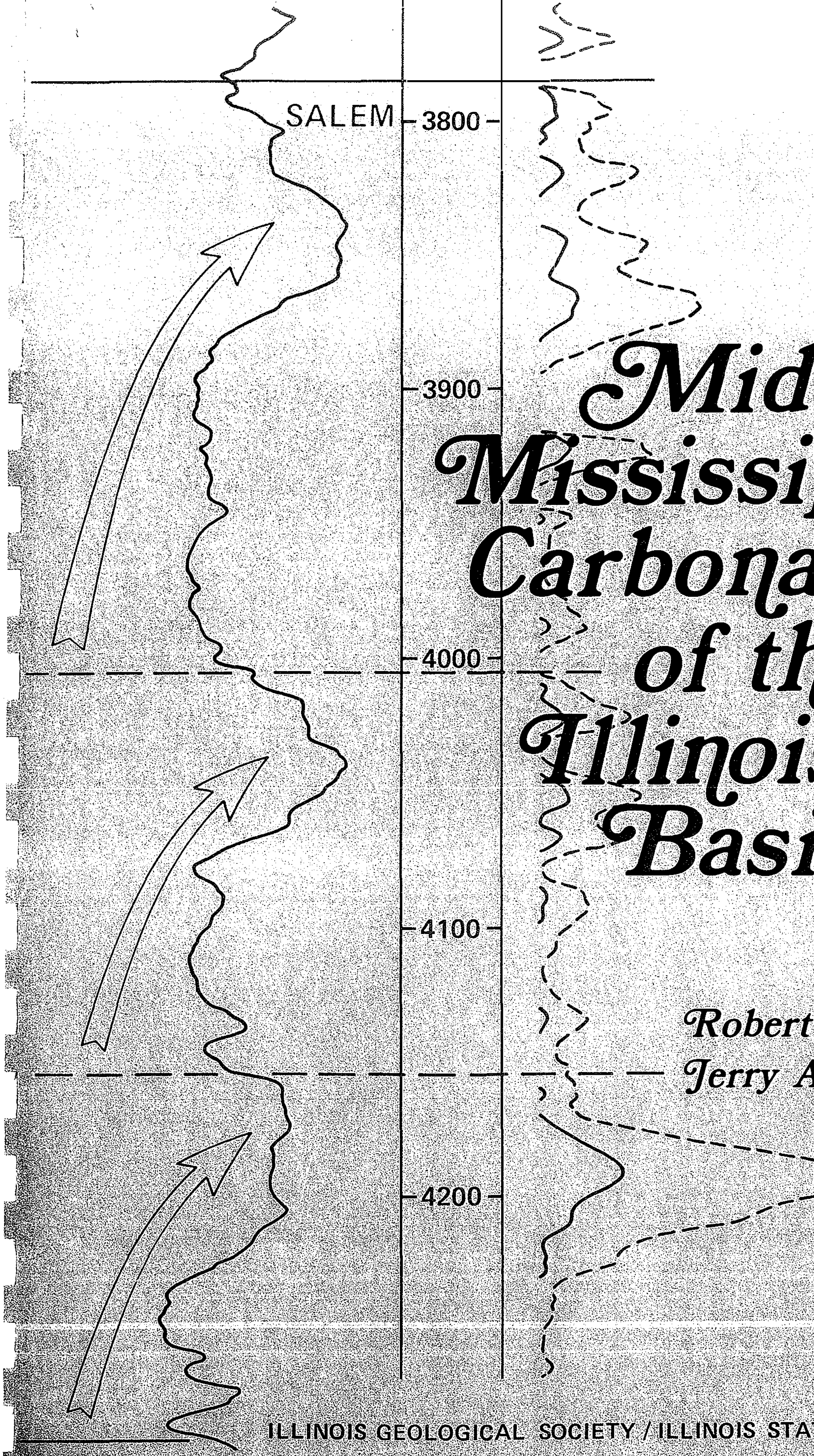

Middle Mississippian Carbonates of the Illinois Basin

Robert M. Cluff
Jerry A. Lineback

ILLINOIS GEOLOGICAL SOCIETY / ILLINOIS STATE GEOLOGICAL SURVEY

MIDDLE MISSISSIPPIAN CARBONATES OF THE ILLINOIS BASIN:

a seminar and core workshop

April 23rd and 24th, 1981

Mt. Vernon, Illinois

Co-sponsored by the Illinois Geological Society
and the Illinois State Geological Survey

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MIDDLE MISSISSIPPIAN CARBONATES OF THE ILLINOIS BASIN

Robert M. Cluff

INTRODUCTION

About 20 percent of the oil and gas reserves of the Illinois Basin are trapped within Valmeyeran (middle Mississippian) carbonate rocks. From the mid-1930s until the early-1970s the prolific "Ohara" and "McClosky" pays in the Ste. Genevieve Limestone were considered the effective floor for significant oil accumulations within the central area of the Illinois Basin, and only a few venturesome wildcatters risked tests to deeper stratigraphic horizons. In 1972, however, the increased price of crude oil and several encouraging new discoveries in the Salem Limestone of Illinois triggered a round of deeper exploratory drilling to the Salem and Ullin ("Warsaw") Limestones that has continued to the present day. The discovery of commercial oil accumulations in fractured reservoirs in White County, Illinois, also spurred a brief period of deep Ft. Payne drilling during the late 1970s. Drilling to objectives within the Valmeyeran carbonates will probably continue to dominate Illinois Basin exploration activity for the foreseeable future. As the remaining anticlinal prospects are rapidly drilled and tested, the emphasis of this activity will, by necessity, shift to more elusive stratigraphic traps.

The purpose of this seminar and core workshop is to review the major characteristics of Valmeyeran carbonate rocks in the Illinois Basin. Major emphasis of this workshop will be on recognition and interpretation of carbonate facies in their depositional context—relating what is seen in these ancient sediments to our knowledge of modern carbonate environments. Explorationists may be disappointed to learn that carbonate environments are so complex and laterally variable that it is rarely possible to pinpoint where traps might occur, although favorable trends can usually be outlined with considerable confidence. On the bright side, both exploration and development geologists will find that an understanding of carbonate sediments and deposition greatly helps the development of fields once they have been discovered. Dry holes also take on new meaning when evaluated in the light of carbonate depositional models—not every unsuccessful test indicates that the limits of a reservoir have been reached.

WORKSHOP FORMAT

This workshop consists of four parts, each of which includes a short lecture (35-40 minutes) followed by a longer laboratory session (1-1½ hours). The laboratory sessions will focus on examination of polished cores and comparison of cores to well cuttings and geophysical logs. Acetate peels and thin sections will be available for many of the cores used in this workshop, although these are not the major emphasis of the laboratory sessions.

The first session will consist of two distinct parts. The lecture will be a brief overview of carbonate deposition in modern shelf environments that are similar to what the Illinois Basin must have been like during the Valmeyeran. The laboratory session will cover the basics of carbonate classifications and will review the key aspects of texture and composition necessary for description and interpretation. This laboratory session also affords an opportunity to view most of the important carbonate facies present in the Valmeyeran of the Illinois Basin, without concern for stratigraphic position or age. Selected samples of recent carbonate sediments will be available for comparison to their ancient, lithified counterparts. Special sections on description and classification of porosity and on anhydrite classification are also included.

The second session will cover early Valmeyeran deposition in the Illinois Basin, including the major carbonate sequences (the Burlington-Keokuk bank and Ullin-Ft. Payne Formations), and the intervening clastic episode represented by the Borden Siltstone delta. Cores through these rocks are few and far between because of the scarcity of significant oil and gas reservoirs in the lower Valmeyeran. Oil and gas exploration in the lower Valmeyeran section will no doubt continue, and significant new pools are likely to be found. The Ullin-Ft. Payne sequence is probably the least understood portion of the Mississippian in the Illinois Basin; the interpretations presented in this workshop book are a major departure from previous thinking.

The third session covers late Valmeyeran deposition in the basin—the Salem, St. Louis, and Ste. Genevieve Limestones. These shallow water carbonates contain numerous, prolific oil and gas reservoirs, and cores are available from many fields across the Illinois Basin. Most of the near-future exploration in the Illinois Basin will probably focus on this sequence of carbonates in which large, stratigraphically entrapped petroleum accumulations are most likely to be discovered. The transition from Valmeyeran carbonate deposition to predominantly clastic deposition in the Chesterian will also be examined—with a few examples of the enigmatic Aux Vases and Spar Mountain Sandstones.

Finally, the fourth session will cover logging and evaluation of carbonate reservoirs, using case studies and examples from the Illinois Basin. The materials for this session will be provided separately by Schlumberger Well Services and are not included in this workbook.

These workshop notes are intended to serve as a short summary of the recent literature and of concepts of Valmeyeran carbonate deposition in the Illinois Basin. Perhaps most useful for future reference will be the many core photographs and photomicrographs of common Valmeyeran facies. For most of the cores on display we will provide brief core descriptions and geophysical logs to facilitate comparison of log characteristics in wells throughout the basin with the facies described in this workbook.

Although this workshop has been arranged along stratigraphic lines, this is only to present the material in a logical sequence, following the evolution of the Illinois Basin throughout Valmeyeran time. This is not a workshop on stratigraphy, and little attention will be paid to resolving the many problems in tracing and defining the bounds of various stratigraphic units. The petroleum geologist must recognize that the Mississippian stratigraphy of the Illinois Basin has been superimposed on a complex succession of laterally and vertically gradational facies. Many of these facies occur throughout the Valmeyeran section with minor variation, whereas others are fairly distinctive and unique to certain stratigraphic intervals. It is only with an appreciation for the diversity of facies and the depositional environments they represent that the geologist can consistently apply and use the formal stratigraphic nomenclature.

SUGGESTED GENERAL REFERENCES ON CARBONATE SEDIMENTOLOGY

The following references are a selection of some of the most useful and readily available books on carbonate sedimentology that are especially useful for petroleum explorationists. Many additional references are cited throughout this workshop book and in the general texts listed below.

General texts

Bathurst, R.G.C., 1975, Carbonate sediments and their diagenesis: Elsevier Scientific Publishing, Amsterdam, 2nd edition, 658 p.

This is an excellent general reference on carbonate sediments and is currently used as a textbook in most graduate level courses in carbonate sedimentology. The focus is on modern sediments—their physical properties, origin, diagenesis, and geochemistry. Bathurst is "heavy reading" for most geologists—but a lot of good information is packed between the covers.

Wilson, J. L., 1975, Carbonate facies in geologic history: Springer-Verlag, New York, 471 p.

The book is another excellent reference on carbonate sedimentology, using an approach entirely different from Bathurst. Wilson focuses on ancient carbonates and their changes through geologic history. Many subsurface and oil field examples are used throughout the book. Most petroleum geologists will find this book easier reading and more understandable than Bathurst; however, if you aren't familiar with modern carbonates, you may miss a lot of "between the lines" information. We consider the two books to be complementary.

Classification

Ham, W. E. (editor), 1962, Classification of carbonate rocks, a symposium: American Association of Petroleum Geologists Memoir 1, 279 p.

Without a doubt the standard reference work on classification of carbonates. Contains the key papers on the most widely applied classification systems, as well as several good papers using more specialized classifications. The article by Powers on Arabian reservoirs is interesting to compare to the Ste. Genevieve and Salem reservoirs of the Illinois Basin.

Carbonate Rocks I: Classifications-Dolomite-Dolomitization: American Association of Petroleum Geologists Reprint Series 4, 237 p.

Includes three papers on classification; one is a useful comparison of grain size classifications and another is the original (1959) version of Folk's classification.

Petrography and description of carbonates

Scholle, P. A., 1978, A color illustrated guide to carbonate rock constituents, textures, cements, and porosities: American Association of Petroleum Geologists Memoir 27, 241 p.

A beautiful color picture book of carbonate rocks in thin section and a few scanning electron microscope photos. A remarkably low price makes this an exceptional buy—but only if you work with thin sections infrequently. For those who never look at one and those who use thin sections constantly, this book will rarely be opened.

Johnson, J. H., 1971, revised edition, An introduction to the study of organic limestones: Quarterly of the Colorado School of Mines, v. 66, no. 2, 185 p.

An inexpensive and useful reference for identification of fossils in carbonates; especially using thin sections. Again most useful for the infrequent petrographer. Many books on calcareous algae have been published by the same author through the School of Mines.

Collections of papers on carbonate sedimentology

Friedman, G. M. (editor), 1969, Depositional environments in carbonate rocks: SEPM Special Publ. 14, 209 p.

A collection of 11 papers heavily biased towards the Pennsylvanian and Permian of West Texas and vicinity. Three papers focus on "deep-water" limestones and provide an interesting comparison to lower Valmeyeran rocks of the Illinois Basin.

Cook, H. E., and Enos, P. (editors), 1977, Deep-water carbonate environments: SEPM Special Publ. 25, 336 p.

Another collection of papers focusing on the deep-water environment and basin-shelf facies transitions. Also useful for comparison to the Illinois Basin, although none of the papers cover this area.

Jordan, C. (editor), 1978, Sedimentary processes: carbonate sedimentology: SEPM Reprint Series 5, 235 p.

An excellent collection of papers on modern carbonate sediments in Florida, the Bahamas, the Persian Gulf, and other areas. A great companion to Bathurst's book.

Collections of papers on dolomites and diagenesis

Carbonate Rocks I: Classifications-dolomite-dolomitization: AAPG Reprint Series 4, 237 p.

Ten papers on dolomites and dolomitization are included in this volume, covering a wide range of ages and probable origins. Most of these are older references and are most useful for the detailed descriptions of dolomites and their stratigraphic distribution, rather than offering insights to their origin.

Pray, L. C., and Murray, R. C., 1965, Dolomitization and limestone diagenesis, a symposium: SEPM Special Publication 13, 180 p.

Another collection covering both dolomitization (mostly of modern sediments) and recrystallization of limestones.

Porosity and petroleum reservoirs

Carbonate Rocks II: Porosity and classification of reservoir rocks: AAPG Reprint Series 5, 197 p.

Several papers on development of porosity in carbonates, characteristics of porosity, and classification of porosity. A useful collection for the petroleum geologist. Includes Choquette and Pray's (1970) article on porosity classification.

Stratigraphic traps in carbonate rocks: AAPG Reprint Series 23, 217 p.

Ten papers on stratigraphic traps in carbonate rocks; emphasis is on reefs and other buildups. The papers on Jay Field (a Smackover trap) and Zelten Field (Libya) are more relevant to shelf-type carbonates like the Mississippian of the Illinois Basin.

CLASSIFICATION AND DESCRIPTION OF CARBONATE ROCKS

Robert M. Cluff

INTRODUCTION

Basic to any detailed discussion of carbonate rocks is an understanding of common carbonate textures and classification schemes. The first portion of this workshop is therefore devoted to a review of carbonate classifications and stresses the key aspects of texture and composition that the geologist should pay close attention to when describing carbonates in the field or on a well site.

Of the many classifications proposed for carbonates through the years, only three have gained widespread acceptance and usage. These are Grabau's classification by mean grain size; Folk's classification by grain and matrix composition; and Dunham's classification by depositional texture. Each of these classifications differs in philosophy and emphasis, and each has unique advantages depending on the interest and needs of the user. In the literature on Valmeyeran carbonates of the Illinois Basin the Grabau and Dunham classifications have been the most widely used; however, the Folk classification is certainly applicable to these rocks.

Each of these three carbonate classifications will be reviewed in the following paragraphs. In addition to these general classification schemes, specialized classifications are very useful for describing certain specific textural features of carbonate rocks. The most widely used classifications for porosity and for anhydrite textures will also be reviewed, as these are especially pertinent to Mississippian reservoirs in the Illinois Basin. The following discussions are not comprehensive, but emphasize the major points, advantages, and disadvantages of each classification scheme. For further information the reader should consult the outstanding "Classification of Carbonate Rocks" symposium volume, published by the American Association of Petroleum Geologists as Memoir 1 (1962). Several other useful papers on classification have been reprinted in AAPG Reprint Series numbers 4 and 5.

GRABAU CLASSIFICATION

The well-known terms calcilutite, calcarenite, and calcirudite were introduced early in the history of carbonate geology by A. W. Grabau (1904, 1913) and have withstood the test of time by persisting in usage to the present day. Grabau's simple subdivisions were intended to be directly parallel with the major categories of clastic rocks: rudaceous for rocks with an average grain size >2mm; arenaceous for rocks with an average grain size from 2 - 0.062 mm; and lutaceous for all finer sizes. In subsequent years Grabau's classification has been modified and further subdivided using the Wentworth grade scale (fig. 1), but the basic concept has remained unaltered. Folk (1959) recognized the importance of separating the grain size scale for transported

		Carbonate Terminology	
size (mm)	*Clastic terminology* (Wentworth, 1922)	Transported Constituents (Folk, 1959)	Authigenic Constituents (Folk, 1959)
	cobbles	v. coarse calcirudite	extremely coarsely crystalline
64......	pebbles	coarse calcirudite	
16		medium calcirudite	
4......	granules	fine calcirudite	very coarsely crystalline
2......	v. coarse sand		
1......	coarse sand	coarse calcarenite	coarsely crystalline
0.5....	medium sand	medium calcarenite	
0.25...	fine sand	fine calcarenite	medium crystalline
0.125..	v. fine sand	v. fine calcarenite	
0.062..	silt	coarse calcilutite (or calcisiltite)	finely crystalline
0.031..	clay	medium calcilutite	
0.016..		fine calcilutite	very finely crystalline
0.008..		v. fine calcilutite	
0.004..			aphano crystalline

Figure 1. Grain size classifications for terrigenous clastic and carbonate rocks.

constituents (e.g., oolites, fossils, pellets) from authigenic constituents (e.g., crystalline cements); therefore he proposed a parallel size classification scheme for the authigenic components (fig. 1).

When naming a rock type using the Grabau system, modifers are used to further subdivide and refine the grain size root term (e.g., fine calcarenite, medium calcilutite), to denote dominant constituents (e.g., oolitic calcarenite, algal calcilutite), or to convey mineralogical variations (e.g., dolomitic calcarenite, calcareous dololutite). The possible combinations are extremely diverse and are limited only by length—too many modifers will result in rock names that are cumbersome and awkward. The major strength of this classification scheme and the main reason for its continued popularity is this ability to construct easily visualized and highly descriptive rock terms.

The major weakness of the Grabau system is the interpretation of the significance of average grain size in carbonate rocks. Grain size classification is most useful for carbonate rocks which were deposited in a similar manner to clastic rocks—that is, for limestones largely composed of transported debris. In these depositional settings the average grain size of the transported constituents can be related to duration of transport and mean energy of the environment, much as grain size in sandstones and siltstones is interpreted. Unfortunately, the vast majority of carbonate rocks do not originate in this manner. Most carbonates are distinctively local in origin—the fossils, pellets, and lime mud that compose the rock were formed in the immediate vicinity of the depositional site. In this case, average grain size is more a function of biological processes, especially the size of skeletal particles contributed to the sediment by organisms, rather than physical processes. Even the processes that act to break down carbonate grains into fine mud are mostly biological—including boring by microorganisms (algae, sponges), mastication and ingestion by sediment feeders, decay of binding organic matter, etc. (Matthews, 1966).

Interpretation of grain size is least ambiguous for those rocks in which the dominant grains have obviously been transported, sorted, and abraded. Cross-bedded oolitic calcarenites are an outstanding example; many of the non-oolitic skeletal sands in the Ste. Genevieve, Salem, and Ullin Limestones also fall into this category. Even when the interpretation of average grain size is in doubt, however, this classification is still of great use for purely descriptive distinctions among rock types.

FOLK'S CLASSIFICATION

R. L. Folk's classification scheme is one of the first and most successful attempts at erecting a classification especially suited for carbonate rocks. This classification was first published in 1959 and was later modified in 1962 in the Classification of Carbonate Rocks symposium (Folk, 1959, 1962). The emphasis of his classification is on clastic-textured limestones, as is the Grabau classification, and establishes only broad categories for reef rocks, dolomites, and other nonclastic types.

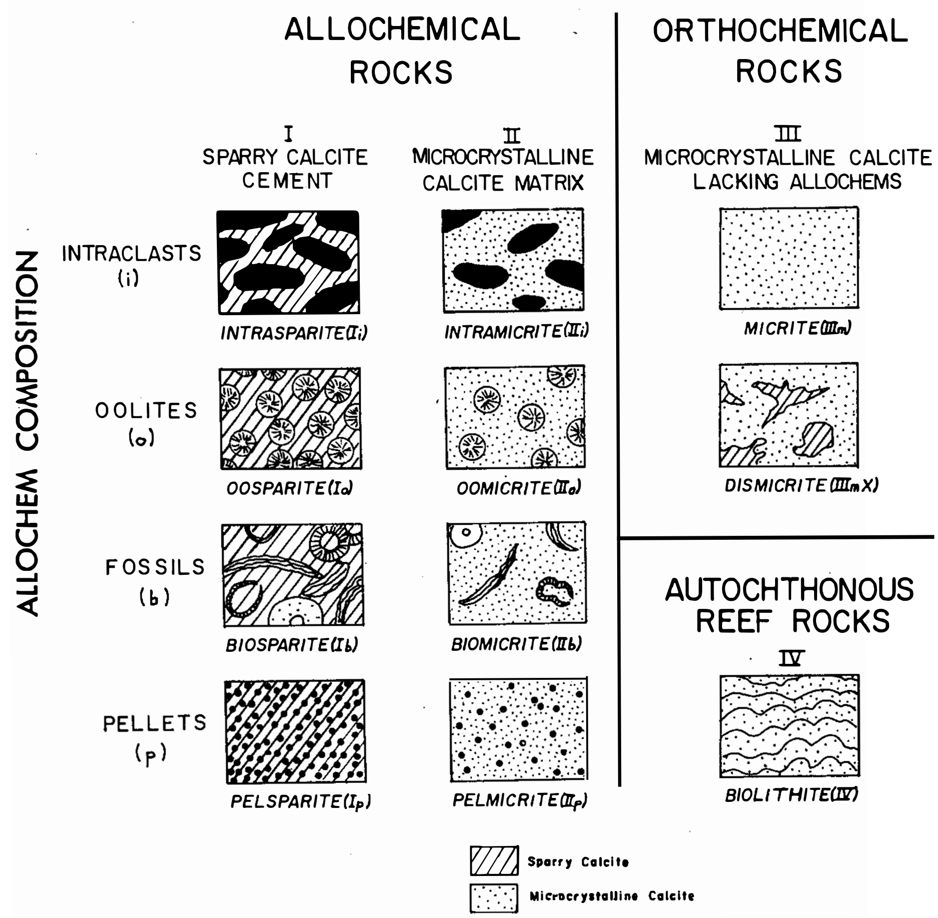


Figure 2. Folk's (1962) classification of carbonate rocks. (Reprinted with permission of the American Association of Petroleum Geologists.)

