, ferroan dolomite abundant at base and top, top is sparsely fossiliferous, rooted and wavy bedded, lower 3 ft. are massive, sharp base.
(4 ft. 9 in.)

Excello Shale Member

5. Shale, gray, nodules of sparsely fossiliferous limestone.
(0 ft. 3 in.)

4. Shale, black, fissile, phosphatic nodules, gradational contacts.
(2 ft. 9 in.)

3. Shale, gray to black, fossiliferous limestone nodules with pyrite.
(1-2 ins.)

Cherokee Group

Cabaniss Formation

Mulky coal member

2. Coal.
(1 ft. 0 in.)

1. Shale, clayey, light gray, base covered.
(0 ft. 6 in.)

Stratigraphic Section MB

Northeast cutbank of Osage River at Marble Bridge, 3 1/2 miles southeast of Amoret, NW1/4, NW1/4, Sec. 2, T.39N., R.33W., Bates County, Missouri.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member
            9. Limestone, light gray calcilutite, thin wavy beds, crinoids, abundant fusulinids near top; brown chert nodules concentrated 3-4 ft. above base.
(12 ft. 10 in.)

        Little Osage Shale Member
            8. Claystone, contains limestone nodules.
(1 ft. 0 in.)

            7. Limestone, gray fossiliferous calcilutite.
(0 ft. 8 in.)

            6. Shale, black shale, poorly exposed.
(approx. 4 ft.)

            5. Claystone, gray to orange, whole brachiopods, top poorly exposed.
(0 ft. 8 in.)

    Morgan School Shale
        Summit coal Member
            4. Coal.
(2-3 in.)

            3. Claystone, mottled orange, green, and gray, organic-rich, poorly exposed.
(approx. 2 ft.)

            2. Siltstone, contains limestone nodules, top covered, grades into massive limestone below.
(approx. 4 ft. 4 in.).

    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            1. Limestone, orange, massive calcilutite, brachiopods, base covered.
(approx. 2 ft. 6 in.)

Stratigraphic Section BUT

East face of active quarry, SW1/4, SE1/4, Sec. 19, T.40N., R.31W., Bates County, Missouri.

Marmaton Group
    Labette Shale
        3. Shale, contains thin coal several feet above base.
            (thickness not measured)

    Wolverine Creek Formation
        Houx-Higginsville Limestone Member
            2. Limestone, light gray fossiliferous calcilutite, wavy bedded, upper 3 ft. massive with fusulinids, shaly partings containing fusulinids just below top; brown chert nodules concentrated in upper half.
                (20 ft. 0 in.)

        Little Osage Shale Member
            1. Shale, black, horizontal burrows on fissile bedding planes at top; forms floor of quarry; contact with overlying limestone covered.
                (approx. 1 ft.)

Stratigraphic Section U

Road cut at top of hill on Highway K, 2 1/2 miles north of Highway 18, SW1/4, SW1/4, NW1/4, Sec. 34, T.42N., R.28W., Henry Co., Missouri.

Marmaton Group
    Wolverine Creek Formation
        Houx-Higginsville Limestone Member
            16. Limestone, calcilutite with algal blades, crinoids, brachiopods, and fusulinids; top eroded.
                (approx. 5 ft.)

        Little Osage Shale Member
            15. Shale, dark gray, flakey with gradational base, grades into green claystone at top.
                (2 ft. 3 in.)

            14. Shale, black, fissile.
                (2 ft. 8 in.)

            13. Limestone, nodular, contains brachiopods.
                (0 ft. 3 in.)

    Morgan School Shale
            12. Shale, gray, brachiopods, 2 ft. silty limestone zone weathering as nodules on outcrop about 5 ft. up in shale.
                (13 ft. 5 in.)

    Dry Branch Creek Formation
        Blackjack Creek Limestone Member
            11. Limestone, massive fossiliferous calcilutite.
                (1 ft 0 in.)

        Excello Shale Member
            10. Shale, dark gray, grades into black shale below and green claystone above.
                (1 ft. 0 in.)

