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Stratigraphy and Depositional History of the Iola Limestone
Upper Pennsylvanian (Missourian),
Northern Midcontinent U.S.

by

John C. Mitchell

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STRATIGRAPHY AND DEPOSITIONAL HISTORY

OF THE IOLA LIMESTONE

UPPER PENNSYLVANIAN (MISSOURIAN),

NORTHERN MIDCONTINENT U.S.

by

John Charles Mitchell

A thesis submitted in partial fulfillment
of the requirements for the degree of
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Thesis supervisor: Professor Philip H. Heckel

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee
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ABSTRACT

The Iola Limestone is one of the best developed and most laterally extensive, yet least studied Missourian cyclic carbonates in the Midcontinent Upper Pennsylvanian. Along with adjacent shales, five members constitute the Iola cyclothem, a typical "Kansas" cyclothem. In ascending order these are: Chanute Shale; Paola Limestone; Muncie Creek Shale; Raytown Limestone; and Lane/Bonner Springs Shale.

Both the Chanute and Lane/Bonner Springs shales are thick sandy shales with local non-marine deposits such as red shales, channel sands, and coal. A sparse marine biota is typically present. Macerated plant fragments are common. These shales probably represent deposition in a marginal marine-deltaic environment during increased detrital influx.

The Paola Limestone is a thin skeletal calcilutite with a diverse and abundant marine biota including phylloid algae. Grain-supported texture grading up to mud-supported texture, diverse fauna and relatively abundant algal debris suggest that deposition occurred during deepening from

shallow water to below effective wave base, but still in the photic zone.

The Muncie Creek Shale, is a thin, laterally continuous non-sandy shale. Throughout most of the study area, black fissile phosphatic shale rich in heavy metal and organic matter and lacking a benthic fauna is sandwiched between gray marine shales with a sparse to abundant marine fauna. Thinness, lateral continuity, absence of benthic fauna and algal remains, fine grain size and presence of abundant non-skeletal phosphorite suggest slow sedimentation offshore in deeper, sediment-starved, often anoxic water.

The Raytown Limestone is a relatively thick, locally algal-rich skeletal calcilutite. Generally, the Raytown grades from skeletal calcilutite deposited below effective wave base upward into calcarenites with evidence of shoal-water deposition including ooids, grain abrasion, cross-bedding and micritization. A basal non-abraded, invertebrate calcarenite with no evidence of micritization, abrasion, cross-bedding or algal debris is locally present. Lateral facies change along the outcrop belt is greatest in the upper Raytown. Shoreline deposits including laminated carbonate mudstone and paleocaliche are present in the northern portion of the study area. The succession recorded in the Raytown reflects deposition in an originally quiet, offshore, open-marine environment that

became more agitated and locally restricted as water depth decreased.

Although traditional interpretation of cyclothems (e.g., Moore, 1936) regarded all shale as nearshore, shallow-water deposits, Iola lithology and stratigraphy support the more recent hypothesis (e.g., Heckel, 1977) that the cyclothem represents a single transgressive-regressive event, with maximum transgression occurring during deposition of the Muncie Creek Shale. Dolomitization, compaction brecciation of sediment within a framework of algal blades, and probable submarine cementation are the most conspicuous diagenetic features seen. Major trends in dolomitization are: preferential dolomitization of mud-supported limestones; extensive dolomitization of limestones adjacent to shales; and extensive dolomitization of all limestones in the north. Probable former botryoidal aragonite preserved as fan-shaped bodies composed of coarsely-crystalline calcite spar is present, making up a "sparite" lens in the Raytown. It also occurs as fans growing within cavities and spherulites apparently neomorphic after lime mud.

Distribution of conodonts reflects the depositional pattern of the Iola cyclothem. Vertical variation far outweighs lateral variation in abundance and diversity. The following groupings reflect probable depth zonation:

Stepanovites conflexa in shallow, agitated water; _Adetognathus lautus_ most common in early transgressive and late regressive deposits; _Aethotaxis advena_, _Idiognathodus_ spp., _Anchignathodus minutus_, and _Diplognathodus_ sp. in surface waters over all depths, with _Idiognathodus_ spp. most abundant over deeper waters; _Gondolella bella_, _Anchignathodus_? sp. A, and to a lesser extent _Idioprioniodus typus_ confined to deeper, less-oxygenated waters.

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28 April 1981
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CHAPTER I

INTRODUCTION

Upper Pennsylvanian (Missourian) strata of the
northern Midcontinent are characterized by a cyclic
alternation of laterally persistent sandy shales and
laterally persistent limestones containing thin shales,
which comprise a sequence of distinct repeating rock units
termed cyclothems. Most Missourian units in the northern
Midcontinent (figure 1) have received or are presently
undergoing detailed petrographic study. One of the best
developed and most laterally extensive, yet least studied
Missourian cyclic deposits is the Iola Limestone, the
subject of this dissertation. Closely spaced exposures
throughout the Kansas-Oklahoma outcrop belt south of the
limit of Pleistocene glaciation and the availability of
adequate core material from southwestern Iowa and eastern
Nebraska make the Iola ideal for the study of lateral and
vertical lithologic variation of one complete cyclothem.

Figure 1.   Generalized Pennsylvanian stratigraphic column
             for northern Midcontinent. Capitalized
             formation names denote limestone formations
             that constitute the most marine portions of
             "Kansas" cyclothems; names in lower case are
             other names applied to similar cyclothems.
             Asterisks denote units that have undergone
             detailed study; small case x denotes units
             currently undergoing study by graduate students
             at the University of Iowa: Fort Scott-K.L.
             Knight; Pawnee-R.C. Price; Lenapah-R.W.
             Parkinson; Hertha-R.L. Ravn; Cherryvale-C.J.
             Siebels. (From Heckel, 1977, Figure 1).

90 ⊤ 300

m ┆ ft
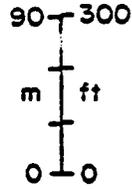
Approximate
scale
(limestones expanded
at expense of shales)

0 ⊥ 0

Formation	Group	Stage	Series
	WABAUNSEE		
TOPEKA			
DEER CREEK	SHAWNEE		
LECOMPTON			
OREAD *		VIRGILIAN	
Toronto *M	DOUGLAS		
Haskell *M			
S. Bend *M			
STANTON*	LANSING		
PLATTSBURG*			
WYANDOTTE*			
IOLA	KANSAS		
DRUM (Quivira)			
Lwr. Cherryvale X	CITY	MISSOURIAN	UPPER PENNSYLVANIAN
DENNIS *			
SWOPE *			
HERTHA x			
	PLEASANTON		
LENAPAH x			
ALTAMONT*	MARMATON		
PAWNEE x		DESMOINESIAN	MIDDLE PENN.
FORT SCOTTx			
Excello *	CHEROKEE		

Figure 1.

Purpose of Investigation

The purpose of this study is five-fold:

1. Describe the Iola Limestone over the major portion of its exposure.

2. Interpret the depositional history and certain aspects of the diagenetic history of the Iola on the basis of field and laboratory study of the stratigraphy and petrography.

3. Obtain data on vertical and lateral distribution and abundance of conodonts in the Iola and adjacent units.

4. Attempt to show whether the relationship between lithology, conodont assemblage and interpreted depositional environment demonstrated by Heckel and Baesemann (1975) in a single Missourian vertical sequence holds true laterally for the Iola Limestone.

5. Provide a stratigraphic and petrographic basis for further studies of the Iola, for example, relating macrofossil assemblages to depositional environment.

Previous Work

Previous work on Upper Pennsylvanian units in the northern Midcontinent may be placed into four time frames:

1. General reconnaissance geology and the beginnings of systematic stratigraphic work in the middle to late 1800s. Moore (1948) summarized early investigations in the Pennsylvanian of the Midcontinent.

2. Work done in the 1920s and 1930s by R.C. Moore, N.D. Newell, J.M. Jewett and their contemporaries. During this time, the cyclic character of the rock sequence was recognized, and stratigraphic correlation of most major units along the outcrop belt was accomplished.

3. More detailed stratigraphic and petrographic work and description of anomalous thickenings, now recognized as algal-mound complexes, was carried out from the 1940s to the 1960s, and has appeared as theses, county geologic reports and published papers by a number of authors, including Oakes (1940, 1952, 1959), Harbaugh (1959, 1960, 1964), and Wilson (1962).

4. Since the late 1960s, there has been intensive study of vertical and lateral lithologic variation, depositional environments, paleogeography, and relationship of micro- and macrofossil assemblages to rock type. Important papers include those by Heckel (1968, 1975a and b, 1977, 1978, 1979, 1980, in press), Heckel and Cocke (1969), Heckel and Baesemann (1975), Senich (1975, 1978), and Wood (1977). Most of the limestone formations of the Missourian stage of the Upper Pennsylvanian in the northern Midcontinent have undergone varying degrees of petrologic study. Works include those by Harbaugh (1959, 1960), Payton (1966), Crowley (1969), Mossler (1970, 1973), Frost (1975), Nelson

(1978), Ravn and Heckel (1978), and Ravn, Mitchell, Nelson and Heckel (1978).

Moore (1948) summarized early work on the Iola. More recently, stratigraphic sections and brief descriptions of the Iola have appeared in guidebooks, county geologic reports, and theses, including those by Schooler (1955), Watson (1955), Ball (1957), Hershey, Brown, Van Eck and Northrup (1960), Lineback (1961), Fishburn (1962), Harbaugh (1962), Miller (1963, 1966, 1969), Jungmann (1966), Seevers (1969), and Heckel (1978, 1979).

Method of Investigation

Twenty-one "primary" (complete or nearly complete) exposures of Iola Limestone, top of the underlying Chanute Shale, and base of the overlying Lane Shale were measured, described and sampled during 1977, 1978, and 1979 (figure 2). Samples for petrologic and micropaleontologic investigations were collected from the top, middle and bottom of beds. Thick-bedded sequences were sampled at approximately 0.5 foot (15 cm) intervals and/or wherever lithologic changes were noted. Additional "secondary" exposures were visited in order to delineate the extent of different facies and detect any lithic variations not seen in primary sections. Secondary exposures were sampled at localities where it was possible to determine the stratigraphic position of the outcrop within the Iola. No

Figure 2.   Location map of Iola exposures (black dots)
             and cores (bullseyes) studied. Solid line
             connecting localities denotes line of cross-
             section. Thin wavy line denotes trace of Iola
             outcrop in eastern Kansas and northeastern
             Oklahoma. Refer to Appendix A and B for
             locality codes.
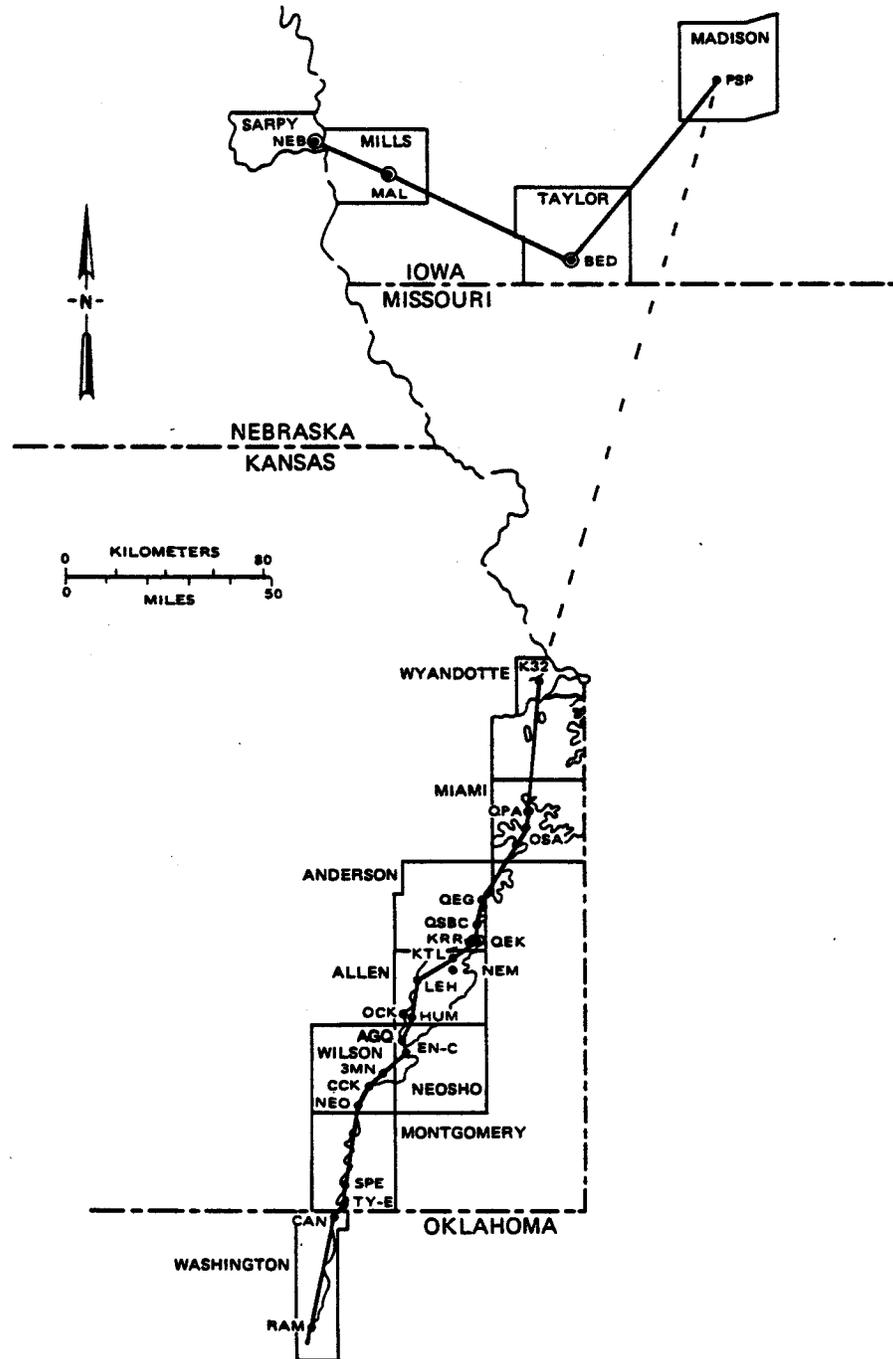
Figure 2.

attempt was made to expand this study by tracing the Iola westward into the subsurface.

Location of exposures was obtained from advisor's field notes, state geologic survey open-file reports, literature review, and detailed examination of 7-1/2 minute topographic quadrangles of the study area.

Two relatively complete cores of the Iola were provided through the courtesy of the Kansas Geological Survey, two cores with Iola were made available by the Iowa Geological Survey, and a fifth core was examined at the Nebraska Conservation and Survey Division in Lincoln.

The bulk of the field work was carried out in eastern Kansas, where intensive study is necessary in order to understand complex lateral facies changes that occur in this area. Northward, few outcrops were sampled due to cover by Pleistocene glaciation. Data from cores was heavily relied upon throughout Iowa and Nebraska.

Petrographic study of approximately 300 thin sections and polished slabs was undertaken to help ascertain depositional and post-depositional history. Thin sections and polished slabs prepared from each sample were stained with alizarin red-S and potassium ferricyanide (Dickson, 1966) to facilitate recognition of ferroan and non-ferroan calcite and dolomite. Dunham's (1962)

classification of carbonate rocks based on depositional texture is used throughout this study.

Clay mineralogy of selected samples from the Iola Limestone, Chanute Shale and Lane Shale was determined by x-ray diffractometry.

Limestone and shale samples from seventeen exposures of the Iola and adjacent units were processed and picked for conodonts. Methods used are discussed in a later section.

Vertical Sequence: Cyclothems

The cyclic nature of Middle and Upper Pennsylvanian strata in the northern Midcontinent has long been recognized (Moore, 1936); however, a model adequately explaining depositional environments of all cyclothem members has only recently been developed. Facies and depositional environments of the Iola Limestone and adjacent shales are considered within the framework of the basic "Kansas" cyclothem (Heckel, 1977, 1980), the depositional unit characterizing most Missourian strata in this area. The discussion that follows is based on the work of Heckel (1975a and b, 1977, 1978, 1979), Heckel and Cocke (1969), Toomey (1969), Troell (1969), Crowley (1969), Frost (1975), Payton (1966), Harbaugh (1959), Mossler (1973), Haggiagi (1970), Evans (1967), Schenk (1967), and James (1970) and on personal observations of this author and of R.C. Price,

S.R. Schutter, and R.L. Ravn, fellow students at the
University of Iowa.

Depositional Sequence

Five members constitute the typical "Kansas" or
"Missourian" cyclothem (Heckel, 1977, 1980). In ascending
order these are: "outside" (nearshore) shale, "middle"
(transgressive) limestone, "core" (offshore) shale, "upper"
(regressive) limestone, and "outside" (nearshore) shale
(figure 3). Heckel regards each cyclothem as a single
transgressive-regressive event with greatest water depth
(maximum transgression) occurring during deposition of the
core shale.

Outside (Nearshore) Shale

Outside shales are generally thick, (typically 50-130
feet, 15-40 m), gray to brown sandy shales that locally
contain non-marine deposits including red shales, fluvial
sandstones, coal, and underclay. Bivalves, gastropods, and
brachiopods constitute the sparse marine fauna that is
usually restricted to the upper few meters of the unit.
Plant fragments are relatively common in local, thin
sandstones and siltstones. Outside shales probably repre-
sent deposition in a marginal marine to deltaic environment
during times of increased detrital influx.

Figure 3.   Basic vertical sequence of typical "Kansas"
             cyclothem. This transgressive-regressive
             depositional unit characterizes most of the
             Marmaton, Kansas City, Lansing and Shawnee
             Groups of the Pennsylvanian in the northern
             Midcontinent (Modified from Heckel, 1977,
             Figure 2).
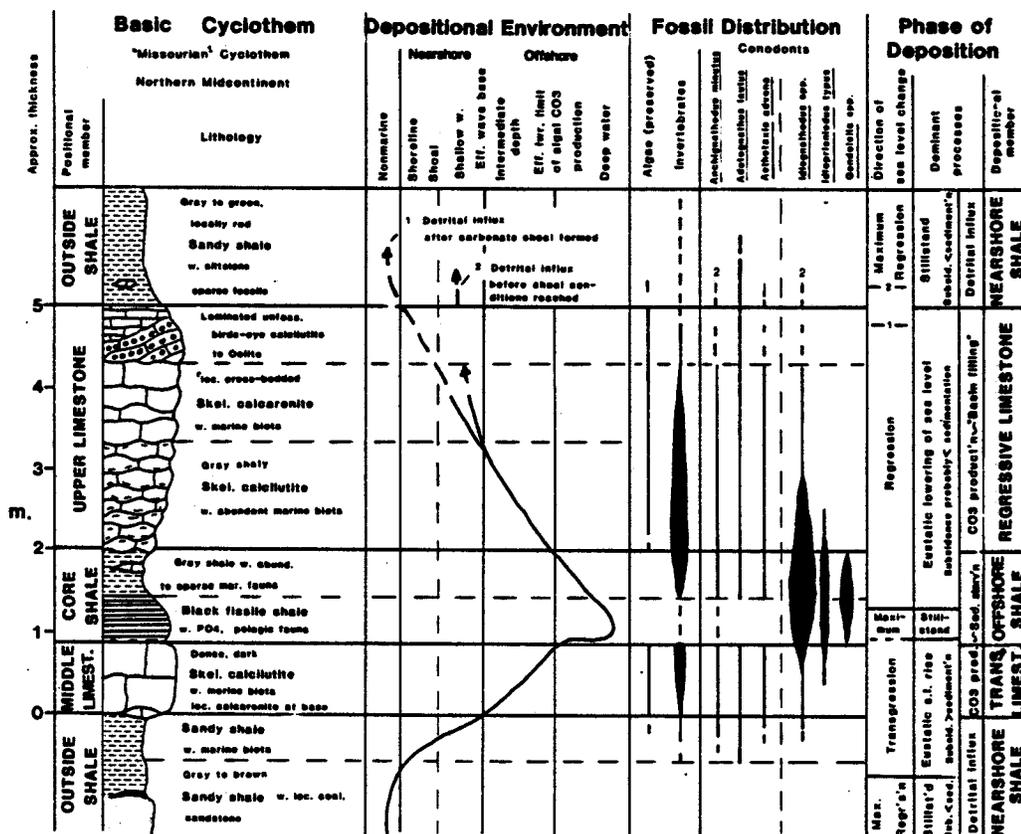
Figure 3.

Middle (Transgressive) Limestone

Middle limestones typically are thin (0.3-2 m, 1-6 ft.), dense, skeletal calcilutites with a relatively diverse and abundant marine biota including brachiopods, echinoderm debris, bryozoans, corals, molluscs, foraminifers, sponges, ostracodes, trilobites, and red, green and blue-green algae.

The base of the unit is locally gradational with underlying outside shales; shoal-water facies (e.g. oolites and stromatolites) are developed in the base of a few transgressive limestones. Mud-supported textures, diverse fauna, and scattered to abundant algal material in the bulk of the middle limestone suggest that most carbonate deposition took place below effective wave base, but still in the photic zone.

Core (Offshore) Shale

Core shales are relatively thin (10 cm-2 m, 4 in.-6 ft.), essentially non-sandy shales relative to outside shales that are laterally continuous over long distances. Black fissile shales that are rich in heavy metals and organic matter and lack a benthic fauna are typically "sandwiched" between gray marine shales that contain a sparse to abundant benthic fauna with echinoderm debris, brachiopods, bryozoans and sponges. Non-skeletal phosphate is abundant in both gray and black shales. Some core

shales show lateral thickening with transition of black shale into non-black, fossiliferous, sandier marine shales as paleoshoreline is approached.

Thinness, lateral continuity, lack of benthic fauna, absence of algal remains, fine grain size and presence of abundant non-skeletal phosphorite are suggestive of slow sedimentation offshore in deeper, sediment-starved, often anoxic water.

Upper (Regressive) Limestone

Upper limestones typically are relatively thick (6-80 ft.; 2-25 m), thin-bedded to massive, locally algal-rich skeletal calcilutites with an abundant and diverse marine biota. Many regressive limestones grade upward into calcarenites with evidence of shoal-water deposition including ooids, grain abrasion and rounding, cross-bedding, and extensive grain micritization. A few upper limestones grade upward into shoreline deposits such as laminated calcilutites with mudcracks, and birdseye structures. Paleocaliche is locally present.

Skeletal calcarenites are found at the base of a few upper limestones. In contrast to the calcarenites developed at the top of this member, these show no evidence of grain micritization, grain abrasion and rounding, cross-bedding, or algal debris. These deposits

record deposition below effective wave base and possibly below the limit of significant algal production.

The vertical succession in upper limestones records deposition in an originally quiet, offshore open-marine environment that became more agitated and locally restricted as water depth decreased.

Depositional Model

Earlier, traditional interpretations of depositional environments of cyclothems in Illinois and Kansas either had ignored the core shale, or else interpreted it as a nearshore, extremely shallow-water deposit (Weller, 1930, 1931; Weller and Wanless, 1932; Moore, 1932, 1936). In order to account for the high organic-matter content and the necessary restriction of circulation that resulted in anoxic, quiet water conditions responsible for the black facies in very shallow waters, many workers (Weller, 1956; Zangerl and Richardson, 1963; Merrill, 1975; Merrill and von Bitter, 1976; Merrill and Martin, 1976), have invoked the existence of an enigmatic algal "flotant".

This "shoreline" or "lagoonal" model does not adequately explain many features of these black shales including scarcity of sand, lack of preserved algal material, offshore nature of adjacent limestone units, and extreme lateral persistence with no gradation into recognizable shoreline deposits.

The concept of the core shale being deposited farthest
offshore during maximum transgression is relatively new and
has been considered somewhat heretical. The idea was first
proposed by Evans (1967), Schenk (1967), and James (1970),
and was further developed by Heckel and Baesemann (1975)
and Heckel in a series of papers and guidebooks (1977,
1978, 1979, 1980, in press).

While recognizing the possibility of existence of
shallow-water or lagoonal black shales, Heckel (1977),
proposed a deep-water model to account for the origin of
laterally-extensive phosphatic black shales. This model
involves changes in water circulation during maximum
transgression when water depth was sufficient to allow the _speculation_
development of a thermocline, thus preventing bottom
circulation and oxygenation by wind-driven vertical
currents. A large scale quasi-estuarine circulation cell
set up by prevailing trade winds (Heckel, 1977; figure 5), _in equatorial area_
brought about upwelling of cold, oxygen-poor, nutrient-rich
bottom waters. Organic matter from resultant plankton
blooms in surface waters settled back into bottom waters,
further depleting oxygen while at the same time increasing
phosphate content.

In part, the controversy over the environmental
significance of the core shale seems to arise from
provincialism among workers. The most ardent proponents of

the idea that "black shale means shallow water" appear to be those whose experience has been largely restricted to the Illinois and Appalachian Basins. In the "typical" Illinois cyclothem (which lacks a transgressive limestone; Heckel, in press), the black shale directly overlies coal; in the "complete" Illinois cyclothem, the black shale is separated from the coal by a thin marine limestone and occasionally by up to 50 feet (15 m) of gray shale. The fact that a black shale often lies directly above an authochthonous coal has been cited by several authors, including Merrill and Martin (1976) as evidence that the black shale cannot possibly be interpreted as having an offshore, deeper-water origin.

The offshore black-shale model can satisfactorily explain the "complete" Illinois cyclothem (which is essentially a Kansas cyclothem) without modification, and with only slight modification, can account for the "typical" Illinois cyclothem (Heckel, in press). Here, the lack of a widespread transgressive limestone may reflect the proximity of the inundated coal swamp to depositional substrate, which resulted in conditions unfavorable for much marine life including all carbonate-producing algae during deepening to the depth of black shale deposition.

A detailed discussion of possible controls of Pennsylvanian cyclic deposition is beyond the scope of this

study. Mechanisms proposed include eustatic sea level changes such as would be caused by episodes of Carboniferous Gondwanan glaciation (Crowell, 1978; Heckel, 1980), which probably controlled the widespread cycles. Relatively local mechanisms such as repeated deltaic progradation and abandonment (Ferm, 1970) may have also played a role, particularly with respect to local changes in thickness and lithology of nearshore deposits.

Recent work (Sarg, 1979, 1980; Carothers, 1979) has demonstated that it is possible to recognize and differentiate cycles controlled by eustatic sea level changes and those caused by local delta shifts.

Lateral Variation: Facies Belts

Cyclic units of Upper Pennsylvanian rocks of the Midcontinent also exhibit lateral facies changes. Heckel (1968) established a framework of four regional facies belts: northern shoreward, open marine, phylloid-algal mound, and terrigenous detrital (figure 4). Lateral facies changes that define the facies belts are best developed in upper limestones and to some extent in the outside shale members; other units of the cyclothem exhibit less lateral change. Lateral trends for each cyclothem member are discussed in detail by Heckel (1977) and are only summarized below and in Figure 5.

Figure 4.   Pennsylvanian outcrop in eastern Kansas and
             adjacent region showing generalized positions
             of four major facies belts. Stage boundaries
             are shown with solid lines, Missourian facies
             belts are separated by solid dots. Facies
             belts are best developed in upper limestone
             members. Location of belts is idealized for
             the entire Missourian, and actual location of
             each facies belt for a particular formation
             varies from this model. (Modified from Heckel,
             1978).
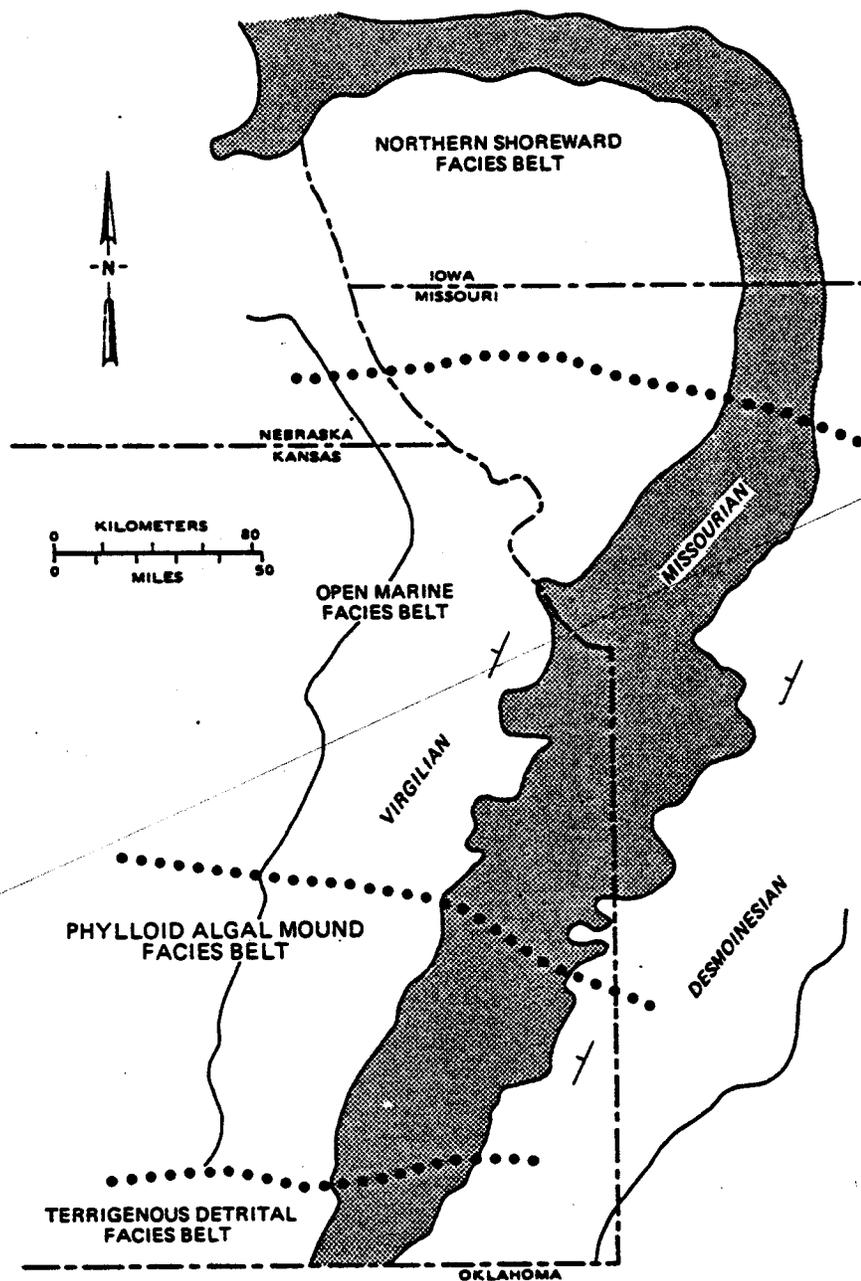
Figure 4.

Figure 5.   Generalized north-south cross-section of Upper
             Pennsylvanian "Kansas" cyclothem along northern
             Midcontinent outcrop. Cross-section shows
             relation of members and facies to transgression
             and regression. Long dashed line labelled
             "deepest water" shows positions of deposits
             laid down in deepest water during time of
             maximum transgresion. E.W.B. = effective wave
             base. Datum is interpreted sea level at time
             when increased influx of terrigeneous detritus
             terminated deposition of upper limestone
             member. (From Heckel, 1977, Figure 4).

Figure 5.

South   North

OKLAHOMA   SOUTHEAST KANSAS   NORTHEAST KANSAS   IOWA-NEB.

TERRIGENOUS   ALGAL MOUND   OPEN MARINE   NORTHERN   PHASE OF
DETRITAL   SHOREWARD   MEMBERS   DEPOSITION

                                                                       OUTSIDE   NONMARINE TO
                                            DATUM   SHALE   SHALLOW
SANDSTONE   SHORELINE CO3   UPPER   WATER
& SHALE   SKELETAL CALCARENITE   LIMESTONE   E.W.S.
                  ALGAL CALCILUTITE   CALCILUTITE   CORE
                             SKELETAL   SHALE   DEEPEST WATER
                                        BLACK SHALE   MIDDLE
FOSSILIFEROUS   SKELETAL   CALCILUTITE   L.S.   E.W.S.
    SHALE   SANDY SHALE & SILTSTONE   RED SHALE   OUTSIDE   SHALLOW WATER
DEEPEST   LOCAL SANDSTONE, COAL   SHALE   TO NONMARINE
WATER
    SANDSTONE
    & SHALE

23

In northeastern Kansas, the open marine facies belt is characterized by limestone consisting mainly of skeletal calcilutite with a diverse open marine fauna. In southeastern Kansas where the open marine facies belt grades southward into the phylloid algal mound facies belt, practically all upper limestone members abruptly thicken into algal mound complexes. Several rock fabrics dominated by phylloid algal-rich skeletal calcilutites constitute the mound facies. Shoal-water "mound-associated" facies, typically cross-bedded skeletal/oolitic calcarenites, overlie and flank the mound facies. In southernmost Kansas, some limestones thin southward into shaly and sandy limestones; others grade directly southward into sandstone and shale which define the terrigenous detrital facies belt. Mound complexes are developed in a few limestone units in northeastern Oklahoma, but all units grade into clastics somewhere south of the Kansas-Oklahoma border.

To the north in Iowa and Nebraska, shoreline carbonate facies including laminated carbonate mudstones with mudcracks and birdseye appear in upper limestones. Red shales are present in some outside shales.

Paleogeography and Paleotectonic Setting

Figure 6 shows a generalized paleogeographic and paleotectonic setting for the northern Midcontinent during the late Pennsylvanian. The paleoequator is based on

Figure 6.   Generalized map of northern Midcontinent
showing location of Upper Pennsylvanian
outcrop, paleotectonic, and paleodepositional
setting. Paleolatitudinal base is from Heckel
(1977, p. 1056). Hachured line shows
approximate Upper Pennsylvanian outcrop in the
northern Midcontinent. Major positive features
mentioned in text are shown in gray. (Modified
from Moore, 1979; Heckel, 1980).

Figure 6.
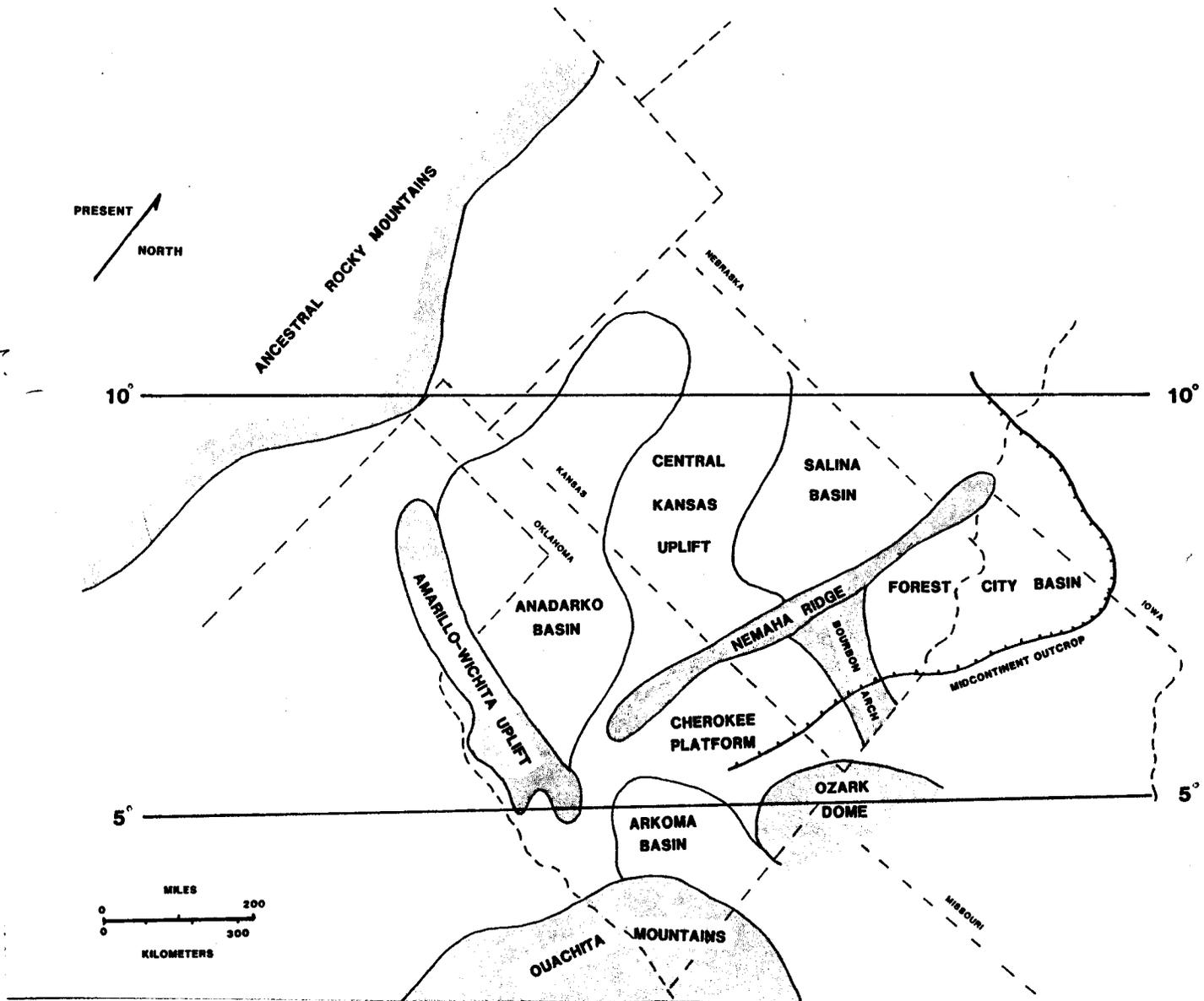
Heckel's (1977) fit accounting for distribution of climate-sensitive lithologies such as coals, red beds and evaporites, which deviates only slghtly from the paleoequator location determined from paleomagnetic data by van der Voo and French (1974).

During Missourian time in the Midcontinent, sediments shed from the rising Appalachian positive element were deposited in a gradually westward-thinning wedge of deltaic deposits (McKee, et. al., 1975). The Ozark Dome was stable or only slightly positive at this time and of little importance as a clastic source. The importance of the much-reduced Nemaha Ridge also was negligible. To the south, in present-day Oklahoma, uplift and shedding of large amounts of clastics continued along the Amarillo-Wichita and the Ouachita positive areas from which delta-front and prodeltaic sediments prograded northward.

The northern Midcontinent comprises many minor tectonic features (Moore, 1979; Jewett, 1951); including the northwest-southeast trending Bourbon Arch (figure 6), which apparently was a low positive feature during the time of Iola deposition.

General Overview of the Iola

The name Iola was given to exposures of a prominent light gray limestone in and near the town of Iola in Allen Co., Kansas by Haworth and Kirk (1894). The formation

crops out in a narrow belt extending from northeastern Oklahoma, across eastern Kansas, through northwestern Missouri and southwestern Iowa and into eastern Nebraska, (figure 2).

Three members, corresponding to the most marine portion of the Iola cyclothem, constitute the Iola Limestone. In ascending order these are (figure 7): Paola Limestone ("middle" limestone); Muncie Creek Shale ("core" shale); and Raytown Limestone ("upper" limestone). The Iola overlies the Chanute Shale with apparent conformity, and underlies the Lane (Lane/Bonner Springs) Shale, both of which are "outside" shales bounding the Iola cyclothem.

The Paola Limestone Member (Newell, 1932) is present throughout most of the study area. In its type area in Miami Co., Kansas, the Paola is a thin (2 ft.; 0.6 m), dense, laterally uniform, blue-gray skeletal calcilutite with a relatively diverse and abundant marine biota.

The Muncie Creek Shale Member (Newell, 1932) is laterally continuous and relatively uniform. In its type area in Wyandotte Co., Kansas, the Muncie Creek consists of a thin (2 ft.; 0.6 m), black, phosphatic, fissile shale that is sandwiched between gray marine shales to form a 3-foot (0.9 m)-thick unit.

At its type locality near Kansas City, the Raytown Limestone Member (Hinds and Greene, 1915), is approximately

Figure 7.   Generalized columnar section of Iola Limestone
             and adjacent units in Midcontinent. Vertical
             scale is approximate. Standard lithologic
             symbols are used, except for convex-upward
             curve, which represents phylloid algal-rich
             limestones (Modified from Heckel and Cocke,
             1969).

Figure 7.

NORTHEASTERN OKLAHOMA

KANSAS, MISSOURI, IOWA, NEBRASKA

30
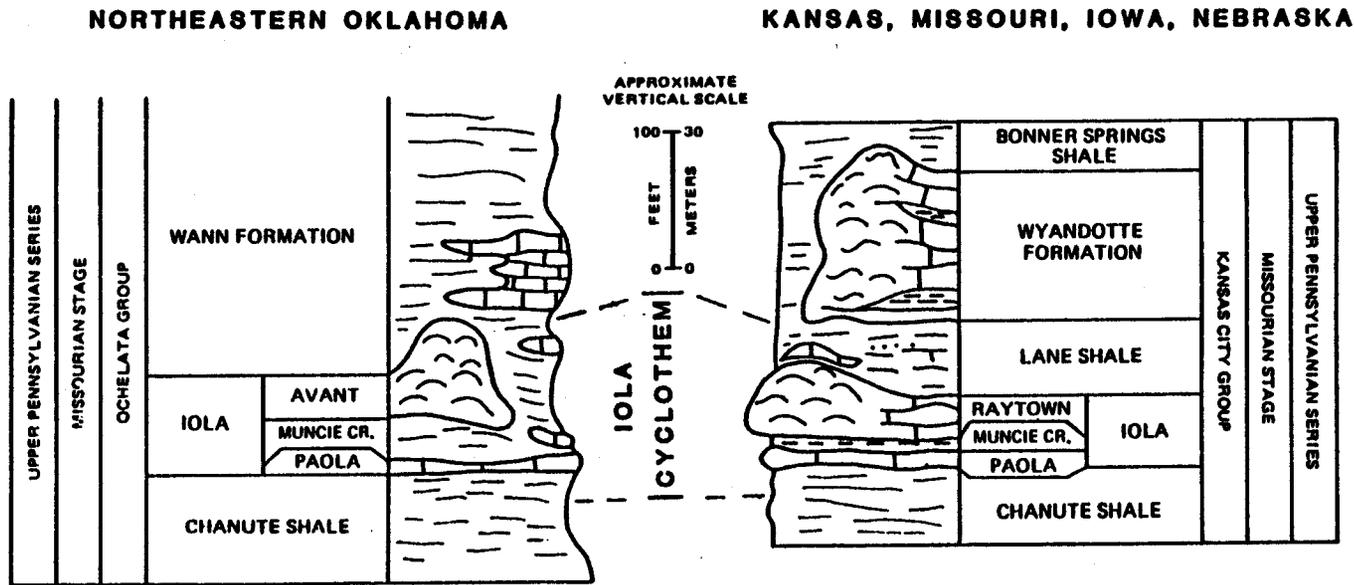
9 feet (2.7 m) thick and is typically a tan to buff, wavy-bedded, skeletal to phylloid algal-rich skeletal calcilutite.

Member names are recognized along the entire Mid-continent outcrop except for the Avant Limestone Member of northeastern Oklahoma, which is essentially equivalent to the Raytown of Kansas, Missouri, Iowa and Nebraska.

Lateral facies changes in the upper Raytown Member define facies belts. Location of boundaries between facies belts differ somewhat from those generalized for the Missourian (figure 4) by Heckel (1968). The boundary between the algal mound facies belt and the terrigenous detrital facies belt for the Iola cuts across southeastern Osage and adjacent Tulsa Counties in Oklahoma, considerably farther south than the generalized boundary shown by Heckel (1968).

The generalized framework is additionally modified for the Iola by the fact that two mound-complexes are developed: one in southern Anderson, Allen, and northernmost Neosho Counties in Kansas; and a second mound in the Avant Member in southern Washington and adjacent Osage Counties in Oklahoma. Throughout the "inter-mound" area, in the Kansas-Oklahoma border region, the Raytown and equivalent Avant Limestones are thin, shaly, and calcilutitic.

CHAPTER II

STRATIGRAPHY AND LITHOLOGY

A closer look at the nature and lateral variation of
each member of the Iola Limestone and adjacent units will
facilitate interpretation of its depositional history.
Figure 8 is a generalized cross-section of the Iola
Limestone showing correlation of individual stratigraphic
sections and general lithology.

Chanute Shale

The Iola Limestone overlies the Chanute Shale with
apparent conformity throughout the outcrop belt. The
Chanute in turn, rests locally ~~unconformably~~ on the Drum
Limestone and in places cuts into the underlying Cherryvale
Formation. The Chanute thins northward from a maximum
thickness of 200 feet (60 m), including much sandstone, in
southeastern Kansas to 3.5 feet (1 m) of mostly shale in
eastern Nebraska. The Chanute typically shows considerable
thickness variation over relatively short distances,
particularly near the Kansas-Oklahoma border (Haggiagi,
1970; Miller, 1966).

The following discussion is based on personal
observation, stratigraphic sections on file at the Kansas

Figure 8. Generalized north-south cross-section of Iola
           Limestone. Datum is upper surface of Paola
           Limestone Member. Lithologic symbols used are
           as follows:
           Solid black = black, fissile shale.
           Horizontal dashes = gray shale.
           Blank white = carbonate mudstone to wackestone.
           Double vertical lines = carbonate packstone.
           Double vertical lines with G = carbonate
           grainstone.
           Thin brick pattern with wavy lines = shoreline
           calcilutites, including laminated carbonate
           mudstone.
           Oblique slashes = probable exposed and
           calichified carbonates.
           Fine stipple = sandstone to sandy carbonate
           packstone.
           Circles = abundant ooids.
           Eye symbol = birdseye structures.
           Convex-upward curves = abundant phylloid algae.
           Solid vertical lines indicate that section was
           measured and described by author; short
           horizontal slashes show top and bottom of
           section. Dashed vertical lines indicate that
           section description comes from literature. See
           Appendix A for section description and key to
           location codes, and Appendix B for more
           detailed individual stratigraphic columns.

Figure 8.
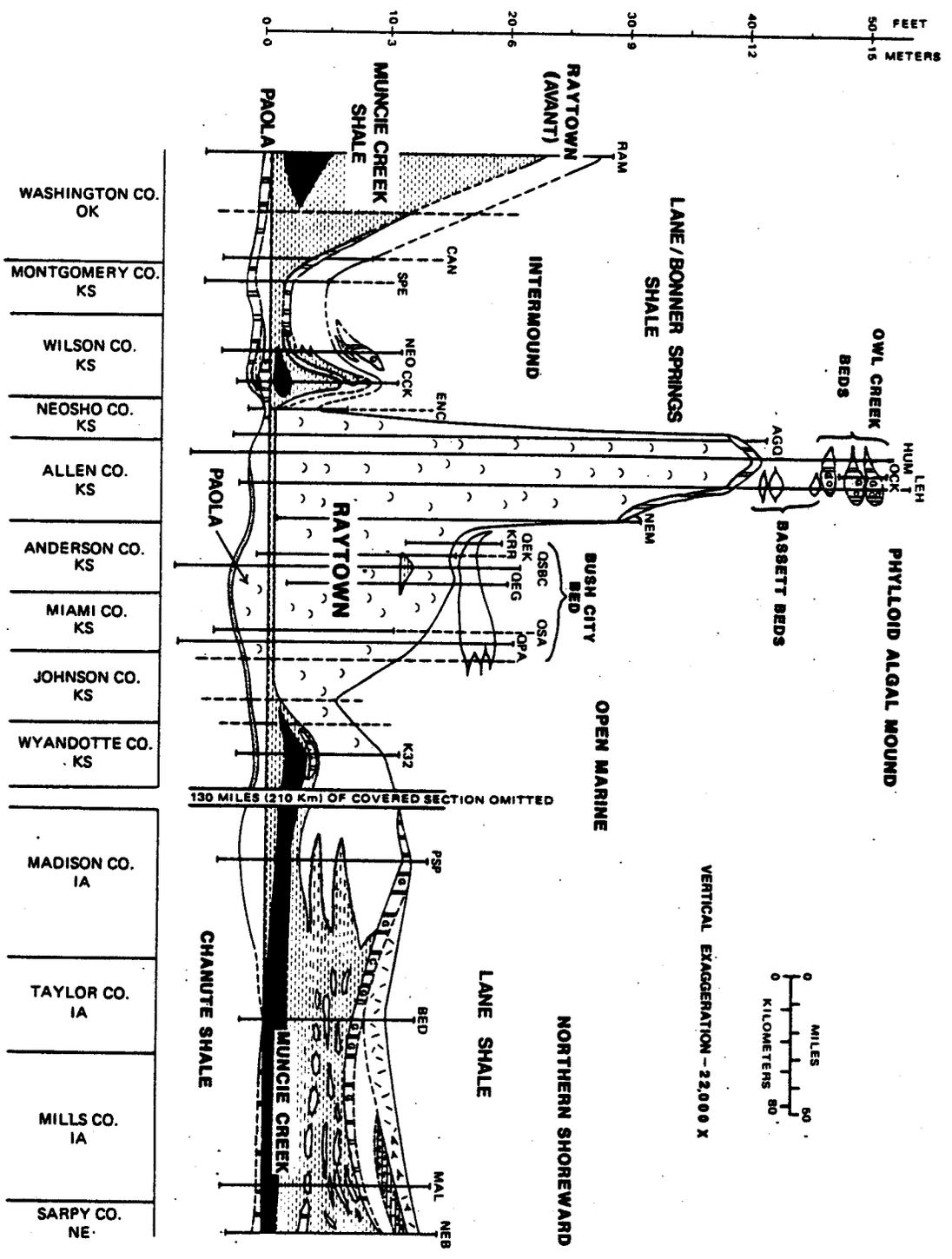
and Iowa Geological Surveys, and the work of Haggiagi
(1970), Hershey, Brown, Van Eck and Northrup (1960),
Lineback (1962), Miller (1963, 1966, 1969), and Oakes
(1940, 1952, 1959).

Four members constitute the Chanute, in ascending
order: Noxie Sandstone, "unnamed" shale, Thayer Coal, and
Cottage Grove Sandstone. All members are thickest and best
developed near the Kansas-Oklahoma border. Units become
less distinguishable northward.

Near the Kansas-Oklahoma border (figure 9), thickness
ranges from 15 to approximately 200 feet (4 to 60 m).
Maximum thickness is developed where the lower portion of
the Chanute (lower Noxie Sandstone with basal limestone
conglomerate), fills a pre-Chanute erosion channel. The
Noxie Sandstone is up to 80 feet (24 m) thick in this area
and is a massive, relatively coarse-grained, cross-bedded
sandstone. The "unnamed" shale, a lateral facies
equivalent of the Noxie, particularly to the north, ranges
from 0 to 60 feet (0 to 18 m) thick and is a locally
sandy, gray to yellow, clay shale. The laterally
persistent Thayer Coal is up to 1.5 feet (0.5 m) thick in
the Kansas-Oklahoma border region and separates the Noxie
Sandstone from the overlying Cottage Grove Sandstone. The
Cottage Grove is a buff, micaceous, fine-grained, thin-
bedded to massive sandstone, which is up to 40 feet (12 m)

Figure 9.   Isopach map of the Chanute Shale.   Contour
             interval = 25 feet.   Small x's are control
             points.   Location of primary and secondary
             exposures mentioned in present study are
             indicated by bullseyes.   Modified from Haggiagi
             (1970).

ISOPACH MAP OF THE
CHANUTE SHALE

CONTOUR INTERVAL - 25 FEET
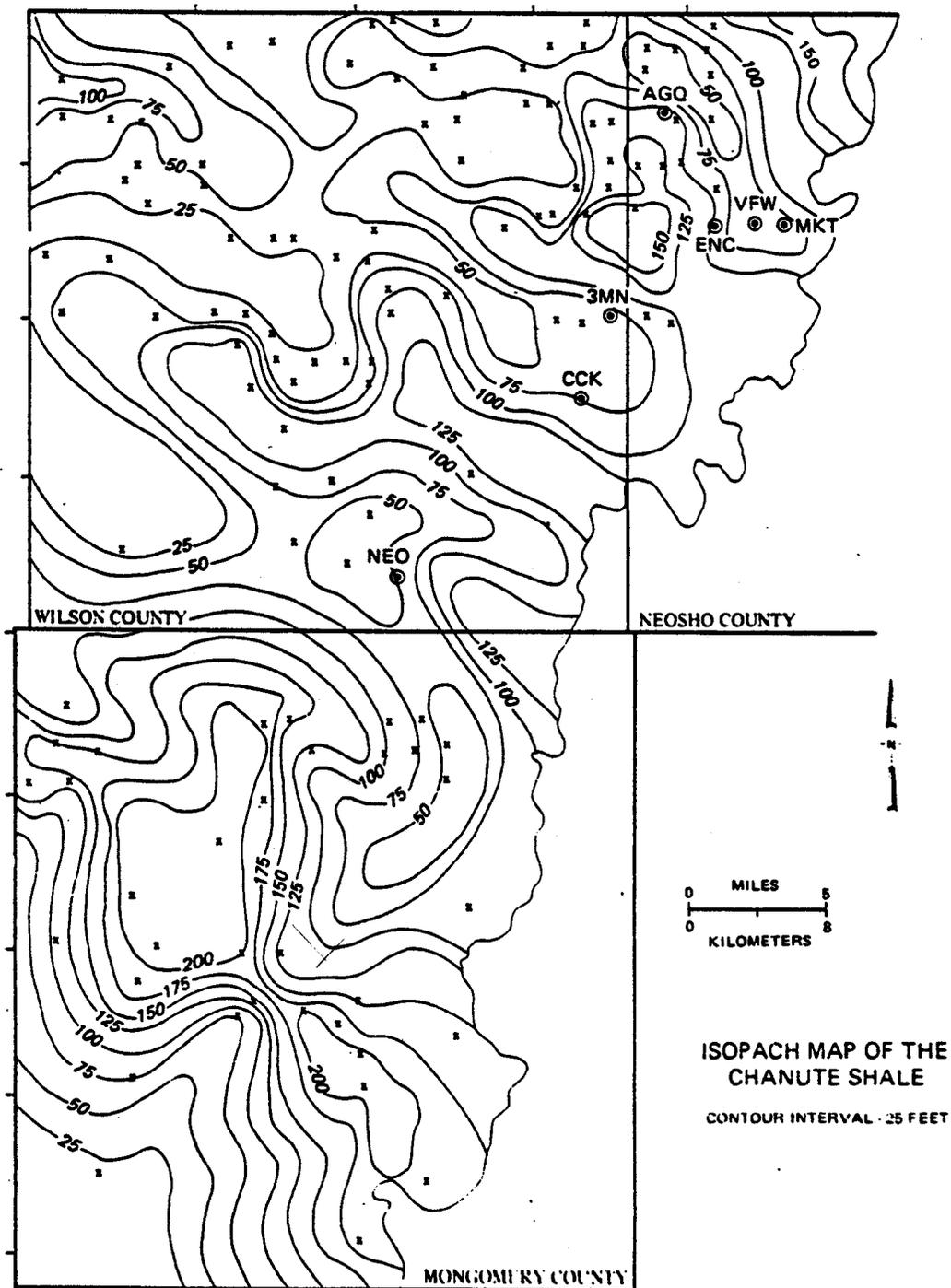
Figure 9.

thick. A thin zone of carbonaceous shale and coal smuts is present at the top of the Cottage Grove in places.

To the north in Allen, Anderson, and Miami Counties, Kansas, the Chanute ranges from 20 to 70 feet (6 to 21 m) thick. In this area it is typically an olive to bluish gray, sandy shale with yellow to buff, thin-bedded silt-stones and sandstones. Plant remains and thin coal streaks are locally present.

The Chanute is thin throughout northeastern Kansas, Iowa, and Nebraska, ranging from 3.5 to 5 feet (1 to 1.5 m) thick. In this area the Chanute is a locally carbonaceous, gray to green clay shale. Macerated plant fragments and thin coal smuts are common. Laminae are locally disrupted by burrowing and/or rooting activity.

Paola Limestone Member

The Paola Limestone, "middle" limestone member of the Iola cyclothem, shows little lithologic variation throughout the study area. Two informal units are recognized everywhere except in southwestern Iowa and eastern Nebraska: basal sandstone to locally sandy skeletal packstone, and upper skeletal wackestone. Together these make up all of the Paola (figure 8).

Basal Sandy Skeletal Packstone

The basal Paola is chiefly a thin (1-4 inch,
2.5-10 cm), platy, fossiliferous sandstone to locally sandy
skeletal packstone (figures 8 and 10A). Fossiliferous
sandstone consists mainly of fine-grained subrounded to
subangular quartz sand with minor glauconite and mica. A
relatively diverse and abundant fauna is present, and is
dominated by fragmented and possibly abraded echinoderm
debris, brachiopods, and encrusting foraminifers in
association with minor bryozoans, trilobites and ostracodes
(figure 11). The contact with the underlying Chanute is
gradational, and therefore arbitrarily placed where
skeletal debris becomes abundant. The sandstone grades
vertically and laterally into silty to sandy skeletal
packstone.

The skeletal packstone comprises mud and abundant
echinoderm debris, brachiopods, encrusting foraminifers,
with subordinate trilobites, molluscs, fusulines, sponges,
vaguelly-laminated (probably blue-green algal) clumps, and
phylloid algae (figure 12). Skeletal grains are mostly
disarticulated and broken, with sutured contacts common.
Many grains are crushed and flattened in the plane of
bedding. Grains are neither substantially abraded nor
rounded. Locally, medium to coarse silt-sized dolomite
rhombs replace the lime mud matrix and embay presumably

Figure 10.   Iola Limestone outcrop photographs.

      A.   Locality NEO, Wilson Co., Kansas.
          Contact of irregular-bedded basal Paola
          sandy skeletal packstone (BP) with
          subjacent coaly Chanute Shale. Portion of
          tape measure visible in photograph is 1 ft.
          (30 cm) long. Refer to Figure 76 for
          stratigraphic section of Locality NEO.