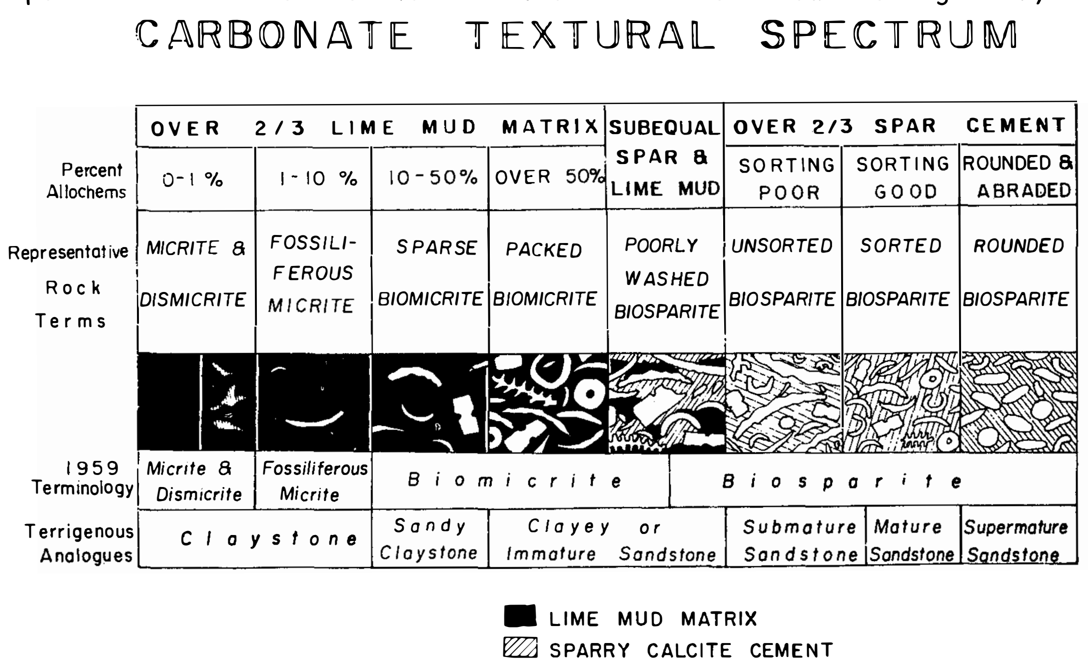


Figure 3. Folk's (1962) classification with subdivisions based on carbonate textures. (Reprinted with permission of the American Association of Petroleum Geologists.)

Folk's major subdivisions are based on the relative proportions of three major rock elements: allochems (including intraclasts, oolites, fossils, and pellets), micrite, and sparry cement (fig. 2). Folk considers allochems as analogous to the sand or gravel grains in terrigenous clastic rocks, micrite as analogous to clay matrix in sandstones, and sparry calcite as analogous to the various pore-filling cements precipitated in sandstones. In the 1962 revision of his classification Folk refined his major classes by using three criteria: (1) the relative proportion of lime mud vs. sparry cement in the matrix; (2) the amount of allochems (in percent) in mud-rich rocks; and (3) the degree of sorting and rounding of allochems in mud-lean rocks (fig. 3). Although these refinements were largely in answer to the challenge posed by Dunham's classification of carbonate rocks (discussed next), Folk's classification still treated carbonates in a manner parallel to common sandstone classifications; he does not emphasize the unique attributes of carbonate textures. The important relationship between grains and their matrix, which is the basis of Dunham's scheme, is not conveyed by Folk's classification.

Nonetheless, Folk's terms do convey considerable information on the composition of carbonate rocks. Because his subdivisions are semiquantitative, each rock name incorporates the actual proportions of various components in the rock. Appropriate modifers can be used to specify grain size, major and minor components, mineralogy, etc. (e.g., crinoidal biosparite; medium grained oolitic biosparite; dolomitic pelmicrite). Folk's terms also can become long and awkward if several modifiers are used, so discretion is well advised. Because Folk's classification has not been as widely used in the geological literature as Dunham's, many geologists are less familiar with Folk's classes and do not find them as easy to visualize.

DUNHAM'S CLASSIFICATION

In 1962 R. J. Dunham published a simple classification of carbonate rocks based on their depositional texture (Dunham, 1962). This classification was not intended to substitute for other classifications based on mineralogy and kinds of components, but rather as an adjunct used to focus attention on certain key aspects of carbonate texture. In practice, however, Dunham's classification has enjoyed extremely wide popularity and has often been used to the exclusion of other classifications. Most writers have opted toward using appropriate modifiers to specify the mineralogy, grain size, proportions, and types of components preceeding a Dunham rock term. Few papers use a dual classification scheme (e.g., both Dunham and Folk terms).

The major emphasis of Dunham's classification is the relationship between grains and matrix. Dunham noted that it is difficult to make a meaningful distinction between sediment deposited in quiet water and sediment deposited in agitated water. Classifications that emphasize average or maximum grain size as a hydraulic indicator erroneously assume that grain size is solely governed by current energy and that all types of particles are equally significant hydraulically. This emphasis on "currents of delivery," as Dunham called them, may be appropriate for terrigenous clastic rocks but is clearly inappropriate for carbonates. Many of the large grains in carbonates are

TABLE I. CLASSIFICATION OF CARBONATE ROCKS ACCORDING TO DEPOSITIONAL TEXTURE

DEPOSITIONAL TEXTURE RECOGNIZABLE					DEPOSITIONAL TEXTURE NOT RECOGNIZABLE
Original Components Not Bound Together During Deposition				Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.	
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain-supported		
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains				(Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	Crystalline Carbonate

Figure 4. Dunham's (1962) classification of carbonate rocks based on depositional textures. (Reprinted with permission of the American Association of Petroleum Geologists.)

locally derived (for example, large fossil fragments) and much of the fine material owes its size to factors other than transport and abrasion (for example, the natural small size of microfossils; size reduction by bio-erosion; etc.). Dunham circumvented this problem by focusing attention on "currents of removal"; that is, how effectively was lime mud and other fine material winnowed out of the sediment at the site of deposition. The most fundamental division in Dunham's classification is therefore between mud-free carbonates (grainstones) and muddy carbonates (mudstones, wackestones, and packstones) (fig. 4).

Dunham further subdivided muddy carbonates on the basis of the proportion of grains (or allochems) in the rock, which introduced the important distinction between grain-supported and mud-supported textures. In sediments where allochems are the predominant constituent the grains form a self-supporting framework; that is, if all of the interstitial material were removed the rock fabric would still retain its integrity. Mud-free carbonates (grainstones) are of course grain-supported. Grain-supported rocks containing minor amounts of mud are termed packstones (fig. 4). Muddy carbonates that contain a prominent proportion (>10%) of allochems, but are matrix-supported rather than grain-supported, are termed wackestones by Dunham. If less than 10% of the rock volume is composed of grains, the rock is termed a mudstone (fig. 4). Note that the essential subdivision is made by the textural relationship between grains and matrix—not the absolute percentages of each. Grains that are very large and irregular shaped—such as platy algae or bryozoan fronds—might form a grain-supported texture even when they make up only a minor portion of the total rock volume. Grains that are very regular in shape, such as oolites, will generally compose 50 to 60 percent of the volume in a grain-supported rock.

Dunham set aside separate classes for organically bound sediments: boundstones, mostly consisting of various reef facies; and for rocks that have been so thoroughly recrystallized that no depositional texture remains, crystalline carbonate, including many dolomites. Embry and Klovan (1971) found Dunham's classification was inadequate to subdivide the full range of textures observable in reef sediments and proposed a modification of his scheme to deal with these rocks (fig. 5). They also established new categories for the very coarse-grained carbonate conglomerates that are common in the vicinity of reefs, but also form in other carbonate environments. These refinements of Dunham's classification do not have wide application to the Mississippian carbonates of the Illinois Basin, but one should become familiar with the terms as they often appear in the carbonate literature.

Dunham's classification is very easy to learn and apply, partly accounting for its popularity. Most of the literature on Mississippian carbonates of the Illinois Basin uses the classification systems of Dunham and Grabau. Dunham's system is the classification we have found most useful and practical for studies of Illinois reservoirs. Because the various types of grains present are not relevant to the classification, modifiers must be used in a descriptive rock name (e.g., oolitic grainstone; coarse crinoidal wackestone; pelletal—foraminiferal packstone). The major weakness of the

<table>
<tr><td colspan="6">ALLOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS NOT ORGANICALLY BOUND DURING DEPOSITION</td><td colspan="3">AUTOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS ORGANICALLY BOUND DURING DEPOSITION</td></tr>
<tr><td colspan="4">LESS THAN 10% > 2mm COMPONENTS</td><td colspan="2">GREATER THAN 10% > 2mm COMPONENTS</td><td rowspan="4">BY ORGANISMS WHICH ACT AS BAFFLES</td><td rowspan="4">BY ORGANISMS WHICH ENCRUST AND BIND</td><td rowspan="4">BY ORGANISMS WHICH BUILD A RIGID FRAMEWORK</td></tr>
<tr><td colspan="3">CONTAINS LIME MUD (<.03 mm)</td><td>NO LIME MUD</td><td rowspan="3">MATRIX SUPPORTED</td><td rowspan="3">> 2mm COMPONENT SUPPORTED</td></tr>
<tr><td colspan="2">MUD SUPPORTED</td><td colspan="2" rowspan="2">GRAIN SUPPORTED</td></tr>
<tr><td>LESS THAN 10% GRAINS (>.03mm < 2mm)</td><td>GREATER THAN 10% GRAINS</td></tr>
<tr><td>MUD-STONE</td><td>WACKE-STONE</td><td>PACK-STONE</td><td>GRAIN-STONE</td><td>FLOAT-STONE</td><td>RUD-STONE</td><td>BAFFLE-STONE</td><td>BIND-STONE</td><td>FRAME-STONE</td></tr>
</table>

Figure 5. Embry and Klovan's (1971) classification of limestones according to depositional texture, incorporating several modifications and refinements into Dunham's (1962) classification. (Reprinted with permission of the Canadian Society of Petroleum Geologists.)

classification is the difficulty in distinguishing between packstones and wackestones in mud-rich rocks; if the grain shapes are irregular, this problem is especially acute. Only experience can reduce the uncertainty.

POROSITY CLASSIFICATION

Although porosity is one of the most important facets of carbonate rocks to the petroleum geologist, scant attention was given to systematic description of carbonate porosity until very recently. Such informal and ill-defined terms as "pinpoint," "vugular," "chalky," and "sucrosic" are still used to describe porosity, although a far superior but under-utilized nomenclature exists.

In 1970 P. W. Choquette and L. C. Pray published a classification system for carbonate porosity developed at Marathon Oil Company's Denver research lab. The system is simple, easy to learn, and incorporates both descriptive and genetic terms. This classification, illustrated in figure 6, incorporates a basic root term describing the porosity type (e.g., interparticle, fenestral, shelter), preceeded by modifiers to specify the inferred time and process of formation (genetic modifier), and a term to describe the predominant or average pore size. The porosity type, thus described, can be followed by its estimated volume percentage in the rock, or by a ratio term where more than one porosity type is present. Choquette and Pray (1970) illustrated examples of all of the common porosity types encountered in carbonates and included a comprehensive discussion and glossary on porosity. Scholle (1978) also includes a section on carbonate porosity and many fine photographs of the various porosity types.

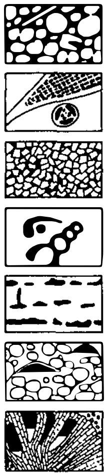
Three types of porosity are common in middle Mississippian carbonate reservoirs of the Illinois Basin. Primary (i.e., formed at the time of deposition) interparticle porosity is by far the most important—being the dominant type found in the oolitic grainstone reservoirs of the Ste. Genevieve (Ohara and McClosky) and Salem Limestones. Intraparticle porosity is volumetrically much less important, but is also found throughout these zones. Both intraparticle and interparticle porosity are typical of the Ullin reservoirs in Illinois.

Secondary (i.e., formed during diagenesis) intercrystalline porosity is the dominant type found in the microcrystalline dolomites of the lower Ste. Genevieve and St. Louis Limestones (Choquette and Steinen, 1980). Porosities of 25 to 40 percent are common in these reservoir rocks and the porosity is very evenly distributed and uniform. Moldic porosity—mostly resulting from dissolution of fossil fragments—is common in many dolomitized limestones, but is volumetrically minor.

Secondary fracture porosity is the only other common porosity type in the Valmeyeran of the Illinois Basin. It is difficult to assess the volumetric contribution of fractures to reservoir porosity, but fracturing is undoubtedly a major factor affecting well life and productivity. At least one recent discovery in Illinois—the Ft. Payne reservoir in New Harmony Consolidated field, White County—can be entirely attributed to fracture porosity. Detailed study of a continuous core through the Ft. Payne in the area revealed no trace of any porosity type other than fractures.

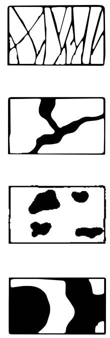
BASIC POROSITY TYPES

FABRIC SELECTIVE



INTERPARTICLE	BP
INTRAPARTICLE	WP
INTERCRYSTAL	BC
MOLDIC	MO
FENESTRAL	FE
SHELTER	SH
GROWTH-FRAMEWORK	GF

NOT FABRIC SELECTIVE



FRACTURE	FR
CHANNEL*	CH
VUG*	VUG
CAVERN*	CV

*Cavern applies to man-sized or larger pores of channel or vug shapes.

FABRIC SELECTIVE OR NOT

BRECCIA	BR
BORING	BO
BURROW	BU
SHRINKAGE	SK

MODIFYING TERMS

GENETIC MODIFIERS

PROCESS		DIRECTION OR STAGE	
SOLUTION	s	ENLARGED	x
CEMENTATION	c	REDUCED	r
INTERNAL SEDIMENT	i	FILLED	f

TIME OF FORMATION

PRIMARY	P
pre-depositional	Pp
depositional	Pd
SECONDARY	S
eogenetic	Se
mesogenetic	Sm
telogenetic	St

Genetic modifiers are combined as follows:

PROCESS + DIRECTION + TIME

EXAMPLES:

solution-enlarged	sx
cement-reduced primary	crP
sediment-filled eogenetic	ifSe

SIZE* MODIFIERS

CLASSES				mm†
				256
MEGAPORE	mg	large	lmg	
				32
		small	smg	
				4
MESOPORE	ms	large	lms	
				1/2
		small	sms	
				1/16
MICROPORE	mc			

Use size prefixes with basic porosity types:

mesovug	msVUG
small mesomold	smsMO
microinterparticle	mcBP

*For regular-shaped pores smaller than cavern size.

†Measures refer to average pore diameter of a single pore or the range in size of a pore assemblage. For tubular pores use average cross-section. For platy pores use width and note shape.

ABUNDANCE MODIFIERS

percent porosity (15%)

or

ratio of porosity types (1:2)

or

ratio and percent (1:2) (15%)

CONSTRUCTION OF POROSITY DESIGNATION

ANY MODIFYING TERMS ARE COMBINED WITH THE BASIC POROSITY TYPE IN SEQUENCE GIVEN BELOW:

GENETIC MODIFIER + SIZE MODIFIER + BASIC POROSITY TYPE + ABUNDANCE

EXAMPLES:

intraparticle porosity, 10 percent	WP(10%)
primary mesointraparticle porosity	P-msWP
solution-enlarged primary intraparticle porosity	sxP-WP
micromoldic porosity, 10 percent	mcMO(10%)
telogenetic cavern porosity	St-CV

Figure 6. Classification of porosity types and format for the construction of porosity names, from Choquette and Pray, 1970. (Reprinted with permission of the American Association of Petroleum Geologists.)

In some places other types of porosity will be seen in cores and samples of Valmeyeran rocks in the Illinois Basin. Vug porosity is common beneath hardgrounds and various types of exposure surfaces in the Ste. Genevieve and Salem Limestones—but as a generalization, far more reservoir porosity has been called "vugular" than actually exists. Fenestral (also known as "birdseye") and shelter porosity is also found in many places, but is volumetrically minor. Growth-framework porosity applies mainly to reefs, which are unknown in the Mississippian of this area. Channel and cavernous porosity may occur, but we know of no documented examples of either.

ANHYDRITE CLASSIFICATION

Anhydrite is the only significant evaporite mineral found in the Valmeyeran of the Illinois Basin. Very small quantities occur throughout the section, but anhydrite is most common in the upper Valmeyeran strata (Salem, St. Louis, Ste. Genevieve). Anhydrite is abundant throughout the St. Louis Limestone, and much of the chert in that formation has textures that suggest it is a replacement of anhydrite.

Because anhydrite is so common, most Illinois Basin geologists will have many opportunities to observe it in cores (only rarely in cuttings, unfortunately). It is therefore useful to review the common forms of anhydrite and their classification. Although many papers and books have been published on evaporites, only one of these presents a systematic and practical classification of anhydrite structures and textures. This paper—by Maiklem, Bebout, and Glaister (1969)—was published in the Bulletin of Canadian Petroleum Geology with the result that it has been overlooked by most U.S. petroleum geologists. The text of their publication is brief as the classification does not require much explanation; most of the remainder of the paper is a photographic atlas of anhydrite structures and textures. It is well worth having a copy for reference.

Their classification is really a dual system. Anhydrite structure is defined as the shape and spatial relationship of anhydrite masses within a rock. They are defined and classified using four parameters (fig. 7):

1) External form — crystal shaped, where the external form of the anhydrite masses are defined by crystal boundaries; or noncrystal shaped, where the masses are irregular.

2) Anhydrite-matrix relationship — the degree of separation of the anhydrite masses by matrix.

3) Bedding — subdivided into bedded vs. nonbedded types; the type of bedding can be further described as wavy, even, curved, parallel or nonparallel, continuous or discontinuous, or any combination of the above.

4) Distortion — most anhydrite structures also have a distorted equivalent; the distortion may be due to gypsum-to-anhydrite conversion, slumping, compaction, solution, etc. Extreme examples are highly distorted or brecciated structures—where the original structural type is unrecognizable.

Anhydrite texture refers to the shape, size, and spatial relationship of individual crystals or flakes within an anhydrite mass. The textures are classified mostly on the basis of size and shape (fig. 8). Anhydrite textures are best described using thin-sections, but careful examination of cores or cuttings under a low-power binocular microscope will suffice.

Our experience with anhydrite in the Valmeyeran of Illinois is limited, but nodular and nodular-mosaic structures are the types we have found most common. Isolated cauliflower-shaped nodules of anhydrite are found throughout the Salem, St. Louis, and Ste. Genevieve Limestones; very small nodules occur sparsely in the Ullin and Ft. Payne. Nodular-mosaic and bedded nodular-mosaic anhydrite occur in the St. Louis Limestone in many cores. Anhydrite is rarely found in outcrops around the basin margins; however, the intraformational breccias common in these areas have long been suspected to be the product of near-surface dissolution of evaporites.

Crystallotopic anhydrite is commonly present in thin sections of Salem grainstones, often replacing oolites and various skeletal grains. These patches of crystalline anhydrite are usually very small and cut across all depositional textures. They may have been formed in the deep subsurface by reaction with saline formation waters.

FIELD DESCRIPTION OF CARBONATES—A CHECKLIST

At some time, you may have wondered what is important when describing a carbonate rock. The amount of detail recorded in any description is, of course, largely dependent on the time available and the importance of the description. Several key observations are necessary to classify and interpret rock types, however, and a few others are of particular interest to the petroleum explorationist. The following checklist of observations is far from comprehensive and has been customized for the Mississippian rocks of the Illinois Basin. Much of this list was distilled from a three-page key given in Wilson (1975).

Basic textural observations

A. Relative amounts of major rock components:

- —skeletal grains
- —nonskeletal carbonate grains
- —mud matrix
- —cement
- —terrigenous clastic material
- —evaporites
- —porosity

B. Bulk fabric of the rock

- —predominant grain size
- —grain-supported vs. mud-supported fabric
- —bedding (horizontal, cross-bedded, massive, etc.)
- —bioturbation

—sorting and rounding
—preservation of grains
—color (general; detail not necessary)
—geopetal structures, fenestrae, stylolites, hardground or erosion surfaces, any other distinctive features

Composition (note abundance and distribution, if not uniform)

A. Skeletal grains

—diversity of organisms
—predominant types
—accessory or minor types
—degree of disarticulation and breakage

B. Nonskeletal grains

—oolites
—superficially coated grains
—peloids and fecal pellets
—intraclasts
—aggregate grains ("grapestone lumps")

C. Matrix

—lime mud
—sparry calcite cement
—isopachous or fibrous rim cements
—microcrystalline dolomite

D. Noncarbonates

—terrigenous silt and sand
—shale interbeds
—clay seams and insoluble residues (as along stylolites)
—anhydrite

Porosity (again note abundance, distribution, and degree of interconnection between pores.)

A. Primary

—interparticle and intraparticle voids
—fenestral porosity
—shelter porosity
—enhancement or reduction by diagenesis

B. Secondary

—intercrystalline porosity (esp. dolomites)
—fractures
—moldic porosity
—vuggy porosity

Illinois State Geological Survey
Oil and Gas Section
CARBONATE ROCK DESCRIPTION

Sample type: cuttings core outcrop Sample number ______________

Well ______________ Sec-T-R ______________ County ______________

Sample depth ______________ Formation ______________ Age ______________

Described by ______________ Date ______________

COMPOSITION

Skeletal grains

—abundant:

—common:

—rare:

Non-skeletal grains

—abundant:

—common:

—rare:

Clastics, evaporites, etc.