            9. Shale, black, fissile.
                (3 ft. 0 in.)

Cherokee Group

Cabaniss Formation

Mulky coal member

8. Coal, 1 in. of rusty coal flakes and clay at top. (1 ft. 1 in.)

7. Claystone, green. (3 ft. 0 in.)

Breezy Hill Limestone Member

6. Limestone, sandy, mottled brown and green, nodular, and barren. (3 ft. 3 in.)

Lagonda Sandstone Member

5. Shale, blue-green with brown blotches, flakey and soft. (3 ft. 3 in.)

4. Limestone, gray to brown, nodular, large brachiopods. (1 ft. 0 in.)

3. Shale, poorly exposed. (approx. 2 ft.)

2. Limestone, irregular bedding, gray, contains crinoid columnals, poorly exposed. (6 in.-1 ft.)

1. Shale and siltstone, brown and tan, laminated, sandstone exposed further down, base covered in drainage ditch. (approx. 3 ft.)

Stratigraphic Sections from the Literature

Schell (1955)

Section CM

South bank of Verdigris River in approximate center Sec. 13, T.22N., R.15E., Rogers County, Oklahoma.

Jefferies (1958)

Section J39

About 2.5 miles east of Leeton in road cuts of County Road EE west of small drain, in NW1/4, NE1/4, NE1/4, NW1/4, Sec. 23 and in the SW1/4, SE1/4, SW1/4, Sec. 14, T.44N., R.25W., Johnson County, Missouri.

Section J48

About 6 miles west of Warrensburg in south cut of new U.S. Highway 50, in the SW1/4, SW1/4, Sec. 13, T.46N., R.27W., Johnson County, Missouri.

Section J69

A composite section about 0.5 miles west of Hodge in bluff of Missouri River, Lafayette County, Missouri. Mulky coal through Blackjack Creek Limestone were measured in a small ravine, in the NE1/4, SW1/4, SW1/4, SW1/4, Sec. 11, T.51N., R.25W.; Morgan School Shale through the Higginsville Limestone were measured in road cuts along a private road, in the SW1/4, SW1/4, SW1/4 of the same section.

Section J90

About 2 miles north of Avalon in cuts of gravel road, along north line of the NW1/4, NW1/4, Sec. 12, T.56N., R.23W., Livingston County, Missouri.

Section J91

A composite section about 3.5 miles northwest of Avalon. Excello Shale through Little Osage Shale were measured in drain south of bridge, east of T-road north, in the northeast corner of Sec. 4, T.56N., R.23W.; Houx through Higginsville Limestones were measured at T-road south, in the northwest corner of Sec. 3, T.56N., R.23W., Livingston County, Missouri.

Section J113

About 0.2 mile south of Mapleton, in east cut of gravel road on south bluff of Dog Branch, in the SE1/4, NW1/4, NE1/4, Sec. 17, T.65N., R.16W., Putnam County, Missouri.

Section J116

About 1.8 miles northeast of Hartford in north bluff of small drain west of farm house, in the SW1/4, SE1/4, SE1/4, Sec. 28, T.66N., R.17W., Putnam County, Missouri.

