THE UNIVERSITY OF TULSA

THE GRADUATE SCHOOL

PROFILE OF AN UNUSUAL OOLITE DEPOSIT - DEPOSITIONAL

FACIES OF THE DRUM LIMESTONE (PENNSYLVANIAN,

MISSOURIAN), MONTGOMERY COUNTY, KANSAS

by
William Paul Stone, Jr.

A thesis submitted in partial fulfillment of

the requirements for the degree of Master of Science

in the Department of Geosciences

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A THESIS

APPROVED FOR THE DEPARTMENT OF

GEOSCIENCES

By Thesis Committee

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ABSTRACT

Stone, William Paul, Jr.   (Master of Science in Geology)

Profile of an Unusual Oolite Deposit - Depositional Facies

     of the Drum Limestone (Pennsylvanian, Missourian),

     Montgomery County, Kansas   (140 pp. - Chapter V)

Directed by Dr. John B. Comer

(137 words)

The Upper Pennsylvanian (Missourian) Drum Limestone in
Montgomery County, Kansas, is characterized by an unusual,
thick body of cross-bedded oolite that formed by filling a
paleobathymetric depression. Seemingly delicate fossils,
protected from breakage and abrasion by thick algal coatings
acquired before introduction into the high-energy oolitic
environment, are abundant. The taxonomically diverse, robust
(not dwarfed) fauna did not live in the ooid-forming environ-
ment, but was transported into it from lower-energy environ-
ments.

Ooliths formed in association with small bryozoan-
algal banks on a shallow subtidal shelf. Mountainous regions
to the south, and lowlands to the northeast and southeast,
provided terrigenous sediments to the study area through
deltaic processes before, during, and after Drum deposition.

Wholesale leaching and cementation began (1) when

deltaic distributaries eroded into the oolite soon after its deposition, and (2) perhaps when oolite shoaled to above sea level.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

Purpose of Study

The evaluation of depositional environments is fundamental to understanding carbonate rock sequences and is important in determining paleogeographic and climatic settings. It is also a necessary preliminary step in understanding the early diagenetic history of a carbonate rock. Consequently, three major reasons for studying the Drum are as follows:

(A) To determine the depositional environment of the Drum Limestone in southeastern Kansas.

(B) To determine why the Drum consists predominantly of oolite, whereas thickenings in the other major Lansing-Kansas City limestones in southeastern Kansas tend to be biogenic buildups.

(C) To determine the reason for the unusual association of fossils and ooids in the Drum. The limestone is richly fossiliferous, and, even upon casual observance, it is apparent that the remains of very delicate organisms were well preserved in cross-bedded oolite.

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This association of fossils and ooids is unusual, as it would seem likely that very delicate organisms would be easily and quickly broken into small fragments in an environment where cross-bedded oolite forms. Conversely, it also seems unlikely that a cross-bedded oolite would be formed where delicate fossils are being preserved.

The Drum provides an ideal opportunity to accomplish these goals, because (1) its outcrop and (2) cores through the entire Drum section taken from the vicinity of its outcrop are both available for study.

Study of the Drum is additionally significant because, even though much has been learned about modern ooid shoals in the past several years, it is perhaps just as important to examine well-exposed ancient rocks, as pointed out by Pray (1978), for use as comparative models.

Besides the intrinsic academic importance of the study of the Drum Limestone, it has significance for hydrocarbon exploration and production:

(A) Oolitic rocks of various geologic ages are important reservoirs in many parts of the world; for example, the Arab D Formation of Saudi Arabia and the Smackover Formation of northern Louisiana and southern Arkansas. Where the Drum thickens, it is predominantly

oolite with abundant oomoldic porosity, and
it may serve as a model for subsurface
exploration.

(B)   The Drum is productive in the subsurface
west of the study area, although not neces-
sarily from oolitic facies.

Procedures

Four two-inch diameter cores, each representing the
entire section of the Drum Limestone were rough-cut length-
wise and provided by Amoco Production Company.   These cores
were then studied through the use of polished slabs, thin
sections, acetate peels, stains, and X-ray diffractometry.
(See Figure 3 for the locations of the cores.)   The cores
were the major sources of information in this study and were
logged in detail with respect to various aspects of lithology,
sedimentary structures and textures, and biotic and non-
biotic constituents.   Generalized logs appear in Appendix A.
The cores totaled 495 ft (150 m) in length.

More than 300 thin sections, cut from samples of the
Drum Limestone from surface exposures in Montgomery County,
Kansas, were also obtained from Amoco and examined.   Figure 3
shows the locations of these exposures.   Field excursions
were undertaken to enhance the data control.

Cross-sections and isopach maps of various intervals
were made from outcrop, core, and subsurface data to facili-
tate interpretations of facies distributions and of deposi-
tional environments.

Previous Investigations

Although the Drum Limestone has been described and
noted by many authors, a detailed petrographic study of the
formation in its type locality has not been published. What
follows is a review of the important published works con-
cerning the stratigraphy, distribution, and general lithology
of the Drum Limestone.

Date	Author(s)	Action (or Contribution)
1894	Haworth and Piatt	First geologic description. Gave it formational rank, calling it the Independence Limestone. Type locality just east of Independence, Kansas, alongside Drum Creek. Erroneously correlated with Fort Scott Limestone (Oswego of the subsurface).
1897	Bain	Described the DeKalb Limestone in Iowa for a unit correlative with the Drum in northern Missouri.
1898	Haworth	Again described the Drum, still calling it the Independence Limestone.
1900	Beede	Described part of the fauna of Pennsylvanian rocks in Kansas and included the Drum Limestone in the Kansas City area.
1903	Adams and others	Proposed the name "Drum" for the limestone at its type locality alongside Drum Creek, because the name "Independence" was preoccupied as a formational name by the Independence Shale of Iowa. Also gave an incomplete faunal list and correlated it with the Erie Limestone.

Date	Author(s)	Action (or Contribution)
1905	Haworth and Schrader	Gave a general description of the Drum Limestone in the Independence area and reported that the company quarrying it at Independence tested it to be a very pure lime carbonate.
1906	Schrader and Haworth	Considered the Drum to be one thick limestone formation near Independence, dividing into three members to the south.
1908	Schrader	Described the Drum again.
1908	Beede and Rogers	Studied the unusual molluscan fauna of the Drum Limestone, stating that the Drum is the most strongly marked stage in the Kansas Coal Measures, characterized by a fauna so different from those of other oolites that it forms a distinct chapter in the geological history of the state.
1908	Haworth and Bennett	Believed the Drum Limestone of the Independence area to be the same as the "Kansas City Oolite", based on faunal evidence supplied by Beede, although it had not been traced in detail to Kansas City.
1908	Siebenthal	Described the thickness and areal extent of the Drum, southwest of Coffeyville, Kansas.
1915	Culbertson	Studied the fauna of the oolites in the Kansas City area, noting that they may or may not be equivalent to the Drum. (Probably described what is now the Westerville Limestone Member of the Cherryvale Formation, frequently called the Kansas City Oolite.)
1915	Girty	Studied the fauna of Pennsylvanian rocks in Missouri and regarded the Drum Limestone as a member of the Kansas City

Date	Author(s)	Action (or Contribution)
		Formation. Pointed out that its decidedly molluscan fauna is a dwarf fauna in the Kansas City area, whereas it is a robust fauna at its type locality near Independence, Kansas.
1915	Hinds and Greene	Speculated on the correlation of the Drum with the DeKalb Limestone of Iowa, based on a series of sections purporting to show that the Drum of the Kansas City area was traceable to the Missouri-Iowa boundary line. Also named the Cement City Member for a small community in eastern Jackson County, Missouri.
1917	McCourt	Described the Drum in Jackson County, Missouri, and gave a faunal list prepared by J. Bennett.
1920	Tilton	Believed that Hinds and Greene (1915) had incorrectly applied the name "Drum" to the limestone in Missouri. Concluded the Drum should be called the DeKalb Limestone, contending that their formation was correlative with a limestone which Baine (1897) had previously named the DeKalb Limestone in Iowa.
1925	U.S. Geological Survey	Tentatively correlated the Drum Limestone of southeastern Kansas with the Dewey, Nellie Bly, and Hogshooter Formations of northeastern Oklahoma, according to Sayre (1930). This reference was not found in researching the present study.
1930	Sayre	Described the Drum Limestone of Kansas, concentrating on its fossil assemblage.

Date	Author(s)	Action (or Contribution)
1932	Moore	Applied the name "Corbin City" to the upper member of the Drum Limestone, from exposures near Corbin City in Montgomery County, Kansas.
1933	Newell	Briefly considered the Drum in a stratigraphic study of the Missourian Series in western Kansas.
1935	Moore	Briefly described the Drum and gave the detailed history of its stratigraphic correlation to that time.
1935	Jewett and Newell	Described the Drum and noted that it was often referred to as the "building ledge" in the vicinity of Kansas City because of its extensive use in construction. Included measured sections of the Drum in Wyandotte County, Kansas.
1935	Newell	Pointed out the previous mis-correlation of the Drum Limestone with the Kansas City Oolite in the Kansas City area, as a result of the similarities in lithology and fauna between the two limestones. Contended that the Kansas City Oolite extends no farther southwest than Martin City in Jackson County, Missouri, and that it is equivalent to the Westerville Limestone Member of the Cherryvale Shale, since it lies below the Cement City Member of the Drum Limestone. Stated that the Drum Limestone of Sayre (1930) near Kansas City is actually the Westerville Limestone. Also noted the great amount of variation in the characteristics of the Drum at its type locality and described the Drum in Johnson and Miami Counties, Kansas, noting changes in thickness, lithology,

Date	Author(s)	Action (or Contribution)
		and faunal/floral content. Provided many measured sections of the Drum in both Johnson and Miami Counties.
1937	Moore	Briefly described the limestone conglomerate thought to be reworked Drum at the base of the Noxie Sandstone just west of Coffeyville, Kansas.
1944	Moore and others	Cited faunal, lithologic, stratigraphic, and thickness data for the Drum Limestone along the length of its outcrop in eastern Kansas.
1957	Branson	Provided a set of tables correlating Pennsylvanian strata in southeastern Kansas with those of northeastern Oklahoma, in which the Drum was shown to be equivalent to the Dewey Limestone of Oklahoma.
1961	Hall	Studied cross-bedding in the sandstones and limestones of the Kansas City Group throughout Kansas, including the Drum Limestone.
1962	O'Conner	Briefly mentioned the Drum Limestone in a summary of the geology of Montgomery County, Kansas.
1962	Wagner	Briefly mentioned the Drum in a summary of the geology of Wilson County, Kansas.
1963	Miller	Noted the variations in thickness and lithology of the Drum in Miami County, Kansas.
1965	Parizek	Briefly described the Drum Limestone in the Kansas City area.

Date	Author(s)	Action (or Contribution)
1966	Jungmann	Briefly described the distribution and lithologic variation of the Drum in outcrop in Neosho County, Kansas.
1966	Miller	Briefly described the distribution and lithologic variation of the Drum in outcrop in Miami County, Kansas.
1969	Hamblin	Studied cross-bedding and paleocurrent directions in Kansas City Group limestones in eastern Kansas, including the Drum. Offered suggestions regarding paleogeography during Kansas City time.
1969	Miller	Briefly described the Drum in outcrop in Allen County, Kansas.
1969	Seevers	Briefly described the Drum in Linn County, Kansas.
1971	O'Connor	Described the distribution and characteristics of the Drum in Johnson County, Kansas.

CHAPTER II

GEOLOGIC SETTING

Tectonic Framework

Kansas is situated in the North American craton on the southern extension of the Canadian Shield (Figure 1). The location of the study area is shown in Figure 2. Since this region has been relatively stable throughout Phanerozoic time, only a thin veneer of, sediments has accumulated over the Precambrian surface (Merriam, 1963), and the structural geology is simple in comparison to mobile belts such as the Ouachita system to the south. Many of the tectonic elements presently evident in Kansas had their origins in post-Mississippian - pre-Desmoinesian time (Merriam, 1963), and the major ones are shown in Figure 4-B. Most of these major structures are not readily detectable at the earth's surface, because they are buried, and have been discovered only through geophysical and hydrocarbon exploration projects.

The present study area is located in the Cherokee Basin, sometimes called the Pryor Basin (Figure 4-B). This basin is a northern extension of the Arkoma, or McAlester, Basin in Oklahoma and Arkansas, and occupies approximately 8400 square miles in southeastern Kansas and northeastern Oklahoma. It is separated from the Sedgwick Basin to the west by the Nemaha Ridge and from the Forest City Basin to
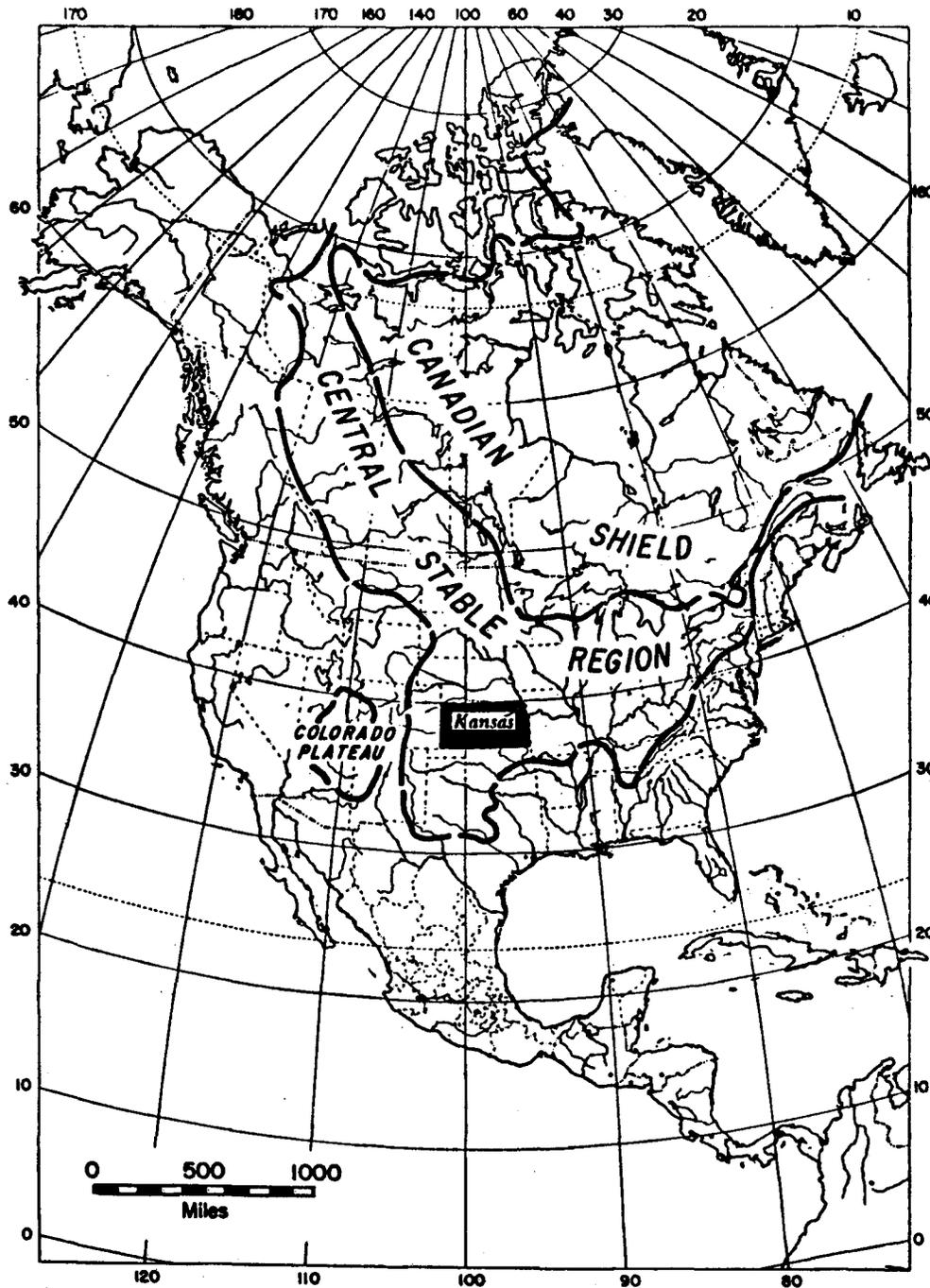
Figure 1.   Index map showing location of Kansas in
relation to the Canadian Shield and the
Central Stable Region (from Merriam,
1963).

DRUM OUTCROP

STUDY AREA

0   50   100
Scale in miles

0   50   100
Scale in kilometers
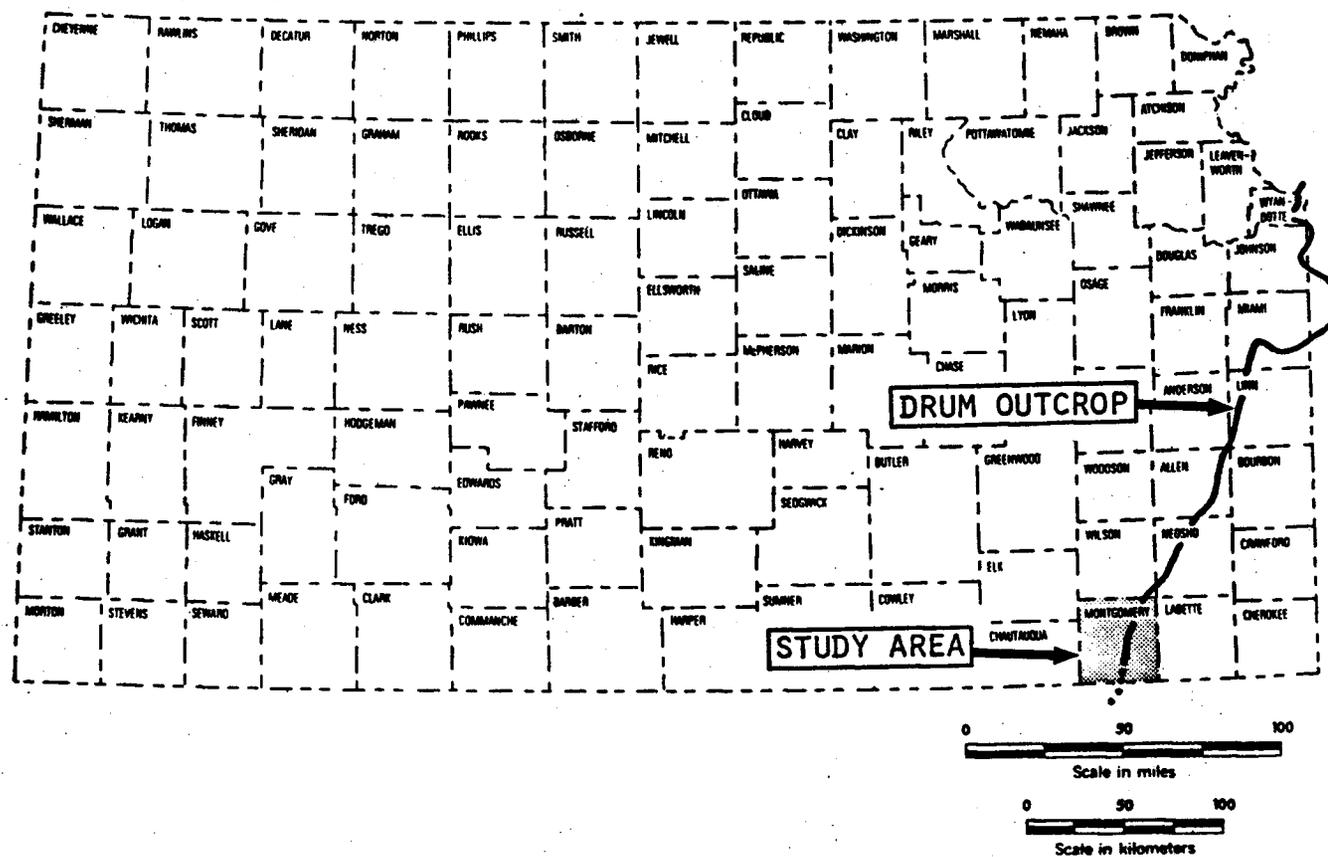
Figure 2. Map of Kansas showing generalized outcrop pattern of the Drum
Limestone. Correlation of the Drum is uncertain near the
Kansas-Oklahoma border in Montgomery County, the study area
(base map from Kansas Geological Survey, 1977).
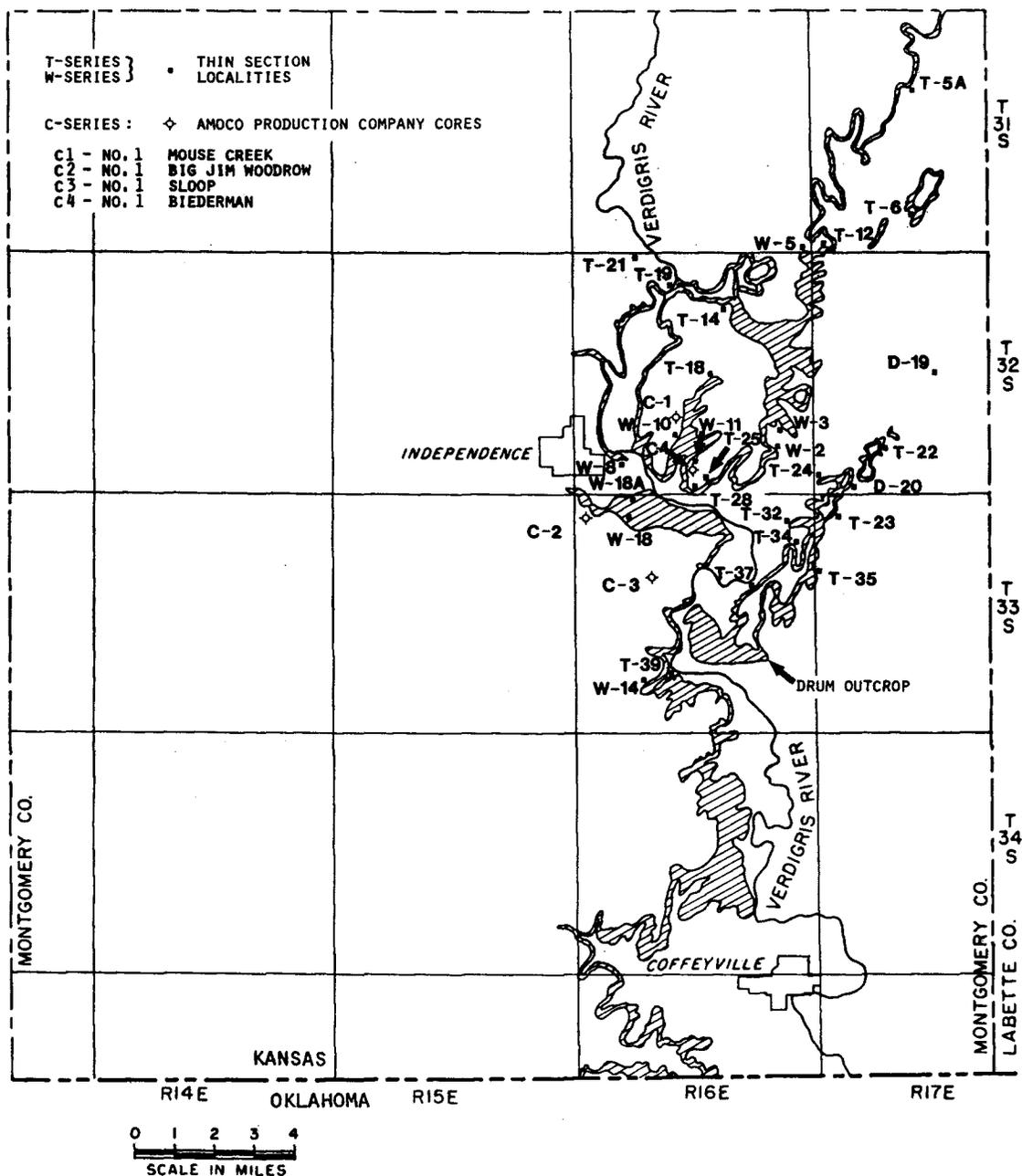
Figure 3. Index map of Montgomery County, Kansas, showing
(1) the localities of the four Amoco Production
Company cores, and (2) some outcrop localities
which were sampled by Amoco geologists. The
thin sections borrowed from Amoco for this study
were made from specimens taken from these out-
crops. The numbering scheme is Amoco's and has
been used here to facilitate future studies.

the north by the Bourbon Arch. The eastern boundary of the Cherokee Basin is the Ozark Uplift. The sedimentary rocks in the Cherokee Basin dip gently westward or northwestward, except for local anomalies and near the Nemaha Ridge, where reversals in dip are not uncommon. Merriam (1963) reported the maximum thickness of sedimentary rocks in the Cherokee Basin to be approximately 3500 ft (1065 m). This basin was developed at the former site of the Chautauqua Arch, a west-ward anticlinal extension of an early phase of the Ozark Uplift (Figure 4-A). As a result of uplifts on the arch, non-deposition and erosion of pre-Pennsylvanian rocks have resulted in the deposition of Lower Pennsylvanian sediments on Cambrian-Ordovician rocks throughout most of the basin (Merriam, 1963). The downwarping of the Chautauqua Arch appears not to have been substantial, because the Pre-cambrian surface does not even reflect the presence of the Cherokee Basin (Figure 5).

The Bourbon Arch is a vaguely defined positive feature of low relief. The sedimentary sequence on the arch re-sembles that of the Forest City Basin. Although it was not subaerially exposed, McMillan (1956) concluded that this arch influenced sedimentation as late as the Pennsylvanian. How-ever, Merriam (1963) warned against placing too much emphasis on the arch as a physiographic divide between the Cherokee and Forest City Basins during Pennsylvanian time.

The Nemaha Ridge is a southward-plunging anticlinal feature which extends from Omaha, Nebraska, to Oklahoma City,
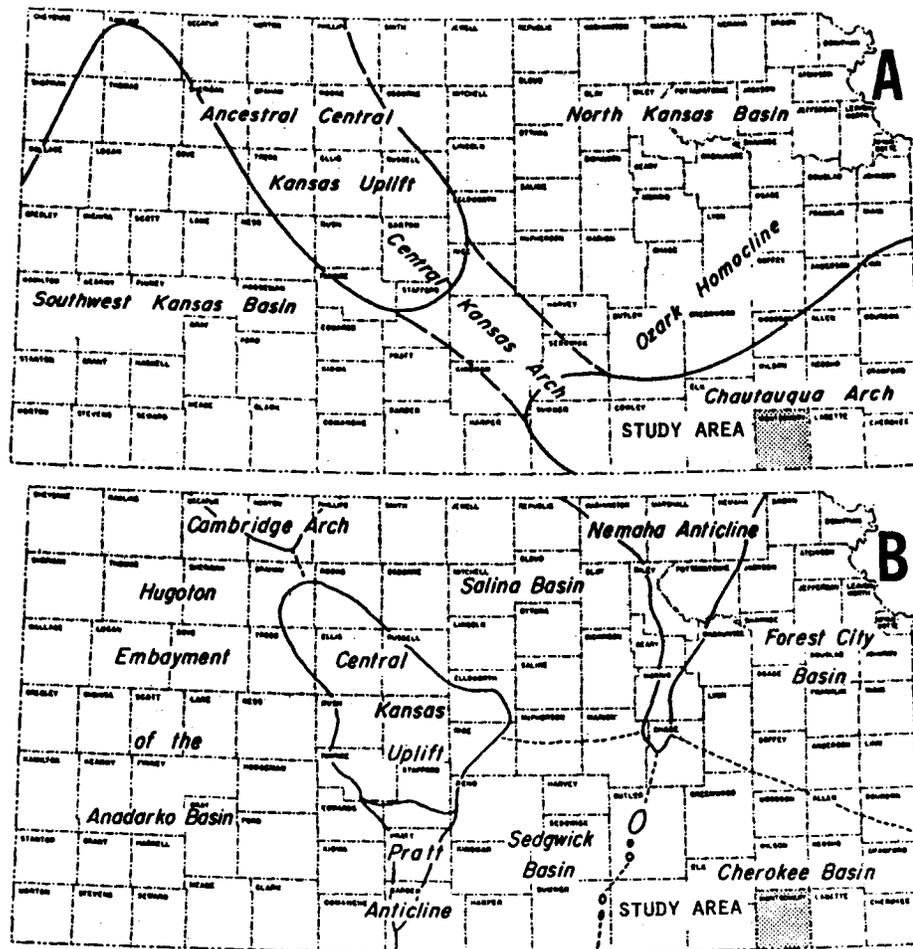
Figure 4.   Major structural features of Kansas.
(A) Pre-Mississippian post-Devonian; and
(B) pre-Desmoinesian post-Mississippian
(from Merriam, 1963).

Oklahoma, and forms the western boundary of the Cherokee

Basin (Figure 4-B). The eastern flank of the ridge is

characterized by high-angle faulting, and pre-Pennsylvanian

beds of the Cherokee Basin are upturned and truncated over

the ridge. Pennsylvanian rocks onlap the older truncated

rocks toward the Nemaha Ridge from both the east and west,

and they overlie rocks as old as Precambrian along the crest

of the ridge.

The Forest City Basin occupies approximately 9500

square miles, with only its western portion extending into

Kansas. It was part of the older North Kansas Basin which

was divided into the Forest City and Salina Basins by the

uplift of the Nemaha Ridge, and was a site of deposition

from post-Arbuckle time through Permian time.

The Sedgwick Basin is a northern extension of the

Anadarko Basin in Oklahoma, and, as the Cherokee Basin, it

is characterized by facies changes to the south. It occupies

approximately 8000 square miles.

Upper Paleozoic beds dip gently westward and north-

westward in eastern Kansas as a result of movement in the

Ozark Uplift in Missouri. This feature is called the Prairie

Plains Homocline and is illustrated in Figure 6. The

monotony of this homocline is interrupted by local domes,

anticlines, and synclines whose origins are mostly post-

Kansas City in age (A. R. Troell, personal communication,

July, 1979). The linear features have two preferred

orientations which parallel the major structural features --

Figure 5. Contour map on top of the Precambrian basement complex in Kansas. Contour interval 500 feet (from Merriam, 1963, modified from Cole, 1962).
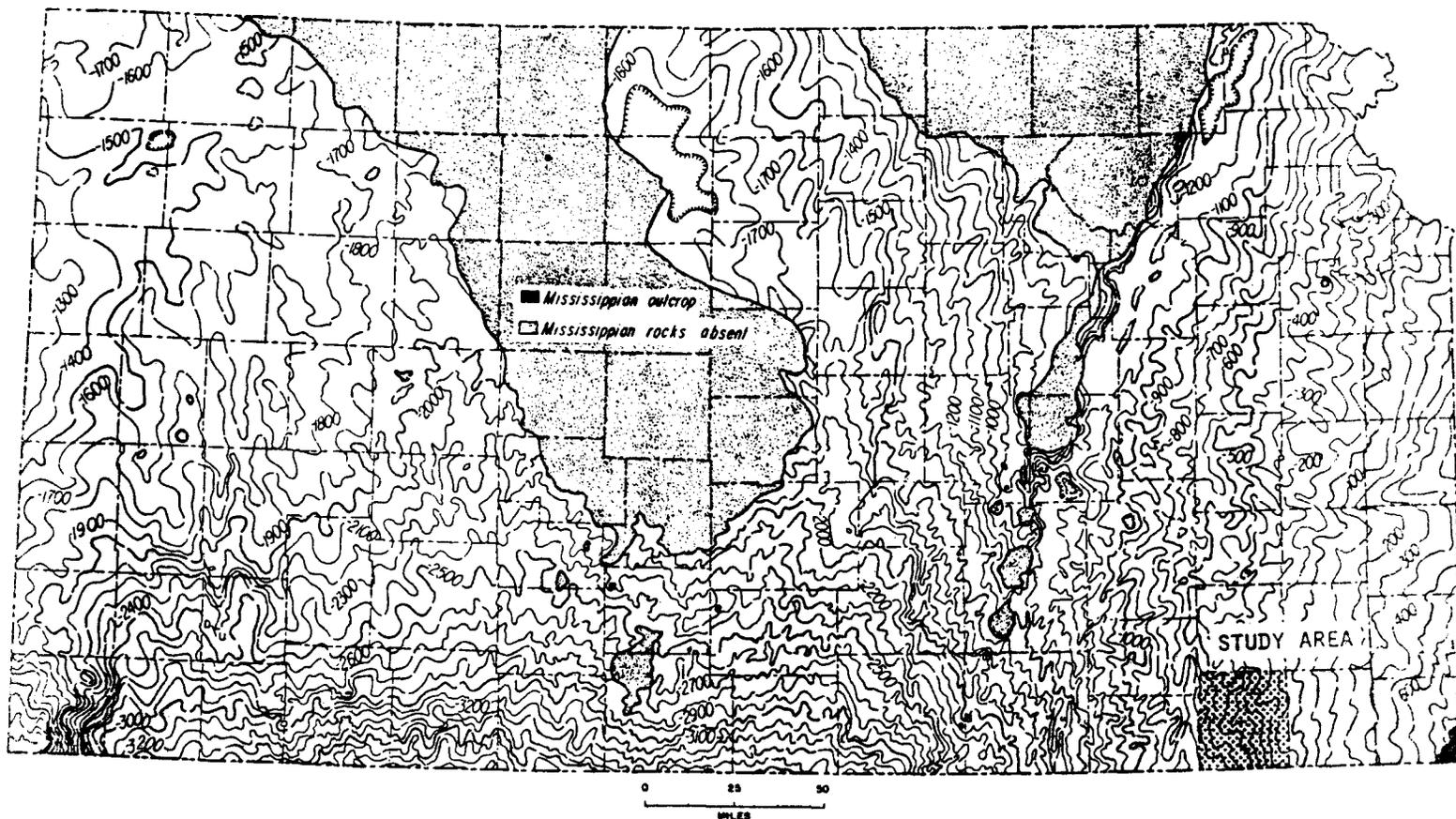
Figure 6. Structural map contoured on top of the Mississippian
rocks in Kansas. Contour interval 100 feet (from
Merriam, 1960).

generally northeast-southwest and generally northwest-southeast. Where some of the larger of these elements intersect, intrusives occur, as in the southern portion of Woodson County (Figure 7). These intrusives are apparently dikes emplaced along faults into Pennsylvanian rocks (Knight and Landes, 1932; Wagner, 1954).