Matrix

TEXTURE

Mean grain size ______________

Clasticity ______________

Sorting ______________

Rounding ______________

Fragmentation ______________

Burrowing ______________

Grain contacts ______________

Packing ______________

Porosity ______________

____

____

Cementation ______________

____

____

Sedimentary structures ______________

____

____

Neomorphism ______________

____

____

ROCK CLASSIFICATION: ______________

OVER FOR SPECIAL REMARKS

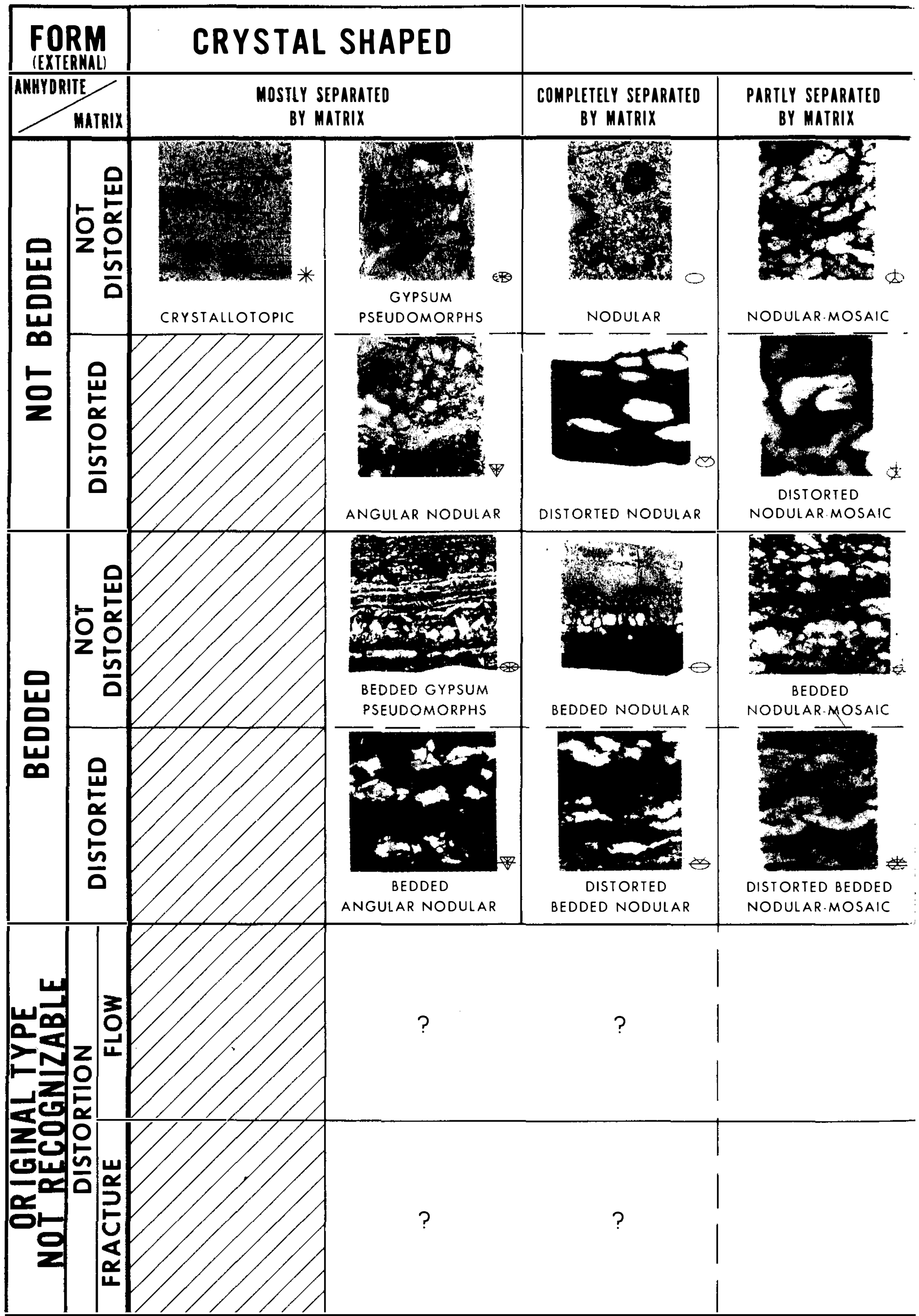
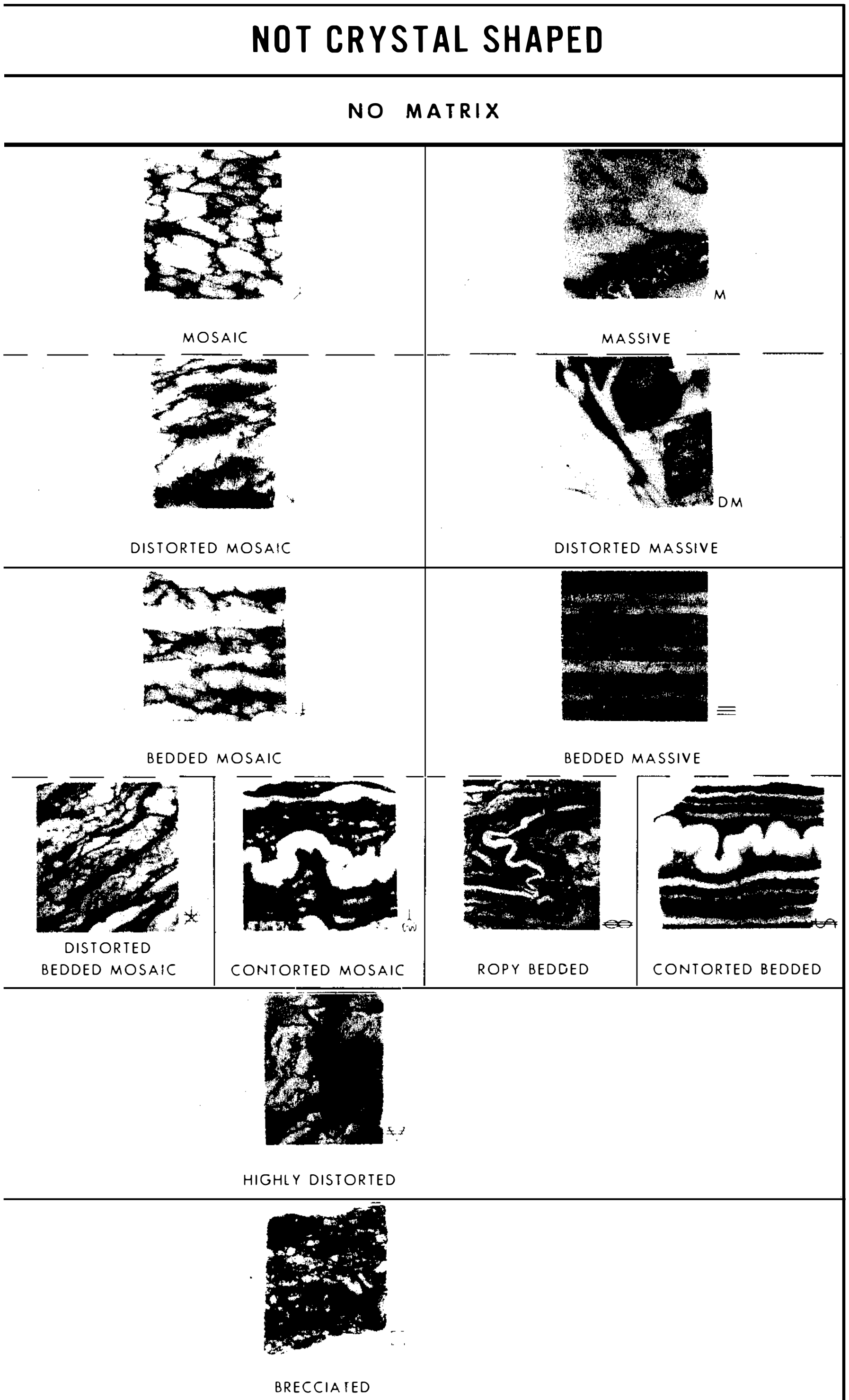


Figure 7. Classification of anhydrite structures (from Maiklem, Bebout, and Petroleum Geologists.)



Glaister, 1969). (Reprinted with permission of the Canadian Society of

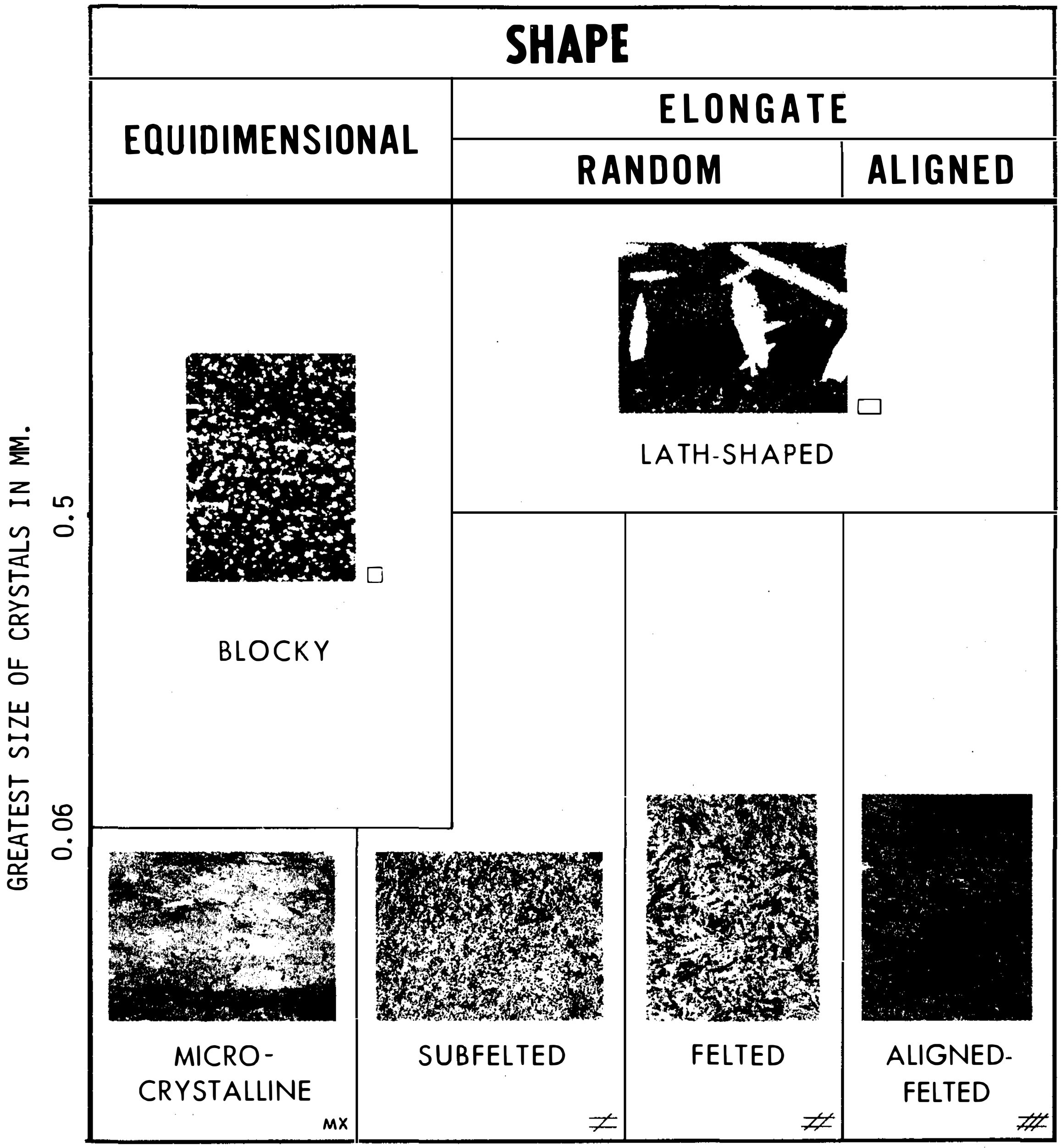


Figure 8. Classification of anhydrite structures (from Maiklem, Bebout, and Glaister, 1969). (Reprinted with permission of the Canadian Society of Petroleum Geologists.)

LOWER VALMEYERAN DEPOSITION

Jerry A. Lineback

VALMEYERAN BASIN STRUCTURE

The structural development of the Illinois Basin played an important part in the distribution of Mississippian sedimentary facies. The main structural elements existing at the beginning of Valmeyeran deposition were similar to the structural elements of the present basin (fig. 9). The basin consists of a western shelf area separated from the structurally deeper part of the basin (Fairfield Basin) by a shelf edge where basinward dips increase. The position of this structurally controlled shelf edge has moved somewhat through time but lay along the eastward pinchout of the Burlington-Keokuk Limestone during early Valmeyeran time. An eastern shelf area lay mostly in Indiana. The eastern shelf is separated from the Fairfield Basin by the La Salle Anticlinal Belt, marked by steep basinward dips along its western side. Thickness maps of several Paleozoic units show that the La Salle Anticlinal Belt, the eastern shelf, and the western shelf underwent relatively less subsidence than did the Fairfield Basin from the Middle Devonian through the Valmeyeran. This differential subsidence had the effect of keeping the Fairfield Basin area below the zone of primary benthic carbonate production during the early Valmeyeran and caused the development of a sediment-starved basin.

EARLY VALMEYERAN FACIES

Four major lithofacies of variable thickness and consisting of eight formations occupy the stratigraphic interval between the Chouteau and Salem Limestones in southern Illinois (fig. 10). These strata are early Valmeyeran (middle Mississippian) in age.

The Crinoidal Carbonate Bank

Red, green, and gray shale and limestone of the Fern Glen Formation and light-colored cherty crinoidal limestone of the Burlington and Keokuk Limestones crop out along the Mississippi River where they are part of the type section of the Mississippian System. Similar strata are present in a region across Kansas and Missouri and into Iowa and Illinois. The cherty limestones abruptly terminate in a sharply defined belt as little as 2 miles wide in the subsurface of central and southwestern Illinois (Lineback, 1966, and, in press) (fig. 11).

The Burlington and Keokuk Limestones are part of a carbonate bank that stood more than 300 feet above the floor of a deep-water sediment-starved basin that lay to the east. The Burlington and Keokuk do not grade laterally into the Borden Siltstone to any great extent except in extreme eastern Illinois. Individual beds in the Burlington and Keokuk thin eastward across a 2 mile wide interval until the entire limestone sequence wedges out between the overlying clastics and the Fern Glen Formation. The Warsaw Shale, which overlies the

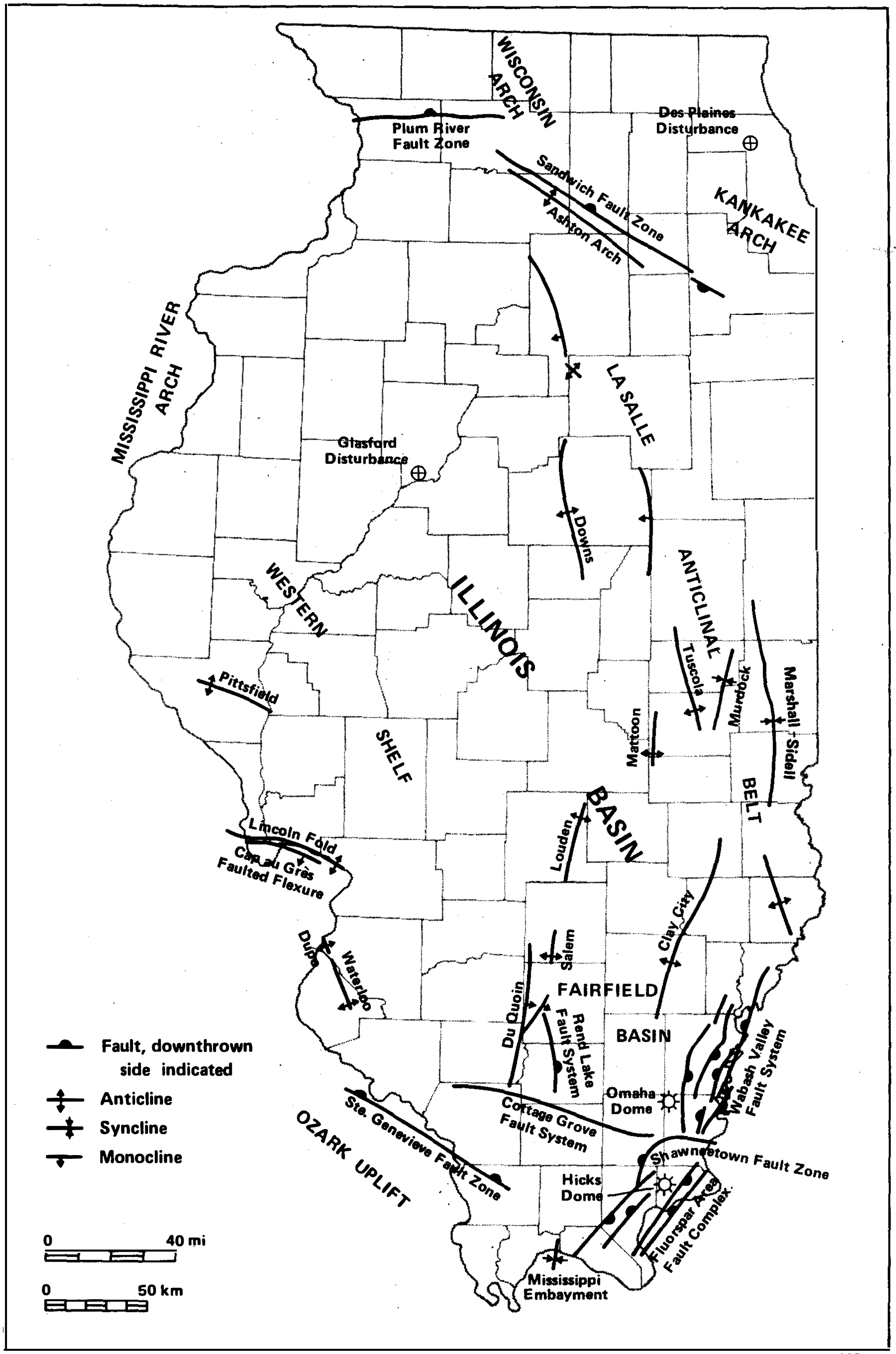


Figure 9. Major geologic structures of Illinois (J.D. Treworgy, 1979).

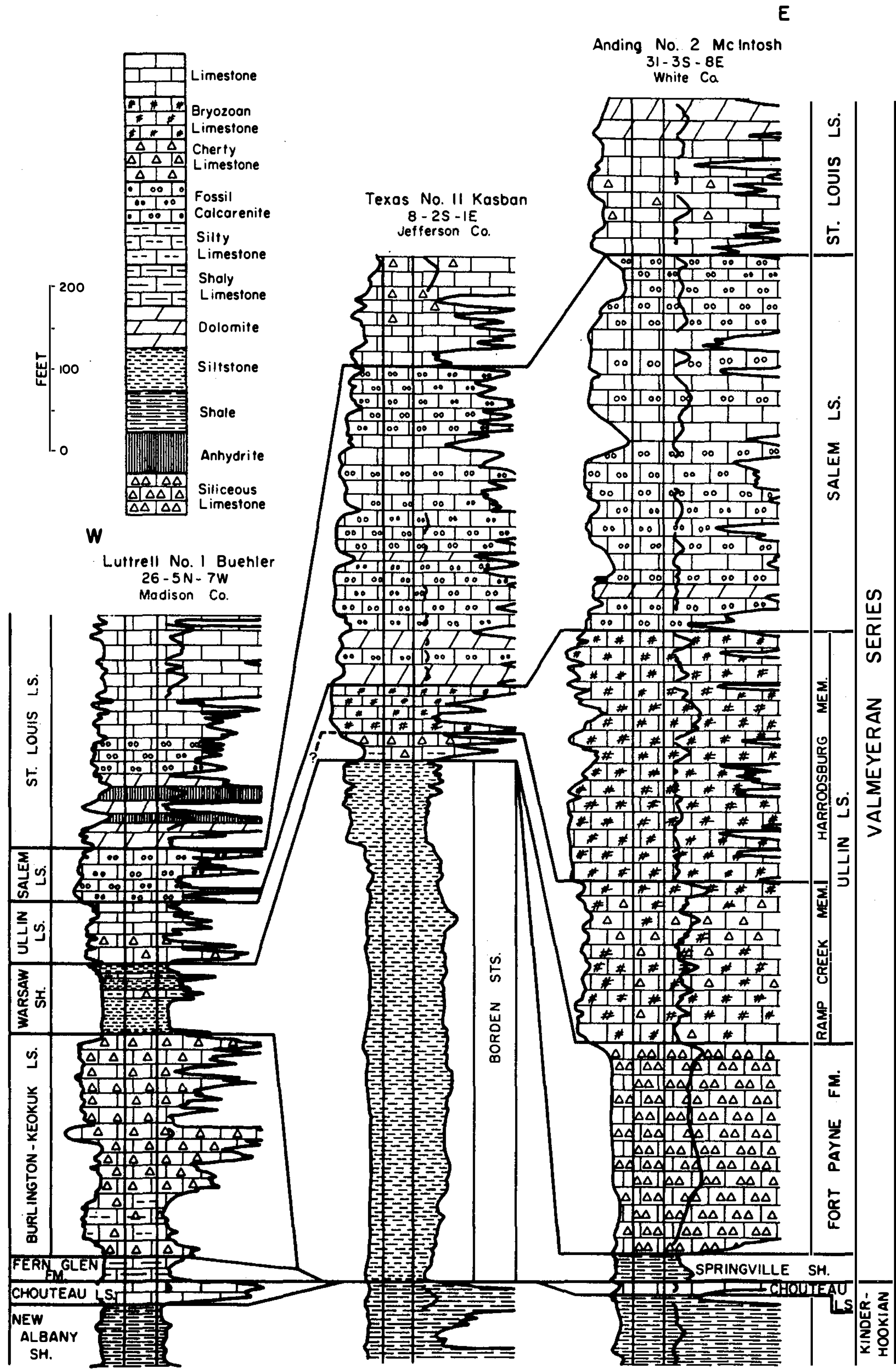


Figure 10. Electric and lithologic logs showing the four major lower Valmeyeran units and stratigraphic nomenclature (from Lineback, 1966).

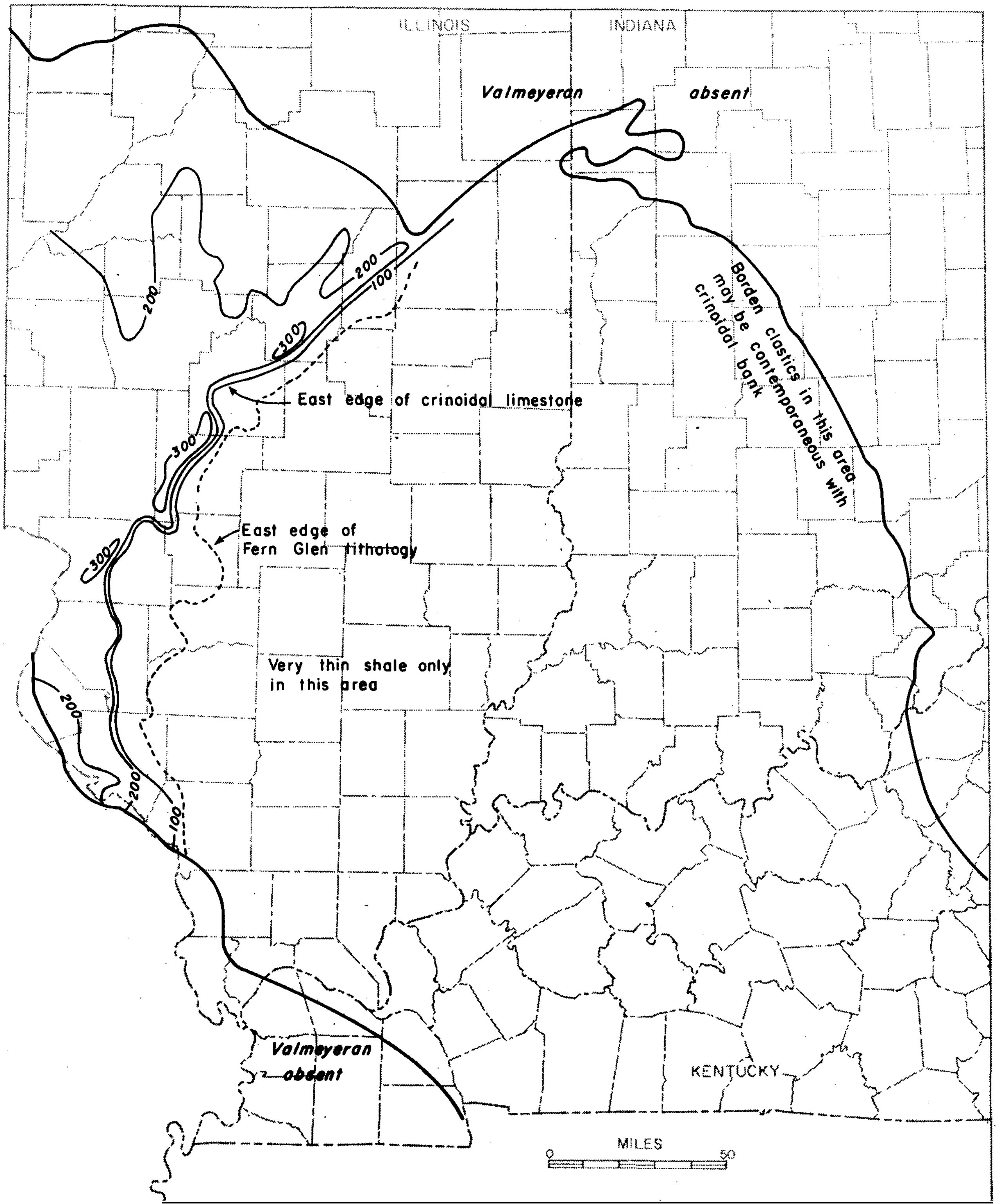


Figure 11. Thickness of the crinoidal limestone bank consisting of the Fern Glen Formation, Burlington Limestone, and Keokuk Limestone (from Lineback, 1966).

Keokuk Limestone, is equivalent to all except the lower few feet of the Borden Siltstone in southern Illinois. During the deposition of the Fern Glen, Burlington, and Keokuk, only a few feet of mud accumulated above the Chouteau Limestone in the sediment-starved basin in southern Illinois. The abrupt eastern margin of the crinoidal carbonates may be related to the eastward deepening of water at the shelf-slope break. Carbonate deposition ceased temporarily in the shelf area of Illinois owing to turbidity from the advancing clastics of the Borden-Warsaw.

The Fern Glen Formation is characterized by red, green, and gray shale that contains increasing amounts of limestone upward. Limestone in the Fern Glen is mostly red, green, or gray, is argillaceous, and is somewhat cherty crinoidal packstone or wackestone. Limestone beds are thin and separated by shale partings. The Burlington and Keokuk are similar in appearance to each other, and generally are not separable in the subsurface. They consist of thin, irregular beds of medium gray to white crinoidal wackestone and packstone with thick argillaceous shale partings (fig. 12). Chert, much of it secondary, is abundant. The unit is dolomitized in places. A thin bed of oolitic grainstone is present at places in the Keokuk (fig. 13).