APPENDIX B

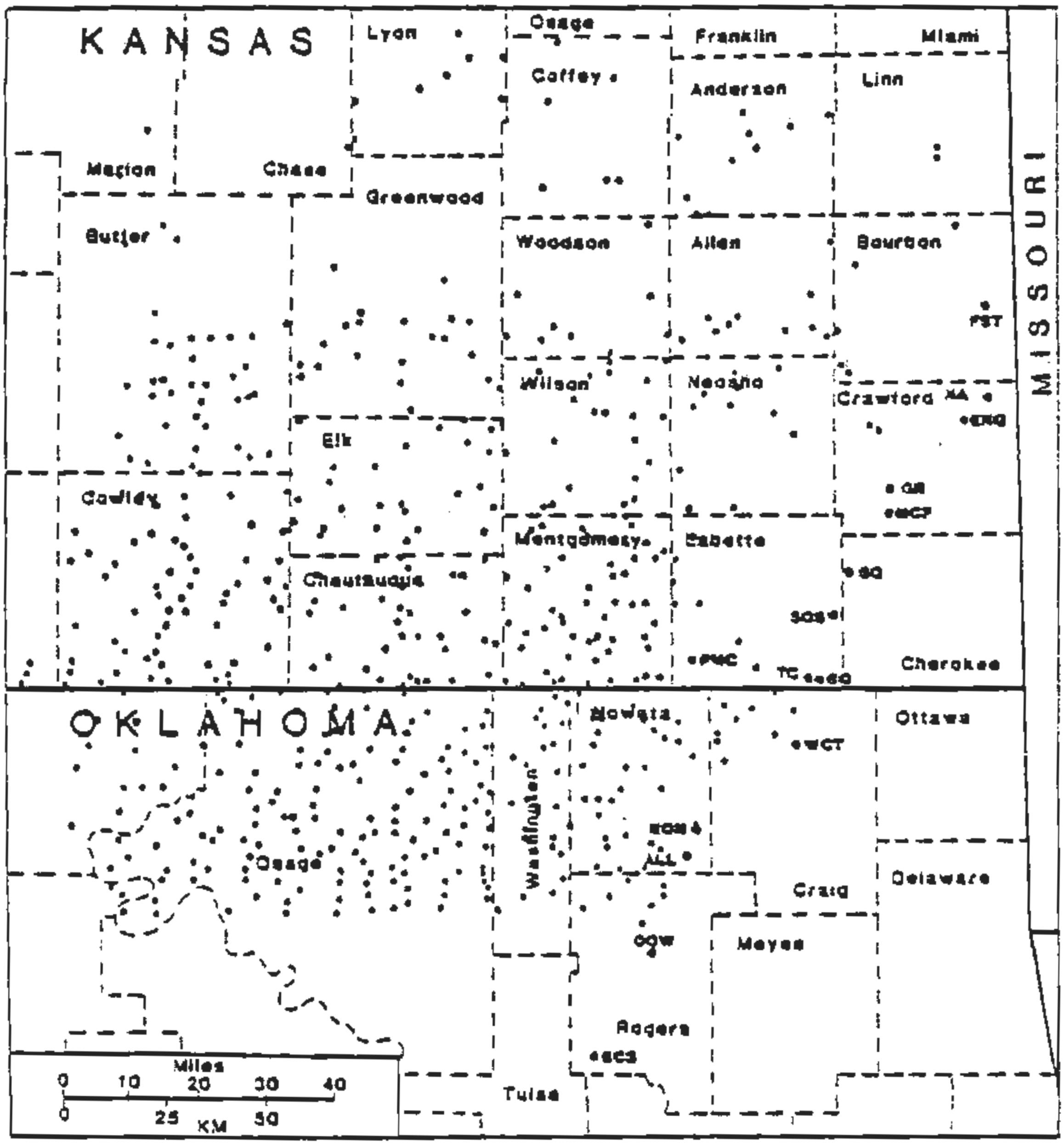
SUBSURFACE DATA

Approximately 545 radioactivity logs from northeastern Oklahoma and southeastern to east-central Kansas were used to correlate lithologic units in the subsurface, to aid their correlation along the outcrop, and to construct isopach and isolith maps of limestone and shale units in the Breezy Hill Limestone-Labette Shale interval (Fig. 45).

Figure 46 illustrates a radioactivity log typical of the Breezy Hill Limestone-Labette Shale interval in southeastern Kansas near the Kansas-Oklahoma border. Interpretation of lithologies and selection of lithologic contacts in the Breezy Hill Limestone-Labette Shale interval were based on comparisons between well-logs and nearby outcrops and the core at Section PMC.