Most of the post-Mississippian - pre-Desmoinesian tectonic elements are discernible on the Precambrian surface (Figure 5). All major positive features plunge southward, and the overall slope of the Precambrian surface in Kansas is to the south.

The area now occupied by the Ouachita Mountains, south of the Arkoma Basin, was a positive and tectonically unstable area during deposition of the Drum (McKee and others, 1975) (Figure 8). This tectonic feature affected Late Pennsylvanian sedimentation in southeastern Kansas more than any other, supplying great amounts of terrigenous material, which were transported northward into the carbonate province of southeastern Kansas. Other positive tectonic elements included the Arbuckle-Wichita trend in southern Oklahoma (Frezon and Dixon, 1975), the ancestral Appalachian Mountains far to the east (Wanless, 1975), and the ancestral Rocky Mountains to the west (Mallory, 1975) (Figure 8).

The Brewster Oil Field is developed on an anticlinal feature in Montgomery County, directly below the thickening of the Drum Limestone (Figure 9). This structure developed after Drum deposition, according to A. R. Troell (personal

EXPLANATION

QUATERNARY SYSTEM
Loess and river valley deposits

Sand dunes

Glacial drift deposits

Limit of Kansan Glacier

TERTIARY SYSTEM

CRETACEOUS SYSTEM

JURASSIC SYSTEM

PERMIAN SYSTEM

PENNSYLVANIAN SYSTEM

MISSISSIPPIAN SYSTEM

SILURIAN-DEVONIAN SYSTEMS

CAMBRIAN-ORDOVICIAN SYSTEMS

PRECAMBRIAN SYSTEM

IGNEOUS ROCKS→

STUDY AREA→

| 0 | 50 | 100 |

Scale in miles

| 0 | 50 | 100 |

Scale in kilometers

Figure 7.   Generalized surficial geologic map of Kansas (modified
from Kansas Geological Survey, 1977).
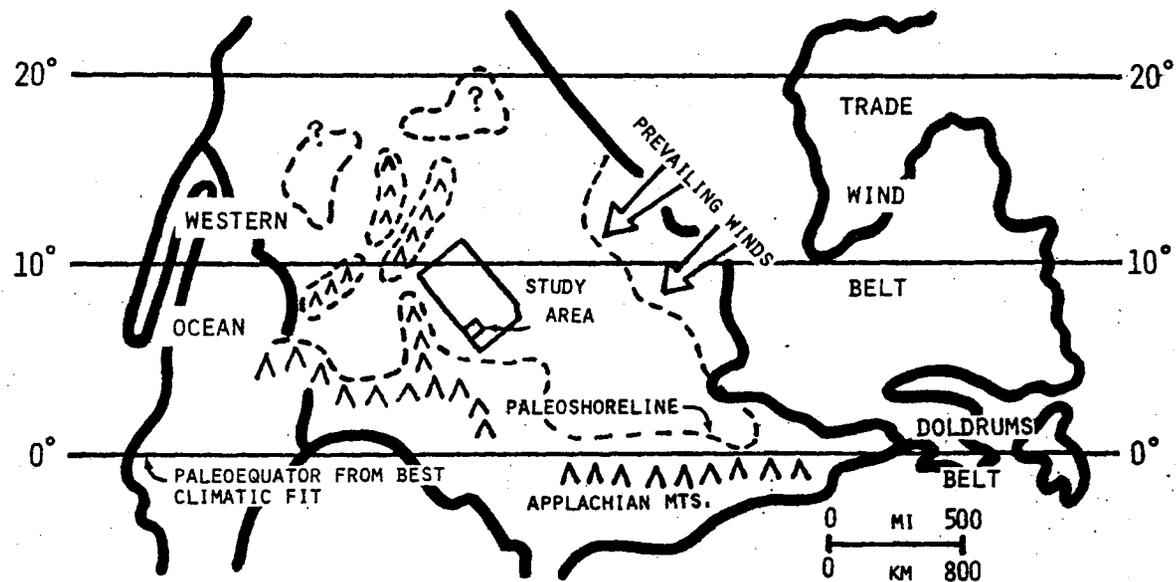
Figure 8. Possible relation of the study area to the equator during Drum deposition (modified from Heckel, 1977).
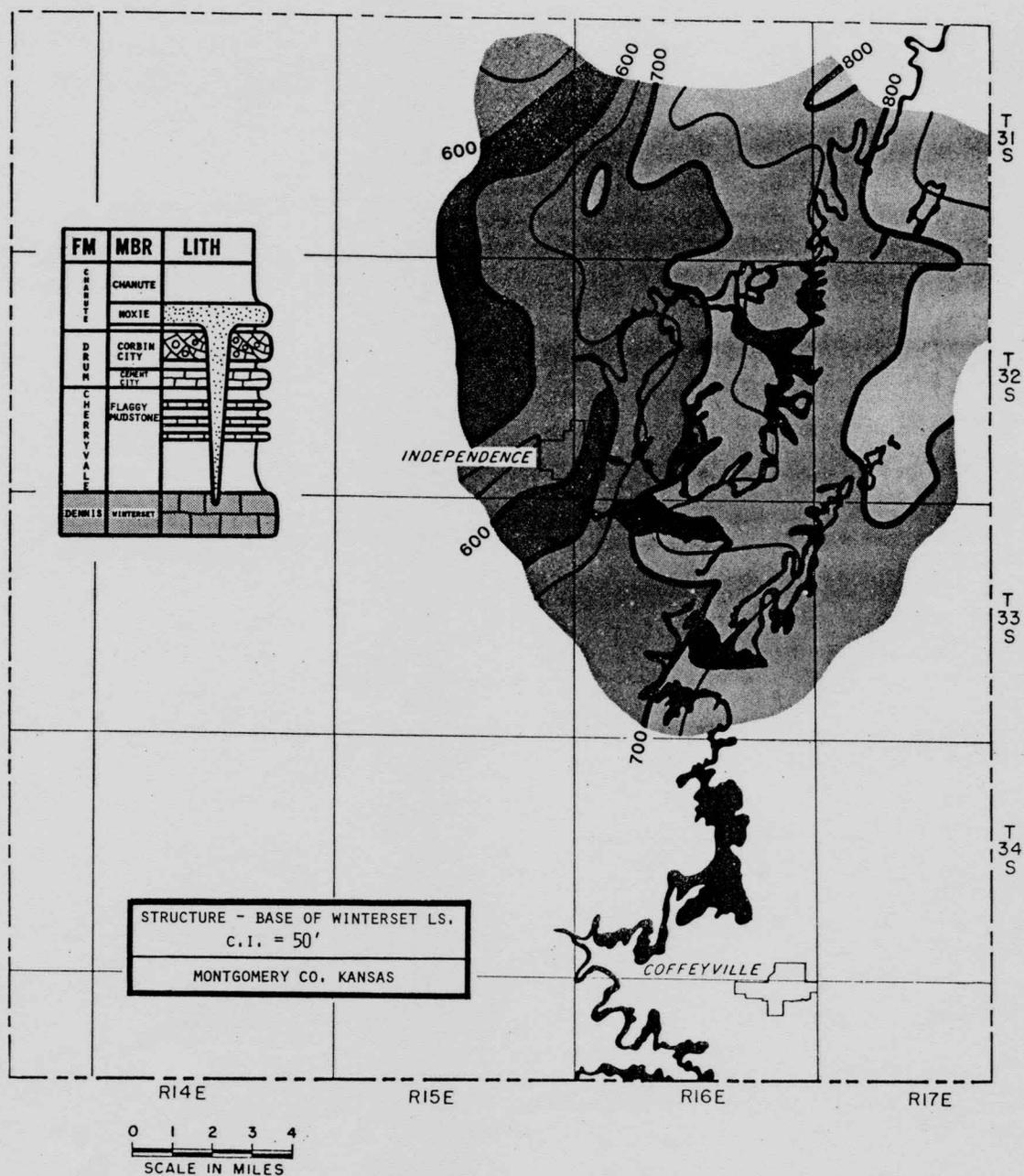
Figure 9. Structure map contoured on the base of the Winterset Limestone Member of the Dennis Formation. The Brewster Oil Field is developed on the anticlinal feature in the northern portion of T33S, R16E. (Based on Amoco Production Company data.)

communication, July, 1979). Consequently, it did not
affect the deposition of the Drum Limestone.

Summary

The tectonic element most influential on Late
Pennsylvanian sedimentation in the study area was the
Ouachita fold belt, because of its large contributions of
terrigenous sediment into southeastern Kansas. Although
the Ozark Uplift contributed sediments, it did not contri-
bute nearly the volume which came from the Ouachitas. The
Arbuckle Mountains in southern Oklahoma may have contributed
sediments to the study area, but sediments from the Wichita
Mountains were prevented from entering the study area by the
presence of the Nemaha Ridge and were thus deposited in the
Anadarko Basin.

The Nemaha Ridge was probably important in that it
affected the circulation of water in the vast Pennsylvanian
epeiric sea by restricting the circulation of the deeper
waters to the basins such as the Cherokee Basin. The
Bourbon Arch probably only slightly affected water circula-
tion.

The most important structural events prior to the
deposition of the Drum Limestone took place during the
period of tectonic instability in post-Mississippian - pre-
Desmoinesian time. During this time, not only were the
mountainous terrigenous sediment sources created, but the
major tectono-sedimentary basins in Kansas were formed as

well. The sizes and shapes of the basins were defined, both
of which affected overall sedimentation patterns.

Probable subsequent periods of rejuvenation of uplifts
in the Ouachitas, Arbuckles, and the Ozarks throughout the
Pennsylvanian affected sedimentation in Kansas, providing
increased deltaic advancement. These periods of high
detrital influx decreased carbonate production, contributing
to the patterns of vertically alternating carbonate and
terrigenous rocks now seen in southeastern Kansas.

The majority of small structures superimposed on the
Prairie Plains Homocline apparently formed after deposition
of the Kansas City Group (A. R. Troell, personal communi-
cation, July, 1979), and thus did not affect the sedimentation
of the Drum Limestone.

Stratigraphic Framework

The Pennsylvanian System crops out in the eastern part
of Kansas, striking roughly northeast-southwest. It dips
northwest and is present throughout most of the Kansas sub-
surface. The system contains the following series in ascend-
ing order: the Morrowan, Atokan, Desmoinesian, Missourian,
and Virgilian (Figure 10). The Missourian Series contains
the following groups in ascending order: the Pleasanton,
Kansas City, Lansing, and Pedee. The Drum Limestone Forma-
tion occurs in the Kansas City Group above the Cherryvale
Shale and below the Chanute Shale (Figure 10), and is known
by the petroleum industry as the "H-Unit" in the subsurface

Figure 10. Generalized stratigraphic section of the Kansas City Group and its relation to older and younger rocks (modified from Moore and others, 1952).

of western Kansas (Figure 11).

Drum Limestone Formation

The Drum Limestone was first described by Haworth and
Piatt (1894), but its present name was proposed by Adams and
others (1903) for its type locality alongside Drum Creek,
east of Independence, Kansas. The outcrop pattern of the
Drum is generalized in Figure 2; the Montgomery County,
Kansas, area is shown in more detail in Figure 3. Moore and
others (1944) reported the Drum to vary in thickness along
its outcrop from a featheredge to more than 60 ft. Moore
(1937b) contended that the Drum is discontinuous across the
Chautauqua Arch because of pre-Chanute Shale erosion. Moore
(1937a) reported the Drum to be missing from the section in
many places west of Coffeyville, Kansas, and his measured
section indicated that the Drum consisted simply of debris
in a conglomerate at the base of the Noxie Sandstone Member
of the Chanute Shale. In the area west of Coffeyville, the
conglomerate pinches out and disappears over short distances.
Because of the poor quality of outcrops south of T33S,
this study is essentially confined to the area in Montgomery
County north of T34S.

The Drum consists of two members, the Cement City
Limestone, below, and the Corbin City Limestone, above.
Where both members of the Drum are present, they are commonly
separated by a few inches of shale. This shale is unnamed
(O'Connor, 1971) and was included in the Corbin City Member
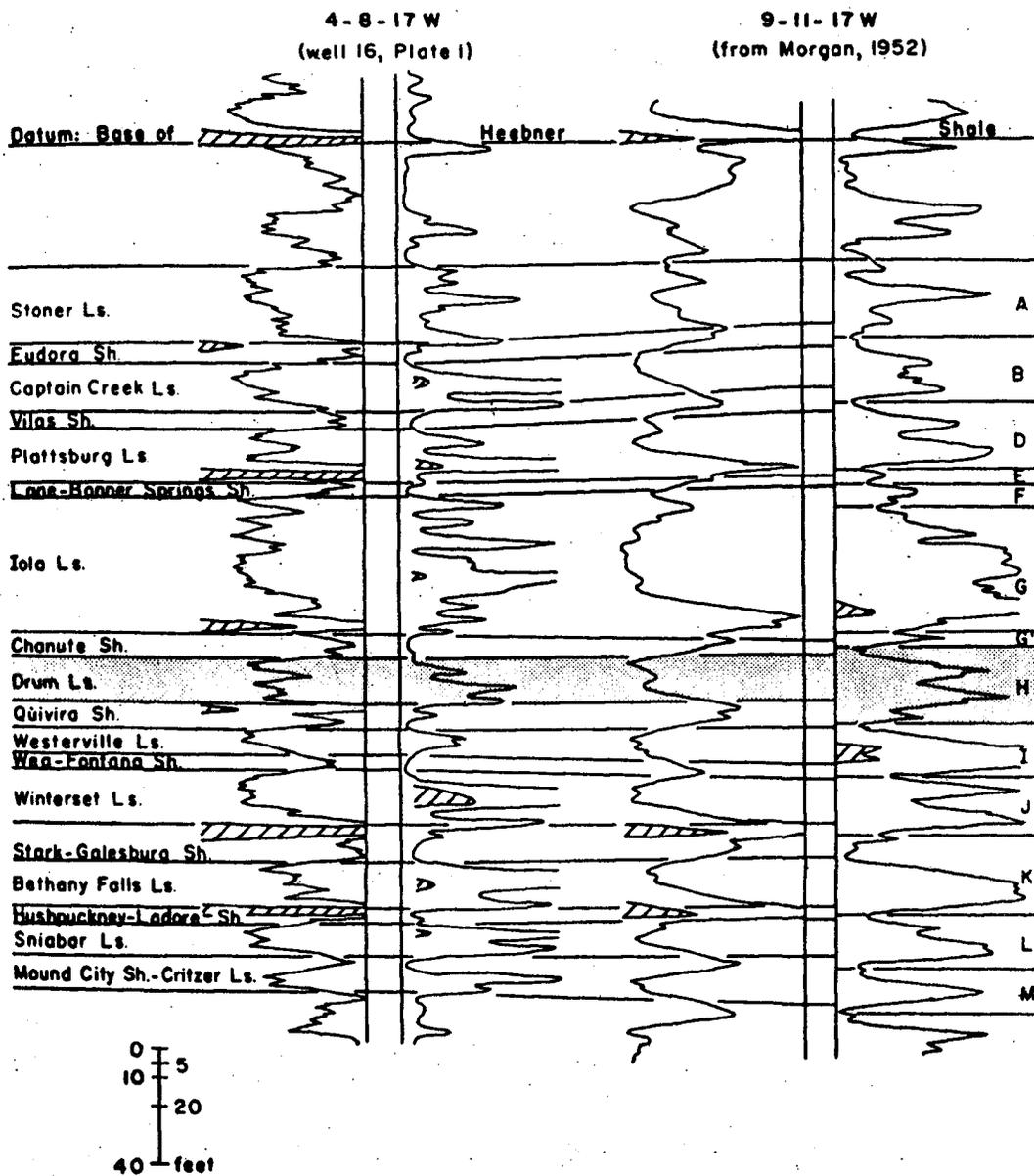
Figure 11.   Correlation of surface and subsurface
             terminology of Lansing and Kansas City
             rocks in Kansas (from Parkhurst, 1959).

by Moore and others (1944).

  <u>Cement City Member</u>. The Cement City Limestone is sometimes called the Dewey Limestone because (1) it has been tentatively correlated with the Dewey of northeastern Oklahoma by several authors (e.g., Branson, 1957), and (2) the Dewey was named by Ohern (1910) earlier than the Cement City was named in Kansas. However, because this correlation is presently uncertain, the member will be referred to as the Cement City in this study.

  The Cement City is the more widely distributed member in the outcrop belt of the Drum Limestone. Named for a small community in eastern Jackson County, Missouri, by Hinds and Greene (1915), it is recognized almost everywhere along the outcrop belt in Kansas and, in many places, represents the entire formation. Although its thickness ranges up to approximately 10 ft near Kansas City, Kansas (Jewett and Newell, 1935; Parizek, 1965), Newell (1935) reported its thickness to vary little from slightly more than two feet between Miami County, Kansas, and Cherryvale, in Montgomery County, Kansas. This consistency in thickness has also been substantiated by Moore and others (1944), Jungmann (1966), Miller (1969), Seevers (1969), and O'Connor (1971).

  Where present, the Cement City Member rests conformably on the Cherryvale Shale (Moore, 1935) (Figure 12). In northeastern Kansas and Missouri, it overlies the Quivira Shale Member of the Cherryvale Shale. The limestone members
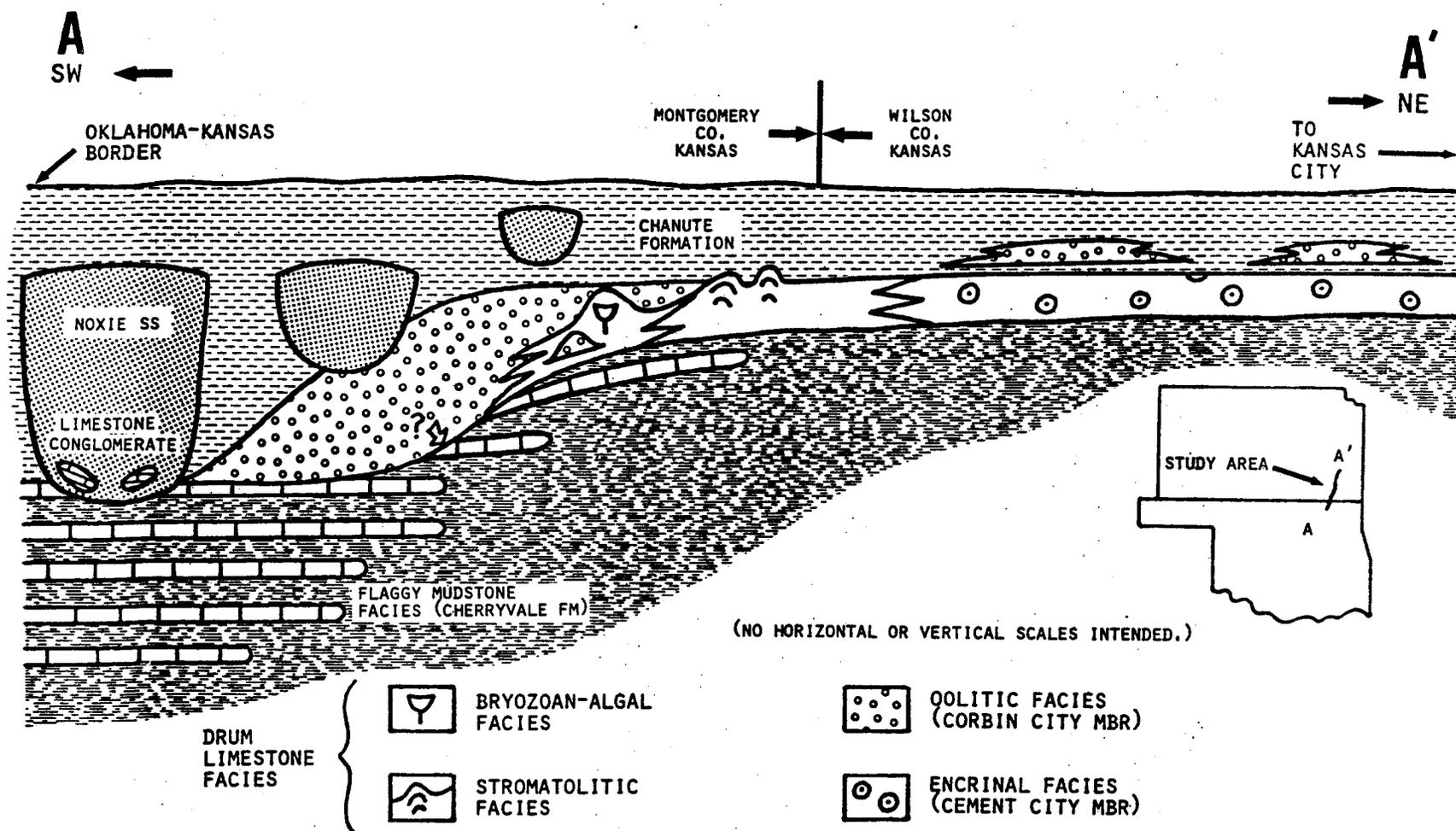
Figure 12.   Schematic stratigraphic cross-section of the Drum Limestone along its outcrop belt.

of the Cherryvale are lost between Kansas City and the
Independence area of Montgomery County, where the Cement
City rests on the undifferentiated shale called the Quivira-
Fontana Shale, or simply, the Cherryvale Shale (Moore and
others, 1944). Where the Cement City is overlain by the
shale separating it from the Corbin City Member, its upper
surface is conformable. West of Cherryvale, Kansas, the
oolitic facies of the Corbin City Member rests disconformably
on the Cement City Member, according to Moore and others
(1944), filling hollows up to five feet deep in the lower
member (Figure 12). Also in southern Kansas, the upper
surface of the Cement City may be unconformable with the
Noxie Sandstone resting above the unconformity surface. In
many places in southern Kansas, pre-Chanute erosion has
removed all of the Drum Limestone, and the Noxie Sandstone
may occupy channels cut so deeply that they intersect the
Winterset Member of the Dennis Formation. This relationship
is illustrated in Figure 10.

The lithology of the Cement City Member is fairly
uniform throughout its outcrop belt. It is non-oolitic and
is frequently described as a dense, fine-grained, or coarsely
to finely crystalline, massive limestone (e.g., Moore, 1935;
Moore and others, 1944; Jungmann, 1966; Miller, 1966, 1969;
O'Connor, 1971). Although it was not found to be directly
stated in the literature, I believe these descriptions sug-
gest that this member is mostly micritic.

Detailed faunal/floral assemblage descriptions of the

Cement City are available from Schrader (1908), Girty (1915),
and McCourt (1917); but here, only trends in these assemblages
are noted. The authors mentioned in the previous paragraph,
among others, have indicated variability in the fossil
abundance in this member, ranging from very sparse to abundant,
but they have invariably reported marine fossils. Miller
(1966, 1969) and Moore (1935) believed that the most character-
istic feature of this member in Johnson, Miami, and Allen
Counties, Kansas, to be the abundance of white crinoidal
debris evenly distributed in the otherwise dark bluish-gray
to brown limestone. At many localities, the crinoid debris
is very abundant, and other fossils are entirely absent.
A zone containing abundant remains of a horn coral reported
to be Caninia torquia by Moore and others (1944) and O'Connor
(1971), and Campophyllum torquium by Jewett and Newell (1935),
Moore (1935), and Newell (1935) is found near the top of the
Cement City Member in northeastern Kansas. This zone is
areally persistent, and the coral is not found in any of the
adjacent limestones (Moore, 1935). The zone is a good marker
for correlation in this vicinity. Throughout its outcrop
belt, this member contains brachiopods such as Neospirifer,
Marginifera, and Composita; fenestrate and ramose bryozoans;
and, less commonly, other marine invertebrates.

Figure 12 illustrates that the stratigraphic position
immediately below the oolitic Corbin City Member in the
study area is occupied by unfossiliferous flaggy lime mud-
stone, regularly interbedded with shale. Moore and others

(1944) and Moore (1964) interpreted these limestone flags to be beds within the Cherryvale Shale. If this correlation is correct, then the mudstone flags are analogous to those of the Block Limestone Member of the Cherryvale in the Kansas City area. Based on (1) these correlations, (2) field work performed by geologists of Amoco Production Company, (3) cross-sections utilizing outcrop data and subsurface data, and (4) the fact that the lithology of the flaggy mudstone facies is unlike that of the Cement City Member everywhere in outcrop outside the study area, the flaggy mudstone facies is herein considered a part of the Cherryvale Shale Formation. Consequently, throughout much of the study area, the Cement City Member is not present. In Chapter IV, all of the non-oolitic limestone facies of the Drum in the study area are shown to be coeval with the oolitic facies. If the Cement City Member is present in the study area, it is, at least in part, the same age as the oolitic Corbin City Member; and indeed, the oolitic facies of the Drum in the study area may actually be a separate facies of the Cement City Member.

Corbin City Member. The Corbin City Limestone Member is defined as representing the upper part of the Drum Formation. Although it is widely distributed along its out-crop belt in Kansas, it is lenticular, and, in most places, it is missing altogether. In most places where it does occur, it is only a few centimeters to two meters thick. However, near Independence, Kansas, it thickens to more than 60 ft

(18 m) (Newell, 1935) (Figure 13).

In northeastern Kansas, the Corbin City Limestone rests conformably on a thin green shale separating it from the underlying Cement City Limestone Member. This shale is not named and has been included as a part of the Corbin City Member by Moore and others (1944). In many places, the shale is absent, and the Corbin City Member rests disconformably on the Cement City Member, as it does west of Cherryvale, Kansas, according to Moore and others (1944). In northeastern Kansas, the Chanute Shale conformably overlies the Corbin City Member, but in some parts of southeastern Kansas, the Corbin City is disconformably overlain by the Noxie Sandstone (Moore and others, 1944). In places, the entire member has been removed by pre-Chanute erosion. The Corbin City varies greatly in thickness over very short distances, but descriptions of its lateral contacts are absent in the literature. Based on the present study, it is believed that, where the member is thickest, in the vicinity of Independence, Kansas, it inter-fingers laterally and is consequently partially contemporane-ous with the Chanute Shale.

The most characteristic feature of the Corbin City Member is its oolitic lithology. In all but one of the descriptions of this member found in the literature, it was described as oolitic. The exception occurs in Moore and others (1944, p. 190), where the member is described as "1 foot or less of chiefly algal limestone in the Kansas City area." Moore (1935) had previously described what was

FM	MBR	LITH
CHANUTE		
NOXIE		
CORBIN CITY		
QUIET CITY		
FLAGGY MUDSTONE		
WINTERSET		

ISOPACH-DRUM LS. OOLITIC FACIES
C.I. = 20'
MONTGOMERY CO., KANSAS

0 1 2 3 4
SCALE IN MILES
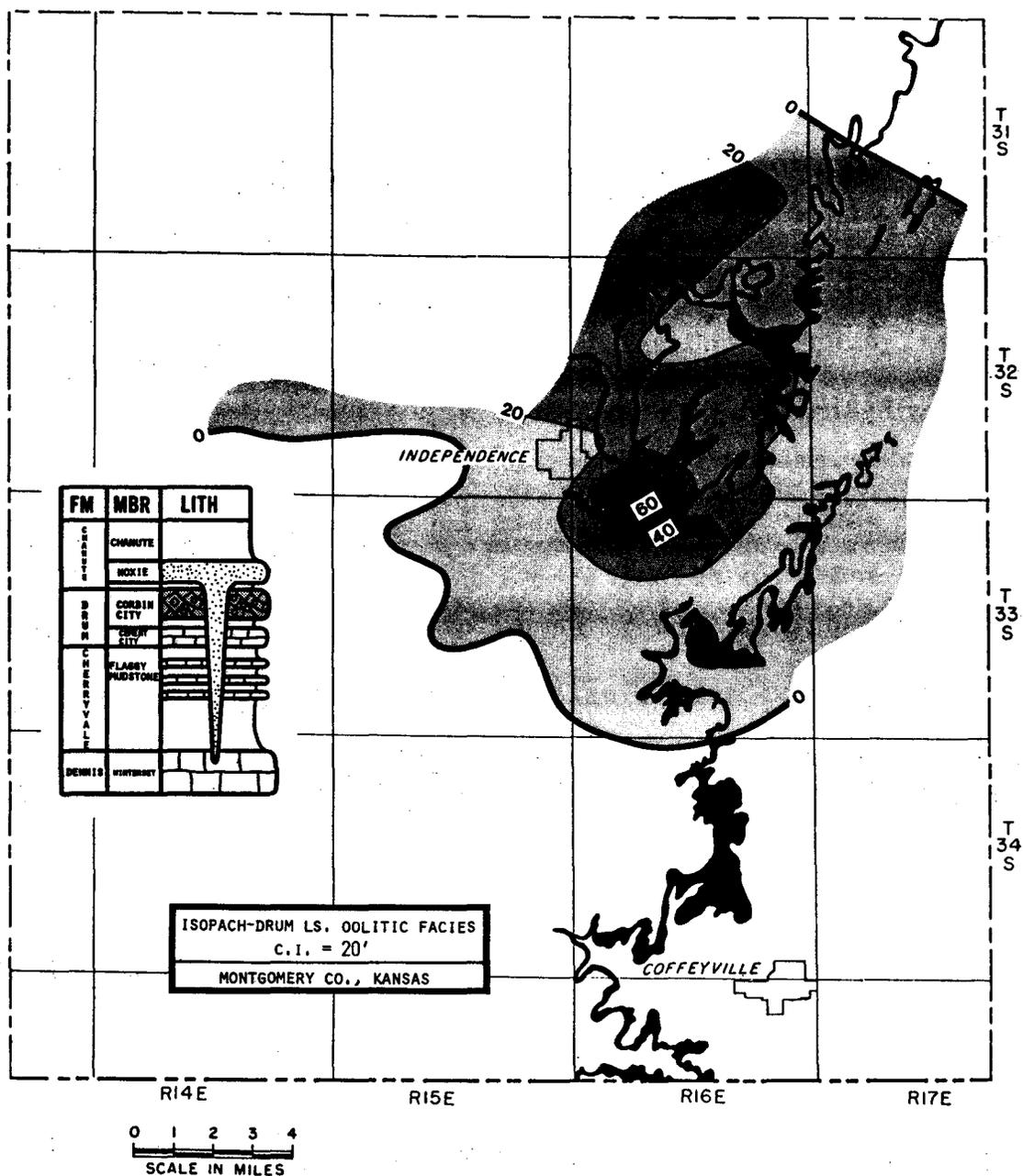
Figure 13. This map shows the Drum oolite to thicken to greater than 60 feet (18 m) southeast of Independence, Kansas. The area of no oolite southwest of the thick area is probably the result of post-oolite erosion rather than non-deposition (based on Amoco Production Company maps and data).

believed to be the Corbin City Member near Kansas City as suboolitic to coquinoid limestone, one foot or less in thickness and containing the algal assemblage Osagia. It is probably this algal form that was later considered by Moore and others (1944) to be the dominant characteristic of the member near Kansas City, although an oolitic fabric is present there as well. (It should be made clear at this point that Osagia is present in many other Upper Pennsylvanian limestones in the Mid-Continent region and is associated with many ancient carbonate banks in southeastern Kansas. However, it is an encrusting algal assemblage and not one of the phylloid algae so abundant in the core facies of these biogenic buildups.)