Borden Siltstone

The Borden Siltstone is an elongate, tongue-shaped delta complex lying immediately east of the margin of the Burlington and Keokuk Limestones. It is continuous with the Borden Group of Indiana but is considered a formation in Illinois. The Borden consists dominantly of gray to brownish-gray, fine-grained, clayey siltstone with lesser amounts of silty mudstone, limestone, coarse-grained siltstone, and fine-grained sandstone. The siltstone is calcareous or glauconitic in places and is more than 700 feet thick in eastern Illinois (fig. 14).

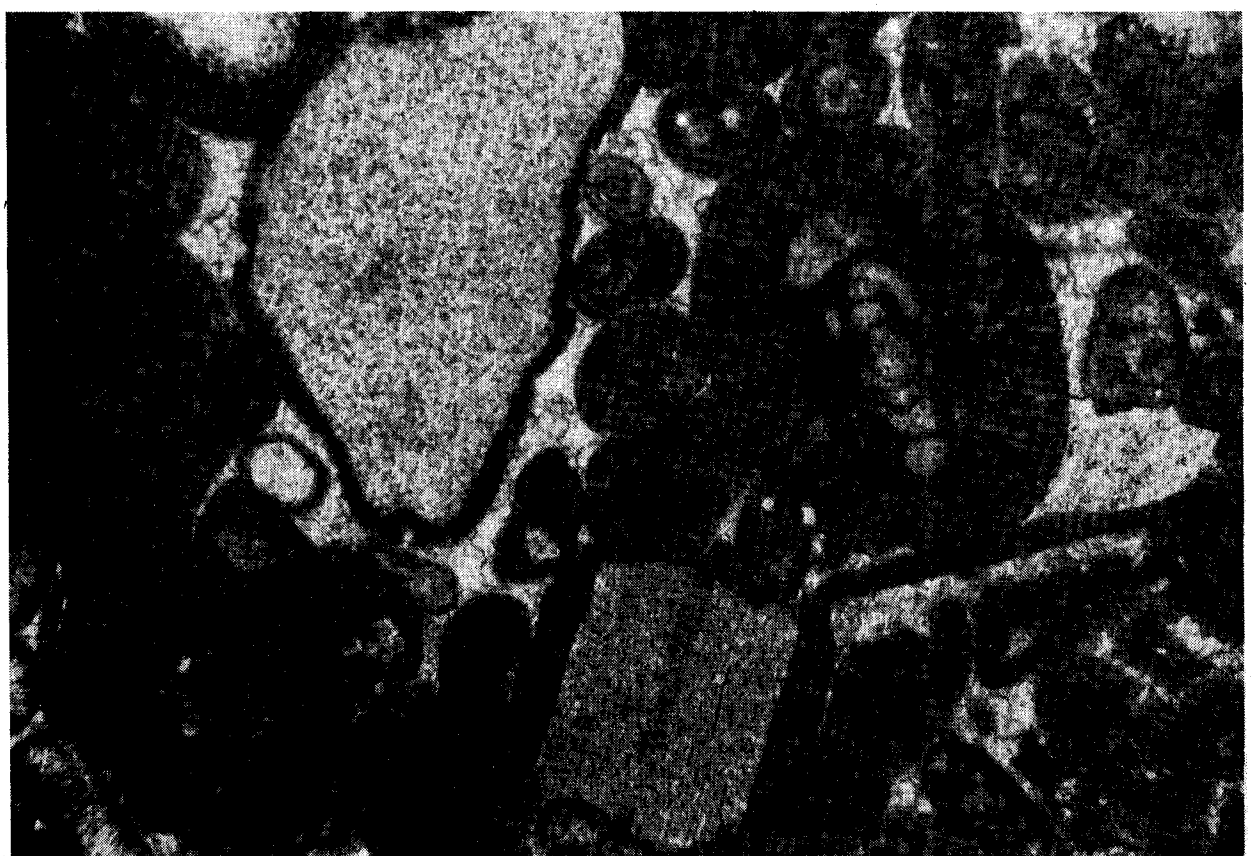
The Borden Siltstone delta was deposited as a complex series of southward-growing, imbricated topset, foreset, and bottomset beds (Swann, Lineback, and Frund, 1965). Post-compactional depositional dips of foreset bedding planes range from 25 to 120 feet per mile toward the delta margin. The Borden delta was built into the deep-water starved basin by a river system.

Warsaw and Springville Shales

The Warsaw Shale and Springville Shale are rock-stratigraphic units equivalent to the Borden Siltstone. The names continue to be used because they were named prior to the realization of their equivalence. The Warsaw is separated from the Borden at the eastern pinchout of the Burlington and Keokuk Limestones (fig. 14). The Warsaw is the silt and mud derived from the Borden delta that overrode the crinoidal carbonate bank. The Warsaw thins westward and grades into limestone beyond the influence of clastics in Iowa and Missouri.

Figure 12. Crinoid-bryozoan grainstone typical of most of the Burlington and Keokuk Limestones. Thin section, G.W. Miller #1 Sample core, 1382 ft., 11-15N-3W, Sangamon Co., Illinois.

Figure 13. Oolitic grainstone in the lower part of the Keokuk Limestone. Many skeletal grains are only superficially coated, while others have thick and well developed coatings. Thin section, G.W. Miller #1 Sample core, 1372 ft., 11-15N-3W, Sangamon Co., Illinois.



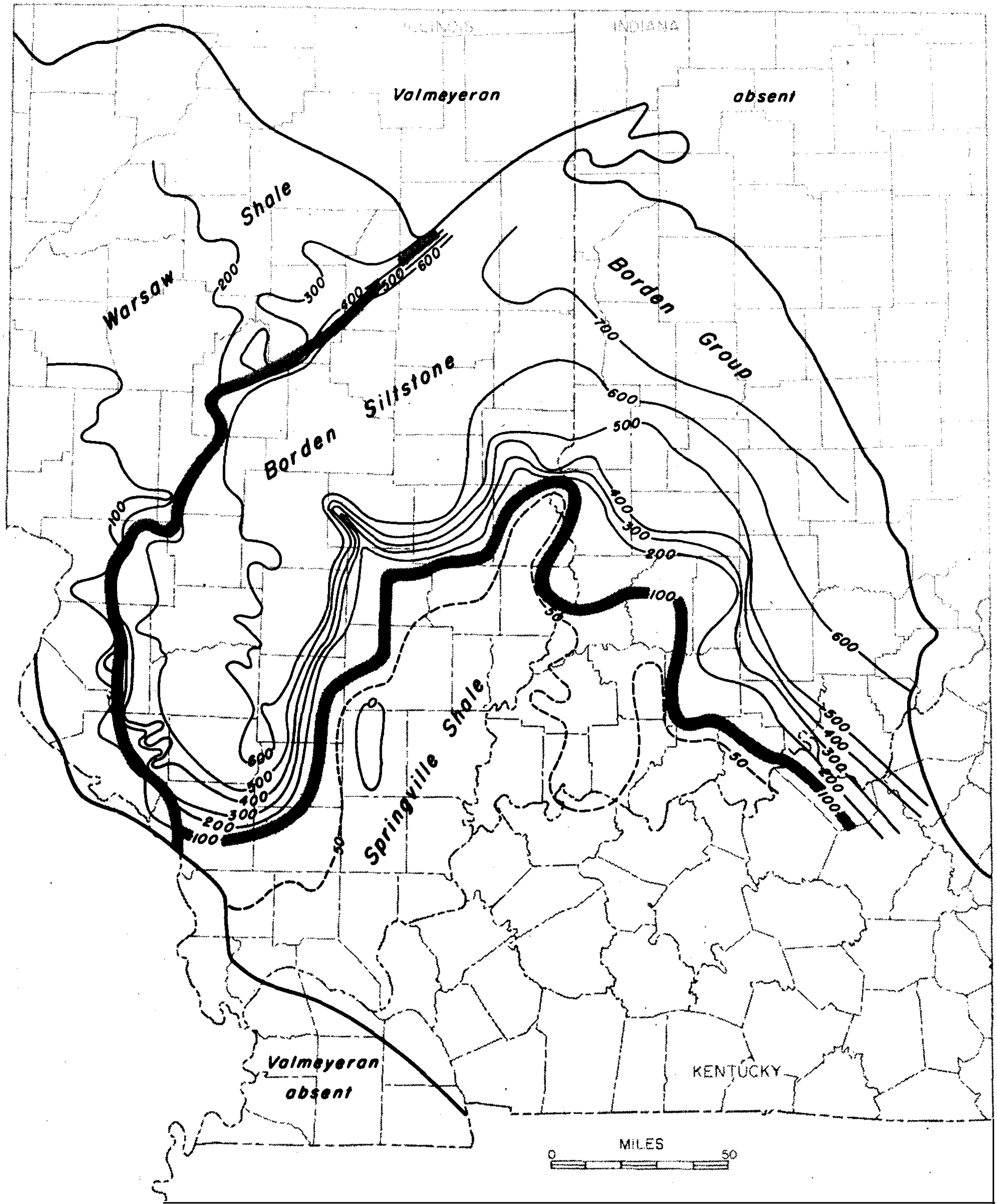


Figure 14. Thickness of early Valmeyeran deltaic sediments (from Lineback, 1966).

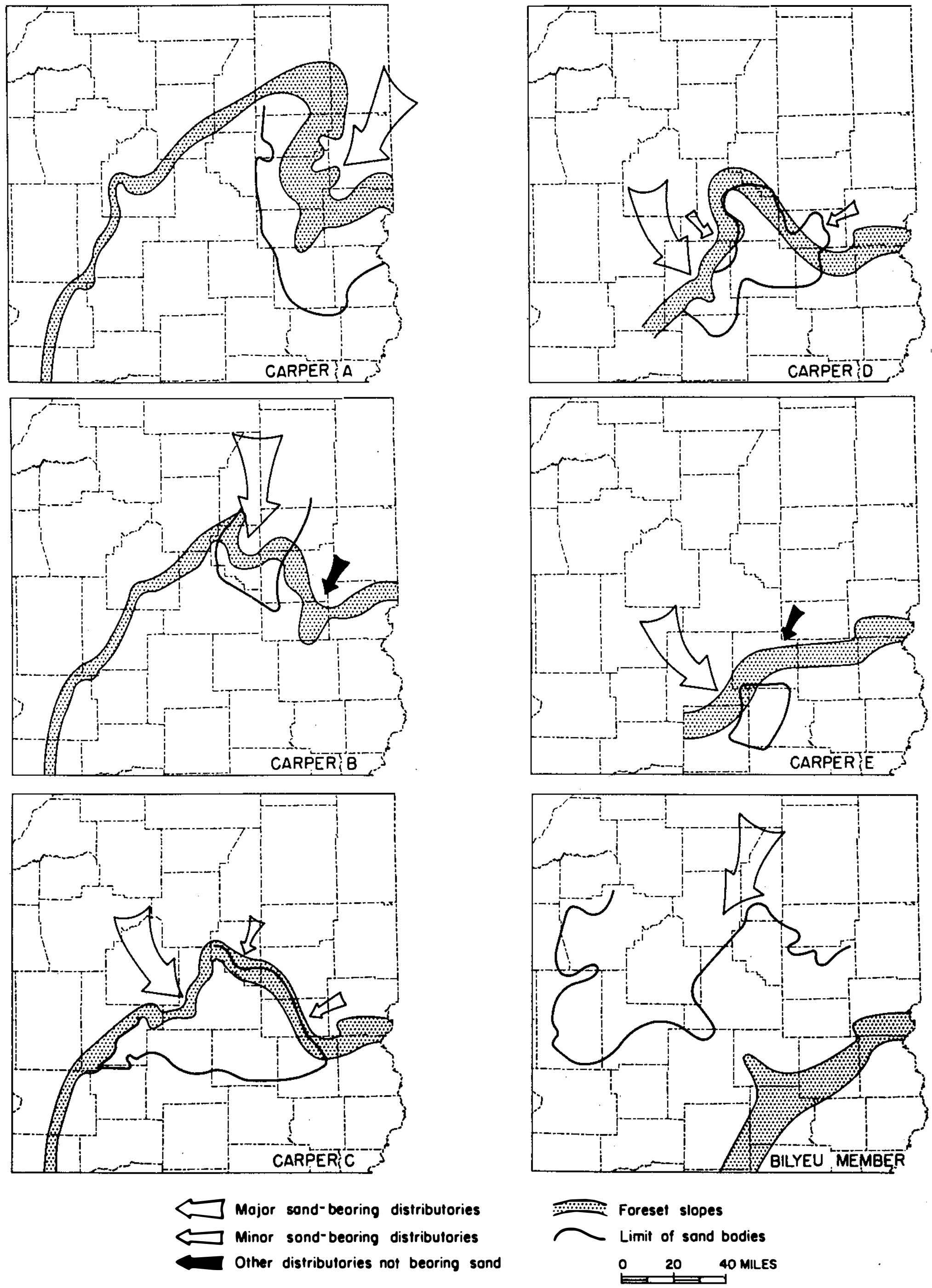


Figure 15. Maps summarizing the positions of major and minor distributary outlets, the migration of distributary outlets, and the migration of the foreset slope of the Borden delta during deposition of the Carper sandstones and the Bilyeu Member in east-central Illinois (from Lineback, 1968).

The name Warsaw continues to be used by many geologists as another name for the Ullin Limestone in Illinois and for an argillaceous facies of the Salem Limestone in Kentucky. These uses of Warsaw should be discouraged to effect proper geologic communication and consistency of nomenclature.

The Springville Shale is the deep-water bottomset equivalent of the Borden. Over large areas of the deeper part of the Illinois Basin, less than 50 feet of dark brownish-gray mudstone was deposited during the entire period of time during which the Fern Glen, Burlington, Keokuk, and Borden were deposited. The Springville is arbitrarily separated from Borden at the 100-foot thickness contour (fig. 14).

"Carper Sand"

The "Carper sand" is an informal term applied to several discrete bundles of fine sandstones that are present in the Springville Shale or basal Borden Siltstone. They are believed to have originated as turbidities deposited off delta distributary outlets at various times during the advance of the Borden delta complex (fig. 15) (Lineback, 1968). These fine sands contain petroleum in places, but the unit has very low permeabilities that are due to its fine grain size and abundant interstitial clay sized material (Stevenson, 1964).

Post-Borden Carbonate Rocks (Ullin and Ft. Payne)

Shelf areas typically produced abundant carbonate sediment throughout the Valmeyeran unless the carbonate production was overpowered by clastic turbidity. Shelf areas in Illinois returned to carbonate environments as soon as the source of the Borden clastics ceased to operate. The sea quickly transgressed across the exposed topset beds of the delta because of the compaction of the siltstone and, possibly, the continued basin subsidence. Thus, the shallow water areas available for carbonate production had been vastly increased owing to deposition of the Borden delta. The western structural shelf of the Illinois Basin was completely buried by the Borden, whereas the eastern shelf, beginning at the west margin of the La Salle Anticlinal belt and extending eastward to the delta front in Indiana, was a deep shelf apparently capable of carbonate production. The remainder of the unfilled Illinois Basin was still too deep (probably below the photic zone) for much indigenous carbonate production. The entire deep-water basin was quickly filled with carbonate sediments, however, during the period between the end of Borden deposition and the beginning of Salem Limestone deposition. These carbonate rocks presently exceed 800 feet in thickness in places (fig. 16).

Three main environments can be recognized in the post-Borden carbonate rocks: deep basin, deep shelf, and shelf. The Fort Payne Formation is a dark colored, siliceous, even bedded, lime mudstone (fig. 17). Few fossil fragments can be recognized in the Fort Payne; these are mostly crinoid columnals and sparse bryozoan fragments. The rock is finely laminated and partially bioturbated in places (fig. 17). A few interbeds of light-colored crinoidal-bryozoan packstone and wackestone are present. The Fort Payne lithofacies is confined to the deep-water part of the basin. Its even bedding, fine

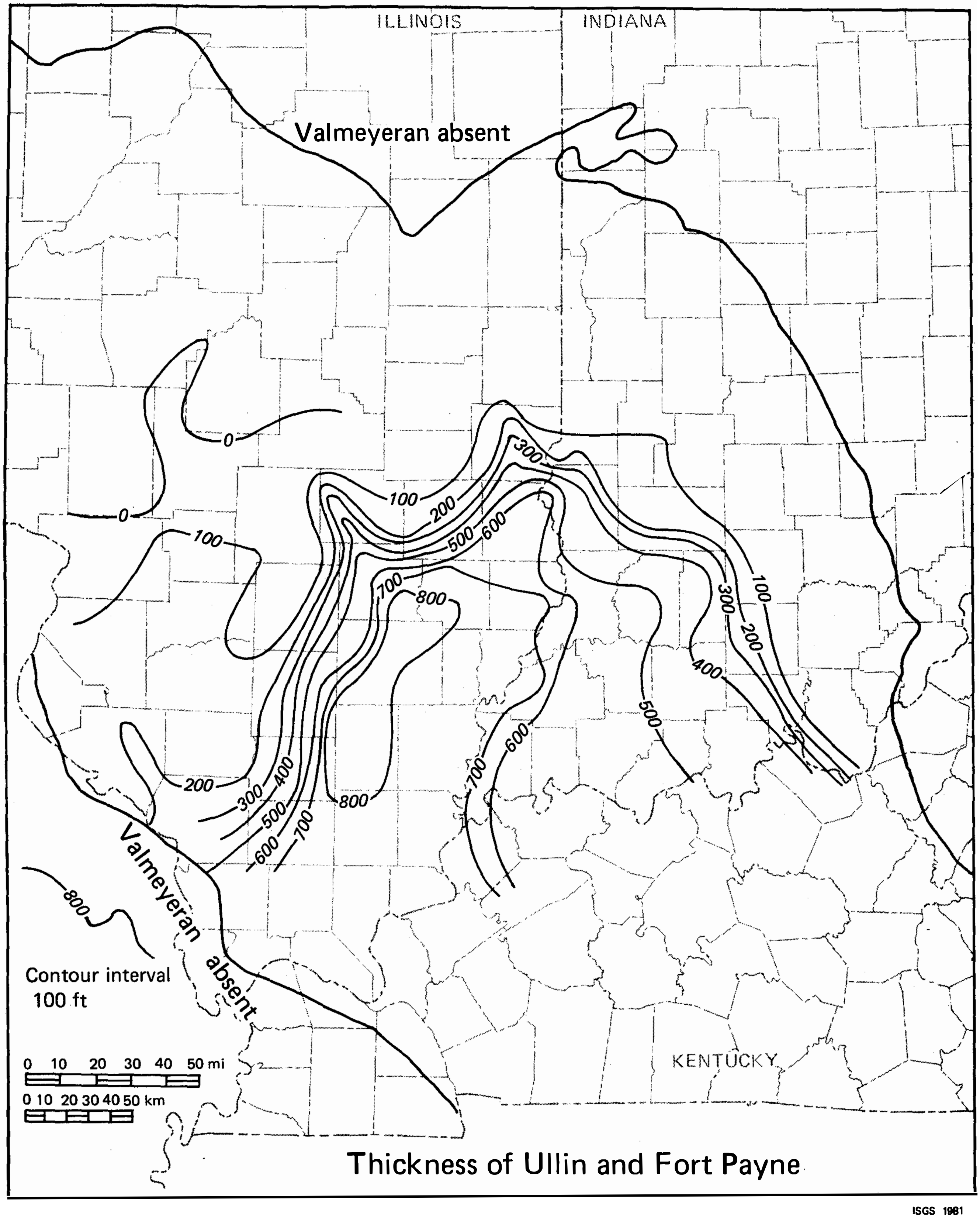


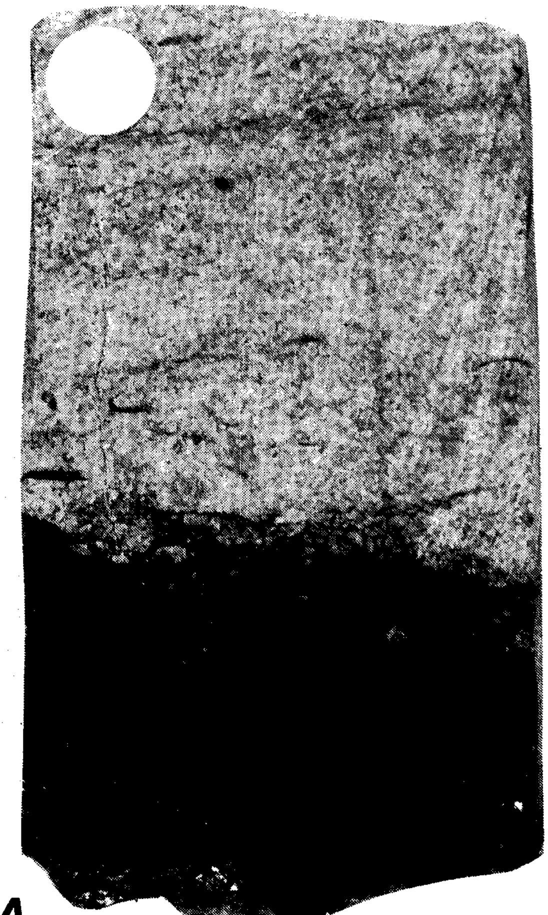
Figure 16. Thickness of the Ullin Limestone and Ft. Payne Formation.

Figure 17. Siliceous limestones of the Ft. Payne Formation. All samples are core slabs from the Superior Oil Co. #30 E.S. Greathouse well, 4-5S-14W, White Co., Illinois.

A) Contact between crinoid-bryozoan grainstone and dark siliceous lime mudstone in the Ullin-Ft. Payne transition zone. 3963 ft.; spot=2 cm.

B) Coarse crinoidal debris in a siliceous skeletal wackestone. The irregular patches of chert are typical of the upper portion of the Ft. Payne Formation. 3976 ft.; spot= 2 cm.

C) Very irregular chert nodule in dark micritic limestone. Fractures in the lower part of the chert nodule are filled by white quartz. 4073 ft.; spot= 2 cm.



A

B

C

Figure 17 (continued)

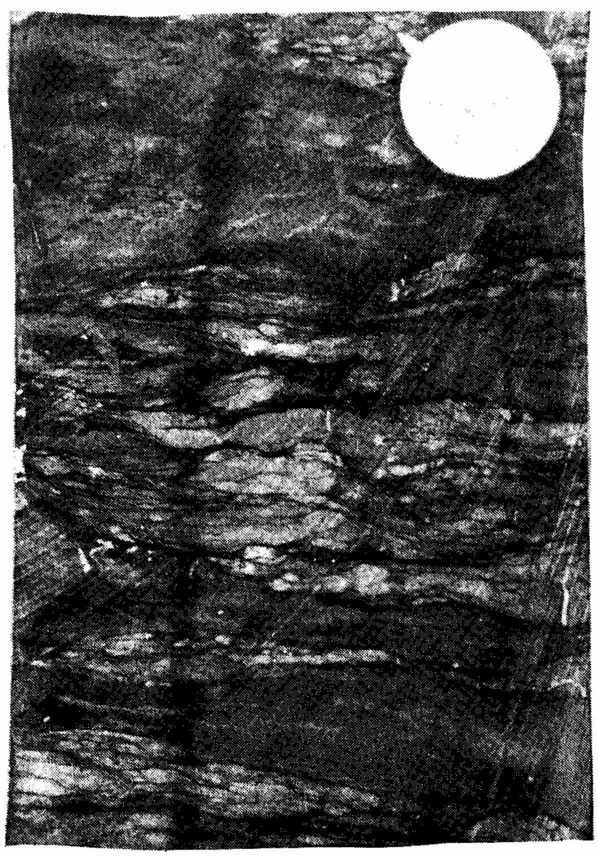
D) Trace fossils with dark centers (*Chondrites?)* in highly silicified areas of dark micrite. Where the limestone matrix is less siliceous these trace fossils are highly compressed, attesting to compaction of these lime muds before lithification. 4130 ft.; quarter for scale.