      B.   Locality KTL, Allen Co., Kansas.
          Thin, gray Muncie Creek Shale facies (MC)
          typical of algal mound tract. Muncie Creek
          is underlain by Paola skeletal wackestone
          (P), and overlain by Raytown normal marine
          skeletal wackestone/packstone (R). Thin,
          flaggy-bedded Raytown is typical of
          weathered outcrops. For scale, Paola is
          approximately 2 ft. (60 cm) thick. Refer
          to figure 67 for stratigraphic section of
          Locality KTL.
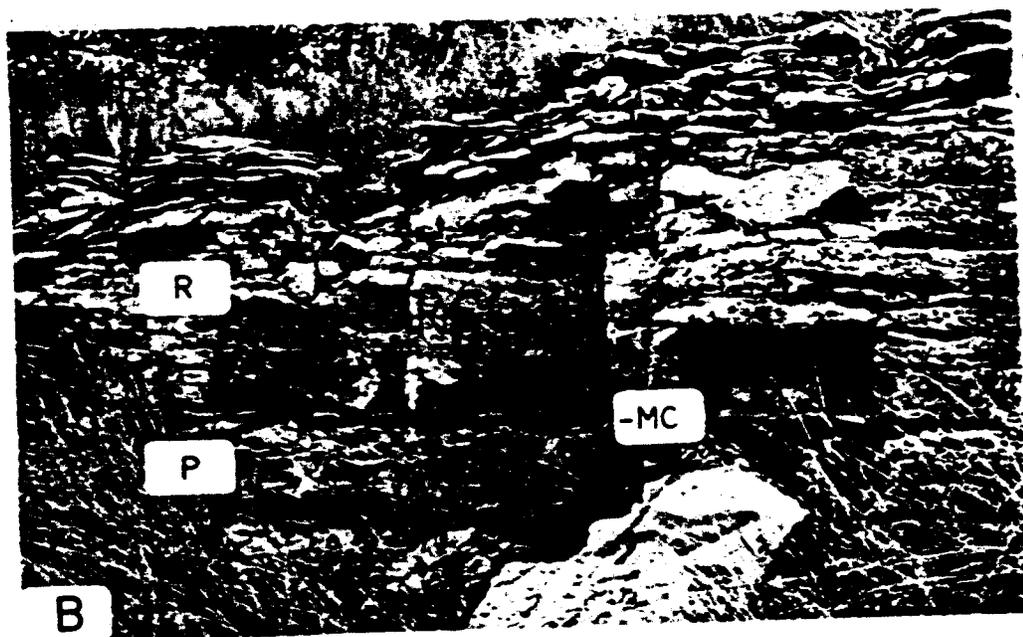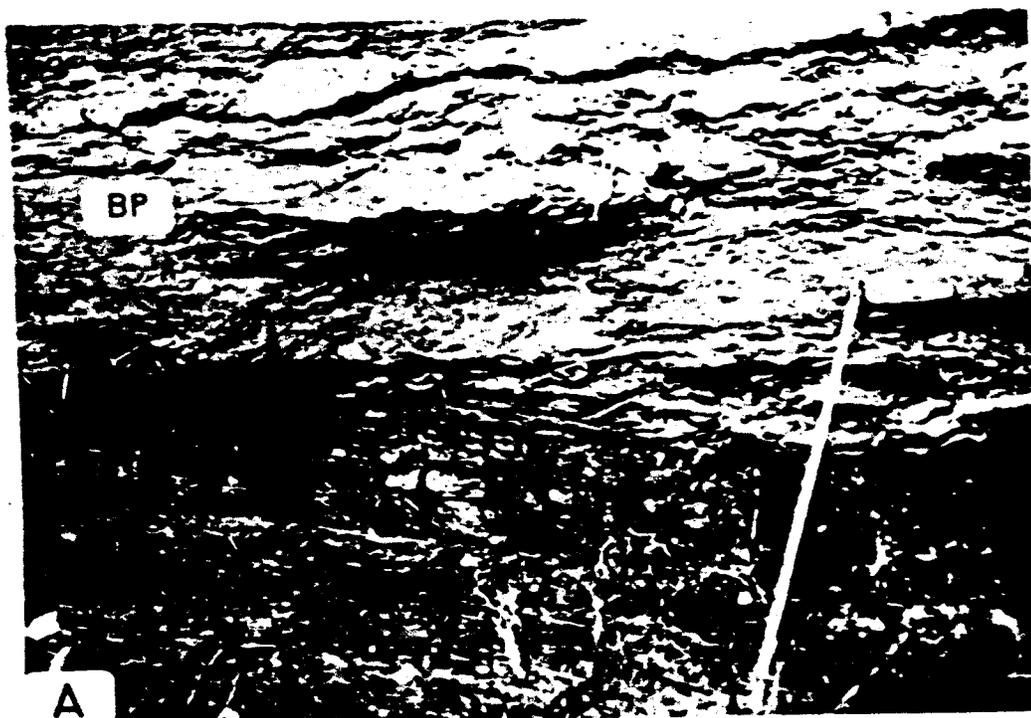
Figure 11. Basal Paola fossiliferous sandstone.

    A. Slabbed and polished hand specimen of basal
        Paola fossiliferous sandstone from locality
        CCK in Wilson Co., Kansas. Whole and
        disarticulated brachiopods (dark) and
        echinoderm debris (white) are visible. Bar
        for scale = 5 cm. CCK – Unit 4 – bottom.
        Refer to Figure 75 for exact stratigraphic
        location of sample.

    B. Thin section photomicrograph of basal Paola
        fossiliferous sandstone from locality CCK
        in Wilson Co., Kansas. Fine sand-sized
        quartz is predominant grain type. Broken
        and pyritized brachiopods, bryozoans, and
        echinoderms are present. Bar for scale =
        2.5 cm. Plane polarized light. Refer to
        Figure 75 for exact stratigraphic location
        of sample. CCK – Unit 4 – bottom.
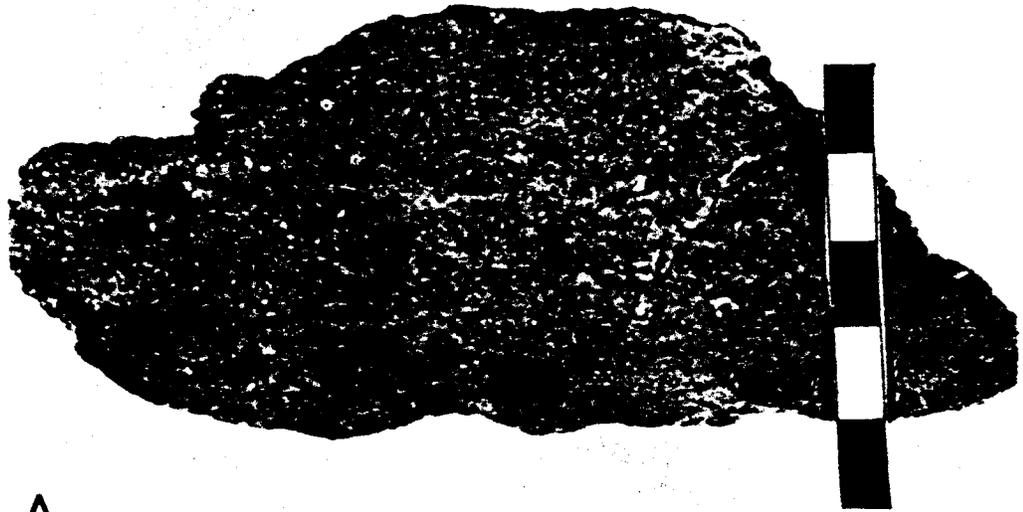
A
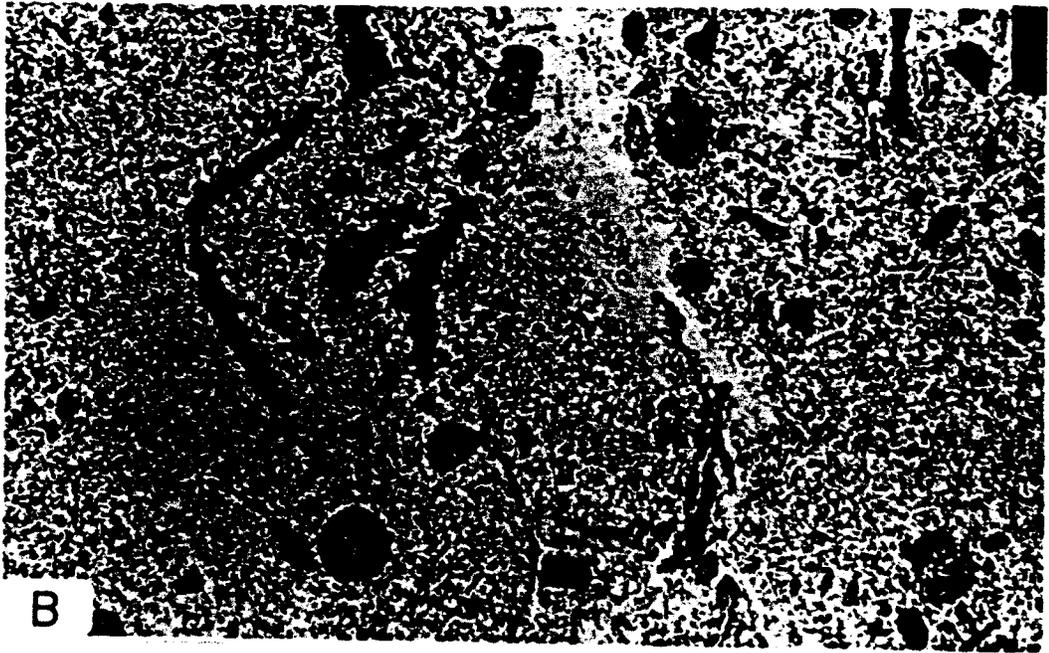
B

Figure 12. Basal Paola sandy skeletal packstone.

A. Slabbed and polished hand specimen of basal
Paola sandy skeletal packstone from
locality RAM in Washington Co., Oklahoma.
Bar for scale = 5 cm. RAM - Paola. Refer
to Figure 80 for exact stratigraphic
location of sample.

B. Thin section photomicrograph of slightly-
sandy basal Paola skeletal packstone from
locality OSA in Miami Co., Kansas. Broken
brachiopods and echinoderm debris are most
common skeletal grains; bryozoans are also
present. Many skeletal grains are
encrusted by foraminifers (dark coatings).
Bar for scale = 5 cm. Plane polarized
light. OSA - Paola - 1B. Refer to Figure
61 for exact stratigraphic location of
sample.

A

B

1

originally aragonitic skeletal grains such as phylloid
algae, bivalves, and gastropods. In addition, coarsely-
crystalline ferroan dolomite partly replaces intraparticle,
blocky calcite spar.

Upper Skeletal Wackestone

The upper Paola is typically a dense, locally algal-
rich skeletal wackestone (figures 10B and 13). Northward
from the Kansas City area, it grades into a
peloidal/skeletal wackestone to packstone. Thickness along
outcrop ranges from 12 inches (30 cm) at locality AGQ
(figure 72) in Neosho Co. to a maximum of 44 inches
(1.1 m), just north of locality QSBC (figures 15 and 63)
in Anderson Co. The upper Paola carries a diverse and
abundant biota including phylloid algae, brachiopods,
bryozoans, echinoderm debris, encrusting foraminifers,
laminar to subspherical red algae/foraminifer-encrusted
grains, and minor fusulines, trilobites, ostracodes, and
calcareous sponges. Vaguelly laminated (probably blue-
green algal) clumps with incorporated quartz silt and small
skeletal fragments are also present (figure 14A).

Most skeletal grains are disarticulated, broken or
crushed. Encrustation by foraminifers and/or bryozoans is
common. Micritization of skeletal debris is pervasive,
ranging from thin micrite envelopes to complete
obliteration of original grain structure (figure 14B).

Figure 13.   Upper Paola skeletal wackestone.

A.   Slabbed and polished hand specimen of
typical upper Paola skeletal
wackestone from locality CAN in Washington
Co., Oklahoma. Brachiopods, echinoderms,
and bryozoans are most abundant skeletal
grains. Bar for scale = 5 cm.
CAN - Paola - upper. Refer to Figure 79
for exact stratigraphic location of sample.

B.   Thin section photomicrograph of typical
upper Paola skeletal wackstone from
locality CAN in Washington Co., Oklahoma.
Lime mud matrix is now mostly micrite with
minor dolomite. Broken and disarticulated
brachiopods, bryozoans, and echinoderms
are most common skeletal grains; a few
skeletal grains are encrusted by
foraminifers. Bar for scale = 5 cm. Plane
polarized lght. CAN - Paola - upper.
Refer to Figure 78 for exact stratigraphic
location of sample.

amount
? ?

A

B

Figure 14. Paola Limestone Member.

A. Photomicrograph of vague encrustation
surrounding brachiopod fragment. Minor
amounts of finely-divided skeletal debris
and quartz silt are incorporated in
encrustation. Plane polarized light. Bar
for scale = 1 mm. NEO - Unit 7. Refer to
Figure 76 for exact location of sample in
section.

B. Thin section photomicrograph documenting
obliteration of internal structure of
skeletal grains by micritization. Degree
of alteration ranges from thin micrite
envelope, through partly micritized grains,
to complete obliteration, resulting in
formation of irregular peloids. Plane
polarized light. Bar for scale = 1 mm.
BCRS - Paola - middle. Refer to Figure 63
for location of sample in section.

C. Discrete peloids occupying sheltered area
underneath micritized phylloid algae blade.
Peloids comprise probable fecal pellets and
skeletal grains with internal structure
completely or partly obliterated by
micritization. Plane polarized light. Bar
for scale = 1 mm. PSP - Paola - RUB - 3.
Refer to Figure 58 for location of sample
in section.

D. Ferroan dolomite (D) filling void space
within bryozoan fragment. Plane polarized
light. Bar for scale = 0.1 mm. BCRS -
Paola - 1B. Refer to Figure 63 for
location of sample in section.

E. Gastropod completely replaced by non-
ferroan dolomite (D). Plane polarized
light. Bar for scale = 0.4 mm. AGQ -
Paola - top. Refer to Figure 72 for
location of sample in section.

Figure 14.   (cont'd.).

       F. Fracture cutting matrix and fusuline.
          Fracture void-space is filled with
          coarsely-crystalline, sparry, non-ferroan
          dolomite (D). Note fragments of fusuline
          in middle of fracture void. Plane
          polarized light. Bar for scale = 0.4 mm.
          AGQ - Paola - top. Refer to Figure 72 for
          location of sample in section.
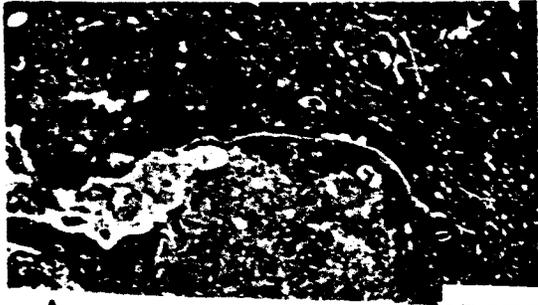
A

D
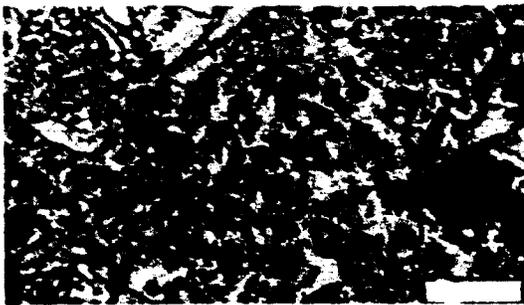
B

E
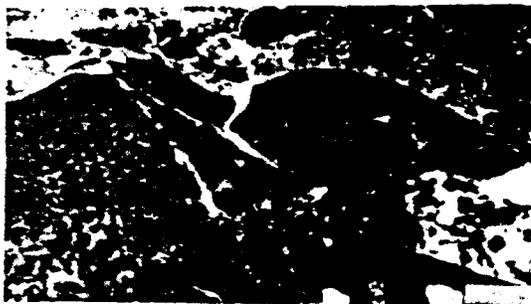
C
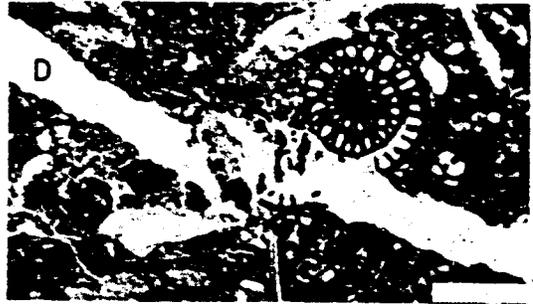
F

The carbonate mud matrix is burrowed and locally peloidal. Peloids become much more abundant northward along outcrop and are an important rock constituent from the Kansas City area north into Iowa. Small (0.02-0.3 mm), sub-round peloids (probable fecal pellets) are most common and are best preserved where sheltered by "umbrellas" of brachiopod valves and phylloid algae blades (figure 14C). Elsewhere the peloids are "mashed" together, giving the rock a clotted or grumeleuse texture (Bathurst, 1975). Larger (up to 5 mm), more irregularly shaped peloids, which are probably completely micritized skeletal grains, are also present.

In east central Anderson Co., Kansas (figures 15 and 63), the Paola thickens to about four feet (1.1 m). Nearly all the thickening is manifest as locally sparry, algae-rich skeletal wackestone (figures 15B and C), in which large blades of phylloid algae shelter voids from infilling by carbonate mud before later filling with calcite spar, ("umbrella" effect of Harbaugh, 1960).

Dolomitization increases in intensity upwards through the Paola, but no lateral trends are discernible. Dolomite most commonly occurs as medium to coarse silt-sized non-ferroan rhombs that replace lime mud matrix, especially where burrowed. Dolomite fills intraparticle pore space (figure 14D) and also embays or partly replaces skeletal

Figure 15. Paola Limestone Member.

A. Locality BCRS, Anderson Co., Kansas.
    Roadcut exposure approximately one mile
    north of locality QSBC (Figure 2). Paola
    Member (P) reaches its maximum known
    thickness (approximately 4 ft., 1.2 m) at
    this locality; comprising locally sparry,
    algal-rich wackestone. Gray Muncie Creek
    Shale (MC) is approximately 6 inches
    (15 cm) thick throughout this area.
    Raytown Limestone (R) is up to 24 ft. (7.2
    m) thick in this area. Refer to Figure 63
    for stratigraphic column.

B. Slabbed and polished hand specimen of Paola
    phylloid algae-rich skeletal wackestone
    from locality BCRS. Bar for scale = 5 cm.
    BCRS - Paola - middle. Refer to Figure 63
    for location of sample in section.

C. Thin section photomicrograph of sheltered-
    void spaces (SV) filled with calcite spar.
    Sample is of Paola phylloid algae (PA)-rich
    skeletal wackestone at locality BCRS. Bar
    for scale = 2.5 mm. Plane polarized light.
    BCRS - Paola - upper. Refer to Figure 63
    for location of sample in section.

A

B

C

PA

SV

R

MC

P
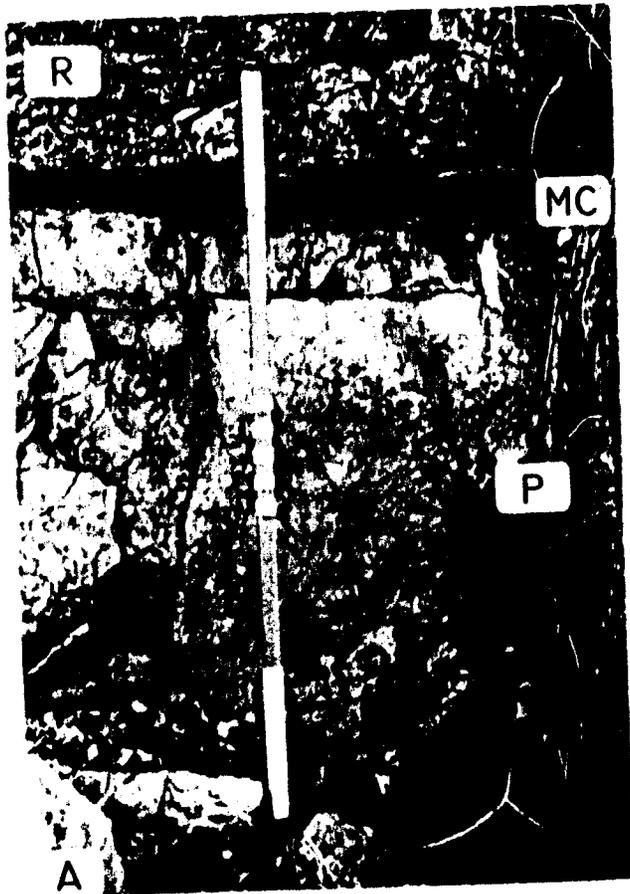
grains, in particular those molluscs and algal blades that probably were originally aragonitic and are not altered to blocky calcite spar (figure 14E). Coarser-grained ferroan dolomite is also present, filling interparticle and intra-particle porosity. Fractures, cutting across skeletal grains and matrix alike, are commonly filled with relatively coarsely crystalline ferroan and non-ferroan dolomite spar (figure 14F).

The Paola is thin and discontinuous throughout southwestern Iowa and eastern Nebraska. In a former highwall exposure in a quarry near the town of Atlantic, Cass Co., Iowa, the Paola is lenticular, pinching out both east and west in a relatively short distance (P.H., Heckel, personal communication, 1980). It is absent in a number of cores taken in southwestern Iowa and its absence was observed in the Bedford core (locality BED) where the Muncie Creek Shale rests directly on the Chanute Shale (figures 8 and 57). Where present, as in the core from locality NEB at Offutt Air Force Base in Sarpy Co., Nebraska, the Paola is a thin (6 inch, 15 cm.), argillaceous skeletal calcarenite with abundant whole brachiopods. The rock grades upwards into a thin gray-green calcareous shale, which in turn is overlain by black, fissile Muncie Creek Shale (figures 8 and 55).

Muncie Creek Shale Member

The Muncie Creek Shale is the "core" shale member of the Iola cyclothem. Although continuous throughout the study area, it does show lateral and vertical variation in thickness and lithic nature.

In its type area in northeastern Kansas, the Muncie Creek Shale is up to three feet (0.9 m) thick. Here, a black, phosphatic, fissile shale facies is "sandwiched" between two gray shales (figures 8, 59, and 16A). At a typical exposure of the Muncie Creek Shale in this area (locality K32, figure 16A), approximately one foot (30 cm) of gray shale with a diverse and abundant benthic fauna grades upward into a two-foot (60 cm) thick, black fissile shale with conspicuous and abundant subround to nearly discoidal phosphorite nodules that average 1-2 inches (2.5-5 cm) in diameter. The black shale lacks a benthic fauna, but contains a probably pelagic fauna of conularids, conodonts, fish remains and orbiculoid brachiopods. It grades up into 0.5 feet (15 cm) of gray shale, with a sparse benthic fauna returning.

To the north, in Iowa and Nebraska, the Muncie Creek maintains a thickness of approximately three feet (1 m) and displays both gray and black facies (figures 8, and 55-57). Here however, the gray shale is thicker (two feet, 60 cm), with a less abundant benthic fauna. In addition,

Figure 16. Iola outcrop photographs.

A. Locality K32 in Wyandotte Co., Kansas.
Roadcut exposure showing well-developed
Iola cyclothem in open-marine facies belt.
Chanute Shale (C) = gray sandy shale with
thin layers of quartz siltstone to
sandstone; Paola Limestone Member (P) =
skeletal wackestone with diverse biota;
Muncie Creek Shale Member (MC) = black
fissile phosphatic shale sandwiched between
gray shales; Raytown Limestone Member (R) =
skeletal wackestone with diverse biota.
Unabraded nonalgal skeletal grainstone is
present at base of Raytown. Iola Limestone
at this locality is approximately 10 ft. (3
m) thick. Refer to Figure 59 for
stratigraphic section.

B. Raytown/Muncie Creek contact at locality
NEO in Wilson Co., Kansas. Black, fissile
Muncie Creek Shale (MC) is sandwiched
between gray shales. Muncie Creek is
overlain by slightly-fossiliferous Raytown
sandstone (R). Tape measure is
approximately 3 ft. (1 m) long. Refer to
Figure 76 for stratigraphic section.
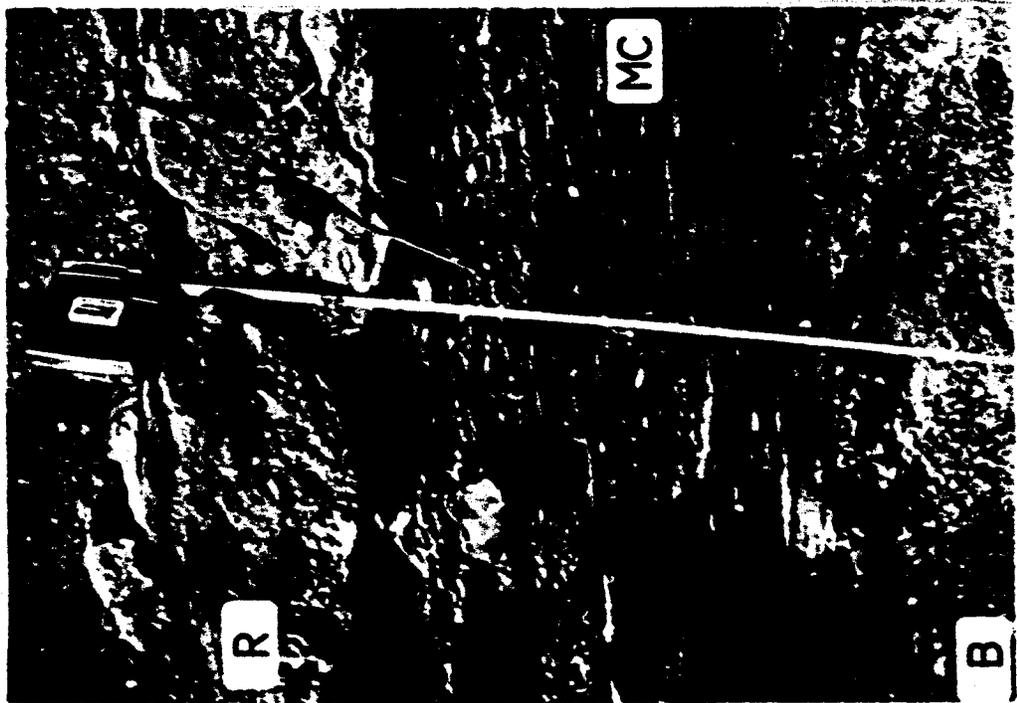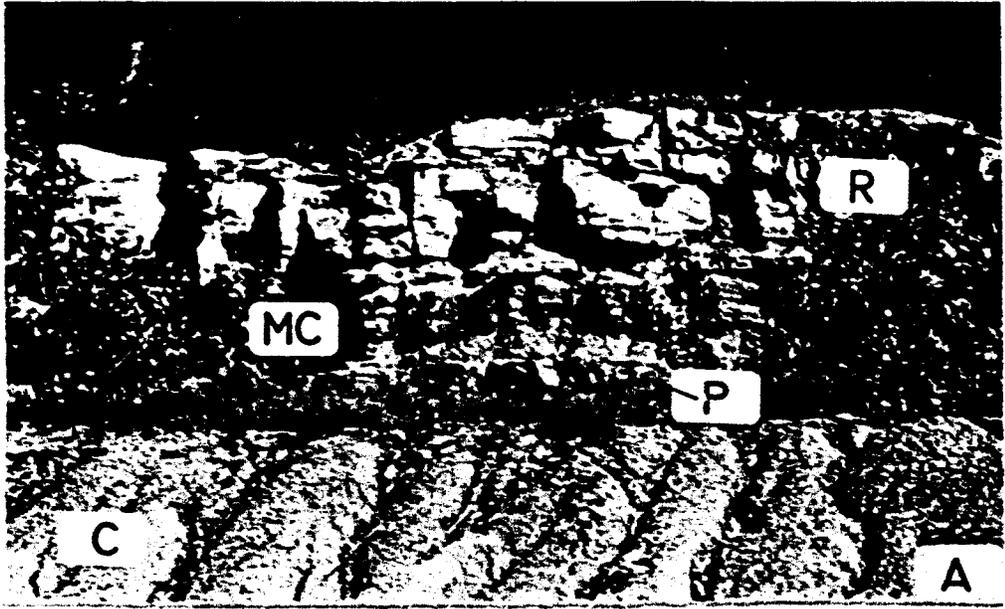
conspicuous phosphorite nodules are not present, although grains of presumably non-skeletal phosphate were recovered from heavy-liquid separations.

Southward from its type area, the black facies disappears and the Muncie Creek thins to 2-6 inches (5-15 čm) of yellow-gray clay shale (figures 8, 10B, and 15A) with conspicuous and abundant phosphorite nodules. A fairly abundant and diverse benthic fauna is present, comprising bryozoans, brachiopods, echinoderm debris, and sponges.

The Muncie Creek thickens to several feet south of the overlying Raytown mound (figures 8, 75, and 76). The black facies reappears, overlying a thin gray shale in Wilson Co., Kansas (localities CCK and NEO, figure 16B). Farther southward in Washington, Co., Oklahoma (locality RAM, figures 8 and 80), the Muncie Creek thickens to up to 30 feet (9 m) of mostly gray shale, with black facies and less abundant phosphorite nodules present in the lower part of the shale.

Qualitative and semi-quantitative X-ray diffractometry of phosphorite nodules, and the silt and clay-sized fractions of the Muncie Creek were performed on selected samples throughout the study area.

Phosphorite nodules are dominantly fluorapatite with minor quartz and calcite. No systematic variation in

composition throughout the study area was seen. This essentially agrees with the report of Runnels, Schleicher, and Van Nortwick (1953) that a carbonate-bearing fluorapatite (with a chemical composition lying between that of fluorapatite and dahlite), quartz, calcite, and illite constitute Muncie Creek nodules collected from Wyandotte and Wilson Counties in Kansas.

Sand-sized quartz, often with euhedral overgrowths is present, but uncommon throughout the Muncie Creek, as is mica and feldspar. Quartz, feldspar, dolomite, and calcite compose the silt-sized fraction.

Illite and illite-mixed layer clays dominate the clay-sized fraction; kaolinite and chlorite are also present. Presence and relative abundance of kaolinite and chlorite varies systematically along outcrop (figure 17). In Iowa, chlorite is third in abundance to illite and illite-mixed layer clays, whereas kaolinite is either absent or present in minor amounts. Southward, in Kansas and Oklahoma, kaolinite is more abundant than chlorite. This same north-south trend in increasing relative abundance of kaolinite to chlorite is also seen in the Chanute Shale. No vertical trend in relative abundance of clay minerals is evident in the Muncie Creek Shale.

Trace element studies of phosphorite nodules and bulk samples from the Muncie Creek Shale (Runnels, 1949;

Figure 17. Relative abundance of clay minerals from shales within the Iola Limestone and adjacent units. Black dot gives location of each shale sample. Clays are listed in order of relative abundance. I = illite, M = illite-mixed layer clay, C = chlorite, K = kaolinite. Question mark indicates that presence of a particular clay mineral is questionable. Refer to Appendix A for location codes.

Figure 17.

R.C. Coveney, 1979, personal communication to P.H. Heckel), reveal that the member is enriched with respect to heavy metals, namely Cd, Cr, Cu, Mo, Pb, V, and Zn.

Raytown Limestone Member

The Raytown Limestone, "upper" limestone member of the Iola cyclothem, shows considerable lithologic variation throughout the study area. Seven facies are recognized: "normal" marine skeletal wackestone to packstone; abraded skeletal grainstone; non-abraded invertebrate grainstone; laminated carbonate mudstone; peloidal packstone; terrigenous; and mound complex, comprising mound and mound-associated facies (figure 8). Thickness of the Raytown ranges from slightly less than 4 feet (1.2 m) in the Kansas-Oklahoma border region to approximately 50 feet (15 m) in Allen Co., Kansas.

Normal Marine Skeletal Wackestone to Packstone

The normal marine skeletal wackestone/packstone facies (figures 18 and 19) is present throughout the entire study area. In outcrop, the facies is typically thin to medium-bedded, with thin fossiliferous shale partings.

The diverse assemblage of macrofossils includes abundant brachiopods, echinoderm debris, and bryozoans. Other skeletal grains present are ostracodes, trilobites, gastropods, bivalves, encrusting foraminifers, and sponges. Phylloid algae are sparse to very abundant (figure 19A).

Figure 18. Raytown normal marine skeletal
wackestone/packstone facies.

A. Thin section photomicrograph of typical
normal marine skeletal wackestone. Bar for
scale = 5 mm. Plane polarized light.
K32 - Raytown - 3U. Refer to Figure 59 for
exact location of sample in section.

B. Slabbed and polished hand specimen of
typical normal marine skeletal wackestone.
Bar for scale = 5 cm. K32 - Raytown - 3U.
Refer to Figure 59 for location of sample
in section.

C. Sheltered-void space underneath poorly
preserved red phylloid algae. Well-
developed micrite envelopes surround
algal/mollusc (?) debris lying within the
void space. Discrete fecal pellets are
visible underneath sheltering brachiopod
valve; elsewhere pellets are mashed
togther. Plane polarized light. Bar for
scale = 4 mm. K32 - Raytown - 2B. Refer
to Figure 59 for location of sample in
section.
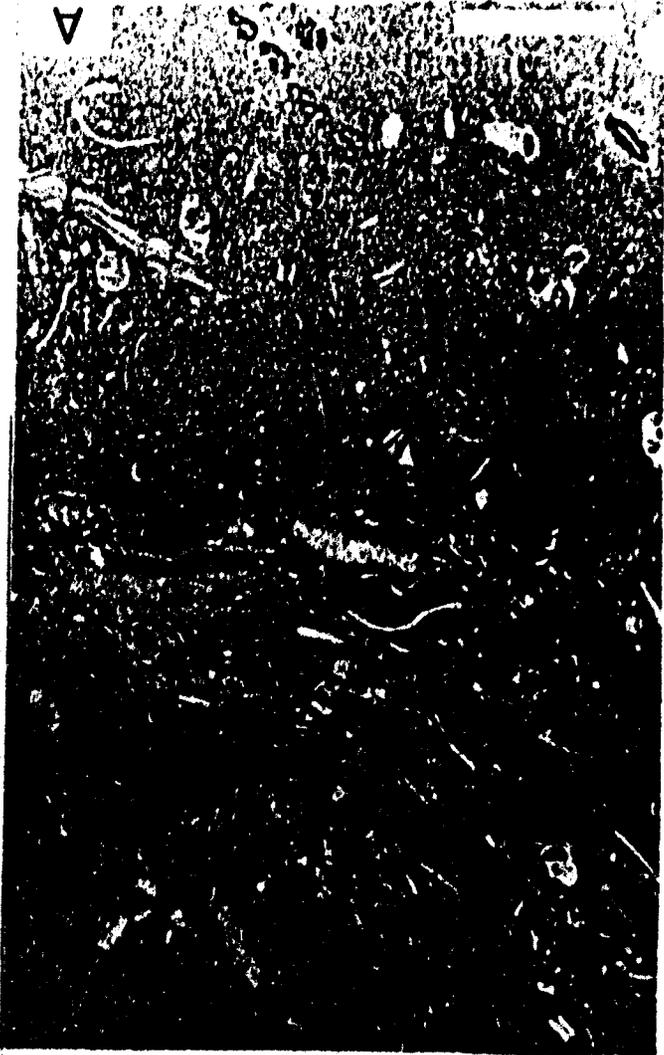
Figure 19.   Raytown normal marine skeletal
             wackestone/packstone facies.

A.   Phylloid algae-rich skeletal
     wackestone/packstone from locality OSA in
     Miami Co., Kansas. Algal blades are poorly
     preserved and partly replaced by ferroan
     and non-ferroan dolomite rhombs. Bar for
     scale = 5 mm. Plane polarized light.
     OSA - Raytown - 2. Refer to Figure 61 for
     location of sample in section.

B.   Raytown normal marine skeletal packstone,
     echinoderm-rich variant from locality TYE
     in Montgomery Co., Kansas. Bar for scale =
     4 mm. Plane polarized light. TYE - Second
     Limestone - E. Refer to Figure 78 for
     location of sample section.

C.   Raytown normal marine skeletal wackestone,
     bryozoan-rich variant underlying Raytown
     mound facies at locality HUM in Allen Co.,
     Kansas. Echinoderms, trilobites, and
     pyritized bryozoans are most conspicuous
     skeletal grains. Mud matrix has been
     partly replaced by silt-sized non-ferroan
     dolomite (light areas). Bar for scale = 4
     mm. Plane polarized light. Refer to
     figure 70 for location of sample in
     section. HUM - Raytown - base.

Skeletal grains are commonly somewhat fragmented, but not
abraded. Epizoans, including encrusting foraminifers and
fistuliporid bryozoans abound; micrite envelopes are common
(figure 18C).

Matrix material is mostly micrite and/or microspar,
commonly with a "clotted" or grumeleuse appearance
especially under sheltering shells (figure 18C). Fabric is
typically homogenized by extensive burrowing.

Normal marine skeletal wackestone/packstone
constitutes the bulk of the Raytown in its type area,
ranging from six to eight feet (1.8-2.4 m) thick (locality
K32; figures 8, 16A, 18, and 59). The facies becomes
shaller northward into Iowa and Nebraska, ranging from 4 to
10 feet (1.2-3 m) thick (localities NEB, MAL, BED, and PSP;
figures 8, and 55 through 58). In southwestern Iowa and
eastern Nebraska, (localities MAL and NEB) a lower, shaly
packstone to wackestone variant without grain
micritization, and an upper shale-poor wackestone variant
with micritized grains are recognized.

Phylloid algae are abundant (up to 35 percent of the
rock), and sheltered void-filling spar (Harbaugh, 1960;
Heckel and Cocke, 1969) is locally conspicuous (figure
19A), south of the Kansas City vicinity in Miami, Anderson,
Allen, and Neosho Counties in Kansas. In this area, the
facies ranges up to 12 feet (3.6 m) thick and is laterally

and vertically gradational into the phylloid algal mound facies. Normal marine skeletal wackestone/packstone, with only rare phylloid algae (figure 19B), dominates the Raytown Member near the Kansas-Oklahoma border (localities CCK, NEO, SPE, TYE, CAN, and RAM; figures 8, and 75-80). Here, it is up to 4 feet (1.2 m) thick and commonly interbedded with thin fossiliferous shale. Mica and quartz silt constitute up to 11 percent of the rock.

Degree of dolomitization varies throughout this facies; both lateral and vertical trends are discernible, as is discussed in the section on diagenesis. Dolomite most commonly occurs as medium to coarse silt-sized, non-ferroan rhombs that replace lime mud matrix, especially where burrowed. Intensity of dolomitization of the matrix ranges from a few scattered rhombs to complete replacement. Silt-sized non-ferroan dolomite also partly replaces calcite spar and mud that both fill intraparticle pore space, calcite spar-filled fractures, and skeletal grains, particularly molluscs and phylloid algae. Coarser-grained ferroan dolomite is present, filling intercrystalline, intraparticle and fracture porosity.

Abraded Skeletal Grainstone

The abraded skeletal grainstone facies is widely distributed throughout the study area, occurring in the middle to upper portions of the Raytown. Two subfacies are

recognized: intraclastic abraded skeletal grainstone, and sandy encrusted-grain abraded skeletal grainstone. Grainstones overlying thick Raytown mound facies in Allen and Neosho Counties, Kansas, are not included in this discussion as they are considered a subdivision of the algal mound complex.

Intraclastic abraded skeletal grainstone is present in the middle to upper Raytown in south central and southwestern Iowa (localities MAL, BED, and PSP; figures 8 and 56 through 58). It is thin, ranging from 0.5 to 1.0 feet (15 to 30 cm) thick; it overlies and is somewhat gradational with normal marine skeletal wackestone. The diverse biota includes abundant brachiopods, echinoderm debris, and fusulines, with less common gastropods, bivalves, ostracodes, trilobites, encrusting foraminifers and poorly-preserved red algae (figure 20A). Skeletal grains are fragmented and micritized, typically showing evidence of abrasion and rounding. Micrite envelopes are commonly broken and crushed (figure 20B). Intraclasts are present, but not abundant; their recognition is facilitated by the presence of truncated skeletal grains, abraded and rounded edges, and remnants of mud matrix (figure 20C). Blocky non-ferroan calcite spar constitutes interparticle cement. No isopachous rim cement is seen.

Figure 20. Raytown abraded skeletal grainstone facies.

A.   Thin section photomicrograph of abraded
      skeletal grainstone from locality PSP in
      Madison Co., Iowa. Echinoderms, fusulines,
      and abraded brachiopod fragments are the
      most common skeletal grains. Equant
      calcite spar fills interparticle void
      space. Plane polarized light. Bar for
      scale = 2 mm.
      PSP - IPN - 10 - top. Sample courtesy of
      P.H. Heckel.

B.   Detail of crushed micrite envelope (ME).
      Void space is filled with equant calcite
      spar. Abraded skeletal grainstone from
      locality PSP in Madison Co., Iowa. Plane
      polarized light. Bar for scale = 0.6 mm.
      PSP - IPN - 10 - top.

C.   Intraclasts (I) comprising lime mud,
      bryozoans, gastropods, and bivalve debris
      scattered throughout skeletal grainstone
      from Bedford core (locality BED) in Taylor
      Co., Iowa. Interparticle pore space is
      filled with equant calcite spar. Plane
      polarized light. Bar for scale = 2 mm.
      BED - 200. Refer to Figure 57 for location
      of sample in core.

A

B

ME

C

Sandy, encrusted-grain skeletal grainstone up to
1.3 ft. (40 cm) thick occurs in the upper Raytown in Wilson
Co. Kansas (localities 3MN and NEO; figures 8, 74 and 76).
It overlies and is separated from normal marine skeletal
wackestone by thin fossiliferous shale. Skeletal grains
include echinoderm debris, encrusting foraminifers,
brachiopods, bryozoans, bivalves, gastropods, and
trilobites (figures 21A, B, C). Grains commonly are
disarticulated and broken, but are not as conspicuously
abraded as in the northern variant. Micrite envelopes are
common. Epizoans, including both bryozoans and
foraminifers, abound; skeletal grains are typically
encrusted and bound into irregular-shaped aggregates
(figure 21C). Coarse silt to fine-sand-sized quartz, minor
mica, and glauconite constitute up to ten percent of the
rock. Cement comprises blocky ferroan and non-ferroan
calcite spar.

Considerable variation in degree of dolomitization is
seen in this facies. In Wilson Co., Kansas, dolomitization
is confined to very minor replacement of probable
originally aragonitic skeletal debris by silt-sized rhombs
of non-ferroan dolomite. Northwards, in southwestern Iowa,
the matrix is partly to completely replaced by silt-sized
dolomite; skeletal grains, particularly those that were

Figure 21. Raytown abraded skeletal grainstone facies.

A. Slabbed and polished hand specimen of sandy
    encrusted-grain skeletal grainstone from
    locality NEO in Wilson Co., Kansas. Bar
    for scale = 3 cm. Refer to Figure 76 for
    location of sample in section. NEO - Unit
    17b.

B. Thin section photomicrograph of sandy
    encrusted-grain skeletal grainstone from
    locality 3MN in Wilson Co., Kansas. Some
    brachiopod fragments and echinoderms show
    some abrasion. Bar for scale = 5 mm.
    Plane polarized light. 3MN - Upper
    Limestone - lower sample. Refer to
    Figure 74 for location of sample in
    section.

C. Detail of sandy encrusted-grain skeletal
    grainstone from locality 3MN showing
    plumose foraminifer encrustation (on right)
    and sparry void-filling cement. Plane
    polarized light. Bar for scale = 1 mm.
    3MN - Upper Limestone - lower sample.
    Refer to Figure 74 for location of sample
    in section.

A

B

C
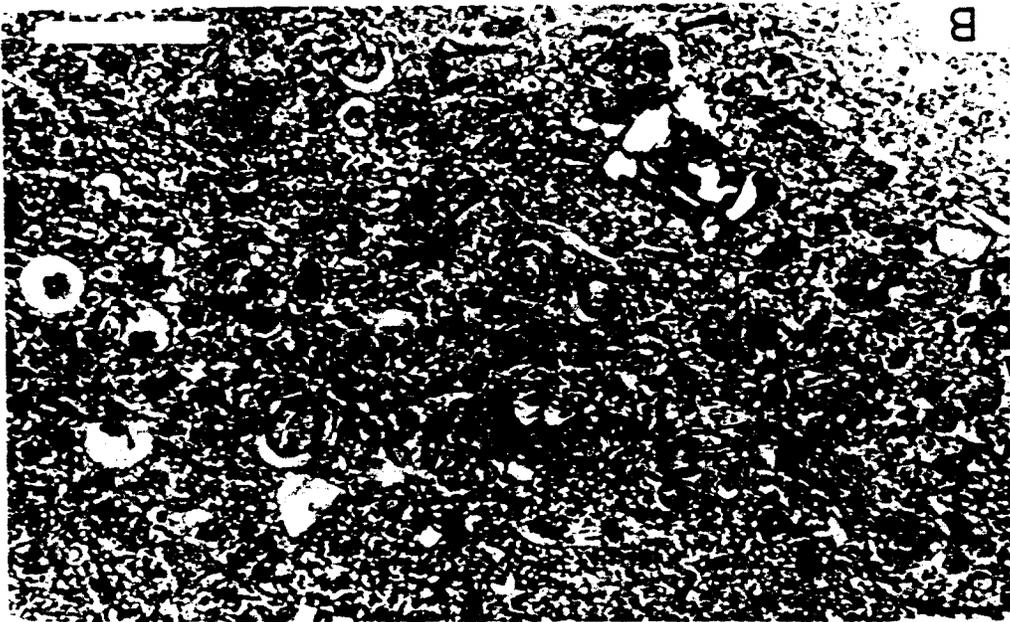
presumably originally aragonite, suffer only minor
replacement by silt-sized dolomite.

Non-abraded Invertebrate Grainstone

This facies is restricted to the basal Raytown and is
found throughout the Kansas City vicinity. It is a thin
(7 inches, 18 cm), yellow-brown, poorly indurated,
argillaceous grainstone (figure 22A) that immediately
overlies the Muncie Creek Shale. At locality K32 in
Wyandotte Co., Kansas (figures 8, 16A, and 59), it is
separated from overlying normal marine skeletal wackestone
by approximately 0.5 feet (15 cm) of gray fossiliferous
shale. No cross-bedding is seen in this grainstone.

Echinoderm debris, encrusting foraminifers,
brachiopods, and bryozoans are the most abundant
constituents. Minor skeletal grains include trilobites,
ostracodes, and bivalves. Most grains are at least
superficially encrusted by foraminifers. Algal remains are
absent, and no evidence of micritization is seen. Grains
are "overpacked", and have stylolitic or sutured contacts
(figure 22B). Although most grains are disarticulated and
broken, there is no evidence of grain abrasion or rounding.

Medium silt to very fine sand-sized quartz, and minor
glauconite is present. Calcite and ferroan-calcite spar
constitute intergranular cement (figure 22C). No
dolomitization is seen in this facies.

Figure 22. Raytown non-abraded invertebrate grainstone
            facies.

       A.   Slabbed and polished hand specimen of basal
            Raytown non-abraded invertebrate grainstone
            from locality K32 in Wyandotte Co., Kansas.
            Bar for scale = 3 cm. Refer to Figure 59
            for location of sample in section.
            K32 - BASCAR.

       B.   Thin section photomicrograph of basal
            Raytown non-abraded invertebrate grainstone
            showing no evidence of grain abrasion,
            micrite envelopes or algal remains. Dark
            grains and encrustations are encrusting
            foraminifers. "Overpacked" fabric and
            sutured grain contacts are common. Plane
            polarized light. Bar for scale = 2.5 mm.
            Refer to Figure 59 for location of sample
            in section. K32 - BASCAR.

       C.   Basal Raytown non-abraded invertebrate
            grainstone. Equant calcite spar fills
            intergranular pore spaces. Plane polarized
            light. Bar for scale = 0.4 mm.
            K32 - BASCAR. Refer to Figure 59 for
            location of sample in section.

A

B

C
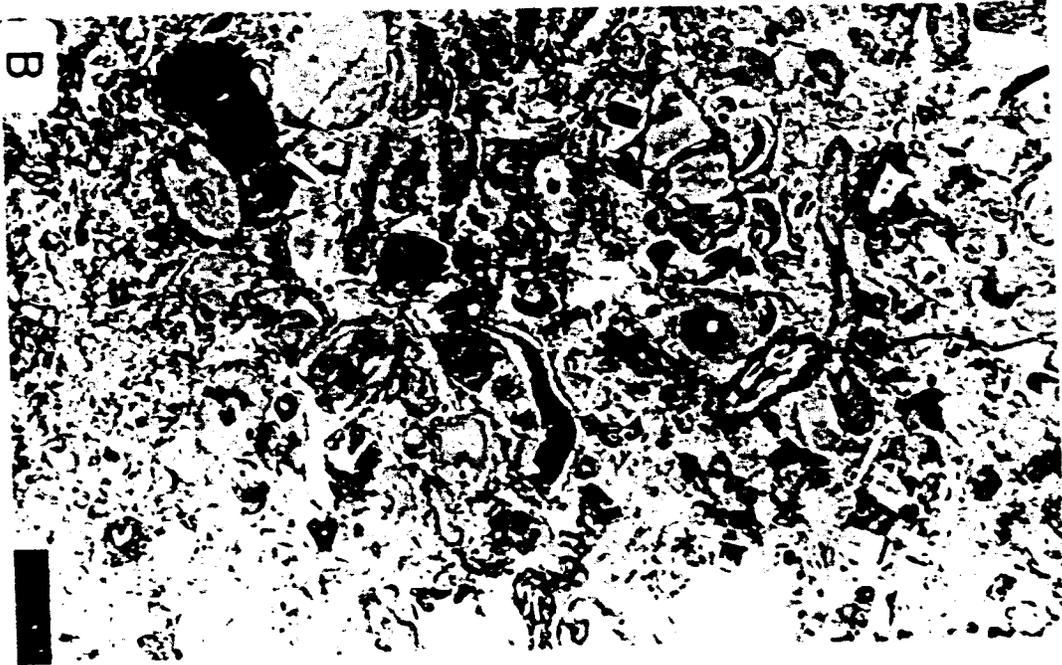
Laminated Carbonate Mudstone

The laminated carbonate mudstone facies is present in the upper Raytown in eastern Nebraska and southwestern Iowa (localities NEB and MAL; figures 8, 55 and 56). Thinly laminated, light green to tan carbonate mudstone that is interbedded with thin greenish-tan shale constitute the facies. Overall thickness ranges from 1 to 2 feet (30 to 60 cm).

The rock chiefly is extensively dolomitized, laminated carbonate mudstone (figures 23A, B). Laminae are undulatory and approximately 1.0 mm thick. Light and dark laminae alternate; dark laminae consist of very fine-grained dolomite, lighter laminae comprise slightly coarser-grained dolomite and quartz silt (figure 24A). Laminae may be algal in origin, but no preserved algal structures are seen. Gastropods and ostracodes constitute the sparse fauna.

An extensive network of burrows is present (figure 23B). These are typically 1 to 2 mm in diameter and partly filled by peloidal sediment with a "swirled" texture. The remainder of each burrow is filled by coarsely crystalline (0.2-0.3 mm) ferroan-dolomite spar. In addition, small, subround to horizontally elongate voids, 0.1 to 0.3 mm wide

Figure 23. Raytown laminated carbonate mudstone and
peloidal packstone facies.

A. Slabbed and polished hand specimen of
Raytown laminated carbonate mudstone from
locality NEB in Sarpy Co., Nebraska.
Collected from core at Offutt Air Force
Base. Bar for scale = 1 cm. NEB - 2B.
Refer to Figure 55 for location of sample
in core.

B. Thin section photonegative print of Raytown
laminated carbonate mudstone from locality
NEB in Sarpy Co., Nebraska. Birdseye (B),
partly-filled burrows, wavy laminae, and
fractures are visible. Bar for
scale = 5 mm. Refer to Figure 55 for
location of sample in core. NEB - 2B.

C. Calichified (?), fractured (?), sparsely-
fossiliferous to barren peloidal packstone
from locality BED in Taylor Co., Iowa. Bar
for scale = 1 cm. Refer to Figure 57 for
location of sample in core. BED - 244.
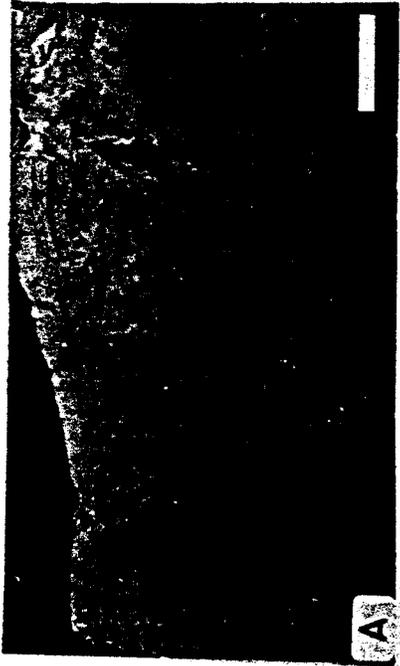
and filled with ferroan dolomite and ferroan calcite, are present; these are probably birdseye structures.

The mudstone is locally brecciated; ferroan-dolomite-filled fractures cut across and run parallel to lamination (figure 23A, B). Polygonal crack patterns, possibly desiccation fractures, are preserved on parting surfaces. Crystals with a morphology suggestive of evaporites (figure 24B) are present, but rare.

Peloidal Packstone

The peloidal packstone facies is restricted to the top of the Raytown in the northern portion of the study area (figure 8). It variously overlies rocks of the skeletal grainstone facies as at locality BED (figure 57), or the laminated carbonate mudstone facies as at locality MAL (figure 56); and in turn is overlain by the Lane Shale. Thickness ranges from a feather-edge in Sarpy Co., Nebraska (locality NEB) to a maximum of 21 inches (54 cm) in the core from Bedford, Taylor Co., Iowa (locality BED).

Both fossil abundance and diversity decrease upwards in this facies. Bryozoans, brachiopods, echinoderm debris, gastropods, bivalves, ostracodes, encrusting foraminifers, and fusulines are relatively abundant at the base (figure 24C) at Bedford. In contrast, skeletal debris is rare in the upper portion of the facies, where only a few foraminifers, bivalves, calcispheres (?), and small

Figure 24.   Raytown laminated carbonate mudstone and
peloidal packstone facies.

A.   Laminations in carbonate mudstone from core
at locality NEB. Dark laminae are composed
of very fine-grained dolomite, light
laminae comprise slightly coarser-grained
dolomite and quartz silt. Bar for scale =
0.4 mm. Plane polarized light. Refer to
Figure 55 for location of sample in core.
NEB - 3B.

B.   Lath of original evaporite mineral now
replaced by calcite in laminated carbonate
mudstone from locality NEB. Plane
polarized light. Bar for scale = 0.1 mm.
Refer to Figure 55 for location of sample
in core. NEB - 2A.

C.   Relatively abundant and diverse biota from
base of peloidal packstone facies at
locality BED. Plane polarized light. Bar
for scale = 1 mm. Refer to Figure 57 for
location of sample in core. BED - 230.

D.   Upper portion of peloidal packstone facies
from locality MAL. Vaguelly peloidal
texture with probable birdseye voids.
Skeletal debris is rare in upper portion of
facies in contrast to lower portion. Plane
polarized light. Bar for scale = 1 mm.
Refer to Figure 56 for location of sample
in core. MAL - 1U.

E.   Cross-section of linear, sub-vertical
structure from peloidal packstone facies.
Possibly a "rhizocretion", resulting from
calichification and cementation along
former plant roots. Sparry non-ferroan
calcite core is surrounded by irregular
clotted zone. Matrix is partly to
completely replaced by dolomite. Plane
polarized light. Bar for scale = 0.4 mm.
Refer to Figure 57 for location of sample
in section. BED - 244.

F.   Network of calichified and cemented root
casts (= rhizocretions). Plane polarized
light. Bar for scale = 1 mm. Refer to
Figure 57 for location of sample in
section. BED - 254.

A

B

C

D

E
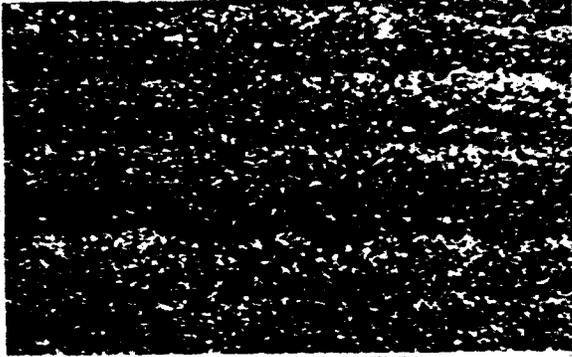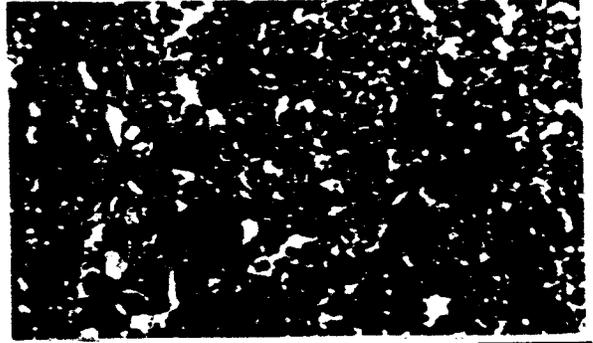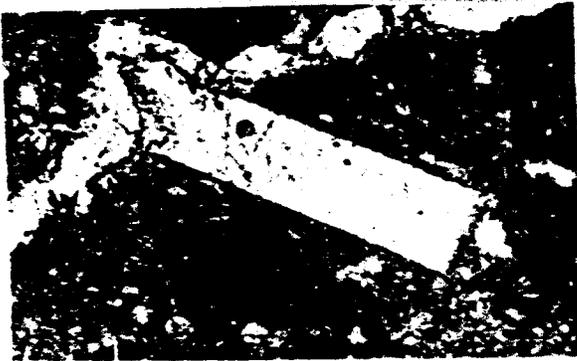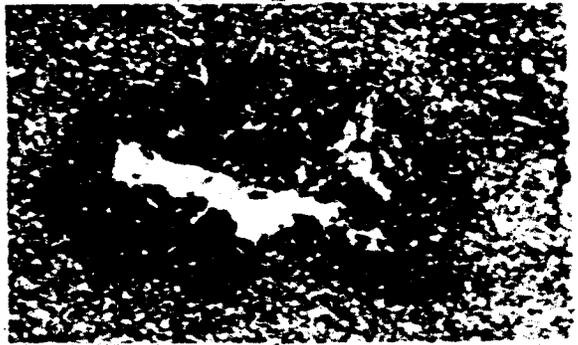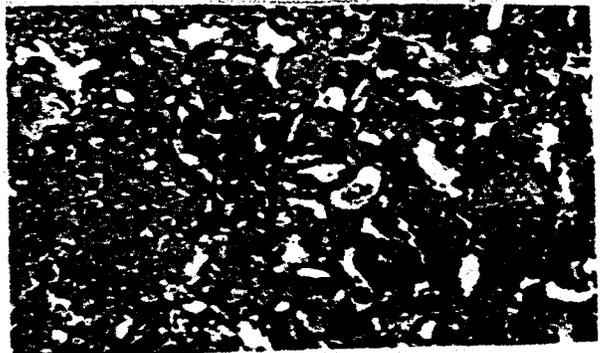
F

indeterminate skeletal fragments are present (figure 24D).
Skeletal grains typically are encrusted by foraminifers.
Micrite envelopes are common.

The most distinctive attribute of the upper portion of
this facies consists of more or less linear, subvertical
structures that are filled with brownish calcite spar
(figure 23C). These may reflect disruption of sediment by
plant roots or else may be fractures due to desiccation, a
sort of caliche breccia, forming in response to continuous
wetting and drying of sediment during alternating wet and
dry seasons (Wilson, 1975, p. 85).

In addition, networks of relatively small, probable
calichified and cemented root casts and root hairs
(rhizocretions; Wilson, 1975, p. 86) are present (figures
24E and F). In cross-section, rhizocretions (figure 24E)
consist of sparry, non-ferroan calcite cores that are
surrounded by irregular "clumps" of peloids. Individual
peloids in these clumps typically are subround and range in
size from .02 to 0.5 mm. Fine to medium silt-sized quartz
and finely divided skeletal debris are incorporated into
the clumps. No preserved algal structures are seen, but
many clumps show vague laminations.

Rhizocretions have been only slightly dolomitized, in
contrast to the rest of the rock, which has undergone
extensive dolomitization. Original texture of the bulk of

the facies has been obscured by replacement with fine silt-sized, non-ferroan dolomite. Molds of skeletal grains and birdseye structures are filled with relatively coarse (0.3 mm) ferroan dolomite spar.