In addition to its oolitic nature, the Corbin City Limestone Member is locally highly fossiliferous, containing a wide variety of normal marine fossils (Adams and others, 1903; Beede and Rogers, 1908; Girty, 1915; McCourt, 1917; Sayre, 1930; Moore, 1935; Newell, 1935; and many others). Newell (1935) documented the strongly molluscan nature of the fauna in the oolitic facies. Girty (1915) characterized the fauna of the oolitic Drum in the Independence area as "robust" -- similar in content and types of species, but consisting of larger individuals than those normally found associated with oolite. Although Girty incorrectly correlated the Drum with the Westerville Limestone Member of the Cherryvale Formation (frequently called the "Kansas City Oolite"), he noted that the fauna of the latter limestone in

the Kansas City area is a dwarfed fauna, as is more commonly
found associated with oolitic facies than normal-sized or
"robust" faunas. Notwithstanding his miscorrelation of the
two limestones, the fact that the fauna of the oolitic Corbin
City Member in southeastern Kansas is "robust" seems signifi-
cant and is discussed in Chapter IV.

Because of the present uncertainty of the correlation
of the oolite in the Independence area described above, the
oolitic facies of the Drum Limestone in the study area are
herein called the Drum oolite.

Pennsylvanian Sedimentation - Cyclothems

Shale formations containing sandstones, alternating
with limestones, characterize most of the Middle and Upper
Pennsylvanian sequence in Kansas, including the Kansas City
Group (Figure 10). Moore (1935, 1949) designated couplets
of limestone and shale members "cyclothems". He noticed
that, frequently, distinct sequences of limestone-shale
couplets occur repeatedly in successive formations, produc-
ing repetitive cycles of cyclothems which he called "mega-
cyclothems". In the most complete megacyclothems, five
limestones are present. In ascending order, they are the
lower, middle, upper, super, and fifth limestones (Figure 14).
The upper and lower boundaries of each megacyclothem are
marked by the occurrence of sandy shale formations called
"outside shales". Heckel (1977) contended that, in most
cyclic sequences, the megacyclothems are incomplete, the
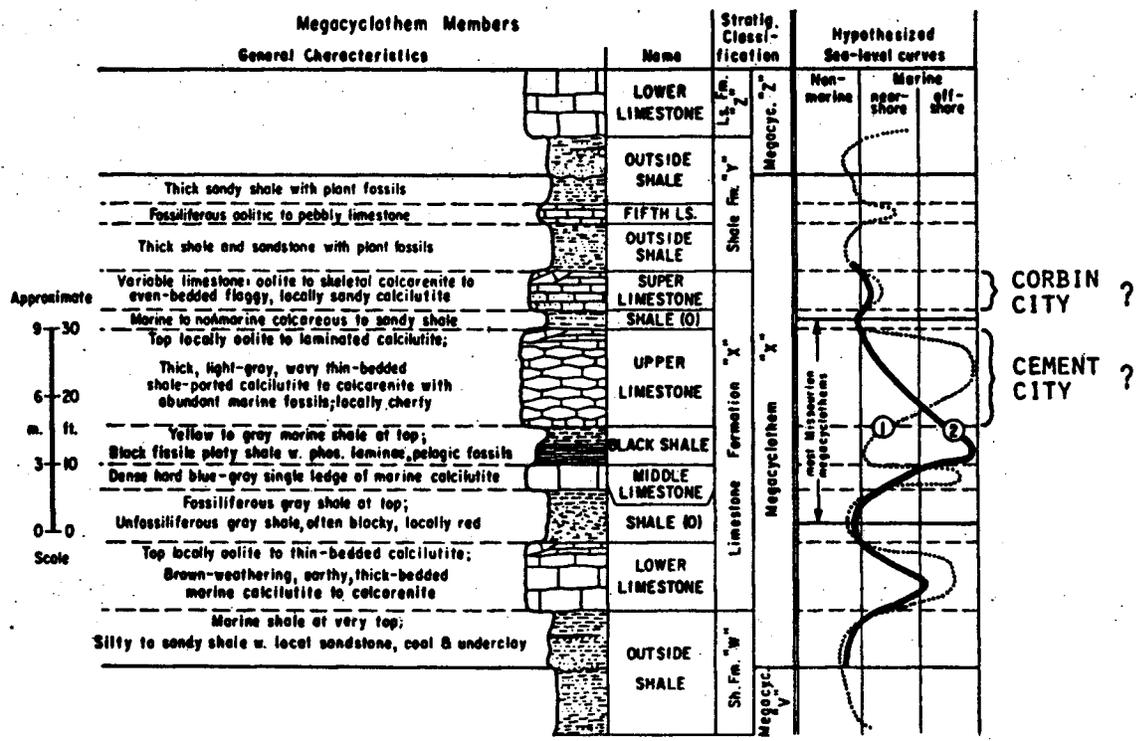
Figure 14. "Ideal" megacyclothem. Moore (1935) believed the Cement City Member of the Drum Formation to be an upper limestone of a megacyclothem and the Corbin City Member to be a super limestone (from Heckel and Baesemann, 1975).

middle and upper limestones being the only limestones present.
Heckel and Baesemann (1975) considered the other limestones
fortuitous. In the Missourian rocks of Kansas, and particu-
larly those of the Lansing and Kansas City Groups, the most
common basic vertical sequence is, in ascending order, the
following: sandy (outside) shale formation -- middle lime-
stone member -- black (core) shale member -- upper limestone
member -- sandy (outside) shale formation. This portion of
the ideal megacyclothem was called the "Kansas-type cyclo-
them" by Heckel (1977). It is indicated in Figure 14 and
can be seen by the heavy curve (No. 2) to represent a single
transgression and regression of the sea. Heckel (1977) con-
cluded that the middle transgressive limestones of Kansas-
type cyclothems are commonly thinner than the upper and super
limestones, because of (1) the progressive stranding of
detrital influx farther away during transgression, and (2)
the possible difficulty in generating carbonate material over
the decaying vegetation of the deltaic plain and/or in
rapidly deepening water. The upper and super limestones of
the regressive phase, however, are typically thicker, at
least locally. These are represented by the Missourian
limestones which developed dramatic thickenings in the form
of phylloid-algal mounds in Kansas (Figure 15).

Moore (1935) concluded that the lower Cement City
Member of the Drum Limestone is probably an upper limestone
of a megacyclothem, and that the upper Corbin City Member is
a super limestone. This interpretation suggests that both

Figure 15. Generalized stratigraphic column of part
of the Upper Pennsylvanian section in
eastern Kansas and northeastern Oklahoma.
Asterisks mark limestone units with
phylloid-algal mound complexes; double
asterisks signify two regional mound
developments (from Heckel and Cocke,
1969).

members formed during the regressive phase of a megacyclo-
them.

The problem of eustatic sea-level changes has been
extensively discussed with respect to the Pennsylvanian
cyclothems in the Mid-Continent of North America. Wells
(1960) and Vail and others (1977) have recognized the
probability of worldwide eustatic sea-level changes during
the Pennsylvanian. However, Ferm (1970) and Galloway and
Brown (1973), both recognizing the probable influence of
extrabasinal controls such as sea-level oscillations,
demonstrated that the simplest way to explain cyclicity in
the Pennsylvanian deposits of the Appalachians and north-
central Texas, respectively, is to invoke local sedimentary
control through processes of delta building and abandonment.
Nevertheless, in Pennsylvanian times, both marine and
deltaic strata were deposited on top of one another in cyclo-
themic fashion, across vast portions of eastern and mid-
continent North America. Considering the relative importance
of extrabasinal and local controls on cyclothem production
in the Pennsylvanian, Heckel (1977) stated the following:

> It is far easier to explain this wide-
> spread distribution of both marine rocks
> and delta wedges if mean shoreline
> swept back and forth periodically from
> central Kansas to the Appalachians, than
> if shoreline remained in the same general
> position and was modified only by local
> delta outbuilding and abandonment.

There is substantial evidence that eustatic sea-level

changes must be invoked for late Middle and Upper Pennsylvanian deposits in Kansas (Schenk, 1967; Heckel, 1975; Heckel and Baesemann, 1975; Heckel, 1977) and in the Appalachians (Wanless, 1972), and for the Upper Pennsylvanian of New Mexico (Wilson, 1967).

However, eustatic sea-level changes do not preclude local transgressions and regressions related to deltaic processes from occurring. Both widespread (eustatic) and local (deltaic) sequences have been shown to be present in eastern and mid-continent North America by Wanless (1966, 1972; Wanless and others, 1970). Ferm (1970) contended that the proper approach to interpreting the causes of Pennsylvanian cyclic transgressions and regressions is not to choose between eustatic sea-level changes and local changes in response to deltaic processes, but rather to determine the degree to which eustatic changes affected deltaic processes.

Paleogeography

Upper Pennsylvanian clastic wedges thickening from Kansas, to the northeast, east, and especially to the south, suggest that highlands existed during that time beyond Kansas in those directions (Walton, 1960; Ball, 1964; Crowley, 1969; Heckel and Cocke, 1969; McKee and others, 1975). These highlands, which contributed sediments during Late Pennsylvanian time, probably included the Ouachita Mountains in Oklahoma and Arkansas, the Wichita-Arbuckle

Mountains in southern Oklahoma, the Ozark Dome in Missouri, and perhaps areas with less topographic relief to the north and the northeast. The Appalachian Mountains were standing high to the east, as were the ancestral Rocky Mountains in Colorado and New Mexico to the west (Heckel, 1977). The character of the western portion of the North American continent during the Late Pennsylvanian is not well understood, but beyond the ancestral Rockies was probably open ocean.

The Ouachita fold belt was the most important of these positive features with respect to Late Pennsylvanian sedimentation in southeastern Kansas, providing large amounts of detrital sediments. That the bulk of detrital sediments introduced into southeastern Kansas in the Late Pennsylvanian originated in the Ouachita province is suggested (1) by northwest paleocurrent indicators in the Upper Pennsylvanian sandstones of northeastern Oklahoma and southeastern Kansas (Figure 16); (2) by the areal distribution of terrigenous facies (Figures 17 and 18); and (3) by the dramatic thickenings of the Pennsylvanian clastic wedges from southeastern Kansas into the Arkoma Basin, toward the Ouachita province (Figure 19).

The Upper Pennsylvanian carbonate members in southeastern Kansas outnumber those in northeastern Oklahoma. The limestones thin and become less numerous southward (Figure 19). The influx of sediment from the southeast apparently significantly limited the southern extent of carbonate production.

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Figure 16. Cross-bedding directions in Upper Pennsyl-
vanian sandstones associated with limestones
studied by Hamblin (1969). The rose dia-
grams summarize directions in the Vamoosa
Formation of Oklahoma and the Douglas, Kansas
City, and Marmaton Groups in Kansas. They
illustrate the general directions of sand
transportation in the Late Pennsylvanian and
suggest terrigenous sediment sources south,
east, and northeast of the study area during
much of that time (from Hamblin, 1969).

KANSAS

EXPLANATION

Average cross-bedding direction.

Outcrop belt of Douglas Group and Vamoosa Formation.

Outcrop belt of Marmaton Group.

STUDY AREA

OKLAHOMA

N
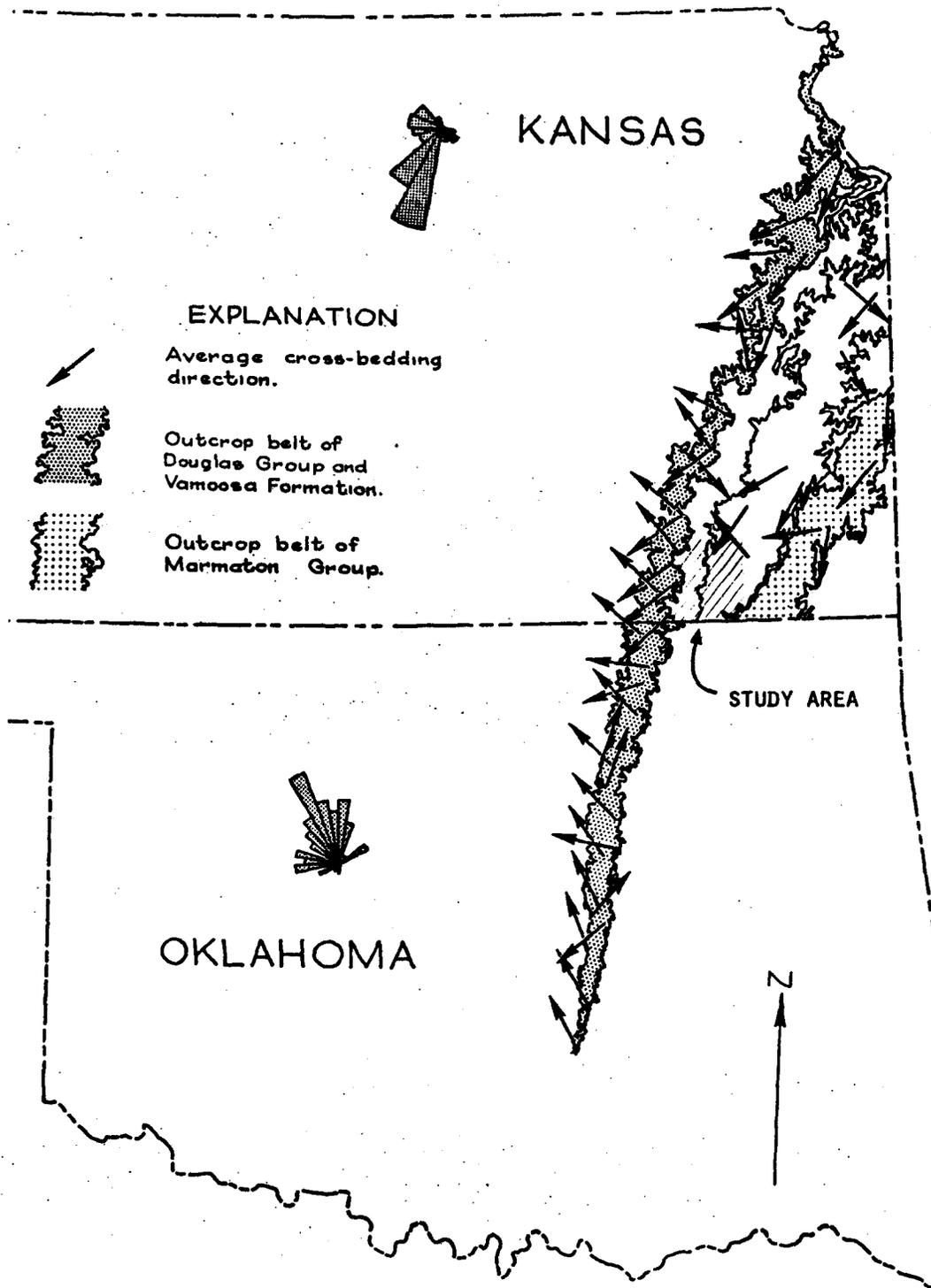
Figure 17. Environmental map showing deltas in basal Missourian sediments in the Illinois Basin (Exline Sandstone Member, Modesto Formation); in Iowa, Missouri, and Kansas (Hepler Sandstone Member, Pleasanton Group); and in northern Oklahoma (Cleveland Sandstone Member, Pleasanton Group) (prepared by D. E. Orlopp, 1964) (from Wanless and others, 1970).

LEGEND

LOW POSITIVE AREA	LOW POSITIVE AREA, EXPOSED GRANITE
SEA, RESTRICTED CIRCULATION, DARK-BLACK MUDS	SEA, OPEN CIRCULATION, GRAY MUDS
SEA, OPEN CIRCULATION, RED-VARIEGATED MUDS	DELTA MUDS
FLOODPLAIN MUDS	CHANNEL SANDS
DELTA SANDS	FLOODPLAIN SANDS
OPEN MARINE AREAS, NORMAL MARINE LIME	PIEDMONT AREA; RED, SANDY SHALE, ARKOSE AND CHERT

SCALE

0   20   40   60 MILES
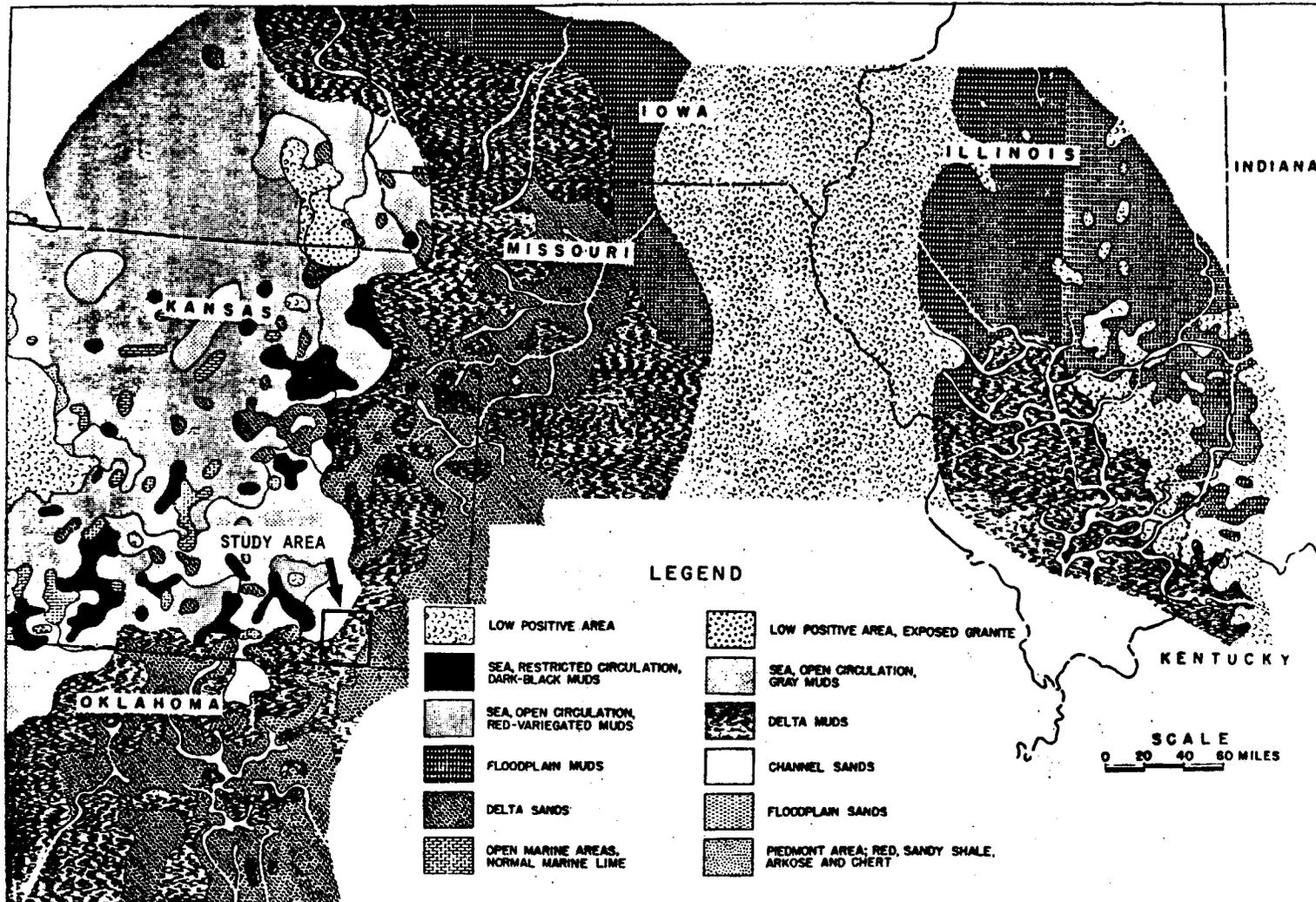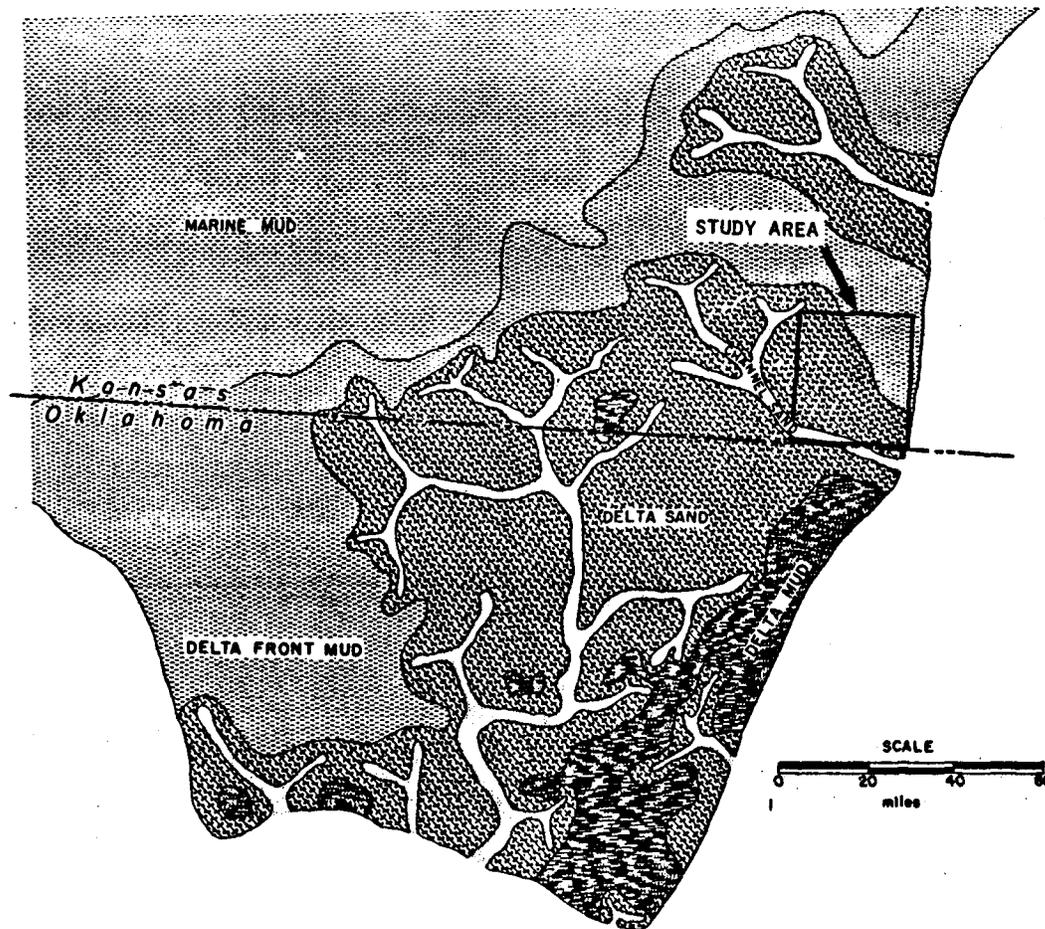
Figure 18.   Environmental map of the deltaic sediments of
the Noxie Sandstone Member of the Chanute Forma-
tion and contemporary strata in southeastern
Kansas and northeastern Oklahoma.   This map
suggests the shoreline advanced northwestward
and the study area was transformed into a deltaic
plain soon after deposition of the Drum Limestone
(from Horne, 1965).
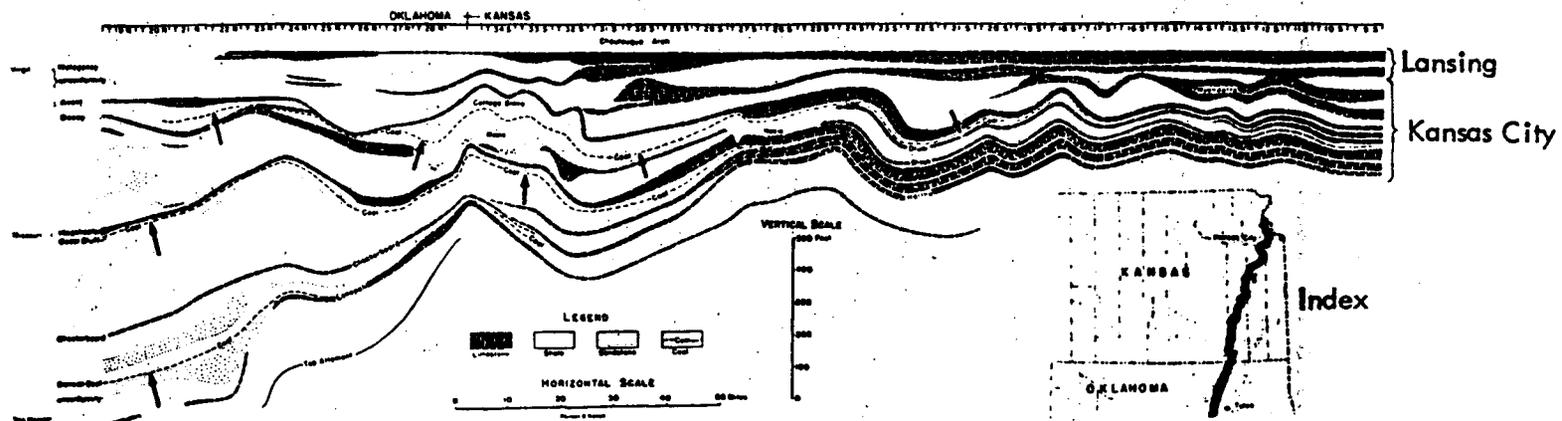
Figure 19. Diagrammatic section of Missourian strata in eastern Kansas and northeastern Oklahoma illustrating the southward disappearance of limestones, accompanied by thickening of clastic deposits (modified from Moore, 1964, based on sections by N. D. Newell).

During periods of high detrital influx and marine regression,
the carbonate facies were onlapped from the southeast by
terrigenous clastic facies, and the southern limit of
carbonate production was forced northward into Kansas.

Carbonate sedimentation alternated with deltaic sedi-
mentation prior to the deposition of the Drum Limestone in
the study area. Deltaic advancement was from the southeast,
as illustrated in Figure 17. Periods of extensive delta
building may have been the result of (1) renewed uplift in
the Ouachita belt, (2) periods of greater humidity and rain-
fall, or (3) both (1) and (2).

A period of deltaic encroachment into the study area
succeeded Drum deposition. Figure 18 shows the distribution
of deltaic sediments of the Noxie Sandstone Member of the
Chanute Formation in southeastern Kansas. The relationship
of the Noxie Sandstone to the Drum Limestone is discussed
in Chapter IV.

The Drum Limestone was not deposited during a period
of maximum deltaic advancement, but some distant deltaic
activity probably affected sedimentation in the study area
during Drum deposition. Evidence of this influence is pre-
sented in Chapter III and discussed in Chapter IV.

The shallow epeiric seas in which the Upper Pennsyl-
vanian cyclothems were deposited extended 2000 kilometers
from the Appalachians to West Texas during periods of maxi-
mum transgression. They apparently communicated with the
open sea through a strait at the Midland Basin in West Texas

(Heckel, 1977). Estimates of water depths in these seas have been made for different periods throughout Pennsylvanian time by Elias (1937, 1964), McCrone (1964), Heckel (1977), and many others. Heckel (1975, 1977) advanced a hypothesis in which periods of maximum transgression (deepest water) in the Mid-Continent were marked by deposition of the black phosphatic "core" shales of his ideal Kansas-type cyclothems (Figure 14). He suggested water depths of up to 200 meters at the narrow strait in the Texas panhandle during maximum transgressions. This hypothesis requires an average depositional slope of only 0.1 m/km (approximately 0.5 ft/mi) from the northern Appalachian shoreline. Because the Mid-Continent was transgressed and regressed many times by Late Pennsylvanian seas, as discussed above, the water depth at any given place changed frequently. Most of the phylloid algal mounds developed in the limestones of the Kansas City Group of southeastern Kansas probably rose slightly above the surrounding sea floor, although evidence for substantial depositional relief is lacking (Harbaugh, 1962). Yet, the luxuriant algal floras proliferated, indicating the waters were shallow enough to allow photosynthesis on the sea floor. Holmes (1957) reported that, under the optimum conditions of clear ocean water and a zenith sun, only 10% of the total incident light energy reaches a depth of 110 ft (34 m), and less than one percent penetrates to 300 ft (90 m). Consequently, most modern calcareous algae are restricted to depths of less than 200 ft (60 m) (Heckel, 1972). Wilson

(1975) reported that most modern mud-producing algae are restricted to approximately 50 ft (15 m) of water depth. In addition, most of the mounds are flanked and capped by cross-bedded grainstone facies, suggesting that the mounds frequently accreted at least to above wave base, or that the wave base was lowered to below the tops of the mounds. Some mounds were apparently emergent at times, forming islands. These lines of evidence indicate that the Late Pennsylvanian seas in southeastern Kansas were, at least sometimes, very shallow -- on the order of 100 ft (30 m) or less.

Figure 17 shows the distribution of basal Missourian deltaic sediments and associated facies in Kansas. The map suggests a shoreline in southern, eastern, and northern Kansas, concave westward, with land to the south, east, and north; and a marine environment to the west. The position of the shoreline during deposition of the Drum Limestone is thought to have been similar to that shown in Figure 17, except that the encroaching deltas had not advanced the shorelines quite as far from the south and southeast. This interpretation is based on facies maps similar to Figure 17, but for later sediments, as well as on paleocurrent data from Hamblin (1969). Figure 20 illustrates the probable position of the shoreline during Drum deposition.

The land to the east, northeast, and immediately to the southeast was probably low-lying, perhaps only several feet above sea level. It contained many coal swamps (Wanless, 1961, 1969; Wanless and others, 1963; Wanless and
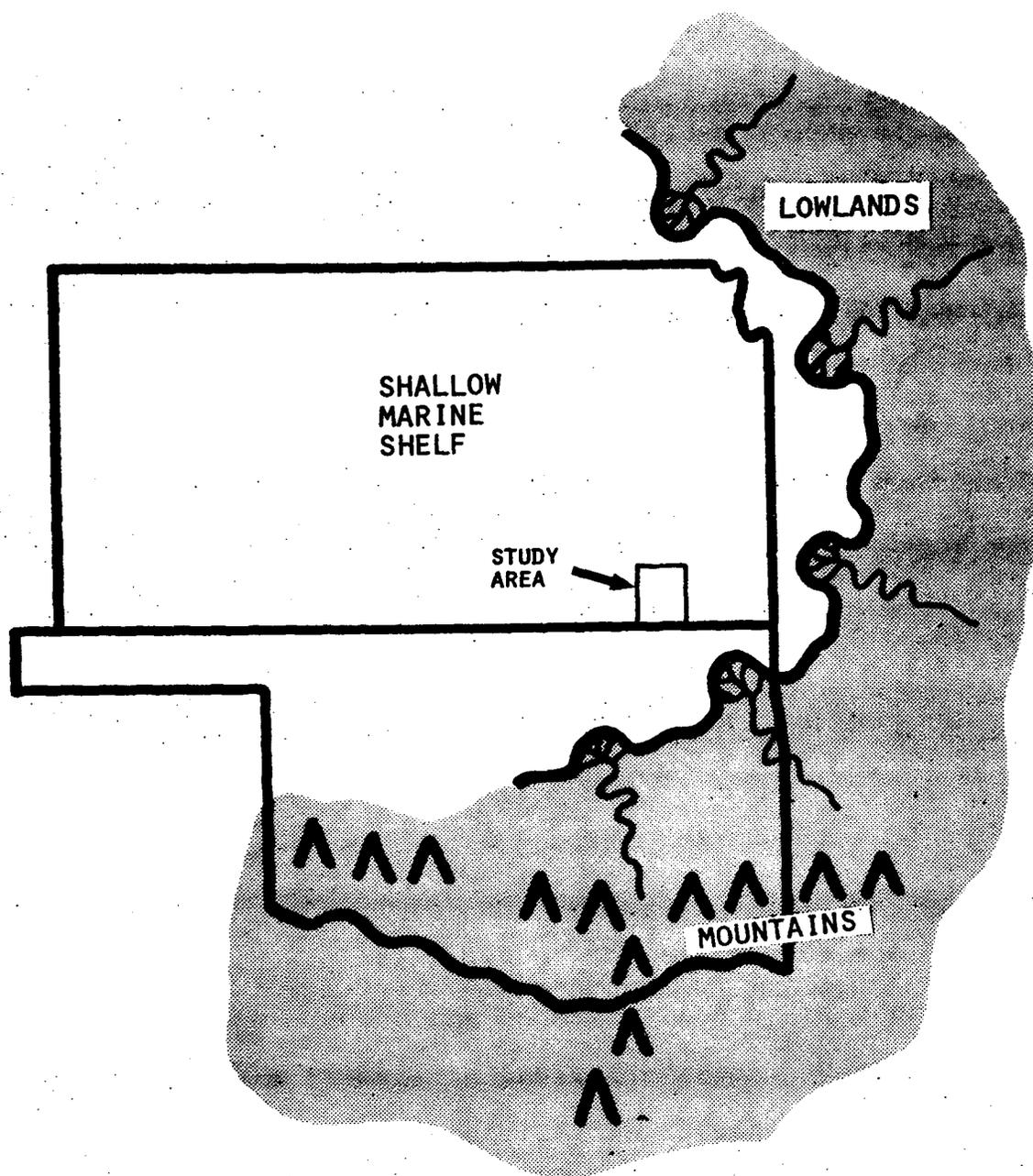
Figure 20. Generalized paleogeography during Drum
oolite deposition.

others (1969) and sluggish, sediment-choked streams which formed a wide deltaic plain (Stewart, 1975).