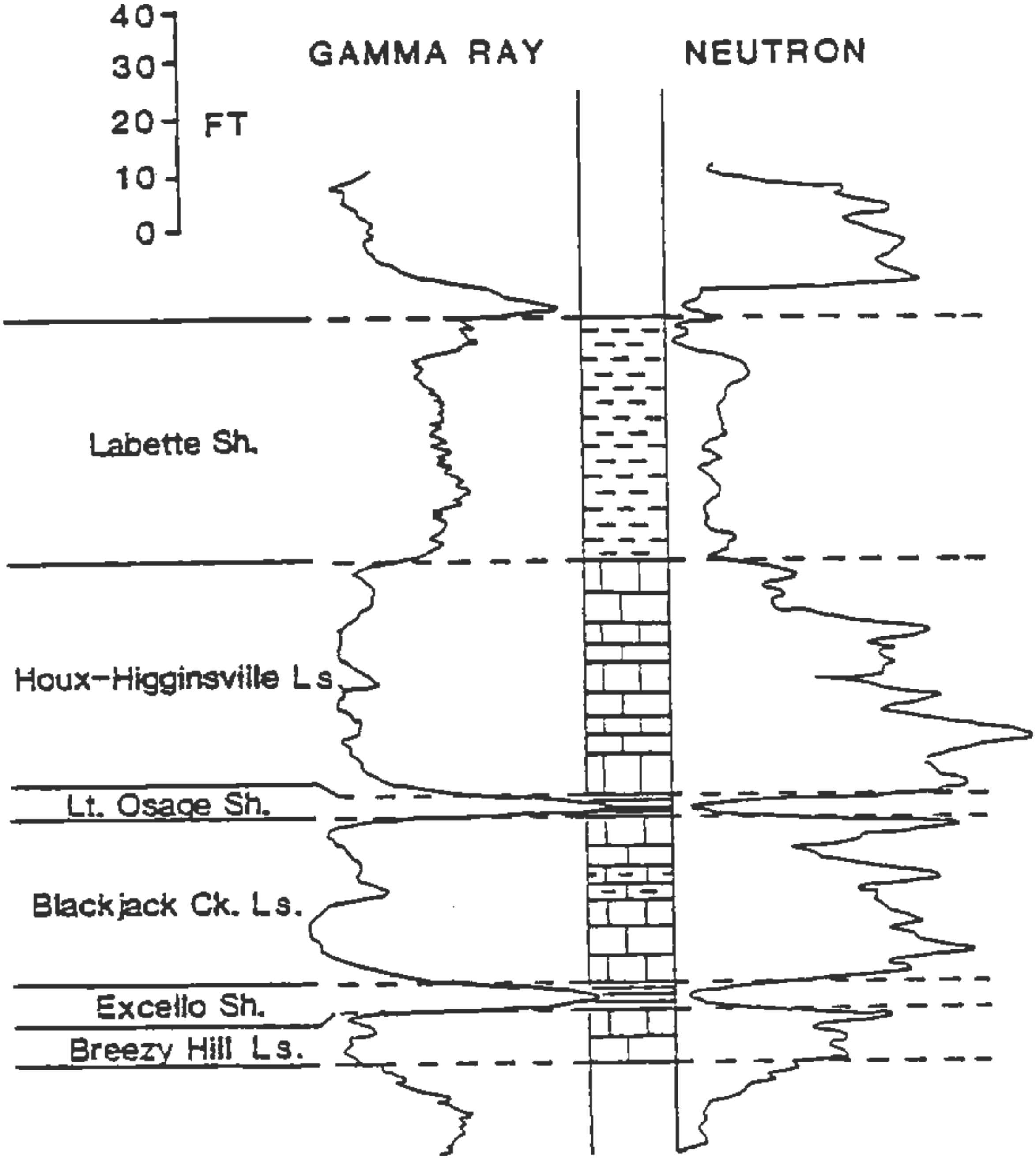
Of particular importance in locating the Breezy Hill Limestone-Labette Shale interval in the subsurface and thus the Cherokee-Marmaton boundary is the gamma ray curve's "doublet" of peaks created by the highly radioactive Excello and Little Osage Shales and separated by the less radioactive Blackjack Creek Limestone.

Figure 45. Well-log control points. Small dots indicate location of wells for radioactivity logs used in this study. Due to partial absence of interval in log or to intervals containing faulty data, not all points were necessarily used to construct particular isopach or isolith maps.