Terrigenous Facies

The terrigenous facies comprises fossiliferous calcareous shale and sandstone (figure 25A). The shale is ubiquitous, but the sandstone occurs only in the lower Raytown at localities NEO and CCK in Wilson Co., Kansas (figures 8, 75 and 76).

Fossiliferous, slightly silty, calcareous shale occurs throughout the Raytown. The varied and well-preserved fauna comprises brachiopods, bryozoans, echinoderm debris, and sponges.

In outcrop, the sandstone occurs as one or two thin, resistant, apparently structureless beds ranging from 0.3 to 1.0 feet (10 to 30 cm) thick (figure 16B). It is mostly very fine to fine sand-sized quartz, with minor quartz silt, mica, glauconite and rare, small phosphorite nodules (figure 25B). Macerated plant fragments are common (figure 25A, C); brachiopods, gastropods, echinoderm debris, and encrusting foraminifers and present, but rare (figure 25C). Fine-grained ferroan calcite, limonite and clay constitute the matrix.

Figure 25. Raytown terrigenous facies.

A. Slabbed and polished hand specimen of
Raytown fine-grained sandstone from
locality CCK in Wilson Co., Kansas.
Coalified (?) plant fragments (black
specks) are scattered throughout rock. Bar
for scale = 5 cm. Refer to Figure 75 for
location of sample in section. CCK - Unit
6.

B. Thin section photomicrograph showing small
phosphorite nodule (PO4) embedded in
Raytown sandstone from locality NEO in
Wilson Co., Kansas. Plane polarized light.
Bar for scale = 1 mm. Refer to Figure 76
for location of sample in section.
NEO - Unit 10.

C. Echinoderm grain (E) and plant debris
(black specks) scattered throughout Raytown
fine-grained sandstone from locality CCK in
Wilson Co., Kansas. Plane polarized light.
Bar for scale = 1 mm. Refer to Figure 75
for location of sample in section. CCK -
Unit 7.

A

PO₄

B

E

C
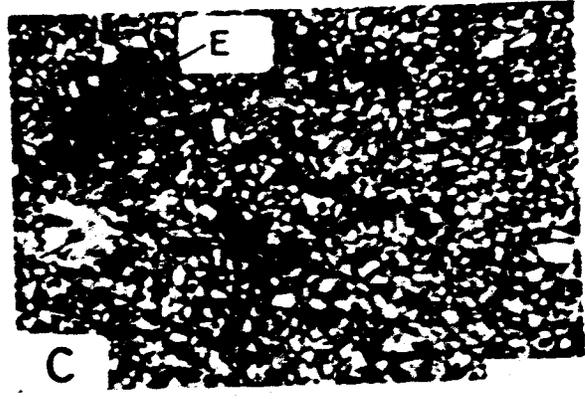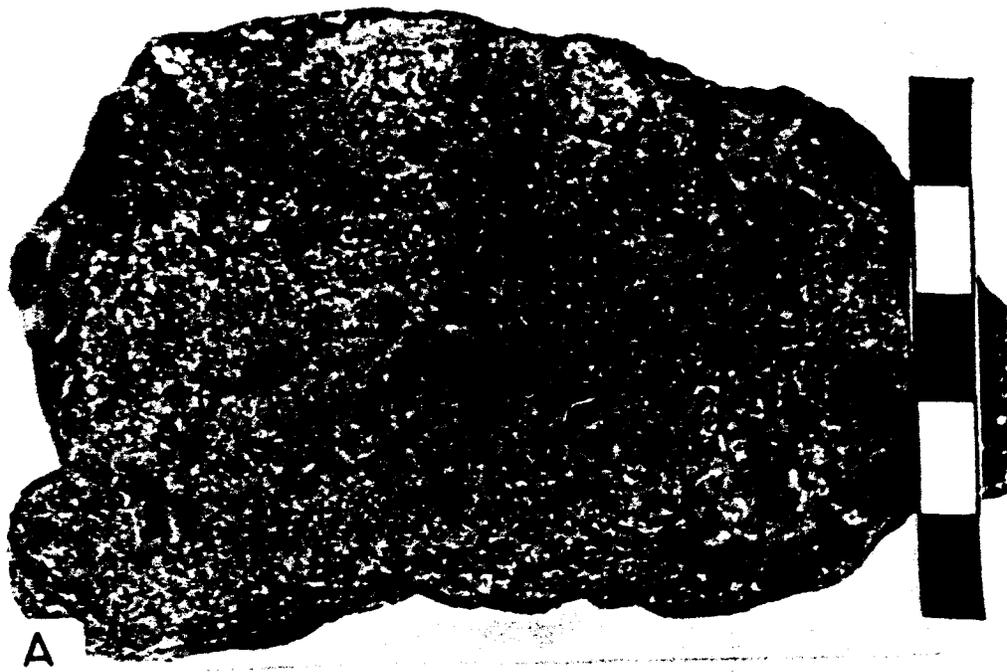
Phylloid Algal Mound Complex

Following Heckel and Cocke (1969), the Raytown algal mound complex comprises: 1) mound facies, consisting chiefly of massive to thick-bedded skeletal wackestone with abundant phylloid algae, which typically overlies thin to medium-bedded normal marine skeletal wackestone to packstone (figure 26A); and 2) relatively thin-bedded mound-associated facies overlying the mound and consisting mainly of skeletal-oolitic grainstone and skeletal wackestone to packstone with locally abundant encrusted grains.

The Raytown mound complex is traced for 40 miles (65 km) along outcrop. Maximum width of the mound tract in outcrop is approximately 10 miles (16 km) in central Allen County. Gradually thickening southward from the type area in the Kansas City vicinity, the Raytown Member reaches 17 feet (5.1 m) in east central Anderson Co.; 30 feet (9 m) in northern Allen Co.; and 40 to 50 feet (12-15 m) in central Allen and northwestern Neosho Counties. The northern boundary of the complex is not well defined as no abrupt change in thickness or lithology is seen. In contrast, the southern boundary is quite abrupt; here, the Raytown thins from approximately 40 feet (12 m) of mound rock (locality AGQ) to four feet of skeletal wackestone (locality ENC) in a distance of approximately 3 miles (5 km).

Figure 26. Raytown mound facies.

    A.   Monarch Cement Quarry (locality HUM), south of Humboldt, Allen Co., Kansas. Typical massive, thick-bedded Raytown moundrock in fairly fresh exposure. Lower five feet (1.5 m) of exposure is relatively thinly-bedded normal marine skeletal wackestone/packstone. Mound is approximately 30 feet (9 m) thick. Upper surface of Paola Limestone serves as quarry floor. Refer to Figures 70 and 71 for stratigraphic columns.

    B.   Slabbed and polished hand specimen of Raytown sparry algal-rich skeletal wackestone ("moundrock") from locality OSA in Miami Co., Kansas. Bar for scale = 5 cm. Refer to Figure 61 for location of sample in stratigraphic section.
OSA - Raytown - 3.

B

A

Although it is outside the present study area, an algal mound complex is present in the approximately equivalent Avant Limestone Member in southern Washington and southeastern Osage Counties in Oklahoma. The Avant mound can be traced for approximately 15 miles (24 km) along outcrop, and is up to 40 feet (12 m) thick (Heckel and Cocke, 1969; Oakes, 1940).

Mound Facies

The mound facies ("moundrock") is chiefly sparry algal-rich skeletal wackestone (figures 26B and 27A) that is gradational into algal-rich skeletal wackestone (figure 27B); hereafter referred to as sparry algal wackestone and algal wackestone. Basic components of the moundrock are lime mud matrix, phylloid algae, and calcite spar. Other volumetrically less important lithologies include skeletal wackestone, packstone, and grainstone. Algal "sparite" (Heckel and Cocke, 1969; Ravn, Mitchell, Nelson, and Heckel, 1978) is present, but rare, occurring as a thin lens in the lower Raytown at locality KTL. This rock type is further described in the section on diagenesis.

Phylloid algae include red (coralline) and green (codiacean?) forms (figure 28A, B). Although typically broken into small subrectilinear fragments (figure 28C), blades up to 5 cm long are not uncommon in the Raytown. Preservation is typically poor, due to original composition

Figure 27. Raytown mound facies.

A. Thin section photomicrograph of sparry
algal wackestone from locality AGQ in
Neosho Co., Kansas. Phylloid algal blades
(P) served as umbrellas trapping carbonate
mud (M) on their upper surfaces, thus
preventing complete infilling of subjacent
sheltered void space by sediment.
Preserved void space was subsequently
filled by calcite spar (S). Later collapse
and brecciation, probably due to compaction
and partial solution of sediment mass,
broke grains and matrix alike, forming
wedge-shaped fractures (F). Bar for scale
= 5 mm. Plane polarized light. Refer to
Figure 72 for location of sample in
section. AGQ - Raytown - 3T.

B. Thin section photomicrograph of algal
wackestone from locality BCRS in Anderson
Co., Kansas, showing poorly-preserved
phylloid algal blades in lime mud matrix.
Bar for scale = 5 mm. Plane polarized
light. Refer to Figure 63 for location of
sample in section. BCRS - Raytown - Sample
U.

C. Thin section photomicrograph of sparry
algal wackestone from locality QEK in
Anderson Co., Kansas. Sparry calcite (S)
in this thin section fills fractures and
smooth-sided molds of algal blades.
Apparent collapse of at least partly
lithified lime mud and rigid algal blades
resulted in brecciation of sediment mass.
Void space is partly filled with skeletal
debris and angular clasts of matrix
material (MC). Bar for scale = 5 mm.
Plane polarized light. Refer to Figure 65
for location of sample in section.
QEK - Raytown - 6B.

(aragonite and high magnesium calcite), and calcification of only the outer cortex in the case of green phylloid algae. A few blades retain traces of original structure (figure 28A, B), but most have been altered by diagenesis and now consist of a sparry calcite mosaic (neomorphic and/or void fill) that is commonly enclosed by a micrite envelope. Algal fragments near the top of the mound facies at locality AGQ show evidence of leaching followed by partial infilling of some voids with sediment (figure 28D).

Although questions concerning growth position and form of phylloid algae and their ability to baffle and trap sediment have been raised (Ball, Pollard and Roberts, 1977), most workers hypothesize the existence of algal "thickets" potentially capable of baffling and trapping lime mud (Wilson, 1975, p. 196). Even relatively flat-lying algal blades served as "umbrellas" (Harbaugh, 1960), trapping mud on their upper surfaces while preventing complete infilling of subjacent sheltered-void space by sediment. Preserved sheltered-void space was later mostly filled by coarsely-crystalline ferroan and non-ferroan calcite and ferroan dolomite spar.

Other marine organisms such as brachiopods, bryozoans, echinoderm debris, fusulines, encrusting foraminifers, and molluscs occur with phylloid algae, but the algae are dominant.

Figure 28. Raytown Limestone Member - mound facies.

A. Preservation of cellular microstructure in red phylloid algae from locality AGQ in Neosho Co., Kansas. Bar for scale = 0.4 mm. Plane polarized light.
AGQ - Raytown - 1T. Refer to Figure 72 for location of sample in section.

B. Mud-filled utricles (MSX) in otherwise poorly preserved green (codiacean ?) phylloid algae from locality QPA in Miami Co., Kansas. Plane polarized light. Bar for scale = 0.4 mm. Refer to Figure 60 for location of sample in section. QPA - Lower Limestone - Sample M.

C. Subrectilinear fragments of phylloid algae from algal wackestone at locality QEK in Anderson Co., Kansas. Replacement of algae by sparry calcite and/or dolomite is typical. Bar for scale = 5 mm. Plane polarized light. Refer to Figure 65 for location of sample in section.
QEK - Raytown - 4.

D. Geopetal carbonate sediment partly filling leached phylloid algal blade from top of Raytown mound facies (sparry algal wackestone) at locality AGQ in Neosho Co., Kansas. Remainder of leached grain is filled with equant, non-ferroan calcite spar. Bar for scale = 0.4 mm. Plane polarized light. Refer to Figure 72 for location of sample in section.
AGQ - Raytown - 9T.

E. "Mottle" surrounding bivalve. Mottle comprises calcite spar, silt-sized nonferroan dolomite, and skeletal debris. Bar for scale = 1 mm. Plane polarized light. Refer to Figure 72 for location of sample in section. AGQ - Raytown - 4M.

F. "Spar-fingers" extending into lime mud matrix in sample of Raytown sparry algal wackestone from locality AGQ in Neosho Co., Kansas. Bar for scale = 1 mm. Plane polarized light. Refer to Figure 72 for location of sample in section.
AGQ - Raytown - 4U.

Figure 28.   (cont'd.).

    G. Detail of spar-fingers (S) extending into
        lime mud matrix. Blunt terminations of
        fingers resemble square ends of acicular
        aragonite crystals. Plane polarized light.
        Bar for scale = 0.4 mm. Refer to Figure 72
        for location of sample in section.
        AGQ - Raytown 4U.

    H. Silt-sized non-ferroan dolomite (D) in
        sheltered area provided by poorly-preserved
        red (?) phylloid algae. Dolomite in the
        Iola is especially common in sheltered
        areas and burrows, both of which are
        locations where permeability and micro-
        porosity are likely to have been relatively
        high. Bar for scale = 1 mm. Plane
        polarized light. Refer to Figure 68 for
        location of sample in section.
        LEH - Limestone - Z.
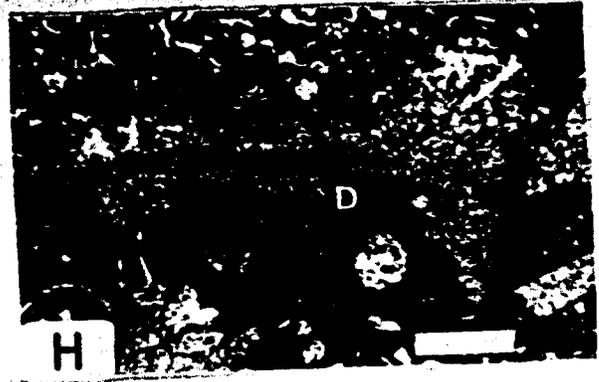
Matrix locally has a clotted or peloidal texture and comprises micrite, microspar, finely-divided skeletal debris, and minor quartz silt. Subround to irregularly shaped "mottles" or patches (figure 28E, F, G) comprising calcite microspar and silt-sized non-ferroan dolomite rhombs occur scattered throughout the mound rock matrix at locality AGQ. Some mottles appear vaguely laminated, but others are apparently structureless; in addition, mottles may or may not surround and/or incorporate finely divided skeletal debris (figure 28E). In many cases "fingers" composed of silt-sized non-ferroan calcite spar radiate outward from mottled areas and extend into surrounding mud matrix (figure 28 F, G).

Most moundrock has been little affected by dolomitization, except for beds adjacent to shales and in burrowed or sheltered areas (figure 28H). Where present, the nature and occurrence of dolomite is quite similar to that seen in the normal marine skeletal wackestone/packstone facies.

Some of the sparry carbonate in the sparry algal wackestone fills fractures (figure 27A). Apparent collapse of at least partly lithified lime mud and rigid algal blades resulted in a brecciated heterogeneous mass with many fractures. Fractures range from small wedge-shaped cracks that die out within mud matrix and skeletal grains

alike (figure 27A) to large voids that are partly filled
with skeletal debris and angular clasts of matrix material
(figure 27C). Fracture void space has been mostly filled
by coarsely-crystalline non-ferroan calcite and minor
ferroan dolomite spar.

Mound-Associated Facies

Mound-associated facies comprising both calcarenite
and calcilutite overlie the Raytown mound in southern
Miami, Anderson, Allen, and northwestern Neosho Counties in
Kansas (localities QPA, QSBC, LEH, OCK, HUM, and AGQ;
figures 8, 50, 64, and 68 through 72). In addition to
"mound-capping" beds immediately overlying the Raytown
mound facies, three informally named beds are recognized:
Owl Creek, Bush City, and Bassett beds.

Mound-capping beds

Locally algal-rich skeletal grainstone to packstone
constitutes beds that immediately overlie the Raytown mound
at localities LEH, HUM, and AGQ. At Ash Grove Quarry,
these are referred to as the "Crustaceous" beds by quarry
workers. Thin-bedded rubbly calcarenite immediately
overlying the algal mound typically grades upward from an
algal-rich skeletal packstone (figure 29A) to a slightly
sandy, encrusted-grain skeletal packstone (figure 29B).
Echinoderm debris, bryozoans, and fragments of phylloid

Figure 29. Raytown mound-associated facies.

A. Thin section photomicrograph of algal-rich mound-capping packstone immediately overlying Raytown algal mound facies at Monarch Cement Quarry (locality HUM), Allen Co., Kansas. Poorly-preserved red phylloid algae, echinoderm debris, and gastropods are the most conspicuous skeletal grains. Light patches (DOL) are portions of matrix replaced by silt-sized, non-ferroan dolomite. Plane polarized light. Bar for scale = 2 mm. Refer to Figure 71 for location of sample in section. HUM - sample MT.

B. Thin section photomicrograph of mound-capping skeletal packstone ("Crustaceous beds"), from Ash Grove Cement Company Quarry (locality AGQ) in Neosho Co., Kansas. Plane polarized light. Bar for scale = 2 mm. Refer to Figure 72 for location of sample in section. AGQ - CAR.
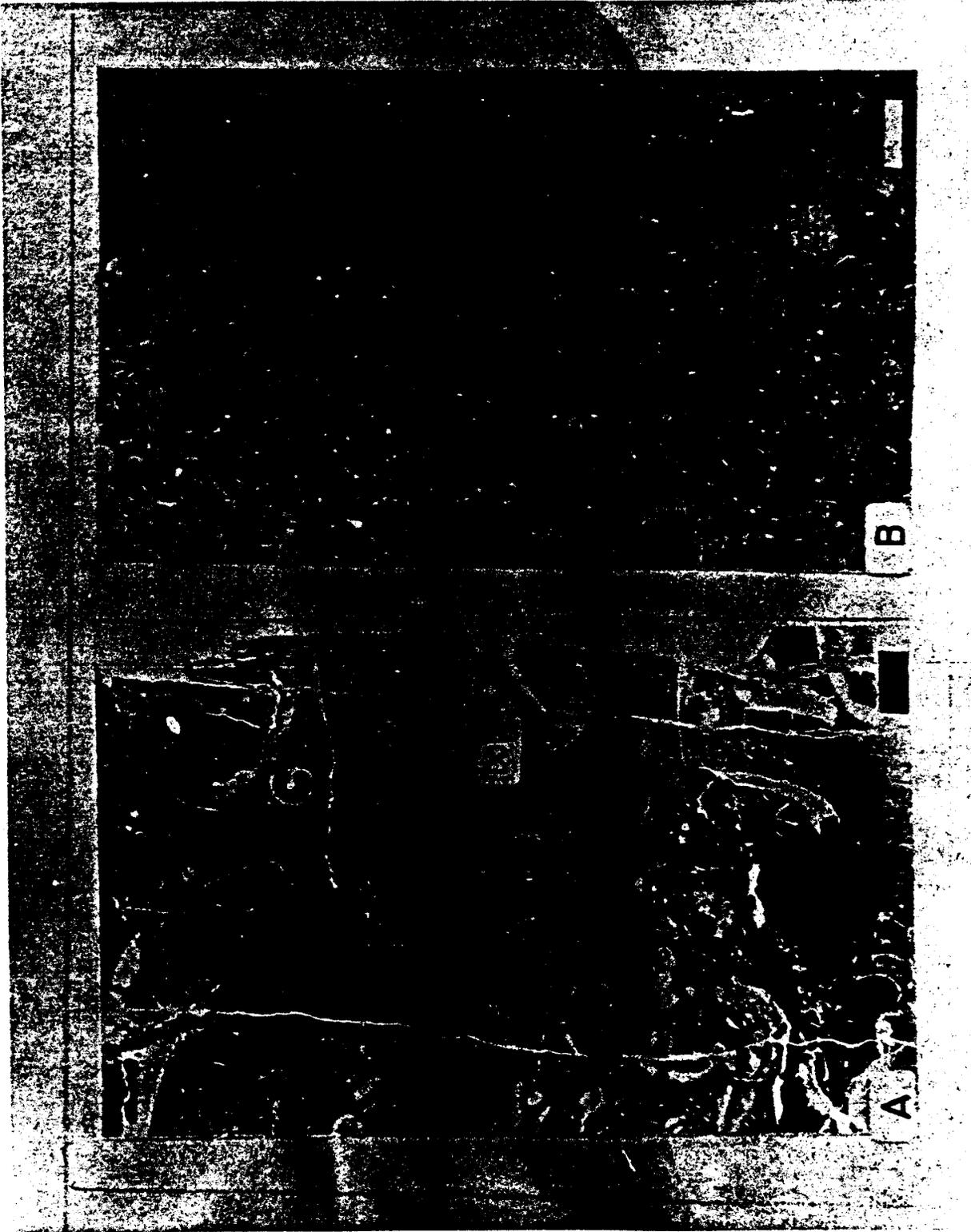
algae are most abundant, with brachiopods, gastropods,
bivalves, trilobites, and ostracodes less so.
Foraminifer/algal(?)-encrusted grains are common. Skeletal
grains are fragmented and show evidence of abrasion and
rounding. Grain micritization is extensive. Matrix
comprises micrite and microspar with minor quartz silt to
fine-grained sand.

Owl Creek beds

The Owl Creek beds were named by P.H. Heckel after
calcarenite exposures in the bank of Owl Creek (locality
OCK) in southwestern Allen Co., Kansas. These are similar
lithologically to a five-foot (1.5 m) sequence of thin to
medium-bedded skeletal-oolitic grainstone to packstone with
thin shale partings which is separated from the Raytown
mound by up to 10 feet (3 m) of fossiliferous shale at
localities HUM and LEH (figures 8, 30A, 71, and 72).

Foraminifer/algal(?)-encrusted skeletal debris, ooids,
peloids, intraclasts, and fragmented, abraded and
micritized skeletal grains constitute the bulk of the Owl
Creek beds (figure 30B, C, and D). Ooids make up about 15
percent of the rock and range from 0.1 to 0.8 mm in
diameter. Nuclei include peloids, skeletal debris, and
quartz sand; concentric lamellae are well preserved (figure
30E). The abundant and diverse biota includes echinoderm
debris, brachiopods, encrusting foraminifers, molluscs,

Figure 30. Raytown mound-associated facies - Owl Creek beds.

A. Interbedded fossiliferous shale and skeletal/oolitic grainstone to packstone at locality HUM in Allen Co., Kansas (= Owl Creek beds). Owl Creek beds overlie the Raytown algal mound and are gradational into overlying Lane/Bonner Springs Shale. Gravel road is approximate top of Raytown algal mound. Measuring stick is 5 ft. (1.5 m) long. Refer to Figure 71 for stratigraphic column of this section.

B. Hand specimen of Owl Creek skeletal/oolitic grainstone from locality LEH in Allen Co., Kansas. Ooids, echinoderms, and algal/foraminifer-encrusted grains (EG) are common. Bar for scale = 5 cm. Refer to Figure 68 for location of sample in section. LEH - Limestone Z.

C. Owl Creek skeletal/oolitic grainstone. Interparticle void space is filled with blocky ferroan and non-ferroan calcite spar. Skeletal grains include ooids, echinoderms, brachiopods, and foraminifer/algal-encrusted grains. Bar for scale = 6 mm. Plane polarized light. Refer to Figure 68 for location of sample in section.
LEH - Limestone Z.

D. Detail of probable intraclast (IC). Plane polarized light. Bar for scale = 0.25 mm. Refer to Figure 68 for location of sample in section. LEH - Limestone WX.

E. Detail of ooids from Owl Creek skeletal/oolitic grainstone at locality HUM. Sutured and flattened grain contacts are common, (evidence of solution compaction?). Ooids show a variety of nuclei including quartz sand, skeletal fragments, and lime mud. Interparticle cement is blocky calcite spar. Plane polarized light. Bar for scale = 0.4 mm. HUM - T6 - Main. Refer to Figure 71 for location of sample in stratigraphic section.
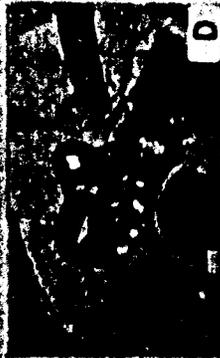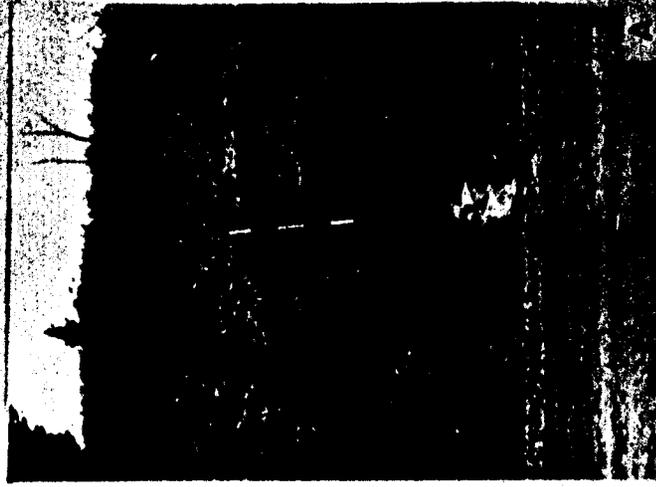
sponges, trilobites, ostracodes, and small orthocone cephalopods. Flattened and sutured grain contacts are common (figure 30E). Matrix is chiefly blocky non-ferroan and ferroan calcite spar with minor argillaceous and carbonate mud. Cement and skeletal debris has been replaced in part by non-ferroan and ferroan dolomite.

Bush City bed

Two to five feet (0.6-1.5 m) of thin to thick-bedded encrusted-grain skeletal wackestone to packstone with thin shale partings overlie the Raytown mound facies in Anderson and southern Miami Counties (localities QPA, QSBC, and KRR; figures 8, 60, 64 and 66). This unit is informally named the Bush City bed after an exposure in a quarry just south of Bush City in Anderson Co., Kansas (locality QSBC). The Bush City bed is separated from the main Raytown ledge by up to 8 feet (2.4 m) of fossiliferous gray shale (figure 31A).

The rock typically contains a highly varied and abundant biota with common bryozoans, sponges, and echinoderm debris. Brachiopods, molluscs, ostracodes, trilobites, encrusting foraminifers, and red algae are also present (figure 31B). Grains are typically fragmented; micrite envelopes are present. Encrustations are common (figure 31C, D) and include: 1) partial to complete coating of skeletal debris by foraminifers; 2) discrete,

Figure 31.   Raytown mound-associated facies - Bush City
bed.

A.   Locality QPA in Miami Co., Kansas. Quarry
exposure showing Bush City Bed (BC), which
is encrusted-grain skeletal wackestone to
packstone. At this locality, the Bush City
bed is about 3 ft. (1 m) thick and is
separated from the main Raytown limestone
ledge (R) by approximately eight feet of
gray, fossiliferous shale. Measuring stick
in right center of photo is 5 ft. (1.5 m)
long. Refer to Figure 60 for stratigraphic
section of quarry.

B.   Slabbed and polished hand specimen of
typical Bush City encrusted-grain skeletal
wackestone. Laminar foraminifer/algal (?)
consortia, foraminifer-encrusted skeletal
grains, and irregular, vaguely-laminated
"clumps" are common. Bar for scale = 5 cm.
Refer to Figure 60 for location of sample
in section. QPA - Upper Limestone -
bottom.

C.   Thin section photomicrograph of Bush City
encrusted-grain skeletal wackestone from
locality KRR in Anderson Co., Kansas.
Brachiopods, bryozoans, echinoderms, and
sponges are common. Most grains are coated
by dark foraminifer-algal (?)
encrustations. Matrix material has been
almost completely replaced by silt-sized
dolomite. Bar for scale = 1 mm. Plane
polarized light. Refer to Figure 66 for
location of sample in section.
KRR - Upper Limestone - lower sample.

D.   Thin section photomicrograph of irregular,
vaguely-laminated encrustation in Bush City
skeletal wackestone. Bar for scale = 1 mm.
Plane polarized light. BCRS - Upper
Limestone - sample R. Refer to Figure 63
for location of sample in section.

Figure 31.   (cont'd).

    E.   Thin section photomicrograph of Bush City
        encrusted-grain skeletal wackestone.
        Matrix is completely replaced by medium
        silt to very fine sand-sized non-ferroan
        dolomite. Although some rhombs appear
        zoned, no compositional differences are
        apparent from staining. Bar for scale =
        0.4 mm. Plane polarized light.
        QSBC - Middle Limestone - Sample Z. Refer
        to Figure 64 for location of sample in
        section.

    F.   Sponge nearly completely replaced by
        coarsely-crystalline ferroan dolomite (dark
        gray) and non-ferroan dolomite (light
        gray). Bar for scale = 1 mm. Plane
        polarized light. QSBC - Middle Limestone -
        Sample Z. Refer to Figure 64 for location
        of sample in section.
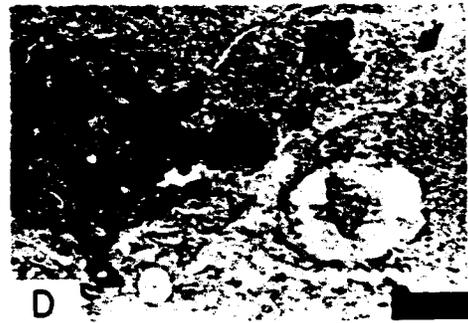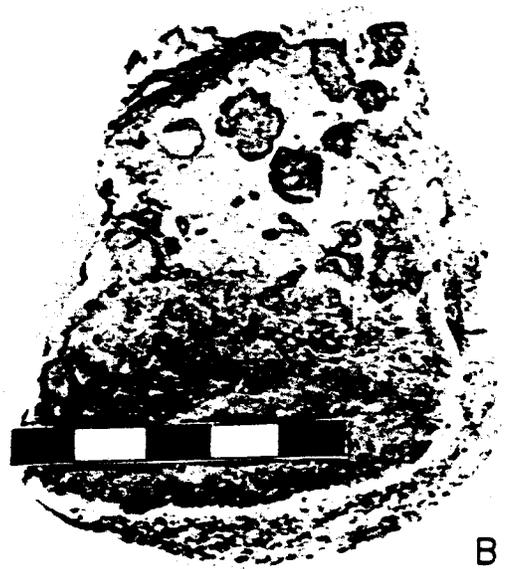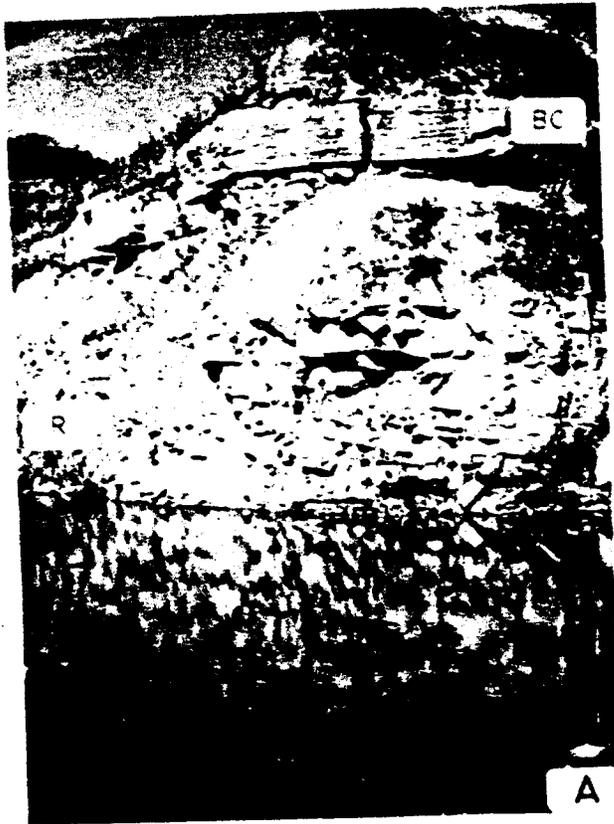
vaguely-laminated (blue-green algal) "clumps", ranging from 0.1 to 2 mm in diameter and incorporating quartz silt and fine skeletal debris; 3) laminar red algae/foraminifer consortia; and 4) rounded to irregular-shaped masses a few centimeters in diameter, comprising skeletal debris bound by a vaguely-laminated coating that is locally intergrown with plumose masses of encrusting foraminifers (Toomey, 1974). The matrix is commonly micrite, with minor microspar.

Dolomitization is locally extensive; lime mud matrix is partly to completely replaced by silt-sized rhombs of non-ferroan dolomite (figure 31E). Skeletal grains, as well as mud and calcite spar that fills intraparticle pore space, have been partly replaced by silt-sized non-ferroan and more coarsely-crystalline ferroan dolomite spar (figure 31F).

Bassett beds

The Bassett beds are named after an exposure in an abandoned limestone quarry (locality LEH) near the town of Bassett in Allen Co., Kansas. They comprise thin-bedded, rubbly, coated-grain, skeletal wackestone that is interbedded with fossiliferous shale. The Bassett beds and associated shales are sandwiched between the Raytown algal mound and the overlying Owl Creek beds. Rock

constitutents, texture and diagenesis are similar to that
of the Bush City bed.

Summary of Iola Stratigraphy and Lithology

The Paola Limestone Member shows little lithologic or
thickness variation throughout the study area. Two facies
are recognized: basal fossiliferous sandstone to sandy
skeletal packstone, gradational with the subjacent Chanute
Shale; and upper skeletal wackestone, present throughout
most of the study area. Mud-supported texture, diverse
fauna, and abundant algal debris are characteristic of the
bulk of the Paola. It is thin or missing throughout
southwestern Iowa and eastern Nebraska.

The Muncie Creek Shale is a thin (0.1-1.0 m, 3 in.-3
ft.), laterally persistent, nearly non-sandy phosphatic
shale. Two facies are recognized: black fissile shale
rich in organic material and heavy metals, but lacking a
benthic marine fauna (although conodonts, fish remains,
orbiculoid brachiopods, and conularids are present); and
gray shale, typically with a sparse to moderately abundant
marine benthic fauna comprising brachiopods,bryozoans,
echinoderms, and sponges. The black facies is sandwiched
between gray shales and is present throughout the study
area except in central southeastern Kansas where only thin
gray shale is present.

The lower portion of the Raytown Limestone Member is relatively laterally persistent throughout the study area, typically comprising normal marine skeletal wackestone/packstone with a diverse marine fauna. A non-abraded grainstone consisting nearly entirely of invertebrate skeletal grains with no evidence of grain micritization or abrasion, cross-bedding, or algal debris is present at the base of the Raytown in northeastern Kansas. In contrast, the upper Raytown exhibits considerable lateral facies changes. In northeastern Kansas, the upper Raytown is composed of skeletal calcilutite. In Iowa and eastern Nebraska the Raytown grades upward into an abraded skeletal grainstone with rounded algal and invertebrate grains, abundant foraminifer-encrusted grains, grain micritization, and intraclasts. Laminated carbonate mudstone with birdseye structures, probable desiccation cracks, and traces of replaced evaporite minerals is present at the top of the Raytown in this area.

Phylloid algal mound complexes are developed in the Raytown Limestone in southeastern Kansas and in the nearly equivalent Avant Limestone in northeastern Oklahoma. Iola moundrock consists mainly of sparry phylloid algae-rich wackestone with subordinate amounts of algal wackestone and skeletal grainstone, packstone and wackestone.

Mound-associated facies, including cross-bedded skeletal oolitic grainstones (Owl Creek beds), and encrusted-grain skeletal wackestone/packstone (Bush City and Bassett beds) overlie the Raytown algal mound. Algal-poor skeletal wackestone/packstone and minor sandstone constitute the bulk of the Raytown in the intermound area near the Kansas/Oklahoma border.

Lane (Lane/Bonner Springs) Shale

The Lane Shale overlies the Iola Limestone throughout the entire study area, except where it is removed by modern erosion. South of Garnett in eastern Anderson Co., Kansas, where the overlying Wyandotte Limestone is absent (Newell, 1932), it is impossible to distinguish the Lane from the overlying Bonner Springs Shale; hence the entire sequence from the top of the Iola to the base of the Plattsburg Limestone is referred to as the Lane/Bonner Springs Shale (Moore, 1948). Oakes (1940) applies the name Wann Formation to all strata lying between the top of the Iola and the base of younger sandstone and limestone in northeastern Oklahoma (figure 7), which Heckel (1975b) correlates with the Stanton Formation.

The following description of the Lane Shale is based on personal observation, stratigraphic sections on file at the Kansas and Iowa Geological Surveys, and the work of Oakes (1940), Schooler (1955), Hershey, Brown, Van Eck, and

Northrup (1960), Lineback (1961), Fishburn (1962), Miller
(1963, 1966, 1969), Jungmann (1966), Crowley (1969), and
Seevers (1969).

Thickness of the Lane/Bonner Springs Shale is variable
in the southern portion of the study area, ranging from 60
to 110 feet (18-33 m). It typically is a yellow-brown,
poorly fossiliferous, arenaceous clay shale with local,
thin to medium bedded micaceous siltstone and lenticular,
fine-grained quartzose sandstone. Plant impressions and
thin carbonaceous streaks are common.

Northward in Iowa and Nebraska, the Lane Shale is
approximately 10 feet (3 m) thick. Here the Lane is a
poorly fossiliferous, slightly sandy, gray to green shale.
Red shale is locally present in southwestern Iowa and
eastern Nebraska.

CHAPTER III

DEPOSITIONAL HISTORY

The preceeding description of the stratigraphy and
lithology of the Iola Limestone and adjacent units permits
the reconstruction of depositional environments during
phases of transgression and regression. The extent of, and
boundaries between, facies within the study area during
various sea-level stands are presented as figures 32
through 39. Heckel (1980) provides more extensive maps
generalized for the late Pennsylvanian that show the extent
of and boundaries between facies during a single idealized
transgressive-regressive event throughout the central
United States.

Pre-transgressive Phase

The Chanute Shale records detrital influx into deltaic
plain to marginal marine environments (figure 32) prior to
the major marine transgression that brought about deposi-
tion of the lower Iola . The Chanute is deposited on a
channeled, subaerially-eroded surface developed during
maximum regression after the preceeding inundative phase.
Demonstrably non-marine deposits in southeastern Kansas,
such as channel sandstones and coal, record a subaerial

Figure 32. Generalized distribution and relationship of
            Chanute facies throughout study area during
            pre-transgressive phase of deposition. Primary
            exposures shown by black dots. Standard
            lithologic symbols used. Paleolatitude base
            from Heckel (1977).
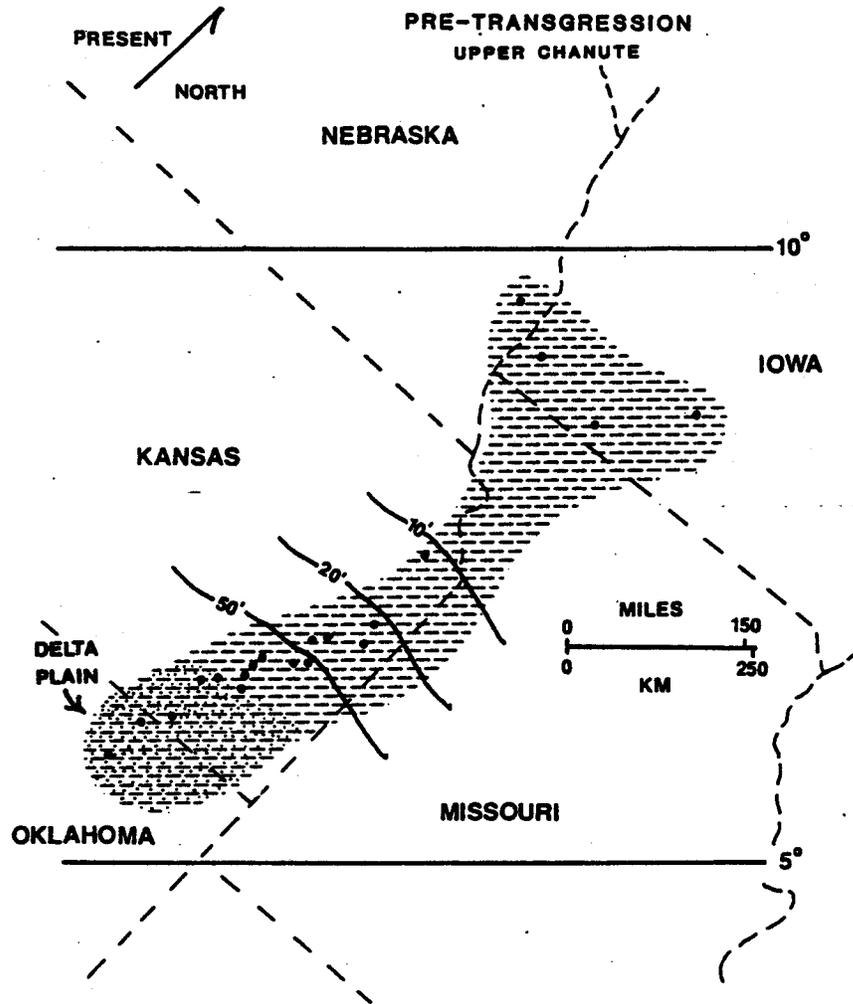
Figure 32.

deltaic plain. Northward into Iowa and Nebraska, thin shales with coals are present. The locally sparsely fossiliferous nature of the Chanute in this region probably reflects reduced influx of terrigenous detritus and local marginal marine conditions.

Substantial thickening in the Kansas-Oklahoma border region (figure 9) and the presence of northwest-trending, elongate and lenticular sandstone bodies that were interpreted by Haggiagi (1970) as bar-finger sands indicate that the major terrigenous detrital source was to the south, probably in the Ouachita Mountains of Oklahoma.

Transgressive Phase

Throughout much of the study area early, middle, and maximum phases of transgression are distinguished. Basal Paola fossiliferous sandstone to sandy skeletal packstone records early transgression except in southwestern Iowa where little carbonate was produced during deepening (figure 33). These deposits represent growth of invertebrates (mainly echinoderms and encrusting foraminifers), in marine water after waning of fresh water and terrigenous detrital influx. Algae may have been excluded by water turbidity, as only a few blades are present. Lateral variation in exact facies variants

Figure 33. Generalized distribution and relationship of
Iola facies throughout study area during early
transgression. Primary exposures shown by
black dots. Standard lithologic symbols used,
except double vertical lines in limestone
pattern represent dominance of packstone.
Paleolatitude base from Heckel (1977).
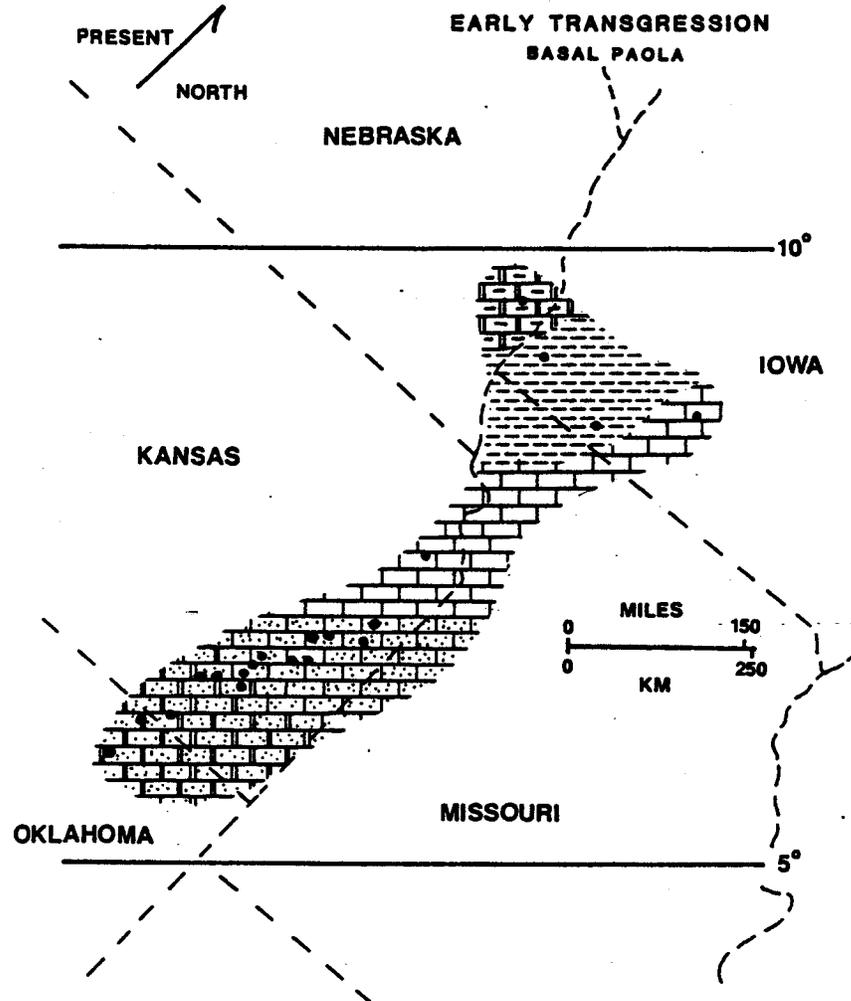
Figure 33.

probably reflects local differences in the inundated surface.

As transgression continued (figure 34), terrigenous detritus was deposited progressively farther away from the present Midcontinent outcrop. Sea-level eventually rose to the extent where nearly all of the sea floor lay below effective winnowing base, although still in the photic zone. As water cleared, fine carbonate mud was produced and settled out; phylloid algae and a diverse and relatively abundant marine invertebrate fauna became established, all resulting in the deposition of a thin skeletal wackestone to packstone over most of the study area. Although carbonate sedimentation was able to partly compensate for continued increase in water depth, the rate of transgression was rapid enough to soon outstrip rate of algal production of carbonate sediment; consequently the sea floor bottom dropped below the effective photic zone, and algal production of sediment stopped.

Thin or missing Paola Limestone throughout southwestern Iowa and eastern Nebraska may reflect either the 1) absence of significant marine incursion into this area until maximum transgression, or 2) inhibition of carbonate mud and invertebrate production during deepening here.

Maximum transgression (figure 35), is represented by the entire Muncie Creek Shale where it is thin, and by its

Figure 34. Generalized distribution and relationship of
Iola facies throughout study area during middle
stage of transgression. Primary exposures
shown by black dots. Standard lithologic
symbols used, except double vertical lines in
limestone pattern represent dominance of
packstone, convex-upward curves within limestone
pattern represent abundant phylloid algae.
Paleolatitude base from Heckel (1977).
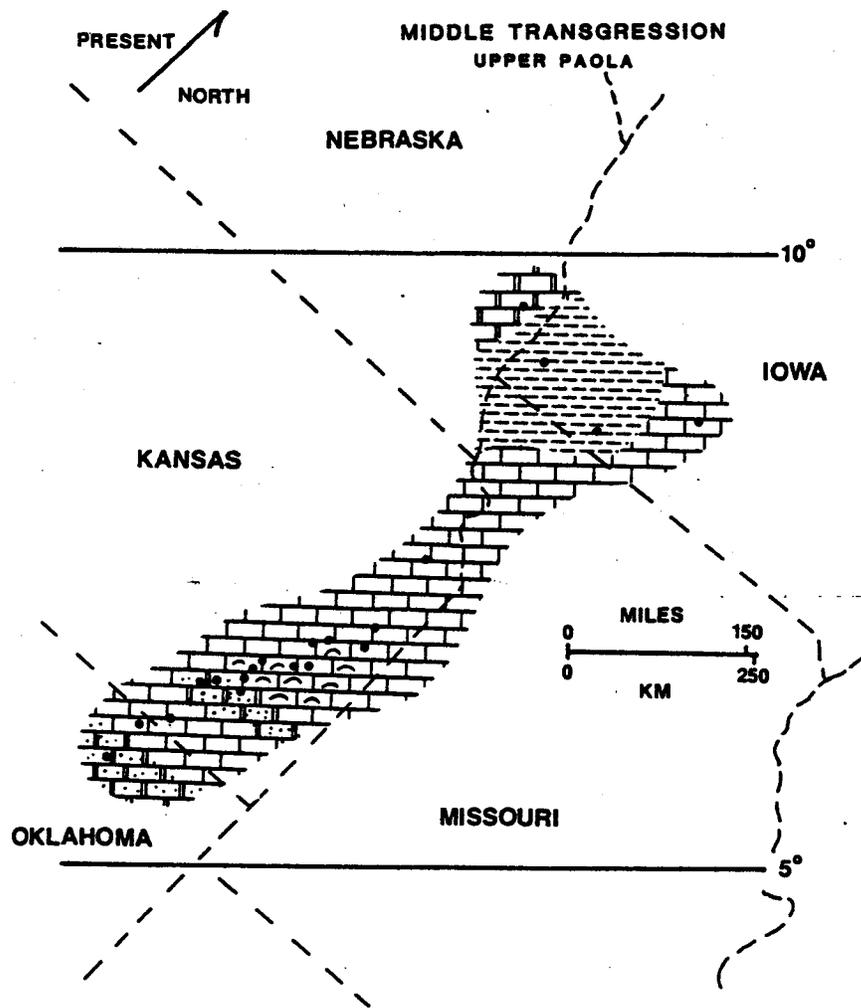
Figure 34.

lower portion where it is thick. Thinness, lateral persistence, fine detrital grain size, and presence of conspicuous non-skeletal phosphorite, all point to slow sedimentation in deep water away from sources of detrital influx. Although the Muncie Creek Shale is continuous throughout the study area, it does show lateral and vertical thickness and lithologic variation. This variation is due to differing proximity to the major detrital source area, and apparently to the effect of local topographic highs within the depositional basin.

During maximum sea-level stand in the Midcontinent, the sea floor lay below the effective photic zone, cutting off algal production of sediment; this, in conjunction with deposition of terrigenous detritus far away from the Midcontinent outcrop area due to impounding of rivers near the Ouachita and Appalachian shorelines, resulted in sediment-starvation. Eventually, enough fine-grained suspended detritus settled out to form the thin gray shale that comprises the entire Muncie Creek where thin and the lower Muncie Creek where it is thick.

During maximum transgression, water depth was sufficient for development of a thermocline and a two-layered quasi-estuarine circulation cell as outlined earlier and discussed in detail by Heckel (1977). Heavy metals and phosphate were concentrated by the

Figure 35. Generalized distribution and relationship of
            Iola facies throughout study area at maximum
            transgression. Primary exposures shown by
            black dots. Standard lithologic symbols used,
            dashed lines represent gray shale, solid black
            lines represent fissile, black shale.
            Paleolatitude base from Heckel (1977).
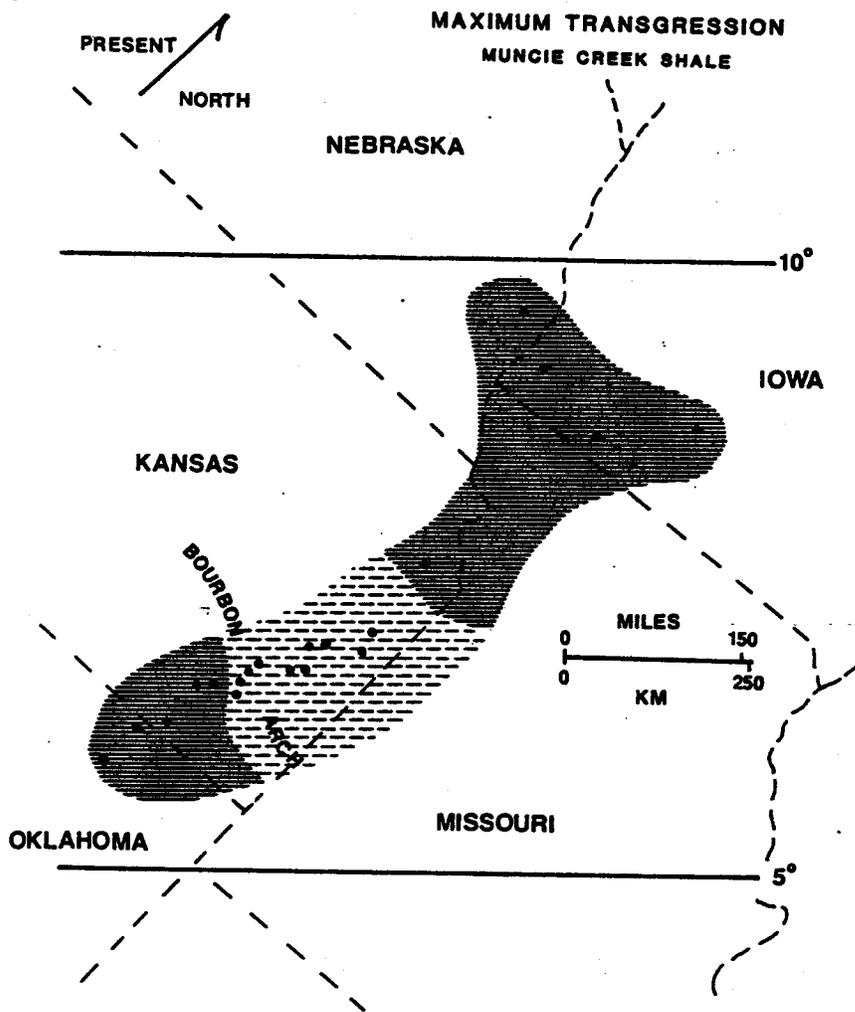
Figure 35.

quasi-estuarine circulation cell, with the latter accumulating as subround to discoidal phosphorite nodules. Local incorporation of phosphorite nodules in the upper Paola surface suggests continued settling of fine-grained carbonate sediment after initial establishment of the sediment-starved basin and circulatory trap. Scarcity of phosphorite nodules in the northern and southern portions of the study area may reflect dilution by increased siliciclastic influx due to proximity to terrigenous detrital source areas.

Where the oxygen-depleted bottom layer of the circulatory cell impinged on sea floor bottom, organic-rich, black, fissile shale that lacked a benthic fauna was deposited. Absence of black shale throughout the mound tract implies that water depth was not sufficient in this area for development of a strong enough thermocline to prevent oxygenation of bottom water, although non-skeletal phosphate did accumulate. It is probably not coincidental that abundant phylloid algal growth took place in both carbonate units in this same area. Topographic highs within the depositional basin probably served as loci favoring initiation and continued growth of phylloid algal mound complexes as proposed by Pray (1961), Choquette and Traut (1963), Crowley (1969), Heckel and Cocke (1969), Frost (1975), and Welch (1977).

Pre-existing topographic highs may be 1) structural in origin (Pray, 1961); 2) due to compaction of shale around underlying, previously existing mound complexes, resulting in "stacking" of algal mounds (Choquette and Traut, 1963; Heckel and Cocke, 1969); or 3) developed on "drowned" deltaic platforms (Crowley, 1969).

Topographic highs, no matter what their origin, would cause water to be shallower in this area; thus effectively raising the depositional substrate into the zone of increasing oxygenation, in addition to providing optimum conditions for algae during lower stands of sea level.

Relatively thick Chanute Shale acting in concert with the active Bourbon Arch (Jewett, 1951; Moore, 1979) most likely gave rise to the topographic high that affected Iola sedimentation in central southeastern Kansas. Although thicker sections of the Chanute occur south of the Raytown mound tract in the Kansas-Oklahoma border region, these lie south of the area influenced by the Bourbon Arch in the inter-mound area, apparently a topographically low-lying area during time of Iola deposition. The Paola/Chanute contact is up to 110 feet (33 m) lower than expected from regional strike and dip considerations at localities VFW and MKT in west central Neosho County. In addition, exploratory holes drilled by the Ash Grove Cement Co., (personal communication, staff engineer, 1979), reveal that

the Paola/Chanute contact is 80 feet (24 m) lower immediately south of the Raytown mound than it is at the southern edge of the mound at Chanute. As a result, black shale facies reappear in the Muncie Creek Shale, and phylloid algae are scarce in the Raytown and Paola Limestones in this area. This topographically low-lying area is located along synclinal alignment (1) of Heckel and Cocke (1969). Heckel (1978) mentioned the existence of a similar topographically low-lying area south of the Stanton mound tract in Montgomery Co., Kansas.

Regressive Phase

The upper portion of the Iola cyclothem was deposited as the sea withdrew across the Midcontinent. Early, middle, late, and final stages of regression are recognized.

Early regression (figure 36), is recorded by the lowermost Raytown Member, and the upper Muncie Creek Shale, where it is thick. As relative sea level fell, the thermocline that maintained quasi-estuarine circulation was destroyed. Concomitant reestablishment of bottom oxygenation resulted in deposition of upper gray Muncie Creek Shale. Vertical gradation from fissile black facies to gray facies is most likely due to sea-level change, not "basin-filling", with sedimentation raising the depositional substrate up out of anoxic bottom water. The

Figure 36. Generalized distribution and relationship of
Iola facies throughout study area during early
phase of regression. Primary exposures shown
by black dots. Standard lithologic symbols
used, except limestone pattern with double
vertical lines and G represents grainstone
dominance, in this case nonabraded,
invertebrate grainstone. Paleolatitude from
Heckel (1977).
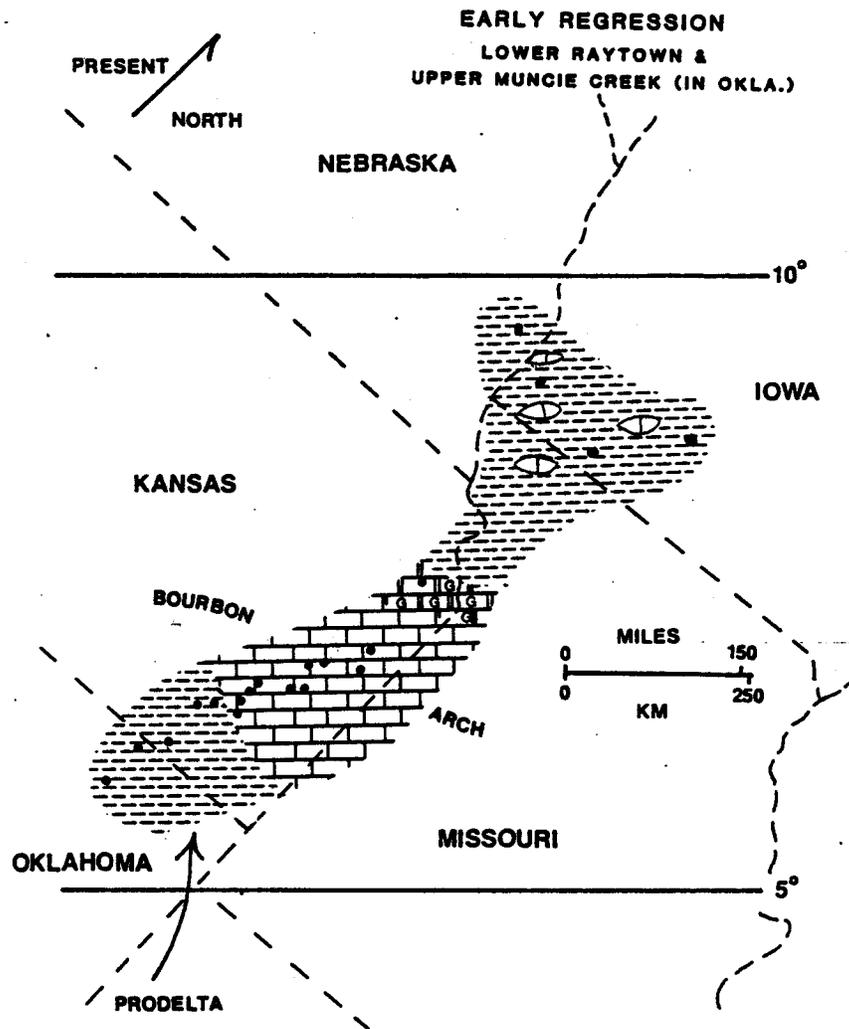
Figure 36.