The climate was probably warm and humid, as suggested by the luxuriant flora abounding in the coal swamps, which included many types of ferns (Moore, 1929, and others), and by the many streams which crossed the low-lying plains.

Schopf (1975) outlined three opposing theories regarding the control of ancient climates. Two theories are dependent on the immobility of continents with respect to their areal distribution on the globe. The third theory is dependent on the mobility of continents through geologic time. It also accepts both the solar control of climate and the indication of past climate by fossils as uniformitarian principles. Utilizing this theory, Köppen and Wegener (1924) reconstructed the positions of the continents during the Carboniferous, with the equator extending approximately from Louisiana through Maine, and the bulk of North America north of the equator. More recent attempts have been made at reconstructing the relationship of the equator to the North American continent during the Pennsylvanian by interpreting rocks sensitive to climate in their formation. Heckel (1977) arrived at a reconstruction similar to Köppen and Wegener's (Figure 8). If this reconstruction is accurate, Kansas lay in the Trade Winds Belt at approximately $6^{\circ} - 8^{\circ}$ north latitude, and the prevailing winds probably blew from paleo-northeast to paleo-southwest (modern north to south) (Figure 8). Other workers have attempted reconstructing the

positions of the continents during the Pennsylvanian by utilizing not only paleoclimatic data, but other types as well, especially paleomagnetic data. Scotese and others (1979) and Dott and Batten (1976), for example, believed North America to be approximately eight degrees south of its position in Heckel's reconstruction, with the study area essentially at the equator. The interpretation of Scotese and others (1979) is illustrated in Figure 21. If this reconstruction is accurate, then the prevailing wind patterns may have varied slightly from those described above, but the overall climate would have been approximately the same -- warm, humid, and tropical.
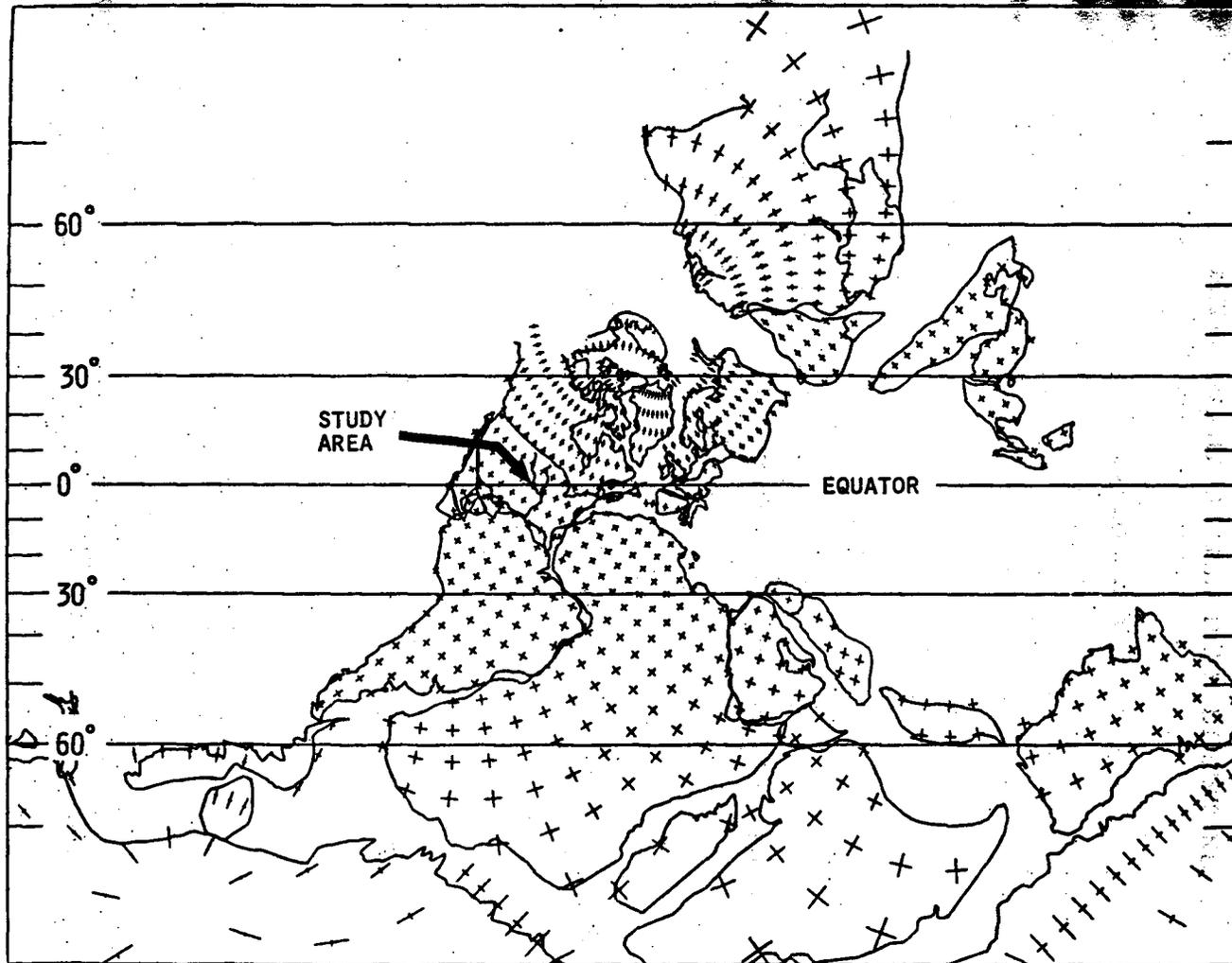
Figure 21.   Reconstruction of the continents in the Late Carboniferous
based on paleomagnetic data (from Scotese and others, 1979).

CHAPTER III

PETROGRAPHY OF THE DRUM LIMESTONE

Introduction

The Drum Limestone was examined on outcrop and in the laboratory through the use of polished slabs, acetate peels, and thin sections. The rocks were stained with Alizarine Red S to aid in determining the mineralogy of carbonate grains and cements.

Four cores, each representing the entire section of the Drum, and more than 300 thin sections prepared from outcrop specimens of the Drum collected from 27 different localities in Montgomery County were borrowed from Amoco Production Company and examined. The cores were studied by standard carbonate petrographic methods including polished slabs, thin sections, acetate peels, stains, and X-ray diffractometry. Additional field specimens were collected, slabbed and polished, and studied in thin section and with acetate peels. The locations of the cores and collecting localities are indicated in Figure 3, and generalized logs of the cores are found in Appendix A.

It is difficult to distinguish among some subfacies whether in the field or in the laboratory if only thin sections or only polished slabs are examined. Consequently,

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the ideal arrangement for studying these facies is for both
polished slabs and thin sections to be available for
examination.

Because the primary goal of this study was to deter-
mine the depositional environment of the Drum Limestone,
differences among the rocks resulting from diagenetic
alteration were considered to be of minimal importance in
categorizing the rocks, while differences in the rocks in-
fluenced by their depositional environment were emphasized.
For example, rocks were not categorized by characteristics
such as amount of secondary porosity, replacement fabrics
or mineralogy. Rather, each rock type is characterized by
a combination of biogenic and non-biogenic grains types,
and sedimentary structures and textures, distinct from that
of any other rock type. Consequently, each rock type re-
flects conditions of its depositional environment, including
water depth, energy, turbidity, and chemistry; climate; and
paleogeography.

Six general carbonate rock types were found to com-
prise the Drum Limestone in the study area, and are named in
the framework of Dunham's (1962) classification of carbonate
rocks, according to depositional texture. They include the
following:

(A)   laminated mudstone,

(B)   fossiliferous oolite grainstone,

(C)   oolite grainstone,

(D)   intraclastic grainstones-packstones,

(E)   pellet wackestones-packstones, and

(F)   bryozoan-algal packstones-wackestones

      and, locally, boundstones.

Figure 22 illustrates the distribution of fossils among the various facies for comparison.

Description of Rock Types

Depositional Aspects

Laminated Mudstone. The laminated mudstone is horizontally laminated and is generally interbedded on a scale of several centimeters with light and dark gray, finely laminated shale. It is almost entirely composed of blue, gray or brown carbonate mud (micrite). In places, it contains very thin laminae of quartzitic silt and sand. The mudstone is essentially devoid of fossils, although some bryozoans and pelecypods are seen in rare oolitic laminae. The laminae at the tops of individual beds within the mud- stone facies are infrequently disturbed by what appears to be burrowing, the burrows being filled with sediment from the overlying facies. Cone-in-cone structures are commonly abundant and very well developed in this facies. The cone- in-cone structures and the stylolites common in other facies indicate that the Drum underwent pressure-solution diagenesis, probably at depths of at least several hundred feet.

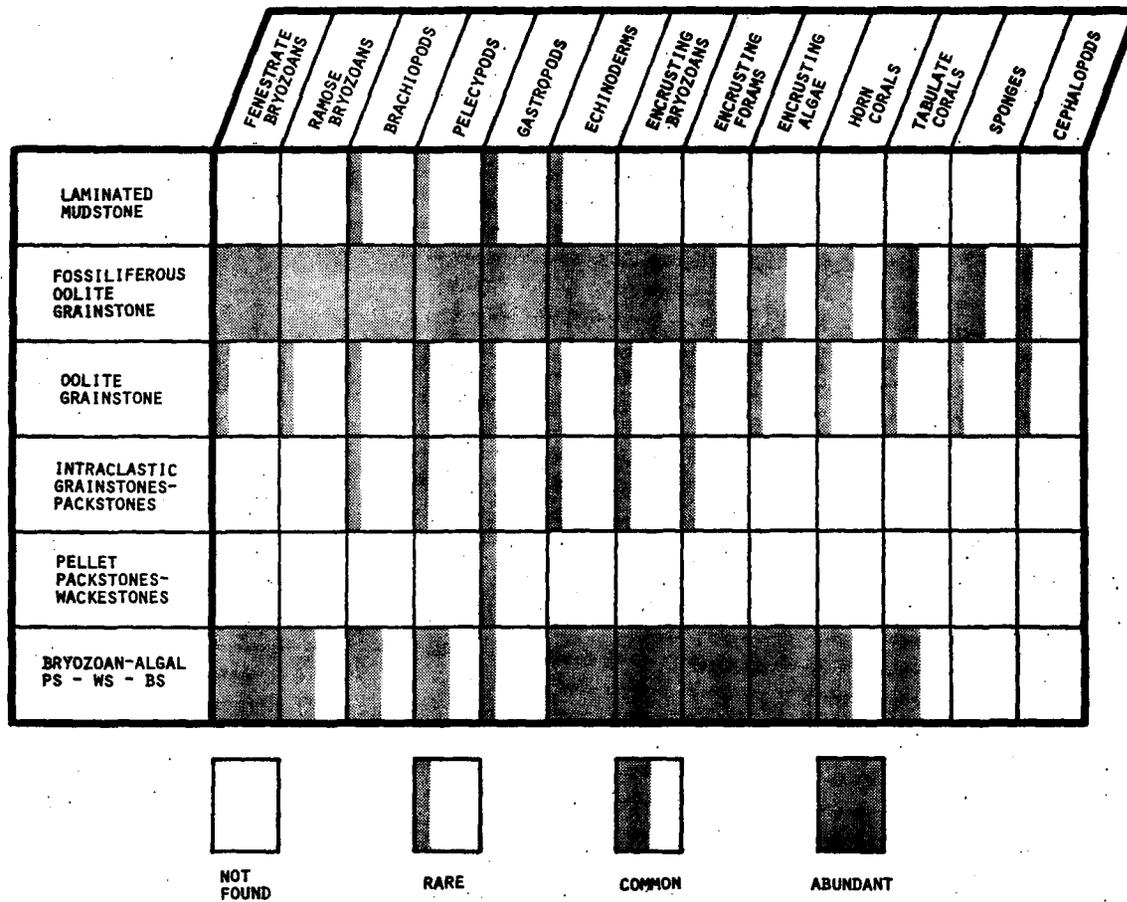Fossiliferous Oolite Grainstone. The fossiliferous

Figure 22. Occurrence of the most common fossils in the facies of the Drum Limestone.

oolite grainstone is a highly variable facies. Although both ooliths and fossils are ubiquitous within this facies, the relative abundances and grain sizes of each, and the types of fossils, vary both vertically and laterally. Alternations of fossiliferous and unfossiliferous zones ranging from several centimeters to more than 30 centimeters in thickness are not uncommon. The average ooid diameter is smaller (near 0.5 mm) in unfossiliferous zones and increases to approximately 1.0 mm in fossiliferous zones. In the highly fossiliferous zones, ooids are rare, the grains are very loosely packed, and most of the intergranular space is occupied by carbonate cement.

This facies is cross-bedded, with a strong southwest directional component in Montgomery County, Kansas. In Amoco's No. 1 Big Jim Woodrow core, depositional dip is up to $15°$ in some places. Approximately one mile east of the No. 1 Woodrow, Hamblin (1969) took 168 measurements of cross-bedding directions in the Drum at 32 locations in the Universal Atlas Cement Company quarry in Section 5, T32S, R16E. Rose diagram plots of his measurements yielded a bi-modal distribution. The primary mode was N. $140°$ W., and the secondary mode was N. $60°$ E. In places, the fossilifer-ous oolite grainstone is interbedded with thin beds of gray to bluish gray laminated shale similar to that found inter-bedded with the laminated mudstone. Interbedding is on the scale of a few centimeters and depositional surfaces in the oolite and the shale, as well as the sharp contacts between

them, commonly have substantial initial dips. In other places, the cross-bedded oolitic facies is uninterrupted by shale.

The fauna in this facies is biotically diverse, although molluscs are the predominant elements. As has been noted in previous works (e.g., Girty, 1915), the fauna is not a dwarf fauna, but is composed of large individuals among its many species. Calcareous algae are present in small amounts as encrusting organisms.

Fossil abrasion is generally at a minimum where fossils are abundant, and at a maximum where they are scarce. Many of the fossils are very well preserved. Among these are seemingly very delicate fossils such as large fragments of fenestrate bryozoan fronds, and paper-thin mollusc and brachiopod valves. They are neither broken into small fragments nor abraded. Especially puzzling in outcrop, most of these fossils can be seen in polished slab and thin section to have been coated oolitically, or by other means. Many fossils, especially fenestrate bryozoans, were thickly coated or encrusted by an organism and/or by an early cement which has been subsequently neomorphosed beyond recognition, and now appears as clear neomorphic spar surrounding the grains (Figure 23). Other fossil grains were circumcrusted by what may be a calcareous algal community, possibly Osagia (Figure 24). The presence of fossil coatings varies from lamina to lamina. In some laminae, the fossils are broken into small fragments, comparable in size to the ooliths, and

1 mm
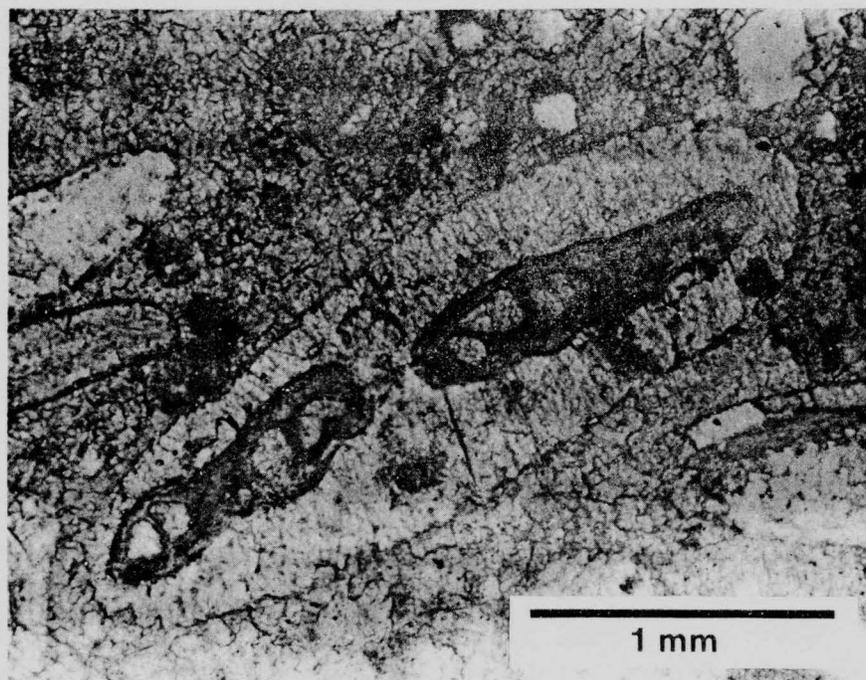
Figure 23.   Photograph of fenestrate bryozoan coated
by what is now neomorphic spar.   Thin
section; plane light.

Figure 24. (A) Photograph of fenestrate bryozoan cir-
cumcrusted by a laminated structure which
may be the algal community Osagia. Such
coatings provided protection for many deli-
cate fossils so that they were able to
survive with little or no breakage or
abrasion, the high-energy oolitic environ-
ment in which they were deposited. Polished
slab. (B) Some oncholites occur in the
bryozoan-algal facies which have multi-
grained nuclei, and may represent encrusta-
tions of Osagia. Photograph; polished slab.
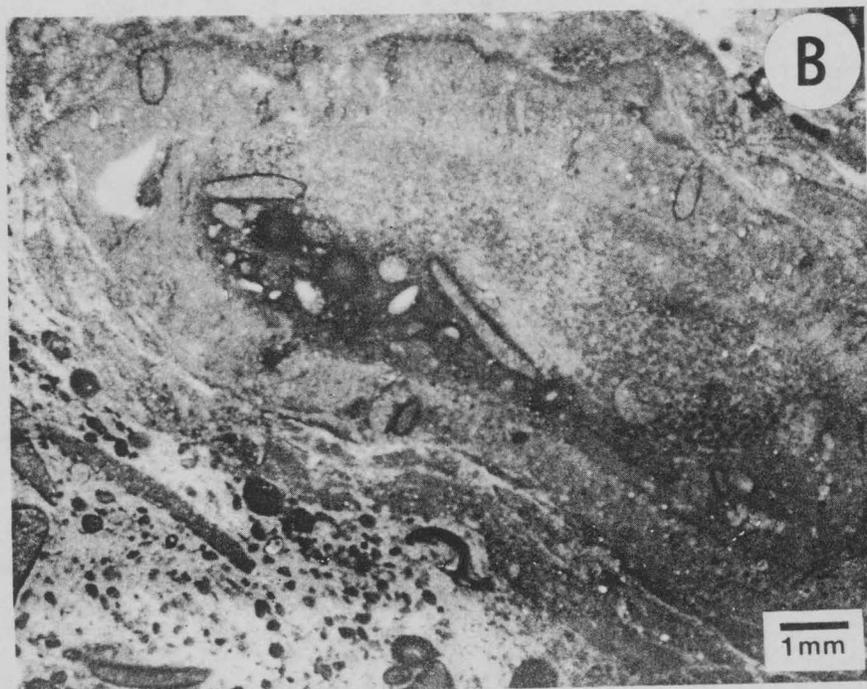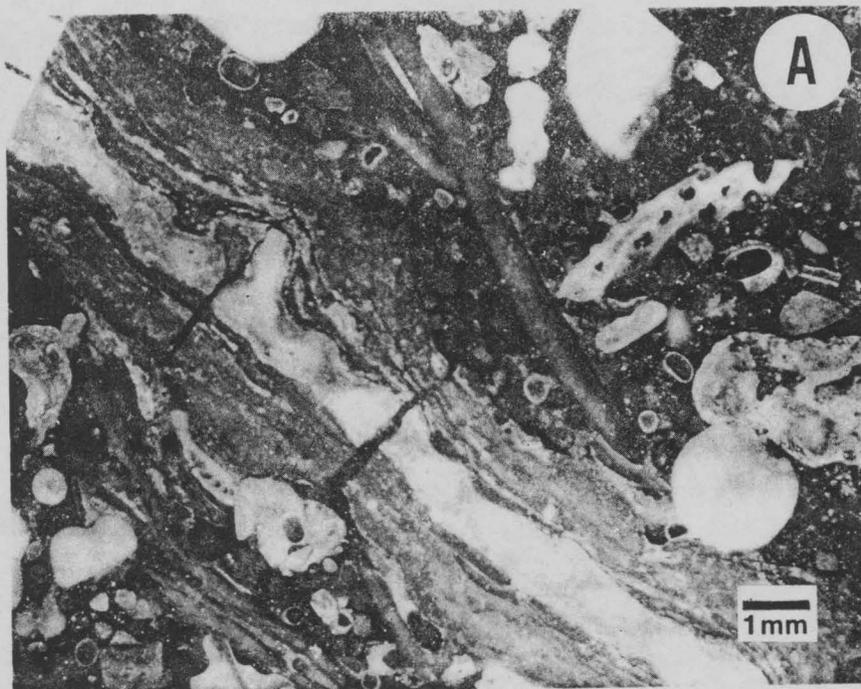
are well sorted.

Some large fossils such as molluscs and brachiopods and some mudstone clasts in this facies have been bored by endolithic organisms. Two different sizes of borings have been noted. The larger ranges up to two millimeters in diameter, and the smaller, to approximately 0.1 mm. Each type is most frequently filled with grains of the host sediment (Figure 25).

Non-skeletal carbonate grains in this facies include abundant ooids and peloids, common mudstone clasts, and rare pisoliths, pellets, and micrite. Shale clasts are not uncommon, and some quartz sand and silt are locally present in small quantities.

The ooliths range in size from 0.3 to 2.0 mm in diameter. The most common size is approximately 0.5 mm. Generally, as the abundance of ooids decreases, their average size increases. This trend is usually accompanied by an increase in fossil abundance. Laminae are frequently composed almost exclusively of fossils (Figure 26). The few ooids that occur in these laminae are generally greater than 1.0 mm in diameter, and it is to these laminae that the pisoliths are virtually restricted. A majority of the ooliths displays a concentric structure, but no radial fabric was seen in any of the ooliths in this, or any other, facies, with one exception. A few very large ooliths and pisoliths which display micritic patches whose arrangement suggests a radial fabric were seen in one thin section from an outcrop

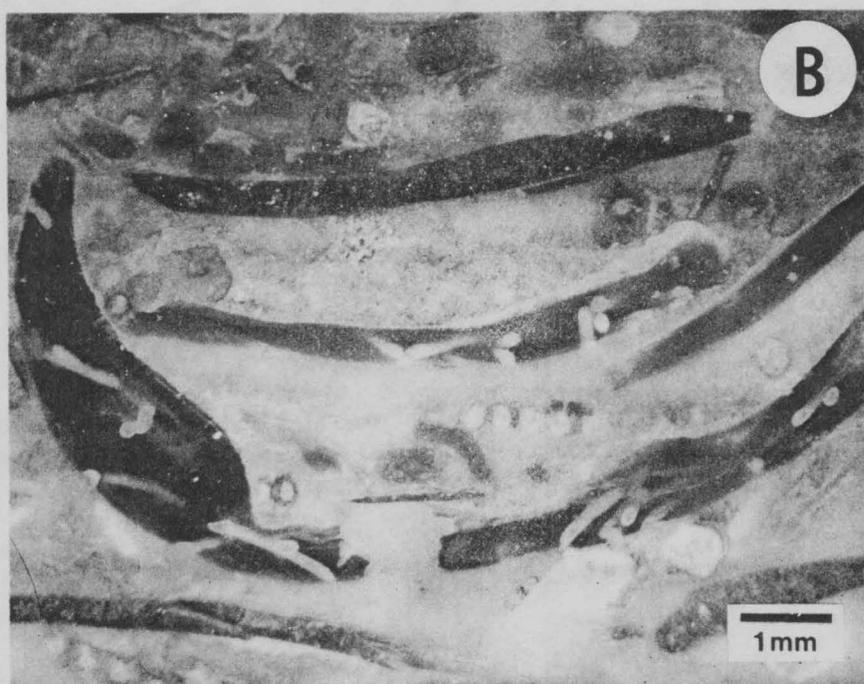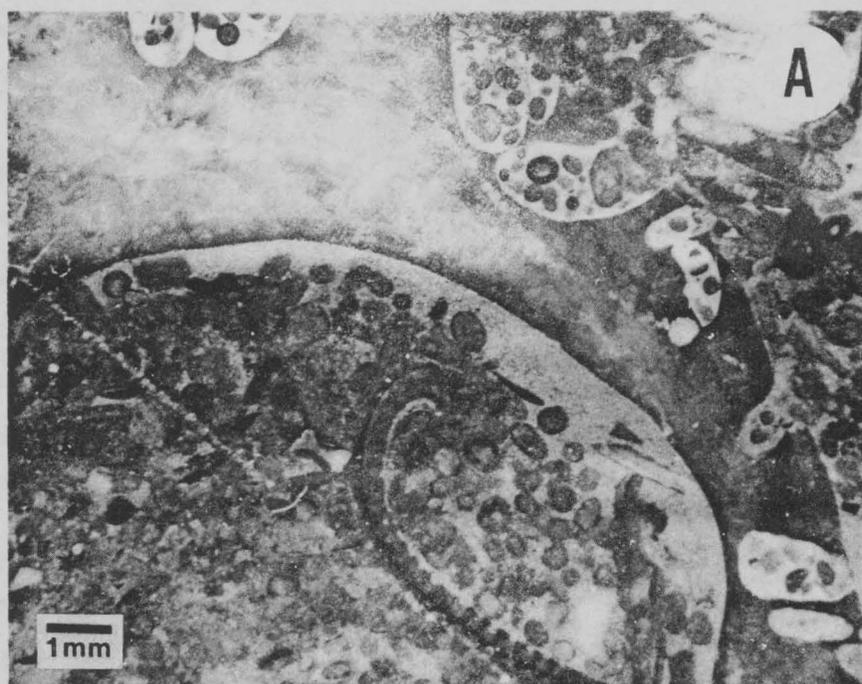Figure 25.   (A) Large borings, possibly made by a sponge,
             in a pelecypod valve. Photograph; polished
             slab.   (B) Small micrite-filled borings in
             pelecypod valves. Photograph; polished slab.
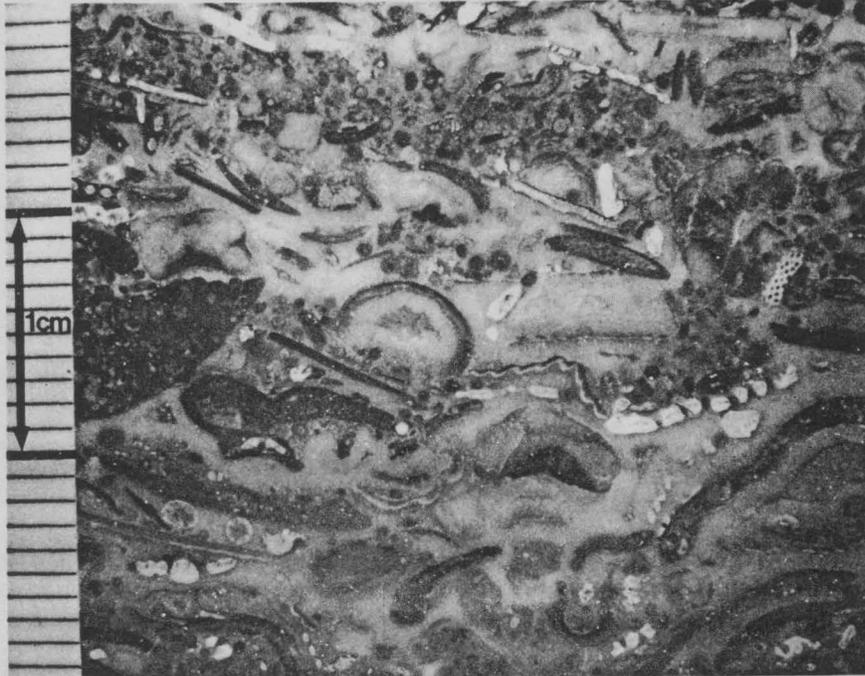
Figure 26.   A fossiliferous lamina in the fossiliferous
oolite grainstone. Note the white isopachous
cement and subsequent void-filling spar.
Photograph; polished slab.

specimen (Figure 27). Ooid nuclei are most commonly either fossil fragments or peloids and they influence the shapes of the ooliths. Ooliths having large, angular or irregularly shaped fossil fragments as nuclei tend to be less spherical than those having very small fossil fragments or peloids as nuclei. The peloids, micritic grains of uncertain origin, also occur in this facies without oolitic coatings. They are generally rounded to subrounded grains. In two dimensions, a great many of them appear rectangular to square, and may actually be cylindrical. The peloids range from approximately 0.2 mm to more than 0.5 mm in diameter.

Shale and mudstone clasts tend to be concentrated in certain zones, being most abundant near shale or mudstone layers. They are most commonly rounded, and ooids and other small grains identical to those comprising the host sediment commonly occur within them, near their edges (Figure 28). Some clasts are laminated.

Pellets and micrite are rare in this facies. Both are found, in small quantities and frequently together, as geopetal sediment inside fossils such as brachiopods and corals (Figure 29) and in intergranular space.