WELL-LOG CONTROL POINTS

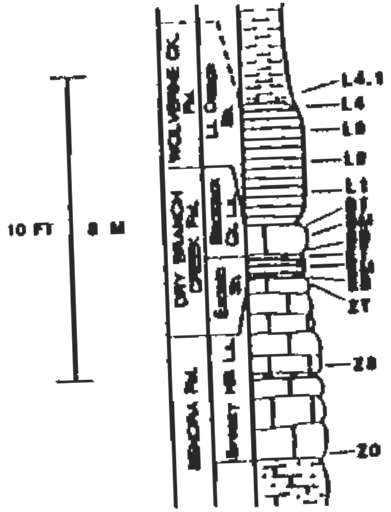
Figure 46. Radioactivity log of Breezy Hill Limestone-Labette Shale interval. Recorded from well in vicinity of Core PMC in southwestern Labette Co., Kansas. Note high gamma ray responses from Excello and Little Osage Shales and argillaceous-rich interval near middle of Blackjack Creek Limestone.


40
30
20
10
0
FT
GAMMA RAY
NEUTRON
Labette Sh.
Houx-Higginsville Ls.
Lt. Osage Sh.
Blackjack Ck. Ls.
Excello Sh.
Breezy Hill Ls.

APPENDIX C

CONODONT DATA

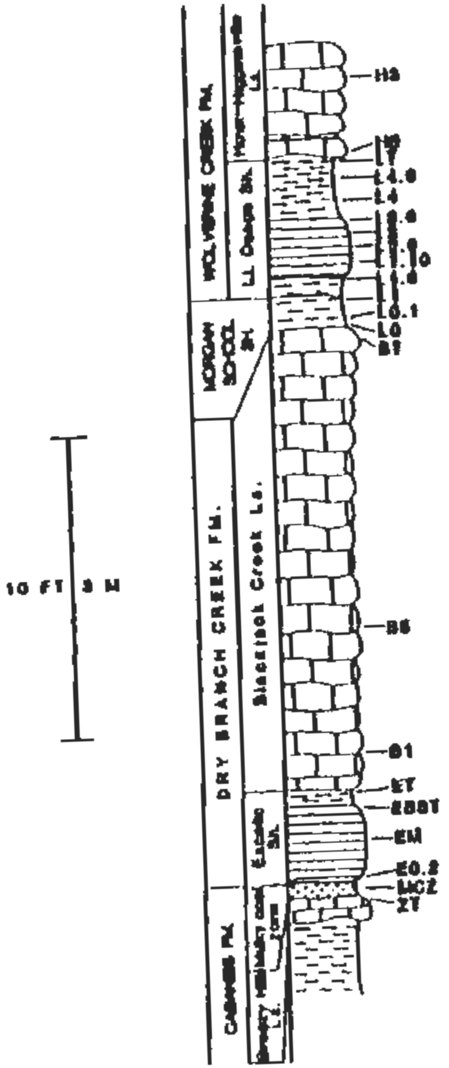
Alphanumeric numbers in first column identify samples collected from illustrated measured section. Second column summarizes lithology of each sample. Symbols for conodonts are Ad=*Adetognathus* spp.; An=*Anchignathodus minutus*; Go=*Gondolella* spp.; Ig=*Idiognathodus* spp.; Ip=*Idioprioniodus* spp.; and Ng=*Neognathodus* spp.



Leonard, Oklahoma (Section LEO)

	Total Cono-donts (actual)	Total Cono-donts (kg)	Ad		An		Go		Ig		Ip		Mg	
			1*	2#	1*	2#	1*	2#	1*	2#	1*	2#	1*	2#
L4.1 gry.sh.	56	114							28	57	5	10	23	47
L4 blk.sh.	33	77							31	65	3	6	3	6
L3 blk.sh.	16	44							14	40	2	4		
L2 fsl.blk.sh.	51	127							33	82	15	37	3	8
L1 fsl.blk.sh.	74	301							28	81	30	155	16	65
BT ls.	2	12							2	12				
BM ls.	29	67					3	7	16	37	4	9	6	14
BB ls.	63	147			2	5	4	9	25	58	11	26	21	49
ZT grn.calcr. sltstn.	811	2903					117	433	519	1908	149	540	26	96
ZM flaky blk.sh.	233	555					18	43	116	276	84	200	15	36
ZB grn.calcr. sltstn.	66	150	6	14					59	134	1	2		
ZY ls.	28	63	2	5	1	2			25	56				
Z3 ls.	13	29	1	2					12	27				
ZO ls.	2	5							2	5				