Muncie Creek is simply too thin throughout most of the study area to have had any direct effect on depositional environment.

Retreat of the sea allowed terrigenous sediment to once again prograde seaward. Increased thickness of the Muncie Creek in northeastern Oklahoma is most likely due to influx of terrigenous detritus shed from the nearby positive area in southern Oklahoma. Lesser thickening of the Muncie Creek in the northern portion of the study area may be due to influx of prodeltaic muds from distant deltas prograding westward from the Appalachian region (Heckel, 1980).

Presence of a thin, invertebrate grainstone without cross-bedding, grain abrasion, micritization, or algal debris in northeastern Kansas records local proliferation of invertebrates soon after restoration of bottom oxygenation, but prior to lowering of sea level sufficient to raise the depositional substrate above the effective lower limit for algal carbonate production.

In central-southeastern Kansas, shallowing over the previously discussed Bourbon Arch topographic high probably initiated algal mud production earlier, and also soon brought about prolific growth of phylloid algae.

Regression eventually raised the sea floor over a large area above the lower photic limit for effective algal

carbonate production (figure 37); yet the sea floor remained below effective winnowing base for some time, resulting in deposition of skeletal wackestone to packstone. Prolific growth of phylloid algae in central southeastern Kansas resulted in formation of the Raytown algal mound facies.

Fine-grained terrigenous detritus probably from westward-prograding deltaic complexes formed thin to thick shale interbeds in the lower Raytown in Iowa and Nebraska. Likewise, northward-advancing deltas in Oklahoma provided enough terrigenous detritus to inhibit phylloid algal carbonate production south of the study area. Pulses of fine siliciclastics periodically overwhelmed the production of carbonate sediment near the south end of the mound tract, forming thin shale interbeds in the lower Raytown mound. Although enough carbonate sediment was produced south of the Raytown mound tract to offset the influx of prodeltaic muds and produce limestone, the approaching detrital source did yield enough clastics to form abundant shale splits and constitute an important part of the rock. A thin, sparsely fossiliferous, fine-grained sandstone is present in the lower Raytown in the topographically low-lying area south of the mound.

The upper Raytown records the late stages of regression throughout the study area (figure 38). The

Figure 37. Generalized distribution and relationship of
Iola facies throughout study area approximately
midway through regression. Primary exposures
shown by black dots. Standard lithologic
symbols used, with convex-upward curves within
limestone symbol representing phylloid algal
mounds. Paleolatitude base from Heckel (1977).
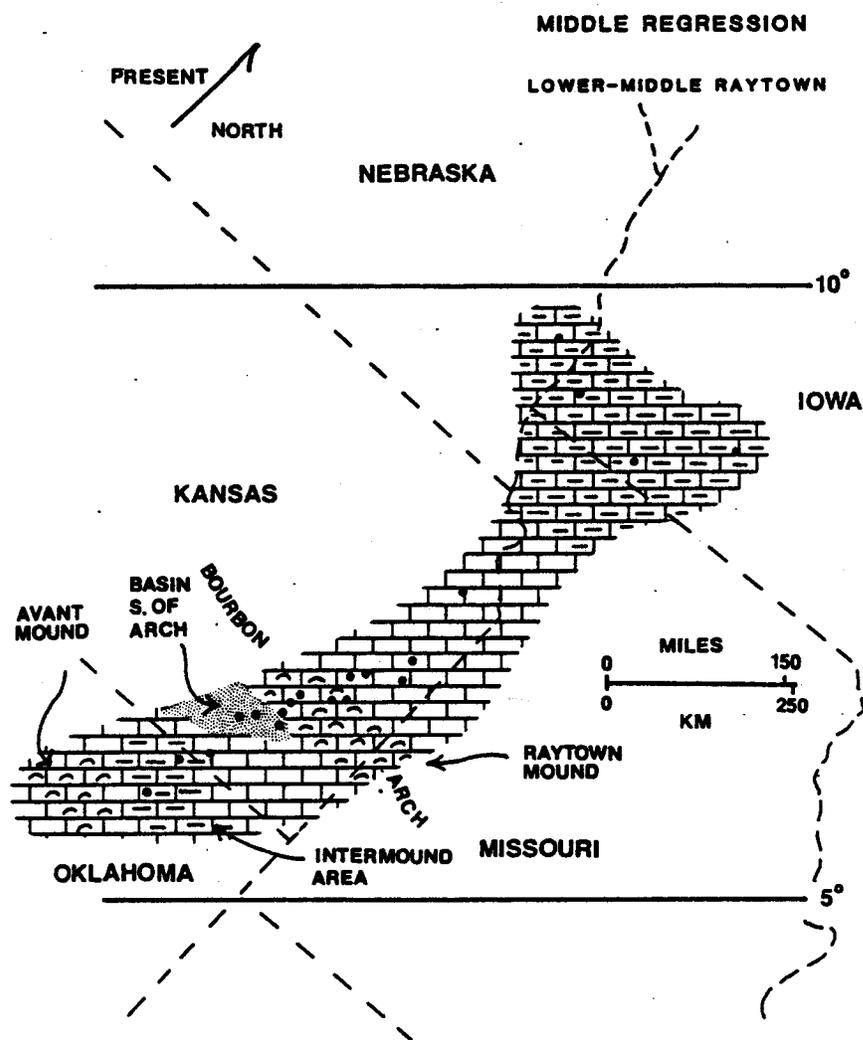
Figure 37.

Figure 38. Generalized distribution and relationship of
            Iola facies throughout study area during
            deposition of upper part of Raytown Limestone
            Member and lower Lane Shale. Primary exposures
            shown by black dots. Lithologic symbols
            standard, except thin brick pattern represents
            shoreline (commonly tidal flat) carbonates,
            limestone symbol with double vertical line and
            G represents grainstone, circles represent
            presence of ooids. Paleolatitude base from
            Heckel (1977).
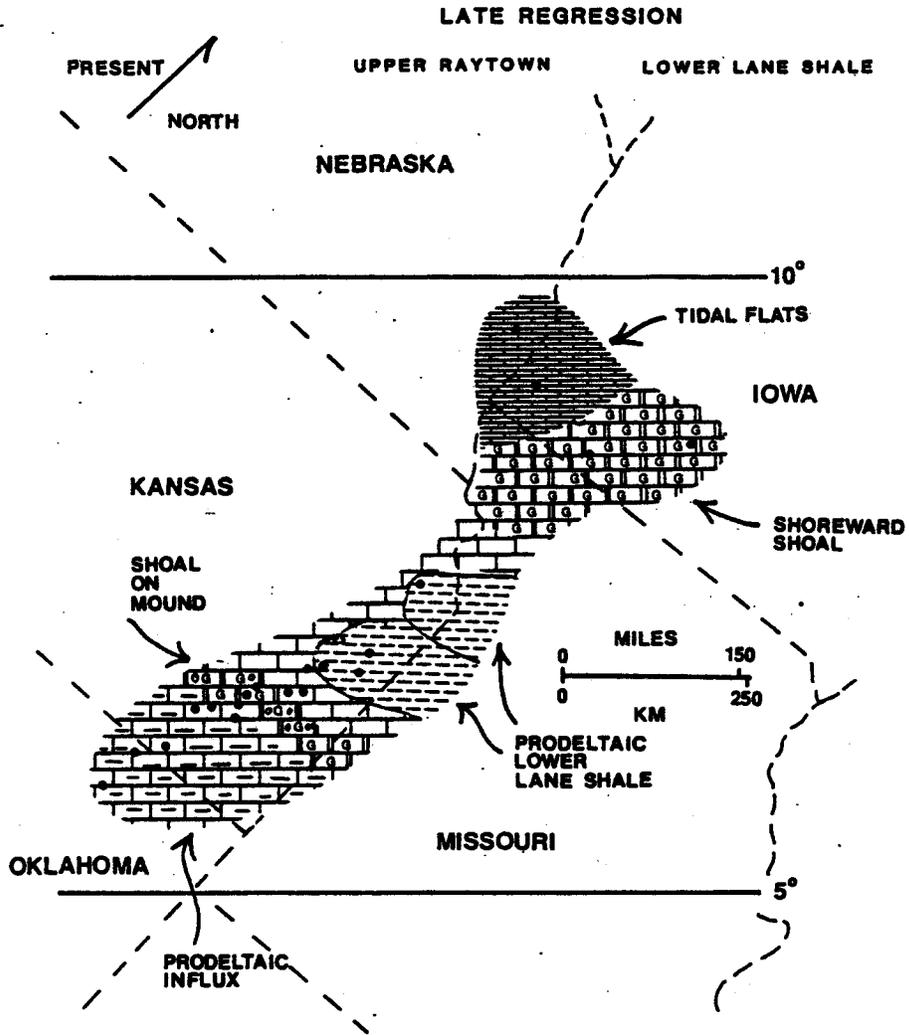
Figure 38.

upper Raytown displays strong development of distinctly
different facies in contrast to the lower and middle
portions of the Raytown.

In and near its type area in northeast Kansas, the
Raytown shows no evidence of shoal-water deposition, as
apparently a major influx of prodeltaic mud initiating
deposition of the Lane Shale overwhelmed carbonate
production in this area while the sea floor was still below
effective wave base (Heckel, 1977, 1978).

To the north in Iowa and eastern Nebraska, shallowing
water resulted in the raising of the sea floor above
effective wave base, with eventual restriction of marine
circulation. As a result, the Raytown grades upward from
normal marine wackestone/packstone through intraclastic,
abraded-grain skeletal grainstone and into muddy shoreline
and supratidal facies comprising sparsely fossiliferous to
barren laminated carbonate mudstones with birdseye, mud
cracks, and evaporites. Sparsely fossiliferous peloidal
packstone facies were probably deposited in quiet, lagoonal
environments (Wilson, 1975, p. 436). Subvertical cracks
and fenestral fabric characteristic of this facies may have
resulted from periodic exposure and desiccation and perhaps
rooting by plants after subaerial exposure.

Influx of fine-grained terrigenous detritus ended
abundant phylloid algal growth throughout the Raytown mound

tract. With continued drop in sea level, thick mound facies throughout Allen and northwestern Neosho Counties in southeast Kansas became subject to effective wave and current action, which led to the deposition of grainstone to mud-lean packstone capping the Raytown mound in this area. Periodic waning of terrigenous detrital influx allowed reestablishment of carbonate sedimentation, but not abundant phylloid algal growth, resulting in the deposition of mound-associated, coated-grain skeletal wackestone to packstone (Bush City and Bassett beds).

Cross-bedded, abraded-grain, skeletal-oolitic grainstone to packstone (Owl Creek beds) overlie the Raytown mound where it is thickest; recording a shoal-water environment. Although it is possible that the Bassett and Owl Creek beds represent a southern extension of the Wyandotte Limestone, generally thought to pinch out near Garnett in Anderson Co., Kansas (Newell, 1932) (see later section), these deposits in either case reflect the influence of the thick Raytown mound and the Bourbon Arch on depositional environments.

In the Kansas-Oklahoma border region, regression resulted in upward gradation from skeletal wackestone to encrusted-grain skeletal grainstone and perhaps earlier overwhelming by prodeltaic shales derived from the nearby Oklahoma source.

The final stage of regression is recorded in the Lane-Bonner Springs Shale when large amounts of siliciclastics from encroaching shoreline detrital sources spread over the remainder of the study area (figure 39). Increased thickness of the Lane-Bonner Springs Shale in the Kansas-Oklahoma border region is due to proximity to the major detrital source area in Oklahoma. Local development of red facies in the thin Lane Shale in southwestern Iowa and eastern Nebraska indicate sufficient subaerial exposure for oxidation and dehydration of iron minerals during soil formation. Subvertical cracks, possibly due to repeated wetting and drying of sediment and probable rhizocretions record subaerial exposure and calichification of the upper Raytown in southwestern Iowa and eastern Nebraska. The sparse, low diversity biota of the Lane-Bonner Springs Shale reflects deposition in a prodeltaic to delta-front environment, where increased detrital influx and attendant marginal marine conditions reduced the abundance and diversity of marine organisms.

Figure 39. Generalized distribution and relationship of facies throughout study area at maximum regression. Primary exposures shown by black dots. Lithologic symbols standard, except brick pattern with oblique slashes represents locally exposed and calichified carbonates. Paleolatitude base from Heckel (1977).
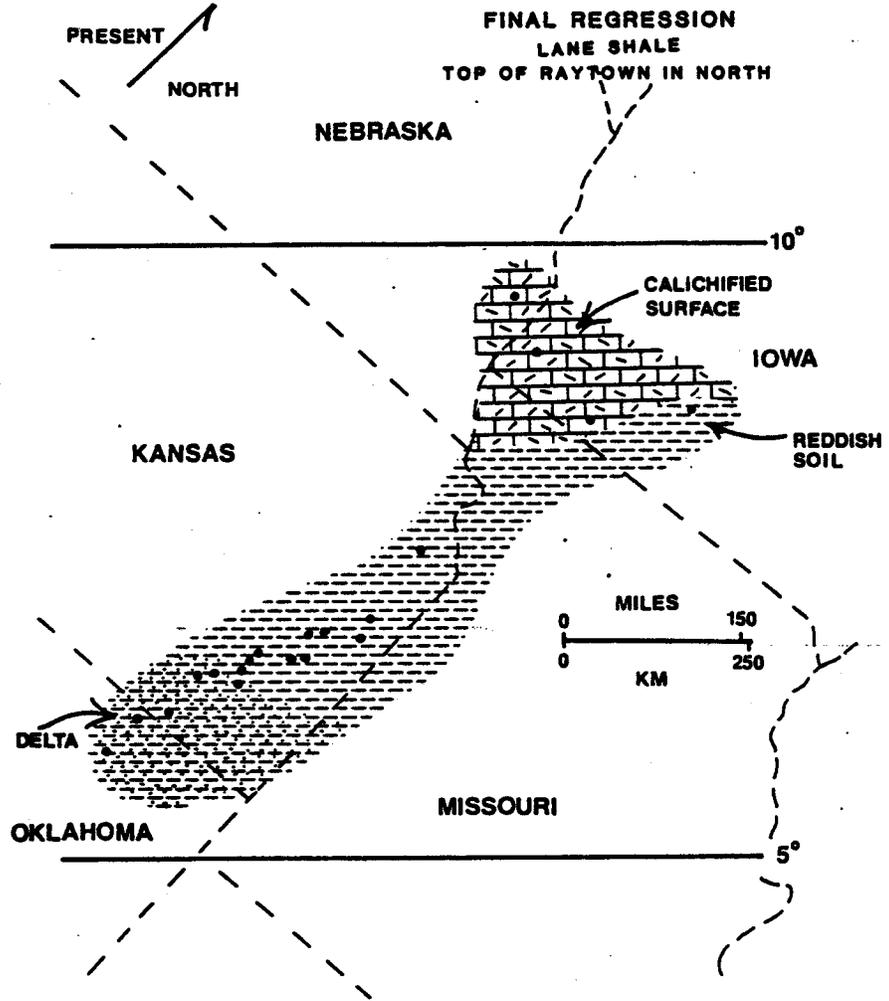
Figure 39.

CHAPTER IV

DIAGENESIS

Dolomitization, collapse and brecciation of sediment within a framework of algal blades, and probable submarine cementation are the most conspicuous diagenetic features seen within the Iola Limestone.

Dolomitization

The Iola Limestone shows considerable vertical and lateral variation in degree of dolomitization throughout the study area. Four varieties of dolomite are recognized: 1) cryptocrystalline non-ferroan dolomite; 2) silt-sized non-ferroan dolomite; 3) slightly coarser crystalline ferroan dolomite; and 4) patches comprising coarse "baroque" ferroan dolomite overlying geopetal silt-sized ferroan dolomite.

1) Cryptocrystalline non-ferroan dolomite is restricted to the northern portion of the study area, occurring exclusively in Raytown laminated carbonate mudstone facies. Original sedimentary texture is well preserved.

2) Fine to coarse silt-sized dolomite rhombs are nearly ubiquitous. Rhombs replace lime mud, skeletal debris, and calcite spar alike.

3) Relatively coarsely-crystalline ferroan dolomite commonly fills void spaces including interparticle, intraparticle, moldic, fracture, and fenestral voids.

4) White, coarsely-crystalline "baroque" ferroan dolomite with a characteristic sweeping extinction pattern in cross-polarized light occurs in patches overlying geopetal silt-sized ferroan dolomite and is present in the Raytown algal sparite facies at locality KTL in Allen Co., and in Avant Limestone mound rock from northeastern Oklahoma. Chemical and mineralogical composition of the patches was ascertained by alizarin red-S and potassium ferricyanide stains and confirmed by EDAX analysis.

The Iola Limestone, like many other units (Schmidt, 1965; Land, 1967; Neal, 1969), displays a definite sequence of susceptibility of rock constituents to dolomitization. Lime mud matrix is most susceptible to replacement, especially where burrowed or somewhat protected from compaction within sheltered areas. It is followed in order of replacement by probable original aragonitic grains, calcitic grains, and sparry calcite cement. Supposed high-magnesium calcite skeletal grains, including red phylloid algae and echinoderm debris, are more apt to be dolomitized

than are low-magnesium calcite grains such as brachiopods. This may be due to incongruent dissolution of high-magnesium calcite (Land, 1967), with resultant magnesium enrichment of the immediate micro-environment.

By taking into consideration how much of the rock has been dolomitized and which rock constituents have been replaced, it is possible to semi-quantitatively categorize intensity of dolomitization throughout the Iola (figure 40). Six increments in degree of dolomitization are recognized, ranging from no dolomitization to complete replacement of lime mud matrix and partial replacement of skeletal grains by dolomite. Several trends are recognized:

1. Rock with mud-supported textures (mudstones and wackestones) are preferentially dolomitized relative to rock with grain-supported textures (packstones and grainstones).

2. Mud-supported limestones adjacent to shales are more extensively dolomitized relative to those that are more distal.

3. In general, limestone beds in the northern portion of the study area are extensively dolomitized irrespective of texture and proximity to shale.

Preferential dolomitization of muddy limestones has been noted by many authors in ancient and modern carbonates

Figure 40. Generalized north-south cross-section of Iola
Limestone showing variation in intensity of
dolomitization. Datum is upper surface of
Paola Limestone Member. See caption to figure
8 for explanation of lithologic symbols used.
Numbers indicate relative degree of
dolomitization; ranging from 0 = no dolomite
seen, to 5 = rock essentially completely
dolomitized. See Appendix A for section
descriptions and key to locality names and
Appendix B for more detailed individual
stratigraphic columns.

Figure 40.

WASHINGTON CO.
OK

MONTGOMERY CO.
KS

WILSON CO.
KS

NEOSHO CO.
KS

ALLEN CO.
KS

ANDERSON CO.
KS

MIAMI CO.
KS

JOHNSON CO.
KS

WYANDOTTE CO.
KS

130 MILES (210 Km) OF COVERED SECTION OMITTED

MADISON CO.
IA

TAYLOR CO.
IA

MILLS CO.
IA

SARPY CO.
NE

RAYTOWN

PAOLA

MUNCIE CREEK

CHANUTE

FEET
METERS

MILES
KILOMETERS
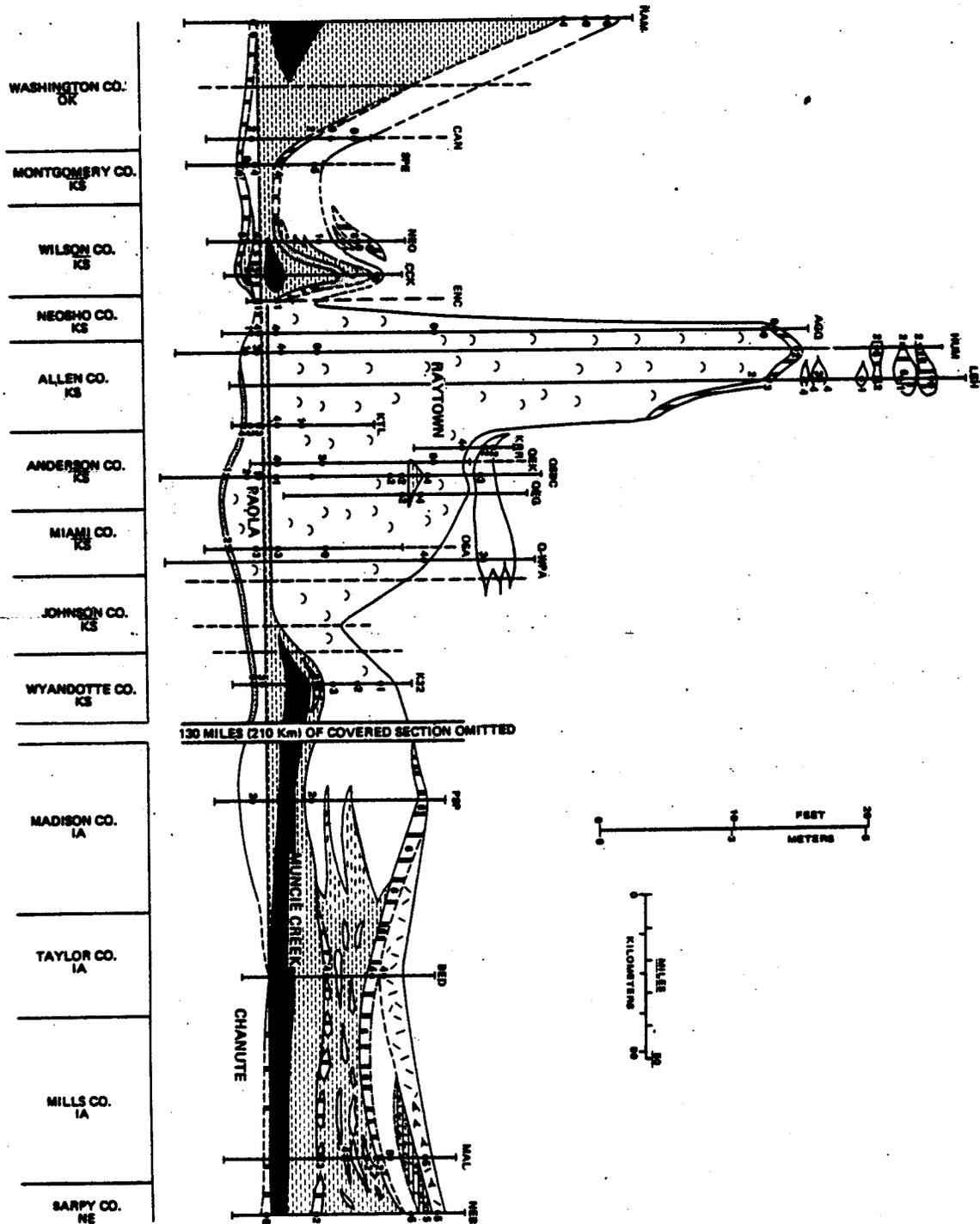
alike (Lucia, 1962; Schmidt, 1965; Land, 1967; Murray and
Lucia, 1967; Shinn, 1968; Passeri and Pialli, 1973;
Lumsden, 1974; and Milner, 1976). This strong selectivity
is most likely controlled by variation in sediment
reactivity due to: high surface area of mud-sized
particles; probable original high-magnesium calcite and
aragonite composition of the lime mud; and "reversal" of
original permeability differences between mud and grain-
supported textures due to predolomitization cementation of
grain-supported rocks (Murray and Lucia, 1967; Kendall,
1977; Davies, 1979).

Preferential dolomitization of mud-supported limestone
adjacent to shale is suggestive of dolomitization by
connate water expelled by compaction (Illing, 1959; Jodry,
1969; Davies, 1979). The Mg:Ca ratio of expelled connate
water may be enriched by exchange reactions with clays
(Kahle, 1965) such as chlorites and illite-mixed layer
clays, which can contain up to 25 percent MgO. Chlorite
and mixed layer clays are both fairly common in shales
within the Iola and in adjacent units (figure 17).
Alternatively, later-invading meteoric waters could enter
into exchange reactions with clays. Freeman (1972) and
Inden and Koehn (1979) regard magnesium derived from
chlorite as being at least partly responsible for
dolomitization. Although other authors (Zenger, 1965;

Hatfield and Rohrbacker, 1966; and Lumsden, 1974) reject the idea that insoluble residues, including clay minerals, play a role in dolomitization; it is noteworthy that no magnesium-bearing clay was identified in any of these studies.

Dolomite in the northern portion of the study area may owe its origin to evaporative reflux of a hypersaline brine that is enriched in magnesium relative to calcite via preciptitation of gypsum (Davies, 1979). Alternatively, mixing of marine-derived connate waters with meteoric-derived water could lead to dolomitization without requisite evaporite precipitation. A number of "mixed-water" models involving interplay between relatively low salinity "fresh" water and relatively high salinity Mg-rich water have been proposed, including: "schizohaline" models (Siedlacka, 1972; Folk and Land, 1975); and "Dorag" models (Badiozamani, 1973; Dunham and Olson, 1978).

Two types of dolomite are recognized in the northern portion of the study area: 1) cryptocrystalline dolomite preserving fine textural detail of laminated carbonate mudstones; and 2) silt-sized non-ferroan dolomite cross-cutting and replacing other rock constituents.

The chemical and physical nature of dolomite formed from hypersaline brines is distict from that formed from dilute solutions. Very early (penecontemporaneous)

dolomitization of a pre-existing host by hypersaline brines yields small, poorly-ordered, non-stoichiometric, calcium-rich dolomite crystals, commonly with high foreign ion concentrations. Slow growth from dilute solutions yields relatively large, well-ordered, stoichiometric dolomite rhombs with low foreign ion concentrations (Siedlacka, 1972; Browning, 1973; Folk and Land, 1975; Land, Morrow, and Salem, 1975; Pearson, 1973). This suggests that the cryptocrystalline dolomite found in the Raytown laminated carbonate mudstone facies was formed by penecontemporaneous replacement of lime mud by hypersaline brines. Coarser grained, obviously replacive dolomite occurring here and elsewhere in the Iola probably formed during later diagenesis through mixing of water. To summarize, it is likely that dolomite in the Iola is of multiple origin. Further study including X-ray diffractometry, isotopic and elemental analysis is needed to confirm this.

Influence of Meteoric Waters

Longman (1980) recognized four major near-surface diagenetic environments: meteoric vadose; meteoric phreatic; mixing; and marine phreatic zones. The normal sequence of diagenesis of a marine sediment during relative lowering of sea level (regression) would be to move from the marine phreatic zone into zones that are influenced by meteoric water. As Dunham and Olson (1978) and Wilson

(1975, p. 52) state; sediment need not be exposed subaerially in order to be affected by meteoric water, as proximity to areas of recharge is sufficient. Upper Raytown rock, particularly in the northern portion of the study area and in the algal mound tract show evidence of diagenesis involving meteoric water.

Probable caliche in upper Raytown peloidal packstone facies in southwestern Iowa and eastern Nebraska (figure 24F) record mobilization and precipitation of calcium carbonate due to alternation of wet and dry conditions within the meteoric vadose environment (James, 1972; Wilson, 1975, p. 85; Longman, 1980).

Solution or precipitation of calcium carbonate may occur in meteoric water-influenced diagenetic environments, depending on the degree of saturation of pore water. This is graphically illustrated by upper Raytown mound and mound-associated facies in southeastern Kansas. Here, probable solution compaction (Wilson, 1975, p. 78; Winchester, 1977) of skeletal-oolitic grainstones (figure 30E), and leaching of phylloid algal blades followed by partial infilling with geopetal sediment (figure 28D) most likely record solution by water undersaturated with respect to calcium carbonate within the zone of solution (Longman, 1980). In addition, leaching of phylloid algal blades comprising high magnesium calcite and aragonite (probably

prior to complete lithification of the lime mud matrix),
resulted in collapse brecciation of the sediment mass
(figure 27C). Similar solution/collapse fabrics are seen
in Pennsylvanian and Permian algal mound complexes in the
southwestern United States (Toomey, Wilson, and Rezak,
1977). Precipitation of an interlocking mosaic of
centrally-coarsening equant calcite cement from actively
circulating waters saturated with respect to calcite
followed, effectively occluding most void space and
creating the typical sparry algal wackestone fabric.

Submarine Cementation

The term algal sparite was used by Heckel and Cocke
(1969) for portions of mounds consisting of coarsely
crystalline calcite and dolomite. In many of these
sparites, probable former botryoidal aragonite preserved as
fan- to nearly spherical-shaped bodies or botryoids
composed of coarsely-crystalline calcite spar with a ghost
radial structure were recognized by Ravn and Heckel (1978)
and Ravn, Mitchell, Nelson, and Heckel (1978).

A lens-shaped mass of sparite about 30 feet (9 m) long
and 3 feet (1 m) thick and consisting almost entirely of
botryoidal fabric is present in the lower Raytown at
locality KTL in Allen Co. The lens overlies algal
wackestone and is gradational upwards into typical sparry
algal wackestone (figure 41A).

Figure 41. Iola sparite.

    A.   Contact of algal sparite lens with
        underlying algal wackestone at localiy KTL
        in Allen Co., Kansas. Sparite comprises
        dull, cloudy brown calcite crystals (gray);
        rusty-weathering ferroan dolomite patches
        (darker gray); and scattered patches of
        skeletal mudstone to wackestone (white).
        For scale, thickness of sparite visible in
        photograph is approximately 1 ft. (30 cm).

    B.   Slabbed and polished hand specimen of
        sparite from locality KTL in Allen Co.,
        Kansas. Cloudy calcite crystals with
        relict radiating bundles of acicular fibers
        constitute most of sample. Patches of
        skeletal mudstone/wackestone (MUD) are
        rare. Patches comprising coarsely
        crystalline ferroan dolomite with darker
        geopetal silt-sized ferroan dolomite (DOLO)
        are conspicuous. Bar for scale = 5 cm.

In hand specimen (figure 41B), the rock consists predominantly of dull, cloudy brown calcite crystals with conspicuous rusty-weathering patches of dolomite. Within each patch, the lower part consists of dark silt-sized geopetal ferroan dolomite, which is overlain by coarsely-crystalline "baroque" ferroan dolomite. Scattered patches of gray, sparsely fossiliferous mudstone to packstone are distributed throughout the sparry lens.

In thin section, botryoids are composed of a mosaic of large, subequant to elongate calcite crystals that contain and cross-cut dark, linear inclusions outlining relict divergent-radial acicular crystals (figure 42A, B). Where discernible, terminations of acicular crystals are blunt or feathery (figure 43A). The botryoidal growth form, acicular nature, and blunt terminations of relict rays suggest that these were originally botryoidal aragonite later neomorphosed to calcite with retention of microfabric detail (Folk and Assereto, 1976; Ravn and Heckel, 1978; Mazzullo and Cys, 1979). Typical equant blocky calcite spar without divergent-radial inclusions fills void space where botryoids have been broken and offset by fracturing (figure 42C, D).

Preliminary EDAX scans across calcite crystals with abundant divergent-radial inclusions do not indicate the presence of strontium or magnesium-rich mineral phases.

Figure 42. Iola sparite.

A. Photomicrograph of several botryoidal masses. Masses now comprise irregular-shaped calcite crystals that contain relict divergent-radial inclusions. Plane plarized light. Bar for scale = 1 mm. KTL - Iola sparite.

B. Same view as A but with crossed polarizers showing present individual calcite crystals.

C. Broken botryoidal mass (F) with radiating lines of fibrous inclusions plainly visible. Void space around it (white) is filled with typical blocky calcite spar (B). Plane polarized light. Bar for scale = 0.4 mm. KTL - Iola sparite.

D. Same view as C but with crossed polarizers.

E. Ferroan dolomite-filled void space (?) within meshwork of botryoidal masses with relict radiating lines of inclusions (FC). Void is partly filled by geopetal silt-sized ferroan dolomite (GD); with remander of void space filled by white, coarsely-crystalline (baroque) ferroan dolomite (BD). Plane polarized light. Bar for scale = 2 mm. KTL - Iola sparite.

F. Same view as E but with crossed polarizers.
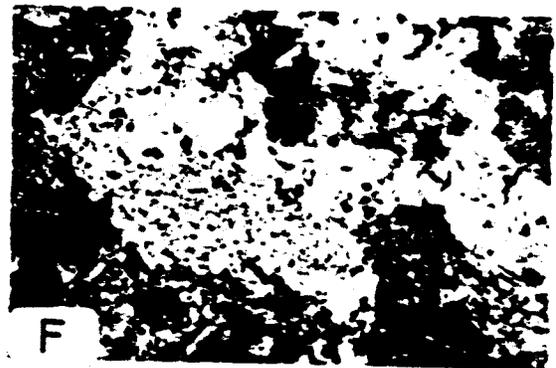
Thus, inclusions may be remnants of organic matter, micrite, or fluid-filled vacuoles caught between precursor acicular crystals (Folk and Assereto, 1976; Mazzulo and Cys, 1979).

Apparent void space of unknown origin among the botryoids was partly filled by geopetal silt-sized dolomite. The remaining upper parts of the voids were later filled by coarsely-crystalline ferroan-dolomite with strongly undulose extinction (figures 42E, F). Close association of white, coarsely-crystalline "baroque" dolomite or traces thereof and botryoidal calcite (former aragonite) have been noted by others, including Davies (1977), Folk and Assereto (ms in preparation; cited by Mazzulo and Cys, 1979), Ravn and Heckel (1978), and Mazzullo and Cys (1979). Folk and Assereto relate the formation of this dolomite to passive precipitation from low-salinity water in cavities; whereas Mazzullo and Cys (1979) cite evidence suggesting that baroque dolomite is a direct replacement of former botryoidal aragonite. In the Iola, presence of geopetal dolomite silt, absence of relict divergent-radial calcite inclusions within dolomite patches, and lack of inheritance of botryoidal crystallographic characteristics all favor an origin by passive precipitation in cavities.

Minor amounts of probable botryoidal aragonite, now preserved as relatively coarsely-crystalline calcite with divergent-radial inclusions, are present elsewhere in the Iola, occurring as: acicular aragonite that is apparently neomorphic after lime mud, similar to Davies' (1977) "spherulitic calcite" (figure 43C, D); and small fans growing outward from walls and ceilings of sheltered cavities (figure 43A, E, F).

In addition, previously described "spar-fingers" radiating outward from vaguely mottled areas (figure 28F, G) are apparently neomorphic after lime mud. They comprise small, blocky calcite spar and minor silt-sized, non-ferroan dolomite rhombs. Although no divergent-radial inclusions are present, their external morphology is reminiscent of acicular aragonite (figure 28G).

Why retention of original acicular aragonitic fabric would occur at one locality whereas dissolution/reprecipitation would occur at another is enigmatic. Folk and Assereto (1976) and Mazzullo and Cys (1979) tentatively address the question of fabric retention of former aragonite now neomorphosed to calcite. They suggest that aragonite paramorphism may occur as a consequence of low fluid flow rate due to pervasive synsedimentary cementation in a geochemical environment with intermediate pH and Mg:Ca ratio.

Figure 43.   Iola sparite.

A.   Photomicrograph of botryoidal mass illustrating square to feathery tips of acicular crystals (small arrow). Plane polarized light. Bar for scale = 0.25 mm. Avant Limestone.

B.   Photomicrograph of upward-growing, fan-shaped, void-filling mass with radiating ghosts of original fibrous mineral precursor (aragonite?) visible. Darker concentric curved surfaces within cement mass probably define growth lines. Plane polarized light. Bar for scale = 0.5 mm. Avant Limestone.

C.   Botryoidal mass with radiating relict fibrous mineral precursors growing into and apparently replacing lime mud matrix material ("spherulitic calcite" of Davies, 1977). Plane polarized light. Bar for scale = 0.4 mm. Avant Limestone.

D.   Photomicrograph of spherical-shaped mass with calcitized fibrous mineral precursors radiating outward from central point. Mass has apparently grown in and replaced lime mud matrix. Plane polarized light. Bar for scale = 0.4 mm. Refer to Figure 60 for location of sample in section. QPA - Middle Limestone - top sample.

E.   Fan-shaped cement mass within void space in laminar foraminifer/red algal intergrowth. Radiating relicts of original (now calcitized) fibrous mineral precursor are recognizable. Plane polarized light. Bar for scale = 0.4 mm. Refer to Figure 59 for location of sample in section. K32 - Paola - 2.

F.   Detail of radiating relict fibrous mineral precursor in void space in laminar foraminifer/red algal intergrowth. Bar for scale = 0.1 mm. Plane polarized light. Refer to Figure 59 for location of sample in section. K32 - Paola - 2.
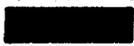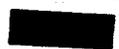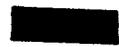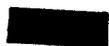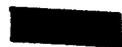
Ginsburg and James (1976), Davies (1977), and Mazzullo and Cys (1977, 1979) note occurrences of botryoidal aragonite in organic buildups near shelf-basin margins. In addition, Ravn and Heckel (1978) remark that with the exception of the Iola sparite, best development of neomorphosed botryoidal aragonite in Pennsylvanian rocks in the northern Midcontinent is found in algal mounds facing a topographically lower detrital basin. Why the Iola is an apparent exception to this generalization is not known.

CHAPTER V

CONODONT DISTRIBUTION

Although vertical variation in associations of
Pennsylvanian conodonts is fairly well documented in places
in the Midcontinent (Merrill, 1973; Heckel and Baesemann,
1975), the degree of lateral variation over relatively long
distances in the same stratigraphic unit is little known
except for the Stanton Limestone (Wood, 1977).
Availability of adequate study material from throughout the
outcrop of the Iola Limestone (figure 44), make this unit
ideal for this type of study.

Purpose and Scope

The purpose of this portion of the study is to
document conodont distribution in the Iola Limestone and
adjacent units on a reconnaissance level and relate
distribution to depositional environments as interpreted
from stratigraphic relationships and lithology.

It must be emphasized that this is neither an
exhaustive taxonomic study nor a greatly detailed
documentation of conodont distribution, but rather a study
designed to detect general vertical and lateral trends in
the distribution and abundance of certain key taxa.

Figure 44. Generalized cross-section of Iola Limestone and
adjacent units giving total abundance of all
conodont taxa. Dots show approximate sample
location within each section; those with no
numbers represent barren samples. Refer to
Appendix A or B for location codes. Except for
Aethotaxis advena, _Idioprioniodus typus_ and
Stepanovites conflexa, only platform elements
are included in abundance counts. For these
three exceptions, recorded abundance is that of
the most common element within a sample. 500-
gram samples were collected from all localities
except for NEB, MAL, and BED; conodont
abundances for these three locations are
extrapolated for a 500-gram sample, actual
abundances are recorded for all other
localities.

Figure 44.
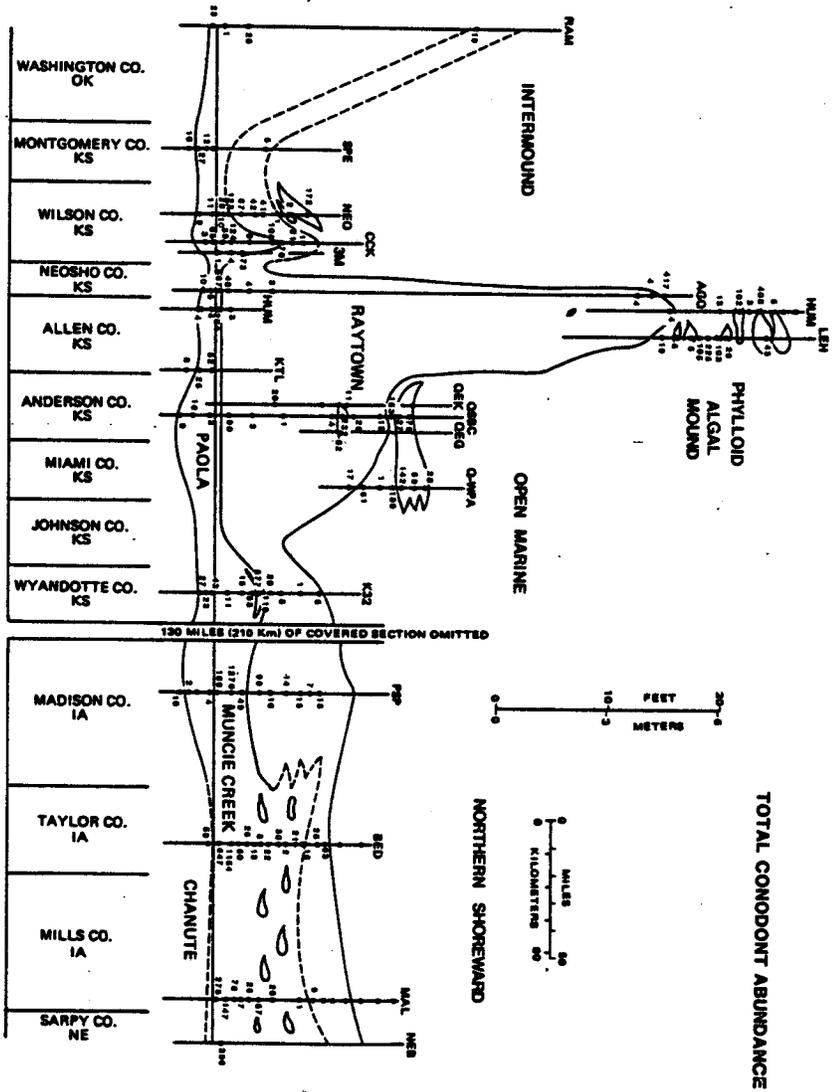
Figure 44.

Method of Study

Standard spot samples of Iola Limestone and adjacent units were collected from outcrop and cores. Figure 44 shows sections sampled and approximate locations of samples within a section. Sample lithology, size, and exact location information is given in Appendix B.

Carbonate samples were processed by digestion in a ten-percent solution of formic acid for 24 hours. Non-black shales were oven-dried and then disaggregated by immersion for one day in Stoddard's solvent, followed by three to five days immersion in water.

The technique used for processing fissile black shales that are rich in organic matter is more involved and time-consuming, usually taking from one to two months to complete. Samples were soaked in a five-percent solution of sodium hypoclorate ("Clorox") for three to five days, and then thoroughly rinsed with water. This process was repeated until the shale did not further break down.

All residues were wet-sieved using standard 120 and 230-mesh screens. Residues recovered from the 120-mesh screen were thoroughly picked for conodonts. Residues from the 230-mesh screen were scanned and occasionally picked. Heavy liquid separation (tetrabromoethane) was used to reduce the size of large residues.

Taxa identified in this study include those recognized and discussed by Baesemann (1973), Wood (1977), Merrill and Martin (1976), and Swade (1977), namely: Adetognathus lautus (= Cavusgnathus of others), Aethotaxis advena, Anchignathodus minutus (= Ozarkodina minuta of some previous authors), Anchignathodus? sp. A, Diplognathodus sp., Idiognathodus spp. (including Streptognathodus of others), Idioprioniodus typus, Gondolella bella, and Stepanovites conflexa. Although great morphological variation in Idiognathodus exists, as discussed in detail by Merrill (1975), Merrill and Martin (1976), Wood (1977), and Baesemann (1973), no attempt was made to subdivide Idiognathodus into species due to this worker's lack of expertise and the extremely gradational nature of the forms involved.

Except for Idioprioniodus typus, Stepanovites conflexa, and Aethotaxis advena, only platform elements were identified and included in abundance counts. For the above three exceptions, recorded abundance is that of the most common element within a sample.

Distribution and abundance data is visually presented as simplified cross-sections showing vertical and lateral variation along the Iola outcrop (figures 46 through 54), and as charts summarizing sample lithology, size, and

abundance and diversity data for all conodont taxa at a particular location (see Appendix B).

For ease of communication, the following terms are used to categorize conodont abundance per half-kilogram in the Iola cyclothem: absent = 0 specimens; rare = 1 to 5; frequent = 6 to 15; common = 16 to 50; abundant = 51 to 250; and very abundant = more than 250 specimens. All specimens identified in this study are reposited at the Department of Geology, The University of Iowa, Iowa City, Iowa 52242.

Previous Work

A large body of work on the distribution and paleoecologic significance of Pennsylvanian conodonts in the central United States has been generated since the mid 1960s. Although there is a general agreement as to the existence of distinct conodont biofacies, the significance of certain assemblages, particularly those associated with black shales, remains controversial. Pertinent work is summarized below.

Midcontinent

Heckel and Baesemann (1975) analyzed conodont distribution and abundance data compiled by Baesemann (1973) with respect to stratigraphic sequence and

depositional environment for Missourian cyclothems in eastern Kansas. Their conclusions follow:

1. Outside (nearshore) shales are characterized by low abundance and diversity with one genus dominant, generally Adetognathus, occasionally Idiognathodus.

2. Middle (transgressive) limestone members show upward-increasing conodont abundance and diversity. Adetognathus or Anchignathodus (= Ozarkodina of authors) is dominant at the base of the middle limestone, passing upwards to Idiognathodus dominance and frequently abundance.

3. Core (offshore) shale members and in many cases adjacent portions of middle and upper limestones are characterized by high conodont abundance and diversity with strong Idiognathodus abundance and the nearly exclusive presence of Gondolella and Idioprioniodus.

4. Upper (regressive) limestone members are characterized by upward-decreasing conodont abundance, with Idiognathodus dominant at the base; grading upward through mixed Idiognathodus, Adetognathus, Anchignathodus, and Aethotaxis abundance.

5. Trends in conodont abundance, diversity, and dominance in the two limestone members are essentially mirror images of one another. Conodont faunas in these limestones are transitional to the two starkly contrasting associations seen in the outside and core shales. Conodont distribution

and relative abundance throughout an idealized "Kansas" cyclothem are summarized in figure 3.

Swade (1977) documented conodont distribution in the Cherokee and Marmaton Groups of Iowa. His study shows that: _Idiognathodus_ and _Diplognathodus_ are ubiquitous; _Gondolella_ is present only in certain black (offshore) shales; _Idioprioniodus_ is most abundant in core shales, with decreased abundance in adjacent limestones and shales; regressive limestones contain _Anchignathodus_ _minutus_ and _Aethotaxis_, both of which are absent in core shales. _Idiognathodus_ and _Adetognathus_ are present, though infrequent, in overlying outside (nearshore) shales. _Anchignathodus_ _minutus_, _Aethotaxis_, and _Stepanovites_ are present in association with _Idiognathodus_ and _Adetognathus_ in limestones developed at the top of the regressive sequence.

Heckel and Swade (1977) compared conodont faunas obtained from two types of black shale facies in the Upper Pennsylvanian of eastern Kansas: 1) laterally persistent phosphatic core shale sandwiched between two marine limestones; and 2) discontinuous lenses in outside shales associated with coal and interbedded with non-fossiliferous gray shales. The core shale, regarded as an offshore deposit by Heckel and Swade, contains an abundant conodont fauna that is dominated by _Idiognathodus_, _Idioprioniodus_,

and _Gondolella_. The other black shale facies, interpreted as a nearshore deposit, yields sparse, fragmentary specimens of _Adetognathus_ and _Idiognathodus_.

Wood (1977), summarized in Wood and Heckel (1977), examined lateral and vertical variation in conodont distribution throughout the terrigenous detrital and phylloid algal mound facies belts of the Stanton Limestone (upper Missourian) of southeast Kansas. Wood's study shows that at least for the Stanton, vertical variation in distribution and abundance far outweighs lateral change. Basic distribution patterns in the Stanton in southeastern Kansas are similar to those noted by Heckel and Baesemann (1975) in the Stanton in the open marine facies belt of northeastern Kansas and strongly support their and Heckel's (1977) interpretation of the cyclic sequence.

Von Bitter (1972), examined conodont distribution in Shawnee (lower Virgillian) cyclothems. Relative abundance plots of _Idiognathodus_ and _Streptognathodus_ versus _Cavusgnathus_ (= _Adetognathus_ of Heckel and Baesemann), show that _Idiognathodus_ and _Streptognathodus_ dominate the core shales and adjacent portions of the upper and middle limestones. _Cavusgnathus_ abundance increases upward through overlying limestones and shales, and downward through subjacent limestones and shales. _Idioprioniodus_ and _Gondolella_ are never common, and occurrences are

restricted only to certain core shales. Von Bitter
interpreted rocks with abundant _Cavusgnathus_ as having
formed under nearshore, marginal marine conditions.
Streptognathodus and _Idiognathodus_ on the other hand, are
predominant in limestones that von Bitter interpreted as
normal marine deposits. Unlike Heckel (1977), von Bitter
regarded outside _and_ core shales as nearshore, marginal-
marine deposits in spite of the fact that core shales:
1) are dominated by _Idiognathodus_ and _Streptognathodus_,
taxa strongly associated with what von Bitter regards as
open marine deposits; 2) contain _Gondolella_ and
Idioprioniodus, taxa not found in the outside shales; 3)
are often lithologically distinct (black and fissile) from
the outside shales. Von Bitter did not offer an
explanation for these anomalies, but since then he (von
Bitter and Heckel, 1978), has accepted the possibility that
the core shales are offshore deposits.

Illinois and Appalachian Basins

Merrill and Martin (1976) identified five conodont
associations in the Missourian La Salle Limestone in
northern Illinois, namely: _Cavusgnathus_; _Aethotaxis_;
Idioprioniodus; _Gondolella_; and
Idiognathodus/_Streptognathodus_ biofacies. With the
exception of the ubiquitous _Idiognathodus_/_Streptognathodus_
biofacies, mixing of biofacies is limited; only

associations of _Cavusgnathus_ and _Aethotaxis_, _Aethotaxis_ and
Idioprioniodus, and _Idioprioniodus_ and _Gondolella_ are
fairly common.

Merrill (1973, 1975) recognized similar sharply
differentiated conodont biofacies in the Appalachian Basin,
and in Desmoinesian strata in the Illinois Basin. Merrill
and von Bitter (1976) summarized conodont distribution in
the Midcontinent, Illinois Basin and Appalachian Basin
(figure 45).

Although conodont distributions and associations
recognized by Merrill and his fellow workers are
essentially identical with those recognized by Heckel and
his fellow workers, interpretation of environment of
deposition of biofacies that are associated with the black
shales is not. According to Heckel (1977), _Gondolella_ and
Idioprioniodus thrived in deep water during maximum
transgression at which time the sea bottom was subject to
inflow of low-oxygen water currents at the base of a quasi-
estuarine circulation cell. Merrill, on the other hand,
concluded that black shales with _Idioprioniodus_ and
Gondolella represent shallow-water, shoreline deposits that
accumulated beneath an algal flotant that prevented bottom
oxygenation.

It is significant to note that _Gondolella_ is absent
and _Idioprioniodus_ scarce throughout the Appalachian region

Figure 45. Summary of conodont distribution and relative
abundance in Applachian Basin, Illinois Basin,
and Midcontinent. Abbreviations are as
follows: AE = Aethotaxis; CV = Cavusgnathus,
(= Adetognathus of this study);
GN = Gondolella; IG = Idiognathodus,
(= Idiognathodus spp. of this study);
SR = Streptognathodus, (= Idiognathodus spp.
of this study). Approximate abundance is
represented by width of black block. Standard
lithologic symbols are used. Adapted from
Merrill and von Bitter, 1976, Figure 4.

Figure 45.

MIDCONTINENT   ILLINOIS BASIN   APPALACHIANS
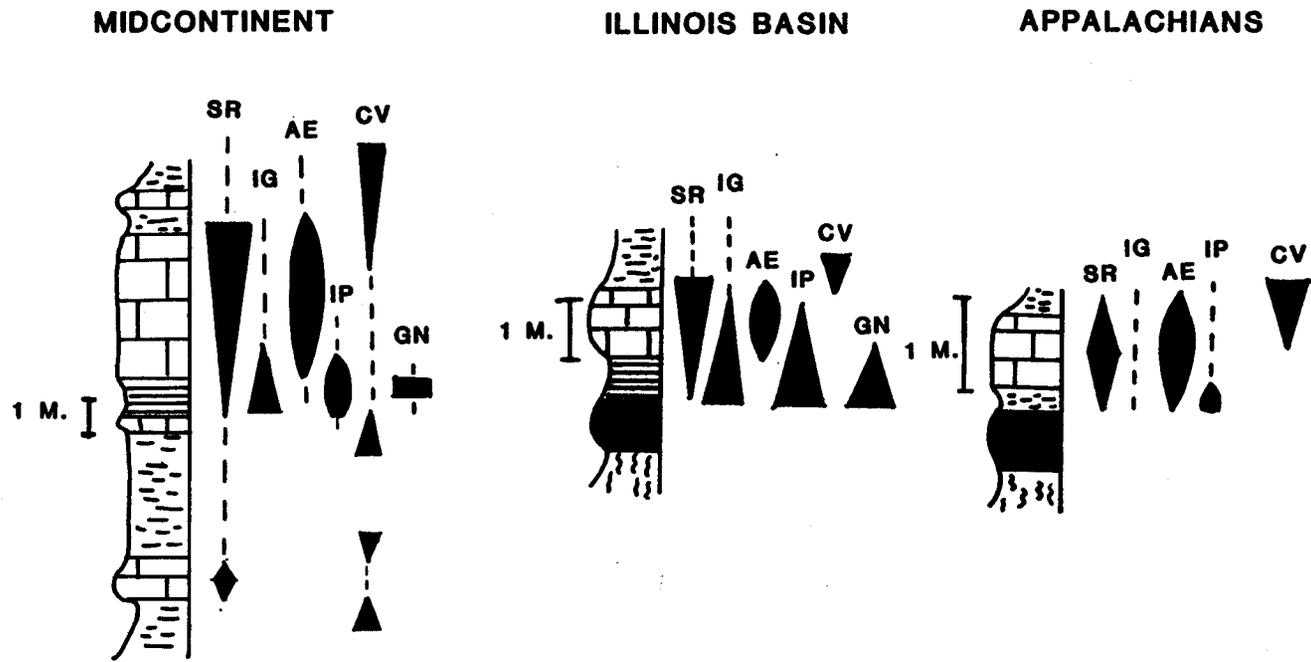
FROM MERRILL AND VON BITTER (1976)

(Merrill, 1973; Merrill and von Bitter, 1976). According
to Heckel and Baesemann (1975), this is explained by
dominance of shallow-water conditions during marine
incursions in the Appalachian Basin. Conditions favorable
for Idioprioniodus were established infrequently, and only
in limited areas. Conditions suitable for Gondolella were
never established. This interpretation is supported by
Donahue and Rollins (1974), who showed much shallow-water,
dark-colored shale, but recognized only four extensive
open-marine horizons in Missourian-equivalent strata in the
Appalachian Basin. If Gondolella and Idioprioniodus were
indeed inhabitants of shallow shoreline environments, then
one would expect their occurrence to be much more common in
the Appalachian Basin than in the Midcontinent.

Examination of stratigraphic sections (Merrill and
Martin, 1976; figures 2 and 3), reveal that the most
distinctive and laterally continuous stratigraphic unit in
the La Salle is a black fissile shale. This unit is
"sandwiched" between gray shales that serve to separate it
from overlying locally algal-rich limestones and a
subjacent coal. According to Merrill and Martin, this
black shale is the only unit that maintains definite
integrity and continuity throughout the study area.
Associated limestones and shales thin and pinch out to the
east. The greatest amount of lateral change occurs in the

upper portion of the limestone unit. This is the expected case for shallow-water deposition, where minor differences in bottom topography would result in distinctly different, laterally gradational facies. In contrast, the black shale shows the least lateral change. This is the expected case for sedimentation in deeper waters, where changes in bottom topography would have little effect on sedimentation, (Heckel, 1977, p. 1053).

Merrill and Martin rejected a deep water origin for the black shale and insisted that the unit was deposited in an extremely shallow, low-energy, low-pH, "lagoonal" environment. Following Zangerl and Richardson (1963), Merrill and Martin invoked the existence of an enigmatic, widespread algal "flotant" to account for the necessary restriction of circulation and high organic matter content.

Evidence cited by Merrill and Martin as proof of shallow water origin of the black shale facies includes: "black shale ... also lies directly above an autochthonous coal and cannot possibly be interpreted as being of deep-water origin." This statement is in direct contradiction with evidence presented by the authors (Merrill and Martin, 1976, figure 2), in which the black shale is shown as being separated from the coal by up to one meter of gray shale. As discussed in a previous section, the absence of an intervening marine limestone in a cyclothem may be due to

insufficient carbonate production before water depth became
too great for effective algal production, either due to
proximity of depositional substrate to the inundated coal
swamp, or perhaps in this case because of continued
detrital influx during transgression as suggested by the
gray shale between the coal and the black shale.

Distribution of Taxa
throughout the Iola Cyclothem

Chanute Shale

Four samples were collected and processed from the
Chanute Shale; one each from the northern shoreward, open
marine, phylloid algal mound, and intermound facies belts,
(figure 44). Baesemann (1973) provides additional
distribution and abundance data for Chanute samples
collected from the Kansas City area.

Idiognathodus spp., Anchignathodus minutus and
Adetognathus lautus were recovered from samples processed
by this author. In addition, Baesemann (1973) recovered
rare Idioprioniodus and Gondolella from samples of upper
and lower Chanute, respectively. As noted by Heckel and
Baesemann (1975), the presence of Gondolella in this part
of a Missourian cyclothem is anomalous and may be the
result of contamination from the overlying Muncie Creek
Shale. More recent analysis of a sample of basal Chanute

from Baesemann's 1973 section yielded no _Gondolella_
(P.H. Heckel, personal communication, 1981).

Idiognathodus spp. is abundant, and dominates the
sample collected at the top in the northern shoreward
facies belt. _Anchignathodus minutus_ and _Adetognathus_
lautus are rare but present. In all other samples of the
Chanute, _Adetognathus lautus_ is rare to common, with
abundance equal to or greater than that of _Idiognathodus_
spp.

In general, the Chanute Shale is characterized by low
abundance and diversity with one taxa dominant; usually
Adetognathus lautus. Overall abundance appears to increase
northward along the outcrop, probably reflecting less
dilution by terrigenous detrital influx; however, this
observation is tenuous due to the small number of samples
studied.

Paola Limestone

A total of twenty three samples of the Paola Limestone
were collected and processed from throughout the study area
(figure 44). In general, there is an increase in conodont
abundance and diversity upwards through the Paola. Rare to
frequent _Adetognathus lautus_ and rare _Stepanovites conflexa_
are restricted to the lower Paola. Rare to abundant
Idiognathodus spp. and rare to frequent _Anchignathodus_
minutus are ubiquitous. Abundance of _Idiognathodus_ spp.

generally increases upward through the Paola,
Idioprioniodus typus and Gondolella bella are rare,
occurring in association with one another only in samples
of Paola adjacent to the overlying Muncie Creek Shale.
Diversity and abundance is markedly lower in Paola samples
collected from Iowa (locality PSP, figure 58); here,
Idiognathodus spp. is rare and is the only taxa present.

Muncie Creek Shale

Thirty three samples of Muncie Creek Shale were
collected and processed from throughout the study area
(figure 44). Although samples from other members of the
Iola cyclothem show high abundance or high diversity, the
Muncie Creek is unique in that it consistently exhibits
both high abundance and high diversity. At locations where
both black and gray shale facies are present, maximum
abundance generally occurs in the black facies. Maximum
diversity may occur in either facies.