E) Discontinuous lenticular laminations in silty lime mudstone. 4140 ft.; spot= 2 cm.

F) Disrupted lenticular laminations in silty lime mudstone. Most of the lower part of the Ft. Payne is less siliceous than the upper part and has few chert nodules. Compaction and minor bioturbation have distorted the fabric of these rocks, which probably looked like E originally. This sample is typical of the lower half of the Ft. Payne in White County. 4160 ft.; quarter for scale.

D

E



F

grain size, dark color, high silica content, lack of intense bioturbation, and organic content are all characteristics of deep-water limestones (Wilson, 1969, 1975). The carbonate was not produced where deposited, but rather represents the fines winnowed from the carbonate-producing shelf environments and transported down the intervening slopes into the deep basin by debris flows and turbidity currents.

The Fort Payne grades laterally eastward into the fine-grained, light-colored, cherty, lower Ullin Limestone. This part of the Ullin has previously been called the Ramp Creek Member of the Ullin (Lineback, 1966). The Ft. Payne-Ullin facies change takes place along the shelf edge at the west side of the La Salle Anticlinal Belt. The lower Ullin is a fine-grained calcarenite composed of broken crinoid and bryozoan fragments (fig. 18). It ranges from a skeletal wackestone to grainstone but mostly consists of packstones. The lower Ullin is commonly cherty, but the silicification tends to be in irregular nodules and patches—the matrix is not as siliceous as the Ft. Payne.

The lower Ullin and the Fort Payne in southeastern Illinois form a carbonate body in which most carbonate production took place on a deep shelf area along the crest of the La Salle Anticlinal Belt and in shallower parts of the basin to the east. Fine carbonate sediment was winnowed out and carried toward the south and west. Coarser material was also carried westward toward the basin and broken and abraded in the process. The westward movement was induced by the general westward dip of the floor of the basin and implemented by combined gravity-induced movements and currents. The fine material carried southwest of the shelf-slope break along the La Salle Anticline was deposited in relatively deep water (∿ 1,000 feet) and bears deep-water characteristics. Evidence for this southward and westward transport of material is found by tracing key beds in the Ullin-Fort Payne, which have generally westward dips (fig. 20; Lineback, 1966, 1969).

The lower Ullin-Fort Payne depositional unit did not entirely fill the basin. The Fort Payne is bounded on the west by a dipping foreset-like depositional slope. A rock unit similar in appearance to the Fort Payne also was deposited on the foreset slope of the Borden delta at the same time (fig. 21). Carbonate in this unit came from the shelf area on top of the Borden. At the end of the deposition of the Fort Payne lithofacies and its correlative portion of the Ullin, there remained a deep-water basin perhaps 30 to 50 miles wide and more than 100 miles long extending from Effingham County southwestward beyond the present limit of Mississippian rocks. Less than 200 feet of Springville through Fort Payne had been deposited in this area. Because relatively shallow shelf areas now were predominant around the basin, the remaining deep-water areas were rapidly filled with coarse-grained, light-colored bryozoan-crinoid skeletal packstones and grainstones of the upper Ullin (fig. 19). Deposition took place along steeply dipping foreset surfaces migrating from both east and west.

The upper Ullin, or Harrodsburg Member as it is called (Lineback, 1966), contains little evidence of algal carbonate production and generally lacks oolitically coated grains. Possibly, the water was too deep for primary algal production (i.e., beyond the range of photosynthesis [∿ 300 feet]).

Possibly a lessening of the rate of basin subsidence or a lowering of sea level occurred to develop shallow-water conditions across the basin at the beginning of Salem Limestone deposition. The transition from Ullin to Salem deposition is characterized by the appearance of rounded skeletal grainstones that are commonly oolitically coated. Facies distribution in the Salem indicates that the central part of the basin was deeper than the margins, but the difference was much less pronounced than during the early Valmeyeran. All parts of the basin were probably in the zone of primary carbonate production at the start of Salem deposition.

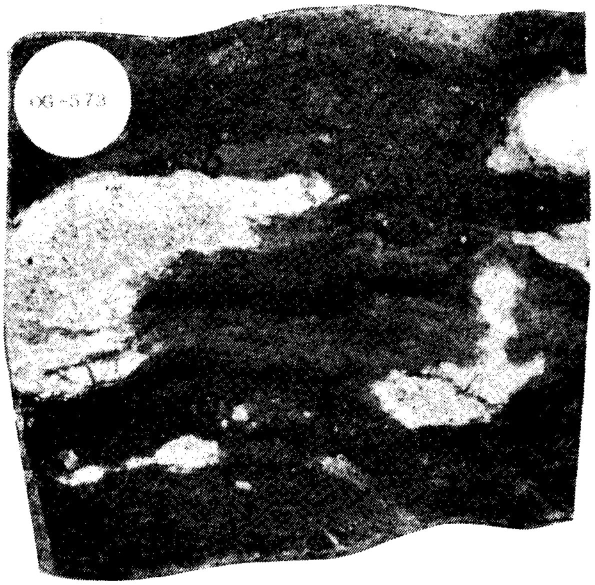
Figure 18. Siliceous skeletal wackestones typical of the lower part of the Ullin Limestone ("Ramp Creek" facies). All samples are core slabs.

A) Irregular silicification (white areas) of medium to fine grained crinoid-bryozoan packstone. Spartan Petroleum #1 T. Hasse core, 3308 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

B) Dark bryozoan wackestone with small silicified patch at base. Spartan Petroleum #1 T. Hasse core, 3293 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

C) Skeletal wackestone with long fenestrate bryozoan fronds aligned parallel to bedding. This facies is common in both the lower part of the Ullin and portions of the Salem Limestone in the deep area of the Illinois Basin. Spartan Petroleum #1 T. Hasse core, 3280 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

D) Isolated silicified areas in bryozoan wackestone. Marathon Oil #43 Miller core, 2219 ft., 19-4N-12W, Lawrence Co., Illinois.



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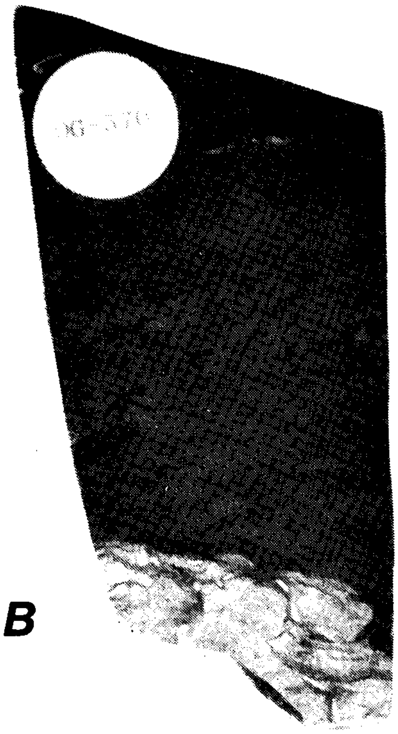


B

C

D

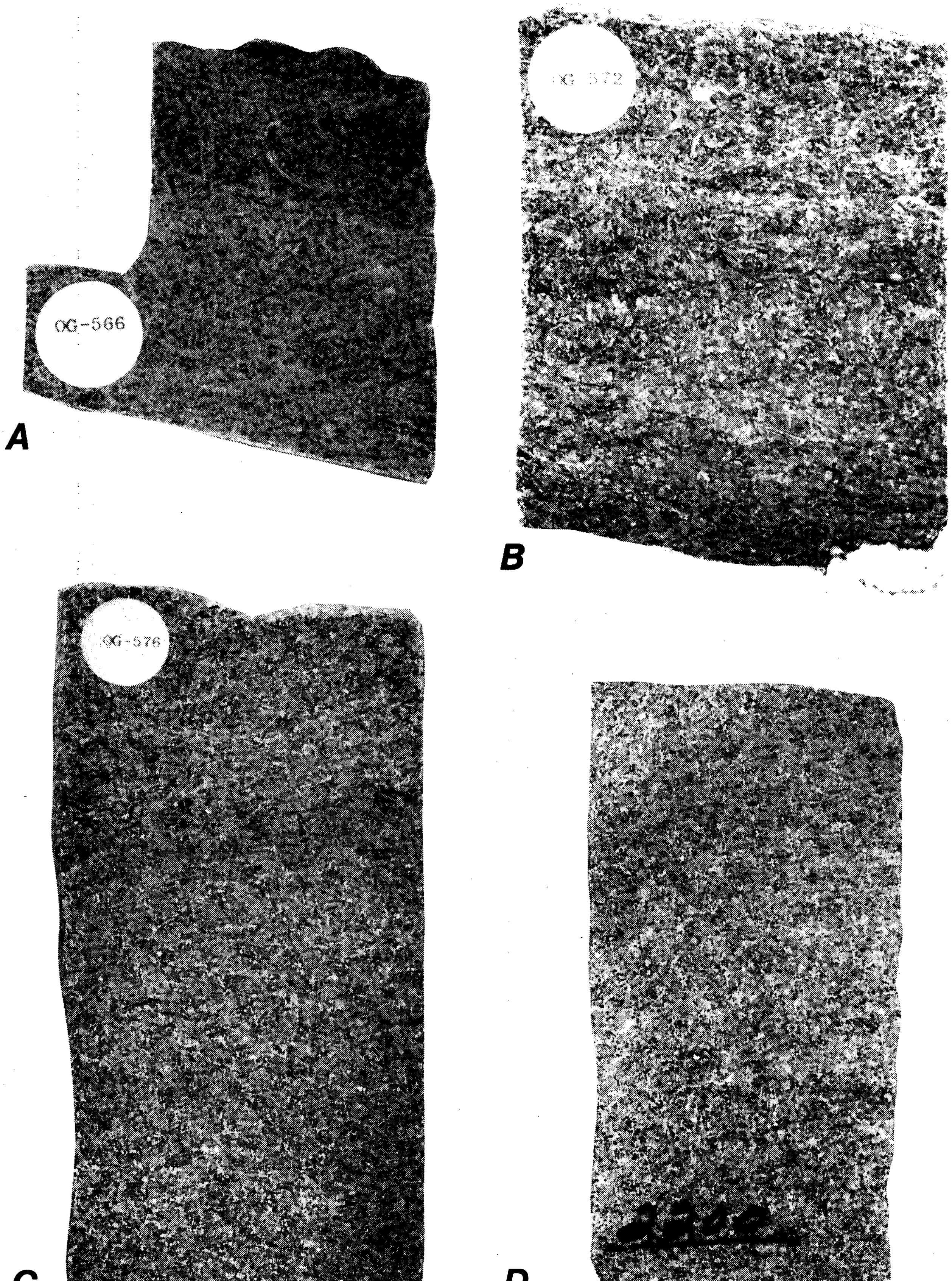
Figure 19. Crinoid-bryozoan grainstones and packstones typical of the upper portion of the Ullin Limestone ("Harrodsburg" facies). This facies also occurs in the lower portion of the Ullin, but is minor compared to the more mud rich facies illustrated in figure 18. Most cores through this facies appear massive or very faintly laminated, only rarely is low angle cross bedding apparent.

A) Spartan Petroleum #1 T. Hasse core, 3277 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

B) Spartan Petroleum #1 T. Hasse core, 3302 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

C) Spartan Petroleum #1 T. Hasse core, 3319 ft., 12-1S-13W, Wabash Co., Illinois. Spot= 2 cm.

D) Marathon Oil #43 Miller core, 2200 ft., 19-4N-12W, Lawrence Co., Illinois. Spot= 2 cm.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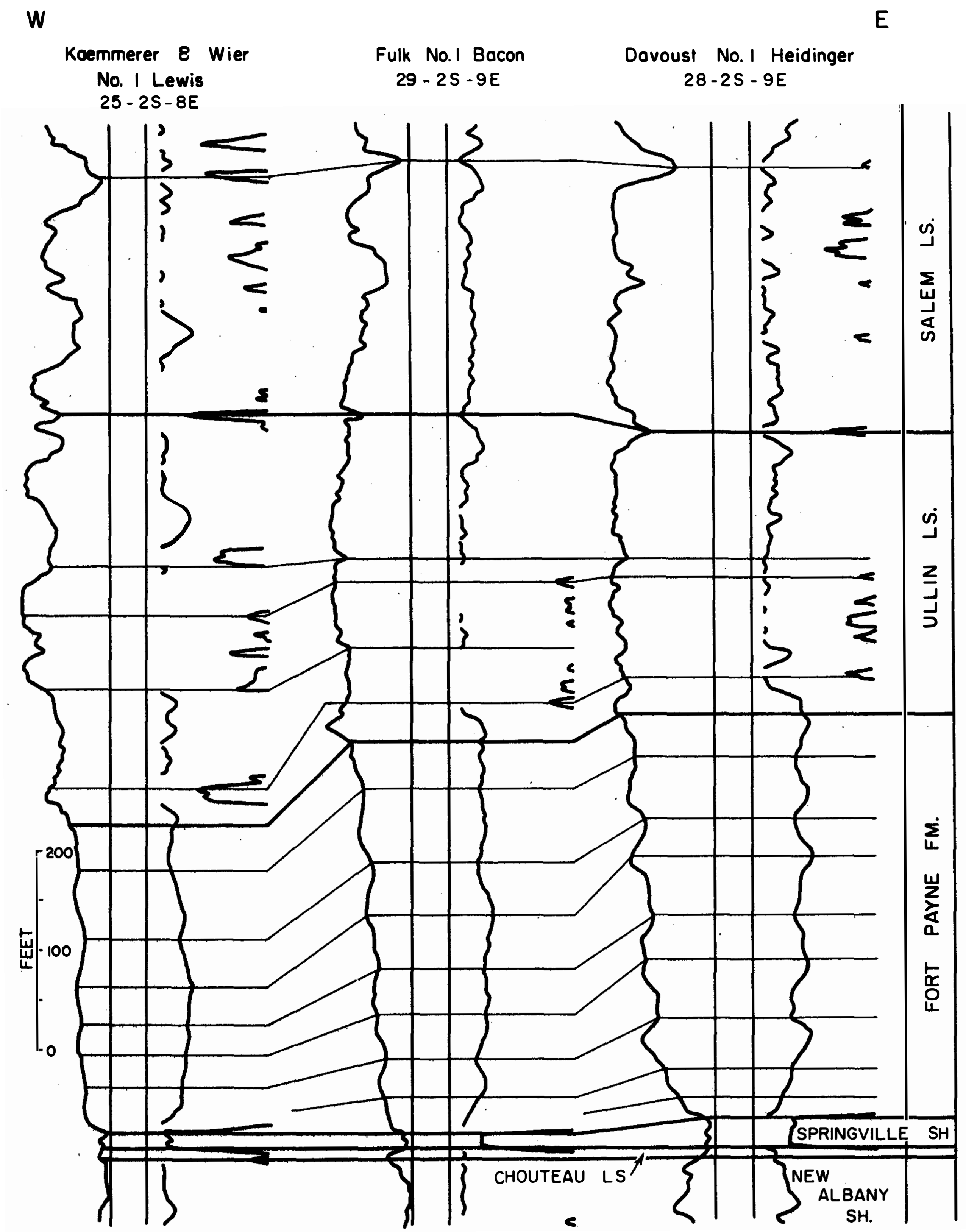


Figure 20. Cross section showing west dip of inclined bedding in the Fort Payne Formation and Ullin Limestone on the west side of the Fort Payne tongue in Wayne County, Illinois (from Lineback, 1966).

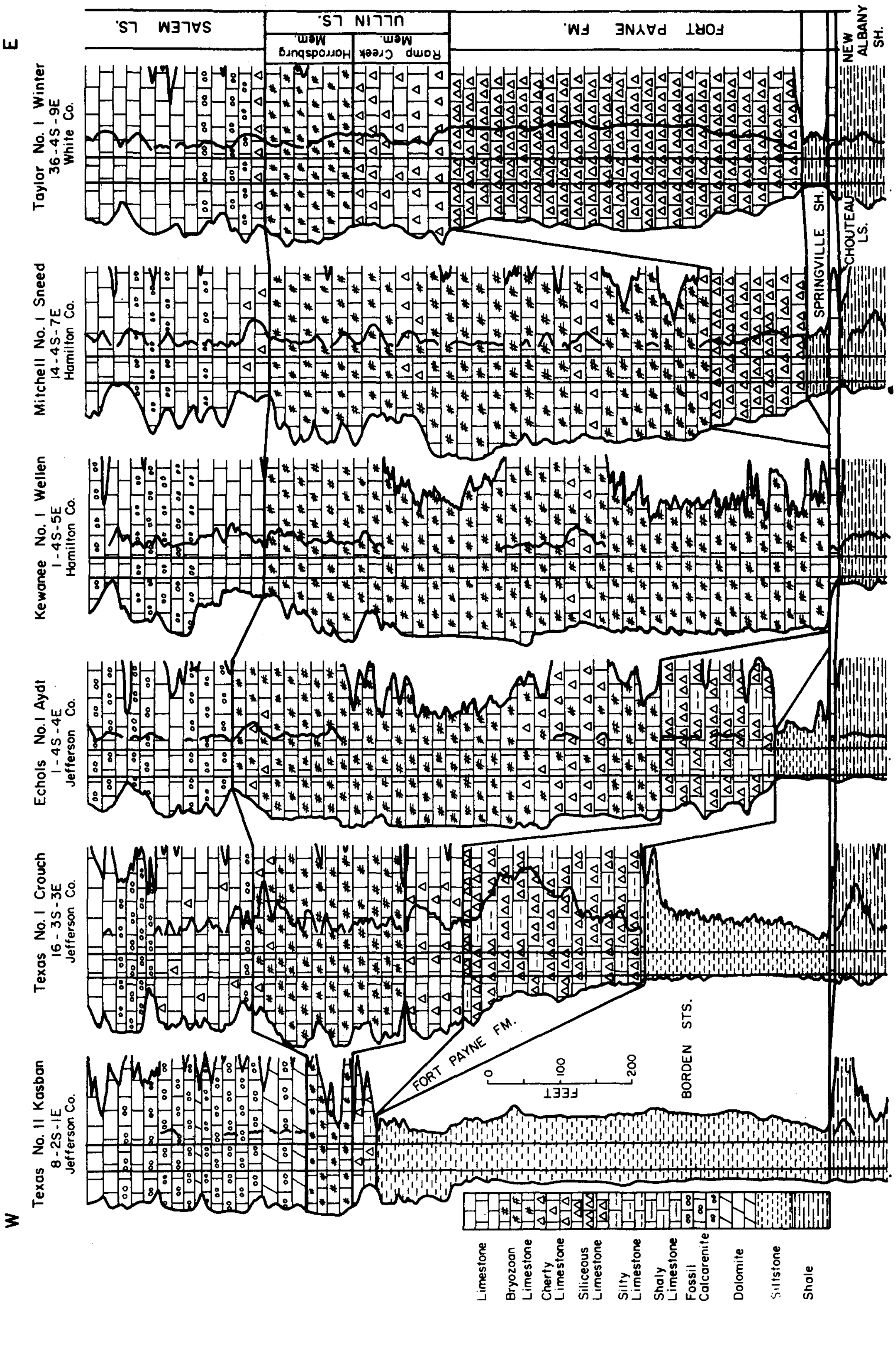


Figure 21. Cross section showing major lower Valmeyeran lithologic units in Jefferson, Hamilton, and White Counties, Illinois (from Lineback, 1966).

UPPER VALMEYERAN DEPOSITION

Robert M. Cluff

UPPER VALMEYERAN BASIN SETTING

Toward the close of Ullin deposition, the Illinois Basin appeared vastly different than at any time during the previous tens of millions of years. The prominent basin-slope-shelf topography that dominated sedimentation patterns throughout the Silurian, Devonian, and early Mississippian had been filled by the deposition of Borden clastics and Ullin-Ft. Payne carbonates. Deep-water areas persisted only in extreme southern Illinois and western Kentucky. Across most of the basin a broad, gently irregular, shallow sea now existed.

The facies which characterize the Salem, St. Louis, and Ste. Genevieve are typical of sedimentation on a shallow carbonate shelf. Comparison to modern carbonate environments such as the Bahamas and the Persian Gulf suggests that over most of the Illinois Basin water depths ranged from sea level to no more than 30 to 100 feet. The characteristic skeletal and oolitic sands of the Salem and Ste. Genevieve are typical of intertidal and shallow subtidal, agitated environments; whereas the skeletal wackestones and the mudstones that occur throughout the upper Valmeyeran sequence are typical of restricted, shallow subtidal areas. Many areas around the basin margins were probably emergent for long periods.

The upper part of the Valmeyeran of the Illinois Basin consists of four stratigraphic units (Salem, St. Louis, Ste. Genevieve, Aux Vases), which have a combined thickness of nearly 1,000 feet near the center of the basin (fig. 22). Each of the units grades laterally into the units above and below and the resulting nomenclature and correlation problems have provided a lasting source of controversy for basin geologists. In spite of the names and correlations attached to these rocks, however, they record an essentially continuous sequence of closely related carbonate environments that shifted across the basin through time. Many cyclic repetitions of lithologies are apparent, which have resulted from repeated migration of carbonate sand shoals across the shallow-shelf environment.

SHOALING-UPWARD SEQUENCES IN CARBONATES

Wilson (1975) devotes considerable attention to the concept of cyclic sedimentation in shelf carbonates. Shelf sediments commonly consist of repetitive sequences of facies spread over large areas, containing individual beds traceable for many miles. Although several types of shelf cycles are known, only one is common in the Valmeyeran of the Illinois Basin. These are the upward-shoaling or fill-in sequences that result from repeated seaward progradation of carbonate sand shoals over a broad, gently sloping platform.

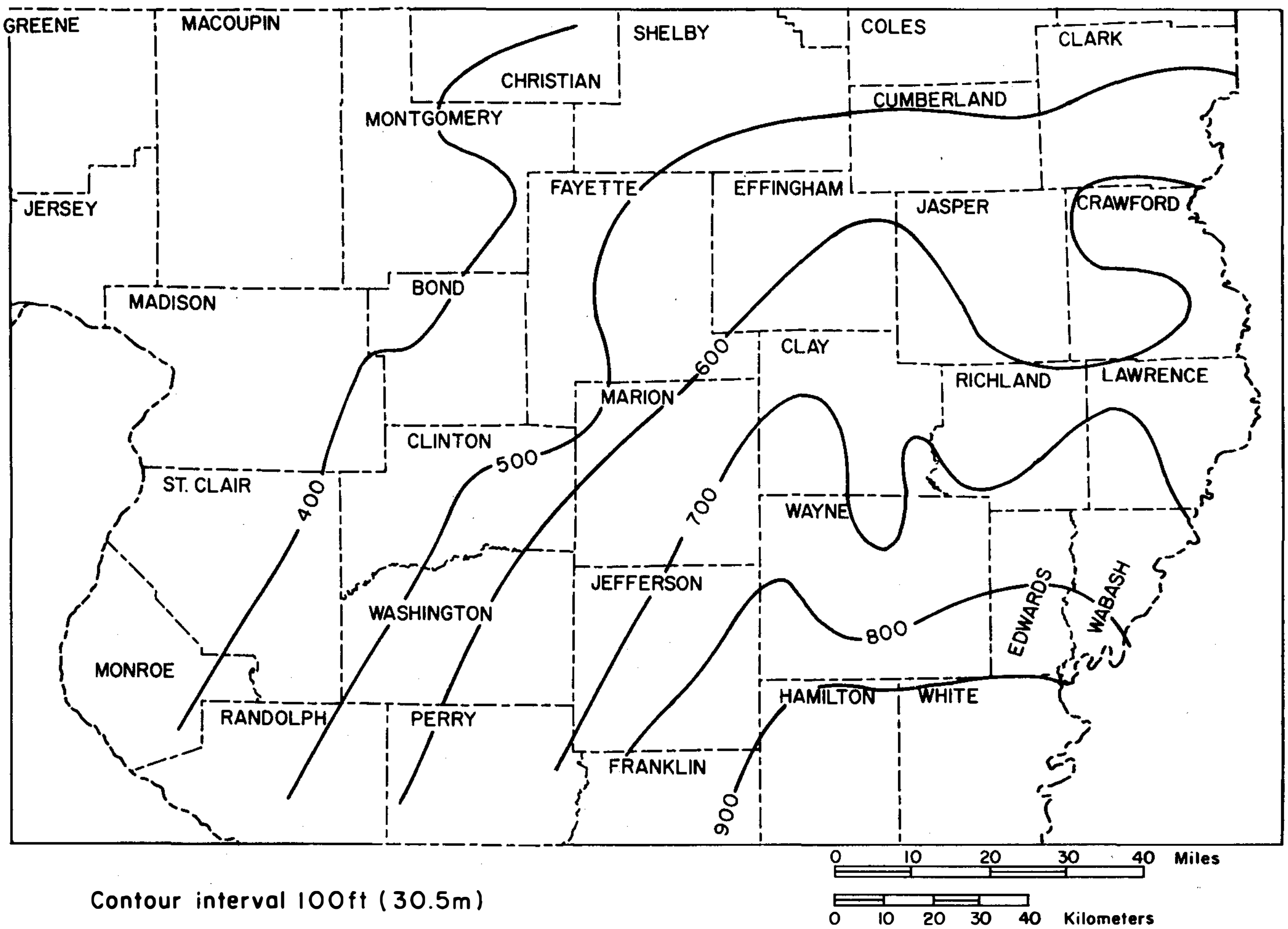


Figure 22. Combined thickness of the Salem, St. Louis, and Ste. Genevieve Limestones in south central Illinois (from Lineback, 1972).