Sorting in the fossiliferous oolite grainstone facies is variable and depends on the ratio of fossils to ooids. Where fossils are scarce, sorting is best, and where ooids are scarce, sorting is worst. Where ooids and fossils occupy a subequal amount of rock volume, sorting is very strongly bimodal.
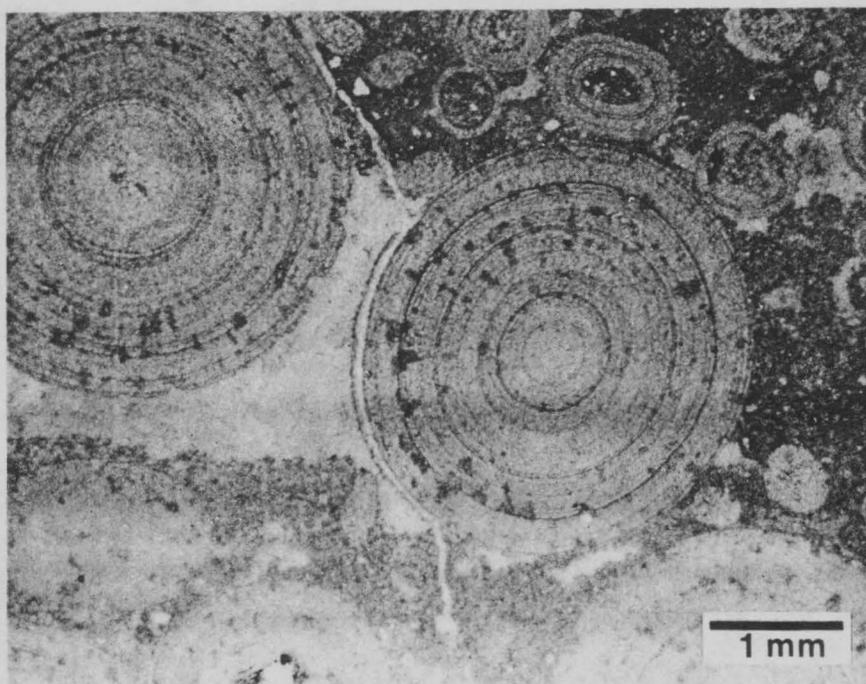
Figure 27. Photograph of pisoliths with micritic patches
suggesting a radial fabric. Note the well-
preserved concentric fabric. The matrix is
micritic pellets. Thin section; plane light.
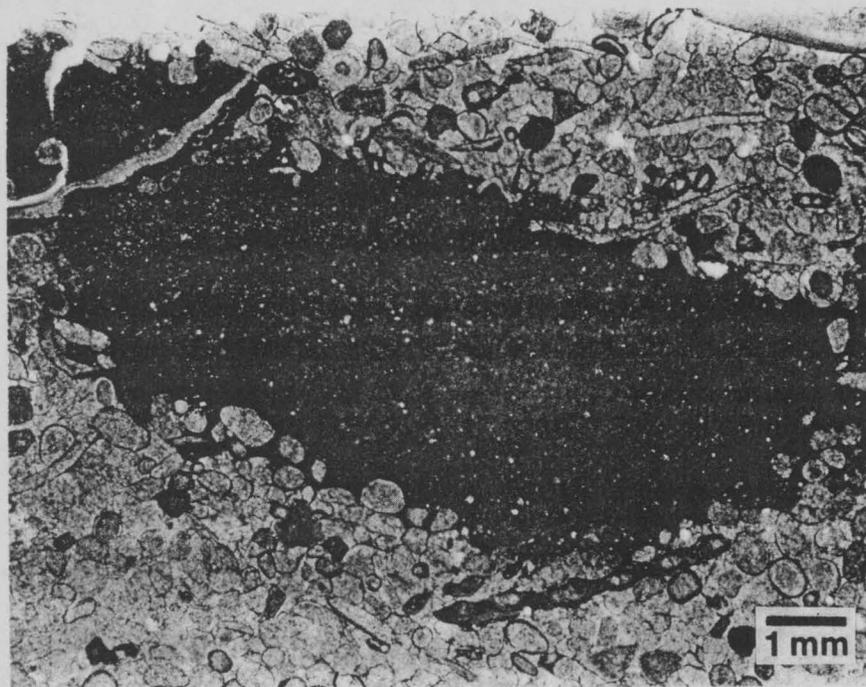
Figure 28. Photograph of a mudstone intraclast with
ooliths contained within its perimeter.
The clast was probably soft when intro-
duced to the oolitic environment and the
ooids were able to squeeze up into it
either as it tumbled along, or under
loading, after it came to rest and was
buried. Thin section; plane light.
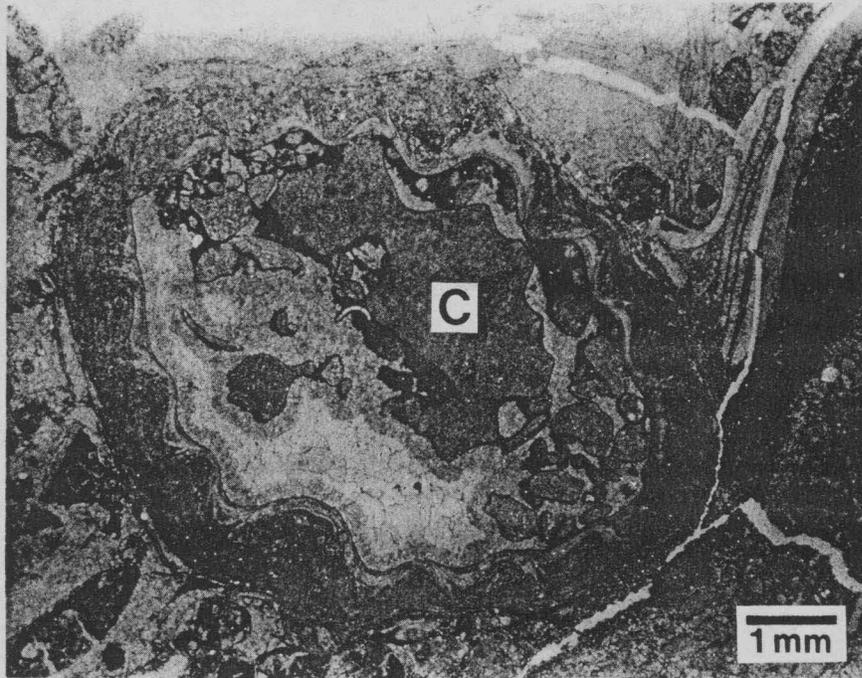
Figure 29. Photograph of brachiopod with geopetal internal
sediment consisting of carbonate mud, pellets,
peloids, ooliths, and micritic internal cast of
the brachiopod (C), apparently jarred loose during
transportation. Geopetal "up" is toward the lower
left, but true "up" is toward the top of the
picture. The isopachous cement held the geopetal
sediment in place during the final transportation
and burial episode of the brachiopod, indicating
that the cement was very early. The brachiopod
was found in the conglomerate marking the dis-
conformity surface between the Drum Limestone and
the Noxie Sandstone in the Amoco No. 1 Big Jim
Woodrow core. This is the same brachiopod as is
shown in Figure 40. Thin section; plane light.

Oolite Grainstone. The oolite grainstone facies is
very similar to the fossiliferous oolite grainstone facies,
except for its obvious scarcity of fossils. However, in
spite of the paucity of fossils in this facies, the biotic
diversity is virtually the same as that of the fossiliferous
oolite facies (Figure 22). Not only are the fossils much
less abundant, but those present are much more broken and
abraded, and the fragments are much smaller than those in the
fossiliferous oolite facies. Most of the fossils are
oolitically coated. Some may be algally circumcrusted.

The non-biogenic grains in this facies are, in order
of decreasing abundance, ooliths, peloids, and mudstone
intraclasts. These grains are identical to those in the
fossiliferous oolite facies in size, composition, and
structure.

Intraclastic Grainstones-Packstones. The intra-
clastic grainstones-packstones are cross-bedded and are
composed primarily of flat pebbles of mudstone and shale,
and of ooliths. Many geopetal fabrics are present, mostly
associated with the sheltering effect of the intraclasts
(Figure 30). The grainstones seem to prevail, and in Amoco's
No. 1 Mouse Creek core, they are interlaminated with the
intraclastic packstones. Folk (1959, 1962) considered the
presence of intraclasts to be very important as an environ-
mental indicator, even if they were only present in small
quantities. In some places, the intraclasts in the Drum

Figure 30.   (A) Photograph of the intraclastic grain-
stone consisting of ooliths and flat pebbles
of laminated mudstone.   Polished slab.   (B)
Detail photograph of intraclastic grainstone
showing geopetal fabric formed by the shelter-
ing effect of the intraclasts.   Note the iso-
pachous cement and the subsequent void-filling
spar.   The isopachous cement at the arrow
resembles botryoidal cement.   The hump in the
cement, however, is probably the result of
the cement wrapping around a grain (e.g., an
ooid) which is just beyond the plane of view.
Polished slab.
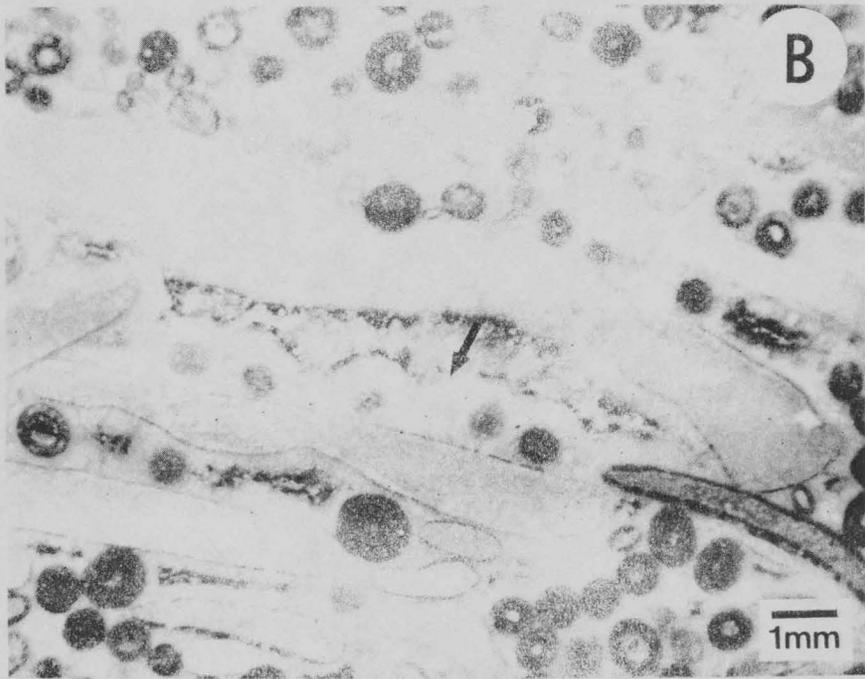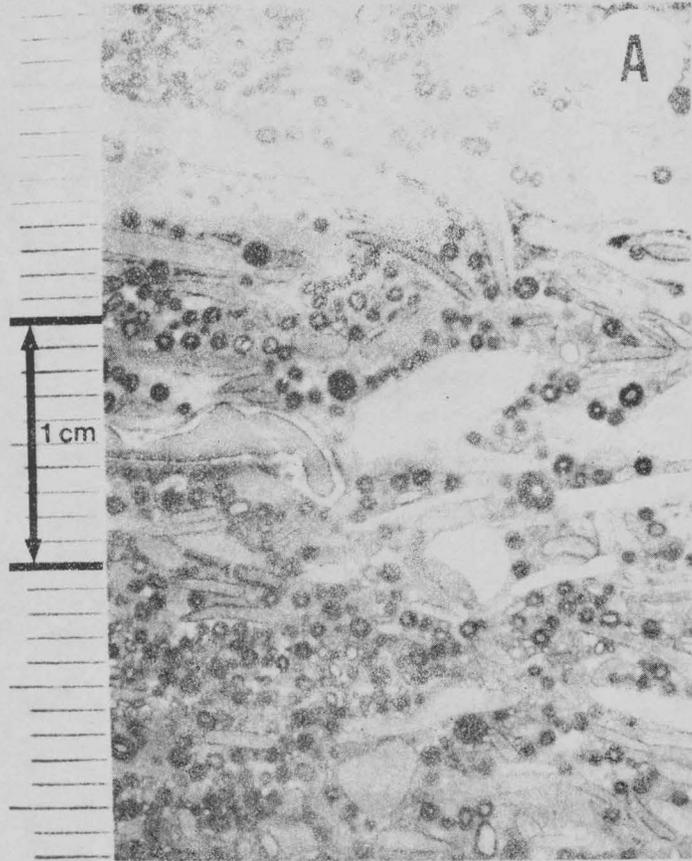
Limestone are greatly outnumbered by other grain types, especially by ooliths, but even those rocks containing only small quantities of intraclasts were classified within this facies.

The flat pebbles are commonly 3 to 15 mm in length and average one to two millimeters in thickness. The mudstone clasts are identical in composition to the laminated mudstone facies already described and greatly outnumber the rare shale clasts. Some of the carbonate mudstone intraclasts contain borings, indicating very early lithification, very similar to those found in the large fossils of the fossiliferous oolite grainstone facies. Most intraclasts are at least superficially oolitically coated. The shale clasts are much more easily distinguished from the carbonate mudstone intraclasts in thin section than in polished slab. They are much more finely and consistently laminated than the mudstone clasts and contain significant amounts of micas and carbonaceous material. The concentric structure of the ooids in this facies is generally well preserved, although the rock is highly neomorphosed.

Many fossils found in the fossiliferous oolite grainstone facies are also common in the intraclastic facies. They are generally broken into small fragments and are frequently oolitically coated.

Pellet Packstones-Wackestones. The pellet packstones are easily recognized. The pellets are ellipsoidal to rounded, almost spherical, grains of micrite approximately

0.2 mm in length (Figure 31). They contrast well in thin section against the sparry carbonate cement which binds them together. The pellet wackestones are much more difficult to recognize because of the greater abundance of carbonate mud matrix, and the lesser amount of intergranular carbonate cement. The micritic pellets in the wackestones are very well camouflaged in their micritic matrix.

The pelletal facies generally do not show bedding structures, but are extremely well sorted. Besides pellets and micrite, this facies contains rare fossils and ooids.

Bryozoan-Algal Packstones-Wackestones and Boundstones. The bryozoan-algal packstones contain very large fenestrate and encrusting bryozoans. Many individual colonies of each type attain diameters of greater than 20 cm. A typical arrangement is that in which the fenestrate bryozoan fronds are oriented with their long axes parallel and horizontal, and are stacked in vertical succession for 30 cm or more. These fenestrate bryozoans are commonly encrusted by the bryozoans Fistulipora nodulifera or Tabulipora heteropora; by a possible algal community which may be Osagia; by an encrusting foraminifer; or by any combination of these (Figure 32). The encrustations on the bryozoans commonly exceed one centimeter in thickness. These encrustations generally surround the bryozoans, apparently not favoring one side over another. Some fenestrate bryozoans are coated by what is now clear neomorphic spar. They occur completely
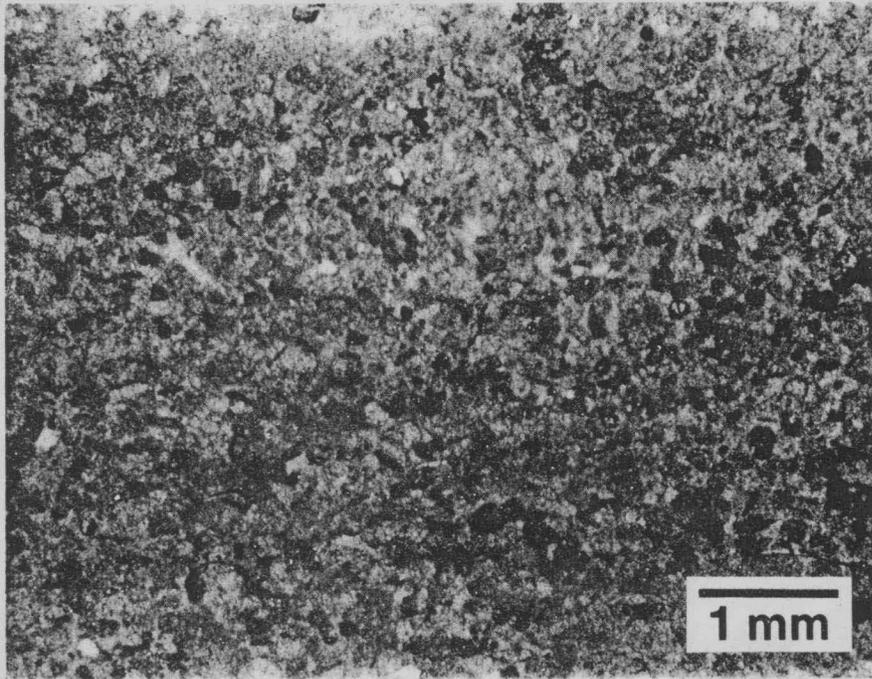
Figure 31.   Photograph of pellet packstone facies.
             Thin section; plane light.
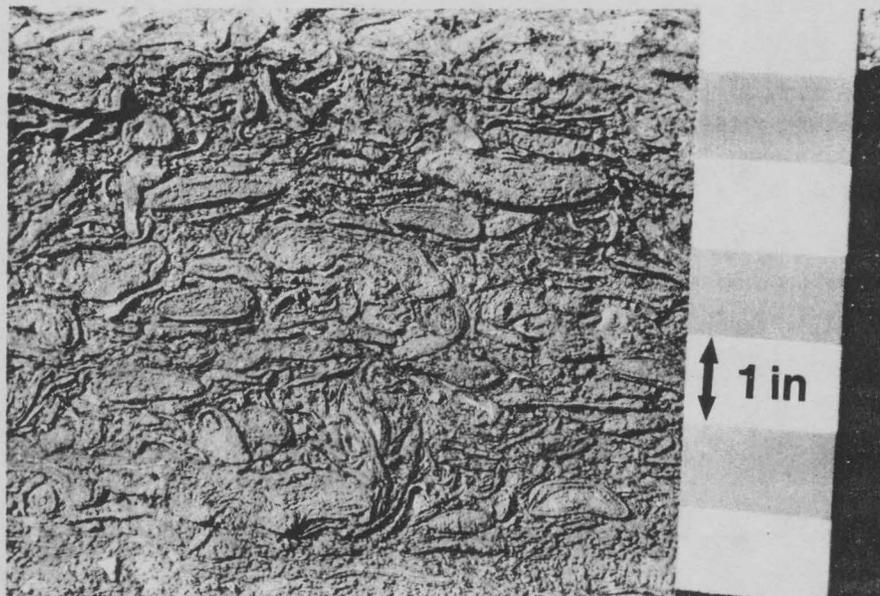
Figure 32. Photograph of fenestrate bryozoan fronds circumcrusted by algae(?) in outcrop at locality T-6 (see Figure 3 for location).

enveloped in this coating but one side seems to have been coated preferentially. Other organisms such as ramose bryozoans, rugose and tabulate corals, and rare crinoid fragments, pelecypods, and brachiopods may be encrusted or coated as well. At some localities, individual encrusting organisms have encrusted more than one grain, and encrusting organisms have been encrusted by others and/or successive generations of the same species. The encrusting organisms thus bound the sediment grains together. Such a rock is called a boundstone according to Dunham's (1962) classification, the encrusting and nucleated fossils having formed the organic framework inherent in the classification of the rock as boundstone. Frequently, a layer of sediment is present between successive encrusters. This sediment is described in a subsequent paragraph of this section.

The other and much less common orientation of fenestrate bryozoans in this facies is apparently that of their growth position. These bryozoan fronds may be traced for several decimeters on rock surfaces in outcrop. Fronds which form a closed ring up to more than 20 cm across are not uncommon. These may or may not be encrusted by the organisms mentioned above. Where they are, however, the rock may also correctly be called a bryozoan boundstone.

A fossil of probable algal origin occurs commonly in the boundstones and appears stromatolitic (Figure 33). It is micritic and laminated and serves as a binding agent in the boundstones. Its laminae are smoother and more regular
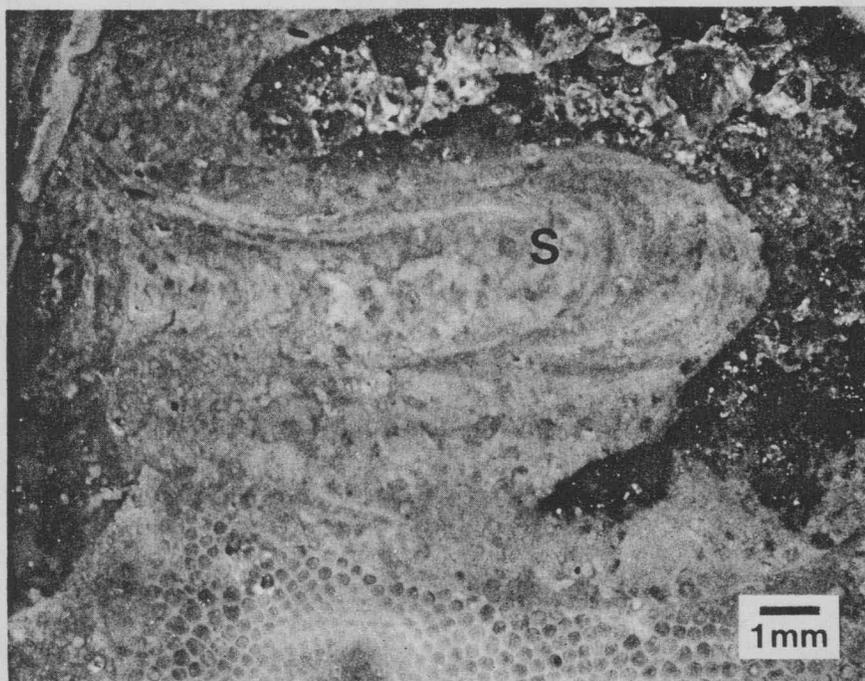
Figure 33. Photograph of a stromatolitic-looking fossil
           (S) which served to bind grains together in
           the bryozoan-algal boundstone facies. This
           structure was growing into a former con-
           structional void now filled with void-filling
           spar. Polished slab.

than those of the Osagia-like fossils. Figure 34 shows much
larger fossils which also appear stromatolitic. These form
non-laterally linked hemi-spheroidal heads up to 45 cm tall
and 60 cm across. The heads have crinkly laminations, and
they trapped and bound many invertebrate skeletons and much
non-skeletal debris during growth. The rock composed of
these heads is also boundstone. Because the boundstones are
rare and are always associated with bryozoan packstones,
they are not categorized as a separate facies.

The matrix of this facies is carbonate mud, ranging
in colors from dark gray to light gray, and from dark brown
to brownish yellow. The distribution of colors is patchy,
although some vertical zonation is not uncommon. Several
generations of sediment occur in some places. Peloids
identical to those in the fossiliferous oolite facies are
very abundant in the bryozoan packstone facies and consti-
tute the major non-fossil grain type in this facies. Few
ooliths are present in this facies. Those that occur have
well-preserved concentric structures and average 1.0 mm in
diameter.

Diagenetic Aspects

The Drum Limestone has suffered extensive diagenetic
alteration. Below are brief discussions of general diagenet-
ic characteristics of each facies.

Mineralogy. Most of the rocks in all of the facies
are now composed of low magnesian calcite. Neither high

Figure 34. Photographs of stromatolitic hemispheroids(?)
            (SH) at outcrop locality T-5A (see Figure 3
            for location). These occur in large boulders
            beside a road. If they are stromatolites,
            then the boulders are upside down. The areas
            between the hemispheroids are filled with
            ooliths, peloids, and marine invertebrate
            skeletal debris. Above the stromatolites
            (if the rocks are indeed upside down) is a
            thin sequence of the bryozoan-algal boundstone
            facies (B-A BS).
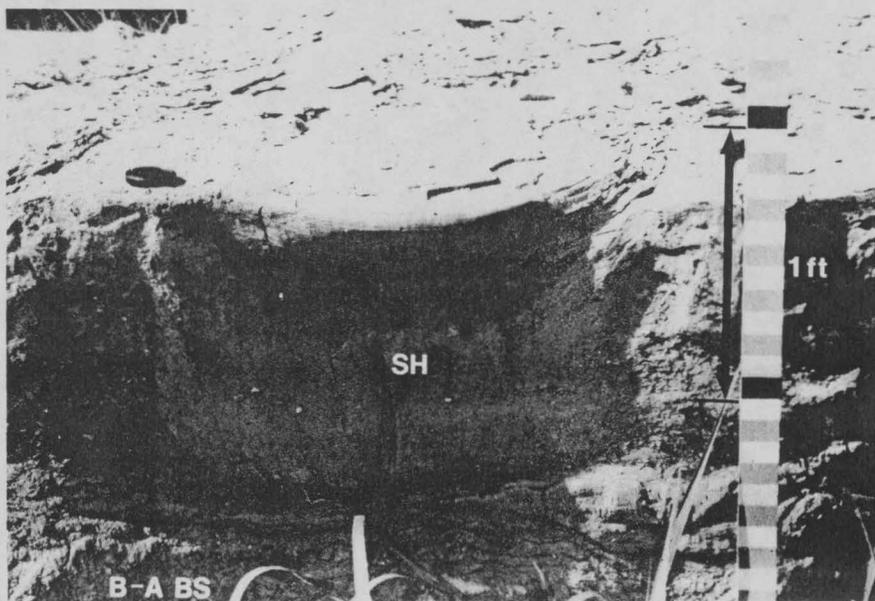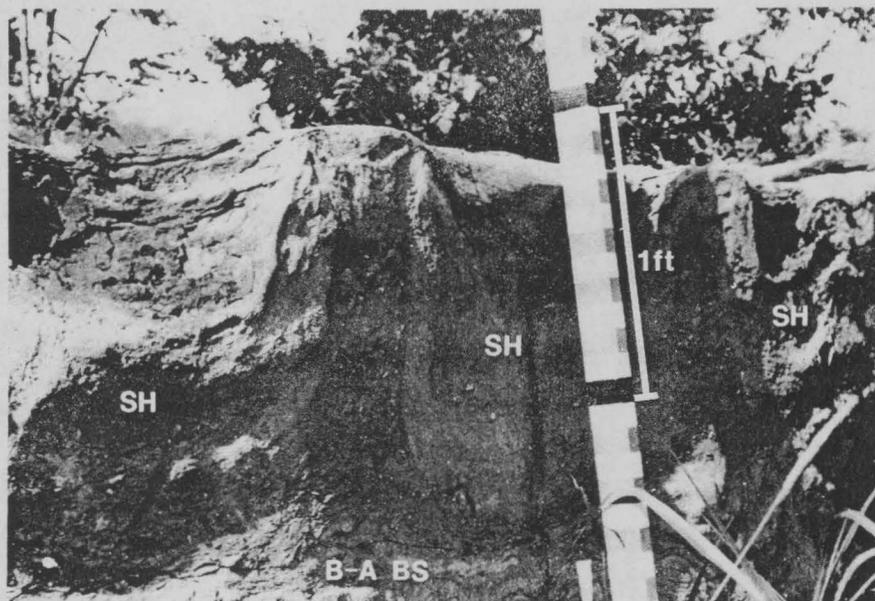
magnesian calcite nor aragonite has survived neomorphism, if
they existed at one time. Dolomite is present as void-
filling cement and neomorphic rhombohedrons in some places.
It is frequently zoned with a dark brown to black substance
which frequently appears rusty, or hematitic, and may be
ankerite (Figure 35).

Laminated Mudstone.

Cements. Since this facies consists almost
exclusively of micrite, no cements can be seen.

Neomorphic Fabrics. Neomorphic microspar and
pseudospar have replaced the micrite in many places.

Porosity. This facies has almost no porosity,
even in association with fracturing.

Fossiliferous Oolite Grainstone.

Cements. In many places, an isopachous fringe
cement occurs adjacent to grain boundaries in both inter-
granular and intragranular space. It is typically 0.3 mm
thick and is conspicuous as a white or very light gray zone
in rough-cut specimens, in polished slabs, and in thin
sections viewed with reflected light (Figures 26 and 29).
Viewed in plane transmitted light, the isopachous fringe is
most commonly inconspicuous, represented only by a cloudy
zone. If the crystals that originally formed it were
fibrous, then the isopachous cement may have been very early,
even syndepositional, and thus could be an important
characteristic of the depositional environment. Four factors
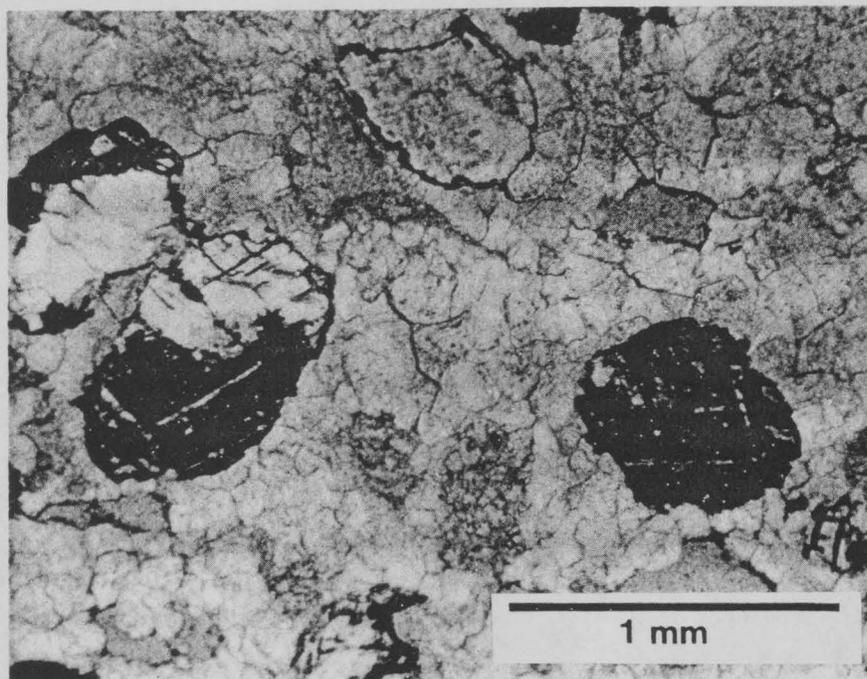
Figure 35. Photograph of former oomolds now filled
with void-filling dolomite zoned with a
dark material which may be ankerite.
Thin section; plane light.

associated with the fringe suggest an originally fibrous habit for the crystals which formed it. (1) The fringe exhibits a fibrous habit, although rarely. Where it does, the fibrous fabric is very faint, and its interpretation should probably be supplemented by the following criteria. (2) In some places, such as between two closely spaced carbonate grains on which the isopachous fringe has nucleated, the fringe extends from both grain surfaces, spanning the entire void. The fringe apparently grew from both grains toward the center of the void until its crystals growing from one grain met the crystals growing from the other grain. Smooth polygonal boundary sutures which parallel the surfaces of the nucleated grains mark where the fringe grew to meet itself and can be seen in the center of the former void (Figure 36). This fabric is characteristic of fibrous crystals and not of more equant crystals. (3) The uniformity of the fringe's thickness suggests a fairly smooth surface lined the cavity after the formation of the fringe. Such a surface would have been produced by many fibrous crystals of a nearly uniform length, growing adjacent to one another and with their long axes oriented perpendicularly to the cavity wall. A fringe of scalenohedral or rhombic crystals would have produced a very jagged inner surface to be recorded by the cloudy fringe. (4) The isopachous fringe frequently appears botryoidal where it lines rock cavities and also in thin section. This also suggests fibrous, instead of more equant, crystals. Caution

POLYGONAL BOUNDARY SUTURES
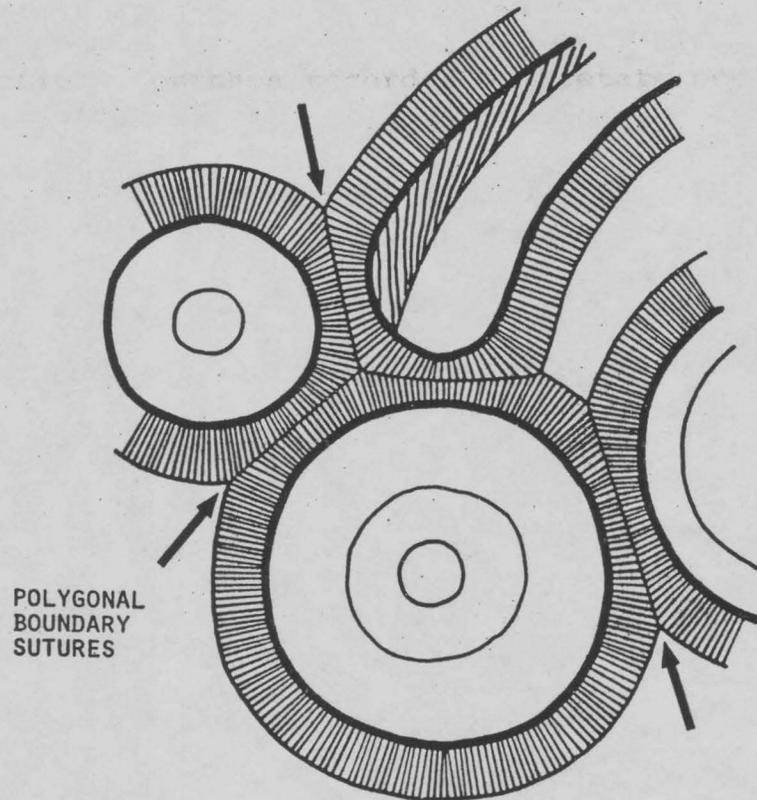
Figure 36. Sketch of polygonal boundary sutures in an isopachous fibrous cement.

is recommended in interpreting the fringe as botryoidal. In polished slab or thin section, what may appear to be a hump in the surface of the fringe resulting from botryoidality may actually be the result of cement nucleation on a grain (e.g., an oolith) which is just beyond the plane of view. This is illustrated in Figure 30. With very closely spaced serial sections, perhaps recorded on acetate peels, the botryoidality of the fringe could be determined, if it indeed exists. A probable example of botryoidal isopachous cement is illustrated in Figure 37. Additional evidence supporting a very early origin of this cement is presented in Chapter IV.

Some former voids are filled, either partially or entirely, by large rhombic crystals of transparent dolomite with undulose extinction. The dolomite is dark brown in polished slab and gray in thin section. In many cases, a single crystal fills an entire oomold. Syntaxial rim cements commonly surround echinoderm fragments. They are generally thin and do not constitute a significant amount of the volume of cement in the rock.

Neomorphic Fabrics. Some organisms whose modern descendants precipitate calcite skeletons (e.g., echinoderms and brachiopods) are not neomorphosed; and some whose modern descendants precipitate partly calcite and partly aragonite skeletons (e.g., some pelecypods) are partially neomorphosed or leached, and partially unaffected diagenetically. Gastropods, as most fossils, have micrite envelopes. Their
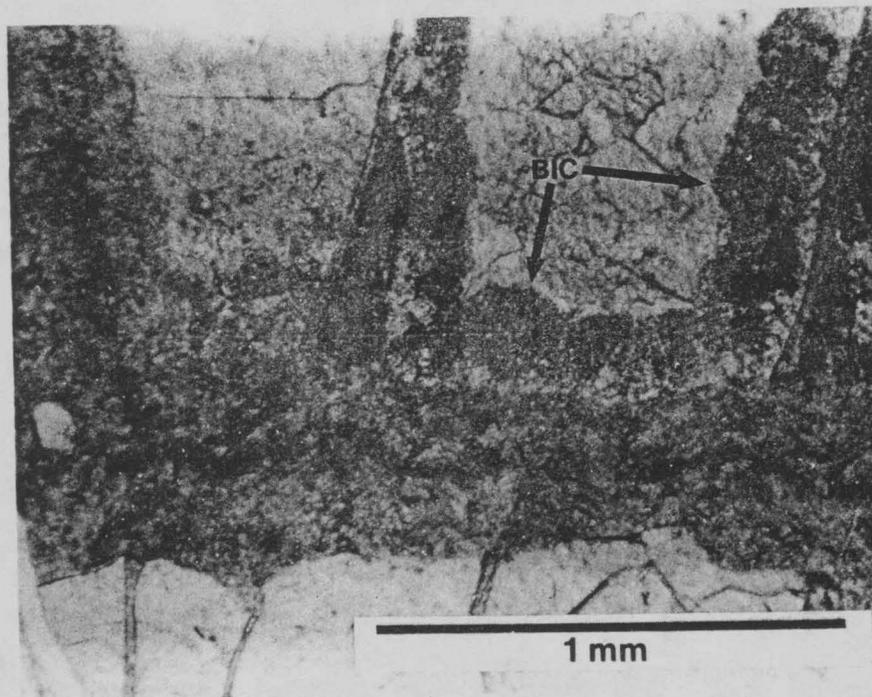
Figure 37. Photograph of probable botryoidal isopachous cement (BIC) inside a tabulate coral chamber. Botryoidality of the cement suggests the cement was originally composed of fibrous crystals and that the cement may have been marine in origin, and, hence, very early. Thin section; plane light.

shells are replaced by void-filling spar.