Idiognathodus spp. is rare to very abundant and is
present in all Muncie Creek samples. At those localities
where both black and gray shale facies are present, its
maximum abundance is found in the black shale. Gondolella
bella is rare to very abundant, and Idioprioniodus typus is
rare to abundant; they were recovered from 11 and 26
samples, respectively. Maximum numbers of these two taxa
were recovered from black, fissile shale, where both black

and gray shale facies are present. Gondolella bella abundance shows a marked decrease in underlying and overlying non-black Muncie Creek; abundance of Idioprioniodus typus likewise decreases, but not nearly as markedly. Anchignathodus minutus is rare to abundant, with scattered occurrences in both black and gray facies of the Muncie Creek (7 samples). Diplognathodus sp. is rare to frequent and Anchignathodus? sp. A is rare; occurring in 2 and 3 samples, respectively. Adetognathus lautus is rare, occurring in one sample of gray, non-phosphatic shale that immediately overlies the Paola Limestone at locality NEO, (figures 46 and 76).

Several trends in lateral distribution are recognized in the Muncie Creek.

1. Gondolella bella is most abundant in the northern localities and shows decreasing abundance across open marine and algal mound belts to only scattered occurrences toward the southern terrigenous detrital source, (figure 51).

2. Anchignathodus minutus also shows a northward increase in abundance. Maximum numbers are recovered from the northern portion of the open marine facies belt and the more seaward portion of the northern shoreward facies belt, (figure 49).

3. _Idioprioniodus_ _typus_ is most abundant in the northern portion of the study area. Although abundance gradually decreases southward (figure 53), it is locally common in samples of thick Muncie Creek from eastern Wilson Co., Kansas.

4. Occurrences of _Anchignathodus_? sp. A and _Diplognathodus_ sp. in the Muncie Creek are restricted to the northern portion of the study area, (figures 48 and 50).

5. No lateral variation in the abundance of _Idiognathodus_ spp. is discernible, (figure 52).

Raytown Limestone

Eighty samples of the Raytown Member were collected and processed from throughout the study area, (figure 44). For purposes of the following discussion, the Raytown is informally split into lower and upper portions.

Lower Raytown

Throughout the study area, the lower Raytown is characterized by high abundance and diversity of conodonts. Skeletal wackestone and packstone constitute most samples; non-abraded skeletal grainstone, shale, and fine-grained sandstone were also processed.

Rare to very abundant _Idiognathodus_ spp. dominates the fauna, occurring in association with rare to abundant _Idioprioniodus_ _typus_, rare to frequent _Anchignathodus_

minutus, rare _Diplognathodus_ sp., and rare _Adetognathus_ _lautus_. _Gondolella_ _bella_ was not recovered from samples processed by this author; however Heckel and Baesemann (1975, p. 492), report the presence of rare to common _Gondolella_ spp. in samples of lower Raytown from the Kansas City area.

Upper Raytown

Conodont distribution in the informal upper Raytown is discussed for northern, central, and southern portions of the study area, these comprise southwestern Iowa, southeastern Kansas northwards to south central Iowa, and the Kansas-Oklahoma border region, respectively.

Upper Raytown - North

Shoal-water skeletal calcarenite and shoreline calcilutite constitute the upper Raytown throughout the northern portion of the study area. Rare to frequent _Idiognathodus_ spp., rare _Adetognathus_ _lautus_, _Anchignathodus_ _minutus_, and _Stepanovites_ _conflexa_ constitute the fauna recovered from shoal-water calcarenites, (2 samples). Five of the six samples of shoreline calcilutite were barren; one sample of peloidal carbonate packstone (locality BED) yielded abundant _Idiognathodus_ spp., frequent _Anchignathodus_ _minutus_, and rare _Adetognathus_ _lautus_.

Upper Raytown - Central

The upper Raytown is divided into several informal stratigraphic/lithologic units throughout the central portion of the study area: main Raytown ledge, including normal marine wackestone and packstone facies, algal mound facies, and shales within the mound; and mound-associated facies including mound-top, Bush City, Bassett, and Owl Creek beds.

Main Raytown Ledge.-- Fairly high diversity and low abundance characterize most samples of normal marine and algal mound facies from the main Raytown ledge. *Idiognathodus* spp. is rare to common, *Diplognathodus* sp. is rare to frequent, and *Anchignathodus minutus*, *Aethotaxis advena*, and *Idioprioniodus typus* are rare. In general, conodont abundance decreases upwards throughout this portion of the Raytown, although abundant *Idiognathodus* spp. and frequent *Idioprioniodus typus* were recovered from 2 samples of gray shale from a thin lens within the upper portion of the main Raytown ledge in Anderson Co., Kansas. Sparseness of conodonts within the algal mound facies is most likely a reflection of dilution by abundant algal production of carbonate sediment.

Mound-Top and Mound-Associated Facies.-- Raytown mound-top and mound-associated facies reflect increased detrital

influx and local shoal-water conditions. Lithologies of
samples include marine shales, encrusted-grain skeletal
wackestone (Bush City and Bassett beds), and skeletal-
oolitic packstone to grainstone (Owl Creek and mound-top
beds).

In samples processed from the mound-top, Bassett, and
Owl Creek beds, Idiognathodus spp. is rare to very
abundant, occurring with rare Anchignathodus minutus and
Adetognathus lautus. Most samples from these beds exhibit
conodont abundances that are nearly equal to those of the
cyclothem "core". Diversity however, is lower here than in
the core of the Iola cyclothem.

The extremely high abundance of conodonts in the Owl
Creek beds, Bassett beds, and associated shales suggest the
possibility that these "mound-associated" facies are
actually a southern extension of the overlying Wyandotte
Limestone; shale samples with upwards of 223 conodonts per
half-kilogram sample (figure 44) may actually represent the
core shale of the Wyandotte cyclothem. The fact that
Gondolella and Idioprioniodus were not recovered from these
samples is not overly troublesome, since Heckel and
Baesemann (1975) report that Gondolella is absent and
Idioprioniodus very rare in samples of the Wyandotte from
northeastern Kansas. Arguments against this suggestion,
however, include: 1) most specimens from these samples

appear size-sorted and somewhat worn, 2) relatively high abundance is known elsewhere from samples of the upper Raytown, 3) high conodont abundance in upper portions of regressive limestones is recognized in other Pennsylvanian cyclothems in the Midcontinent (J.W. Swade, personal communication, 1981).

Idiognathodus spp. is rare to abundant and is the dominant taxon recovered from the Bush City bed and subjacent shale in Anderson and Miami Counties, Kansas. It occurs with rare to frequent *Anchignathodus minutus* and isolated occurrences of rare *Idioprioniodus typus*, *Adetognathus lautus*, *Aethotaxis advena*, *Stepanovites conflexa* and *Diplognathodus* sp.

Upper Raytown - South

Raytown (Avant in Oklahoma) lithologies sampled south of the algal mound tract include marine shale, silty sandstone, and skeletal wackestone, packstone, and grainstone. *Idiognathodus* spp. dominates the fauna and is rare to abundant. *Adetognathus lautus* and *Anchignathodus minutus* are rare and occur scattered throughout the Raytown. *Stepanovites conflexa* is rare, and was recovered only from upper Raytown encrusted-grain skeletal grainstone at locality NEO in eastern Wilson Co., Kansas. *Idioprioniodus typus* is rare and was recovered from silty sandstones at the base in eastern Wilson Co., Kansas.

Lane Shale

Seven samples of the lower Lane Shale (and Lane-Bonner Springs Shale) were collected and processed for conodonts, (figure 44). Two samples were collected from the phylloid algal mound belt, and the remainder are from the northern shoreward facies belt. No conodonts or fragments of conodonts were recovered from any sample. Baesemann (1973) did not sample the lower portion of the Lane, but did recover a few specimens of Idiognathodus spp. from the uppermost Lane Shale in Wyandotte Co., Kansas. The absence or scarcity of conodonts in the Lane Shale probably reflects overwhelming detrital dilution.

Distribution of Individual Taxa

Adetognathus lautus

Adetognathus lautus is present in 25 samples, occurring in low numbers throughout portions of the Iola and in the top of the subjacent Chanute Shale in all facies belts (figure 46). Specimens were recovered from skeletal wackestone and packstone, skeletal-oolitic grainstone, fine-grained sandstone, and gray shale.

It is most common in upper Chanute Shale and basal Paola Limestone, but is also present in shale overlying the main part of the Raytown Limestone in the southern portion of the open marine facies belt. A few isolated specimens

Figure 46. Generalized cross-section of Iola Limestone and adjacent units with abundance and distribution data for _Adetognathus_ _lautus_. Only platform elements are included in abundance counts. Dots show approximate sample location within each section. Recorded abundances are actual. Nonstandard sample sizes were collected from localities NEB, MAL, and BED; standard 500-gram samples were collected from all other sections. Location codes, exact sample size, and sample location are given in Appendix B.

Figure 46.

Adetognathus lautus

189
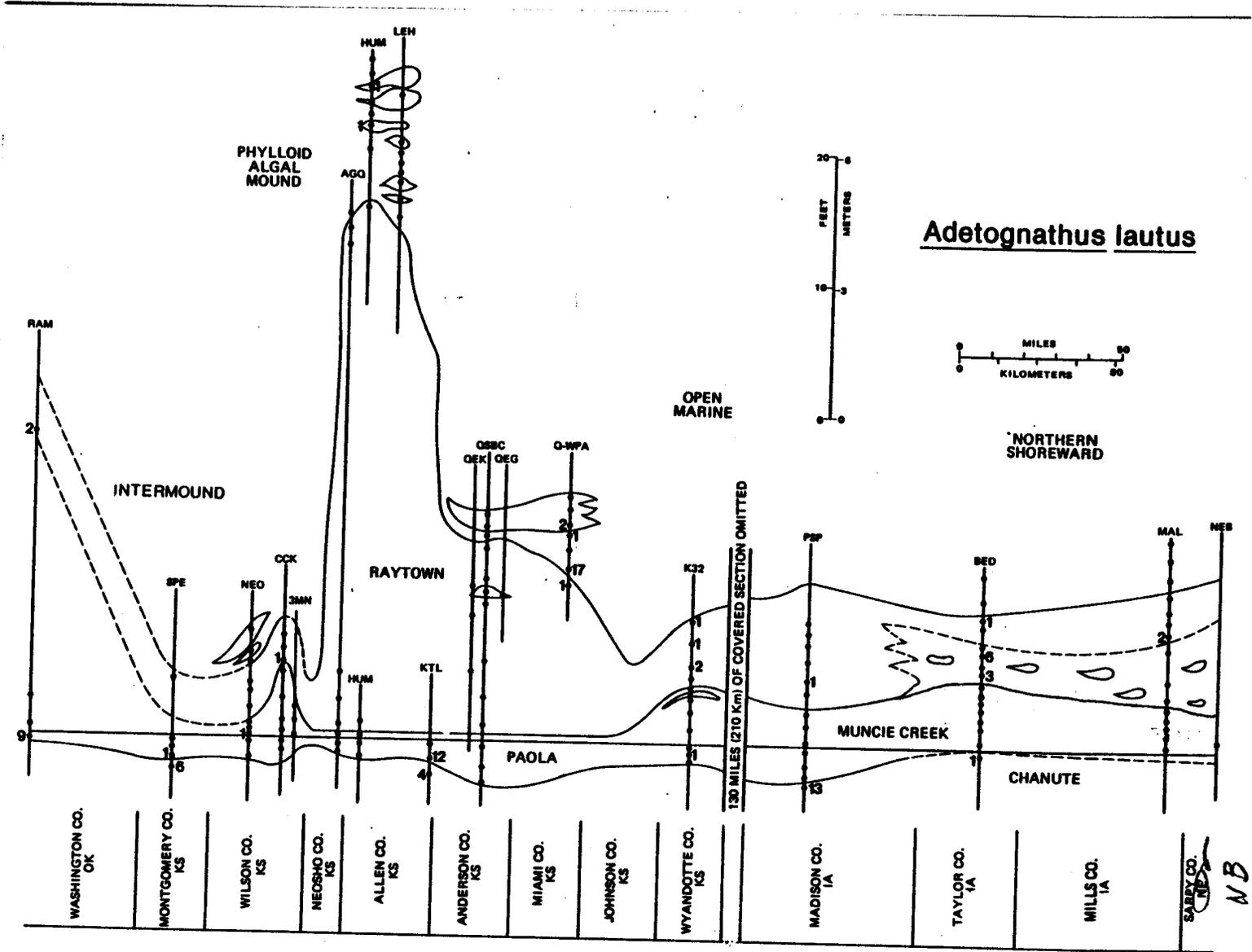
of _Adetognathus_ _lautus_ were recovered from shoal-water,
mound-associated facies in the phylloid algal mound
complex, and from Raytown shales and limestones elsewhere,
particularly in the Kansas City area and Iowa. One
specimen was recovered from gray, non-phosphatic Muncie
Creek Shale south of the mound tract in Wilson Co., Kansas.

Adetognathus _lautus_ frequently occurs with _Idiognathodus_
spp. and _Anchignathodus_ _minutus_ (in 19 and 13 samples,
respectively). It is less frequently found with
Idioprioniodus _typus_ (8 samples), and rarely occurs with
Stepanovites _conflexa_, _Gondolella_ _bella_ or _Diplognathodus_
sp. (only 1 sample each).

Where it is most common (basal Paola and upper
Chanute), _Adetognathus_ _lautus_ is the dominant element of
the fauna, with abundance equal to or greater than that of
Idiognathodus spp. No lateral variation in abundance or
association is recognized.

Aethotaxis _advena_

Aethotaxis _advena_ is rare, and was recovered from only
three samples in northeastern Kansas and south central Iowa
(figure 47). It is restricted to upper Raytown skeletal
wackestone. _Aethotaxis_ _advena_ is found in association with
rare to frequent _Idiognathodus_ spp. (3 samples), rare
Anchignathodus _minutus_ (3 samples), and rare _Diplognathodus_
sp. (1 sample).

Figure 47. Generalized cross-section of Iola Limestone and
adjacent units with abundance and distribution
data for <u>Aethotaxis</u> <u>advena</u>. Recorded abundance
is that of the most common element from each
sample. Dots show approximate sample location
within each section. Recorded abundances for
each sample are actual. Nonstandard sample
sizes were collected from localities NEB, MAL,
and BED; standard 500-gram samples were
collected from all other sections. Location
codes, exact sample sizes, and sample locations
are given in Appendix B.

Figure 47.

Aethotaxis advena

PHYLLOID ALGAL MOUND

OPEN MARINE

NORTHERN SHOREWARD

INTERMOUND

RAYTOWN

MUNCIE CREEK

PAOLA

CHANUTE
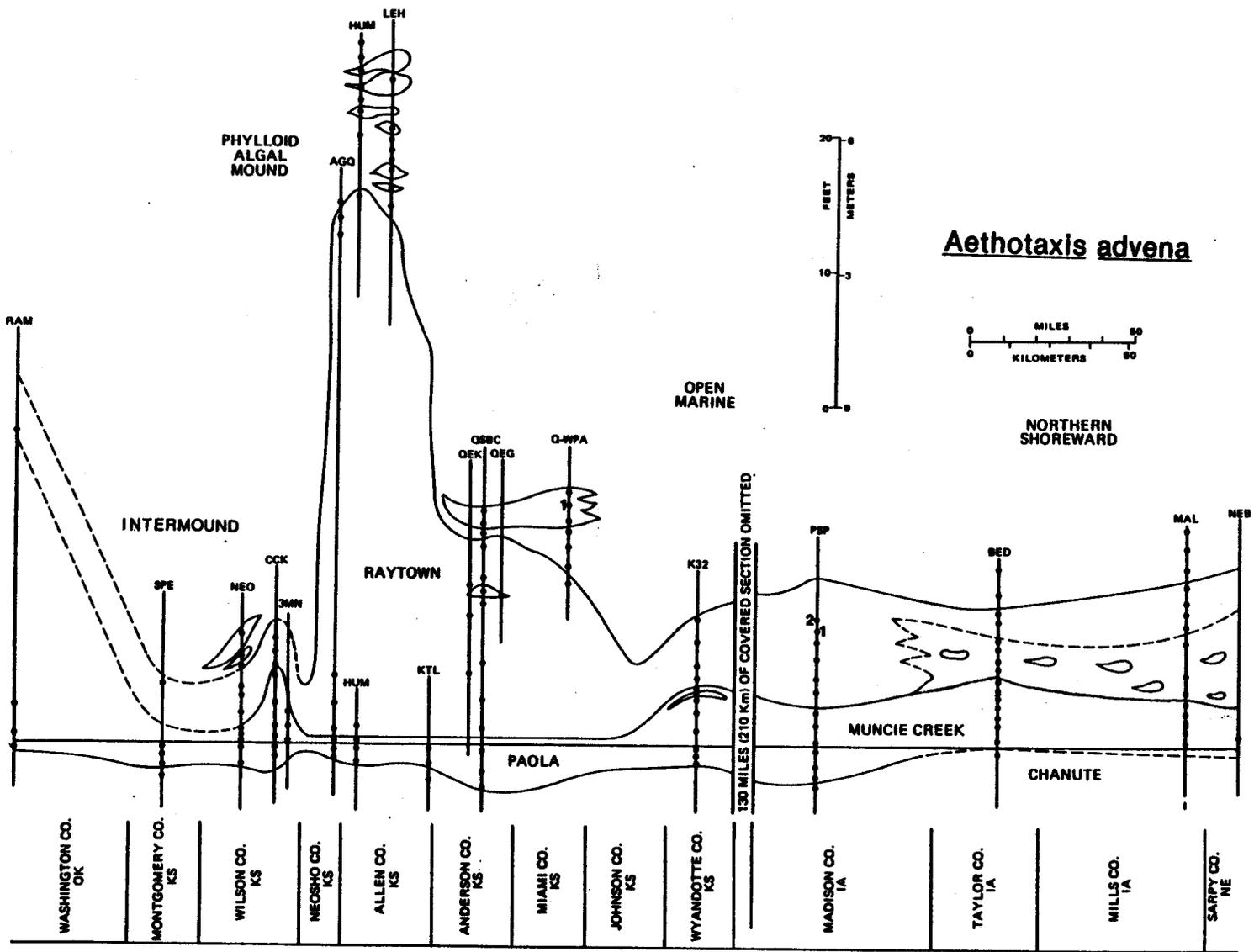
Anchignathodus? sp. A

Anchignathodus? sp. A is rare, and was recovered from three samples in Iowa, where it is restricted to black fissile and gray shales of the Muncie Creek (figure 48). Anchignathodus? sp. A was found with common to very abundant Idiognathodus spp. (3 samples), frequent to very abundant Gondolella bella (3 samples), rare to abundant Anchignathodus minutus (2 samples), rare to abundant Idioprioniodus typus (3 samples), and rare Diplognathodus sp. (1 sample).

Anchignathodus minutus

Rare to abundant Anchignathodus minutus is present in 44 samples. It occurs in all facies belts and was recovered from all three members of the Iola as well as one sample of upper Chanute Shale (figure 49). Lithologies that yielded Anchignathodus minutus are: black fissile shale, gray shale, skeletal packstone, wackestone and grainstone. Although it is fairly widely distributed throughout all members, Anchignathodus minutus is most abundant in the Muncie Creek Shale in south-central Iowa. It is found in association with rare to very abundant Gondolella bella (6 samples) and Idiognathodus spp. (44 samples), rare to abundant Idioprioniodus typus (14 samples), rare to common Adetognathus lautus (13 samples), rare to frequent Diplognathodus sp.

Figure 48. Generalized cross-section of Iola Limestone and
adjacent units with abundance and distribution
data for _Anchignathodus_? sp. A. Only platform
elements are included in abundance counts.
Dots show approximate sample location within
each section. Recorded abundances for all
samples are actual. Nonstandard samples sizes
were collected from localities NEB, MAL, and
BED; standard 500-gram samples were collected
from all other sections. Location codes, exact
sample size, and sample location are given in
Appendix B.

Figure 48.
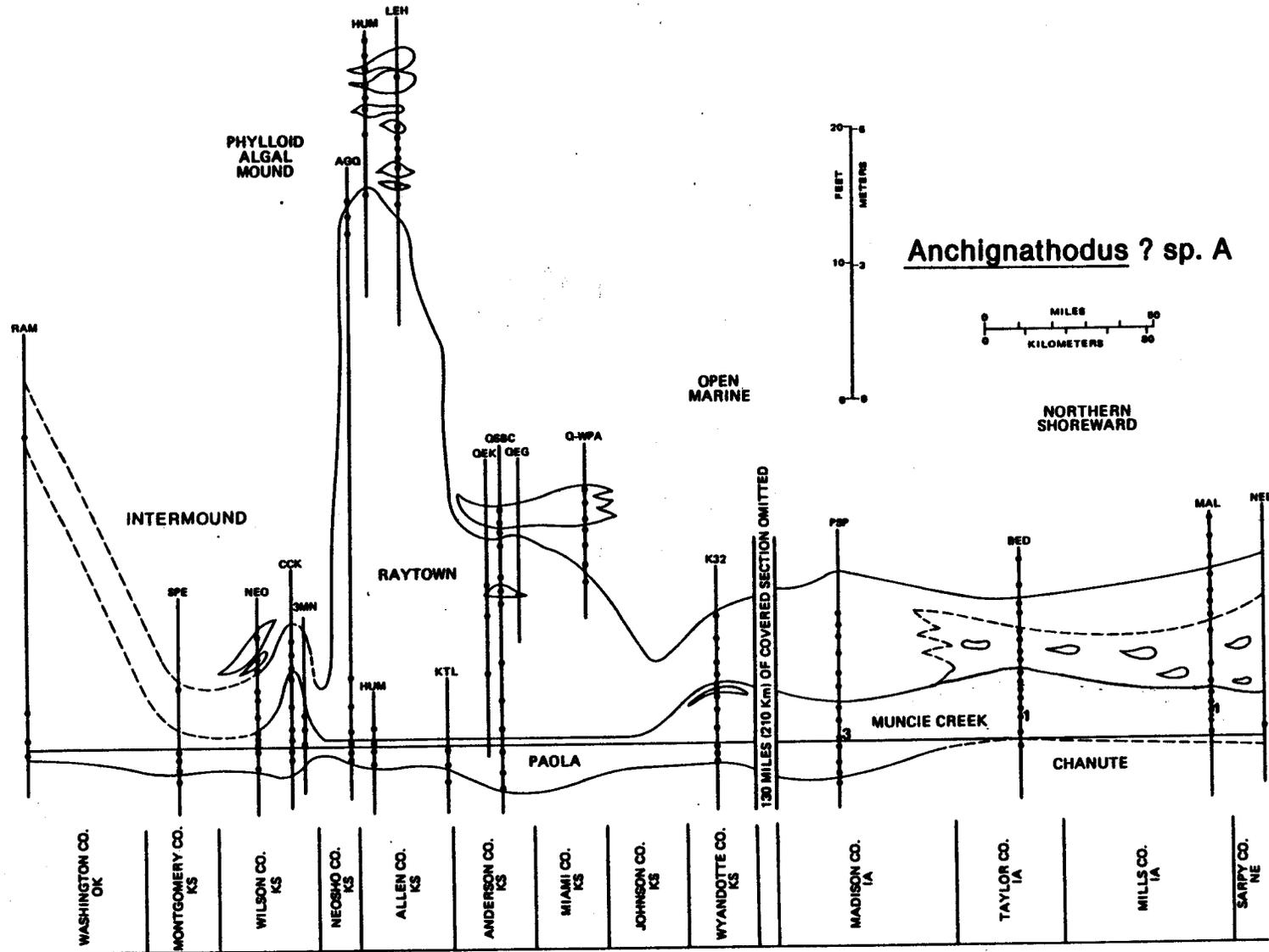
Figure 49. Generalized cross-section of Iola Limestone and
            adjacent units with abundance and distribution
            data for <u>Anchignathodus minutus</u>. Only platform
            elements are included in abundance counts.
            Dots show approximate sample location within
            each section. Recorded abundances are actual.
            Nonstandard sample sizes were collected from
            localities NEB, MAL, and BED; standard 500-gram
            samples were collected from all other sections.
            Location codes, exact sample size, and sample
            location are given in Appendix B.

Figure 49.

Anchignathodus minutus

PHYLLOID ALGAL MOUND

INTERMOUND

OPEN MARINE

NORTHERN SHOREWARD

RAYTOWN

MUNCIE CREEK

PAOLA

CHANUTE

130 MILES (210 Km) OF COVERED SECTION OMITTED

WASHINGTON CO. OK

MONTGOMERY CO. KS

WILSON CO. KS

NEOSHO CO. KS

ALLEN CO. KS

ANDERSON CO. KS

MIAMI CO. KS

JOHNSON CO. KS

WYANDOTTE CO. KS

MADISON CO. IA

TAYLOR CO. IA

MILLS CO. IA

SARPY CO. NE

MILES

KILOMETERS

FEET METERS

197

(6 samples), rare _Stepanovites conflexa_ (1 sample),
Anchignathodus? sp. A (2 samples), and _Aethotaxis advena_
(3 samples).

Diplognathodus sp.

Diplognathodus sp. was recovered from seven samples of
skeletal wackestone and calcareous shale, mainly from the
lower Raytown in Iowa, but including two samples of Muncie
Creek in Iowa and one sample of Upper Raytown in northeast
Kansas (figure 50). _Diplognathodus_ sp. occurs in
association with rare to very abundant _Idiognathodus_ spp.
(7 samples), and very abundant _Gondolella bella_ (1 sample),
rare to abundant _Anchignathodus minutus_ (6 samples), and
rare _Adetognathus lautus_ (1 sample), rare _Aethotaxis advena_
(1 sample), rare _Anchignathodus_? sp. A (1 sample), and rare
Idioprioniodus typus (2 samples).

Extremely small size and apparent fragile nature may
also partly explain why so few specimens of _Diplognathodus_
sp. were recovered from residues remaining on the 120-mesh
sieve.

Gondolella bella

Gondolella bella was recovered from thirteen samples.
It is restricted to the Muncie Creek Shale and immediately
underlying portions of the Paola Limestone (figure 51).
Although found in all facies belts, maximum numbers were

Figure 50.   Generalized cross-section of Iola Limestone and
             adjacent units with abundance and distribution
             data for _Diplognathodus_ sp.   Only platform
             elements are included in abundance counts.
             Dots show approximate sample location within
             each section.   Recorded abundances are actual.
             Nonstandard sample sizes were collected from
             localities NEB, MAL, and BED; standard 500-gram
             samples were collected from all other sections.
             Location codes, exact sample sizes, and sample
             locations are given in Appendix B.

Figure 50.

Diplognathodus sp.

200
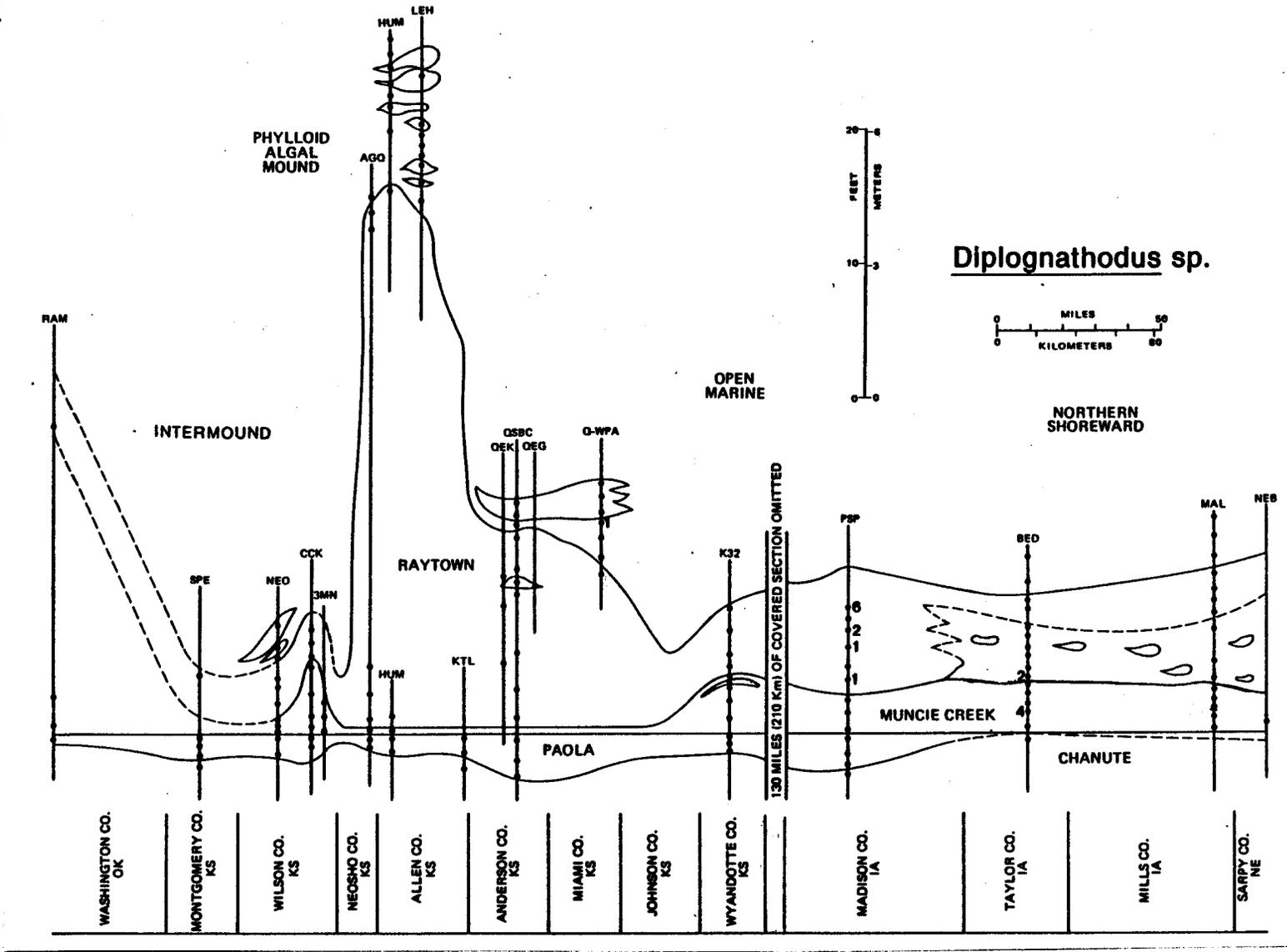
recovered from the black, fissile facies of the Muncie

Creek Shale in Iowa. It decreases in numbers southward

in gray phosphatic shale and occurs in small numbers in

two samples of skeletal wackestone and packstone from the

Paola.

Gondolella bella invariably occurs in association with

rare to very abundant Idiognathodus spp., and is also found

in 12 of 13 samples with rare to abundant Idioprioniodus

typus. It occurs in about half the samples (6) with rare

to abundant Anchignathodus minutus, and in 3 samples with

rare Anchignathodus? sp. A, and 1 sample with frequent

Diplognathodus sp.

One sample of skeletal packstone from the Paola Member

in northern Oklahoma yielded rare Gondolella bella in

association with Adetognathus lautus (locality RAM, figure

80). This association is highly unusual (Merrill, 1973;

Merrill and von Bitter, 1976; Heckel and Baesemann, 1975),

and may be due to mixing of sediment by burrowing activity.

_in a_
packstone

Maximum abundance of Gondolella bella in the Muncie

Creek Shale in the northern portion of the outcrop belt

(figure 51) runs counter to Heckel and Baesemann's (1975)

observation that Gondolella becomes less common northward.

This observation was based on data of Merrill (1973) for

Iowa, which showed that Gondolella was then known from

fewer cyclothems in Iowa than in Kansas. Gondolella is

Figure 51. Generalized cross section of Iola Limestone and
adjacent units with abundance and distribution
data for <u>Gondolella</u> <u>bella</u>. Only platform
elements are included in abundance counts.
Dots show approximate sample location within
each section. Recorded abundances are actual.
Nonstandard sample sizes were collected from
localities NEB, MAL, and BED; standard 500-gram
samples were collected from all other sections.
Location codes, exact sample sizes, and sample
locations are given in Appendix B.

Figure 51.

PHYLLOID
ALGAL
MOUND

Gondolella bella

OPEN
MARINE

NORTHERN
SHOREWARD

INTERMOUND

RAYTOWN

MUNCIE CREEK

PAOLA

CHANUTE

130 MILES (210 Km) OF COVERED SECTION OMITTED

WASHINGTON CO.
OK

MONTGOMERY CO.
KS

WILSON CO.
KS

NEOSHO CO.
KS

ALLEN CO.
KS

ANDERSON CO.
KS

MIAMI CO.
KS

JOHNSON CO.
KS

WYANDOTTE CO.
KS

MADISON CO.
IA

TAYLOR CO.
IA

MILLS CO.
IA

SARPY CO.
NE

203
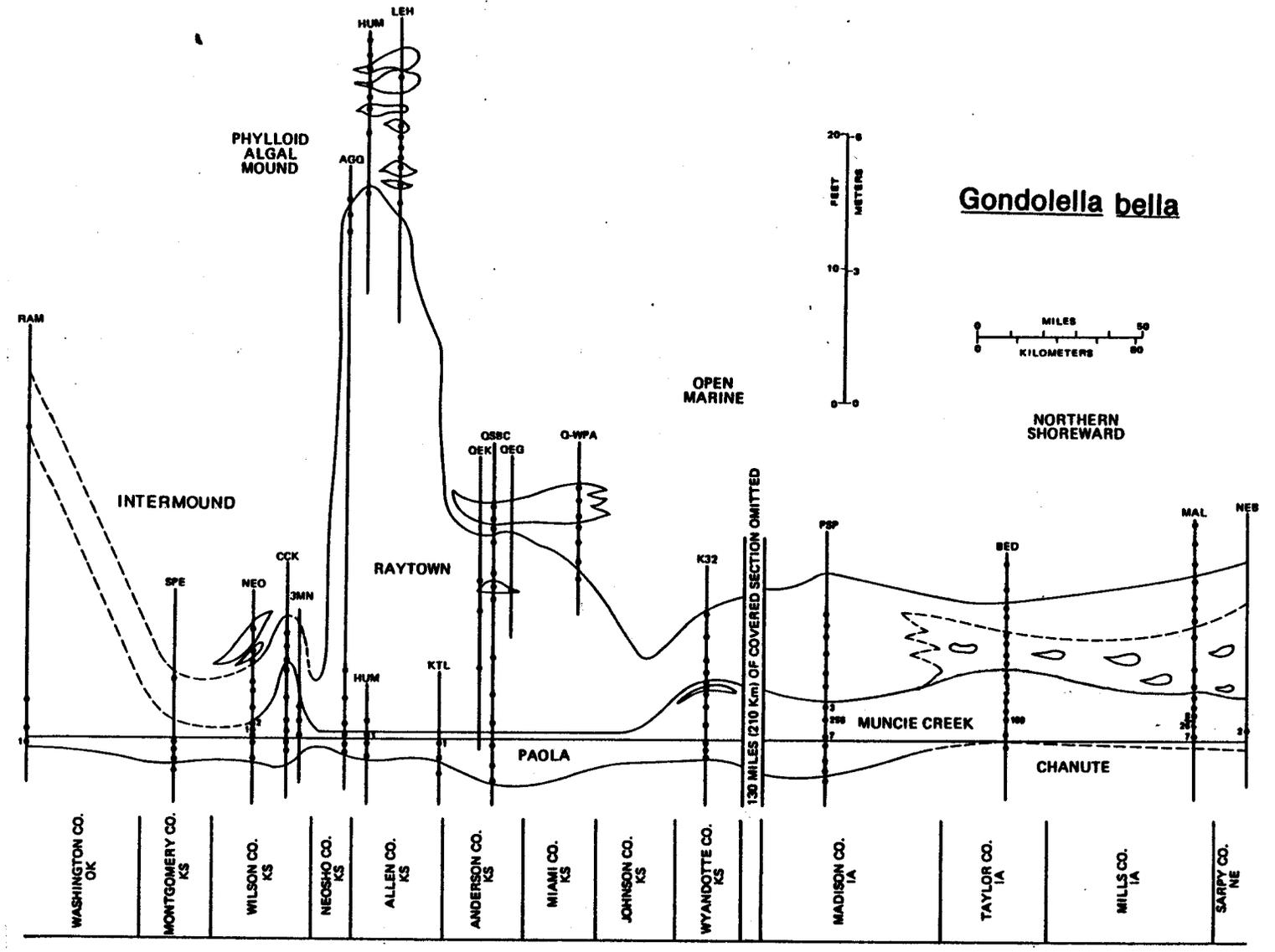
certainly more abundant northward in the Iola, and it is now known in 2 more cyclothems there (J.W. Swade, personal communication, 1981) than were recorded by Merrill (1973, p. 259).

<u>Idiognathodus</u> spp.

<u>Idiognathodus</u> spp. is present in nearly every sample that yielded identifiable conodonts and occurs in association with all other conodonts recognized in this study (figure 52).

Although <u>Idiognathodus</u> spp. is not restricted with respect to lithology or position in the Iola cyclothem, distinct abundance maxima are recognized as follows.

1. High <u>Idiognathodus</u> spp. abundance in association with high to moderate diversity is characteristic of the Muncie Creek Shale and adjacent portions of the Paola and Raytown. *members* Taxa most commonly occurring in association with <u>Idiognathodus</u> spp. in this part (core) of the cyclothem are <u>Gondolella</u> <u>bella</u>, <u>Idioprioniodus</u> <u>typus</u>, <u>Anchignathodus</u> <u>minutus</u>, and <u>Diplognathodus</u> sp.

2. High <u>Idiognathodus</u> spp. abundance characterizes Raytown mound-top and mound-associated facies including the Owl Creek, Bassett, and Bush City beds; here <u>Idiognathodus</u> spp. is associated with low numbers of <u>Anchignathodus</u> <u>minutus</u>, <u>Idioprioniodus</u> <u>typus</u>, and rarely <u>Aethotaxis</u> <u>advena</u> and <u>Adetognathus</u> <u>lautus</u>.

Figure 52. Generalized cross-section of Iola Limestone and
adjacent units with abundance and distribution
data for <u>Idiognathodus</u> spp. Only platform
elements are included in abundance counts.
Dots show approximate sample location within
each section. Recorded abundances are actual.
Nonstandard sample sizes were collected from
localities NEB, MAL, and BED; standard 500-gram
samples were collected from all other sections.
Location codes, exact sample sizes, and sample
locations are given in Appendix B.

Figure 52.

Idiognathodus spp.
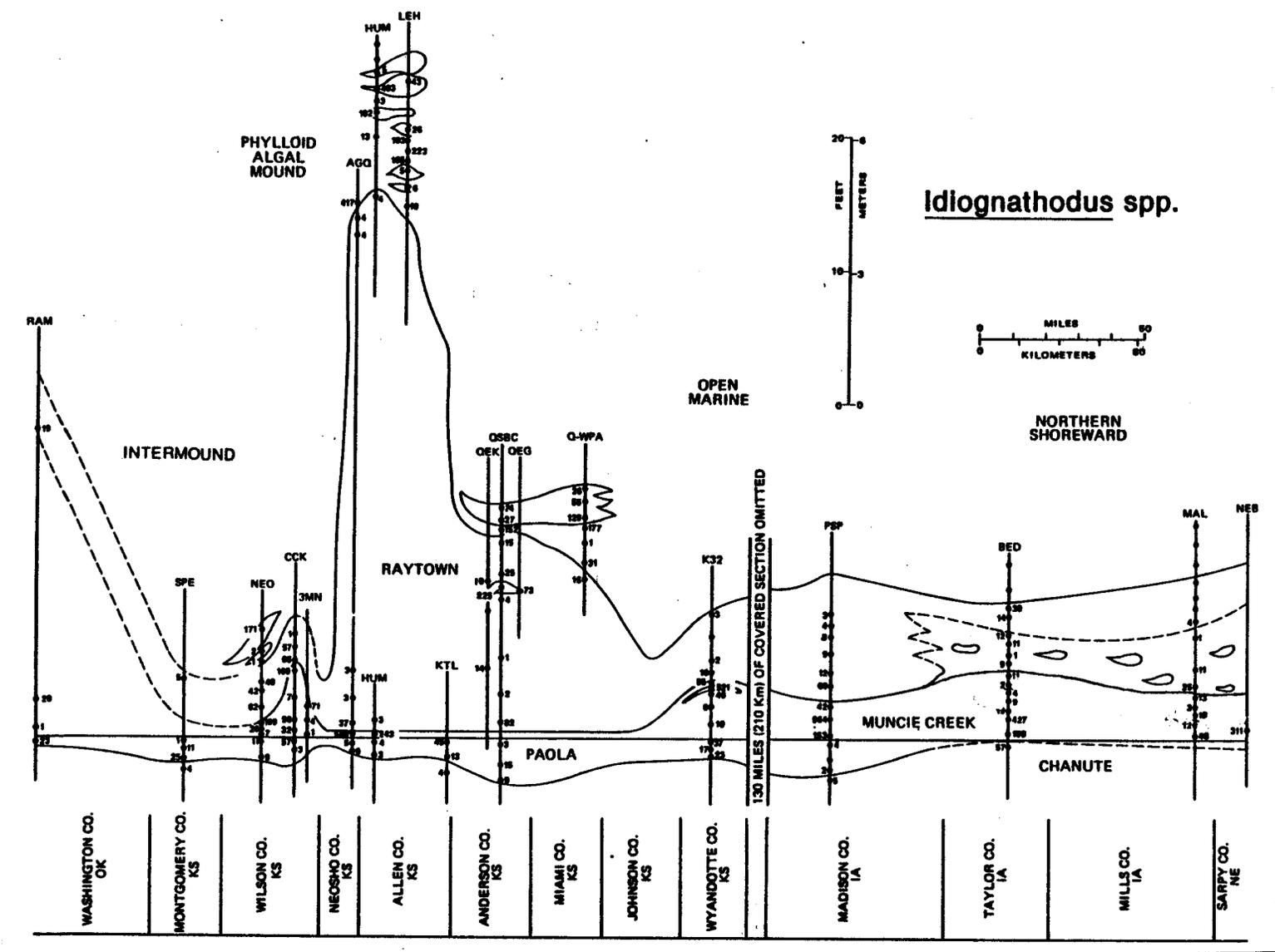
Relatively low abundance in samples from the algal mound facies and in the few samples collected from locality RAM in northeastern Oklahoma suggest dilution by abundant algal production of carbonate sediment and influx of terrigenous detritus from the Oklahoma detrital source, respectively.

Idioprioniodus typus

Idioprioniodus typus was recovered from 44 samples in nearly all sections sampled (figure 53). Although it is closely associated with Gondolella bella, it is not nearly as stratigraphically restricted in its distribution. Idioprioniodus typus is most abundant in the Muncie Creek Shale and adjacent portions of the Raytown and Paola Limestones. Although absent in most of the upper Raytown, it reappears in low numbers in a thin shale lens within the upper portion of the main Raytown ledge and in the overlying Bush City bed in east central Kansas.

Idioprioniodus typus was recovered from black fissile shales, gray shales, sandstones, wackestone, packstones, and unabraded, non-algal grainstones. It is not present in shoreline calcilutites or shoal-water calcarenites.

It occurs in association with rare to abundant Idiognathodus spp. (40 samples), and in most samples in which Gondolella bella is present (12 samples); less commonly with Anchignathodus minutus (14 samples); and only

Figure 53. Generalized cross-section of Iola Limestone and
adjacent units with abundance and distribution
data for Idioprioniodus typus. Recorded
abundance is that of the most common element
from each sample. Dots show approximate sample
location within each section. Recorded
abundances for each sample are actual.
Nonstandard sample sizes were collected from
localities NEB, MAL, and BED; standard 500-gram
samples were collected from all other sections.
Location codes, exact sample sizes, and sample
locations are given in Appendix B.

Figure 53.

Idloprioniodus typus

209
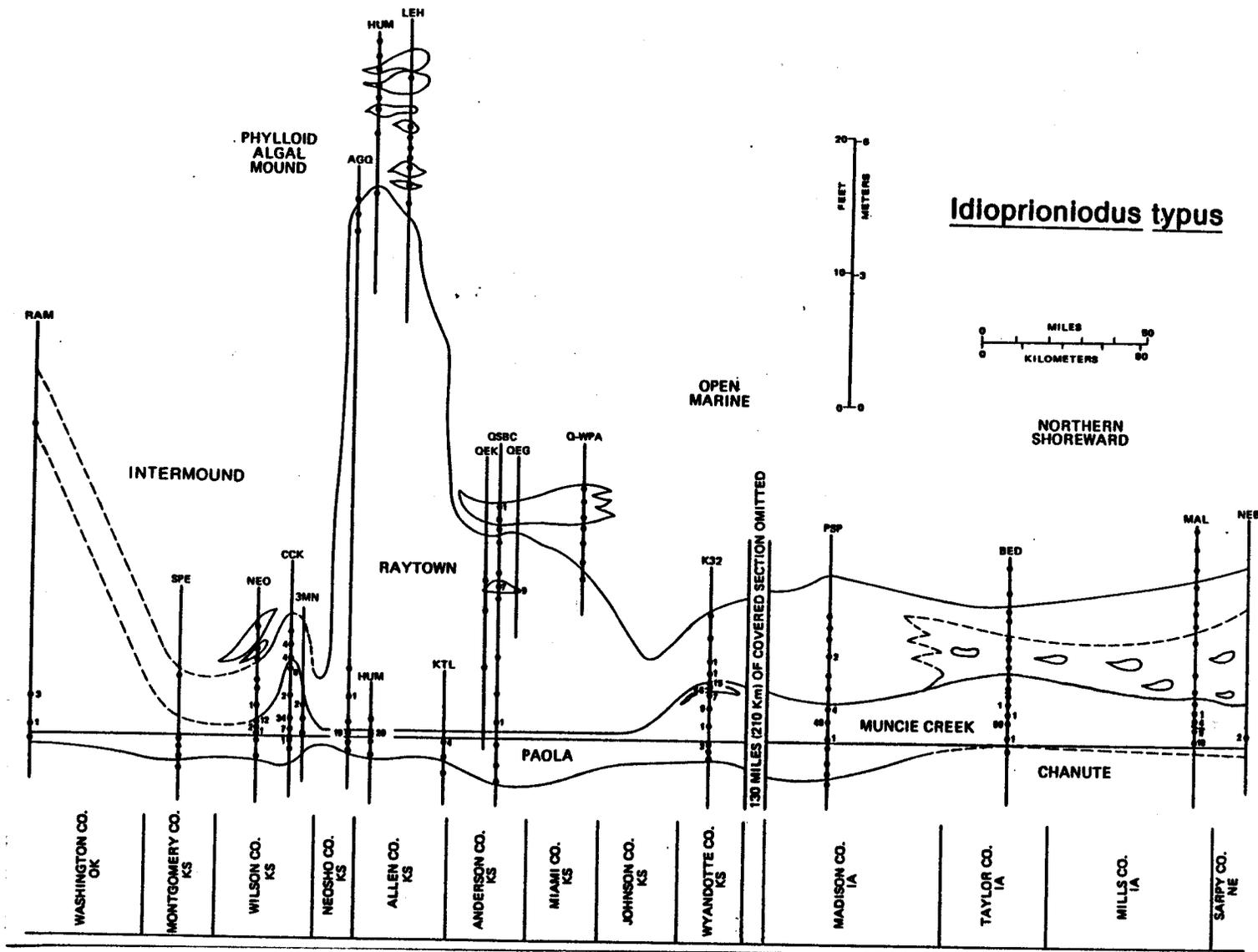
rarely with _Diplognathodus_ sp. (1 sample), and _Adetognathus_
lautus (5 samples).

Stepanovites conflexa

Stepanovites conflexa is present, but rare in four
samples; one of lower Paola and three of upper Raytown
scattered from Iowa to southeastern Kansas (figure 54). It
was found only in lithologies showing evidence of
deposition in a relatively agitated environment (encrusted-
grain abraded skeletal grainstones to mud-lean packstones).
It occurs in strong association with rare to abundant
Idiognathodus spp. (4 samples), rare _Adetognathus lautus_
(3 samples), and rare _Anchignathodus minutus_ (3 samples).

Generalized Distributional Patterns

Distribution of conodonts within the Iola Limestone
and adjacent units reflects the depositional pattern of a
Kansas cyclothem and strongly supports the relationship
between depositional sequence and conodont assemblage
demonstrated by Heckel and Baesemann (1975) for a single
Missourian vertical sequence in northeastern Kansas.
Similar to the findings of Wood (1977) for the Stanton
Limestone, vertical variation in conodont distribution and
abundance far outweighs lateral variation.

Figure 54. Generalized cross-section of Iola Limestone and
adjacent units with abundance and distribution
data for <u>Stepanovites</u> <u>conflexa</u>. Recorded
abundance is that of the most common element
from each sample. Dots show approximate sample
location within each section. Recorded
abundances for each sample are actual.
Nonstandard sample sizes were collected from
localities NEB, MAL, and BED; standard 500-gram
samples were collected from all other sections.
Location codes, exact sample sizes, and sample
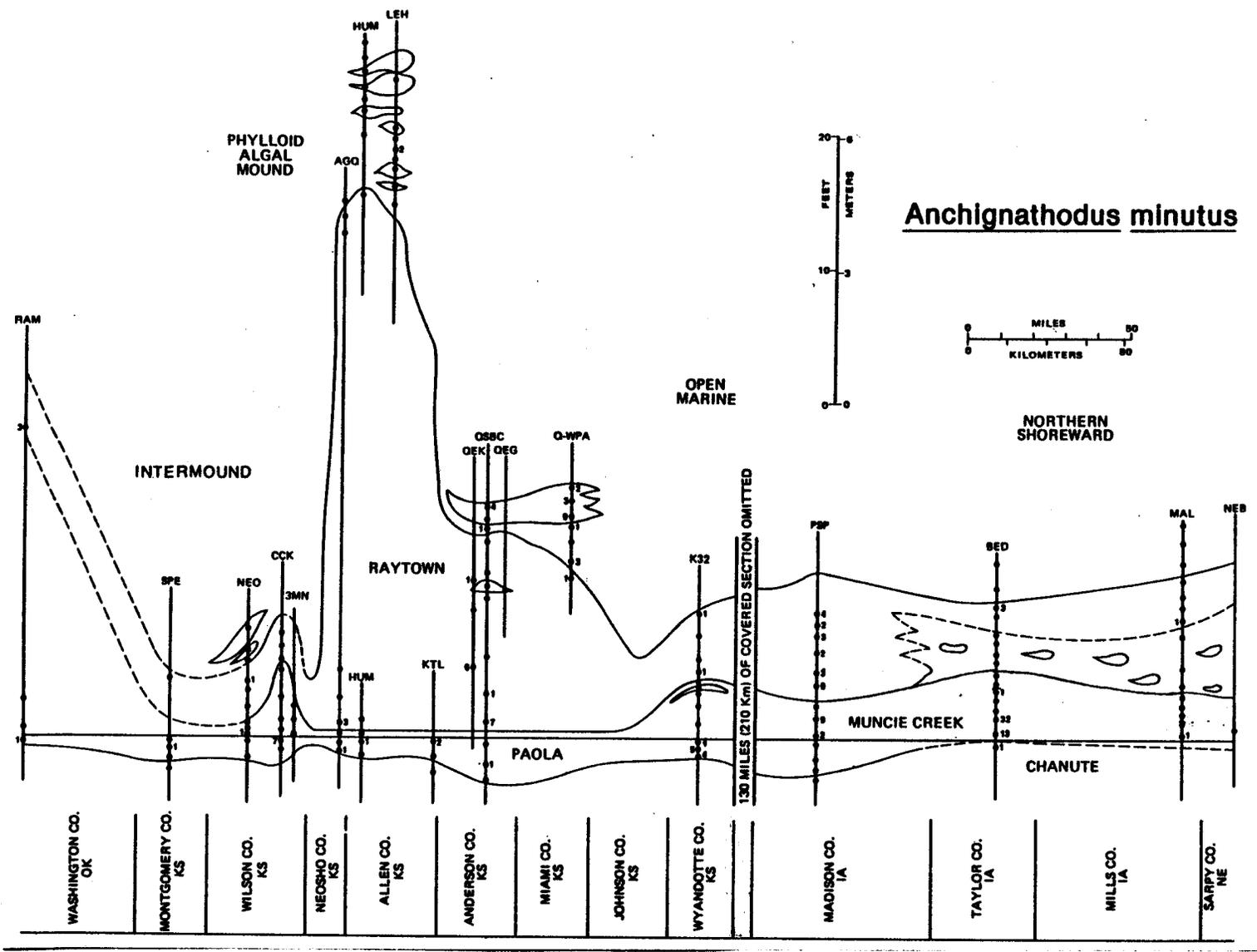locations are given in Appendix B.

Figure 54.

Stepanovites conflexa

212
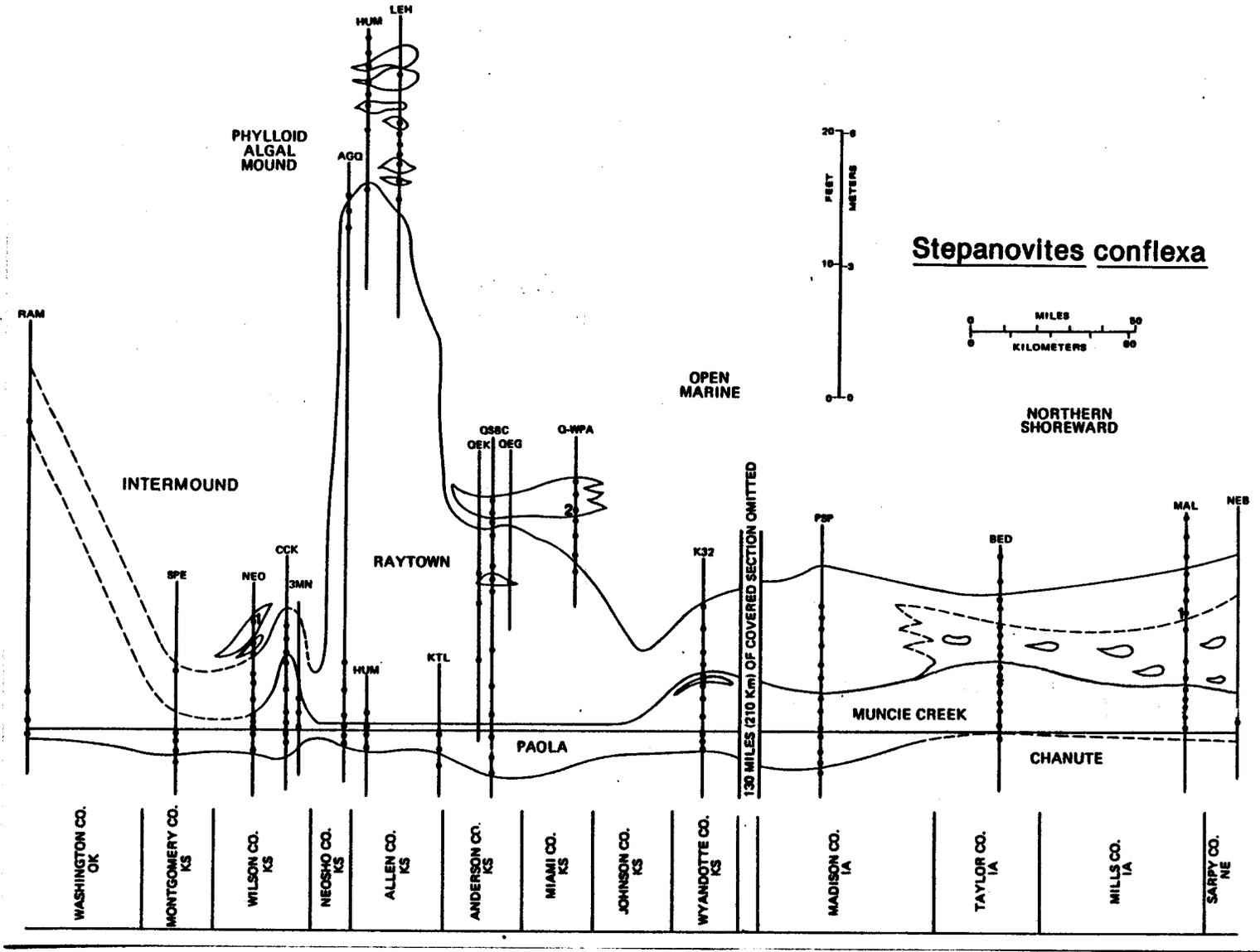
From data on conodont occurrences (figures 44, and 46 through 54, and Appendix B), several distributional patterns are apparent in the Iola cyclothem:

1. The Chanute Shale and the Lane (Lane/Bonner Springs) Shale are characterized by either absence or low abundance of conodonts, (figure 44). Low numbers of _Adetognathus lautus_ dominate the Chanute Shale; _Idiognathodus_ spp., and _Anchignathodus_ minutus are also present. Rare _Idiognathodus_ spp. were recovered from the upper Lane Shale.

2. In general, abundance and diversity increase upwards through the Paola Limestone. Ubiquitous _Idiognathodus_ spp. and _Anchignathodus_ minutus dominate the fauna, with _Idiognathodus_ spp. abundance increasing upwards. _Adetognathus lautus_ and _Stepanovites conflexa_ are restricted to the lower Paola.

3. High conodont abundance (figure 44), in combination with high diversity, characterize the Muncie Creek Shale and adjacent parts of the Paola and Raytown Limestones members (= cyclothem core). Maximum abundance occurs in black Muncie Creek shale facies in northern localities, with abundance gradually decreasing southward towards Oklahoma.

4. _Idiognathodus_ spp. numerically dominates the conodont fauna obtained from samples of the cyclothem core. The core is further characterized by the exclusive presence of _Anchignathodus_? sp. A, and _Gondolella bella_, and the less

exclusive presence of _Idioprioniodus typus_.

5. The vertical trend in conodont faunas in upper limestone members first noted by Heckel and Baesemann (1975), namely: _Idiognathodus_ dominance at the base, passing upwards to _Anchignathodus_ dominance or mixed dominance of combinations of _Idiognathodus, Anchignathodus, Adetognathus,_ and occasionally _Aethotaxis,_ is generally similar to that seen in the Raytown Limestone. Here, _Idiognathodus_ spp., less common _Anchignathodus minutus,_ and typically rare _Adetognathus lautus_ occur throughout the study area; _Aethotaxis advena_ and _Diplognathodus_ sp. are usually rare and are restricted to the more northward locations. Although _Idioprioniodus typus_ is absent in most of the upper Raytown, it reappears in ~~low~~ _lesser_ numbers in a thin shale lens within the upper portion of the main Raytown ledge and in the overlying, mound-associated, Bush City bed in east central Kansas.

In contrast to Heckel and Baesemann's observation that conodont abundance and diversity decrease upward through the upper limestone member, the upper Raytown locally exhibits high abundance and/or diversity, e.g.: approximately 400 specimens of _Idiognathodus_ spp. were recovered from a half-kilogram sample of mound-top mud-lean packstone; samples of the Bush City bed and subjacent

shales display high abundance (100+ specimens per half-kilogram sample) and high diversity. As previously discussed in the section on conodont distribution in Raytown mound-top and mound-associated facies, it is possible that these beds represent the core of a poorly developed, southern extension of the Wyandotte cyclothem.