Each shoaling-upward cycle is constructed by a single episode of sand advance across the shelf that deposited a layer of oolitic and skeletal sands over open-shelf fine-grained carbonates (skeletal wackestones and mudstones), succeeded by deposition of muddy sediments in the restricted lagoonal environment (fig. 23). A typical shoaling upward cycle in the Valmeyeran consists of the following facies from top to bottom (fig. 24):

(1) Sharp contact or erosional unconformity at the top, often associated with hardground surfaces, dolomitization, and various indications of subaerial exposure.

(2) An upper sequence of argillaceous lime mudstones, pelletal packstones, and dolomitic mudstones. Fenestral structures, anhydrite, and bioturbation are common.

(3) A transitional sequence of heavily bioturbated skeletal and oolitic packstones.

(4) A core sequence of skeletal and oolitic grainstones, usually parallel bedded and/or cross bedded.

(5) A basal sequence of coarse skeletal wackstones, usually bioturbated and grading upward into the overlying carbonate sands; sometimes interbedded with oolitic sands.

(6) Usually a sharp contact with the underlying cycle.

Shelf grainstone cycles are usually best developed in areas of moderate subsidence surrounding the basin center (fig. 25). In the deepest, rapidly subsiding central area, open marine sedimentation is predominant, few sand shoals build out into the deeper waters, and cyclic sedimentation is not apparent. The slowly subsiding basin margins remain at or near sea level as carbonate sedimentation is easily able to keep pace with the rate of subsidence—supratidal and intertidal environments are predominant and sedimentation cycles are obscured by diagenesis and numerous omission surfaces. This pattern of three broad facies belts (fig. 25) is characteristic of the upper Valmeyeran of the Illinois Basin, as will be summarized in subsequent sections.

Shoaling-upward cycles are most prominent in the lower part of the upper Valmeyeran (Salem Limestone and lower St. Louis Limestone). At least three, and in some places four, cycles can be recognized in the Salem of southeastern Illinois. These cycles are easily recognized on geophysical logs, especially spontaneous potential logs (figs. 24 and 26). Recognition of these cycles and their characteristics can be extremely important; they form most of the commercial reservoirs in the Salem and Ste. Genevieve Limestones. The lower grainstone and packstone portions of each cycle form the porous pay intervals in most reservoirs, and the upper mudstone and wackestone intervals of each cycle form the dense seals over the reservoirs. Variations in the thickness of the upper and lower portions of each shoaling-upward cycle and local interfingering of these facies result in stratigraphic traps such as Keenville Field in Wayne County, Illinois (Stevenson, 1978).

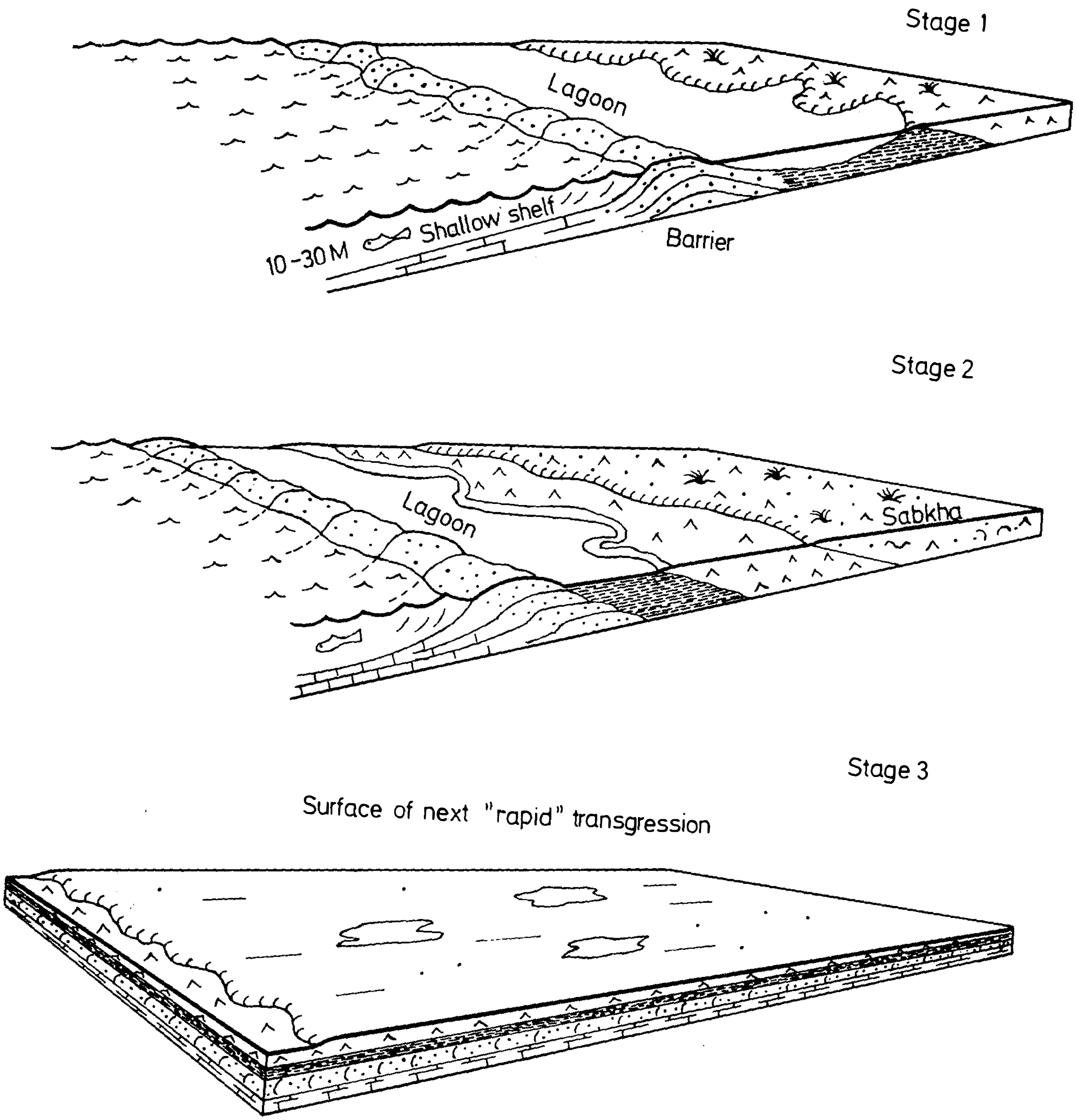


Figure 23. Construction of a single upward shoaling cycle by progradation or seaward outbuilding of carbonate-evaporite facies across open-marine shelf facies (from Wilson, 1975). (Reprinted with permission of Springer-Verlag, New York.)

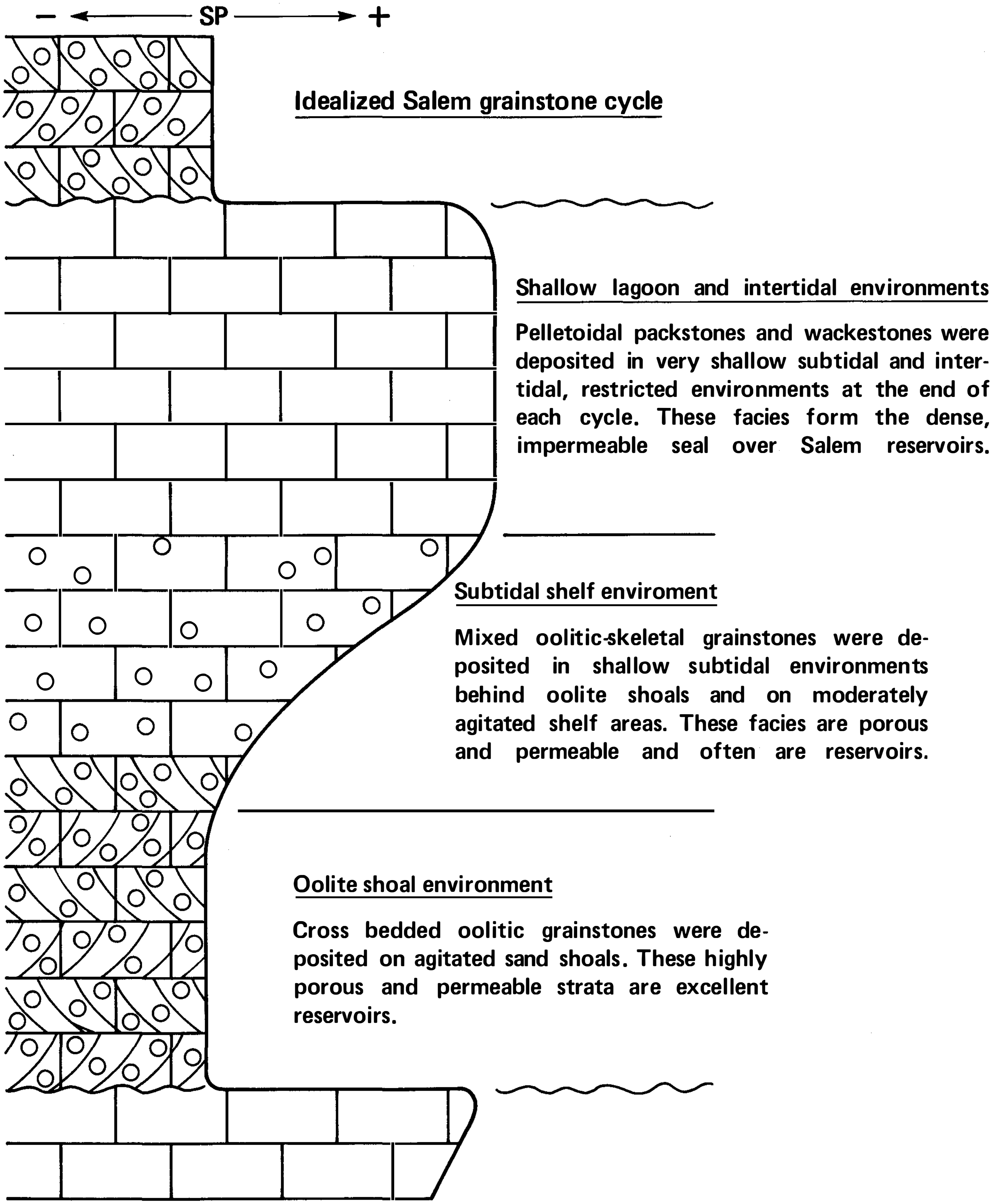


Figure 24. Idealized shoaling-upward cycle in the Valmeyeran of southeastern Illinois.

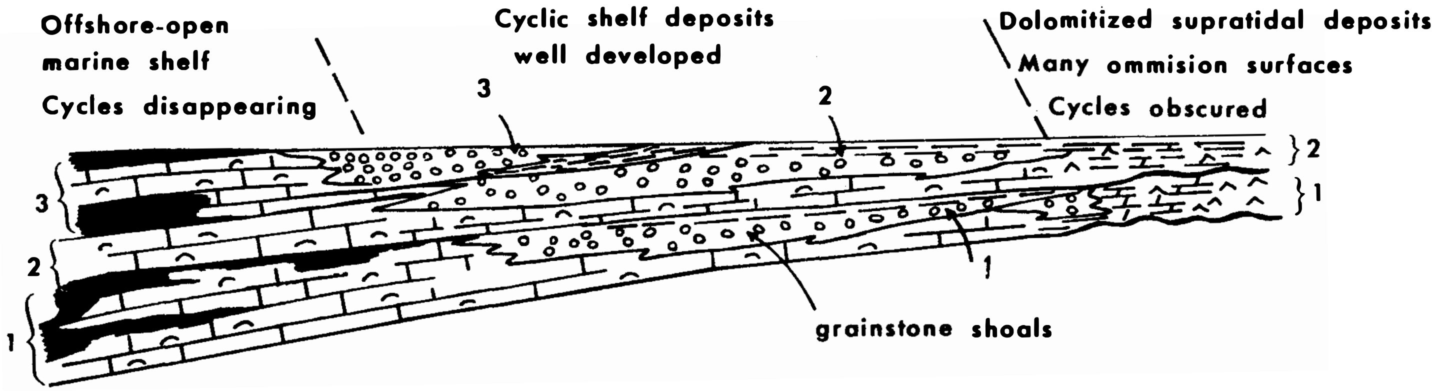


Figure 25. Three cyclic patterns from shelf to basin showing best developed cycles in the intermediate area of moderate subsidence (from Wilson, 1975). (Reprinted with permission of Springer-Verlag, New York.)

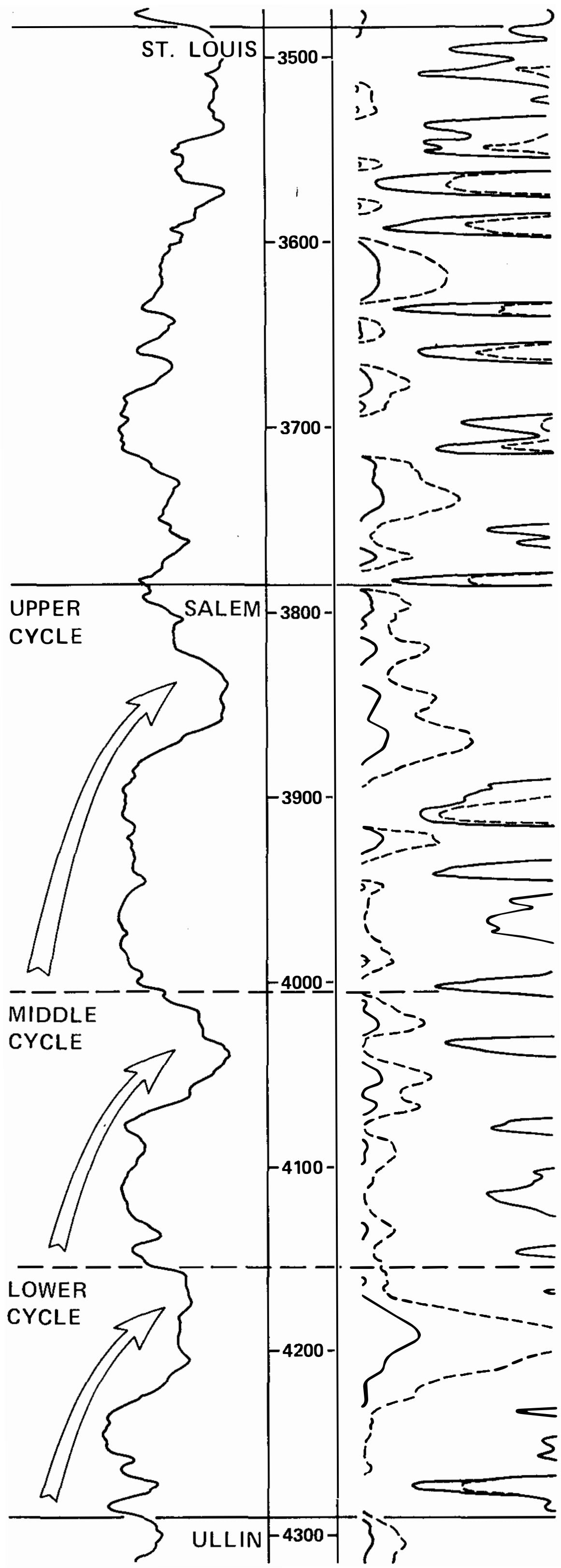


Figure 26. Typical spontaneous potential and resistivity curves through three shoaling-upward cycles in the Salem Limestone. Kaemerer and Wier #1 Lewis well, sec. 25-T.2S.-R.8E., Wayne County, Illinois.

Depositional cycles are not readily apparent within the St. Louis Limestone, although the regional stratigraphic relationships between the Salem and St. Louis Limestones (Lineback, 1972) can be considered one very thick, shoaling-upward "mega-cycle." The thin interbedding of oolitic calcarenties in the Ste. Genevieve Limestone (McClosky and Ohara pays) with dense micritic limestones, however, is again the result of short shoaling-upward cycles. These cycles are much thinner, more closely spaced, and are less widespread than cycles in the Salem. This suggests that upward-shoaling sequences in the Ste. Genevieve resulted from minor variations in sea floor topography, local sedimentation rate, wave agitation, etc., whereas the Salem cycles are probably due to regional subsidence and changes in sea level.

SALEM LIMESTONE DEPOSITION

The Salem Limestone overlies the lighter colored, crinoidal-bryozoan grainstones of the Ullin across most of the Illinois Basin. The Ullin-Salem transition is marked by the first appearance of darker colored, sorted and rounded grainstone beds containing abundant oolitically coated grains (fig. 27A). The Salem also contains a much greater diversity of fossils than does the Ullin, including abundant foraminifera, calcareous algae, bivalves, brachiopods, and gastropods, in addition to crinoids and bryozoans (fig. 27I).

The contact between the two formations is usually gradational and apparently varies in its stratigraphic position over rather short distances. In many areas fine-grained skeletal wackestones and argillaceous, dolomitic mudstones occur between the lowest, Salem-type oolitically coated grainstones and the highest Ullin-type crinoid-bryozoan grainstones. Because the bulk of the Ullin is free of shale interbeds and argillaceous mudstones, the finer grained transition beds have usually been placed in the Salem formation. The transitional nature of the Salem-Ullin contact is believed to reflect slight topographic irregularities in the upper surface of the prograding Ullin carbonates. As a consequence some areas built into the near-surface zone of high agitation before other areas. As a broad generalization, the change from Ullin to Salem deposition marks the filling of the Illinois Basin up to wave base with carbonate sediments.

The Salem Limestone exceeds 500 feet in thickness in White County, Illinois, and vicinity (fig. 28). Approximately one-half of the formation consists of calcarenites in this area, the remainder of the unit is composed of several fine grained lithologies. To the north, west, and east is a broad belt in which the Salem is predominantly calcarenite, including the famous Indiana building stone district. Beyond this area the Salem Limestone grades laterally into fine-grained, cherty mudstones, argillaceous wackestones, and dolomites assigned to the St. Louis Limestone (fig. 29) (Lineback, 1972). To the south in extreme southern Illinois and western Kentucky the Salem mostly consists of dark-colored, micritic limestones containing a few thin calcarenite beds. To the east in west-central Kentucky, the Salem includes an increasing proportion of clastic material (mostly siltstone and calcareous shale) and the characteristic Salem calcarenites become very minor. The overall north-south facies relationships of the Salem Limestone in the Illinois Basin are very similar to the idealized situation illustrated in figure 25.

Figure 27. Common Salem Limestone facies. Examples B through G illustrate a typical sequence through a shoaling-upward cycle in the Salem, from bottom to top.

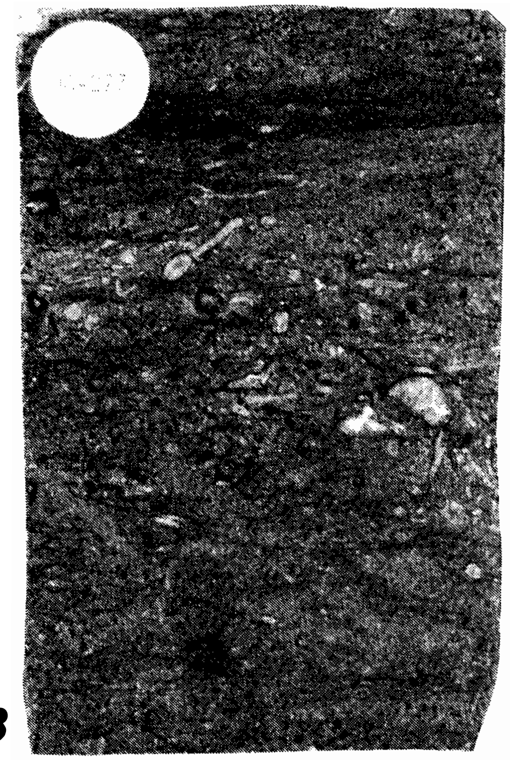
A) Bioturbated oolitic-skeletal grainstone. Texaco #B-1 Wente core, 2859 ft., 21-9N-7E, Cumberland Co., Illinois. Spot= 2 cm.

B) Skeletal wackestone with large crinoid and shell fragments. Juniper Petroleum #24x-15 Wylie-Gray core, 3803 ft., 15-1S-8E, Wayne Co., Illinois. Spot= 2 cm.

C) Transition bed from skeletal wackestone into overlying oolitic-skeletal packstone facies. Juniper Petroleum #24x-15 Wylie-Gray core, 3795 ft., 15-1S-8E, Wayne Co., Illinois. Spot= 2 cm.

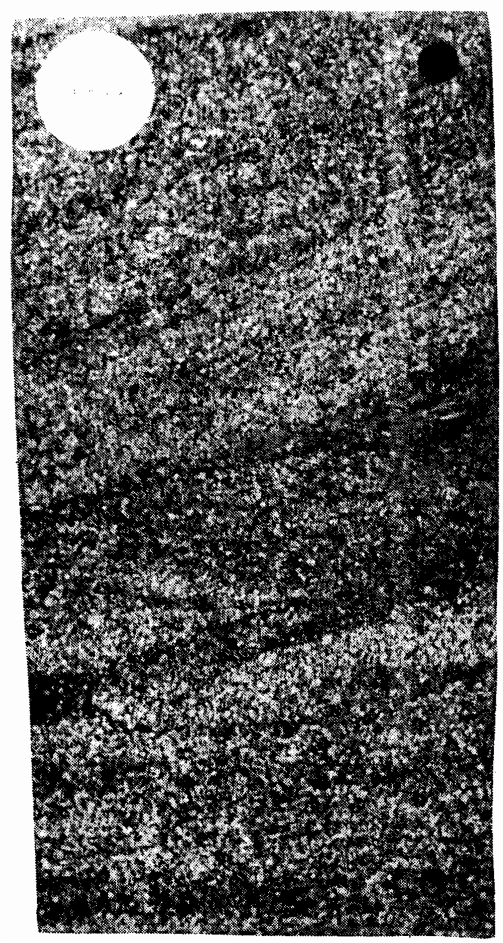
D) Cross bedded oolitic grainstone. F. Farrar #4 R. Reed core, 3634 ft., 27-1S-5E, Wayne Co., Illinois. Spot= 2 cm.