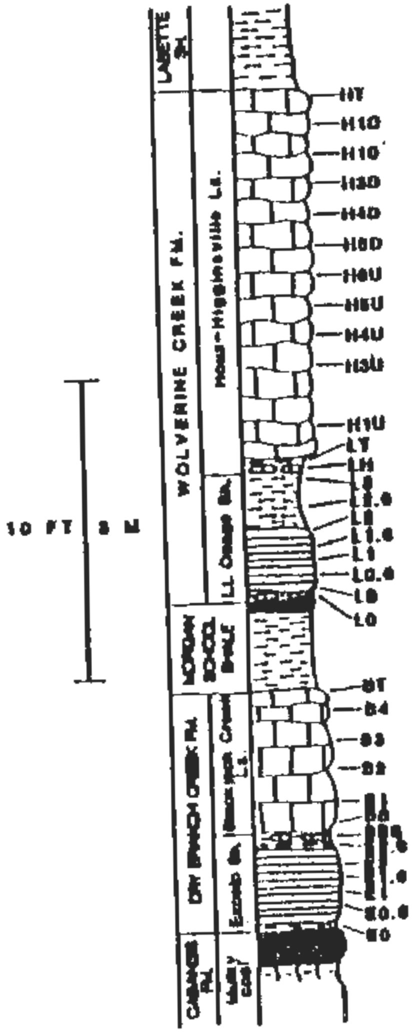
1* = Actual number, 2# = Conodonts/kg.
fsl.blk.sh. = fissile black shale



Oswego, Kansas (Sections SOS and NOS)

	Total Cono- donts (actual)	Total Cono- donts (kg)	Ad		An		Go		Tg		Fp		Ng	
			1^{*}	$2^{\#}$	1^{*}	$2^{\#}$	1^{*}	$2^{\#}$	1^{*}	$2^{\#}$	1^{*}	$2^{\#}$	1^{*}	$2^{\#}$
H3 ls.	6	9							4	6			2	3
NB ls.	3	5							2	3			1	2
LT brn.clystn.	201	404							112	225	45	93	44	88
L4.6 orn.clystn.	425	850							285	570	59	118	81	162
L4 blk.sh.	72	147							50	102	8	16	14	29
L3.6 blk.sh.	47	144							26	80	17	52	4	12
L3 fel.blk.sh.	2	8							1	4	1	4		
L2.6 fel.blk.sh.	34	132							10	39	22	85	2	8
L1.10 fel.blk.sh.	4	19							4	19				
L1.6 dk.gry.to blk. sh.	9	18							8	16	1	2		
L1 gry.clystn.	0													
L0.1 gry.to orn. clystn.	0													
L0 limonitic zone	0													
BT ls.	2	3			1	1			1	1				
B5 ls.	1	2							1	2				
B1 ls.	43	67			5	8			29	45	2	3	7	11
ST gry.clystn.	586	1179			1	2			496	998	40	80	49	99
EBBT fel.blk.sh.	277	796							225	647	31	89	21	60
EM fel.blk.sh.	894	2700					363	1096	439	1326	61	184	31	94
E0.2 fel.blk.sh.	75	198							45	119	28	74	2	5
E0 limonitic, sandy	0													
ZT ls.	1	3							1	3				

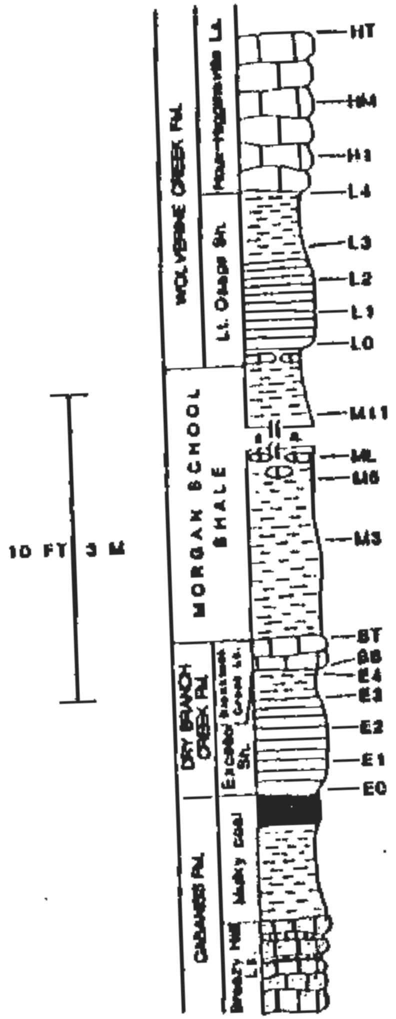
1^{*} = Actual number, $2^{\#}$ = Conodonts/kg.
fel.blk.sh. = fissile black shale