6. Occurrences of <u>Stepanovites</u> <u>conflexa</u> are restricted to lithologies that show evidence of deposition in a relatively agitated environment (encrusted-grain skeletal packstone to mud-lean packstones). It is the only ~~taxon~~ conodont that is restricted to a certain lithology, although <u>Anchignathodus</u>? sp. A and <u>Gondolella</u> <u>bella</u> (with two exceptions) are restricted to the Muncie Creek Shale.

7. The occurrence of <u>Idiognathodus</u> spp., <u>Anchignathodus</u>? sp. A, <u>Idioprioniodus</u> <u>typus</u>, <u>Gondolella</u> <u>bella</u>, <u>Diplognathodus</u> sp., and <u>Anchignathodus</u> <u>minutus</u> in black anoxic facies of the Muncie Creek implies a pelagic mode of existence for these taxa.

8. Probable depth zonation is reflected in the following groupings: a) <u>Stepanovites</u> <u>conflexa</u> in shallow, agitated water; b) <u>Adetognathus</u> <u>lautus</u> is most abundant in deposits laid down during early transgression and late regression; c) <u>Aethotaxis</u> <u>advena</u>, <u>Idiognathodus</u> spp., <u>Anchignathodus</u> <u>minutus</u>, and <u>Diplognathodus</u> sp. above waters of all depths, (though <u>Idiognathodus</u> spp. is present above waters of all

depths, it is <u>most</u> <u>abundant</u> over deeper water); d)
<u>Anchignathodus</u>? sp. A, <u>Gondolella</u> <u>bella</u>, and to a lesser
extent <u>Idioprioniodus</u> <u>typus</u> confined to cooler, less-
oxygenated, deeper water. The latter three groupings
follow Wood and Heckel (1977).

9. Although vertical variation far outweighs lateral
variation, some lateral variation in abundance is seen.

a) Decreased conodont abundance in the Kansas-Oklahoma
border region is probably due to dilution by terrigenoius
detrital influx from a major siliciclastic source area in
Oklahoma. Relatively low abundance in the Raytown in
southwestern Iowa and eastern Nebraska is most likely due
to increased influx of prodeltaic muds from the deltaic
complexes prograding westward possibly from the Appalachians
(Heckel, 1980).

b) Typical absence of conodonts in the upper Raytown in
the northern portion of the study area is likely a
consequence of the presence of shoreline carbonate
environments that were inimical to all taxa.

c) Presence of a topographic high (discussed in previous
sections) in southeastern Kansas effectively raised the
depositional substrate into relatively well-oxygenated
waters; this may explain the low abundance or absence of
<u>Gondolella</u> <u>bella</u> and <u>Anchignathodus</u>? sp. A throughout the
mound tract if they were better adapted to low-oxygen

water. _Idioprioniodus_ _typus_ was apparently less affected

by these more-oxygenated waters, as it is common throughout

this area.

CHAPTER VI

CONCLUSIONS

Lithologic and stratigraphic considerations of the
Iola Limestone and adjacent units support the conclusion of
Heckel and Baesemann (1975) and Heckel (1977, 1980) that
the basic vertical sequence of members in a typical
"Kansas" cyclothem record a single transgressive-regressive
event with deepest water (maximum transgression) occurring
during deposition of the core shale.

The Chanute and the Lane/Bonner Springs Shales
(outside shale members of the Iola cyclothem), record
deposition in a marginal marine to deltaic environment
during time of increased detrital influx as attested to by the
local presence of nonmarine deposits such as channel
sandstones, coals, underclay, and red shale beds. Marine
fossils are sparse or absent. Increased thickness of
outside shales to the south reflects proximity to the
Oklahoma detrital source.

Two facies are recognized in the Paola Limestone Member of the Iola Ls.
(middle limestone member of the Iola cyclothem): basal
fossiliferous sandstone to sandy skeletal packstone,
gradational with the subjacent Chanute; and upper skeletal

wackestone, both present throughout most of the study area. Mud-supported textures, diverse fauna, and abundant algal debris characteristic of the upper Paola, indicate that deposition took place below effective wave base, but still in the photic zone.

The Muncie Creek Shale (core shale member of the Iola cyclothem) is a thin (0.1-1.0 m, 3 in.-3 ft.), laterally persistent, nearly nonsandy phosphatic shale. Two facies are present: black fissile shale rich in organic material and heavy metals, but lacking a benthic marine fauna (although conodonts, fish remains, orbiculoid brachiopods, and conularids are present); and gray shale, typically with a sparse to moderately abundant marine benthic fauna comprising brachiopods, bryozoans, echinoderms and sponges. The black facies is sandwiched between gray shales and is present throughout the study area except in central southeastern Kansas where only thin gray shale is present over what appears to have been a persistent topographic high, the Bourbon Arch. Thinness, lateral continuity, lack of benthic fauna in the black facies, absence of algal debris, fine grain size, and presence of non-skeletal phosphate all suggest that the Muncie Creek formed as a result of slow sedimentation offshore in relatively deep, sediment-starved, often anoxic water.

Seven facies are recognized in the Raytown Limestone
(upper limestone member of the Iola cyclothem). The lower
portion of the Raytown is relatively laterally persistent
throughout the study area, typically comprising normal
marine skeletal wackestone/packstone with a diverse marine
fauna. A nonabraded grainstone consisting ~~nearly~~ *almost* entirely
of invertebrate skeletal grains with no evidence of grain
micritization or abrasion, cross-bedding, or algal debris
is present at the base of the Raytown in the open-marine
facies belt in northeastern Kansas. Thus the lower portion
of the Raytown reflects deposition in quiet water below
wave base, and locally beneath the lower limit of
sufficient light penetration for effective algal growth.
In contrast, the upper Raytown exhibits considerable
lateral facies changes. In northeastern Kansas carbonate
deposition was apparently overwhelmed by detrital influx
prior to sufficient shallowing of water for development of
shoal-water lithologies. In Iowa and eastern Nebraska the
Raytown grades upward into an abraded skeletal grainstone
with algal and invertebrate grains, abundant foraminifer-
encrusted grains, grain micritization, and intraclasts;
thus reflecting increased water agitation as water
shallowed. At the top of the Raytown, shoreline
carbonates, including laminated carbonate mudstones and

paleocaliche, record restriction and subaerial exposure in this area.

Phylloid algal mound complexes are developed in the Raytown Limestone in southeastern Kansas and in the equivalent Avant Limestone in northeastern Oklahoma. Iola moundrock consists mainly of sparry algal-rich wackestone with subordinate amounts of algal wackestone and skeletal grainstone, packstone, and wackestone. Local presence of "sparite" in the Raytown and Avant mounds record the existence of early, probable aragonitic botryoidal cements. Mound-associated facies, including cross-bedded skeletal/oolitic grainstones (Owl Creek beds), and encrusted-grain skeletal wackestone/packstone (Bush City and Bassett beds) overlie the Raytown algal mound; reflecting shoal-water conditions. Algal-poor skeletal wackestone/packstone and minor sandstone constitute the Raytown in the Kansas/Oklahoma border region. This "intermound area" appears to be a small basin lying at least at its north end 100-120 ft. (30-36 m) topographically lower than the Raytown mound tract, just to the north. This low northern limit is located along synclinal alingment (1) of Heckel and Cocke (1969).

Lateral lithologic variation throughout the study area lends further support to a deep-water origin for the Muncie Creek Shale. The Muncie Creek and adjacent portions of the

Paola and Raytown Limestones are laterally persistent and
uniform throughout the study area, as expected in deep
water, where minor variations in bottom topography would
have little or no effect on facies. Although lateral
lithologic variation is seen in the Muncie Creek, it is
only between deeper offshore sediment-starved facies and is
readily explained by the influence of the Bourbon Arch. In
contrast, rapid lateral facies changes occur in the upper
Raytown Limestone, as is expected in shallow water
deposits, where minor variations in bottom topography
result in major facies changes.

Conodont distribution in the Iola Limestone and
adjacent units reflects well the depositional pattern of
the Iola cyclothem as summarized in the preceeding section.
Vertical variation in conodont distribution and abundance
throughout the study area is the same that Heckel and
Baesemann (1975) (showed) in the Kansas City area and far
outweighs lateral variation that is seen, especially in the
upper Raytown. The question of whether capping beds
included within the Raytown in Allen Co., which locally
contain abundant conodont faunas, might represent poorly
developed overlying Wyandotte Limestone, unknown south of
Anderson Co., remains open.

The Bourbon Arch, a low positive feature during the
time of Iola deposition, probably had a greater effect on

Upper Pennsylvanian sedimentation than previously thought.
Relatively thick Chanute Shale in concert with the Bourbon
Arch most likely gave rise to a topographic high in central
southeastern Kansas. It is noteworthy that abundant
phylloid algal growth occurred in both the Paola and
Raytown Limestones in this area. In addition, absence of
black shale facies in the Muncie Creek Shale throughout
this area implies that water depth was insufficient for
development of a thermocline that was strong enough to
prevent oxygenation of bottom water. It is probably not
coincidental that Gondolella bella and Anchignathodus? sp.
A, (conodont taxa probably closely associated with cooler,
less-oxygenated, deeper water) are absent throughout this
area.

APPENDIX A.

SECTION DESCRIPTIONS

Core from Offutt Air Force Base (NEB)

Core from Strategic Air Command Headquarters, Sarpy
Co., Nebraska. Examined courtesy of R.K. Pabian, Nebraska
Geological Survey.

Center SE SE NW sec. 11, T31N, R13E.

LANE SHALE

Raytown Limestone Member

L1 10"+ (25+ cm)   Shale, gray-green, calcareous, barren.
Unit is overlain by red shale.

IOLA LIMESTONE

Raytown Limestone Member

R7 14" (36 cm) Dolomitized calcilutite (mudstone), light
greenish-tan, with thin convoluted cryptalgal laminae.
Grades upward to dolomitized calcilutite (mudstone), light
greenish-tan, intraclastic, barren, with thin laminae and
abundant "birdseye" structures. Unit is bioturbated,
burrows are back-filled with peloidal sediment with swirled
texture. Burrows and birdseye are filled with coarsely-
crystalline ferroan dolomite and/or shale from overlying
unit. Minor traces of evaporites.

R6 10" (25 cm) Dolomitized calcilutite (mudstone), light
greenish-tan, with thin convoluted laminae, microfaulted,
barren. Top 1.5" (4 cm) is intraclastic. Calcilutite

interbedded with greenish-gray shale. Polygonal patterns (desiccation cracks ?) visible on parting surfaces.

R5   3"   (7.5 cm)   Shale, green to gray.

R4   12"   (30 cm)   Shale, green to gray, calcareous, interbedded with thinly-laminated, microfaulted calcilutite (mudstone), greenish-gray, argillaceous.

R3   66"   (1.7 cm)   Skeletal calcilutite (wackestone), buff to greenish-gray, burrowed, thin green-gray shale partings throughout unit. Diverse biota with brachiopods, bryozoans, echinoderm debris, encrusting foraminifers, gastropods, sponges, foraminifer-encrusted grains, ostracodes, and dasycladacean algae. Minor silicification. Vaguely peloidal matrix. Minor replacement of matrix by non-ferroan dolomite.

R2   3"   (7.5 cm)   Shale, greenish-gray, slightly calcareous, with echinoderm debris and brachiopods.

R1   7.5"   (19 cm)   Skeletal calcilutite to skeletal calcarenite (wackestone to packstone), greenish-buff. Brachiopods, echinoderm debris and gastropods. Minor trilobites and encrusting foraminifers. Minor replacement of matrix by coarse silt-sized non-ferroan dolomite. Unit grades upward into green-gray, calcareous shale with brachiopods and echinoderm debris.

Total Raytown thickness: 9.6'   (2.95 m).

Muncie Creek Shale Member

M3 8.5" (22 cm) Shale, greenish-gray, slightly calcareous, with brachiopods and echinoderm debris.

M2 12" (30 cm) Missing interval. Sample removed for testing by U.S. Army Corps of Engineers.

M1 4" (10 cm) Shale, dark gray to black. Pyritiferous. Paper-thin laminae.

Total Muncie Creek thickness: 24.5" (62 cm).

Paola Limestone Member

P2 0.2' (6 cm) Skeletal calcarenite, gray-green, argillaceous, with whole-shell brachiopods. Grades upwards into gray-green calcareous shale.

P1 0.3' (9 cm) Skeletal calcarenite, gray-green, argillaceous, with whole-shell brachiopods.

Total Paola thickness: 0.5' (15 cm).

Total Iola thickness: 12.1' (3.7 m).

CHANUTE SHALE

C2 9" (23 cm) Shale, gray, carbonaceous, with thin coal. Bedding disrupted by burrowing or rooting.

C1 24"+ (61+ cm) Shale, green, with plant fragments.

Malvern Core (MAL)

Core taken near the town of Malvern in Mills Co., Iowa. Examined courtesy of M.J. Avcin, Iowa Geological Survey.

SW NW sec. 5, T71N, R41W.

LANE SHALE

L1 3.8' (1.2 m) Shale, greenish-gray, flaky, slightly calcareous. Non-fossiliferous, slightly pyritic. Irregular contact with Raytown, shale fills fractures in limestone.

IOLA LIMESTONE

Raytown Limestone Member

R7 1.2' (0.37 m) Dololutite (mudstone), tan, intraclastic, peloidal, abundant "birdseye" structures. Sparse gastropods and ostracodes. Lower 0.1' (3 cm) of unit is argillaceous with relatively abundant skeletal debris. Voids partly filled with coarsely crystalline ferroan dolomite.

R6 1.0' (0.3 m) Dololutite (mudstone to boundstone), tan to buff, thinly laminated. Sparse gastropods and ostracodes. "Birdseye" structures present but not abundant. Very fine quartz sand and coarse quartz silt.

R5 1.5' (0.46 m) Calcilutite (wackestone), tan to green, with thin shale partings. Minor quartz silt. Bivalves,

echinoderm debris, brachiopods, encrusting foraminifers, calcispheres (?), gastropods and ostracodes. Micrite envelopes present. Fossil abundance decreases upwards. Minor replacement of matrix by silt sized, non-ferroan dolomite.

R4 0.6' (.18 m) Skeletal calcarenite (packstone to grainstone), light gray, minor fine-grained quartz sand and coarse silt. Diverse biota with brachiopods, echinoderm debris, bryozoans, bivalves, gastropods, red algae, ostracodes, trilobites, encrusting foraminifers and fusulines. Minor replacement of matrix by medium silt-sized, non-ferroan dolomite.

R3 3.6' (1.1 m) Skeletal calcilutite (wackestone), light yellow-gray, burrowed. Conspicuous brachiopods, echinoderm debris and fusulines. Micrite envelopes present. Matrix is partly replaced by silt-sized, non-ferroan dolomite. Void space filled with relatively coarsely-crystalline ferroan dolomite.

R2 0.7' (0.2 m) Skeletal calcilutite (wackestone), greenish-gray, interbedded with greenish-gray calcareous shale. Encrusting foraminifers, fusulines, brachiopods, gastropods, bryozoans, echinoderm debris, bivalves and trilobites. No grain micritization is seen. Matrix is largely replaced by medium to coarse silt-sized, non-ferroan dolomite.

R1 0.7' (0.2 m) Skeletal calcilutite to calcarenite (packstone) with thin shale partings. Gradational with underlying unit. Brachiopods, echinoderm debris, bryozoans, trilobites, gastropods and encrusting foraminifers. Matrix is replaced in part by silt-sized non-ferroan dolomite. Relatively coarsely-crystalline ferroan dolomite partly replaces skeletal debris.

Total Raytown thickness: 9.3' (2.8 m).

Muncie Creek Shale Member

M2 1.8' (0.55 m) Shale, medium to light greenish-gray, hard, calcareous. Lower 0.5' (0.15 m) is sparsely fossiliferous to barren. Upper portion of shale is very fossiliferous with brachiopods and echinoderm debris. Contact gradational with underlying unit.

M1 0.8' (0.24 m) Shale, black, paper-thin laminae. Phosphatic (?). Bottom of core.

Total Muncie Creek thickness: 2.6' (0.8 m).

Total Iola thickness: 10' (3.6 m).

Bedford Core (BED)

Core taken near the town of Bedford in Taylor Co., Iowa. Examined courtesy of M.J. Avcin, Iowa Geological Survey.

NE NE NE sec. 35, T68N, R34W.

LANE SHALE

L2 14.2" (36 cm) Shale, green-gray, silty, sandy, slightly calcareous, with irregular calcite-filled fractures and minor nodular calcilutite.

L1 13.4" (34 cm) Shale, green, sharp oblique contact with underlying limestone.

IOLA LIMESTONE

Raytown Limestone Member

R4 21" (54 cm) Skeletal calcilutite (wackestone), argillaceous, light green, with encrusting foraminifers, brachiopods and bryozoans. Minor fusulines, gastropods, bivalves and ostracodes. Extensive encrustation by forminifers. Micrite envelopes are present. Fossil abundance decreases near top of unit. Clumps (1 mm in diameter) of vaguely laminated peloids. Extensive replacement of matrix by silt-sized, non-ferroan dolomite.

R3 7.1" (18 cm) Skeletal calcarenite (packstone to grainstone), tan to light green, slightly argillaceous,

with bryozoans, gastropods, echinoderm debris and abundant foraminifer-encrusted grains. Minor ostracodes, trilobites, fusulines and bivalves. Clumps (1 mm in diameter) of vaguely laminated peloids. Extensive replacement of matrix and minor replacement of skeletal grains by silt-sized, non-ferroan dolomite.

R2 30" (76 cm) Shale, green, calcareous, and lenses of tan skeletal calcilutite. Diverse biota with echinoderm debris, brachiopods, bryozoans and encrusting foraminifers. Illite, mixed-layer, chlorite.

R1 3.2" (8 cm) Skeletal calcarenite (packstone), tan, with echinoderm debris and brachiopods. Clumps (approximately 1 mm in diameter) of vaguely laminated peloids. Extensive replacement of matrix by silt-sized, non-ferroan dolomite.

Total Raytown thickness: 61.3" (1.56 m).

Muncie Creek Shale Member

M3 22.8" (58 cm) Shale, green, pyritic, slightly calcareous. Abundant nodular calcilutite (wackestone) at top of unit. Matrix of nodules is extensively replaced by silt-sized non-ferroan dolomite. Diverse biota with encrusting foraminifers, brachiopods, echinoderm debris and sponges. Illite, chlorite.

M2 8.7" (22 cm) Interval disrupted by drilling.

M1 11.0" (28 cm) Shale, black, with paper-thin laminae.

Phosphatic? Illite, illite-mixed layer, chlorite.

Total Muncie Creek thickness: 42.5" (1.08 m).

Paola Limestone Member is missing in this area.

Total Iola thickness: 8'7" (2.64 m).

CHANUTE SHALE

C1 2.4" (6 cm) Shale, gray-green, slickensided. Plant fragments and thin coal. Illite, illite-mixed layer, chlorite.

Pammel State Park (PSP)

Roadcut on northeast side of gravel road southeast of Pammel State Park, near Winterset in Madison Co., Iowa. NW sec. 22, T75N, R28W. (Winterset 15' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R3 16"+ (40+ cm) Skeletal calcilutite (wackestone), buff, with thin shale partings. Diverse biota includes echinoderm debris, bryozoans and phylloid algae. Minor ostracodes, trilobites and sponge spicules. Peloidal matrix with slight replacement by medium to coarse silt-sized non-ferroan dolomite. Minor silicification. Skeletal calcarenite (grainstone) is present at top of Raytown. Fusulines, echinoderm debris and brachiopods. Blocky ferroan and non-ferroan calcite interparticle spar.

R2 11" (28 cm) Shale, green-gray, slightly calcareous, with brachiopods, echinoderm debris, sponges and bryozoans.

R1 33" (84 cm) Covered interval.

Total Raytown thickness: 5' (1.52 m).

Muncie Creek Shale Member

M3 6" (15 cm) Shale, green-gray, with brachiopods and echinoderm debris. Illite, illite-mixed layer, chlorite, kaolinite.

M2 12" (30 cm) Shale, black, fissile, with phosphate.
Illite, illite-mixed layer, chlorite.

M1 6" (15 cm) Shale, gray, with brachiopods, echinoderm
debris and bryozoans. Illite, illite-mixed layer,
chlorite, kaolinite.

Total Muncie Creek thickness: 2' (60 cm).

Paola Limestone Member

P1 2' (60 cm) Pelletal-skeletal calcilutite (packstone
to wackestone). Brachiopods, echinoderm debris, bivalves,
gastropods, phylloid algae and encrusting foraminifers.
Matrix and skeletal debris in upper Paola is replaced by
medium to coarse silt-sized non-ferroan dolomite. No
dolomitization is seen in the lower Paola.

Total Paola thickness: 2' (60 cm).

Total Iola thickness: 9' (2.7 m).

CHANUTE SHALE

C1 24"+ (60+ cm) Shale, greenish-gray, slightly silty
with thin coal streaks. Illite, illite-mixed layer,
chlorite, kaolinite.

K32 Roadcut (K32)

Roadcut on north side of Kansas state route 32 in Wyandotte Co., Kansas.

SW SE SW sec. 7, T11S, R25E.

LANE SHALE

L1 12"+ (30+ cm) Shale, gray, with thin siltstone layers.

IOLA LIMESTONE

Raytown Limestone Member

R5 34" (86 cm) Skeletal calcilutite (wackestone), buff to light gray. Bryozoans, echinoderm debris and brachiopods. Minor sponges, gastropods, bivalves and phylloid algae. Micrite envelopes are present. Very slight replacement of matrix by silt-sized non-ferroan dolomite.

R4 12" (30 cm) Algal-rich skeletal calcilutite (wackestone), buff to tan. Brachiopods, bryozoans and abundant phylloid algae. Minor ostracodes, fusulines, bivalves and trilobites. Minor replacement of matrix by fine to medium silt-sized non-ferroan dolomite.

R3 18" (46 cm) Algal-rich to sparry algal-rich skeletal calcilutite (wackestone), light gray, peloidal matrix. Diverse biota with brachiopods, echinoderm debris,

encrusting foraminifers, bryozoans, and abundant phylloid algae. Minor bivalves, fusulines, ostracodes, trilobites and gastropods. Conspicuous sheltered-void spar. Silt-sized non-ferroan dolomite partly replaces skeletal grains and matrix.

R2 5" (13 cm) Shale, gray, calcareous, slightly silty, with echinoderm debris and brachiopods.

R1 7" (18 cm) Skeletal calcarenite (grainstone), yellow-brown, argillaceous, with echinoderm debris, brachiopods, encrusting foraminifers, trilobites, ostracodes, bivalves and bryozoans. Most skeletal grains are encrusted by foraminifers. Sutured grain contacts. Blocky ferroan-calcite interparticle spar. Medium to coarse grained quartz silt, very fine quartz sand, minor glauconite.

Total Raytown thickness: 6'4" (1.9 m).

Muncie Creek Shale Member

M3 3" (8 cm) Shale, gray, calcareous, slightly silty, minor echinoderm and brachiopod debris.

M2 20" (51 cm) Shale, dark gray at base, grading upwards into black, fissile phosphatic shale. Conodonts, conularids, and orbiculoid brachiopods are visible on bedding planes.

M1 12" (30 cm) Shale, dark gray, slightly calcareous. Illite, illite-mixed layer, chlorite.

Total Muncie Creek thickness: 35" (89 cm).

Paola Limestone Member

P3 3" (8 cm) Skeletal calcilutite to calcarenite (wackestone to packstone), medium brown, argillaceous, with bryozoans, brachiopods, encrusting foraminifers, red algae. Minor coarse quartz silt to very fine sand. Burrowed, peloidal matrix. Matrix and skeletal grains replaced in part by non-ferroan silt-sized dolomite.

P2 12" (30 cm) Skeletal calcilutite (packstone to wackestone), light brown, slightly silty. Diverse biota with echinoderm debris, laminate algal?/foraminifer encrustations, bryozoans and brachiopods. Minor red algae, fusulines, dasycladacean algae, trilobites and ostracodes.

P1 1" (2.5 cm) Skeletal calcarenite (packstone), light brown, weathers yellow-orange. Argillaceous, slightly silty. Echinoderm debris, brachiopods, encrusting foraminifers and red algae. Minor gastropods, bryozoans, bivalves, fusulines and sponge spicules.

Total Paola thickness: 1'4" (40.5 cm).

Total Iola thickness: 10'7" (3.2 m).

CHANUTE SHALE

C1 10' (3 m) Shale, greenish-gray, sandy. Illite, chlorite.

Quarry west of Paola (QWP)

Quarry approximately one mile west of Paola in Miami
Co., Kansas.

SE sec. 18, T17S, R23E.   (Paola West 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R3 61" (1.5 m) (Bush City bed) Skeletal calcilutite to
calcarenite (wackestone to packstone). Buff, weathering
orange. Foraminifer-encrusted grains, brachiopods,
bryozoans, sponges, bivalves, echinoderm debris,
gastropods, phylloid algae. Micrite envelopes present.
Vaguely peloidal matrix with minor medium to coarse quartz
silt. Matrix partly replaced by medium to coarse silt-
sized non-ferroan dolomite rhombs.

R2 8'4" (2.5 m) Shale, gray, silty, with brachiopods,
bryozoans, echinoderm debris and sponges. Illite,
kaolinite, chlorite.

R1 11.5' (3.5 m) Algal-rich skeletal calcilutite
(wackestone), light gray to buff. Diverse biota with
brachiopods, bryozoans, echinoderm debris, bivalves,
encrusting foraminifers, and abundant phylloid algae.
Conspicuous sheltered-voids filled with blocky calcite
spar.

Extensive replacement of matrix at top of unit by silt-sized, non-ferroan dolomite. Minor replacement of skeletal grains by ferroan and non-ferroan dolomite. Bottom of unit is covered by water.

Total Raytown thickness: 25' (7.5 m).

Poor Farm East (PFE)

Section exposed in section road directly east of cemetary, approximately 2 miles northwest of Paola in Miami Co., Kansas.

South edge of SW SW sec. 6, T17S, R23E. (Paola West 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R6   6"   (15 cm)   Calcilutite, orange, weathered; sparsely fossiliferous with brachiopods and echinoderm debris.

R5   22.5"   (57 cm)   Covered interval.

R4   6"   (15 cm)   Skeletal calcilutite, buff, weathers orange.   Phylloid algae, brachiopods and bryozoans.

R3   6"   (15 cm)   Covered interval.

R2   4.5"   (11.5 cm)   Skeletal calcilutite, buff, weathers yellow-orange.   Phylloid algae, brachiopods and bryozoans.

R1   4.5"   (11.5 cm)   Skeletal calcarenite, tan, weathers yellow-orange.   Brachiopods, echinoderm debris and bryozoans.

Total Raytown thickness: 3'9"   (1.4 m).

Muncie Creek Shale Member

M1   4"   (10 cm)   Shale, gray, with phosphate nodules. Illite, illite-mixed layer, kaolinite, minor chlorite.

Total Muncie Creek thickness: 4"   (10 cm).

Paola Limestone Member

P3 9" (23 cm) Skeletal calcilutite (wackestone), brown. Abundant phylloid algae, ostracodes, echinoderm debris, bryozoans, bivalves, gastropods and encrusting foraminifers. Minor replacement of originally aragonitic grains by dolomite and ferroan dolomite.

P2 7.5" (19 cm) Covered interval.

P1 3" (8 cm) Fossiliferous fine-grained sandstone with brachiopods and echinoderm debris. Grades into algal-rich, skeletal-peloidal calcarenite (packstone). Red algae, encrusting foraminifers, gastropods, brachiopods, echinoderm debris, bivalves, foraminifers and fusulines.

Total Paola thickness: 19.5" (50 cm).

Total Iola thickness: 5'8" (1.74 m).

CHANUTE SHALE

C1 2'+ (60+ cm) Shale, gray, silty. Illite, illite-mixed layer, kaolinite, minor chlorite.

Osawatomie Roadcut (OSA)

Roadcut on east side of "new" U.S. Highway 169, north of Marais des Cygnes River bridge in Miami Co., Kansas. SW sec. 1, T18S, R22E (Osawatomie 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R2 10' (3.0 m) Skeletal calcilutite (wackestone), yellow-brown. Conspicuous phylloid algae, bryozoans, brachiopods and echinoderm debris. Minor ostracodes, bivalves, encrusting foraminifers and gastropods. Vaguely peloidal matrix. Equant calcite spar fills sheltered-voids. Abundance of phylloid algae decreases towards top of unit.

R1 6" (15 cm) Skeletal calcilutite (wackestone), yellow-brown, minor medium to coarse quartz silt. Echinoderm debris, brachiopods and bryozoans, minor ostracodes and trilobites. Matrix is partly replaced by coarse silt-sized non-ferroan dolomite.

Total Raytown thickness: 10.5' (3.15 m).

Muncie Creek Shale Member

M1 6" (15 cm) Shale, yellow-gray, slightly silty, with phosphate nodules. Illite, illite-mixed layer, kaolinite, chlorite.

Total Muncie Creek thickness: 6" (15 cm).

Paola Limestone Member

P2 35" (90 cm) Skeletal calcilutite (wackestone) light tan to buff. Phylloid algae, brachiopods, bryozoans, echinoderm debris, encrusting foraminifers; minor ostracodes and bivalves. Foraminifer-encrusted grains abundant in upper portion of unit. Matrix vaguely peloidal (peloids are 0.1 to 0.2 mm in diameter). Sheltered-voids are filled with equant non-ferroan calcite spar. Matrix and skeletal debris replaced in part by coarse silt-sized non-ferroan dolomite.

P1 1" (2.5 cm) Fossiliferous, fine-grained sandstone. Minor mica and glauconite. Echinoderm debris, brachiopods, encrusting foraminifers, and bryozoans. Grades upward to sandy skeletal calcarenite (packstone) with minor coarse silt-sized non-ferroan dolomite.

Total Paola thickness: 3' (93 cm).

Total Iowa thickness: 14' (4.2 m).

CHANUTE SHALE

C1 10'+ (3.0+ m) Shale, silty, slumped.

Quarry east of Garnett (QEG)

Quarry on east side of creek, approximately 8.5 miles east of Garnett, in Anderson Co., Kansas.

SE sec. 33, T20S, R21E.   (Garnett SE 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R3   27"   (70 cm)   Encrusted-grain skeletal calcilutite (wackestone to packstone), gray, weathers orange-yellow, slightly cherty.   Echinoderm debris, bryozoans, sponges and abundant foraminifer/algae-encrusted grains.   Minor gastropods and trilobites.   Extensive replacement of skeletal grains and mud matrix at base of unit by silt to fine sand-sized non-ferroan and ferroan dolomite.

R2   9"   (23 cm)   Shale, light gray, weathers yellow-orange, minor quartz silt.   Interbedded with thin argillaceous skeletal calcilutite (wackestone to packstone), with brachiopods, echinoderm debris, bryozoans, encrusting foraminifers, minor ostracodes, bivalves and gastropods. Minor replacement of mud matrix by non-ferroan medium to coarse silt-sized dolomite.   Minor blocky, fracture-filling ferroan-calcite spar.

R1   9'   (2.7 m)   Skeletal calcilutite (packstone), buff. Diverse biota including echinoderm debris, brachiopods, bryozoans and locally conspicuous phylloid algae.   Minor

gastropods, bivalves, ostracodes and encrusing
foraminifers. Grains are micritized. Peloidal matrix with
well-preserved, discrete peloids 0.05 to 0.5 mm in
diameter. Minor infilling of leached skeletal grains with
non-ferroan, silt-sized dolomite. Bottom of unit is
covered.

Total Raytown thickness: 15' (3.6 m).

Roadcut near Sugar Creek (BCRS)

Roadcut on west side of section road approximately one mile southeast of Bush City in Anderson Co., Kansas. NE corner, sec. 30, T21S, R21E. (Bush City 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R1 7' (2.1 m) Skeletal calcilutite (packstone to wackestone), buff, weathers orange-brown. Biota includes brachiopods, echinoderm debris, bryozoans, encrusting foraminifers and abundant phylloid algae. Minor ostracodes, gastropods and bivalves. Peloidal matrix. Slight replacement of matrix and skeletal grains at base of unit by silt-sized, non-ferroan dolomite

Total Raytown thickness: 7' (2.1 m).

Muncie Creek Shale Member

M1 3" (8 cm) Shale,yellow-gray, flaky, slightly sandy, micaceous, with phosphate nodules.

Total Muncie Creek thickness: 3" (8 cm).

Paola Limestone Member

P3 9" (23 cm) Algal-rich skeletal calcilutite (wackestone), yellow-brown. Diverse biota includes brachiopods, echinoderm debris, gastropods, encrusting foraminifers, bryozoans, sponges, trilobites and abundant

phylloid algae. Micrite envelopes are present. Burrowed peloidal maxtrix. Very minor replacement of skeletal grains by non-ferroan silt-sized dolomite. Minor coarse quartz silt. Hummocky upper surface.

P2 35" (90 cm) Algal-rich skeletal calcilutite (wackestone to packstone), light gray, weathers orange. Brachiopods, echinoderm debris, encrusting foraminifers, bryozoans and abundant phylloid algae. Conspicuous sheltered-voids are filled with blocky, non-ferroan calcite spar.

P1 2" (5 cm) Skeletal calcilutite to calcarenite (packstone), medium gray, weathers orange. Sandy, slightly silty. Echinoderm debris, brachiopods and bryozoans. Minor trilobites and foraminifers. Minor replacement of matrix by medium to coarse silt-sized non-ferroan dolomite.

Total Paola thickness: 3.8' (1.2 m).

Total Iola thickness: 10.8' (3.4 m).

Quarry south of Bush City (QSBC)

Quarry just north of section road, approximately 2 miles southeast of Bush City in Anderson Co., Kansas. SE SE sec. 30, T21S, R21E. (Bush City 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member (Units R4 through R6 make up the Bush City bed)

R6 . 18" (46 cm) Encrusted-grain skeletal calcilutite (wackestone), buff, weathers orange-yellow. Abundant foraminifer-encrusted grains, echinoderm debris, bryozoans, encrusting foraminifers, sponges; minor gastropods, bivalves, ostracodes and trilobites. Micritized grains abundant. Peloidal matrix. Lime mud and skeletal debris are partly replaced by medium to coarse silt-sized non-ferroan dolomite. Minor medium to coarse quartz silt.

R5 12" (30 cm) Shale, light gray, weathers yellow-orange, slightly calcareous, with abundant bryozoans, brachiopods and echinoderm debris. Illite, chlorite, illite-mixed layer, and kaolinite. Minor quartz and feldspar. Thin, yellow-orange skeletal calcilutite (wackestone) near top of unit, with echinoderm debris, brachiopods, bryozoans, and abundant foraminifer/algal(?)-encrusted grains.

R4 35" (90 cm) Encrusted-grain skeletal calcilutite

(wackestone), buff to light gray, weathers orange-brown. Diverse biota with echinoderm debris, sponges, brachiopods, bryozoans, encrusting foraminifers; minor trilobites, ostracodes, gastropods. Extensive replacement of matrix by non-ferroan dolomite.

R3 12" (30 cm) Shale, light gray, weathers orange-yellow, slightly calcareous, with echinoderm debris and brachiopods. Illite, kaolinite, illite-mixed layer, chlorite.

R2 12" (30 cm) Skeletal calcarenite (packstone to grainstone), light gray, weathers orange-brown. Brachiopods, echinoderm debris, bryozoans and phylloid algae. Minor gastropods, bivalves and encrusting foraminifers. Extensive grain micritization. Minor replacement of mud matrix by silt-sized, non-ferroan dolomite.

R1 9'3" (2.8 m) Skeletal calcilutite (wackestone), buff to light gray. Diverse biota with brachiopods, bryozoans, echinoderm debris and abundant phylloid algae. Minor gastropods and ostracodes. Blocky calcite spar is conspicuous as sheltered-void filling. Minor replacement of skeletal debris and matrix by non-ferroan medium silt to very fine sand-sized dolomite.

Total Raytown thickness: 16.7' (5.1 m).

Quarry east of Kincaid (QEK)

Quarry on north side of Kansas state route 31-52, approximately 1.5 miles east of Kincaid in Anderson Co., Kansas.

SW sec. 32, T22S, R21E.   (Kincaid 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R3 66" (1.7 m)   Skeletal calcilutite (wackestone), slightly dolomitized, yellow-orange, weathered.   Thin shale partings.   Diverse biota includes bryozoans, echinoderm debris, brachiopods and phylloid algae; minor ostracodes, bivavles, gastropods and foraminifers.   Thin-bedded relative to more massive lower Raytown.

R2 71" (1.8 m)   Skeletal calcilutite (skeletal wackestone to algal-rich skeletal wackestone), buff to light gray. Bryozoans, brachiopods, echinoderm debris and abundant phylloid algae.   Minor skeletal grains include ostracodes, bivalves and encrusting foraminifers.   Conspicuous sheltered-voids filled with blocky calcite spar, minor fracture-filling spar.   Minor replacement of skeletal debris and lime mud matrix by medium to coarse silt-sized non-ferroan dolomite.   Coarser (sand-sized), ferroan-dolomite is associated with stylolitization and blocky fracture-filling calcite spar.

R1 32" (81 cm) Skeletal calcilutite (wackestone).
Extensively dolomitized at base; skeletal debris and matrix
material is replaced by medium to coarse silt-sized non-
ferroan dolomite, intercrystalline pore space is filled
with coarser (fine sand-sized) ferroan-dolomite. Diverse
biota includes brachiopods, echinoderm debris, bryozoans,
encrusted grains and encrusting foraminifers in addition to
minor gastropods and bivalves.

Total Raytown thickness: 14.1' (4.4 m).

Muncie Creek Shale Member

M1 2" (5 cm) Shale, gray, with phosphate nodules.

Total Muncie Creek thickness: 2" (5 cm).

Paola Limestone Member

P1 Top of Paola exposed in quarry floor. Skeletal
calcilutite (wackestone), light brown, dolomitic. Abundant
echinoderm debris. Hummocky upper surface with embedded
phosphate nodules.

Total Iola thickness: 14.25' (4.4 m).

Kincaid Railroad Overpass (KRR)

Roadcut on north side of Kansas state route 31-52, immediately west of railroad overpass in town of Kincaid in Anderson Co., Kansas.

SW corner sec. 31, T22S, R21E. (Kincaid 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member (Units R3 through R9 make up the Bush City bed)

R9   3"   (8 cm)   Encrusted-grain skeletal calcilutite (wackestone), orange-brown. Brachiopods, echinoderms, sponges, encrusting foraminifers and abundant encrusted grains. Minor gastropods, trilobites and bivalves. Minor replacement of skeletal grains and lime mud matrix by coarse silt-sized non-ferroan dolomite. Minor medium to coarse quartz silt.

R8   2"   (5 cm)   Shale, yellow-gray, slightly silty, slightly calcareous. Brachiopods and echinoderm debris.

R7   2"   (5 cm)   Skeletal calcilutite (wackestone), orange-brown, encrusted grains, brachiopods, echinoderm debris, sponges, bryozoans, gastropods and encrusting foraminifers. Minor replacement of matrix by medium to coarse silt-sized non-ferroan dolomite.

R6 3" (8 cm) Shale, yellow-gray, slightly silty, slightly calcareous.

R5 2" (5 cm) Skeletal calcilutite (wackestone), orange-brown, encrusted grains, bryozoans, brachiopods, echinoderm debris, sponges; minor encrusting foraminifers, gastropods, ostracodes. No grain micritization or micrite envelopes present. Minor replacement of skeletal grains and lime mud matrix by silt-sized non-ferroan dolomite. Minor quartz silt, minor mica.

R4 9" (23 cm) Shale, yellow-gray, slightly silty, slightly calcareous, with echinoderm debris and brachiopods.

R3 15" (38 cm) Skeletal calcilutite (wackestone), orange-brown, wavy-bedded, with brachiopods, echinoderm debris, sponges, bryozoans and gastropods. Minor bivalves, and encrusting foraminifers. Slight replacement of skeletal grains and lime mud matrix by silt-sized non-ferroan dolomite. Minor quartz silt and mica.

R2 2" (5 cm) Shale, yellow-gray, slightly silty, slightly calcareous.

R1 17" (43 cm) Skeletal calcilutite (wackestone to packstone), orange-brown, wavey-bedded echinoderm debris, brachiopods, bryozoans and encrusting foraminifers. Minor gastropods, bivalves and ostracodes. Extensive replacement of lime mud, minor replacement of skeletal debris by medium

silt to very fine sand-sized non-ferroan dolomite. Base of unit is not exposed.

Total Raytown thickness: 4.6' (1.4 m).

Katy Lake Outcrop (KTL)

Roadcut on east side of U.S. Highway 59, approximately 3 miles north of Moran in Allen Co., Kansas.

NW NW sec. 13, T24S, R20E. (Moran 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R2 81" (2.0 m) Algal-rich skeletal calcilutite to sparry algal-rich skeletal calcilutite (wackestone), buff to tan, irregular thin to medium-bedded. Vaguely peloidal matrix. Minor dolomite. Abundant phylloid algae with brachiopods and bryozoans. Conspicuous blocky calcite spar fills sheltered-voids formed by phylloid algae blades. 30-foot (10 m) lens of algal "sparite" 3 ft. (1 m) above Raytown/Muncie Creek contact. Sparite consists of coarse, cloudy, yellow-brown, calcite crystals with rusty-weathering patches of ferroan dolomite. Sharp lower contact, upper contact is gradational with sparry algal calcilutite.

R1 3" (7.5 cm) Skeletal calcarenite to calcilutite (wackestone to packstone). Yellow-orange, thin platy beds, minor very fine sand and coarse silt-sized quartz. Abundant and diverse biota with echinoderm debris, brachiopods, bryozoans, encrusting foraminifers. Minor red algae and trilobites. Minor replacement of skeletal grains

by medium to coarse silt-sized non-ferroan dolomite.
Extensive replacement of matrix by non-ferroan, coarse
silt-sized dolomite.

Totay Raytown thickness: 84" (2.1 m).

Muncie Creek Shale Member

M1 3" (7.5 cm) Shale, yellow-gray, with phosphate
nodules in lower portion of unit.

Total Muncie Creek thickness: 3" (7.5 cm).

Paola Limestone Member

P3 3" (7.5 cm) Skeletal calcilutite (wackestone), brown.
Brachiopods, echinoderm debris, encrusting foraminifers,
gastropods, red phylloid algae, bryozoans, bivalves, and
ostracodes. Matrix is partly replaced by medium to coarse
silt-sized non-ferroan dolomite. Minor dolomitization of
originally aragonitic skeletal debris. Hummocky upper
surface.

P2 18" (46 cm) Skeletal calcilutite (wackestone), brown,
peloidal matrix. Brachiopods, encrusting foraminifers,
conspicuous phylloid algae, gastropods, bivalves,
bryozoans, and ostracodes. Sheltered-void filling spar and
matrix replaced in part by medium to coarse silt-sized non-
ferroan dolomite.

P1 4" (10 cm) Skeletal calcarenite (packstone), brown,
argillaceous, slightly sandy, platy. Diverse and abundant
biota with echinoderm debris, brachiopods, encrusting

foraminifers and bryozoans. Minor trilobites, ostracodes and bivalves. Extensive replacement of matrix by medium to coarse silt-sized non-ferroan dolomite. Minor embayment of skeletal grains by non-ferroan dolomite. Ferroan dolomite fills intercrystalline pore space.

Total Paola thickness: 25" (63.5 cm).

Total Iola thickness: 9'4" (2.8 m).

CHANUTE SHALE

C1 12"+ (30+ cm) Shale, gray, sandy, poorly exposed. Chlorite, kaolinite, illite, illite-mixed layer.

Lehigh Portland Cement Company Quarry (LEH)

Quarry south of Iola in Allen Co., Kansas.

E sec. 2, T25S, R18E.   (Iola 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member (Units R4 through R16 make up the
Bassett beds, Units R18 through R22 make up the Owl Creek
beds)

R22 6" (15 cm) Skeletal calcarenite (grainstone), brown-
orange, very thin-bedded, intraclastic. Abundant ooids,
approximately 0.3 to 0.7 mm in diameter. Very fine to
fine-grained quartz sand. Brachiopods, echinoderm debris,
foraminifer/algal(?)-encrusted sponges and cephalopods.
Minor gastropods, bryozoans and bivalves. Equant, blocky,
non-ferroan and ferroan calcite interparticle spar. No
dolomitization.

R21 12" (30 cm) Skeletal calcarenite (grainstone),
brown-orange. Oolitic, intraclastic, coarse silt to fine-
grained quartz sand. Foraminifer-encrusted grains,
bryozoans, echinoderm debris, brachiopods, sponges,
gastropods, encrusting foraminifers and trilobites.
Equant, blocky, non-ferroan and ferroan calcite
interparticle cement. No dolomitization.

R20 24" (60 cm) Skeletal calcarenite (packstone to
grainstone), yellow-brown, cross-bedded, very fine-grained

quartz sand, minor glauconite. Echinoderm debris, bryozoans, brachiopods, foraminifer-encrusted grains, encrusting foraminifers, gastropods, bivalves and trilobites. Minor silt-sized ferroan dolomite scattered throughout matrix.

R19 13" (33 cm) Shale, gray, calcareous, with echinoderm debris, brachiopods, bryozoans and sponges. Lenses and nodules of cemented skeletal debris scattered throughout shale.

R18 5" (13 cm) Skeletal calcarenite (packstone to grainstone), dark gray, discontinuous. Echinoderm debris, bryozoans, brachiopods, sponges, foraminifer-encrusted grains, trilobites, bivalves and encrusting foraminifers. Abraded and rounded grains, no micrite envelopes present. Minor dolomitization.

R17 10" (26 cm) Shale, light to medium gray, calcareous, with brachiopods, echinoderm debris and bryozoans.

R16 5" (13 cm) Skeletal calcilutite (wackestone), light gray, slightly argillaceous. Brachiopods, sponges, encrusting foraminifers, echinoderm debris, gastropods, bryozoans and foraminifer-encrusted grains. Skeletal grains micritized. Slight replacement of skeletal grains by silt-sized, non-ferroan dolomite.

R15 26" (66 cm) Shale, light to medium gray, calcareous. Echinoderm debris, brachiopods, sponges and bryozoans.

R14 2" (5 cm) Skeletal calcilutite (wackestone), light gray. Brachiopods, bryozoans, echinoderm debris, encrusting foraminifers, ostracodes, sponges, trilobites and bivalves. Extensive replacement of matrix by silt-sized non-ferroan dolomite.

R13 4" (10 cm) Shale, light to medium gray, calcareous.

R12 2" (5 cm) Skeletal calcilutite (wackestone), light gray, slightly argillaceous. Echinoderm debris, brachiopods, bryozoans, encrusting foraminifers, gastropods and foraminifer-encrusted grains. Vaguely laminated peloids, 0.1 to 1.0 mm in diameter. Slight replacement of matrix by silt-sized non-ferroan dolomite.

R11 1" (2.5 cm) Shale, light to medium gray, calcareous.

R10 13" (33 cm) Skeletal calcilutite (wackestone), light gray, argillaceous. Bryozoans, brachiopods, echinoderm debris, bivalves, encrusting foraminifers, trilobites, ostracodes and sponges. Mud matrix is extensively replaced by silt-sized non-ferroan and ferroan dolomite.

R9 2" (5 cm) Shale, light to medium gray, calcareous.

R8 9" (23 cm) Skeletal calcilutite (wackestone), light gray, argillaceous. Brachiopods, bryozoans, echinoderm debris, encrusting foraminifers, sponges, trilobites, gastropods, encrusted grains, bivalves. Peloidal matrix. Matrix is extensively replaced by coarse silt-sized ferroan and non-ferroan dolomite.

R7 1" (2.5 cm) Shale, light to medium gray, calcareous.

R6 2" (5.0 cm) Skeletal calcilutite (wackestone), medium gray. Bryozoans, brachiopods, echinoderm debris, sponges, gastropods, encrusting foraminifers and dasycladacean algae. Extensive replacement of matrix, minor replacement of skeletal grains by medium to coarse silt-sized non-ferroan dolomite. Minor coarsely-crystalline ferroan dolomite replacement of skeletal debris.

R5 1" (2.5 cm) Shale, light to medium gray, calcareous.

R4 4" (10 cm) Skeletal calcilutite (wackestone), medium to light gray. Brachiopods, echinoderms, sponges and bryozoans. Matrix partly replaced by silt-sized, non-ferroan dolomite.

R3 16" (41 cm) Shale, light to medium gray, calcareous, with echinoderm debris, brachiopods and bryozoans.

R2 12" (30 cm) Skeletal calcarenite (packstone), brownish-gray, minor coarse silt to very fine quartz sand, peloidal. Brachiopods, bryozoans, echinoderm debris, gastropods and encrusting foraminifers. Minor bivalves, gastropods and phylloid algae. Matrix partly replaced by coarse silt-sized, non-ferroan dolomite. Thin shale split (1", 2.5 cm) separates this unit from underlying limestone.

R1 18" (46 cm) Skeletal calcilutite (wackestone), medium gray, stylolitic. Diverse biota includes bryozoans, echinoderm debris, brachiopods, encrusting foraminifers and

phylloid algae. Minor gastropods and fusulines. Slight
replacement of mud matrix and skeletal grains by
silt-sized, non-ferroan and ferroan dolomite rhombs.
Blocky ferroan and non-ferroan calcite fracture-filling
spar. An additional 35 feet (10.5 m) of Raytown exposed in
this quarry was not described due to inaccessibility.
Total Raytown thickness: 50.5' (15.2 m).

Owl Creek Beds (OCK)

Exposures along north bank of Owl Creek, approximately
3 miles west of Humbolt in Allen Co., Kansas.

NE SE sec. 1, T26S, R17E.   (Humbolt 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R2   24"   (60 cm)   Skeletal calcarenite, gray, weathers
yellow-orange, cross-bedded, glauconitic. Diverse biota
with foraminifer-encrusted grains, brachiopods, bryozoans,
echinoderm debris, encrusting foraminifers and sponges.

R1   12"+   (30+ cm)   Shale, dark yellow-gray, with abundant
echinoderm debris, brachiopods and broyzoans. Bottom of
unit is not exposed.

Total Raytown thickness: 3'+   (90+ cm).

<center>Monarch Cement Company Quarry (HUM)</center>

Quarry on east side of U.S. Highway 169, approximately one mile south of Humboldt in Allen Co., Kansas. SE sec. 9, T26S, R18E. (Humbolt 7 1/2' Quadrangle).

Upper Portion of Quarry

LANE SHALE

L1 7'+ (2+ m) Shale, tan to brown, well developed lamination. Silty, micaceous, calcareous. Illite, illite-mixed layer, chlorite, kaolinite.

IOLA LIMESTONE

Raytown Limestone Member (Units R4 through R8 are Owl Creek beds)

R8 7" (18 cm) Oolite to skeletal calcarenite (grainstone), yellow-brown, very fine to fine quartz sand. Biota includes sponges, encrusting foraminifers, echinoderm debris, brachiopods, gastropods, and foraminifer-encrusted grains. Minor ostracodes, bryozoans and bivalves. Micrite envelopes are present; sutured grain contacts abundant. Blocky ferroan and non-ferroan calcite interparticle spar. Ooids are approximately 0.1 to 0.8 mm in diameter. Minor dolomitization of skeletal grains.

R7 9" (23 cm) Shale, yellow-brown, calcareous; with sponges. Lenses of skeletal calcarenite scattered throughout unit.

R6 3" (8 cm) Skeletal calcarenite (packstone to grainstone), orange-brown, argillaceous, very slightly sandy. Echinoderm debris, encrusting foraminifers, brachiopods, foraminifer-encrusted grains. Minor bryozoans, trilobites, gastropods and bivalves. Minor dolomitization.

R5 14" (36 cm) Shale, orange-brown, calcareous, with brachiopods, echinoderm debris and sponges. Skeletal calcarenite lenses are present throughout unit.

R4 9" (23 cm) Skeletal calcarenite (packstone), yellow-brown, argillaceous; with echinoderm debris, brachiopods, bryozoans, encrusting foraminifers and foraminifer-encrusted grains. Minor gastropods and bivalves. Micrite envelopes present. Minor quartz sand and silt, very minor mica. Minor dolomitization of matrix.

R3 26" (66 cm) Shale, gray, weathers orange-yellow. Bryozoans, sponges and echinoderm debris. Lenses of skeletal calcarenite throughout unit.

R2 3' (0.9 m) Covered interval.

R1 18"+ (46+ cm) Algal calcilutite, tan to gray. Abundant phylloid algae, brachiopods, bryozoans and echinoderm debris. Minor encrusting foraminifers,

gastropods and bivalves. Micrite envelopes present; many
skeletal grains are heavily micritized. Peloidal matrix.
Minor replacement of matrix by non-ferroan silt-sized
dolomite rhombs. Blocky calcite spar is conspicuous as
sheltered-void filling. An additional 38 feet (11.6 m) of
Raytown is exposed in the quarry.

Lower Portion of Quarry

IOLA LIMESTONE

Raytown Limestone Member

R2(lower)   24"   (60 cm)   Skeletal calcilutite (wackestone),
buff to light gray. Brachiopods, bryozoans and conspicuous
phylloid algae.

R1(lower)   2"   (5 cm)   Skeletal calcilutite (wackestone),
tan to buff, argillaceous, slightly silty. Echinoderm
debris, encrusting foraminifers, brachiopods and bryozoans.
Extensive replacement of matrix by fine to medium silt-
sized non-ferroan dolomite. Minor replacement of skeletal
grains by silt-sized, non-ferroan and coarse sand-sized
ferroan dolomite. Ferroan dolomite fills intercrystalline
pore space.

Total Raytown thickness: 48'4"   (14.5 m).

Muncie Creek Shale Member

M1   2"   (5 cm)   Shale, yellow-gray, with phosphate nodules,
sparse echinoderm debris. Illite, kaolinite, illite-mixed

layer, chlorite.

Total Muncie Creek thickness: 2" (5 cm).

Paola Limestone Member

P2 20" (51 cm) Skeletal calcilutite (wackestone), light gray. Diverse biota with brachiopods, phylloid algae, echinoderm debris, encrusting foraminifers, gastropods and bryozoans. Hummocky upper surface. Burrowed, vaguely peloidal matrix. Burrows, sheltered-void fillings, fracture-fillings are all partly replaced by non-ferroan dolomite.

P1 2" (5 cm) Skeletal calcilutite (wackestone), medium to dark gray, platy, thin-bedded, argillaceous. Minor quartz silt to very fine-grained sand. Echinoderm debris, brachiopods, bryozoans and encrusting foraminifers. Minor plant fragments. Very minor, relatively coarsely crystalline (0.2 to 0.4 mm) rhombs of ferroan dolomite.

Total Paola thickness: 22" (56 cm).

Total Iola thickness: 50'4" (15.1 m).

CHANUTE SHALE

C1 12"+ (30+ cm) Shale, medium gray, with plant fragments. Illite, kaolinite, chlorite.

Ash Grove Cement Quarry (AGQ)

Quarry on south side of Kansas state route 39, just west of town of Chanute in Neosho Co., Kansas.

SW sec. 24, T27S, R17E.   (Chanute 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R4 8" (18 cm) Skeletal calcarenite (packstone), orange-brown, heavily weathered, sandy. Echinoderm debris, foraminifer-encrusted grains, encrusting foraminifers, brachiopods, bryozoans; minor trilobites, gastropods, ostracodes. (= "Crustaceous" zone, local quarrymen's term).

R3 6" (15 cm) Skeletal calcarenite (packstone). Echinoderm debris, bryozoans, brachiopods. Minor gastropods, bivalves, encrusting foraminifers, ostracodes, trilobites, coral. Micrite envelopes present; grains abraded and rounded.

R2 30' (9.2 m) Algal-rich skeletal calcilutite to sparry algal-rich skeletal calcilutite (wackestone), light gray to brown, massive, medium to thick-bedded; with echinoderm debris, brachiopods, and bryozoans. Vaguely peloidal matrix. Algal blades typically shelter blocky calcite spar-filled voids. Abundant fracture-filling spar. Top of unit is intraclastic.

R1 8' (2.4 m) Skeletal calcilutite (wackestone to
packstone), light gray, with thin fossiliferous shale
partings. Diverse and abundant biota with brachiopods,
echinoderm debris, bryozoans and locally abundant phylloid
algae. Extensively dolomitized adjacent to shale partings.
Total Raytown thickness: 39'2" (11.9 m).

Muncie Creek Shale Member

M1 4.5" (11.5 cm) Shale, dark gray, with echinoderm and
brachiopod debris. Abundant phosphate nodules in lower
portion of shale.
Total Muncie Creek thickness: 4.5" (11.5 cm).

Paola Limestone Member

P1 12" (30 cm) Skeletal calcilutite (wackestone to
packstone), medium brown, minor coarse silt to very fine
quartz sand. Argillaceous at contacts with overlying and
underlying shales. Echinoderm debris, brachiopods,
encrusting foraminifers, minor bivalves, fusulines,
foraminifer-encrusted grains, ostracodes, gastropods.
Vaguely peloidal matrix. Replacement of matrix by silt-
sized, non-ferroan dolomite. Degree of dolomitization
increases upwards.
Total Paola thickness: 12" (30 cm).
Total Iola thickness: 40'7" (12.3 m).

CHANUTE SHALE

C1 51"+ (1.3+ m) Shale, light gray, silty, with thin coal.

Earlton North Core (ENC)

Core taken for this project on west side of section road, approximately 1.5 miles north of the town of Earlton in Neosho Co., Kansas.

SW corner NW sec. 17, T28S, R18E. (Earlton 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R1   3'+   (90+ cm)   Skeletal calcilutite to calcarenite (wackestone to packstone), with very fine quartz sand and coarse silt, minor mica.   Bryozoans, echinoderm debris, brachiopods, bivalves, encrusting foraminifers and trilobites.   No micrite envelopes are present.   Matrix is completely replaced by coarse silt-sized, non-ferroan dolomite.   Minor embayment of skeletal grains by non-ferroan dolomite.

Total Raytown thickness: 3'+   (90+ cm).

Muncie Creek Shale Member

M1   2"   (5 cm)   Shale, gray, calcareous, with phosphate nodules.

Total Muncie Creek thickness: 2"   (5 cm).

Paola Limestone Member

P1   3"   (8 cm)   Fossiliferous sandstone, sub-angular, very fine to fine-grained quartz sand.   Echinoderm debris.

Ferroan calcite and ferroan dolomite cement. Gradational
with underlying Chanute Shale.

Total Paola thickness: 3" (8 cm).

Total Iola thickness: 3.5'+ (1.0+ m).

Three Mounds North (3MN)

Exposure in south bank of Pumpkin Creek, approximately 0.5 miles north of Three Mounds in Wilson Co., Kansas. SW SW sec. 34, T28S, R17E. (Five Mounds 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member (?)

R1 4" (10 cm) Skeletal calcarenite (grainstone), silty, sandy. Foraminifer-encrusted grains, echinoderm debris, gastropods, trilobites, bivalves and bryozoans. Micrite envelopes present, grains are abraded and rounded. Blocky, non-ferroan calcite interparticle spar. Very minor dolomitization.

Total Raytown (?) thickness: 4" (10 cm).

Muncie Creek Shale Member (?)

M1 36" (90 cm) Shale, bluish-gray, weathers yellow-brown, silty, calcareous, with brachiopods, echinoderm debris and bryozoans.

Total Muncie Creek (?) thickness: 36" (90 cm).

Paola Limestone Member (?)