The overwhelming majority of original intergranular and intragranular pore space of the fossiliferous oolite grainstone facies is now occupied by clear neomorphic spar thought to have replaced void-filling sparry carbonate cement. The crystals of this spar are equant, and very irregularly shaped (Figure 38). The boundaries of the crystals cut indiscriminantly across grain boundaries and original fabrics. These crystals are thought to be neo-morphic spar because of the irregular crystal shapes, the lack of enfacial junctions (Bathurst, 1975), and because of the distribution of these crystals with respect to original fabrics. This neomorphic crystal mosaic probably replaced void-filling spar, as opposed to micrite, as suggested by the large crystal sizes and the common tendency of the crystals to increase in size toward the centers of former voids (Figure 39).

At the centers of former voids, a very clear color-less or brown carbonate spar is seen in polished slabs. This spar can be seen in thin section to consist of bladed to equant crystals (Figure 29). The bladed fabric is more prevalent near the edges of former voids. Also, the bladed crystals increase in size toward the centers of the former voids, and cut across the isopachous zone as though it did not exist (Figure 26). The bladed crystals have long, straight contacts with adjacent crystals, and display undulose extinction when rotated between crossed nicols.
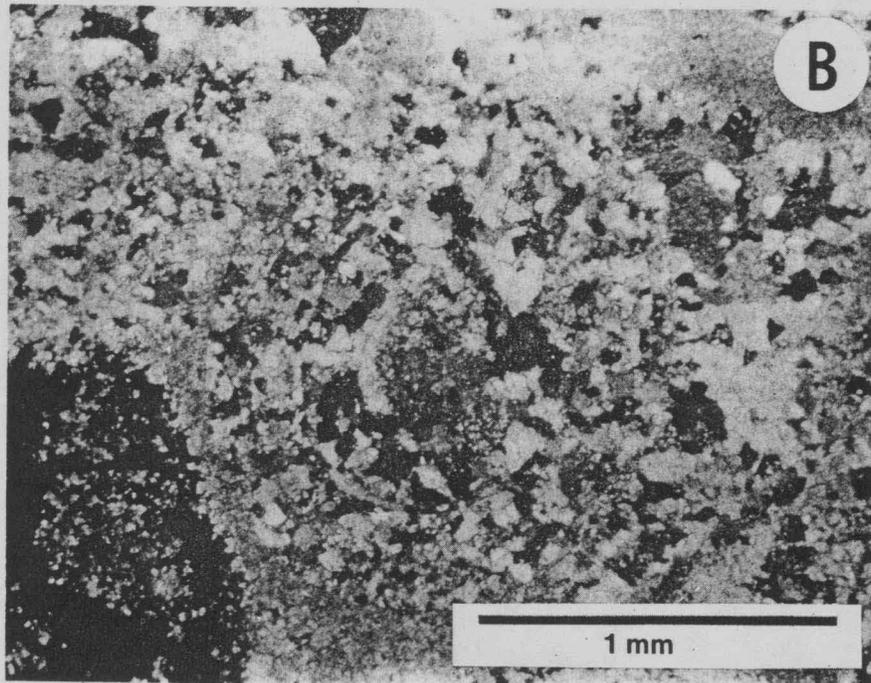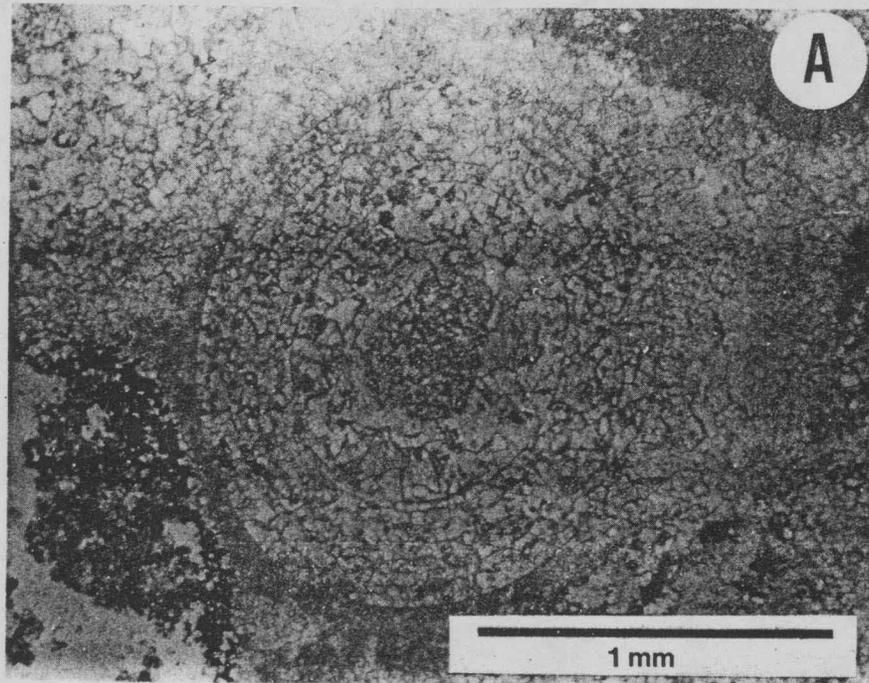
Figure 38. Photographs showing irregularly shaped, patchy crystals of neomorphic spar cutting across primary fabrics. Thin section; (A) plane light, (B) crossed nicols.
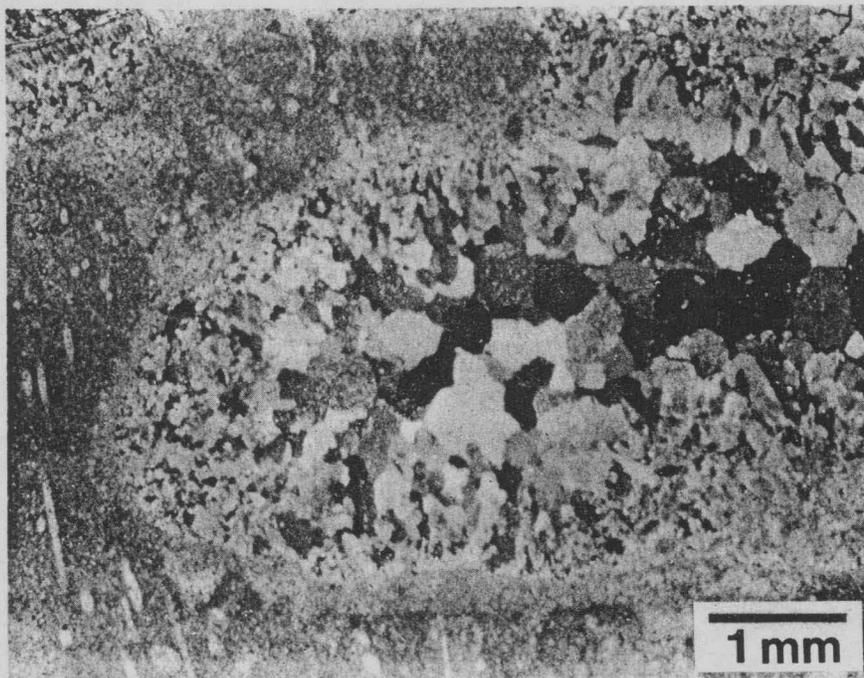
Figure 39. Photograph of neomorphic spar which replaced void-filling spar, and which increases in size toward the center of a former void. Thin section; crossed nicols.

Such characteristics suggest that the bladed cement represents neomorphic spar. The orientation of the bladed crystals perpendicular to former cavity walls also suggests that they may have nucleated on the fibrous crystals of the isopachous fringe cement in optical continuity with some of the fibrous crystals. Subsequent neomorphism may have forced the rest of the fibrous crystals into optical continuity with the bladed crystals resting above them. This could account for the optical continuity of the bladed crystals from void centers, across the isopachous fringe, to the surfaces of carbonate grains (Figure 40). The bladed cements nucleated not only on fossil grains, but on carbonate mud clasts as well, oriented perpendicularly to the clast surfaces. This suggests that the bladed habit and the orientation of these crystals were not always controlled by the microstructure of fossil substrates, as is apparent in some areas.

None of the ooliths or pisoliths displays a stationary pseudo-uniaxial cross when rotated between crossed nicols as do modern and many ancient ooliths and pisoliths. Instead, the ooliths and pisoliths are extensively neomorphosed, and the concentric fabric evident in plane light is most commonly overprinted by coarse neomorphic spar (Figure 41-A). The shapes of the neomorphic crystals are influenced by the original concentric fabric of the ooid cortices, but the crystals frequently cut across it, or seem to have formed with no influence from the concentric fabric at all. The outstanding feature of most of the ooliths between crossed nicols is the
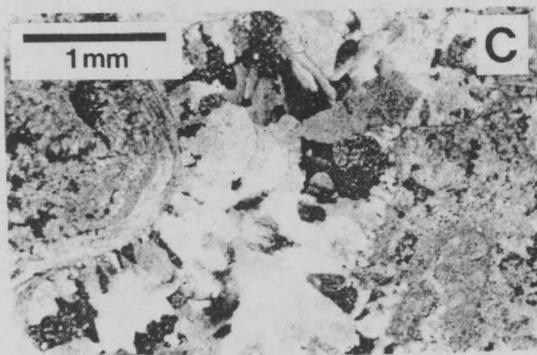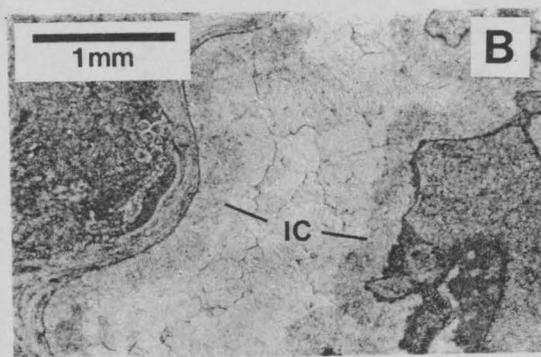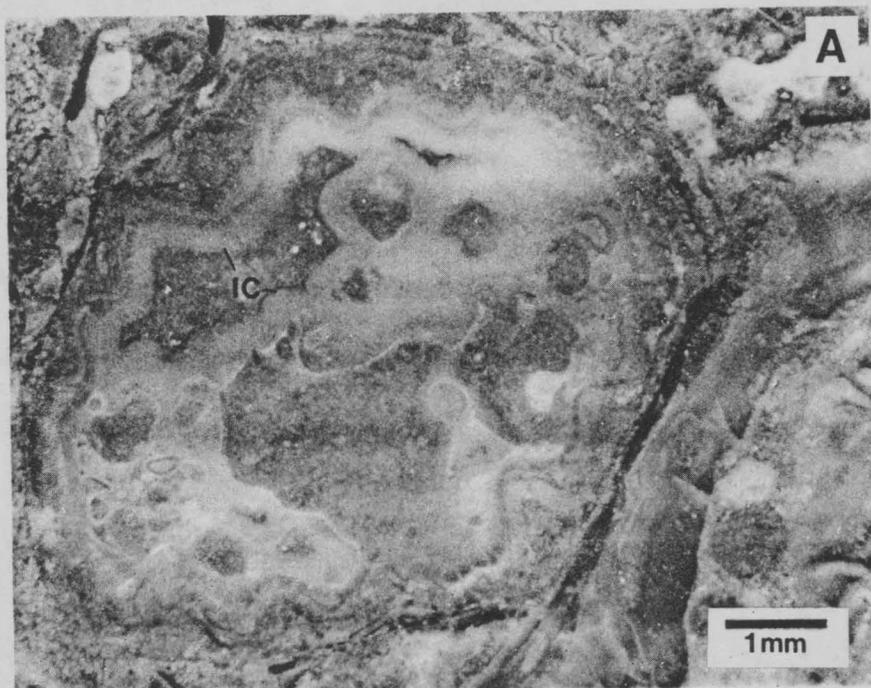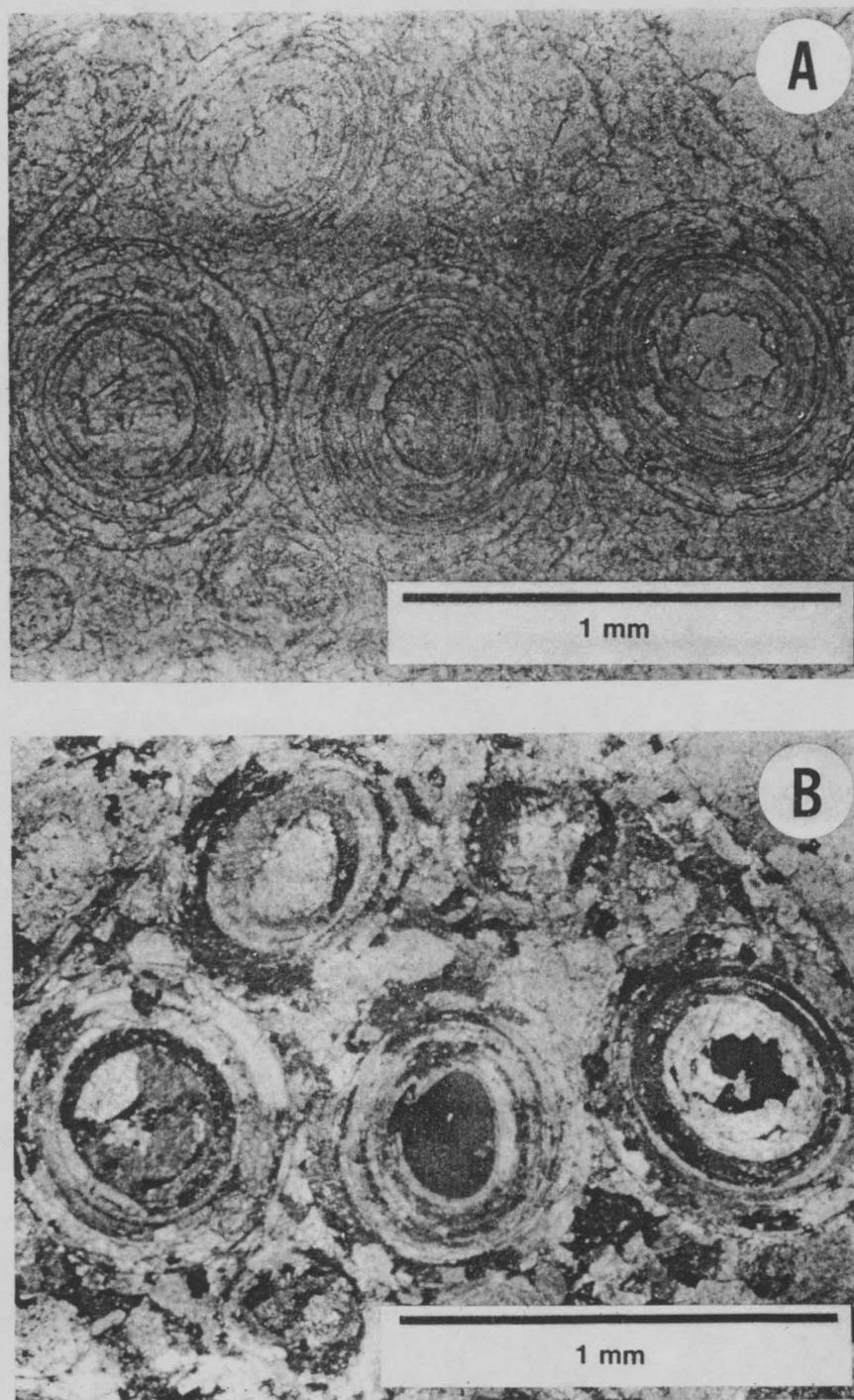
Figure 41. Photographs of ooliths in thin section as they commonly appear in the oolitic grainstone facies. Note the concentric laminations in the cortices and the patchy, irregularly shaped neomorphic crystals which now comprise them. (A) Plane light; (B) crossed nicols.

patchy fabric of the neomorphic crystals at various stages
of extinction (Figure 41-B). When rotated, the amount of
extinction varies in each crystal, but no trace of a pseudo-
uniaxial cross is seen. Many ooids have been partially or
entirely leached, and some are filled partially or entirely
with dolomite which displays undulose extinction. Oomolds
completely filled with a single crystal are not uncommon.
Ooliths that have been entirely leached show no original
internal structures (Figure 42).

     Porosity. The fossiliferous oolite grainstone
facies contains moldic, oomoldic, and minor amounts of pri-
mary intergranular porosity. Oomoldic porosity is most
common and predominates in the less fossiliferous zones.
Moldic porosity predominates in the fossiliferous zones.
The amount of porosity ordinarily varies inversely with
ooid size, and directly with ooid abundance. Some leached
fossils and ooids are completely filled with a void-filling
cement, altered now to neomorphic spar, but many are either
only partially filled or are entirely empty. Some minute
amounts of porosity are also associated with the stylolites
and fractures found in this facies.

Oolite Grainstone.

     Cements. The cements in the oolite grainstone
facies are identical to those in the fossiliferous oolite
grainstone facies. However, ooid leaching is much more
prevalent, and a greater percentage of oomolds is completely
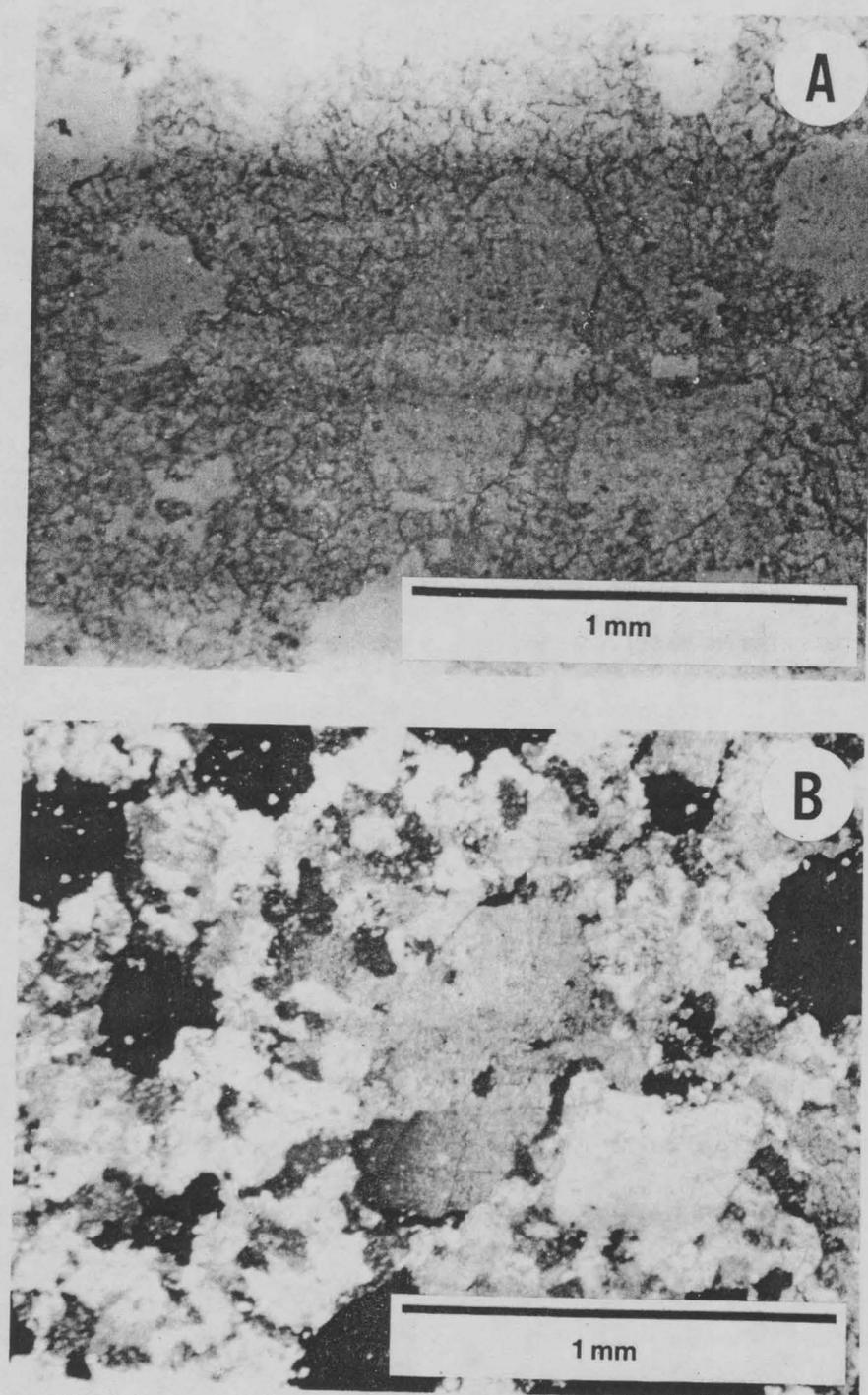
Figure 42. Photographs of former oomolds now filled with
void-filling dolomite cement with undulose
extinction. Thin section; (A) plane light,
(B) crossed nicols.

or partially filled with dolomite in the unfossiliferous facies. Most of the ooliths in this facies have been neo-morphosed to coarse spar. Others have been leached and filled with large crystals of dolomite which display un-dulose extinction. The former type of alteration yields light tan ooids, and the latter, dark brown cement-filled molds. The two fabrics are easily distinguished (Figure 43). The dolomite in this facies is much more commonly zoned with the ankeritic-looking material than that in the fossiliferous facies.

Neomorphic Fabrics. Some laminae and thin beds in this facies are characterized by solution collapse breccias (Figure 44-A). The grains forming the breccia are fragments of former inter-ooid cement. The ooids were leached; the remaining framework of cement was not sub-stantial enough to support itself, and it collapsed. Each of the fragments of cement has several concave-outward surfaces, vestiges of the molds of leached ooids, which are separated by sharp ridges. An ideal section through a grain remnant of cubicly packed ooids would produce a hypo-cycloid of four cusps (Figure 44-B). Because the external surfaces of the grains in the breccias are dominated by concave-outward surfaces and sharp ridges, most of the con-tacts between the grains are point contacts. All of these zones found in the Drum are tightly cemented. With minimal cementation, however, a rock like this would have large amounts of porosity and probably better permeability than its
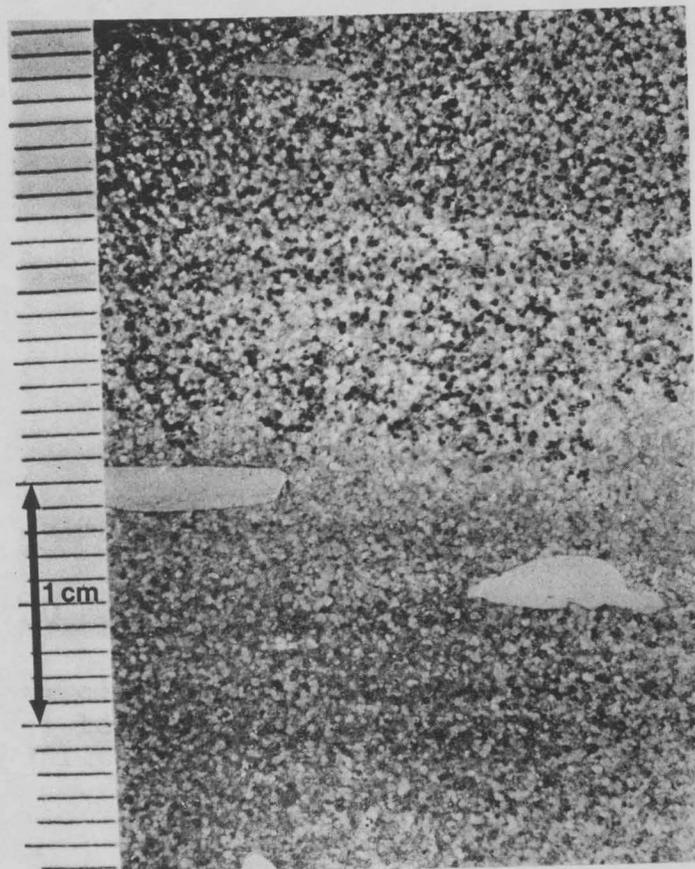
Figure 43. Photograph of former oomolds filled with dark
brown dolomite cement (above) and highly neo-
morphosed, light tan ooliths (below). In spite
of the distinct appearances of the two zones
pictured, they are both part of the unfossilif-
erous oolite grainstone facies. Polished slab.
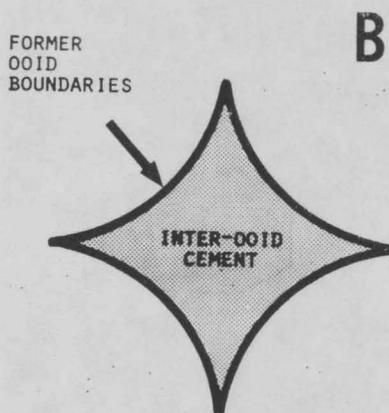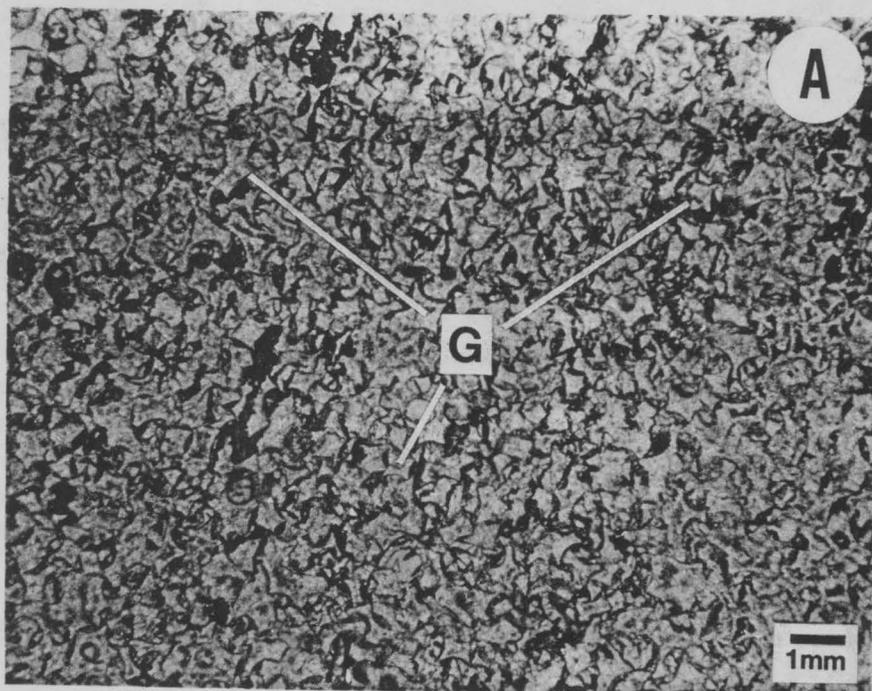
precursor.   If hydrocarbons migrated into these pores before
subsequent cementation, the rock would make an ideal
petroleum reservoir.

Porosity.   This oolite grainstone facies is
generally much more porous than the fossiliferous facies,
because of the increased abundance of oomoldic porosity.   As
in the fossiliferous facies, oomoldic porosity is by far the
most abundant type, and moldic porosity is next most
abundant.   Porosities in the oolite grainstone facies exceed-
ing 60% of the total rock volume are seen more than rarely in
slab and thin section (Figure 45).   However, 12% to 15% is
more nearly normal.   Permeabilities for the oolite facies
were measured by Amoco to average less than 0.05 md in the
Universal Atlas Cement Company quarry southeast of Inde-
pendence.

This facies contains many thin beds and laminae
(1 cm to 5 cm) of light tan rock which have distinct
boundaries with the surrounding darker tan rock.   Unlike
the darker laminae, well-defined oomolds are uncommon in
the lighter-colored ones, and porosities are generally much
lower in them as well.   The most common pore shape in the
light-colored laminae is more linear than spherical and is
typically crescent-shaped.   The pores are commonly oriented
parallel to bedding and are closely associated with very
small stylolites.   These laminae seem to be much more
coarsely recrystallized than the neighboring laminae, having
a sugary appearance under a low-powered microscope, because
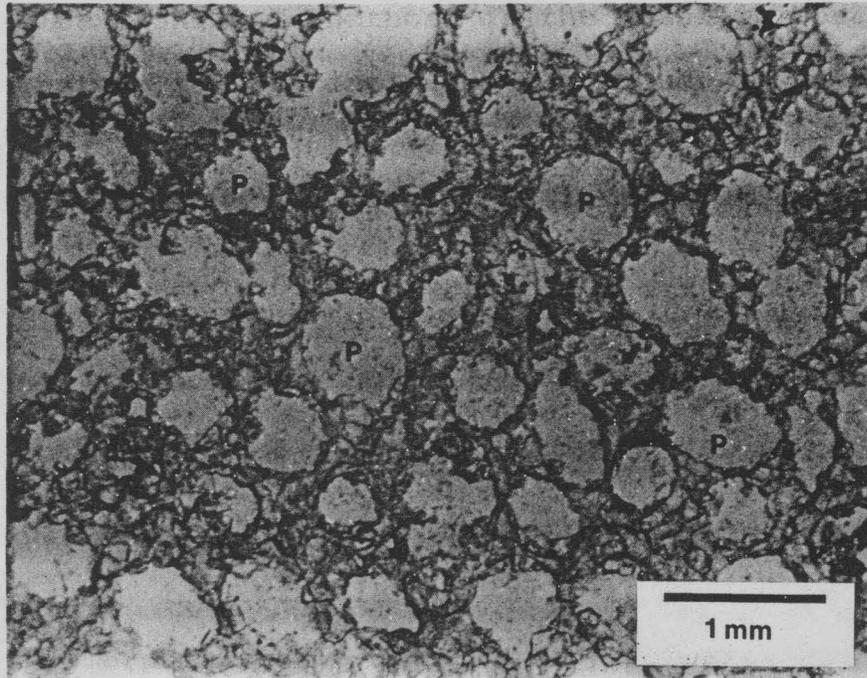
Figure 45. Photograph of oomoldic porosity (P) in the
oolite grainstone facies. The total remaining
rock is neomorphic spar. Thin section; plane
light.

of abundant rhombic carbonate crystals, 0.05 to 0.2 mm across.

Intraclastic Grainstones-Packstones.

Cements. The intraclastic grainstones display cement fabrics identical to those in the fossiliferous oolite grainstone facies, including the cloudy isopachous cement (Figure 30). Its mineralogy is also the same as that of the fossiliferous oolite grainstone facies.

Neomorphic Fabrics. The neomorphic fabrics of this facies are identical to those of the fossiliferous oolite facies.

Porosity. The intraclastic facies is not as porous as either of the oolite grainstone facies. Most of the depositional intergranular porosity is filled with clear carbonate neomorphic spar. Some primary porosity has been preserved, however, in shelter fabrics, below large intra-clasts. Some moldic and oomoldic porosity is also present. The average porosity for the intraclastic grainstones is probably less than five percent, and that for the intra-clastic packstone is much less.

Pellet Packstones-Wackestones.

Cements. The cements of this facies have been altered to neomorphic spar.

Neomorphic Fabrics. Because of the scarcity of intergranular space and the large amounts of intergranular micrite in this facies, visible spar occupies a very small

volume. Where it can be seen, it consists of small, clear, interlocking neomorphic crystals.

Porosity. The pelletal packstones-wackestones are ordinarily non-porous.

Bryozoan-Algal Packstones-Wackestones and Boundstones.

Cements. The cements in this facies are almost exclusively confined to intragranular space, especially to the chambers inside corals. Some occur as void-filling spar in constructional voids in the boundstones.

Neomorphic Fabrics. The cements in this facies have been altered to clear, colorless to dark brown neomorphic spar.

Porosity. Porosity is almost non-existent in this facies. However, at some localities, small amounts are associated with fractures which are otherwise filled with carbonate cements.