A



B

C



D

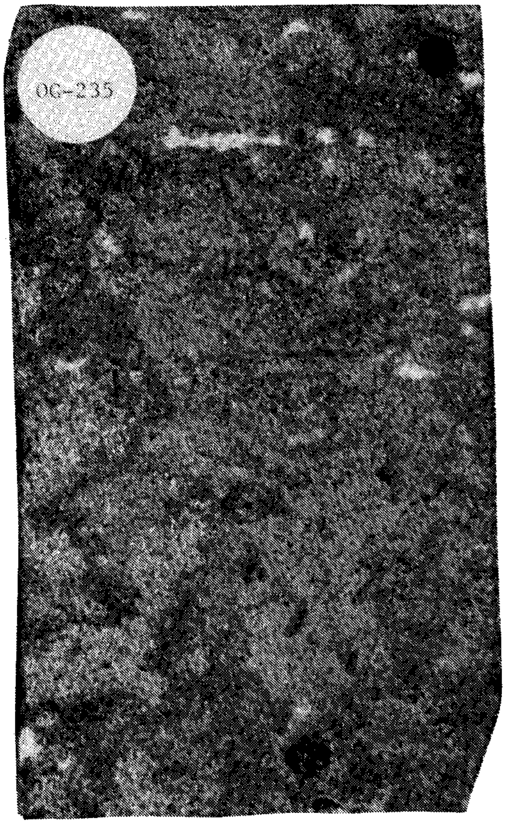
Figure 27 (continued)

E) Highly bioturbated oolitic-skeletal packstone with anhydrite and sparry calcite filled fenestral structures. Juniper Petroleum #24x-15 Wylie-Gray core, 3756 ft., 15-1S-8E, Wayne Co., Illinois. Spot= 2 cm.

F) Bioturbated argillaceous lime mudstone. Texaco #B-1 Wente core, 2842 ft., 21-9N-7E, Cumberland Co., Illinois. Spot= 2 cm.

G) Peloidal-skeletal packstone with abundant fenestral structures. F. Farrar #4 R. Reed core, 3597 ft., 27-1S-5E, Wayne Co., Illinois. Spot= 2 cm.

H) Truncation surface (submarine hardground?) at top of oolitic-skeletal packstone facies and overlain by bioturbated mudstone. F. Farrar #4 R. Reed core, 3602 ft., 27-1S-5E, Wayne Co., Illinois. Spot= 2 cm.



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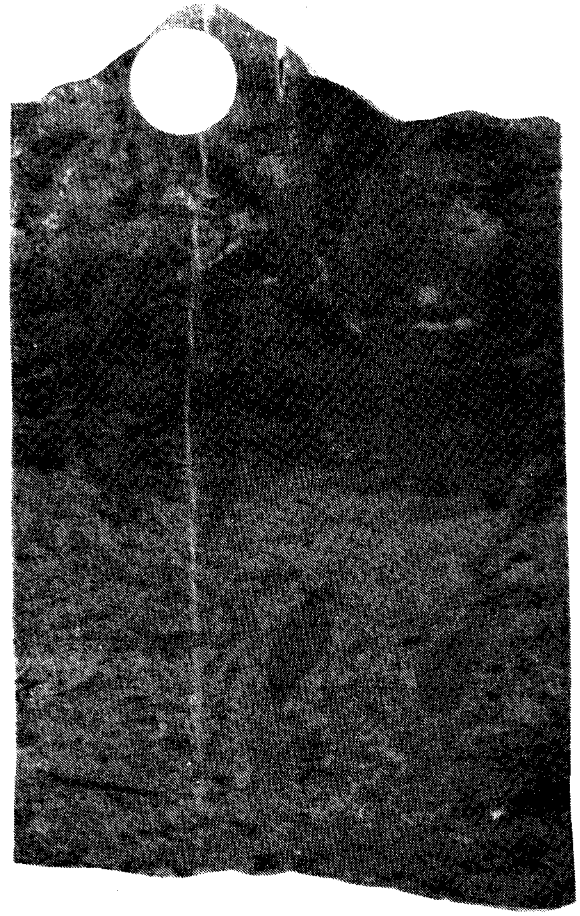

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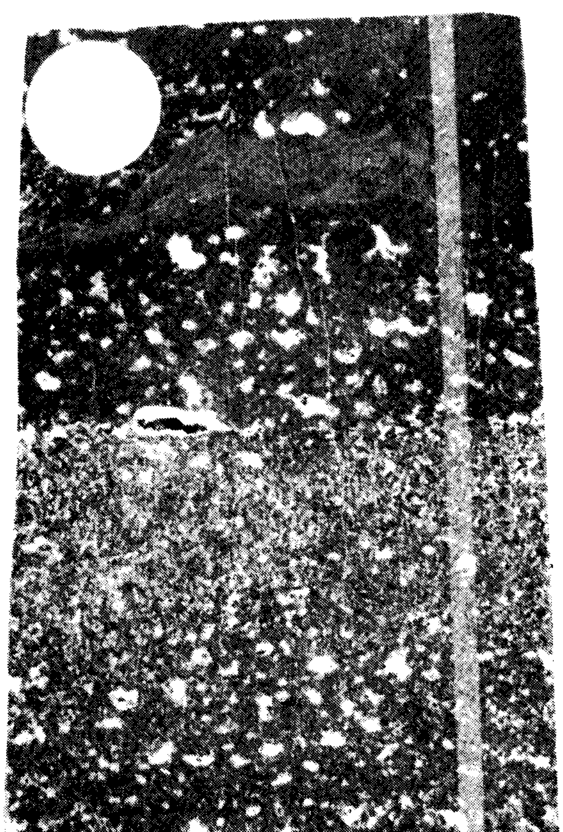
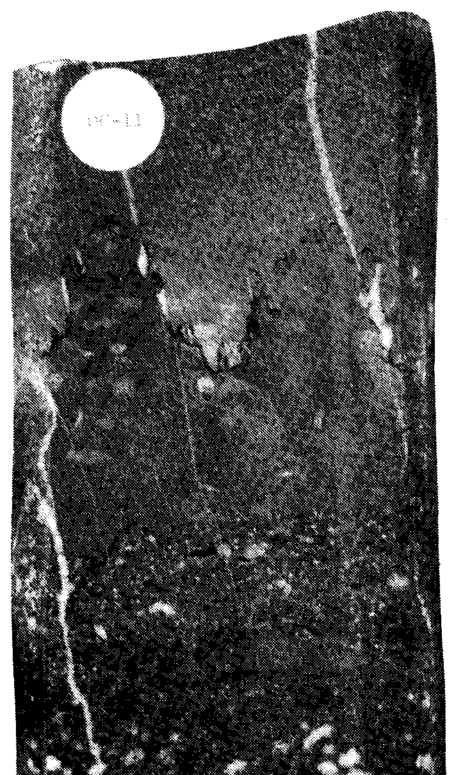


G



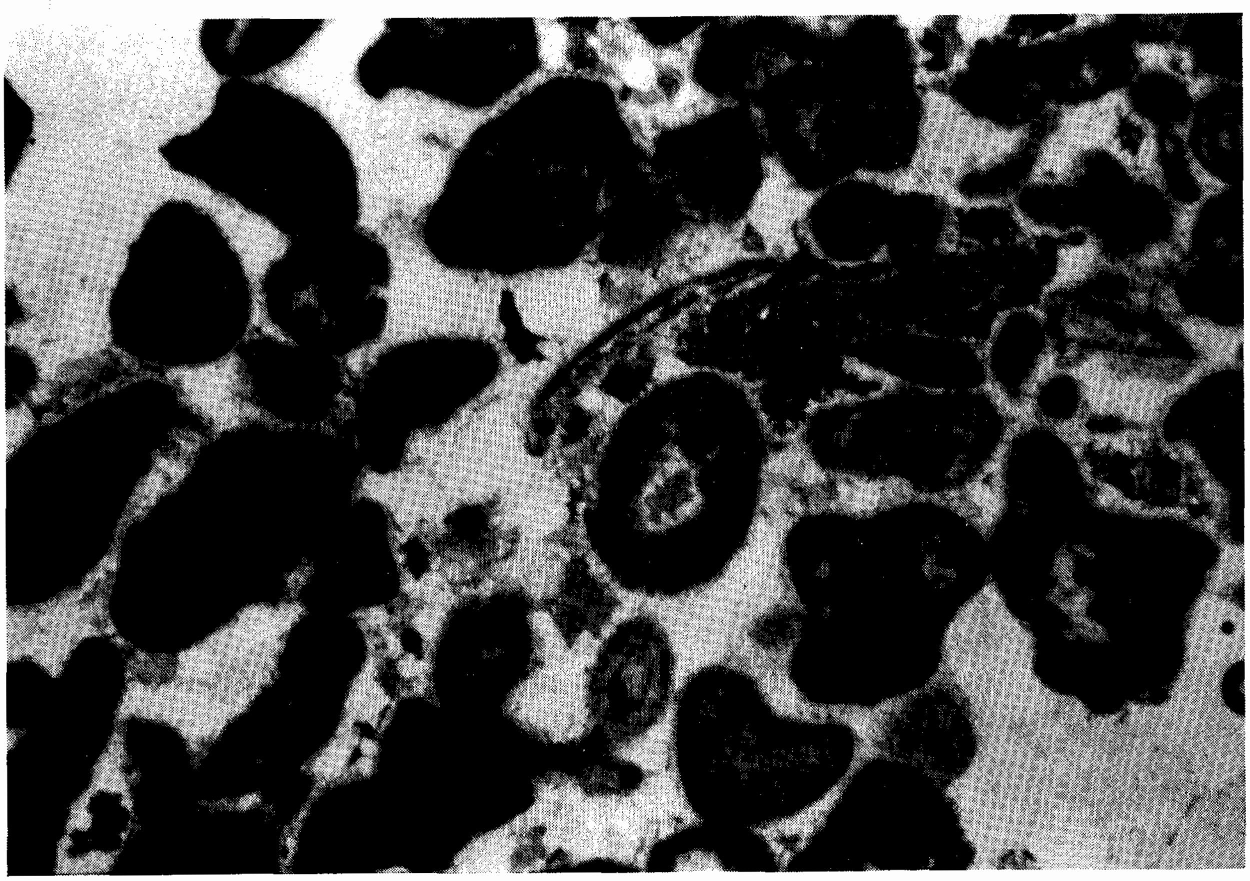
H

Figure 27 (continued)

I) *Endothyrid*-crinoidal-peloidal grainstone, typical of the porous middle portions of most Salem grainstone cycles. This particular sample is from the uppermost portion of the grainstone beds and few grains are oolitically coated. Thin section, F. Farrar #4 R. Reed core, 3606 ft., 27-1S-5E, Wayne Co., Illinois.

J) Peloids in peloidal packstone facies, uppermost portion of a grainstone cycle. Peloids in the Salem were probably formed by micritization of skeletal grains, especially foraminifera and calcareous algae. Crinoid grains appear to have been the most resistant to micritization and are often the only skeletal particles that can be identified. Thin section, F. Farrar #4 R. Reed core, 3595 ft., 27-1S-5E, Wayne Co., Illinois.

I



J

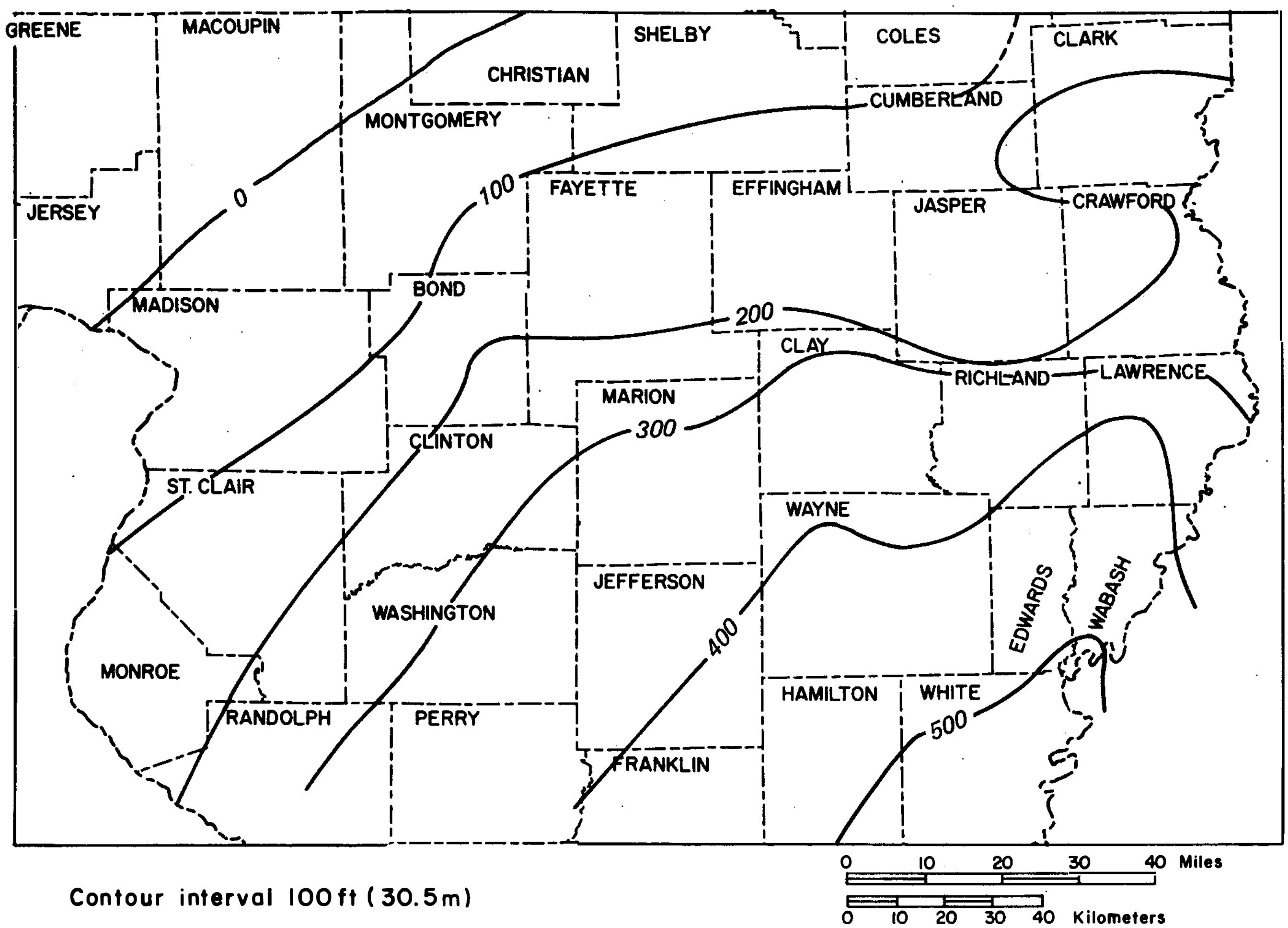


Figure 28. Thickness of the Salem Limestone in south central Illinois (from Lineback, 1972).

Several thick, shoaling-upward cycles characterize the Salem in southeastern Illinois and southwestern Indiana. To the south the cycles lose their identity in the open-shelf mudstone facies; whereas to the north, east, and west, they merge into the finer grained St. Louis interval (Lineback, 1972). The area where these grainstone cycles are best developed is also the area of most significant Salem oil pools; complete development of a cycle is probably essential to the subsequent entrapment of petroleum. Each cycle consists of three or four parts, as described below. The best developed cycles are in the uppermost Salem. The basal cycle is often poorly developed and difficult to define.

The lowermost portion of a typical Salem cycle consists of intensely bioturbated skeletal wackestone and mudstone containing large fossil fragments (fig. 27B). Fenestral structures, omission surfaces, and other exposure indicators are notably absent. These muddy carbonates are often interbedded with thin skeletal and oolitic packstones and invariably grade upward into oolitic grainstones. We interpret these fine-grained limestones as the normal, open-marine shelf carbonates that were deposited in moderately shallow waters seaward of carbonate sand shoals (fig. 23).

The greater portion of the lower and middle part of each cycle is composed of cross-bedded to parallel-laminated, well sorted and rounded oolitic-skeletal grainstones (fig. 27D). Salem grainstones are typically medium- to fine-grained and are predominantly composed of broken and abraded skeletal debris, especially echinoderms, foraminifers, calcareous algae, brachiopods, bivalves, and gastropods. Much of this skeletal material has been heavily micritized, which is visible in thin section as a thick microcrystalline rim (or micrite envelope) surrounding the fossil fragment. In many intervals micritization has been so extensive that the original identity of the fossil is lost and only an irregular micrite particle (or peloid) remains (fig. 27J). Most of the skeletal particles in the grainstone facies are oolitically coated; however, well-formed spherical oolites with thick coatings are not abundant. Cementation of the grainstone facies is variable and apparently related to the degree of oolitic coating; rocks with a large percentage of well-coated grains are usually the most porous and permeable. This facies is typical of oolite bar deposition and probably represents the high-energy environment near the crest of the shoal.

The cross-bedded, oolitic-skeletal grainstone portion of a typical Salem cycle grades upward into bioturbated skeletal packstones (figs. 25 and 27E). This transitional interval is similar in grain size and composition to the underlying oolitic grainstones except that a higher porportion of the particles are micritized, and oolitically coated grains are less abundant. The increase in mud content and the greater degree of cementation result in a rapid upward decrease in porosity and permeability through the transitional interval, although thin, isolated streaks of porous limestone may be present. This facies was probably deposited on the lee side of oolite shoals and represents lagoonal sediments that include material washed over the crests of the shoals by waves and storms.

The uppermost portion of a Salem cycle typically consists of several interbedded fine-grained facies. These usually include tightly cemented pelletal packstones; highly bioturbated argillaceous mudstones (fig. 27F); dolomitic mudstones; and rarely thin shale beds. Most of this upper interval is dense and is characterized on geophysical logs by high resistivity, positive spontaneous potential, and moderate gamma ray count (figs. 24 and 26). Fenestral structures and irregular voids filled with anhydrite are abundant (fig. 27G); hardground and other omission surfaces are found in many cores (fig. 27H). These fabrics indicate that the sediments were intermittently exposed and partially eroded. The top of each cycle usually is sharply truncated by erosion.

The uppermost, fine-grained portions of these Salem cycles probably were deposited in restricted, lagoonal areas behind oolite shoals. As the sand shoals migrated repeatedly across the shelf area of southeastern Illinois and southwestern Indiana, deposition of fine-grained limestones was predominant in the restricted environs to the north, east, and west. The bulk of these fine-grained, restricted facies have been assigned to the St. Louis Limestone.

ST. LOUIS LIMESTONE DEPOSITION

A thick sequence of fine-grained, cherty limestone overlies the oolitic-skeletal grainstone of the Salem across most of the Illinois Basin. Regionally, the lower part of this cherty mudstone sequence grades basinward into the uppermost grainstone cycle of the Salem (figs. 29 and 30). In southeastern Illinois, however, the cherty mudstones are in sharp contact with the underlying fine-grained portion of the uppermost Salem cycle (fig. 25). The geophysical horizon at this contact is traceable across most of southeastern Illinois into southwestern Indiana, apparently maintaining its stratigraphic position with respect to higher marker beds.

The St. Louis consists predominantly of cherty lime mudstone (fig. 31A) interlayered with skeketal wackestone (fig. 31B), skeletal packstone, microsucrosic dolomite (fig. 31C), and anhydrite (fig. 31D). Chert in the St. Louis usually is nodular and similar in size and shape to nodular anhydrite; this suggests that most of the chert is a replacement of former evaporites. Near the center of the Illinois Basin (e.g., White County, Illinois), the St. Louis consists almost entirely of cherty lime mudstone and only a few interbeds of skeletal wackestone, packstone, and dolomite. Around the margins of the basin and along the La Salle Anticlinal Belt, however, the St. Louis becomes more diverse, and fenestral structures (fig. 31E), stromatolitic laminations (fig. 31E), laminated crusts, and possible desiccation surfaces are common.

Microsucrosic dolomite beds that range from a few inches to 30 feet in thickness are interspersed throughout the St. Louis. Because these dolomites are uniformly fine grained and rarely show any relict textures (fig. 31C), they probably formed by early dolomitization of relatively pure lime muds. Dolomite beds commonly grade into lime mudstone above and below across an interval of just a few inches (fig. 31F). Many of these dolomite beds can be traced for tens of miles in the subsurface. They are

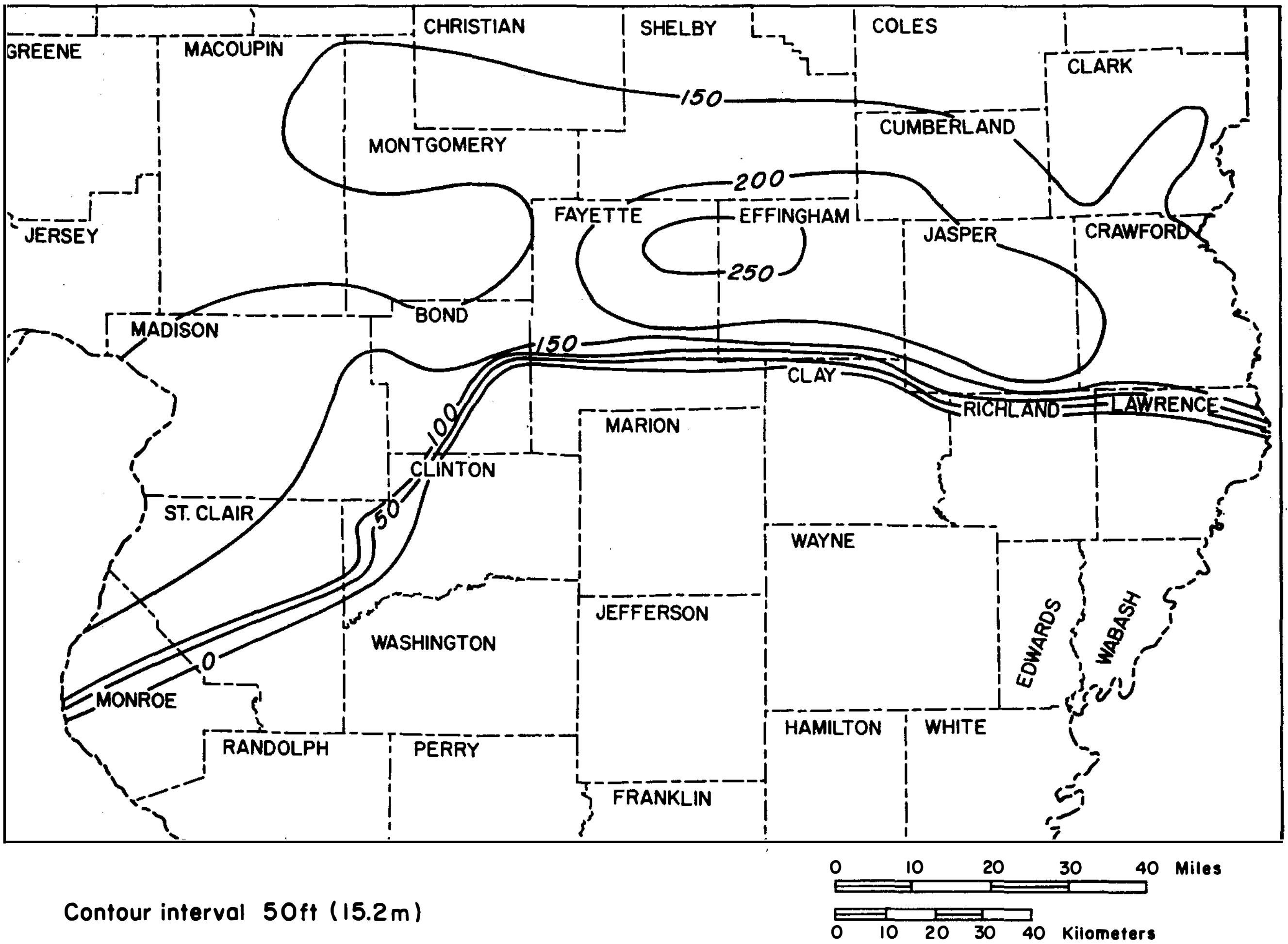


Figure 29. Thickness of the fine-grained facies of the St. Louis Limestone that is stratigraphically equivalent to the Salem Limestone (from Lineback, 1972).