P1 4" (10 cm) Skeletal calcarenite (packstone), yellow-orange. Phylloid algae, brachiopods, encrusting foraminifers, gastropods, bryozoans, ostracodes, trilobites, bivalves and fusulines. Extensive grain

micritization. Minor quartz silt. Minor replacement of
phylloid algae by silt-sized, non-ferroan dolomite. Bottom
contact of unit is covered.

Total Paola (?) thickness: 4" (10 cm).

Total Iola thickness: 3.7' (1.1 m).

Chetopa Creek (CCK)

Roadcut on north side of section road, west of bridge over Chetopa Creek in Wilson Co., Kansas.

South edge, SE SW sec. 16, T29S, R17E. (Five Mounds 7 1/2' Quadrangle).

IOLA LIMESTONE ·

Raytown Limestone Member

R4 8" (20 cm) Skeletal calcilutite (wackestone to packstone), weathers orange, slightly silty. Brachiopods, bryozoans and echinoderms; minor gastropods, encrusting foraminifers, red algae, bivalves and ostracodes.

R3 10" (25 cm) Sandstone, gray, weathers yellow-orange, slightly silty, calcareous, micaceous. Plant fragments and sparse brachiopods.

R2 6" (15 cm) Shale, gray, weathers yellow-orange, silty.

R1 12" (31 cm) Sandstone, gray, weathers yellow orange. Very fine to fine-grained quartz sand, slightly silty, calcareous. Plant fragments and indeterminate skeletal debris.

Total Raytown thickness: 3' (0.9 m).

Muncie Creek Shale Member

M3 33" (84 cm) Shale, dark to medium gray, silty, micaceous, with finely divided plant fragments.

Gradational upward into shaly siltstone, laminated, slightly calcareous.

M2 20" (51 cm) Covered interval.

M1 17" (42 cm) Shale, dark gray, grading upward into black, fissile shale. Orbiculoid brachiopods and conodonts are visible on bedding planes.

Total Muncie Creek thickness: 5'10" (1.8 m).

Paola Limestone Member

P5 7" (18 cm) Sandy, encrusted grain skeletal calcilutite (wackestone to packstone), light gray, weathers orange. Foraminifer-encrusted grains, brachiopods, echinoderm debris and encrusting foraminifers; minor bryozoans, gastropods, fusulines, trilobites and ostracodes. Peloidal matrix partly replaced by medium to coarse silt-sized non-ferroan dolomite. Hummocky upper surface.

P4 1" (2.5 cm) Shale, gray, weathers yellow-orange.

P3 4" (10 cm) Encrusted grain silty sandstone. Fine to medium-grained quartz sand, micaceous. Foraminifer-encrusted grains, echinoderm debris, brachiopods, encrusting foraminifers and ostracodes.

P2 5" (13 cm) Shale, medium gray, weathers yellow-orange, sandy silty, micaceous, calcareous, siderite nodules present. Plant fragments. Illite, illite-mixed layer, kaolinite, chlorite.

P1 7" (18 cm) Siltstone, gray, slightly sandy, micaceous, slightly calcareous. Plant fragments.

Total Paola thickness: 23" (61.5 cm).

Total Iola thickness: 10'9" (3.3 m).

CHANUTE SHALE

C2 14" (36 cm) Shale, gray, weathers yellow-orange. Coal streaks and plant fragments throughout. Gradational with overlying unit, sharp contact with underlying coal.

C1 14" (36 cm) Coal with two thin shale splits.

Outcrop near Neodesha (NEO)

Section under west end of Mill Street Bridge, southeast corner of Neodesha in Wilson Co, Kansas. Center SE SE sec. 20, T30S, R16E. (Neodesha 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R8 1.3' (40 cm) Encrusted-grain skeletal calcarenite (grainstone), orange-brown, sandy, minor glauconite. Abundant foraminifer-encrusted grains, echinoderm debris, encrusting foraminifers and brachiopods. Minor bivalves, trilobites and ostracodes. Grains are extensively micritized and bored; grain contacts are sutured. Equant ferroan-calcite interparticle spar. No dolomitization seen. Interbedded with shale, orange-brown, with echinoderm debris and brachiopods; illite, illite-mixed layer, kaolinite, and chlorite.

R7 2.1' (64 cm) Skeletal calcilutite (wackestone), weathers orange. Slightly dolomitized at base. Biota includes echinoderm debris, brachiopods, bryozoans and encrusting foraminifers. Thin shale split near top.

R6 0.1' (3 cm) Shale,yellow-orange, calcareous, with bryozoans, gastropods, brachiopods and echinoderm debris. Shale lenses out laterally.

R5 0.2' (6 cm) Skeletal calcilutite (wackestone), gray, weathers orange, irregular wavy beds. Echinoderm debris, brachiopods and encrusting foraminifers; minor bryozoans. Minor replacement of molluscs and encrusting foraminifers by blocky ferroan dolomite spar, patches of fine sand-sized non-ferroan dolomite are scattered throughout matrix.

R4 0.6' (18 cm) Shale, gray, weathers orange, calcareous; with echinoderm debris and brachiopods.

R3 0.2' (6 cm) Skeletal calcilutite (wackestone), gray, weathers orange. Very slightly sandy. Irregular wavy beds. Echinoderm debris, brachiopods and encrusting foraminifers. Minor sponges, gastropods, bryozoans, bivalves, ostracodes and trilobites. Minor grain micritization. Slightly dolomitized, molds of originally aragonitic skeletal grains are filled by coarsely-crystalline ferroan calcite and ferroan dolomite spar.

R2 0.5' (15 cm) Shale, yellow-gray, slightly silty, with echinoderm debris and brachiopods. Illite, illite-mixed layer, kaolinite, chlorite.

R1 0.5' (15 cm) Sandstone, very fine grained, silty, micaceous, carbonaceous. Sparsely fossilifrerous with brachiopods, echinoderm debris, encrusting foraminifers and gastropods.

Total Raytown thickness: 5.5' (1.7 m).

Muncie Creek Shale Member

M2 0.5' (15 cm) Shale, black to dark gray. Lower portion is fissile phosphatic black shale with conodonts, fish teeth and orbiculoid brachiopods visible on bedding planes. Black shale grades upwards into a dark gray, sandy, slightly silty shale with brachiopods and echinoderm debris. Illite, illite-mixed layer, kaolinite, chlorite.

M1 0.5' (15 cm) Shale, light gray, silty, micaceous, calcareous, with echinoderm debris and brachiopods. Illite, illite-mixed layer, kaolinite, chlorite.

Total Muncie Creek thickness: 1.0' (0.3 m).

Paola Limesone Member

P3 0.2' (6 cm) Skeletal calcilutite (wackestone), yellow-brown, slightly sady. Echinoderm debris, brachiopods and encrusting foraminifers. Minor ostracodes, trilobites, bivalves, foraminifers and foraminifer-encrusted grains. Peloidal matrix with vaguely laminated algal(?) clots 0.5 to 1.0 mm in diameter.

P2 0.5' (15 cm) Shale, calcareous, with brachiopod and echinoderm debris.

P1 0.3 to 0.7' (9 to 21 cm) Encrusted-grain skeletal calcarenite (packstone), medium gray, sandy, silty, minor mica, poorly indurated. Brachiopods, foraminifer-encrusted grains, encrusting foraminifers and echinoderm debris. Minor bivalves, bryozoans and trilobites. Micrite

envelopes, sutured grain contacts. Unit grades laterally into very calcareous, micaceous, silty sandstone.

Total Paola thickness: 1.4' (0.4 m).

Total Iola thickness: 7.4' (2.4 m).

CHANUTE SHALE

C4 0.6' (18 cm) Shale, light green-gray, sandy, silty, with coal and plant fragments. Thickness variable, scours are cut into shale.

C3 0.9' (27 cm) Coal.

C2 0.5' (15 cm) Claystone, medium to dark gray.

C1 12.3' (3.7 m) Shale, light green-gray, slightly silty, micaceous.

Stony Point East (SPE)

Ditch on north side of section road, approximately one mile east of Stony Point in Montgomery Co., Kansas. SE sec. 29, T34S, R15E. (Tyro 7 1/2' Quadrangle).

IOLA LIMESTONE

Raytown Limestone Member

R3 5" (13 cm) Skeletal calcilutite (wackestone), yellow-orange, minor quartz silt and sand. Echinoderm debris, brachiopods and bryozoans. Extensively dolomitized; carbonate mud matrix is completely replaced by coarse silt-sized, non-ferroan dolomite, skeletal grains partly dolomitized.

R2 26" (66 cm) Covered interval.

R1 5" (13 cm) Skeletal calcilutite (wackestone), yellow-orange, extremely weathered. Echinoderm debris, bryozoans, brachiopods and minor foraminifer-encrusted grains. Minor coarse quartz silt and very fine sand, glauconite. Extensive dolomitization; matrix is replaced by medium to coarse silt-sized non-ferroan dolomite. Blocky ferroan and non-ferroan calcite spar fills fractures.

Muncie Creek Shale Member

M1 18" (46 cm) Covered interval. Includes Muncie Creek Shale from P.H. Heckel field notes from late 1960s and

lower Raytown Limestone.

Total Raytown and Muncie Creek thickness: 4'6"   (1.4 m).

Paola Limestone Member

P4 2" (5 cm) Skeletal calcilutite (wackestone), yellow-orange, highly weathered. Extensively dolomitized; matrix is replaced by silt-sized non-ferroan dolomie. Echinoderm debris, bryozoans, brachiopods; minor foraminifer-encrusted grains, bivalves and gastropods. Phosphate nodules are embedded in hummocky upper surface.

P3 4.5" (11.5 cm) Covered interval.

P2 6" (15 cm) Skeleta calcilutite (wackestone), light gray, weathers orange. Slightly sandy, burrowed. No dolomitization is seen. Diverse biota includes encrusting foraminifers, echinoderm debris, brachiopods, bryozoans and sponges; minor gastropods, phylloid algae and trilobites.

P1 5" (13 cm) Skeletal calcarenite (packstoe), yellow-orange, weathered. Very fine to fine sand-sized quartz, minor glauconite. Echinoderm debris, brachiopods, bryozoans and sponges. Most skeletal grains are encrusted by foraminifers. No dolomitization.

Total Paola thickness: 17.5"   (44.5 cm).

Total Iola thickness: 6'   (1.8 m).

CHANUTE SHALE

C1 5'+ (1.5+ m) Shale, gray, weathers yellow-orange,

silty, with plant fragments. Illite, illite-mixed layer, kaolinite, chlorite.

Tyro East (TYE)

Ditch on south side of "new" U.S. Highway 166, approximately 2 miles east of Tyro in Montgomery Co., Kansas.

NW NW sec. 4, T35S, R15.   (Tyro 7 1/2' Quadrangle).

IOLA LIMESTONE

I6 9" (23 cm) Skeletal calcilutite (wackestone), brown, weathers orange-yellow, burrowed. Echinoderm debris, brachiopods, bryozoans, encrusting foraminifers and gastropods. Very minor dolomitization; slight replacement of matrix by medium to coarse silt-sized non-ferroan dolomite.

I5 14" (36 cm) Covered interval.

I4 8" (20 cm) Skeletal calcarenite (packstone to wackestone), tan, weathers orange-yellow. Abundant and diverse fauna with brachiopods, foraminifer-encrusted grains, bryozoans, echinoderm debris and encrusting foraminifers. Minor trilobites, gastropods and bivalves. Micrite envelopes are present. Very minor replacement of matrix by medium to coarse silt-sized non-ferroan dolomite.

I3 5" (13 cm) Skeletal calcilutite (wackestone), medium to dark gray, poorly indurated. Thin shale partings. Echinoderm debris, bryozoans and brachiopods; minor trilobites, fusulines and encrusting foraminifers. No

grain micritization. Extensive replacement of matrix by silt-sized non-ferroan dolomite; no dolomitization of skeletal grains.

I2 11" (28 cm) Covered interval.

I1 8" (20 cm) Encrusted-grain skeletal calcarenite (packstone to grainstone). Abundant very fine to fine-grained quartz sand. Minor mica and glauconite. Foramnifer-encrusted grains, echinoderm debris, bryozoans and encrusting foraminifers. Minor trilobites and bivalves. No dolomitization seen.

Total Iola thickness: 4.6' (1.4 m).

Canary Oil Field (CAN)

Exposure along oil field access road in northern Washington Co., Oklahoma.

SE SW sec. 8, T29N, R14E (Wann 7 1/2' Quadrangle).

IOLA LIMESTONE

Avant Limestone Member

A4 12" (30.5 cm) Skeletal calcilutite (wackestone), yellow-brown, with echinoderm debris, bryozoans, brachiopods, encrusting foraminifers; minor sponges, trilobites, bivalves. No grain micritization. Blocky ferroan calcite and non-ferroan calcite fills skeletal grain pore space.

A3 36" (91 cm) Covered interval.

A2 7.5" (19 cm) Skeletal calcitutite (wackestone), tan-buff, weathers yellow-orange, burrowed, minor medium to fine-grained quartz silt and mica. Echinoderm debris, brachiopods, bryozoans and encrusting foraminifers. No dolomitization. Ferroan calcite fills interparticle pore space and intraparticle pore space.

A1 4.5" (11.5 cm) Skeletal calcarenite (packstone), yellow-brown, minor quartz silt. Echinoderm debris, brachiopods, gastropods, bryozoans, sponges and encrusting foraminifers; minor bivalves and trilobites. Minor replacement of matrix by medium silt-sized, non-ferroan

dolomite. No replacement of skeletal debris by dolomite. Blocky ferroan and non-ferroan calcite spar fills interparticle and fracture voids.

Total Avant thickness: 5' (1.5 m).

Muncie Creek Shale Member

M1 36" (91 cm) Covered interval.

Paola Limestone Member

P1 12" (30 cm) Skeletal calcilutite (wackestone), tan to buff, weathers yellow-orange, slightly silty. Fine to medium silt-sized non-ferroan dolomite rhombs scattered throughout matrix. Brachiopods, bryozoans, echinoderm debris, sponges and encrusting foraminifers; minor ostracodes, bivalves and gastropods. Upper surface of Paola is littered with phosphate nodules.

Total Paola thickness: 12" (30 cm).

Total Iola thickness: 9' (2.7 m).

CHANUTE SHALE

C1 24"+ (61+ cm) Sandstone, gray, fine-grained, thin-bedded.

Ramona West (RAM)

Ditch on south side of paved road approximately 2.5 miles west of Ramona, in Washington Co., Oklahoma. North edge, SW sec. 30, T24N, R31E. (Ramona 7 1/2' Quadrangle).

IOLA LIMESTONE

Avant Limestone Member

A1 21" (53 cm) Skeletal calcilutite (wackestone to packstone), gray, weathers yellow-orange. Diverse biota includes echinoderm debris, brachiopods, bryozoans and encrusting foraminifers; minor red algae, ostracodes and gastropods. Minor medium to coarse quartz silt, fine quartz sand, minor mica. Basal portion of Avant Member is extensively replaced by medium to coarse silt-sized, non-ferroan dolomite. Upper portion of Avant shows little or no dolomitization.

Total Avant thickness: 21" (53 cm).

Muncie Creek Chale Member

M3 21' (6.4 m) Shale, badly weathered, mostly covered.

M2 15" (38 cm) Shale, black, fissile, with phosphate nodules.

M1 7.5" (20 cm) Shale, gray, weathers orange-yellow, silty, calcareous, with echinoderm debris, brachiopods and bryozoans. Illite, illite-mixed layer, chlorite,

kaolinite; minor quartz and feldspar.

Total Muncie Creek thickness: 22'10" (7.0 m).

Paola Limestone Member

P1 4.0" (10 cm) Skeletal calcarenite (packstone), brown, weathers orange-yellow, fine quartz sand, poorly indurated. Biota includes echinoderm debris, brachiopods, bryozoans, encrusting foraminifers, foraminifer-encrusted grains; minor gastropods and bivalves. Abundant plant fragments.

Total Paola thickness: 4" (10 cm).

Total Iola thickness: 25' (7.6 m).

CHANUTE SHALE

C1 18" (46 cm) Shale, gray, highly weathered. Coal is present at top of unit.

APPENDIX B.

MEASURED STRATIGRAPHIC SECTIONS

Figure 55. Stratigraphic column, Locality NEB.
Generalized stratigraphic section of core from
Offutt Air Force Base in Sarpy Co., Nebraska.
Lithologic symbols are standard, except closely
spaced solid black lines represent black shales
and thin brick pattern with wavy lines
represent laminated carbonate mudstone,
limestone pattern with double vertical lines
represents packstone. One sample was collected
and processed for conodonts. Abundance of
individual taxa from this sample is given as
well as sample size, exact location, and total
sample abundance and diversity. Far right-hand
column of figure gives names and locations of
petrographic thin sections. Asterisks
following thin section names indicate that
sample was point counted (see Appendix C).

OFFUTT AIR FORCE BASE CORE (NEB)
SARPY CO., NEBRASKA

GENERAL LITHOLOGY

SAMPLE LOCATION
SAMPLE SIZE (x100 GRAMS)
ADETOGNATHUS LAUTUS
AETHOTAXIS ADVENA
ANCHIGNATHODUS MINUTUS
ANCHIGNATHODUS ? SP. A
DIPLOGNATHODUS SP.
GONDOLELLA BELLA
IDIOGNATHODUS SPP.
IDIOPRIONIODUS TYPUS
STEPANOVITES CONFLEXA

◇——— DIVERSITY

●——— ABUNDANCE

TOTAL NUMBER

PETROGRAPHIC THIN SECTION NAME

LANE SHALE

IOLA LIMESTONE
RAYTOWN

P. M.CR.

CHANUTE SHALE

| | 4 | | | | | | 2 | 311 | 2 | | | 315 | |

• 2A
• 2W *
• 3B
• 6A
• 6EF *
• 6I
• 8 *
• 12

Figure 55.

Figure 56.   Stratigraphic column, Locality MAL.
Generalized stratigraphic section of core from
Malvern in Mills Co., Iowa.   Lithologic symbols
are standard except closely spaced solid lines
represent black shale; thin brick pattern with
wavy lines represent laminated carbonate
mudstone; thin brick pattern with oblique
slashes represent probable calichified
limestone; limestone with double vertical lines
with and without G represent grainstone and
packstone, respectively.   Fifteen samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diveresity.   Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared and examined from samples
selected from this core.
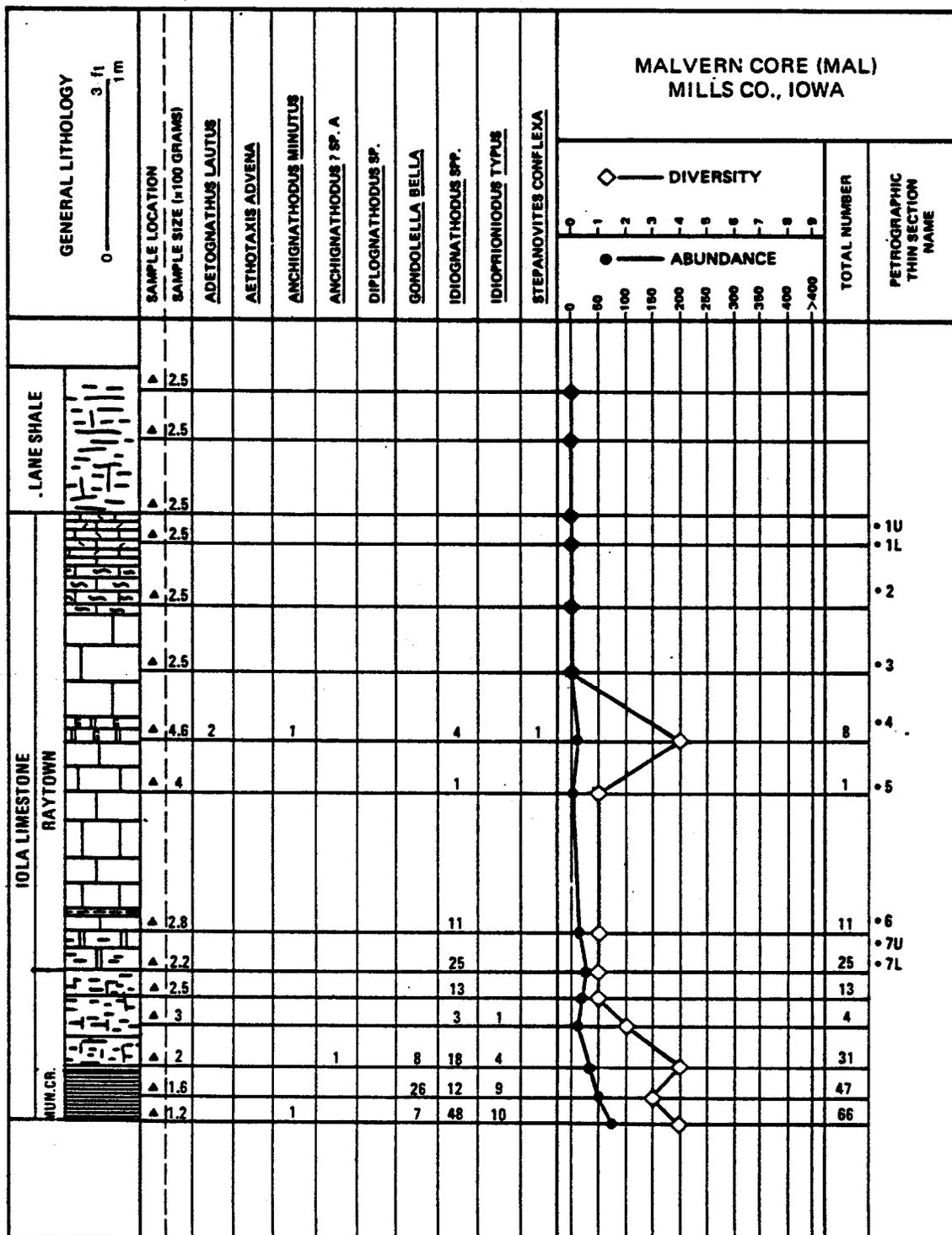
Figure 56.

Figure 57. Stratigraphic column, Locality BED.
Generalized stratigraphic section of core from
Bedford in Taylor Co., Iowa. Lithologic
symbols are standard, as supplemented in
caption to Figure 56. Sixteen samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared and examined from samples
selected from this core.

Figure 57.

Figure 58. Stratigraphic column, Locality PSP.
Generalized stratigraphic section of exposure
near Pammel State Park in Madison Co., Iowa.
See Appendix A for exact location. Lithologic
symbols are standard, as supplemented in
caption to Figure 56. Thirteen samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared and examined from samples
collected from this exposure. Asterisks
following thin section names indicate that
sample was point counted (see Appendix C).

Figure 58.

Figure 59.   Stratigraphic column, Locality K32.
Generalized stratigraphic section from roadcut
in Wyandotte Co., Kansas. Lithologic symbols
are standard, as supplemented in caption to
Figure 56. Twelve samples were collected and
processed for conodonts. Abundance of
individual taxa from each sample is given as
well as sample size, exact, location, and total
sample abundance and diversity. Far right-hand
column of figure gives names and locations of
petrographic thin sections prepared and
examined from samples collected from this
exposure. Asterisk following thin section name
indicates that sample was point counted (see
Appendix C).

Figure 59.

Figure 60. Stratigraphic column, Locality QPA.
Generalized stratigraphic section for quarry
exposure in Miami Co., Kansas. Lithologic
symbols are standard, as supplemented in
caption to Figure 56. Seven samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared and examined from samples
collected from this quarry.

QUARRY – WEST OF PAOLA (QPA)
MIAMI CO., KANSAS

◇ —— DIVERSITY

● —— ABUNDANCE

GENERAL LITHOLOGY		SAMPLE LOCATION	SAMPLE SIZE (x100 GRAMS)	ADETOGNATHUS LAUTUS	AETHOTAXIS ADVENA	ANCHIGNATHODUS MINUTUS	ANCHIGNATHODUS ? SP. A	DIPLOGNATHODUS SP.	GONDOLELLA BELLA	IDIOGNATHODUS SPP.	IDIOPRIONIODUS TYPUS	STEPANOVITES CONFLEXA	DIVERSITY / ABUNDANCE	TOTAL NUMBER	PETROGRAPHIC THIN SECTION NAME
		▲	5			2				26				28	• UL-TOP
															• UL-BOT
		▲	5		1	3				55				59	• ML-TOP
															• ML-C
															• ML-R
		▲	5	2		9				129	2			142	• ML-BOT
IOLA LIMESTONE RAYTOWN		▲	5	1		1	1			177				180	
		▲	5							1				1	
		▲	5	17		3				31				51	
		▲	5	1		1				15				17	• LL-Z
															• LL-M
															• LL-F

Figure 60.

Figure 61.   Stratigraphic column, Locality OSA.
Generalized stratigraphic section for roadcut
exposure in Miami Co., Kansas.   See Appendix A
for exact location.   Lithologic symbols are
standard.   Black dots show location of
petrographic thin sections prepared and
examined from samples collected from this
exposure.   Asterisk following thin section name
indicates that sample was point counted (see
Appendix C).
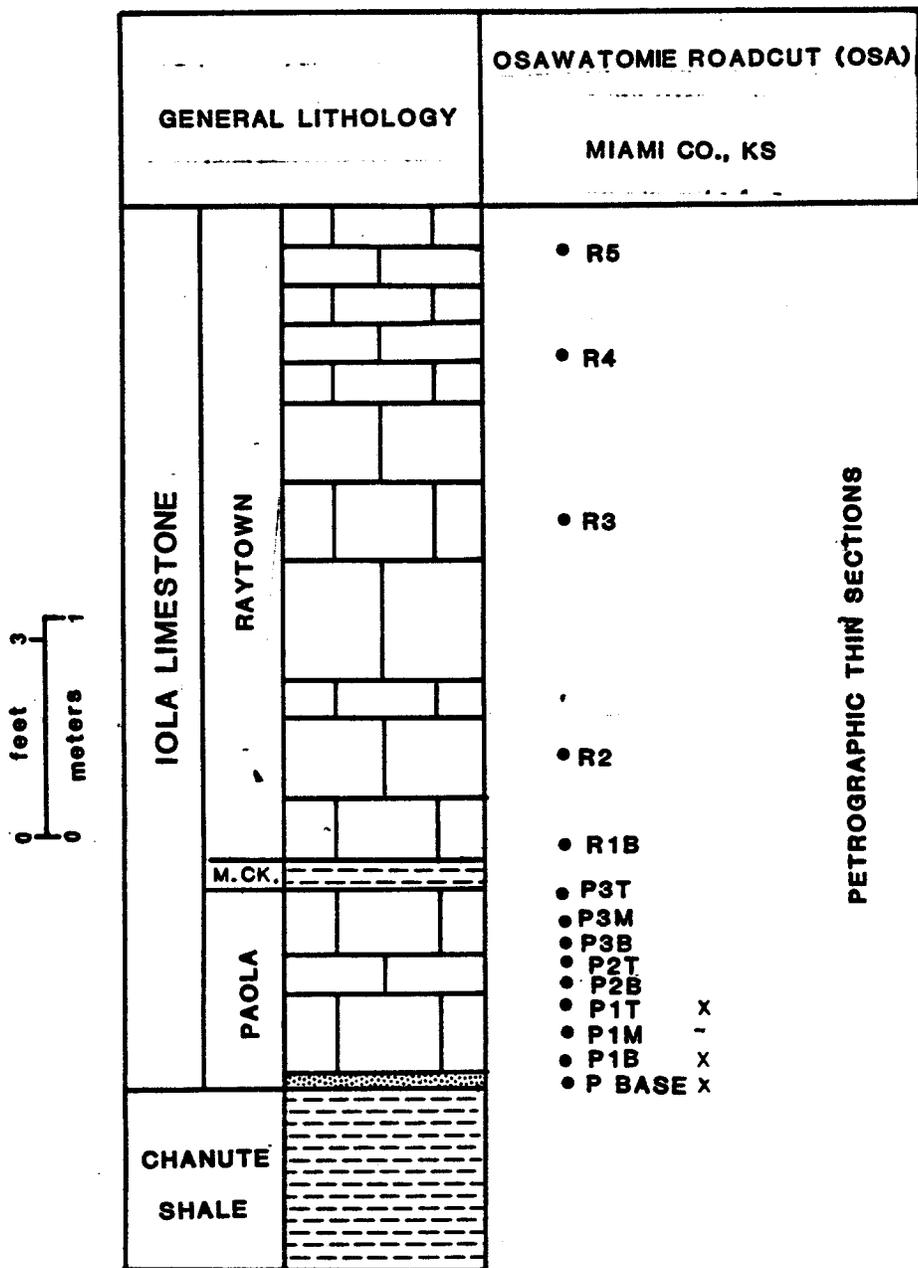
Figure 61.

Figure 62. Stratigraphic column, Locality QEG.
Generalized stratigraphic section for quarry
exposure in Anderson Co., Kansas. See Appendix
A for exact location. Lithologic symbols are
standard, as supplemented in caption to Figure
56. One sample was collected and processed for
conodonts. Abundance of individual taxa from
the sample is given, as well as sample size,
exact location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections sampled and examined from this
exposure.

Figure 62.

Figure 63.   Stratigraphic column, Locality BCRS.
             Generalized stratigraphic section from roadcut
             exposure in Anderson Co., Kansas.   For exact
             locality see Appendix A.   Lithologic symbols
             are standard.   Six samples were collected and
             processed for conodonts.   Abundance of
             individual taxa from each sample is given as
             well as sample size, exact location and total
             sample abundance and diversity.   Far right-hand
             column of figure gives names and locations of
             petrographic thin sections prepared from
             samples collected from this exposure.   Asterisk
             following thin section name indicates that
             sample was point counted (see Appendix C).

Figure 63.

Figure 64.   Stratigraphic column, Locality QSBC.
              Generalized stratigraphic section from quarry
              exposure in Anderson Co., Kansas.   For exact
              location see Appendix A.   Lithologic symbols
              are standard, as supplemented in caption to
              Figure 56.   Eight samples were collected and
              processed for conodonts.   Abundance of
              individual taxa from each sample is given as
              well as sample size, exact location, and total
              sample abundance and diversity.   Far right-hand
              column of figure gives names and locations of
              petrographic thin sections prepared from
              samples from this exposure.   Asterisk following
              thin section name indicates that sample was
              point counted (see Appendix C).

Figure 64.

Figure 65.   Stratigraphic column, Locality QEK.
             Generalized stratigraphic section from quarry
             exposure in Anderson Co., Kansas.   For exact
             location see Appendix A.   Standard lithologic
             symbols are used.   Three samples were collected
             and processed for conodonts.   Abundance of
             individual taxa from each sample is given as
             well as sample size, exact location, and total
             sample abundance and diversity.   Far right-hand
             column of figure gives names and locations of
             petrographic thin sections prepared and
             examined from samples collected from this
             exposure.   Asterisk following thin section name
             indicates that sample was point counted (see
             Appendix C).

Figure 65.

Figure 66. Stratigraphic column, Locality KRR.
Generalized stratigraphic section from roadcut
exposure near Kincaid in Anderson Co., Kansas.
See Appendix A for exact location. Lithologic
symbols are standard. Black dots show location
of petrographic thin sections prepared and
examined from samples collected from this
exposure. Asterisk following thin section name
indicates that sample was point counted (see
Appendix C.)
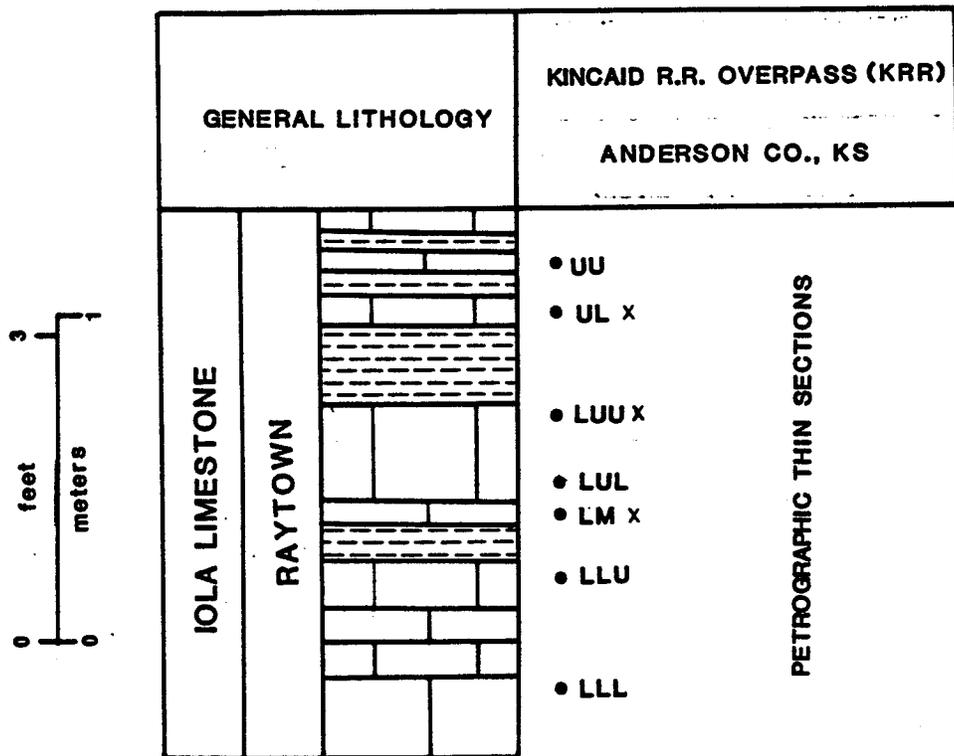
Figure 66.

Figure 67.   Stratigraphic column, Locality KTL.
             Generalized stratigraphic section from roadcut
             exposure north of Moran in Allen Co., Kansas.
             See Appendix A for exact location.   Lithologic
             symbols used are standard, as amended in
             caption to Figure 56.   Three samples were
             collected and processed for conodonts.
             Abundance of individual taxa from each sample
             is given as well as sample size, exact
             location, and total sample abundance and
             diversity.   Far right-hand column of figure
             gives names and location of petrographic thin
             sections prepared from samples collected from
             this exposure.
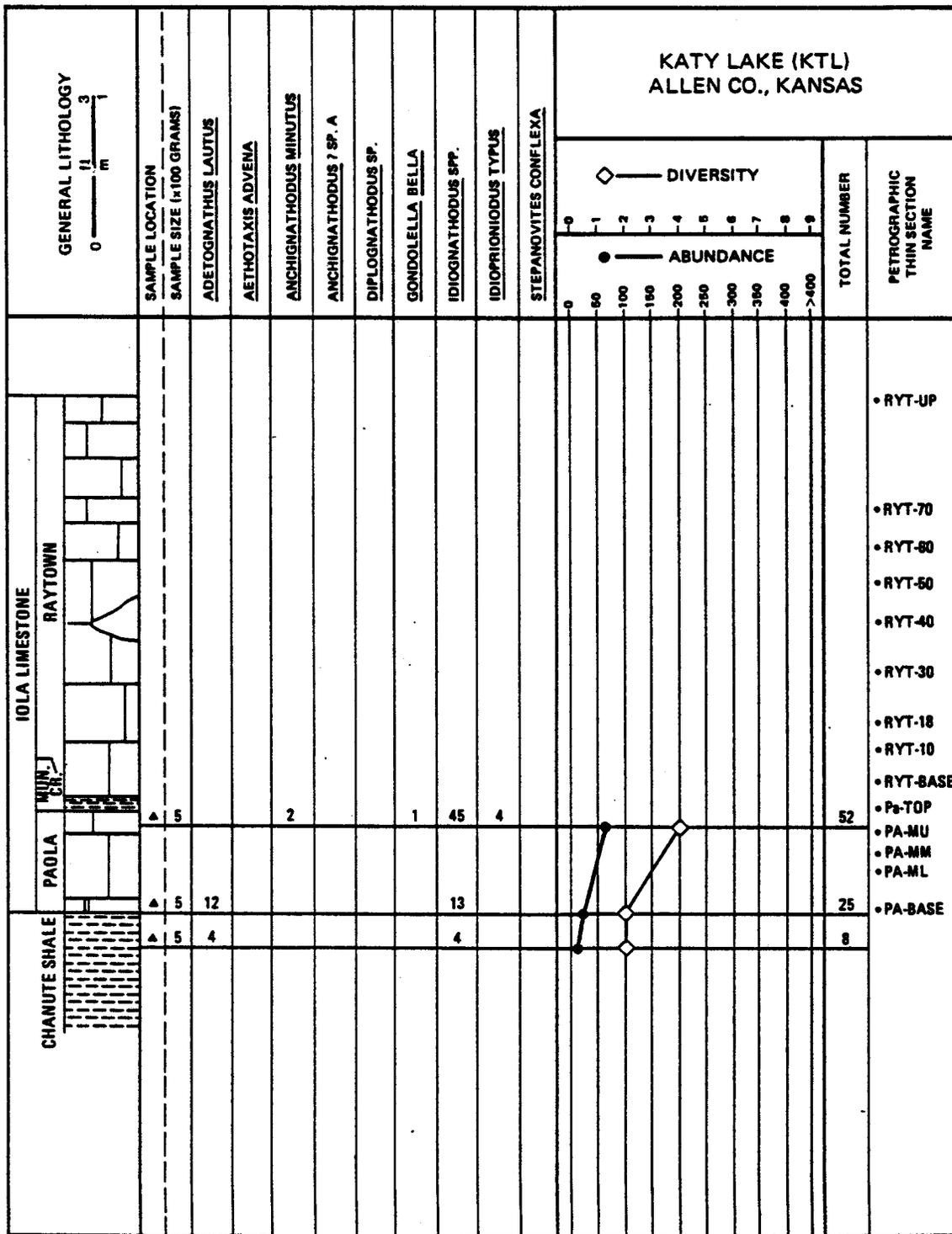
Figure 67.

Figure 68. Stratigraphic column, Locality LEH.
Generalized stratigraphic section from quarry
exposure south of Iola in Allen Co., Kansas.
See Appendix A for exact location. Standard
lithologic symbols are used, as amended in
caption to Figure 56. Eight samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact location
and total sample abundance and diversity. Far
right-hand column of figure gives names and
locations of petrographic thin sections
prepared from samples collected from this
exposure. Asterisk following thin section name
indicates that sample was point counted (see
Appendix C).
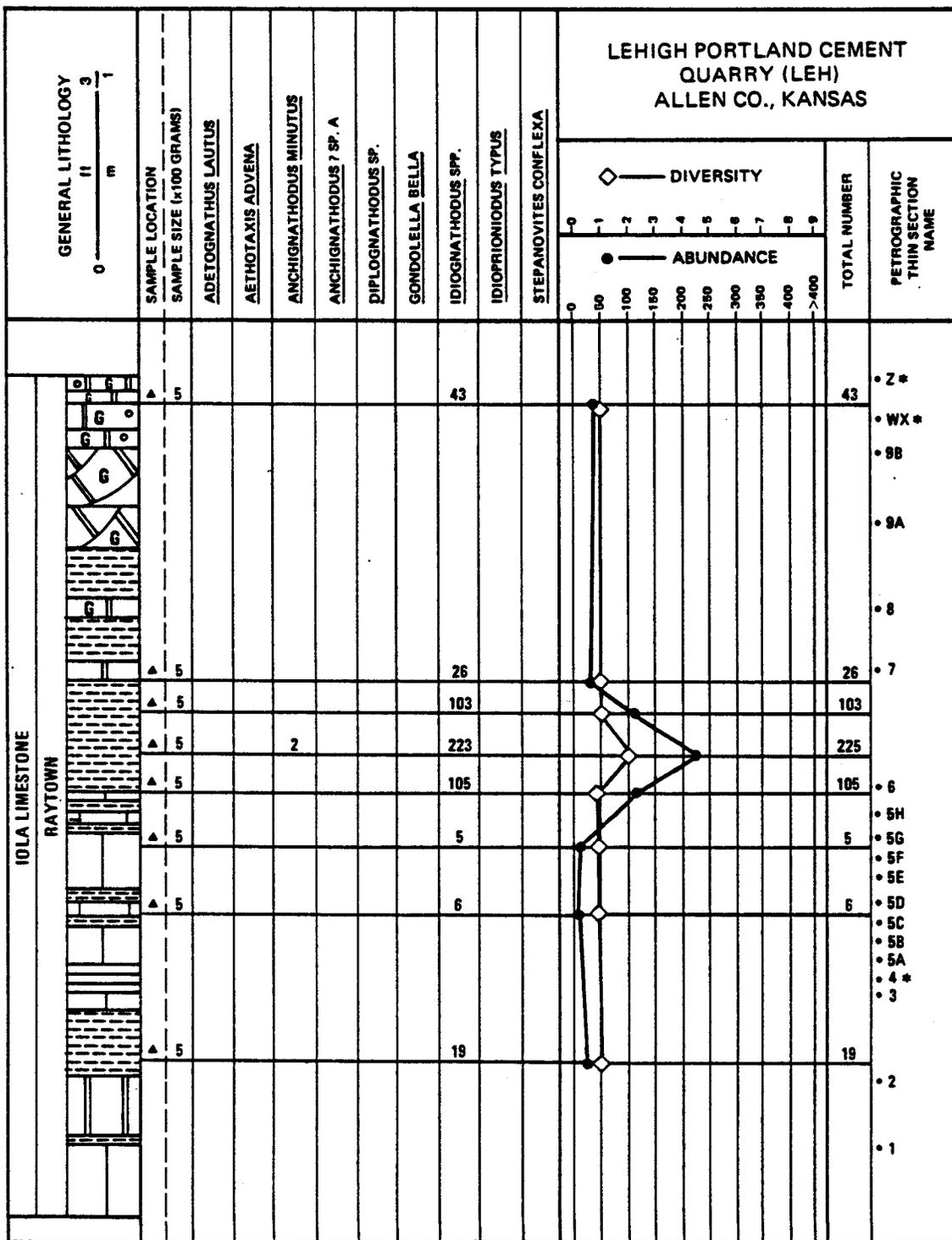
Figure 68.

Figure 69. Stratigraphic column, Locality OCK.
            Generalized stratigraphic section for creek
            bank exposure in Allen Co., Kansas. See
            Appendix A for exact location. Standard
            lithologic symbols used, as supplemented in
            caption to Figure 56.
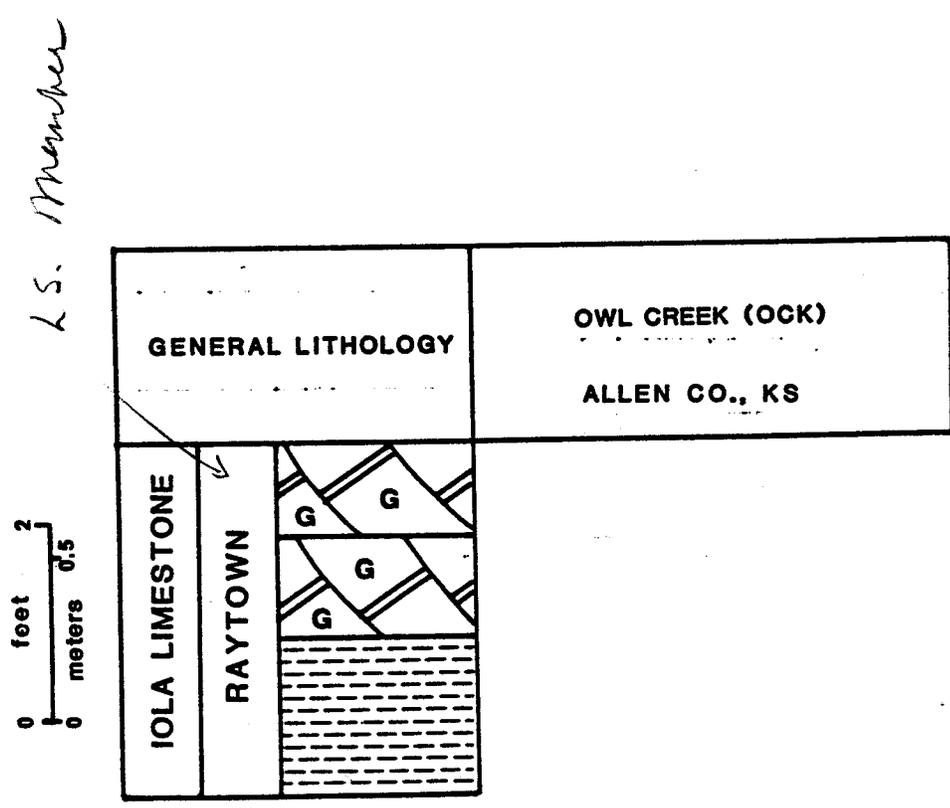
Figure 69.

Figure 70. Stratigraphic column, Locality HUM (lower portion).
Generalized stratigraphic section of lower portion of quarry exposure south of Humbolt in Allen Co., Kansas. See Appendix A for exact location. Lithologic symbols are standard. Four samples were collected and processed for conodonts. Abundance of individual taxa from each sample is given as well as sample size, exact location, and total sample abundance and diversity. Far right-hand column of figure gives names and locations of petrograph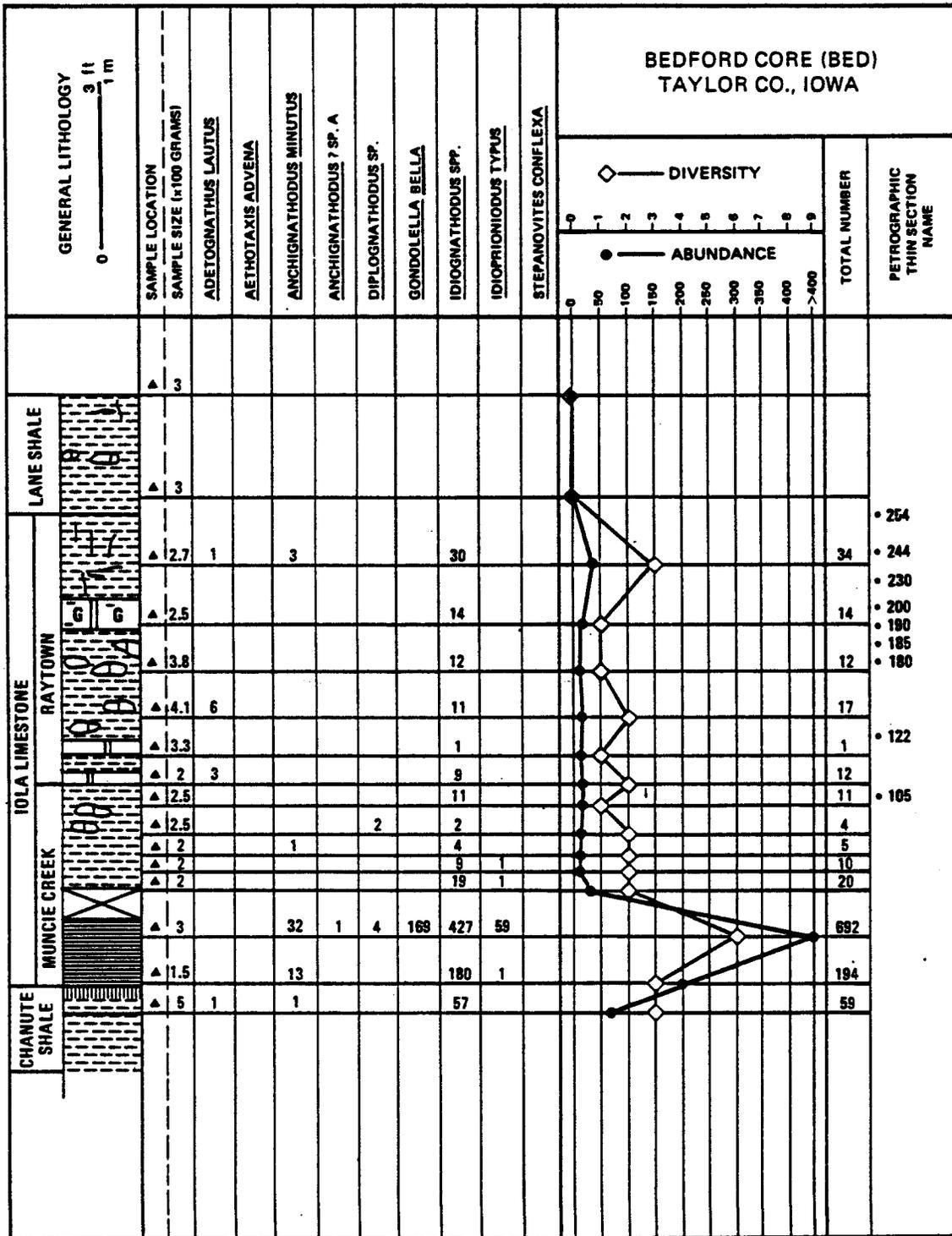ic thin sections prepared from samples collected from this exposure. Asterisk following thin section name indicates that sample was point counted (see Appendix C).
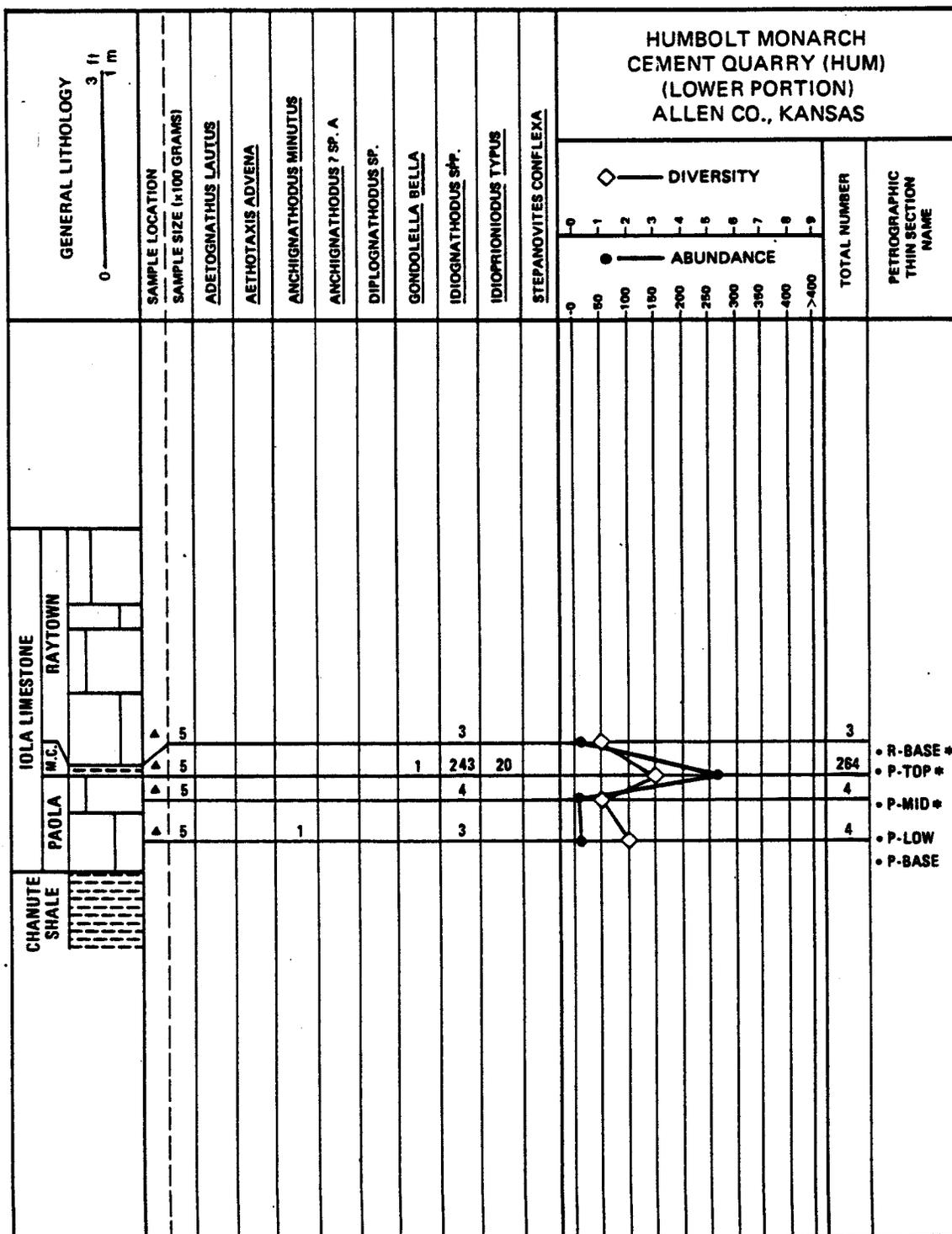
Figure 70.

Figure 71.   Stratigraphic column, Locality HUM (upper
portion).
Generalized stratigraphic section of upper
portion of quarry exposure south of Humbolt in
Allen Co., Kansas.   See Appendix A for exact
location.   Standard lithologic symbols are
used, as amended in caption to Figure 56.
Eight samples were collected and processed for
conodonts.   Abundance of individual taxa from
each sample is given as well as sample size,
exact location, and total sample abundance and
diversity.   Far right-hand column of figure
gives names and location of petrographic thin
sections prepared from samples collected from
this exposure.   Asterisk following thin section
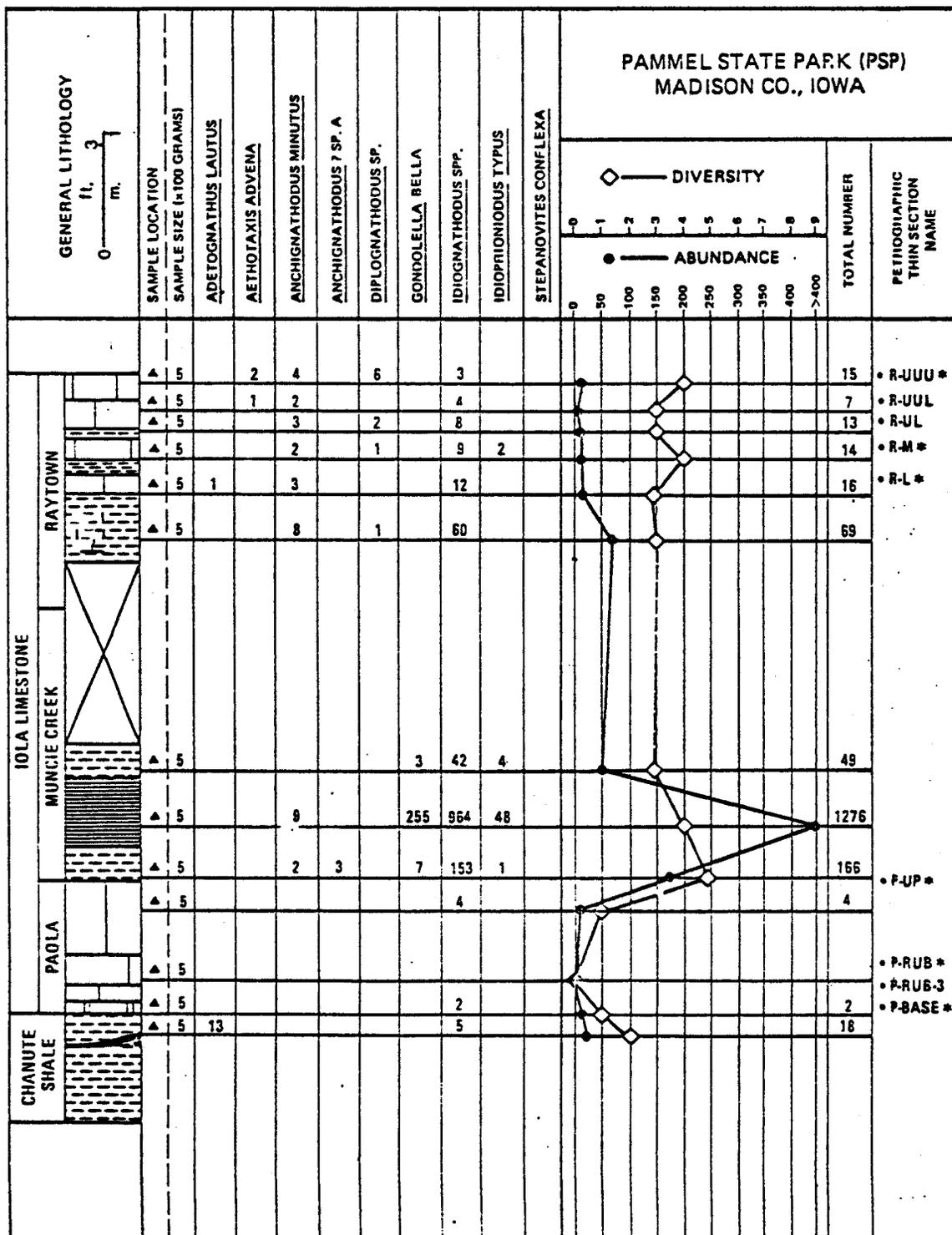name indicates that sample was point counted
(see Appendix C).
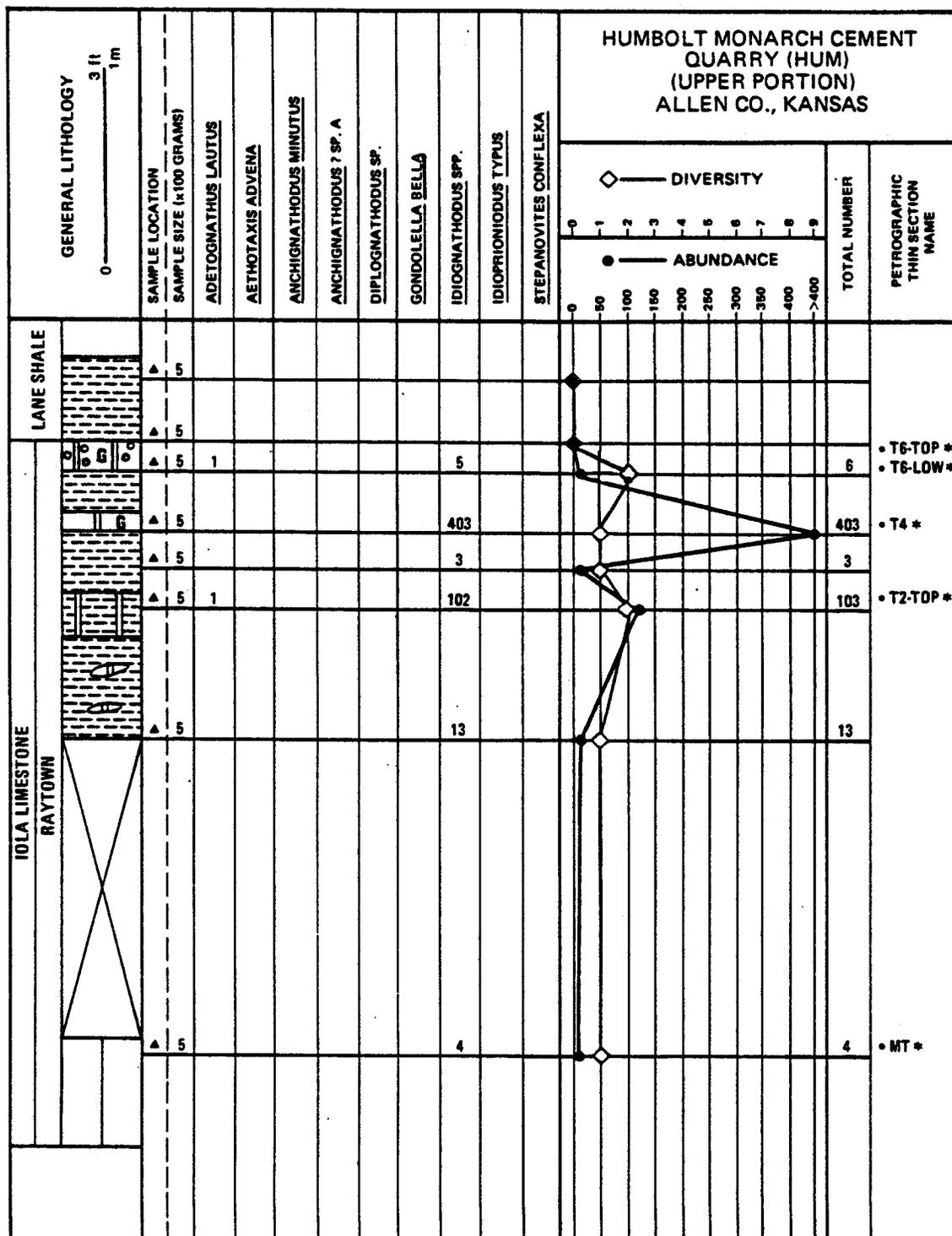
Figure 71.