Summary

Several aspects of petrography have been considered for each facies. Not all of the characteristics of the rock which were described above directly resulted from, or were influenced by, the depositional environment. Below is a list of the important features in each facies related to its depositional environment. The six different facies are compared in Figures 46 and 47 with respect to the most significant of these characteristics.
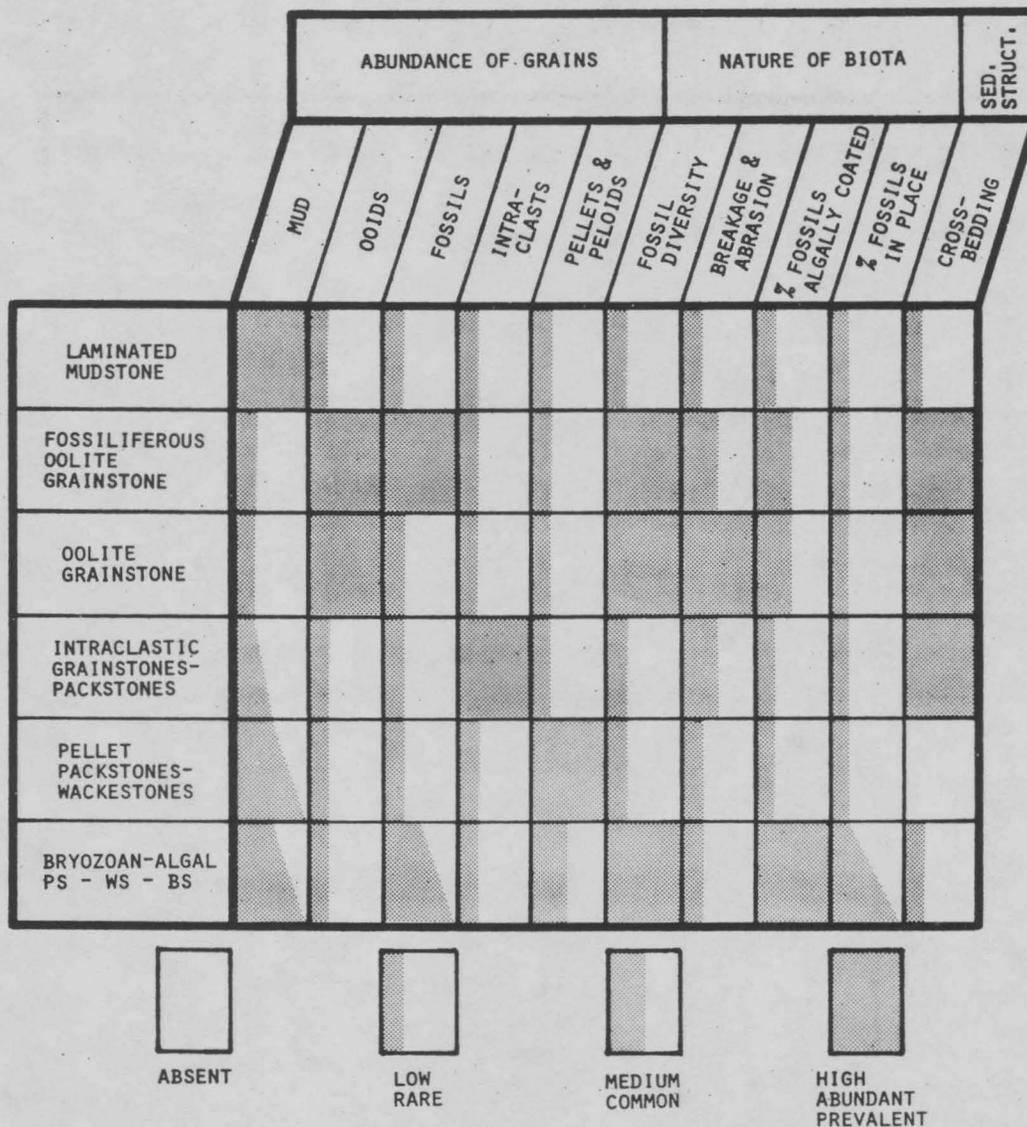
Figure 46. Summary of the environmental indicators in each facies of the Drum Limestone. Slanted shading in a box implies that the parameter varies from the lower to the higher value indicated.

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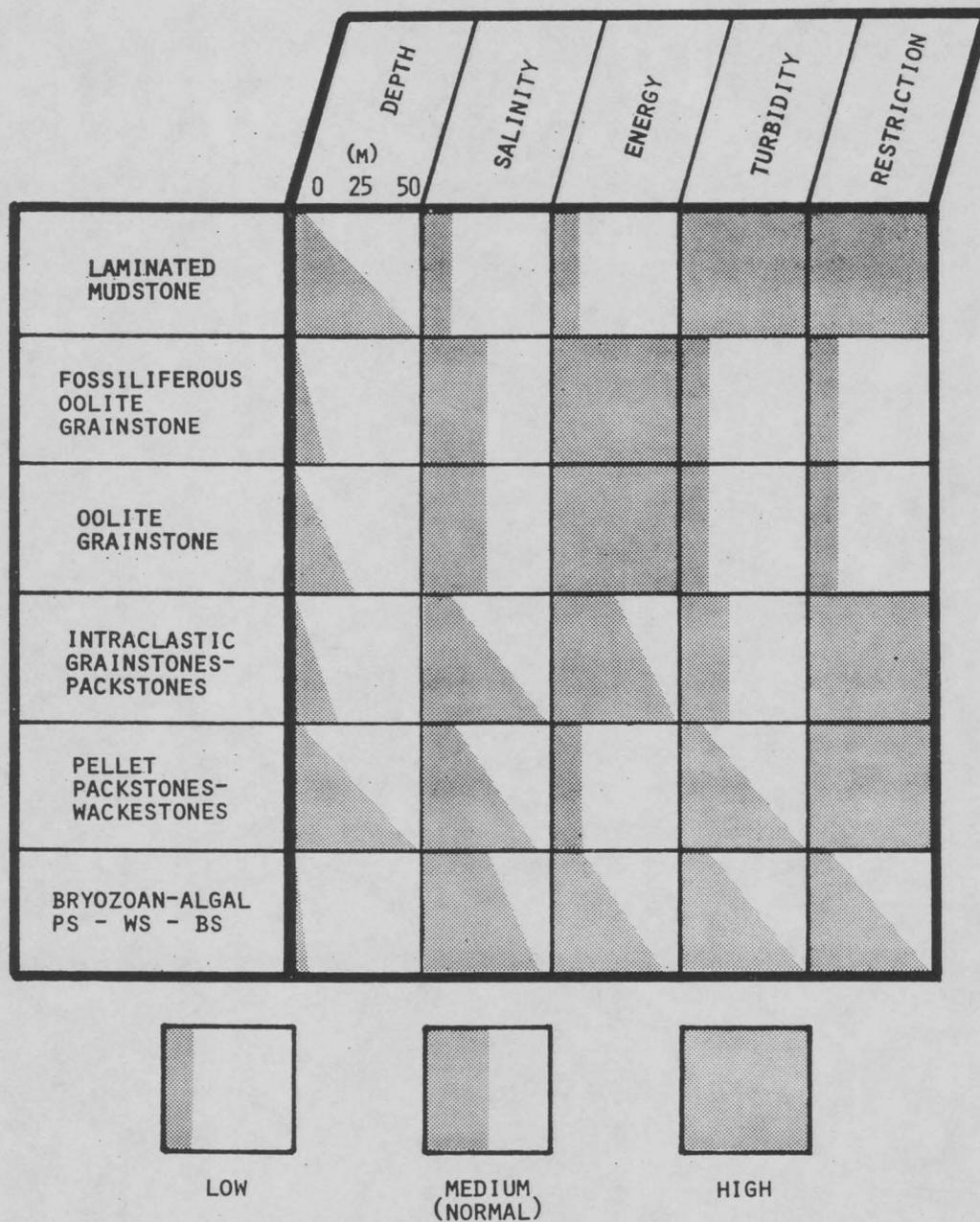
Figure 47. Summary of the water conditions in the depositional environment of each facies of the Drum Limestone. Slanted shading in a box implies that the parameter varies from the lower to the higher value indicated.

Laminated Mudstone.

Abundance of mud.
Scarcity of grains.
Abundance of laminae.
Presence of burrowing.
Interbedding with shale.

Fossiliferous Oolite Grainstone.

Lack of mud.
Abundance of ooliths.
Variety of other non-skeletal grain types.
Abundance of robust fossils.
Diversity of fossils.
Cross-bedding.
Thin bedding.
Interbedding with shale.
Alternations of oolitic and fossiliferous zones.
Lack of fossil abrasion.
Abundance of fossil coatings.
Presence of borings.
Presence of isopachous cement.

Oolite Grainstone.

Lack of mud.
Abundance of ooliths.
Scarcity of fossils.
Diversity of fossils.
Prevalent breakage and abrasion of fossils.
Abundance of fossil coatings.
Cross-bedding.
Thin bedding.

Intraclastic Grainstones-Packstones.

Variability of mud content.
Abundance of intraclasts.
Abundance of ooliths.
Oolitic coatings on intraclasts.
Scarcity of fossils.
Restriction of fossil types.
Fossils badly broken.
Fossils oolitically coated.
Cross-bedding.
Isopachous cement.

Pellet Packstones-Wackestones.

    Abundance of mud.
    Abundance of pellets.
    Scarcity of other grain types.
    Scarcity of fossils.
    Restriction of fossil types.
    Lack of obvious bedding.

Bryozoan-Algal Packstones.

    Abundance of mud.
    Abundance of peloids.
    Scarcity of other non-skeletal grains.
    Abundance of large delicate fossils.
    Presence of fossils in growth position.
    Abundance of encrusting organisms.
    Restriction of fossil types.
    Presence of local boundstones.

Distribution of Facies

Introduction

In the preceding section, the six principal rock types of the Drum Limestone were described, each of which indicates different depositional conditions. In order to interpret the depositional environments of the Drum in a paleogeographical framework, the vertical and lateral distribution of each rock type must be known. Figure 12 shows an idealized distribution of these facies along the outcrop belt of the Drum from Kansas City, Kansas, to the Oklahoma-Kansas border. This figure is a helpful guide to the following discussion of the distribution of rock types in the study area. The discussion is restricted to the areas of the outcrop belt and to the Amoco cores. The distribution of facies in the subsurface is presently unknown.

Vertical Distribution of Facies.

Laminated Mudstone. The laminated mudstone generally occurs interbedded with shale below the oolitic facies of the Drum Limestone. Since this facies occurs below the oolite, it has been considered to be a part of the Cherryvale Shale Formation (Moore and others, 1944). More recently, the laminated mudstone has been interpreted to be the Cement City Member of the Drum Limestone by Amoco Research Company geologists who have done field work in the area (personal communication with D. Winland, 1979). This facies also occurs rarely interbedded with the fossiliferous oolite grainstone, near the top of the oolite.

Fossiliferous Oolite Grainstone. This facies occurs above the unfossiliferous oolite grainstone facies if the unfossiliferous facies is present. If it is not, then the fossiliferous oolite grainstone rests directly on the flaggy laminated mudstone facies.

Unfossiliferous Oolite Grainstone. This facies most commonly occurs above the flaggy laminated mudstone facies and below the fossiliferous oolite grainstone where the fossiliferous facies is present. Where the fossiliferous oolite facies is not present, the unfossiliferous facies is overlain either conformably by shale of the Chanute Formation, or unconformably by the Noxie Sandstone of the Chanute Formation.

Intraclastic Packstones-Wackestones. This facies most commonly occurs at the top of the flaggy laminated

mudstone facies and below the oolitic facies. It also
occurs at the top of mudstone beds within the flaggy mud-
stone facies.

Pellet Packstones-Wackestones. The pelletal
facies occur within the flaggy laminated mudstone facies,
as well as above the mudstone facies and below oolitic
facies.

Bryozoan-Algal Packstones-Wackestones and Bound-
stones. In the northern part of Montgomery County, this
facies occurs above a very thin section of the laminated
mudstone facies and apparently forms the uppermost unit of
the Drum. In T33S, R16E, this facies forms banks three
meters tall and two meters across which rest on laminated
mudstone and are flanked and capped by oolitic grainstones.

Lateral Distribution of Facies.

Laminated Mudstone. The laminated mudstone in-
frequently occurs interbedded with the fossiliferous oolite
grainstone near the top of the Drum, as in Amoco's Mouse
Creek No. 1 and Sloop No. 1 cores. The laminated mudstone is
widespread throughout the study area below the oolitic facies
of the Drum Limestone (Figure 48). It is very thin in the
northern part of the area, but is thicker east of Indepen-
dence, and from there it progressively thickens to the south
and southeast.

Fossiliferous Oolite Grainstone. The fossilifer-
ous oolite grainstone is absent in the northern part of
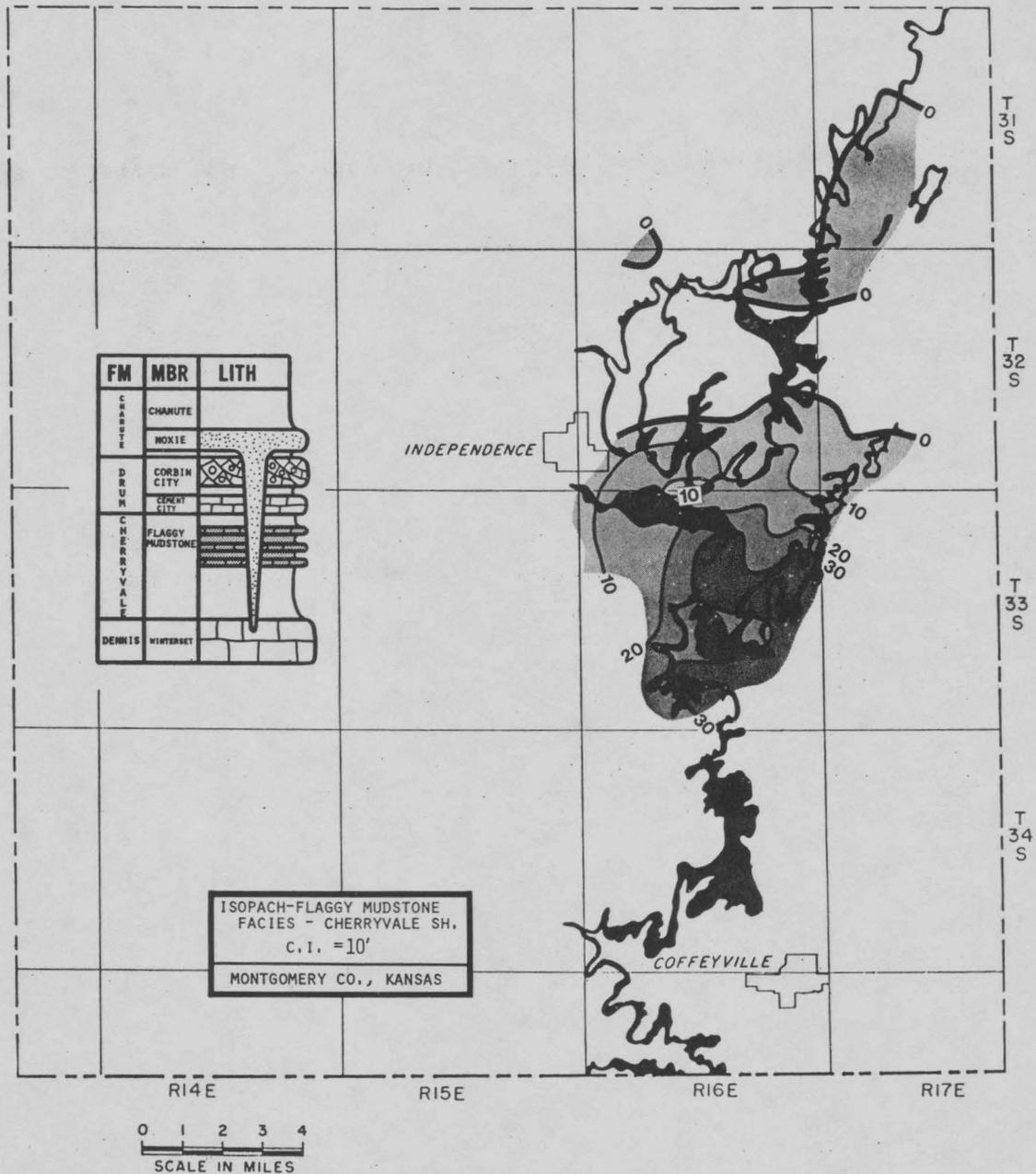
Figure 48. This map illustrates that the flaggy mudstones which underlie the Drum oolite facies are essentially restricted to the area interpreted as a bathymetric depression during ooid deposition (see Figure 49). The mud was probably able to collect in this area because of low water energy in the depression (based on Amoco Production Company maps and data).

T31S. It occurs in thin beds in the southern portion of T31S, and is widespread in T32S and 33S. Where present, it occurs above the unfossiliferous oolite grainstone facies. It is frequently interbedded with the laminated mudstone facies or with gray laminated shale. The thicknesses of the fossiliferous and unfossiliferous oolite grainstone facies were mapped together (Figure 13), primarily because of the difficulty in differentiating between the two facies in the field. This isopach map shows the northeastern limit of oolite in T31S, R17E, and the area of thickening southeast of Independence, where the combined oolite facies thickens to more than 18 m. The area of thickening is restricted in the outcrop belt, although other local thickenings may occur in the subsurface.

The absence of oolite south of the zero isopach line in T32 and 33S is thought to be due to pre-Chanute erosion rather than non-deposition. This will be discussed in more detail in Chapter IV.

Oolite Grainstone Facies. The oolite grainstone facies was not found north of T32S, but is widely distributed throughout the Drum outcrop in T32 and 33S. At locality 5 in Section 1, T32S, R16E, the oolite grainstone forms an ovoid bar approximately 0.5 m high, resting on and enveloped by bryozoan-algal packstone-wackestone-boundstone banks described above.

Intraclastic Grainstones-Packstones. The intra- clastic facies are widespread along the outcrop belt, but are

more prevalent in the eastern portion. They generally occur
as thin beds, usually less than 0.5 m in thickness, with the
laminated mudstone facies below and the oolite grainstone
facies above. At locality D-20 in Section 3, T32S, R17E, the
intraclastic facies occurs at the top of a bed of blue cross-
bedded mudstone approximately 25 cm thick.

Pellet Packstones-Wackestones. The pelletal
facies are almost exclusively restricted to the southern
portion of the study area, in T34S, R16E. They generally
occur between the laminated mudstone below, and the oolitic
grainstone facies, or, if present, the intraclastic facies.

Bryozoan-Algal Packstones-Wackestones and Bound-
stones. The bryozoan-algal packstones-wackestones and bound-
stones are restricted to the north and east sections of the
study area. At most places in Montgomery County north of
T33S, these rocks comprise the entire Drum Limestone and
rest on a very thin section of the flaggy mudstone facies.
South of T32S, the bryozoan-algal facies occur above the
laminated mudstone facies but thicken locally, forming
banks. These banks are flanked and capped by oolite grain-
stones and attain thicknesses up to 2.5 m high and 3.0 m
wide.

CHAPTER IV

INTERPRETATIONS

The petrographic, paleocurrent, and isopach data, as well as the vertical and lateral facies distributions, are the bases for the following fundamental interpretations.

Mode of Ooid Deposition

A major question to be addressed is the paleo-topographic setting of the Drum oolite. The isopach map in Figure 49 indicates that the combined interval of the Cherryvale Shale and Winterset Limestone is thin where the Drum oolite is thickest. If the base of the Winterset Lime-stone was essentially horizontal after deposition of the Cherryvale Shale, then this isopach map simulates pre-Drum oolite paleobathymetry. The thin area would suggest a bathymetric low, indicating that the thick portion of the Drum oolite accumulated in a depression and did not thicken by shoaling. Other evidence supporting the presence of a depression in that area is discussed in this chapter in the section dealing with paleogeography before oolite deposition. My interpretation is that where the oolite is thickest, southeast of Independence, it was deposited as fill in a bathymetric low, perhaps a tidal channel. Amoco Production Company geologists also concluded that the thick oolite
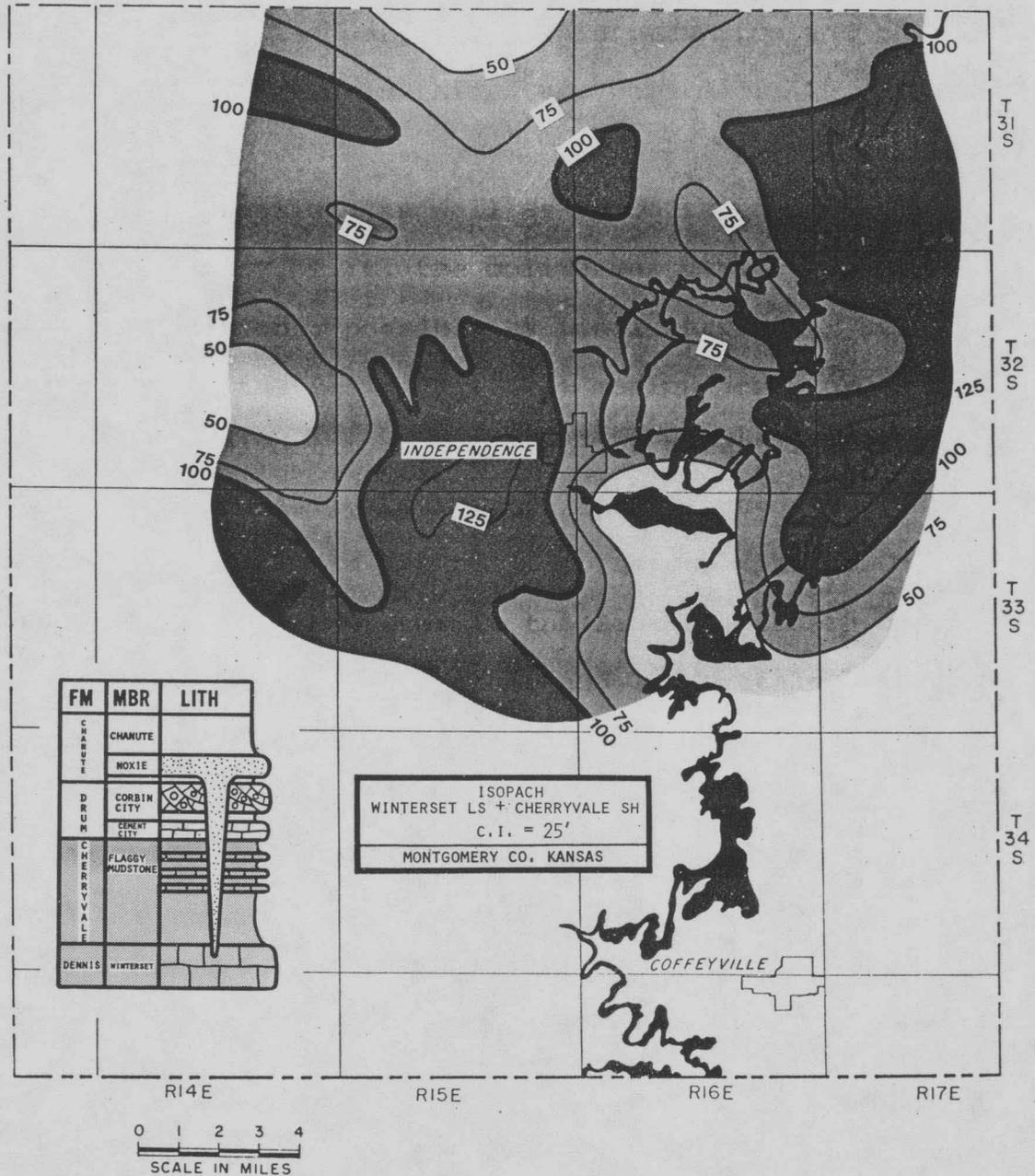
Figure 49. If the base of the Winterset Limestone was essentially horizontal during Drum deposition, then this map simulates pre-Drum oolite paleobathymetry. Thin areas represent paleobathymetric depressions, and thick areas represent paleobathymetric highs. The thin area southeast of Independence corresponds with the thick area of oolite, suggesting the oolite thickened by filling a depression on the sea floor (based on Amoco Production Company maps and data).

accumulated in a depression, according to personal communications with them. However, their interpretation and the interpretation presented in this study were made independently.

In the depression, as well as up on the shallow shelf north and east of it, the oolite was deposited under high energy conditions, possibly by tidal currents. Evidence for this includes the following: (1) medium scale cross-bedding is found almost everywhere in the oolite; (2) the oolite facies essentially lacks mud; and (3) uncoated fossils are broken and abraded in the oolitic facies. In the Cat Cay and Joulters Cay complexes in the Bahamas, modern ooids in tidal channels form medium scale and large scale sand waves (Harris, 1977). J. A. Babcock (personal communication, 1979) noted that, in the tidal channels of these complexes, many ooids are transported in sand waves predominantly by ebb tidal currents. Because they do not form daily, they may be the result of storm ebbs. The medium scale cross-bed sets of oolite in the Drum with their overwhelming southwestern directional component may also have been the result of storm ebb tides. The general paleogeography outlined in Chapter II provides for land to the north and east of the study area during Drum deposition. If this reconstruction of paleogeography is accurate, then storm ebb tides could have produced sand waves of Drum ooids which migrated southwestward -- offshore. The mud clasts found in the oolitic facies may have been ripped up from shallow deposits

during the storms and carried offshore by the strong ebb tides.

Anomalous Association of Fossils and
Cross-Bedded Oolite

In outcrop, the most surprising feature of the Drum is the abundance of large, seemingly delicate, but well preserved, fossils mixed with the cross-bedded oolite. This association seems contradictory in that very delicate fossils would probably be broken and abraded when intro-duced into an environment vigorous enough to be forming medium-scale cross-bedded oolite. Conversely, it is un-likely that cross-bedded oolite would develop in an area where such forms were living. Two observations led to a reasonable explanation for the unusual association. First, the large, well-preserved, delicate fossils occurring in the oolite are algally coated. Second, delicate fossils not thickly coated are broken and abraded. As a result of being armored by thick algal coatings, many large, seemingly delicate fossils were substantial enough to survive breakage and abrasion in the high energy environment of deposition. When these fossils are exposed on outcrop by weathering, the coatings are obscure, and the large, delicate-looking fossils appear to have survived the high energy environment unprotected.

Another unusual characteristic of the fossils in the Drum oolitic facies in Montgomery County is the large size

of individual organisms. As discussed in Chapter I, Girty
(1915) described the fauna of the Drum Limestone near
Independence as robust, and remarked that faunas associated
with oolites are normally dwarfed faunas. He noted that
the fauna of the Westerville Limestone in the Kansas City
area had a dwarfed fauna. Moore (1948) suggested that
dwarfed faunas are the norm for oolites, because the re-
stricted conditions under which ooids form, especially
abnormal salinity, are generally less than ideal conditions
for optimum marine invertebrate development. Besides
dwarfism, a common characteristic of biotic assemblages in
restricted marine environments is that the assemblages are
taxonomically limited. The biota associated with the Drum
oolite, however, is taxonomically diverse. The robust and
diverse characteristics of the Drum oolite fauna together
suggest that, for the most part, the ooids and the fossils
occurring with them did not originate in the same place at
the same time.

Paleogeography Before and During

Oolite Deposition

Fundamental to understanding the depositional environ-
ment of ancient sediments is understanding the paleogeography
of the site of deposition. Several observations led to the
conclusion that the thick Drum oolite did not form on a
pre-existing bathymetric high, but that it accumulated in a
depression, perhaps a tidal channel, and that the areas to

the north and east comprised a very shallow subtidal shelf.
The first observation leading to this important conclusion
was that the Cherryvale + Winterset interval is shown to
be thin below the thickest part of the oolite on the isopach
maps in Figures 13 and 49 and on the cross-section in
Figure 50. If the base of the Winterset Limestone was
essentially horizontal during Drum deposition, then this
thin area was a depression on the sea floor. Second, both
the flaggy mudstone facies (Figure 48) and the pellet pack-
stone-wackestone facies are virtually restricted to the area
of thick oolite. Both of these facies were deposited prior
to the major episode of oolite deposition in the area, and
they may have been restricted to that area primarily because
lower energy conditions prevailed in the depression. The
area to which these facies are restricted could have been
below normal wave base, whereas the surrounding high shelf
was covered by shallower water, possibly of more nearly
normal salinity.

That the depression was adjacent to a shallow shelf,
at least on the north and east sides, is documented by the
restriction of the bryozoan-algal packstone-wackestone,
boundstone, and stromatolitic facies to those areas
(Figure 51). Before oolite accumulation in the depression,
prodelta mud, perhaps from the southeast, was introduced
into it, where it settled, because the depression was an
area of calm water at that time. The terrigenous mud was
deposited in the depression at regular intervals, alternating
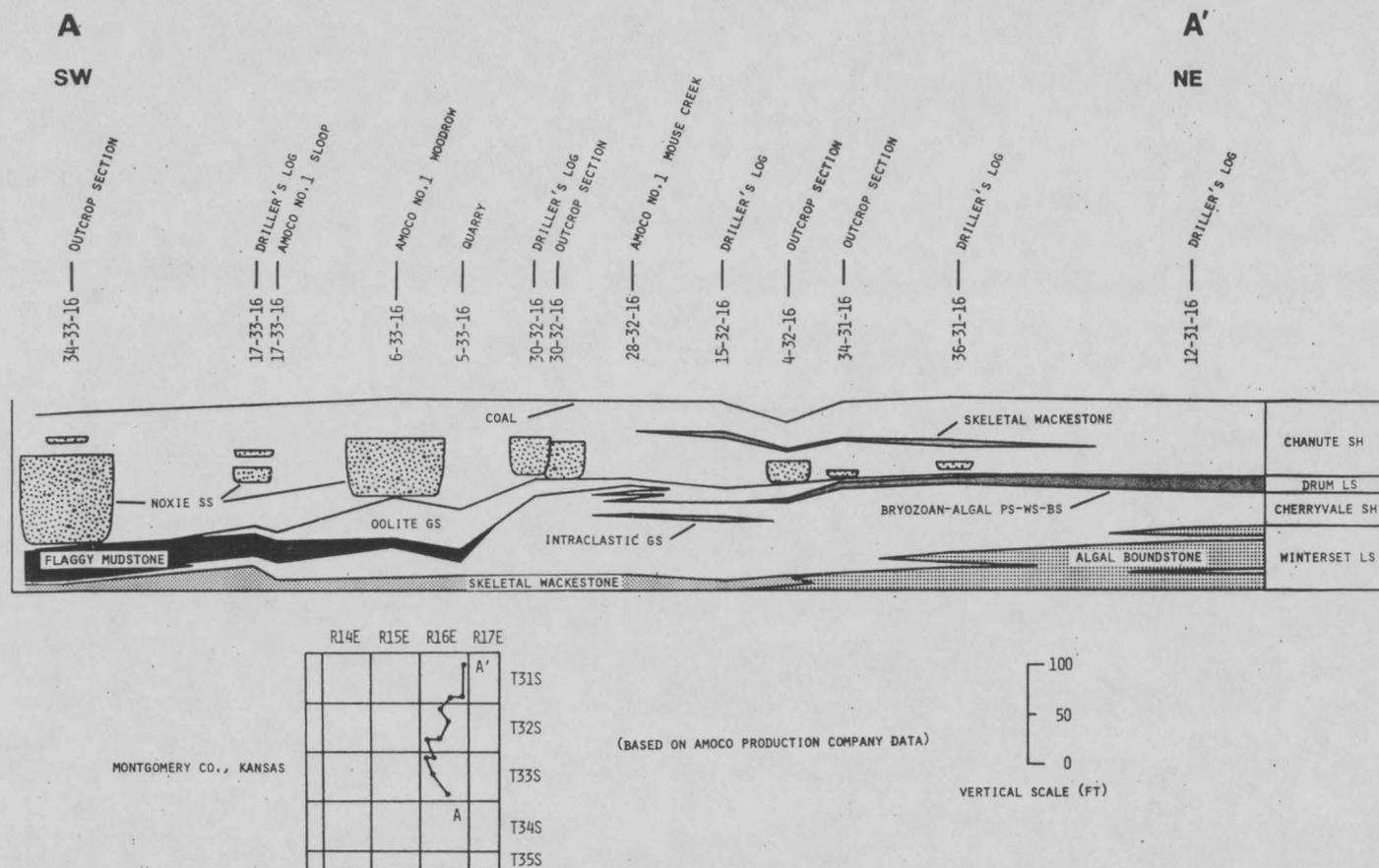
Figure 50. Stratigraphic cross-section of the Drum Limestone and adjacent strata. The oolitic facies of the Drum occurs as a wedge which was apparently formed by the migration of ooids into a depression from the shallow shelf to the north and east. The laminated mudstone facies of the Cherryvale Formation formed in this depression before the major episode of ooid deposition. The oolitic grainstone was eroded by deltaic distributary channels now filled with the Noxie Sandstone, as in the Amoco No. 1 Woodrow core. The dashed line indicates a possible pre-erosion surface of the oolitic facies.
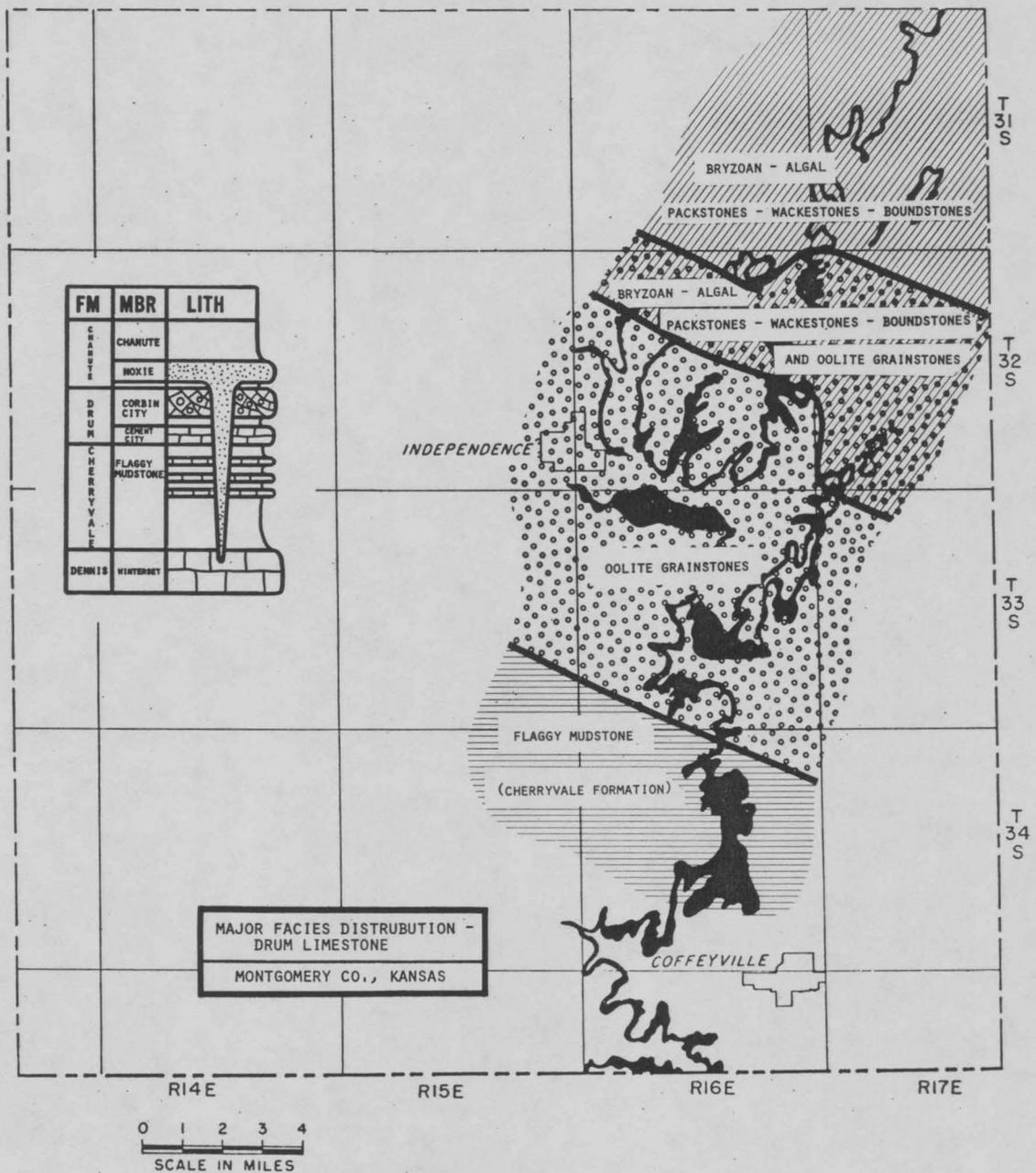
Figure 51. Distribution of the facies of the Drum Limestone.

with periods of carbonate mud deposition. The ensuing
regular interbedding of carbonate mudstone and shale may
have been the result of regularly intermittent periods of
delta progradation as in response to climatic, perhaps even
seasonal, changes. Several disconformities or storms are
recorded for this period in the intraclastic facies associ-
ated with the flaggy mudstone facies.