Fort Scott, Kansas (Section FST)

	Total Conodonts (actual)	Total Conodonts (kg)	Ad 1^a	Ad 2^b	An 1^a	An 2^b	Go 1^a	Go 2^b	Ig 1^a	Ig 2^b	Ip 1^a	Ip 2^b	Mg 1^a	Mg 2^b
HT ls.	1	7							1	3				
H1O ls.	2	6			1	2			1	3				
H1O ls.	0													
H2D ls.	1	1			1	1								
H4D ls.	0													
H5D ls.	0													
H6U ls.	0													
H5U ls.	0													
H4U ls.	0													
H3U ls.	0													
H1U ls.	3	7									1	3	1	5
LT gry.sh.	57	114							20	50	10	26	18	36
LH ls.nod.	0													
L3 dk.gry.sh.	95	233							56	132	13	43	24	52
L2.6 dk.gry.sh.	158	332			1	3			100	212	13	45	31	43
L2 blk.sh.	333	834							243	613	49	126	35	88
L1.6 fsl.blk.sh.	70	311							54	143	14	43	2	6
L1 fsl.blk.sh.	56	136							36	122	12	41	2	7
L0.6 fsl.blk.sh.	33	154							14	67	11	53	7	34
LB fsl.blk.sh.	44	134							35	76	17	37	3	21
L0 limy sh.	0													
BT ls.	0													
B4 ls.	0													
B3 ls.	0													
B2 ls.	0													
B1 ls.	0													
Ba ls.	31	152							10	119	11	9		
BBB ls.nod.	0													
E2.6 gry.sh.	130	343							105	313	7	14	0	15
E2 fsl.blk.sh.	101	464							140	390	22	59	18	37
E1.6 fsl.blk.sh.	125	398					15	16	44	200	21	50	5	12
E1 fsl.blk.sh.	252	561					121	280	109	253	14	42	4	9
E0.6 fsl.blk.sh.	36	137							9	30	18	36	3	13
E0 dk.gry.lmy.sh.	47	133							24	45	31	57	3	5

1^a = Actual number, 2^b = Conodonts/kg.
fsl.blk.sh. = fissile black shale



Urich, Missouri (Section U)

	Total Conodonts (actual)	Total Conodonts (kg)	Ad		An		Go		Ig		Ip		Hg	
			1*	2#	1*	2#	1*	2#	1*	2#	1*	2#	1*	2#
HT ls.	3	6	1	1							2	5		
HM ls.	2	4							2	4				
H1 ls.	7	14							6	12	1	2		
L4 grn.clystn.	163	334							123	252	19	39	21	43
L3 dk.gry.sh.	99	198							52	104	22	44	25	50
L2 fsl.blk.sh.	26	78							16	48	3	9	7	21
L1 fsl.blk.sh.	46	130							30	85	10	28	6	17
L0 blk.sh.	41	146							19	66	16	59	6	21
M11 gry.sh.	0													
ML ls.nod.	0													
M5 gry.sh.	1	3							1	3				
M3 gry.sh.	0													
BT ls.	2	10							1	5	1	5		
BB ls.	1	6							1	6				
E4 gry.to grn.sh.	94	192							78	160	8	16	8	16
E3 blk.sh.	69	259							52	195	11	41	6	23
E2 fsl.blk.sh.	115	237							50	103	56	115	9	19
E1 fsl.blk.sh.	349	1114					137	437	125	399	72	230	15	48
E0 blk.sh.	38	78							20	41	18	37		

1* = Actual number, 2# = Conodonts/kg.
fsl.blk.sh. = fissile black shale

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