Figure 72.   Stratigraphic column, Locality AGQ.
Generalized stratigraphic section of quarry
exposure near Chanute in Neosho Co., Kansas.
See Appendix A for exact location. Standard
lithologic symbols used, as amended in caption
to Figure 56. Nine samples were collected and
processed for conodonts. Abundance of
individual taxa from each sample is given as
well as sample size, exact location and total
sample abundance and diversity. Far right-hand
column of figure gives names and locations of
petrographic thin sections prepared from
samples collected from this exposure. Asterisk
following thin section name indicates that
sample was point counted (see Appendix C).

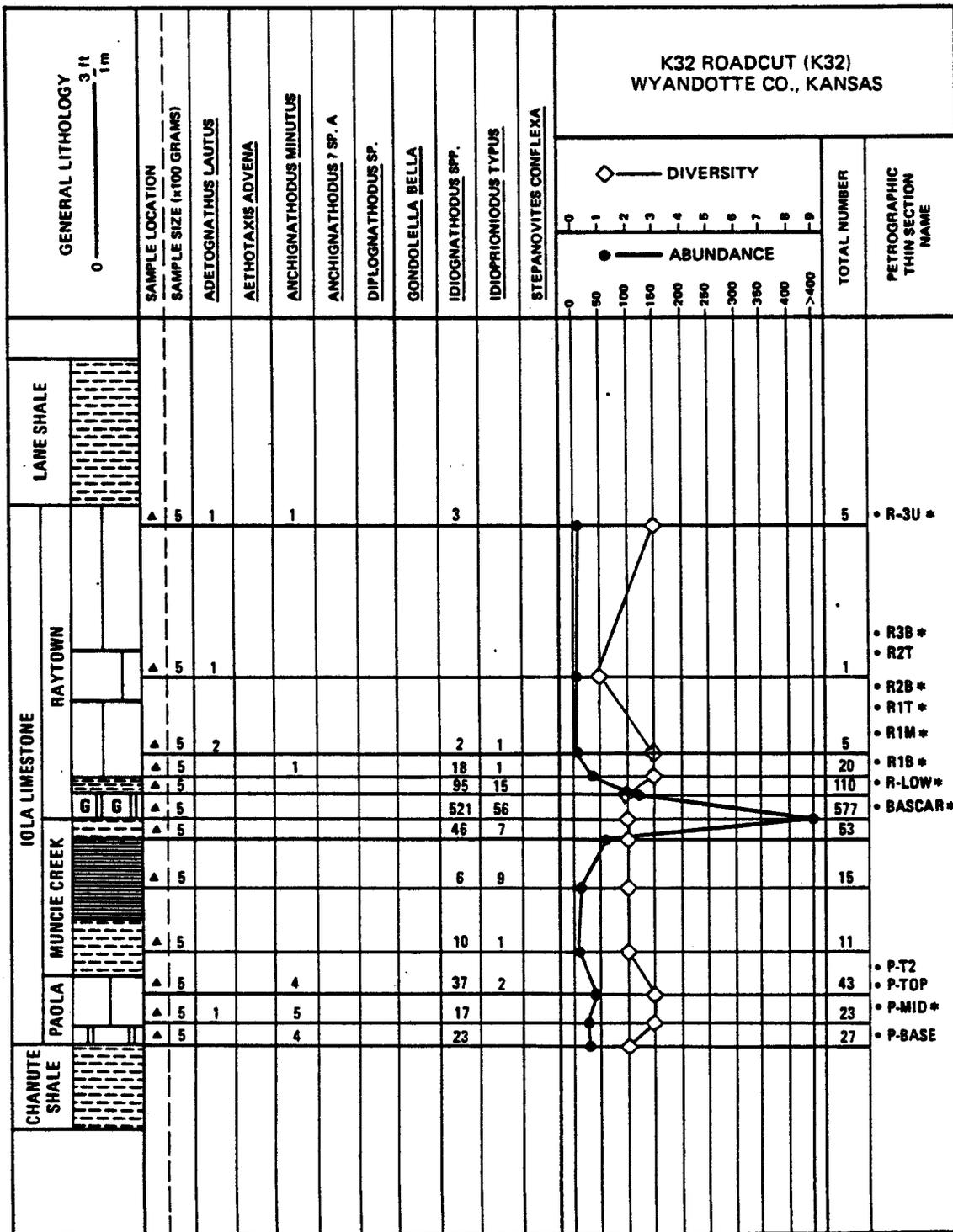Figure 72.

Figure 73. Stratigraphic column, Locality ENC.
Generalized stratigraphic section from core
taken for this project north of Earlton in
Neosho Co., Kansas. See Appendix A for exact
location. Lithologic symbols are standard.
Black dots show location of petrographic thin
section prepared from samples collected from
this core.
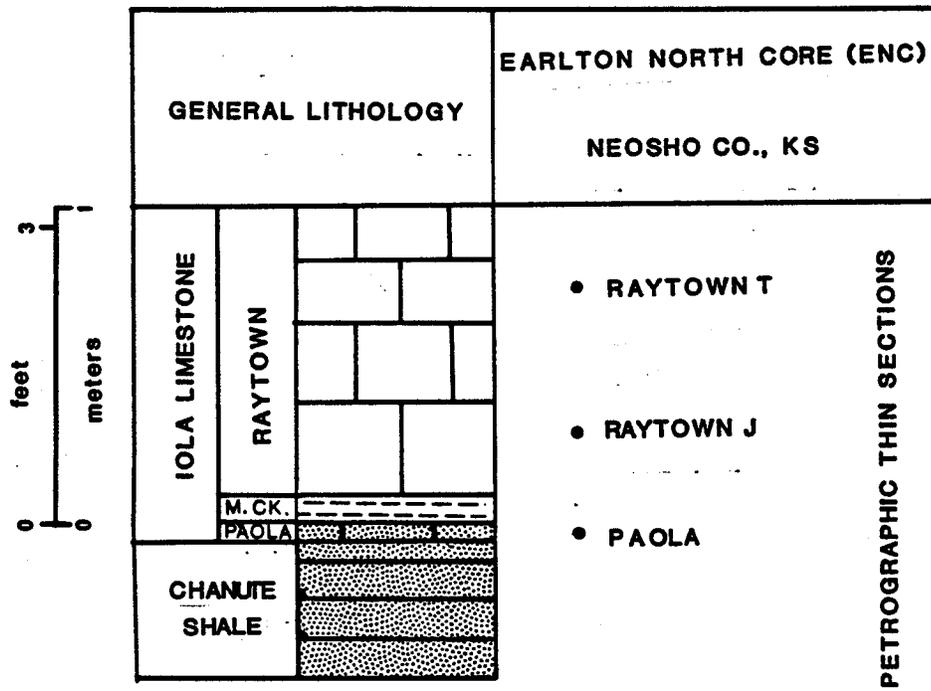
Figure 73.

Figure 74. Stratigraphic column, Locality 3MN.
Generalized stratigraphic section for exposure
north of Three Mounds in Wilson Co., Kansas.
See Appendix A for exact location. Standard
lithologic symbols are used as amended in
caption to Figure 56. Three samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared from samples collected from
this exposure. Asterisk following thin section
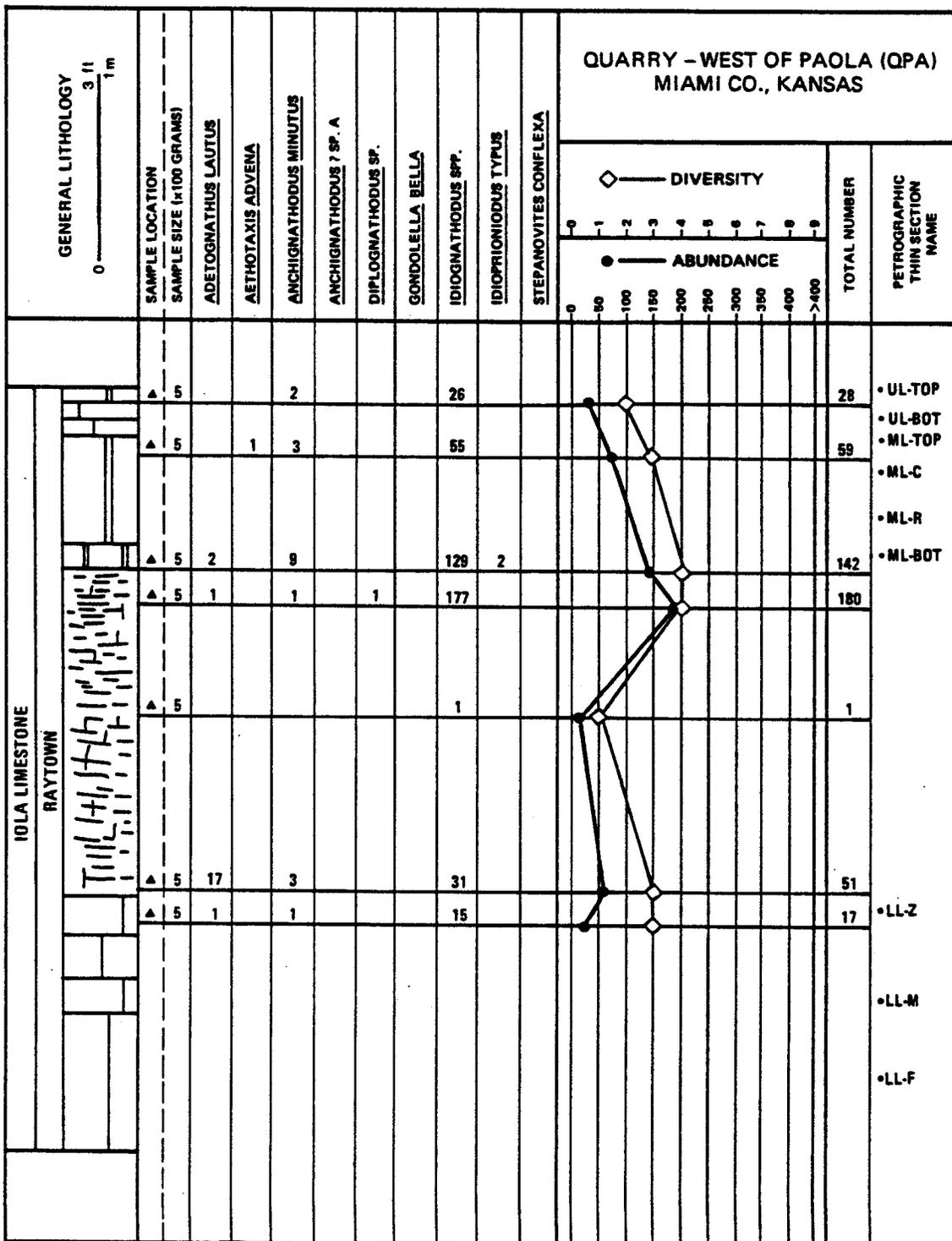name indicates that sample was point counted
(see Appendix C).
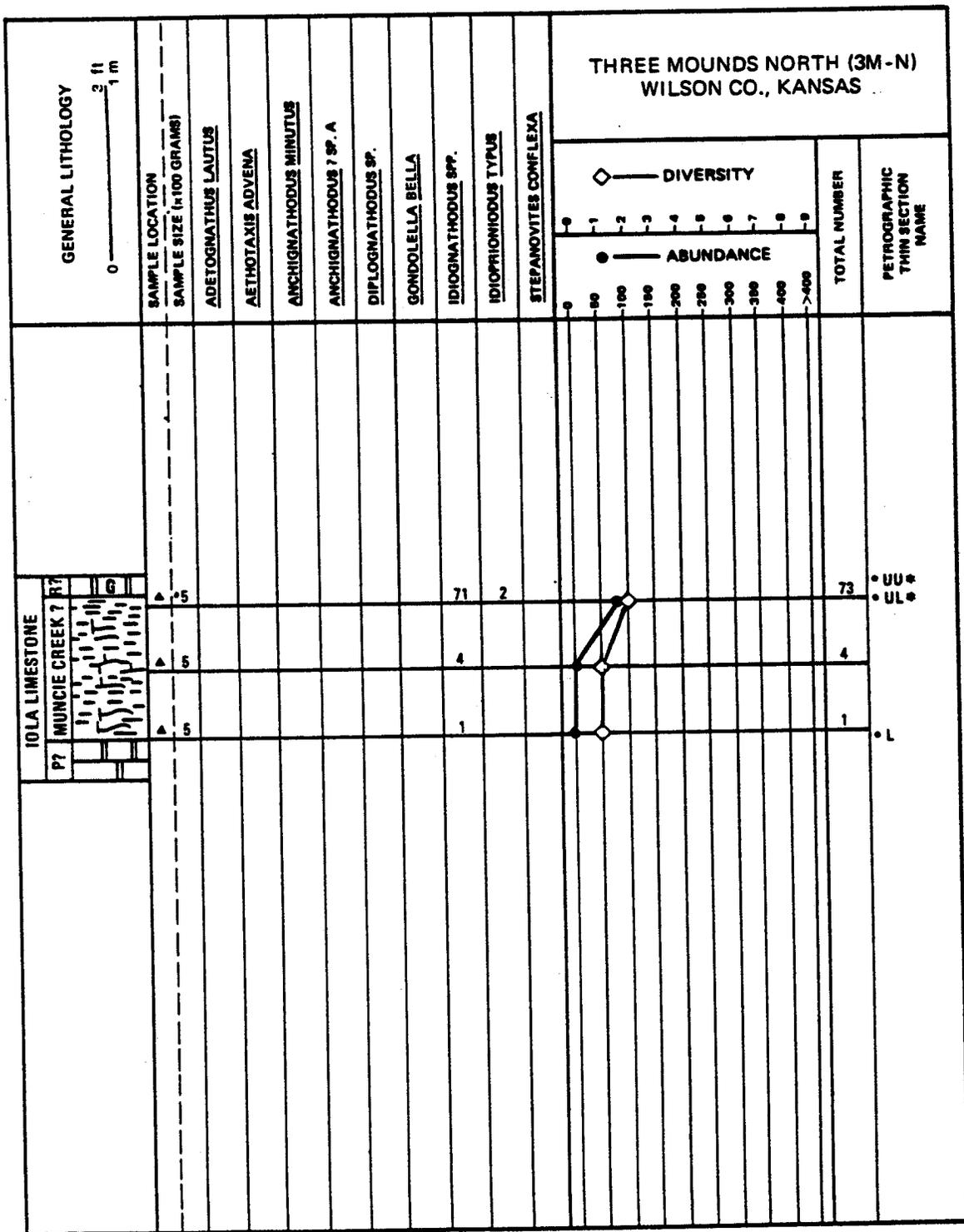
Figure 74.

Figure 75.   Stratigraphic column, Locality CCK.
Generalized stratigraphic section for exposure
near Chetopa Creek in Wilson Co., Kansas.   See
Appendix A for exact location.   Standard
lithologic symbols are used as amended in
caption to Figure 56.   Nine samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity.   Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared from samples collected from
this exposure.   Asterisk following thin section
name indicates that sample was point counted
(see Appendix C).
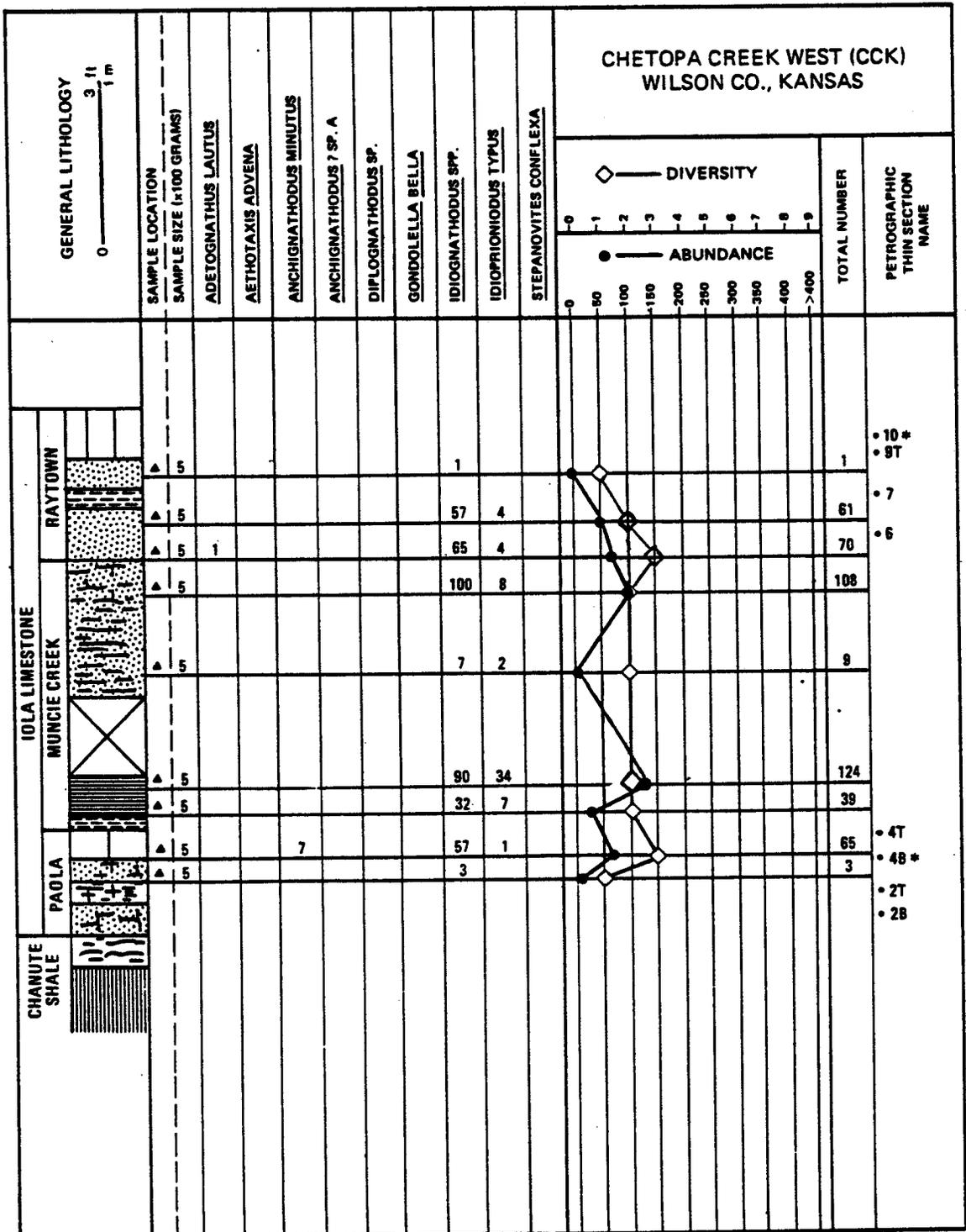
Figure 75.

Figure 76. Stratigraphic column, Locality NEO.
Generalized stratigraphic section from river
bank exposure near Neodesha in Wilson Co.,
Kansas. See Appendix A for exact location.
Standard lithologic symbols used, as amended in
caption to Figure 56. Eleven samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact location
and total sample abundance and diversity. Far
right-hand column of figure gives names and
locations of petrographic thin sections
prepared from samples collected from this
exposure. Asterisk following thin section name
indicates that sample was point counted (see
Appendix C).
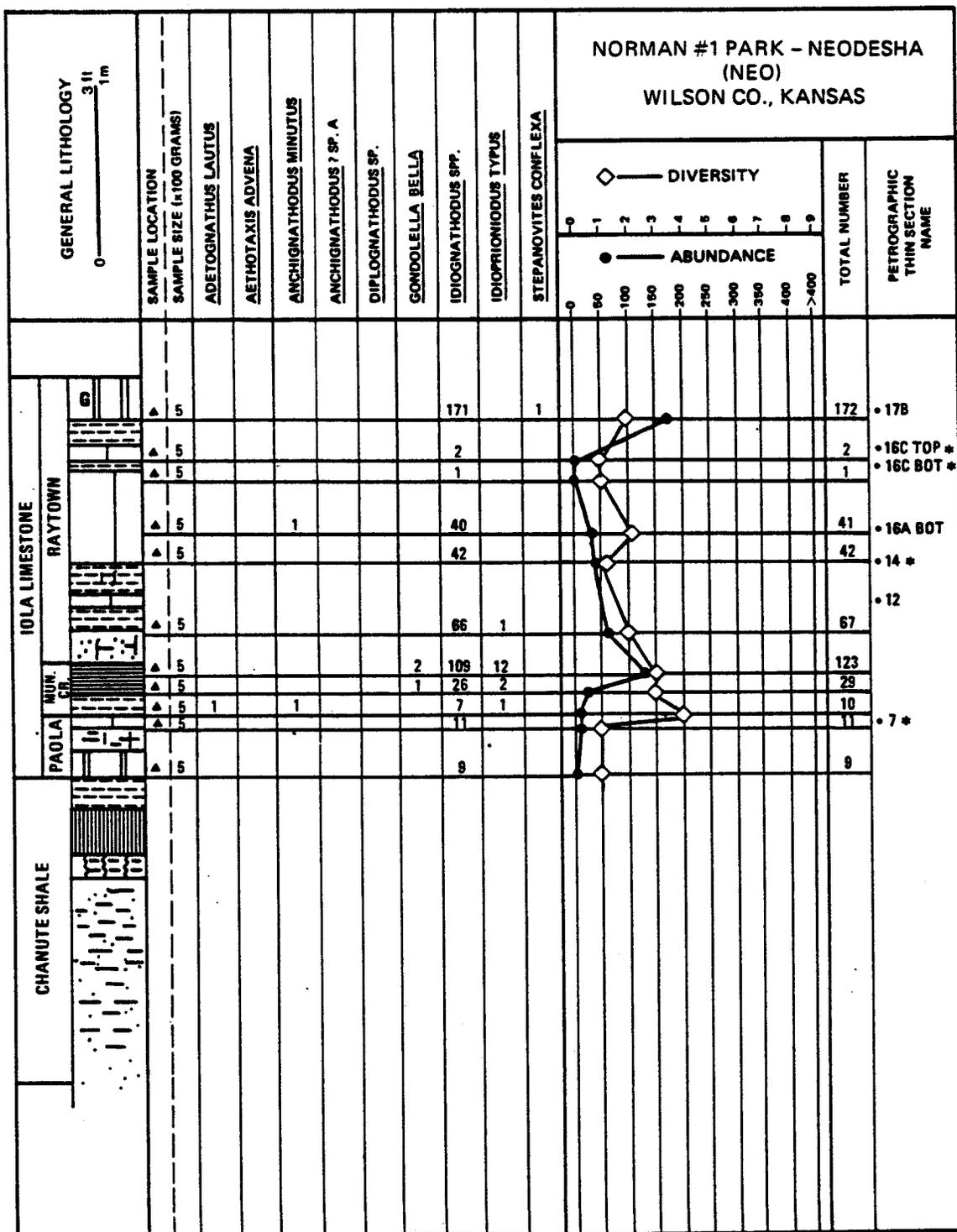
Figure 76.

Figure 77. Stratigraphic column, Locality SPE.
Generalized stratigraphic section from roadcut
exposure east of Stony Point in Montgomery Co.,
Kansas. See Appendix A for exact location.
Standard lithologic symbols used, as amended in
caption to Figure 56. Five samples were
collected and processed for conodonts.
Abundance of individual taxa from each sample
is given as well as sample size, exact
location, and total sample abundance and
diversity. Far right-hand column of figure
gives names and locations of petrographic thin
sections prepared from samples collected from
this section. Asterisk following thin section
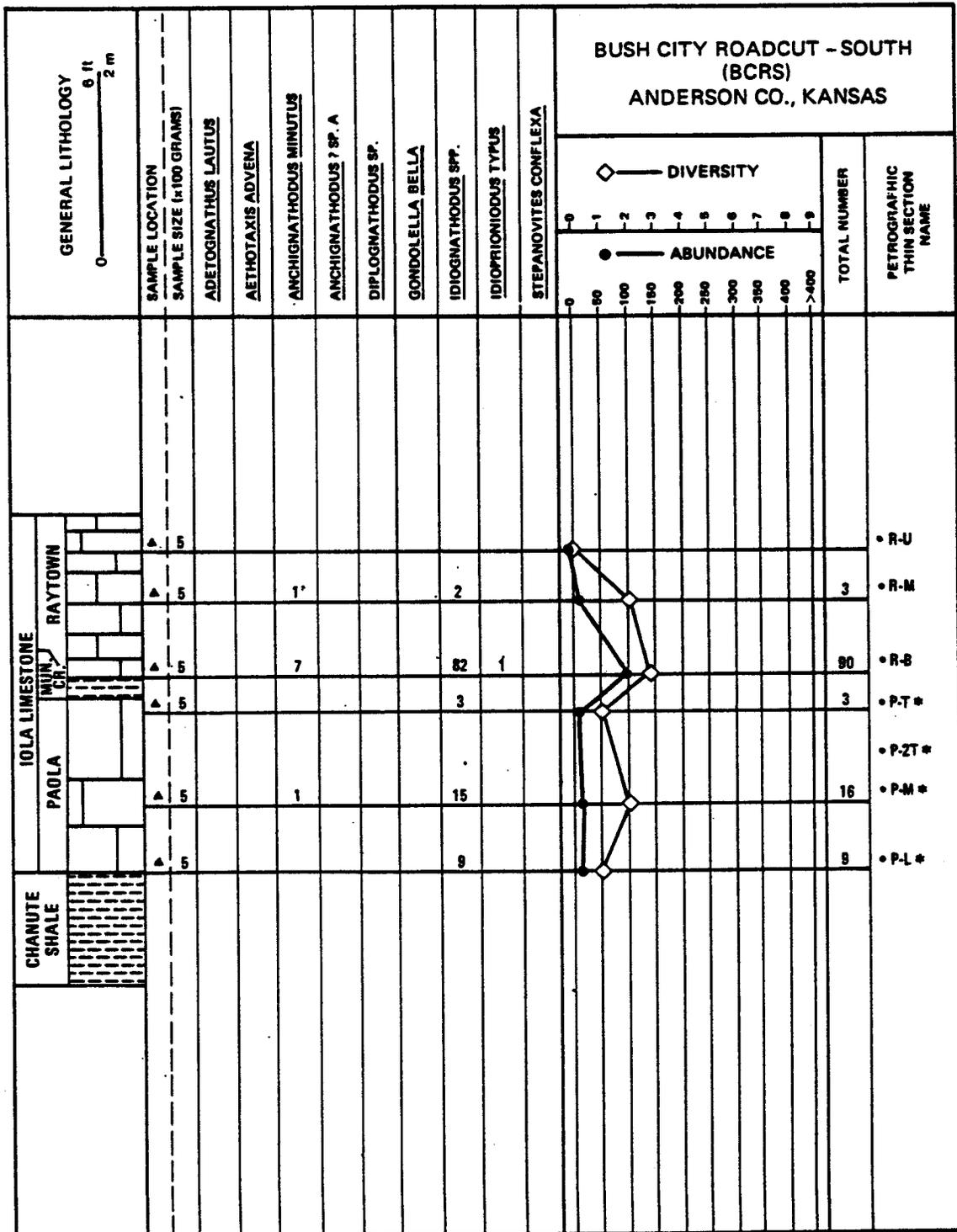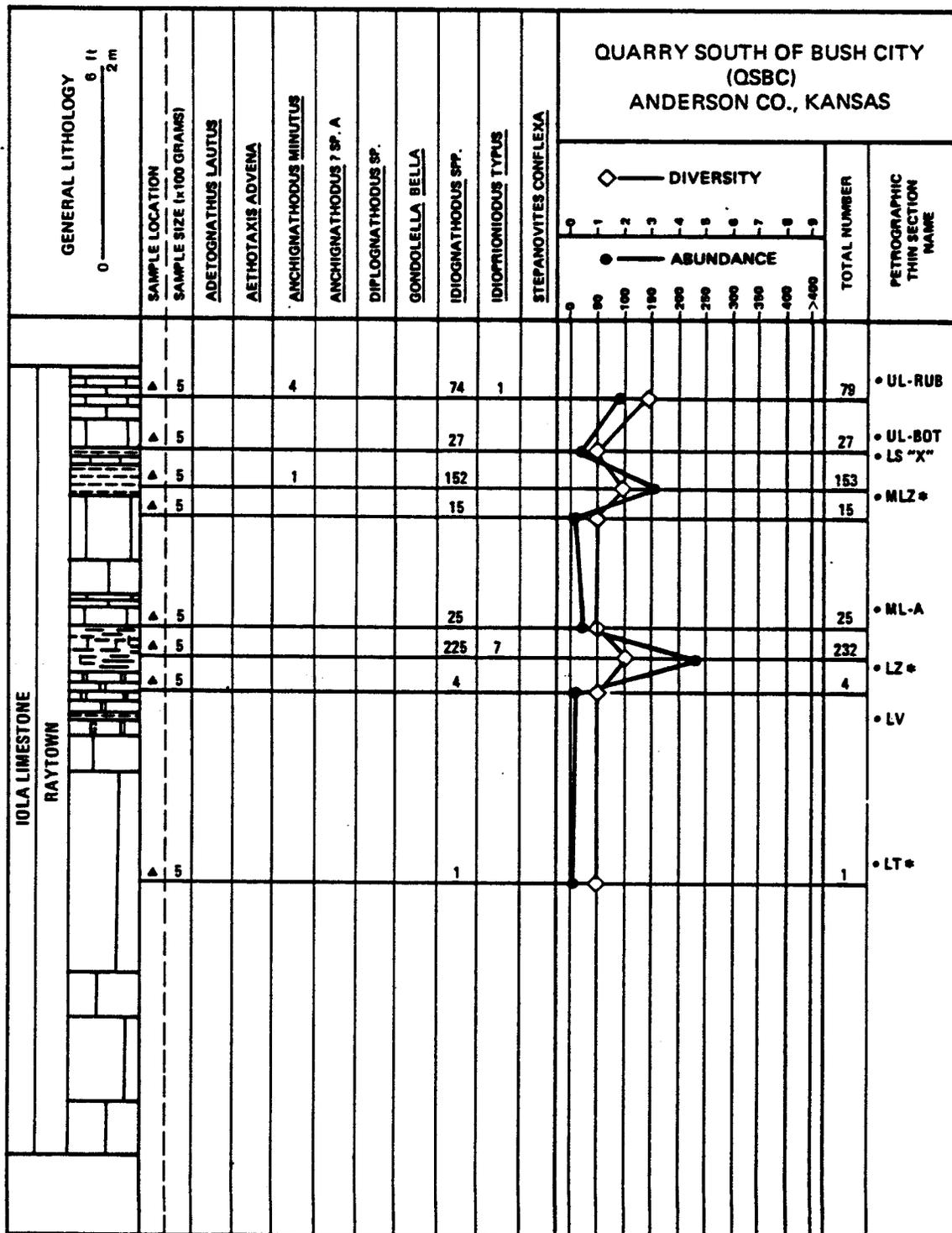name indicates that sample was point counted
(see Appendix C).
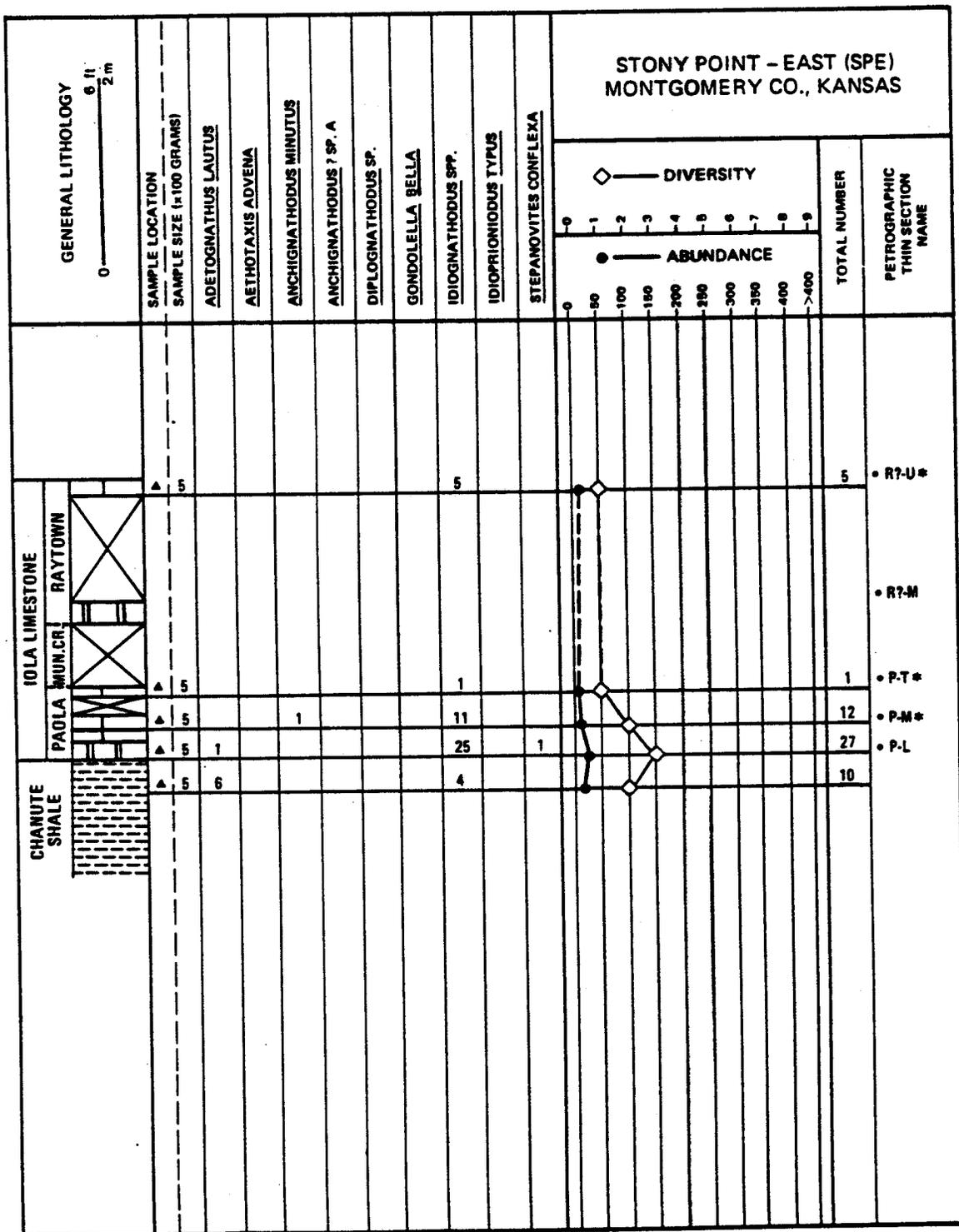
Figure 77.

Figure 78.   Stratigraphic column, Locality TYE.
             Generalized stratigraphic section from road
             ditch exposure east of Tyro in Montgomery Co.,
             Kansas.   See Appendix A for exact location.
             Standard lithologic symbols used, as amended in
             caption to Figure 56.   Five samples were
             collected and processed for conodonts.
             Abundance of individual taxa from each sample
             is given as well as sample size, exact
             location, and total sample abundance and
             diversity.   Far right-hand column of figure
             gives names and locations of petrographic thin
             sections prepared from samples collected from
             this exposure.
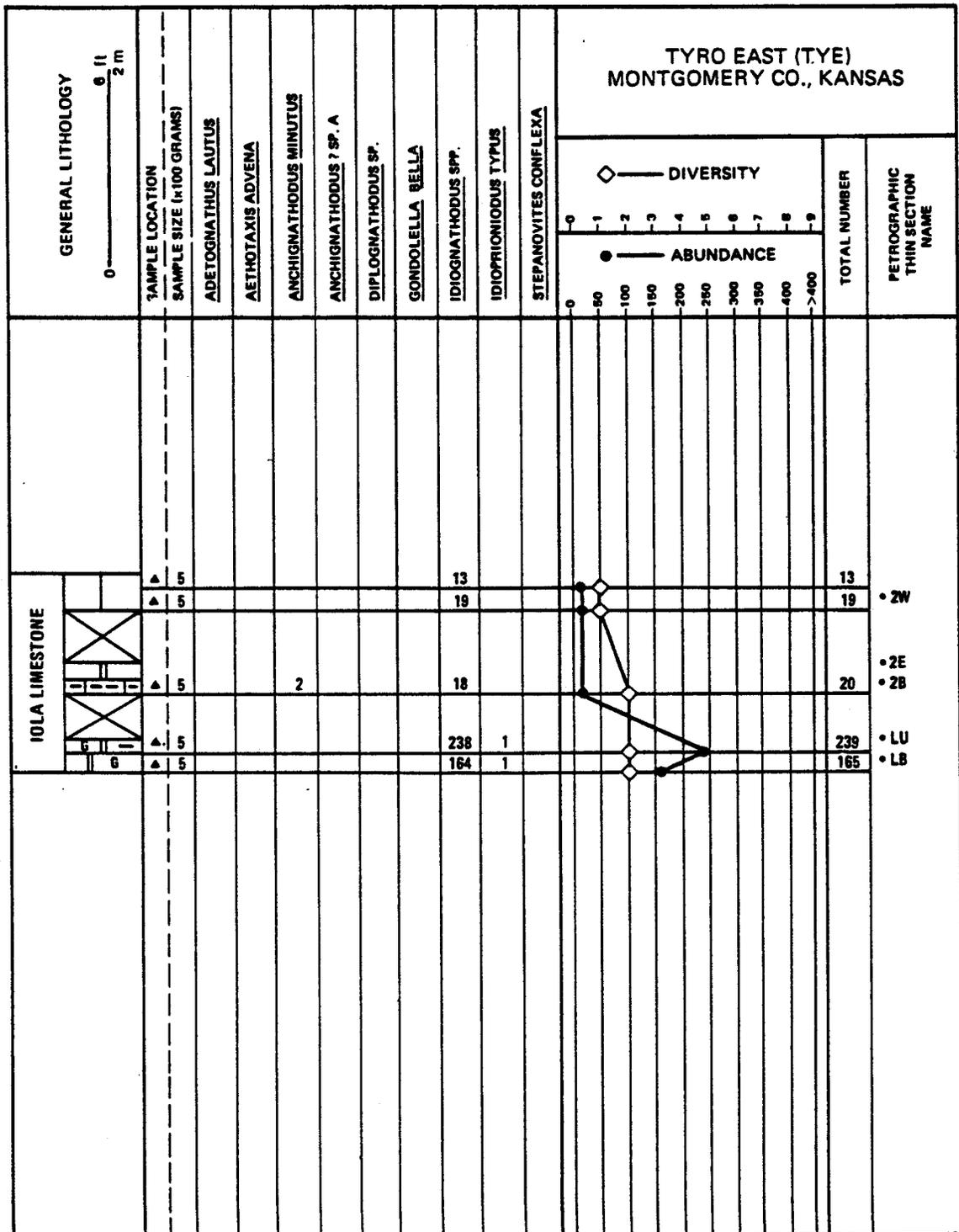
Figure 78.

Figure 79. Stratigraphic column, Locality CAN.
Generalized stratigraphic section for exposure
in oil field access road in Washington Co.,
Oklahoma. See Appendix A for exact location.
Standard lithologic symbols are used, as
amended in caption to Figure 56. Black dots
show location of petrographic thin sections
prepared and examined from samples collected
from this exposure. Asterisk following thin
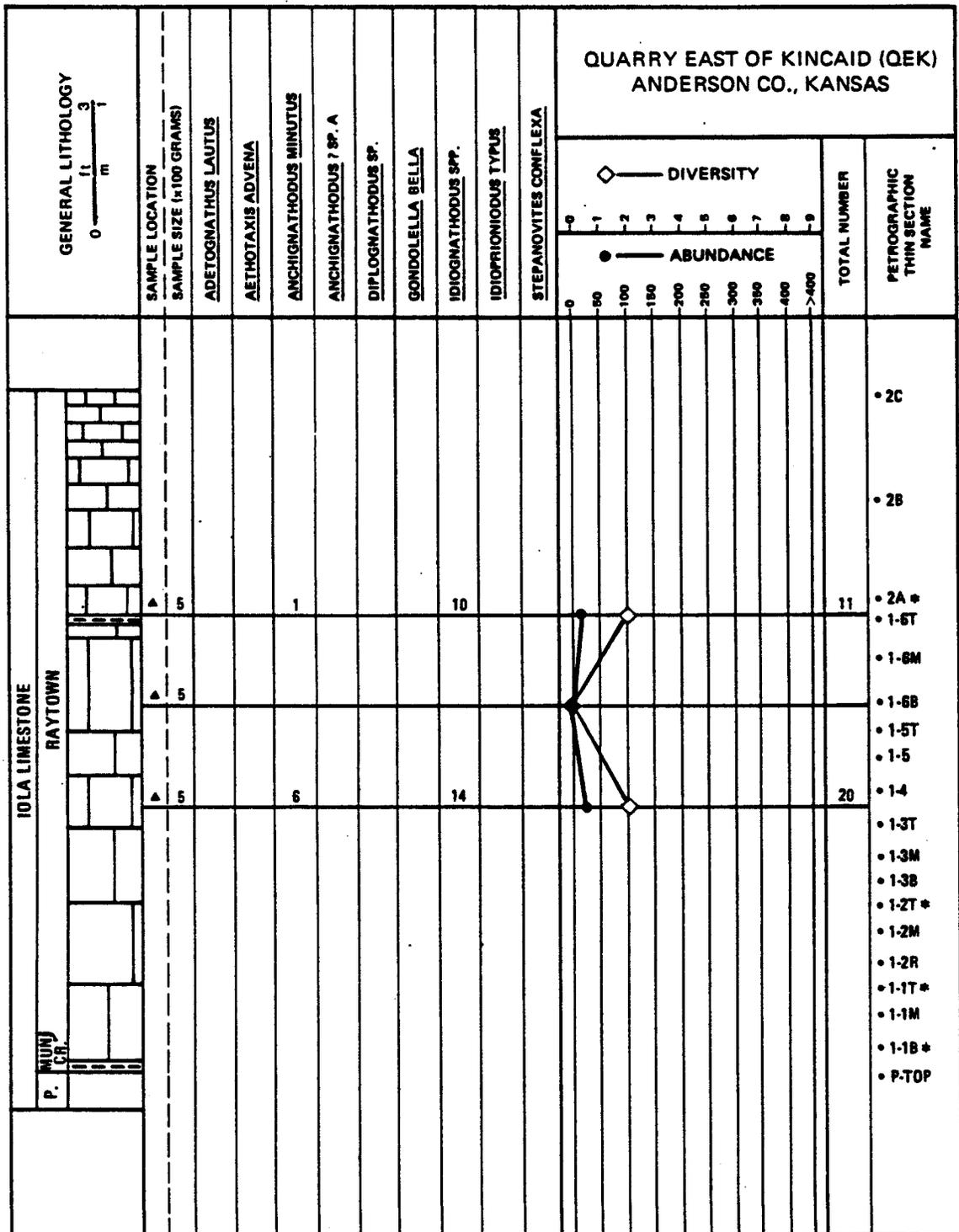section name indicates that sample was point
counted (see Appendix C).
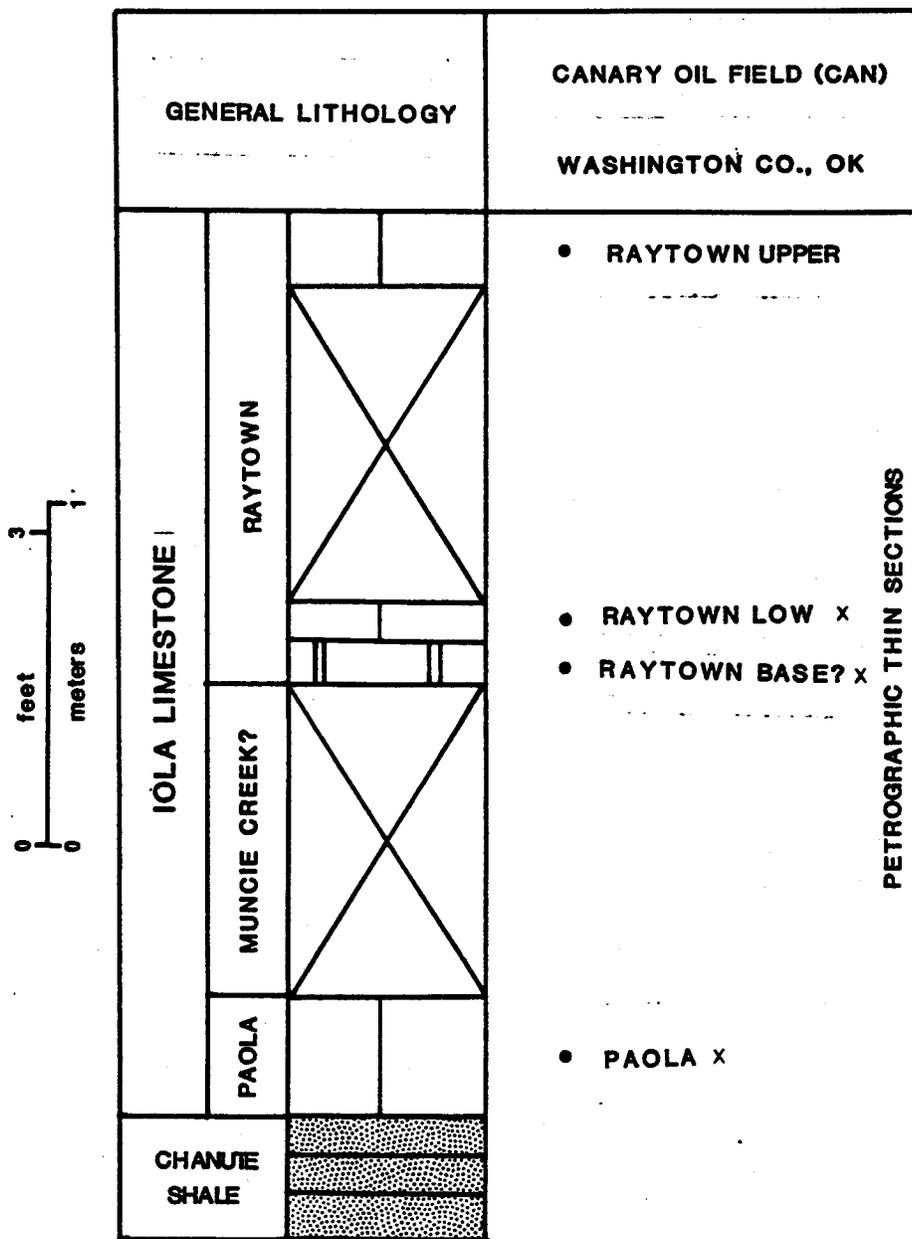
Figure 79.

Figure 80. Stratigraphic column, Locality RAM.
Generalized stratigraphic section for roadcut
exposure west of Ramona in Washington Co.,
Oklahoma. See Appendix A for exact location.
Standard lithologic symbols used, as amended in
caption to Figure 56. Four samples were
collected and processed for conodonts.
Abundance of individual taxa for each sample is
given as well as sample size, exact location,
and total sample abundance and diversity. Far
right-hand column of figure gives name and
location of petrographic thin sections prepared
from samples collected from this exposure.
Asterisk following thin section name indicates
that sample was point counted (see Appendix C).

Figure 80.

APPENDIX C.

POINT COUNT DATA

Table 1.   Point count data.

Table 1.

NEO UNIT 16C TOP	NEO UNIT 16C BOTTOM	NEO UNIT 14	NEO UNIT 7	SPE RAYTOWN? UP	SPE PAOLA TOP	SPE PAOLA MID	CAN AVANT UP	CAN AVANT LOW	CAN PAOLA	RAM AVANT 1	RAM PAOLA	PETROGRAPHIC THIN SECTION
		1	0.6		3	1	1			0.3	0.4	BIVALVE
2	4	7	7	5	5	2	4	4	9	4	3	BRACHIOPOD
5	6	4		17	7	0.3	4	3	8	3		BRYOZOAN
										2		CORAL
30	7	8	3	16	16	10	2	5	3	4	30	ECHINODERM
10	2	1	0.6	3	5	5	3	2	1	0.5	3	ENCR. FORAM.
	0.3		0.3							0.7		FORAMINIFER
												FUSULINID
		0.6			0.7					0.7	0.4	GASTROPOD
		1				3				8		MOL.?/ALGAE?
		0.3	0.6									OSTRACODE
					1.5						6	"OSAGIA"
						3						PHYLLOID ALGAE
						3			1.4			SPONGE
	0.3		0.3			0.7	1					TRILOBITE
5	2	4	9.6	0.6	4	2	2	1	3	1	5	? SKEL. GRAIN
	1.6									0.7		PELOIDS
	65	68	74			67	83	86	69		26	CO3 MUD
				58	55					67		DOLOMITE
												FE-DOLOMITE
												SHELTER-VOID
						0.2						FRAC.-FILL
32		4								4	1	INTERGRAN.
15		0.3			1				3.5		21	QUARTZ SAND
	11					1						QUARTZ SILT
												GLAUCONITE
					3							NON-SKEL. PO4
										0.7	3	PYRITE
												OOIDS
												INTRACLASTS

(SPAR bracket spanning SHELTER-VOID / FRAC.-FILL)

Table 1 (cont'd.).

HUM PAOLA TOP	HUM PAOLA MID	AGQ "CRUSTACEOUS"	AGQ CALCARENITE	AGQ MOUND TOP	AGQ RAYTOWN 3M	AGQ RAYTOWN 1M	AGQ RAYTOWN 1B	3MN UP. LS UPPER SAMPLE	3MN UP. LS LOWER SAMPLE	CCK UNIT 10	CCK UNIT 4B	PETROGRAPHIC THIN SECTION
							1	2	1.3	6		BIVALVE
1	3.2	4	1	4	6	4	10	2	2	6	3	BRACHIOPOD
1		3	16	7	2	4	9	0.5	0.7	7		BRYOZOAN
			5	1								CORAL
0.3	2.5	24	28	6		4	3	48	40	10	6	ECHINODERM
1.4	3.6	5	1			1	3	5	2	0.5	3	ENCR. FORAM.
	0.4											FORAMINIFER
												FUSULINID
0.5	0.3	1	3	2			1		0.7	1		GASTROPOD
9	7	1	3	25		25	6			1		MOL.?/ALGAE?
		1	1	1							1	OSTRACODE
		16						15	26			"OSAGIA"
8	3.6	17	9	3	6		6			0.3		PHYLLOID ALGAE
0.5												SPONGE
		1	1	1				2	1.3			TRILOBITE
	4.3		3	5	2	3	4	4			2	? SKEL. GRAIN
2				1					0.7			PELOIDS
74	75	4	32	38	18	58	57			61		CO3 MUD
					1							DOLOMITE
					16							FE-DOLOMITE
			1							1		SHELTER-VOID
2			3	49								FRAC.-FILL
		11	5	8				12	17	2	31	INTERGRAN.
		2						6	7		49	QUARTZ SAND
										1		QUARTZ SILT
												GLAUCONITE
												NON-SKEL. PO4
		12						4.3	2		5	PYRITE
												OOIDS
											1	INTRACLASTS

(SHELTER-VOID and FRAC.-FILL grouped as SPAR)

Table 1 (cont'd.).

KRR UPPER UNIT LOWER LS	KRR LOW UNIT MID LS	KRR LOW UNIT UP LS UP 1/2	LEH LS Z	LEH LS WX	LEH LS 4	HUM T6 TOP	HUM T6 LOW	HUM T4	HUM T2 TOP	HUM MOUND TOP	HUM RAYTOWN BASE	PETROGRAPHIC THIN SECTION
1	0.6	0.4		1		2.5	0.5		1	2		BIVALVE
1	4	3	1	2	3	1.1	2	5	3	4	7	BRACHIOPOD
1	11	4	5	1	8	0.6	0.5	5	5	4	11	BRYOZOAN
												CORAL
1	6	7	28	30	7	9	11	38	16	4	13	ECHINODERM
2	1.1	4	5	19	1	6.7	9	3	9	7		ENCR. FORAM.
												FORAMINIFER
												FUSULINID
1	0.6	0.8	1	1	1	3.4	1	0.3	0.2	0.8		GASTROPOD
	0.6	2								15		MOL.?/ALGAE?
							0.3					OSTRACODE
39			28	24		24	9	14.5	18.7			"OSAGIA"
										6		PHYLLOID ALGAE
	0.6	11		1	6		4					SPONGE
						0.3		0.7				TRILOBITE
	0.6	3	1	1	3		1.5	15	1.6		0.3	? SKEL. GRAIN
			4			2.5	0.5					PELOIDS
53	75	66			2	2.5	7.5	2	24	46		CO3 MUD
				69							66	DOLOMITE
											2	FE-DOLOMITE
												SHELTER-VOID
											3	FRAC.-FILL (SPAR)
			6	12		15	22	10	18	8		INTERGRAN.
			8	2		1		2				QUARTZ SAND
						2.2	1					QUARTZ SILT
												GLAUCONITE
1												NON-SKEL. PO4
									5	2	0.8	PYRITE
			2	4		29	29					OOIDS
			13	2								INTRACLASTS

Table 1 (cont'd.).

OSA PAOLA BASE	QSBC MID LS SAMPLE Z	QSBC LOW LS SAMPLE Z	QSBC LOW LS SAMPLE T	BCRS PAOLA TOP	BCRS PAOLA 2T	BCRS PAOLA MID	BCRS PAOLA LOW	QEK 2A	QEK SU 2T	QEK SU 1T	QEK SU 1B	PETROGRAPHIC THIN SECTION
	0.5	2		0.3	6			0.6	2	1		BIVALVE
28	2	10	5		5	1.5	47	2.5	3	3	7	BRACHIOPOD
	5	16	4	0.3	4	0.5		3.1	3	5	8	BRYOZOAN
												CORAL
5	5	14	4	1	4		7	1	0.7	1	15	ECHINODERM
0.7	3	1		3	0.7	3				1	0.5	ENCR. FORAM.
			1	0.7	2				0.4			FORAMINIFER
					0.4							FUSULINID
		3		0.7	1			0.3		1		GASTROPOD
	0.3	6	18	29	17	33		16	14	33	3	MOL.?/ALGAE?
								0.3				OSTRACODE
	13										0.5	"OSAGIA"
	0.3	4		3	9	10				1		PHYLLOID ALGAE
	2											SPONGE
		0.5		0.3	0.4		2					TRILOBITE
	1	5		2	5.7	3.5	6	2.5	2	2	1	? SKEL. GRAIN
		5		7		12						PELOIDS
40	5	18	66	52	41	34	27	69	75	48		CO3 MUD
	63	18				3		2			65	DOLOMITE
												FE-DOLOMITE
									1		4	SHELTER-VOID (SPAR)
									3			FRAC.-FILL (SPAR)
			2	0.7								INTERGRAN. (SPAR)
26							12					QUARTZ SAND
												QUARTZ SILT
												GLAUCONITE
												NON-SKEL. PO4
												PYRITE
												OOIDS
												INTRACLASTS

Table 1 (cont'd.).

PSP PAOLA BASE	K32 RAYTOWN 3U	K32 RAYTOWN 3B	K32 RAYTOWN 2B	K32 RAYTOWN 1T	K32 RAYTOWN 1M	K32 RAYTOWN 1B	K32 RAYTOWN LOWER	K32 RAYTOWN BASAL CALCAR.	K32 PAOLA MID	OSA PAOLA 1T	OSA PAOLA 1B	PETROGRAPHIC THIN SECTION
1	2	2					0.8	0.5		0.7	0.4	BIVALVE
1	3	4	1.5	0.4		1	3	6	5	0.7	21	BRACHIOPOD
	8	6	1.5	2	1	1	10	2	3	0.7	4	BRYOZOAN
												CORAL
0.5	1.4	4	0.9	0.4		1	4	49	4	1.3	20	ECHINODERM
	0.3						4	2	3	1.3	5	ENCR. FORAM.
							0.4		0.3	0.7		FORAMINIFER
									0.3			FUSULINID
	0.3	1					1				0.4	GASTROPOD
	4	7		2					1.4	5		MOL.?/ALGAE?
							0.4	0.5				OSTRACODE
								9				"OSAGIA"
	4	5	21	37	7	18	9		21	12		PHYLLOID ALGAE
	4	3	0.6									SPONGE
	0.7		0.3				0.4	0.5			0.7	TRILOBITE
1	3	9	6	3	7		0.8	3	6	4	1	? SKEL. GRAIN
44			4									PELOIDS
44	70	58	59	53	54	79	66		55	47	31	CO3 MUD
			0.3		21							DOLOMITE
												FE-DOLOMITE
				0.8						26		SHELTER-VOID
			0.6	1.2						0.3	0.4	FRAC.-FILL
8			4		5			17			10	INTERGRAN.
	0.4										3	QUARTZ SAND
									0.3			QUARTZ SILT
												GLAUCONITE
												NON-SKEL. PO4
									0.3	0.3	2	PYRITE
												OOIDS
												INTRACLASTS

SPAR

Table 1 (cont'd.).

NEB 8	NEB 6E-F	NEB 2W	PSP RAYTOWN UP. LS UP. ½	PSP RAYTOWN MIDDLE	PSP RAYTOWN LOWER	PSP PAOLA UPPER	PSP PAOLA RUBBLE	PETROGRAPHIC THIN SECTION
						2		BIVALVE
14	1	3	1	4	10	4	7	BRACHIOPOD
5	2	6	5	1	5			BRYOZOAN
								CORAL
6	2	5	4	2	5	1	0.4	ECHINODERM
0.3	0.7	3				5	8	ENCR. FORAM.
0.3								FORAMINIFER
	1		1					FUSULINID
	0.3						0.4	GASTROPOD
				9	3			MOL.?/ALGAE?
	0.3							OSTRACODE
								"OSAGIA"
			4			2	8	PHYLLOID ALGAE
	0.3		11					SPONGE
0.3								TRILOBITE
13	4	4	1	2	3	5		? SKEL. GRAIN
					1	40	41	PELOIDS
56	69		71	68	68	33	22	CO3 MUD
4	8	64				5		DOLOMITE
		5						FE-DOLOMITE
1	8	7						SHELTER-VOID
								FRAC.-FILL (SPAR)
	1		2	13	5		13	INTERGRAN.
0.3		2						QUARTZ SAND
								QUARTZ SILT
								GLAUCONITE
								NON-SKEL. PO4
						4		PYRITE
								OOIDS
								INTRACLASTS

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