In the shallower water, bryozoan-algal banks with
positive topographic relief grew locally into normal wave
base, and in their shoaling stages, ooids formed over them.
The ooids were transported in migrating sand waves south-
westward by currents on the shallow shelf. A substantial
number of the oolites were dumped into the depression south-
east of Independence.

The oolite grainstones northeast of Independence are
interbedded on a small scale with gray laminated shales
interpreted here to be prodelta mud of the Chanute Formation.
This supply of terrigenous mud was probably introduced into
the shallow sea by deltaic processes operating within tens
of kilometers from the site of ooid deposition, probably to
the northeast, east, and southeast. This interpretation
implies that the Chanute Formation is in part coeval with
the Drum oolite.

Origin of the Ooliths

The average diameter of Drum ooliths is 0.5 mm,
although they range up to 2.0 mm. Bathurst (1975) showed

that ooid size is inversely proportional to the amount of
energy in the ooid-forming environment. The most common
shape of the Drum ooliths is very nearly spherical, and
sorting of the ooids is generally excellent. The ooliths
also have many concentric laminae in their cortices.
Modern ooids forming near the shelf margin of the Great
Bahama Bank also have numerous laminae (Bathurst, 1975).
The size, shape, sorting, and numerous concentric laminae
of the ooids suggest that they formed in a vigorous
environment where they were rolled about continuously.

The places where the ooliths actually formed are
suggested by several lines of evidence. First, the Drum
ooliths flank and cap bryozoan-algal banks east and north
of the thickest oolite accumulation. Oolitic and pisolitic
facies very commonly flank and cap phylloid-algal mounds in
other Lansing-Kansas City limestones of eastern Kansas
(Heckel and Cocke, 1969). Presumably, these ooliths formed
during the shoaling stages of mound development. Many
ooliths of the Drum apparently originated in a very similar
manner. Second, ooliths occur in small bars within the
bryozoan-algal facies north and east of the area of thickest
oolite accumulation. Third, the most common ooid nuclei are
peloids and fossil fragments common to the areas north and
east of the thick ooid accumulation. Fourth, cross-bedding
indicates a southwest direction of oolite transport. These

observations collectively suggest that the ooliths probably formed mostly east and northeast of the area of thickest accumulation, although they probably continued their growth during their southwestward migration.

Because of the intimate association of ooids with bryozoan-algal banks, most of the Drum ooliths probably initially formed in a shoaling situation. However, because the thickest oolite, southeast of Independence, developed at the site of a bathymetric low (see the discussion in this chapter concerning paleogeography before and during oolite deposition), the thickening is probably the result of the depression being filled rather than the oolite shoaling there.

Not all ooliths of the Drum Limestone were formed at the culmination of bryozoan-algal growth. The ooliths which occur in small bars within the bryozoan-algal packstone-wackestone facies may not have formed at the same time or place as the organisms in those facies. The position of these bars within the bryozoan-algal facies does suggest, however, that the ooliths were deposited after part of the bryozoan-algal facies was deposited, and that ooid deposition did not occur only at the end of the development of the bryozoan-algal facies. The two facies were coeval.

Paleogeography After Ooid Deposition

The geography of the study area after deposition of the Drum oolite can be speculated upon by interpreting the

lithologies, thicknesses, and distributions of the oolite
and facies coeval with it, and of those facies which im-
mediately overlie them. First, it should be noted that the
upper surface of the Drum Formation was not simply overlain
by succeeding layers of sediment, preserving in all detail
the paleobathymetric features at the end of Drum time. In
the core taken from the Amoco No. 1 Big Jim Woodrow, a thick
body of Noxie Sandstone rests clearly unconformably on the
top of the Drum oolite. This sandstone is interpreted to
represent a back-filled delta distributary channel. It
is evident, then, that the evidence upon which interpreta-
tions of post-oolite paleogeography are based must be
considered cautiously. One such line of evidence is the
isopach map of the interval from the base of the Winterset
Limestone to the top of the Drum Limestone (Figure 52). It
was assumed above that the base of the Winterset was
essentially horizontal during Drum deposition. If the base
of the Winterset was horizontal at the end of Drum deposition
and if the upper surface of the Drum was conformable with
the overlying facies, then this isopach map would simulate
post-Drum paleobathymetry, the thick areas representing
highs, and the thin areas, lows. However, as just noted,
the upper surface of the Drum was not left undisturbed, and
this map can, at best, only approximate post-Drum paleo-
bathymetry. Proceeding with caution, then, the area of
thickest oolite accumulation southeast of Independence is
represented by a thin interval in Figure 52. This could
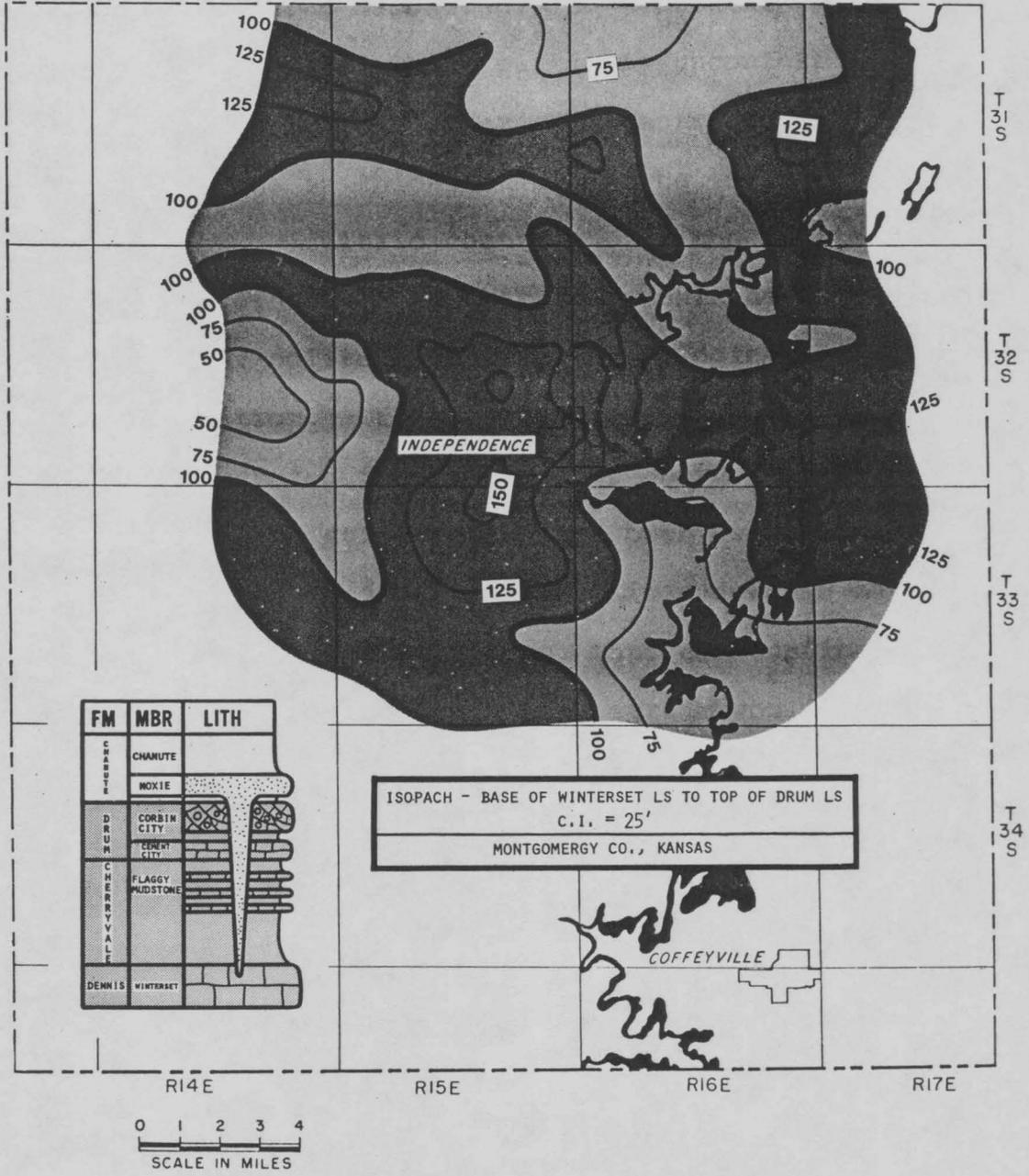
Figure 52. This map approximates the bathymetry at the end
of Drum time, if the base of the Winterset Lime-
stone was horizontal at that time. The map only
approximates post-Drum paleobathymetry since
local post-Drum erosion has been documented.
The thin area southeast of Independence suggests
that the Drum oolite either did not fill the
depression there, or, if it did, that it was sub-
sequently eroded by deltaic distributary channels
now filled with the Noxie Sandstone (based on
Amoco Production Company maps and data).

mean that the oolite did not completely fill the depression into which it was being deposited. However, the oolite in this area is overlain, at least partially unconformably, by deltaic sediments. The low area suggested by the isopach map where the oolite is thick could also be the result of post-Drum erosion by deltaic channels. If the oolite did not fill the depression, then that area would have remained a depression after oolite deposition -- a logical site for deltaic sedimentation. If the oolite did fill the depression, and even if it accreted to sea level or above, the site of the former depression still could have been overtaken by deltaic sedimentation: first, prodeltaic mud would have enveloped the entire oolite buildup, thus eliminating its status as an elevated area, such as a stream would tend to flow around instead of over. The entombment of the oolite would then have been the precursor of erosion of the oolite by deltaic distributaries. Consequently, the absence of the Drum Limestone in the generally east-west trending area west of the thickest oolite (Figure 13) may be the result of post-Drum erosion rather than non-deposition.

The presence of the terrigenous sediments of the Chanute Formation immediately overlying the Drum in Montgomery County and the facies map of the Chanute Formation (Figure 11) suggest that soon after Drum oolite deposition, the shoreline advanced to the north and west, and the study area was transformed into a deltaic plain.

Diagenesis

The Drum Limestone in Montgomery County has been extensively neomorphosed. In many rock specimens, depositional fabrics are difficult or impossible to recognize, because they have been modified or obliterated by neomorphic processes. These diagenetic processes have affected the sediments of the Drum from the time they lay on the sea floor until today. Compounding the problem of how these rocks would appear in the subsurface, as in a petroleum reservoir, is the fact that their most recent diagenetic episode has taken place in the fresh water phreatic and vadose zones, where they are now.

The entire diagenetic history of the Drum Limestone is not an objective of this study. However, aspects of early diagenesis which may have affected the sediments penecontemporaneously are discussed below.

Penecontemporaneous cementation of the Drum sediments is suggested by several lines of evidence. First, the presence of ooliths not only suggests that calcium carbonate was abundant in the sea water, but that it was actually precipitating out of the sea water. Second, the isopachous fringe cement was the first to cement the Drum sediments. Geopetal sediment was held in place by the isopachous cement inside brachiopods while the brachiopods were overturned before final burial. Third, the isopachous cement was originally composed of fibrous crystals. Carbonate cements composed of fibrous crystals have been documented to be

forming in modern marine subtidal environments (Friedman, 1968; Land and Goreau, 1970; Ginsburg and James, 1973; Bathurst, 1975; and Harris, 1977) and to have formed in ancient marine subtidal environments (Dunham, 1970; Babcock, 1977; Mazzullo and Cys, 1977; and Schmidt, 1977). The isopachous cement in the Drum Limestone is interpreted here as a marine cement.

Wholesale complex leaching and cementation possibly occurred when some oolites associated with bryozoan-algal banks shoaled to above sea level, forming islands which served as conduits through which fresh rain water could flow into the pore system of the oolites. Such diagenesis certainly took place as the deltaic distributaries of early Chanute time cut into the top of the oolite, introducing fresh water into the Drum sediments.

CHAPTER V

CONCLUSIONS

(1) The laterally restricted, thick accumulation of the Drum Limestone oolitic facies east of Independence, Kansas, did not form by shoaling, but by filling a bathymetric depression -- perhaps a tidal channel. It accumulated adjacent to a broad, relatively flat, shallow submarine shelf, on which local bryozoan-algal banks were flanked and capped by ooliths. This flat shelf was probably the major site of ooid production.

(2) The association of large, seemingly very delicate, fossils with the cross-bedded oolite at first seems to be paradoxical. However, the unbroken and unabraded fossils were coated, mostly by algal crusts in a less violent environment, before introduction into the depression with the ooliths. Their algal armor prevented the fossils from being broken and abraded by the swift currents and ooliths in the trough. Since many smaller fossil fragments are oolitically coated, and since the large skeletal fragments with their algal coats are well-rounded grains, the fossils probably rolled along the shallow shelf with the ooliths, and the fossils and ooliths were dumped together into the trough.

(3)   The diversity and robust character of the biota associated with the oolite is also anomalous.   Restricted faunas are frequently associated with modern oolites (Bathurst, 1975; Wilson, 1975), and dwarfed faunas are commonly associated with ancient oolites (Moore, 1948). Indeed, Girty (1915) documented a dwarfed oolitic fauna for the Westerville Limestone in the Kansas City area.   It is concluded that the biotic constituents of the oolite probably did not originate in the ooid-forming environment.

(4)   Because most thick accumulations of oolite described in the literature resulted from upward shoaling and accentuation of pre-existing topography, potential oolitic petroleum reservoirs in the subsurface have been sought on paleobathymetric highs.   Thick oolitic accumulations with good porosities can also occupy paleobathymetric lows, as shown by the Drum Limestone in Montgomery County, Kansas.

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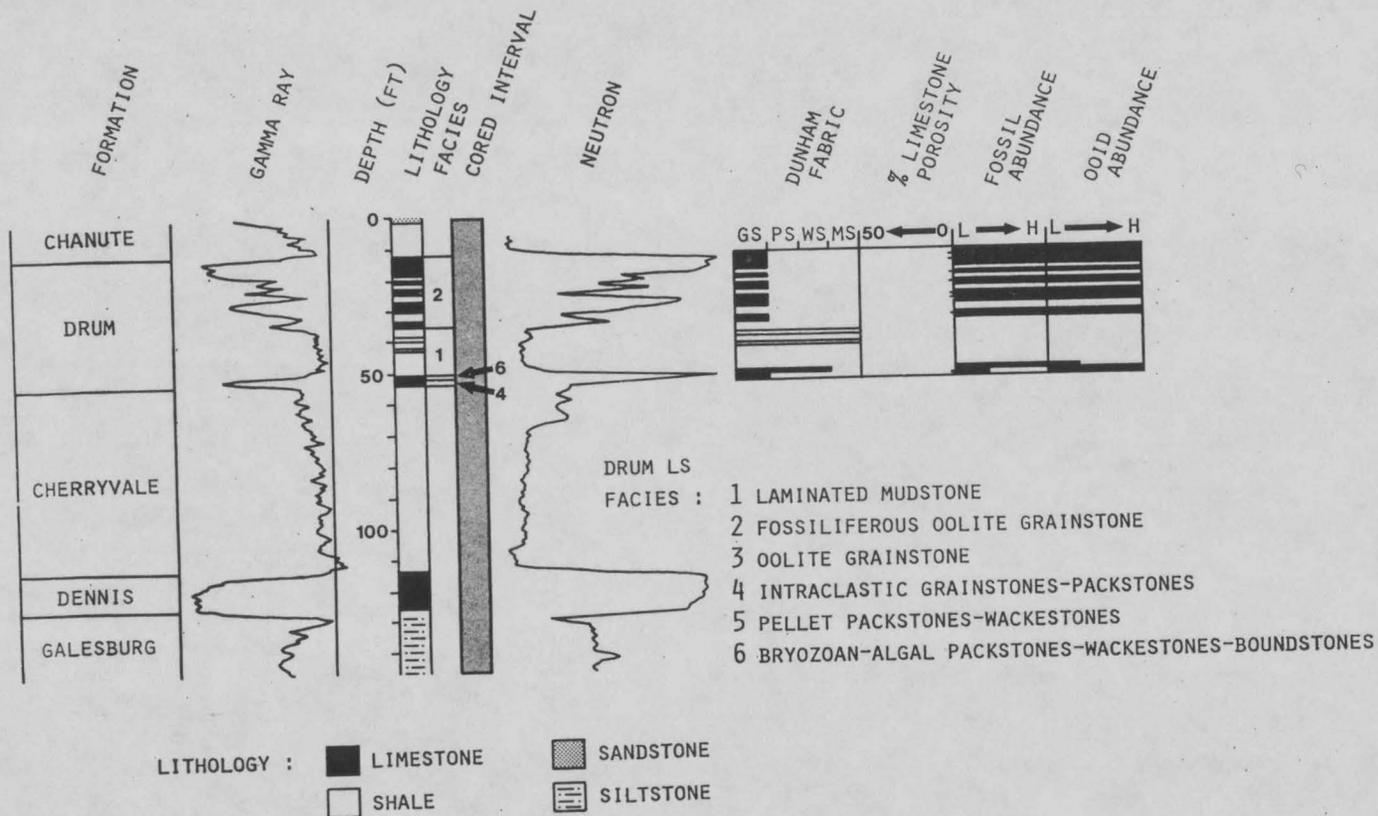
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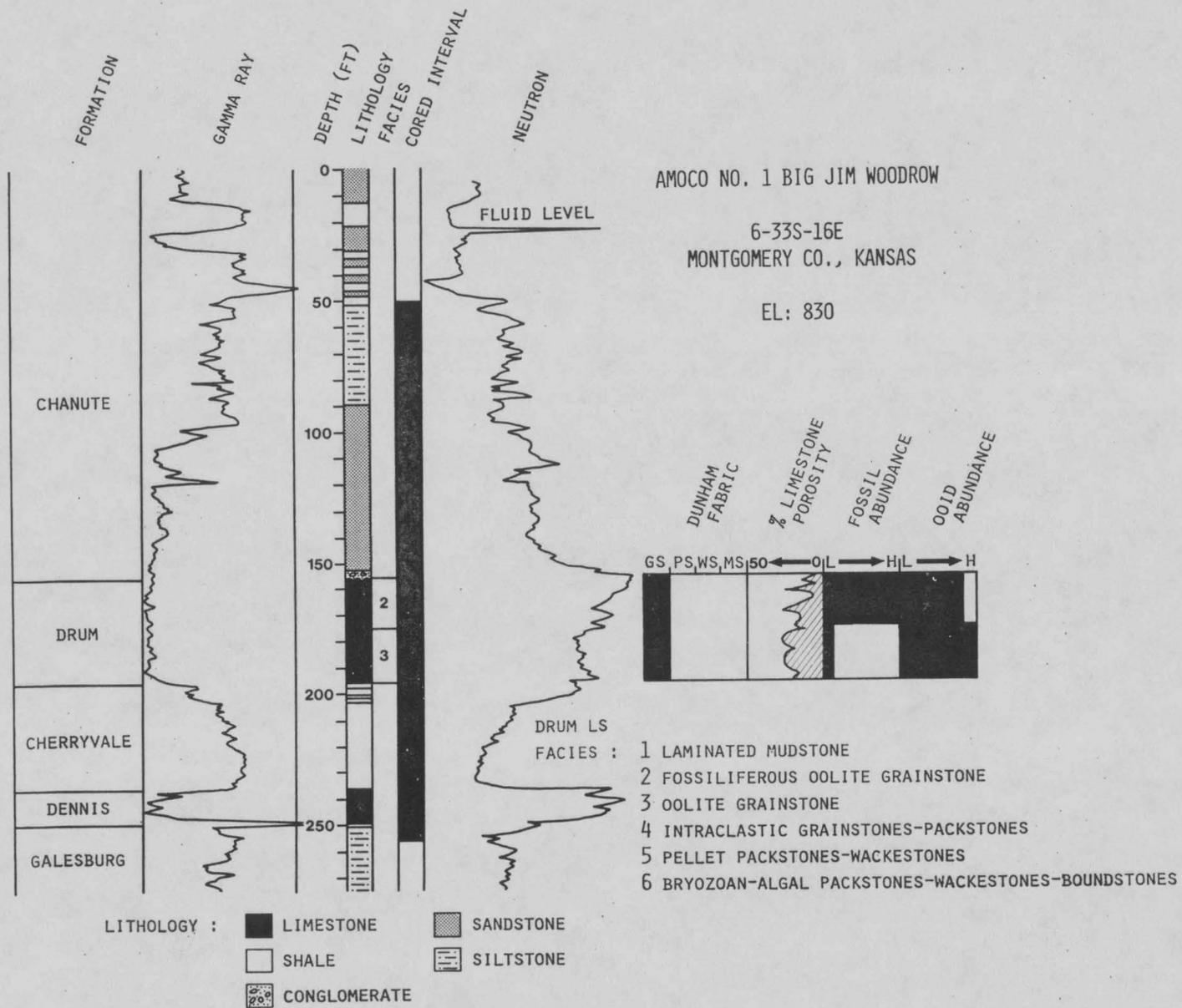
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APPENDIX A

GENERALIZED LOGS OF AMOCO PRODUCTION

COMPANY CORES

AMOCO NO. 1 MOUSE CREEK
28-32S-16E
MONTGOMERY CO., KANSAS
EL: 758

DRUM LS
FACIES : 1 LAMINATED MUDSTONE
          2 FOSSILIFEROUS OOLITE GRAINSTONE
          3 OOLITE GRAINSTONE
          4 INTRACLASTIC GRAINSTONES-PACKSTONES
          5 PELLET PACKSTONES-WACKESTONES
          6 BRYOZOAN-ALGAL PACKSTONES-WACKESTONES-BOUNDSTONES

LITHOLOGY : ■ LIMESTONE   ▨ SANDSTONE
             □ SHALE   ▦ SILTSTONE

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FORMATION GAMMA RAY DEPTH (FT) LITHOLOGY FACIES CORED INTERVAL NEUTRON

0

FLUID LEVEL

AMOCO NO. 1 BIG JIM WOODROW

6-33S-16E
MONTGOMERY CO., KANSAS

EL: 830

50

CHANUTE

100

DUNHAM FABRIC   % LIMESTONE POROSITY   FOSSIL ABUNDANCE   OOID ABUNDANCE

150

GS PS WS MS 50 ← 0 L ← → H L ← → H

DRUM

2

3

200

CHERRYVALE

DRUM LS
FACIES :

1 LAMINATED MUDSTONE
2 FOSSILIFEROUS OOLITE GRAINSTONE
3 OOLITE GRAINSTONE
4 INTRACLASTIC GRAINSTONES-PACKSTONES
5 PELLET PACKSTONES-WACKESTONES
6 BRYOZOAN-ALGAL PACKSTONES-WACKESTONES-BOUNDSTONES

DENNIS

250

GALESBURG

LITHOLOGY : ■ LIMESTONE   ▦ SANDSTONE
□ SHALE   ▤ SILTSTONE
▨ CONGLOMERATE

AMOCO NO. 1 SLOOP
17-33S-16E
MONTGOMERY CO., KANSAS
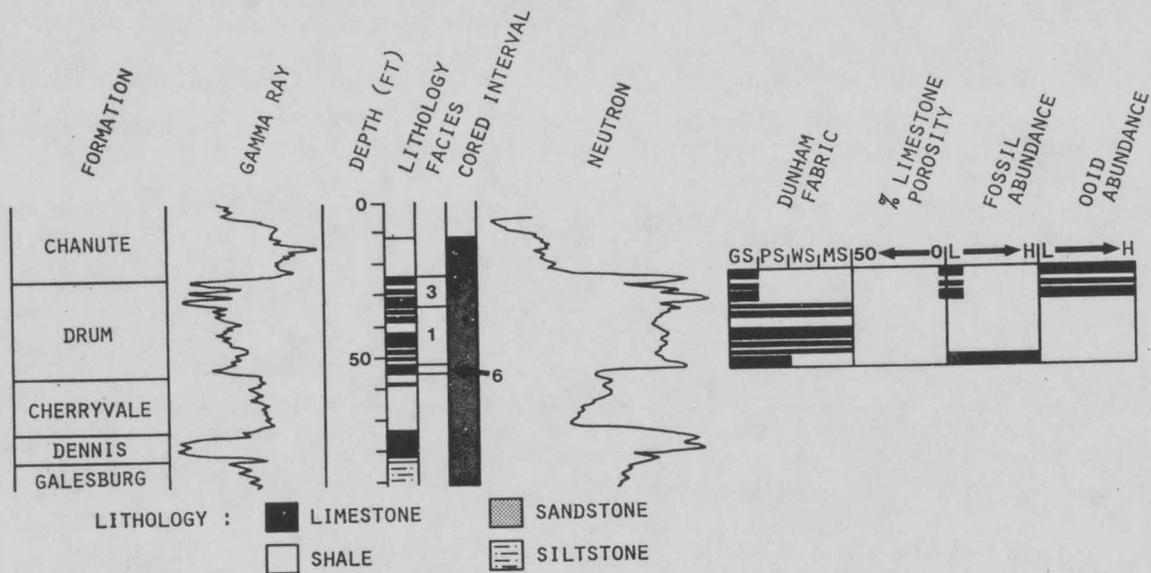
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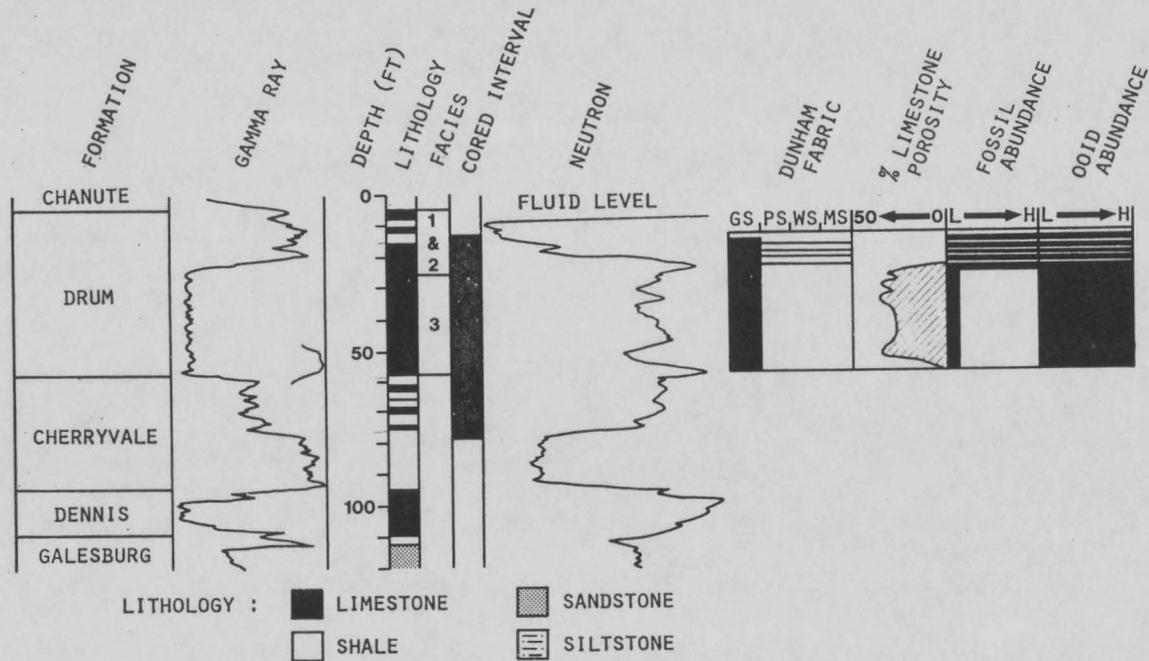

LITHOLOGY : ■ LIMESTONE   ▦ SANDSTONE
             □ SHALE   ▤ SILTSTONE

DRUM LS
FACIES : 1 LAMINATED MUDSTONE
          2 FOSSILIFEROUS OOLITE GRAINSTONE
          3 OOLITE GRAINSTONE
          4 INTRACLASTIC GRAINSTONES-PACKSTONES
          5 PELLET PACKSTONES-WACKESTONES
          6 BRYOZOAN-ALGAL PACKSTONES-WACKESTONES-BOUNDSTONES

AMOCO NO. 1 BRIEDLEMAN
33-32S-16E
MONTGOMERY CO., KANSAS
EL: 780

LITHOLOGY :   ■ LIMESTONE   ▒ SANDSTONE
              □ SHALE   ▤ SILTSTONE

DRUM LS

FACIES : 1 LAMINATED MUDSTONE
          2 FOSSILIFEROUS OOLITE GRAINSTONE
          3 OOLITE GRAINSTONE
          4 INTRACLASTIC GRAINSTONES-PACKSTONES
          5 PELLET PACKSTONES-WACKESTONES
          6 BRYOZOAN-ALGAL PACKSTONES-WACKESTONES-BOUNDSTONES