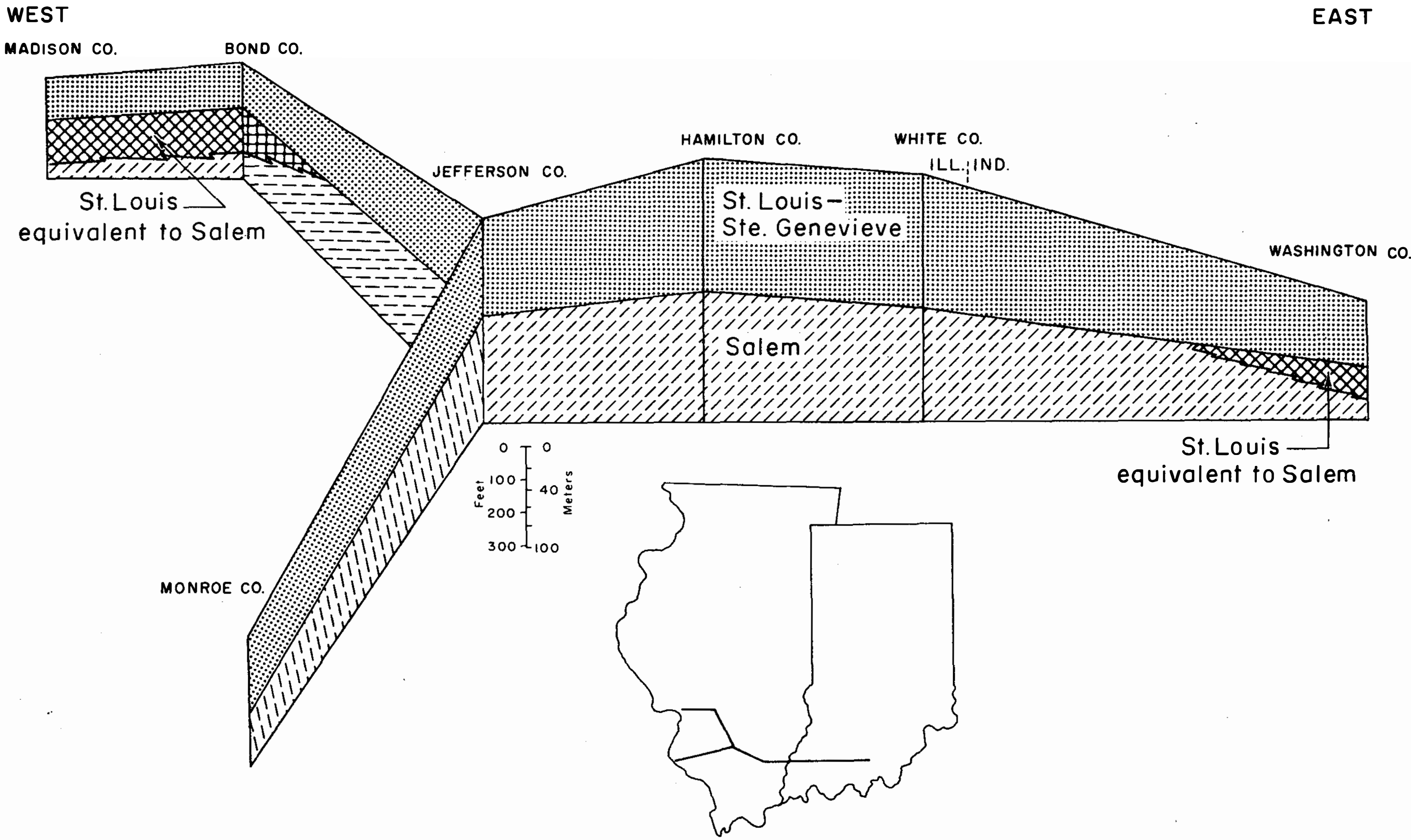


Figure 30. Diagrammatic cross section across the Illinois Basin showing the stratigraphic relationships between the Salem and St. Louis Limestones (from Lineback, 1972).

among the best marker beds in the upper Valmeyeran sequence. Because microsucrosic dolomite beds in the St. Louis have high porosities (∿ 25%) and moderate permeabilities they are outstanding potential oil reservoirs. St. Louis production (mostly from microsucrosic dolomite beds) occurs throughout the Illinois Basin but has been extensively developed in only a few small areas (Bristol and Howard, 1966). These dolomite beds are probably a significant overlooked pay zone in the Illinois Basin.

The fine-grained limestone and dolomite beds of the St. Louis are believed to have been deposited in shallow, subtidal, highly restricted environments similar to modern Florida Bay. The abundance of subaerial exposure indicators and evaporites shows that intertidal and supratidal conditions were predominant around the margins of the basin during St. Louis deposition. The transition to higher energy deposition of grainstone in the overlying Ste. Genevieve Limestone probably was a response to a slight rise in sea level.

STE. GENEVIEVE LIMESTONE DEPOSITION

The Ste. Genevieve Limestone is the uppermost Valmeyeran carbonate unit in the Illinois Basin. It is also the most variable—characterized by thin interbedding of diverse lithologies and by limited lateral extent of individual beds. Few beds are traceable for more than a few miles in the subsurface.

The Ste. Genevieve is similar to the Salem Limestone in that it consists of several cyclic repetitions of calcilutites and calcarenites (fig. 33). Fine-grained intervals include skeletal-pelletal wackestone (fig. 32A), lime mudstone (fig. 32B), and sucrosic dolomite. Coarse-grained intervals are predominantly oolitic-skeletal grainstone (fig. 32C) and lesser amounts of skeletal packstone and sandy calcarenite (fig. 32D). Minor amounts of quartz sandstone and shale are present in the upper part of the formation.

Oolitic grainstone beds in the Ste. Genevieve are probably of most interest to the petroleum geologist because they include the famous "McClosky sands" (fig. 33) that are the major pay zone in many Illinois Basin oil fields. Ste. Genevieve oolite bodies are generally flat-bottomed, convex-upward lenses (Carr, 1973; Choquette and Steinen, 1980) (fig. 34) that rarely extend more than a few miles (fig. 35). They usually thin and grade laterally into dense skeletal wackestone and mudstone; these conditions are ideal for stratigraphic entrapment of oil and gas. Detailed mapping of Ste. Genevieve reservoirs usually reveals that they are subdivided into several separate reservoirs by re-entrants that cut across the oolite bars (fig. 36). The re-entrants are similar in size and orientation to tidal channels on modern oolite shoals. Their common occurrence emphasizes the importance of understanding carbonate deposition when developing a field. Dry holes do not necessarily indicate the final limit of a reservoir.

Oolitic limestones in the Ste. Genevieve almost invariably are cross bedded, but dips may be so low that parallel lamination seems to be present on the scale of a core slab (fig. 32C). Although topography across the Illinois Basin was probably very subdued during Ste. Genevieve deposition, detailed

Figure 31. Common St. Louis Limestone facies.

A) Cherty mudstone with sparse fenestrate bryozoan fronds in upper part. The chert in this sample is a single bed; more common are small cauliflower or lenticular shaped nodules. Superior Oil #33 E.S. Greathouse core, 3085 ft., 4-5S-14W, White Co., Illinois. Spot= 2 cm.

B) Skeletal wackestone with several sparry calcite filled brachiopods near middle of sample. Superior Oil #33 E.S. Greathouse core, 3024 ft., 4-5S-14W, White Co., Illinois. Spot= 2 cm.

C) Microsucrosic dolomite, illustrating the homogeneous texture typical of these beds. Superior Oil #33 E.S. Greathouse core, 3024 ft., 4-5S-14W, White Co., Illinois. Spot= 2 cm.

D) Nodular anhydrite in dolomitic mudstone matrix. Marathon Oil #21 R.M. Clark core, 1795 ft., 17-7N-13W, Crawford Co., Illinois.

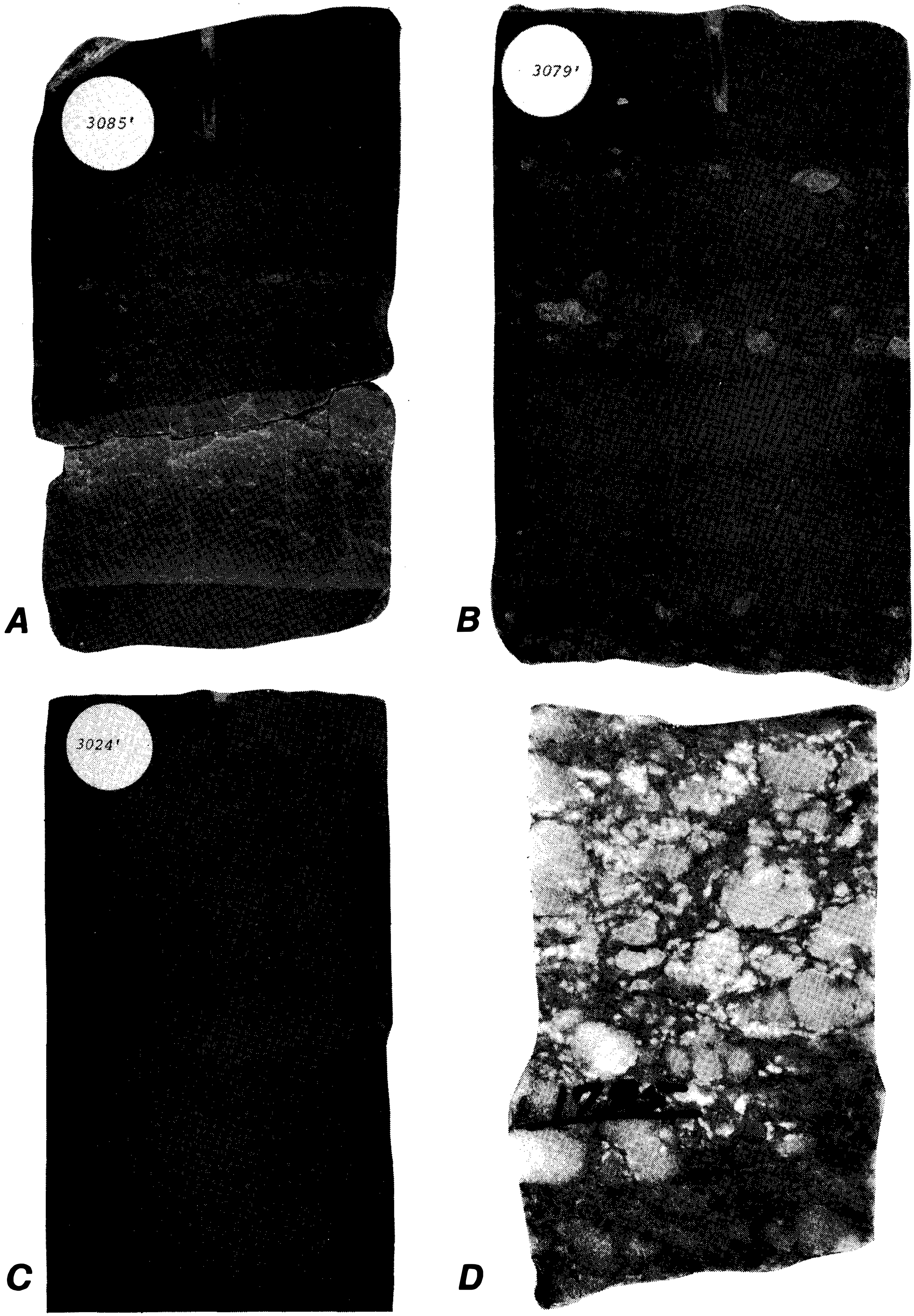
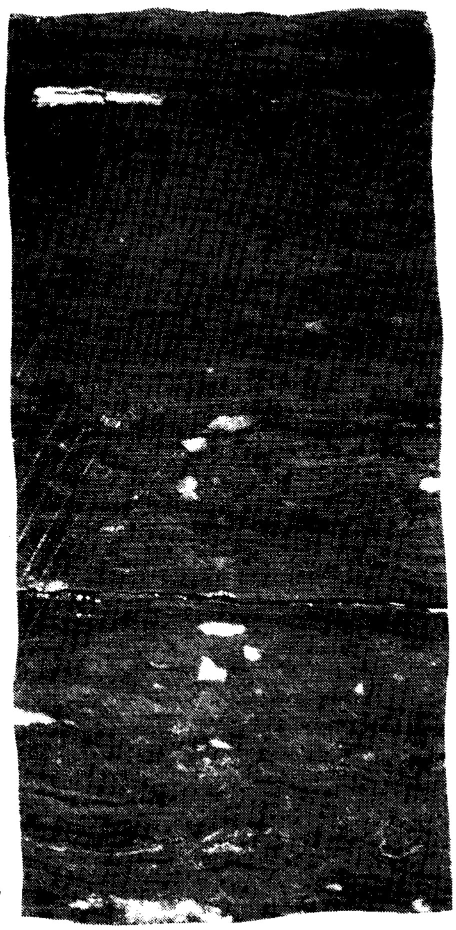

3085'
A
3079'
B
3024'
C
D

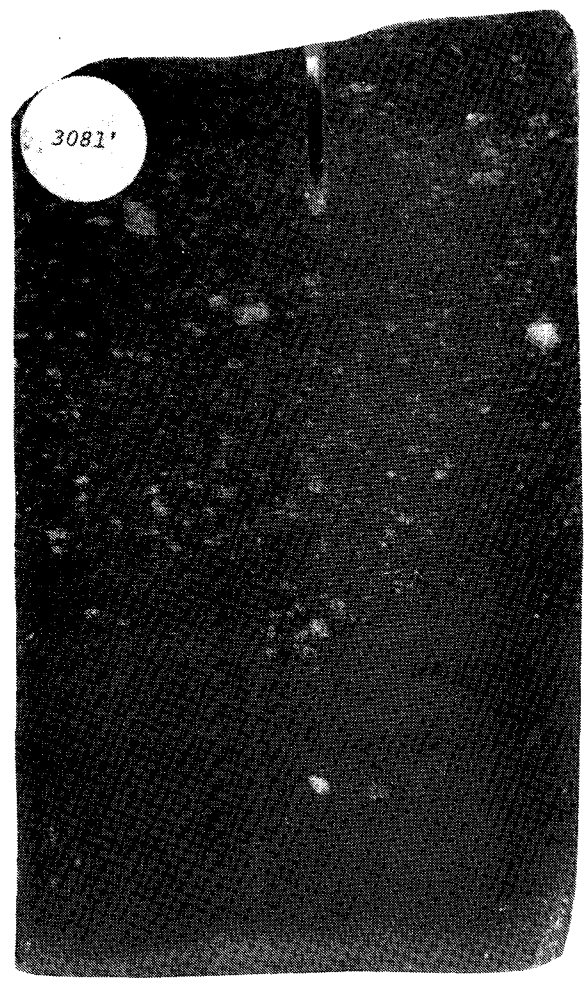
Figure 31 (continued)

E) Fenestral structures and stromatolitic laminations in dolomitic mudstone. Marathon Oil #21 R.M. Clark core, 1799 ft., Crawford Co., Illinois.

F) Contact between microsucrosic dolomite (below) and skeletal wackestone (above). Superior Oil #33 E.S. Greathouse core, 3081 ft., 4-5S-14W, White Co., Illinois. Spot= 2 cm.



E



F

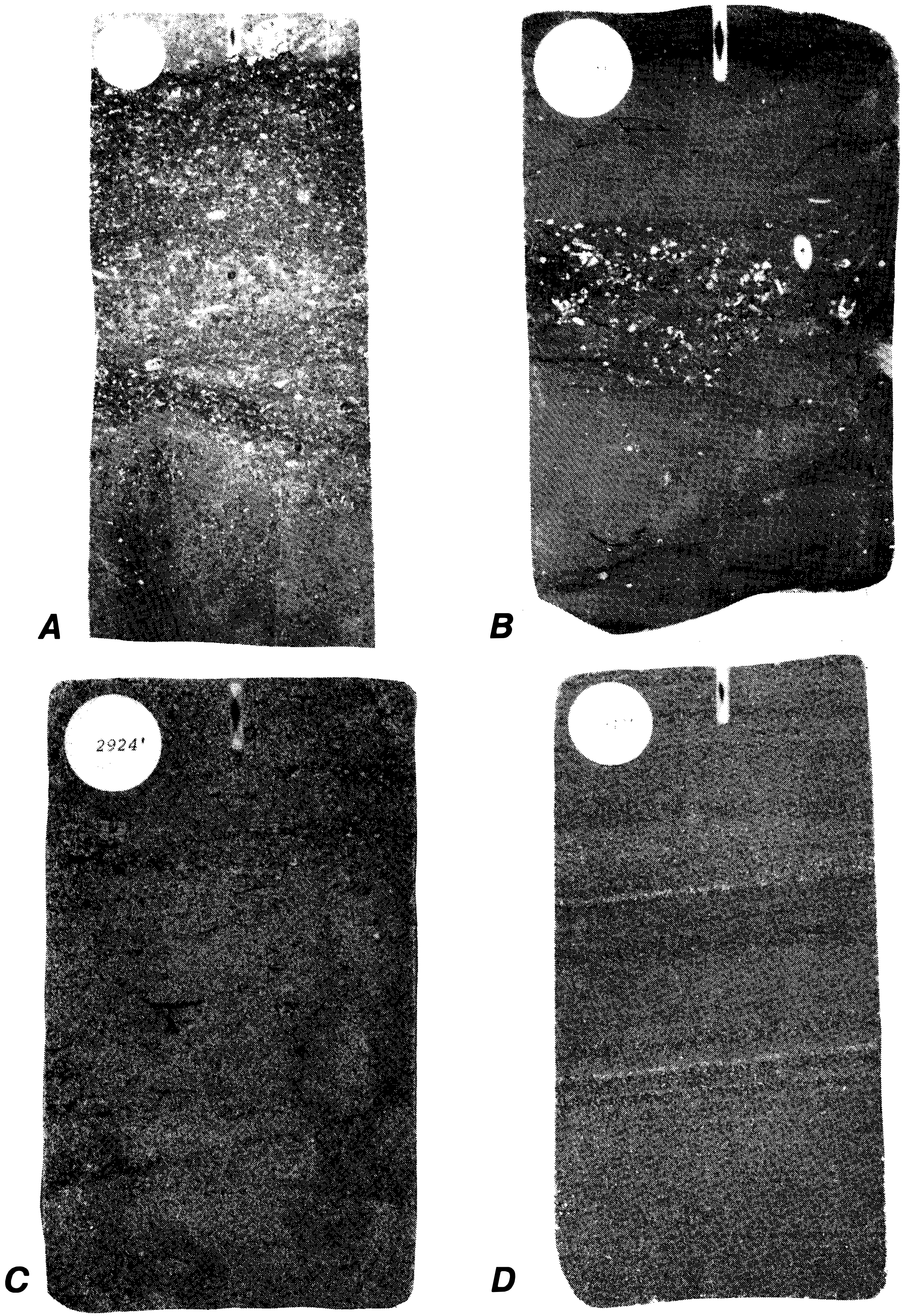
Figure 32. Common Ste. Genevieve Limestone facies. All samples are from the Superior Oil #33 E.S. Greathouse core, 4-5S-15W, White Co., Illinois. Spot in upper left corner of each slab is 2 cm across.

A) Skeletal packstone grading downward into wackestone. 2902 ft.

B) Skeletal mudstone with thin streaks of wackestone. 2914 ft.

C) Oolitic grainstone with faint cross bedding. 2924 ft.

D) Cross bedded sandy limestone, possibly equivalent to the Spar Mountain Sandstone member. 2947 ft.


A
B
2924'
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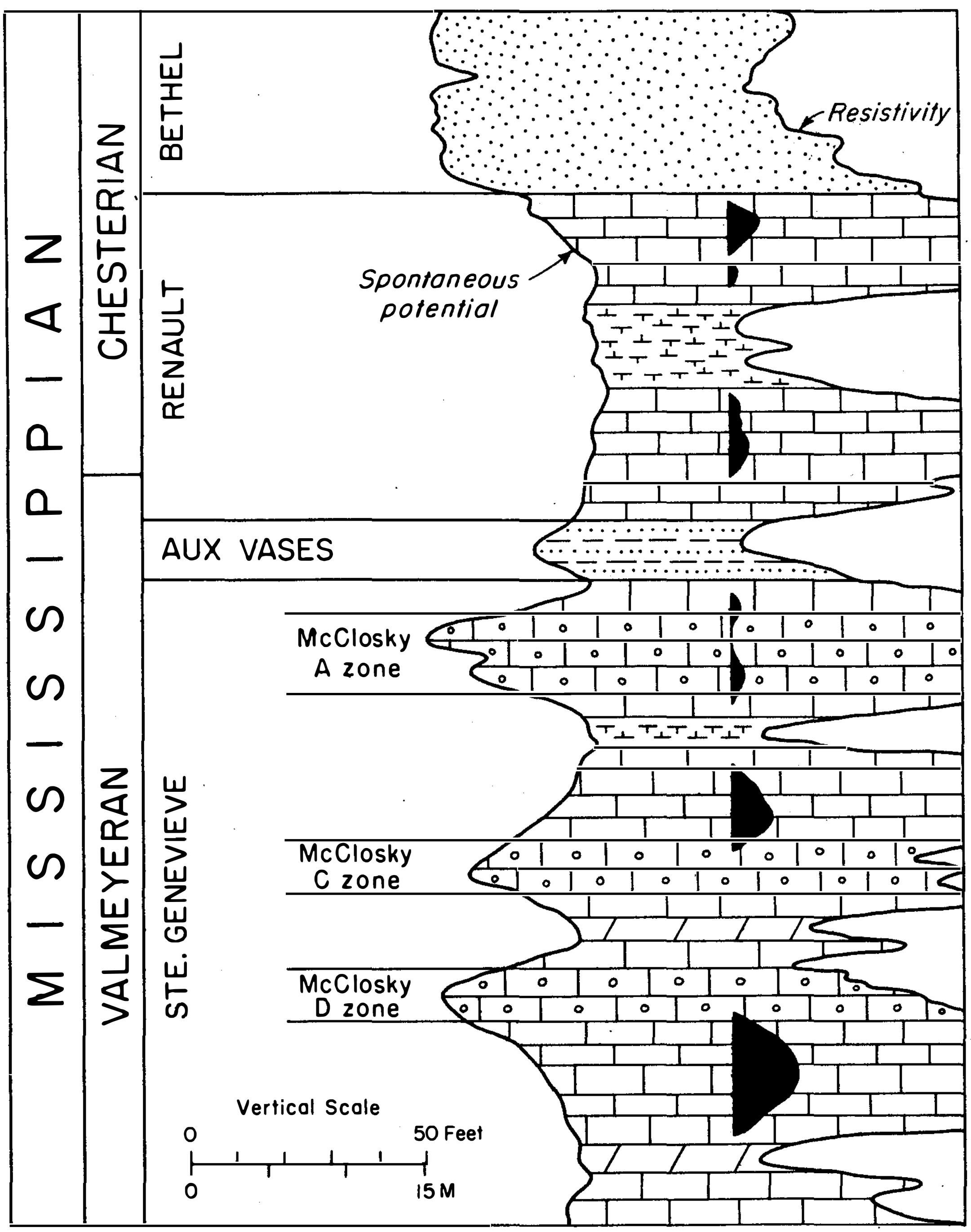


Figure 33. Schematic electric log and stratigraphic column showing position of McClosky porosity zones in the Ste. Genevieve Limestone of southeastern Indiana (from Carr, 1973).

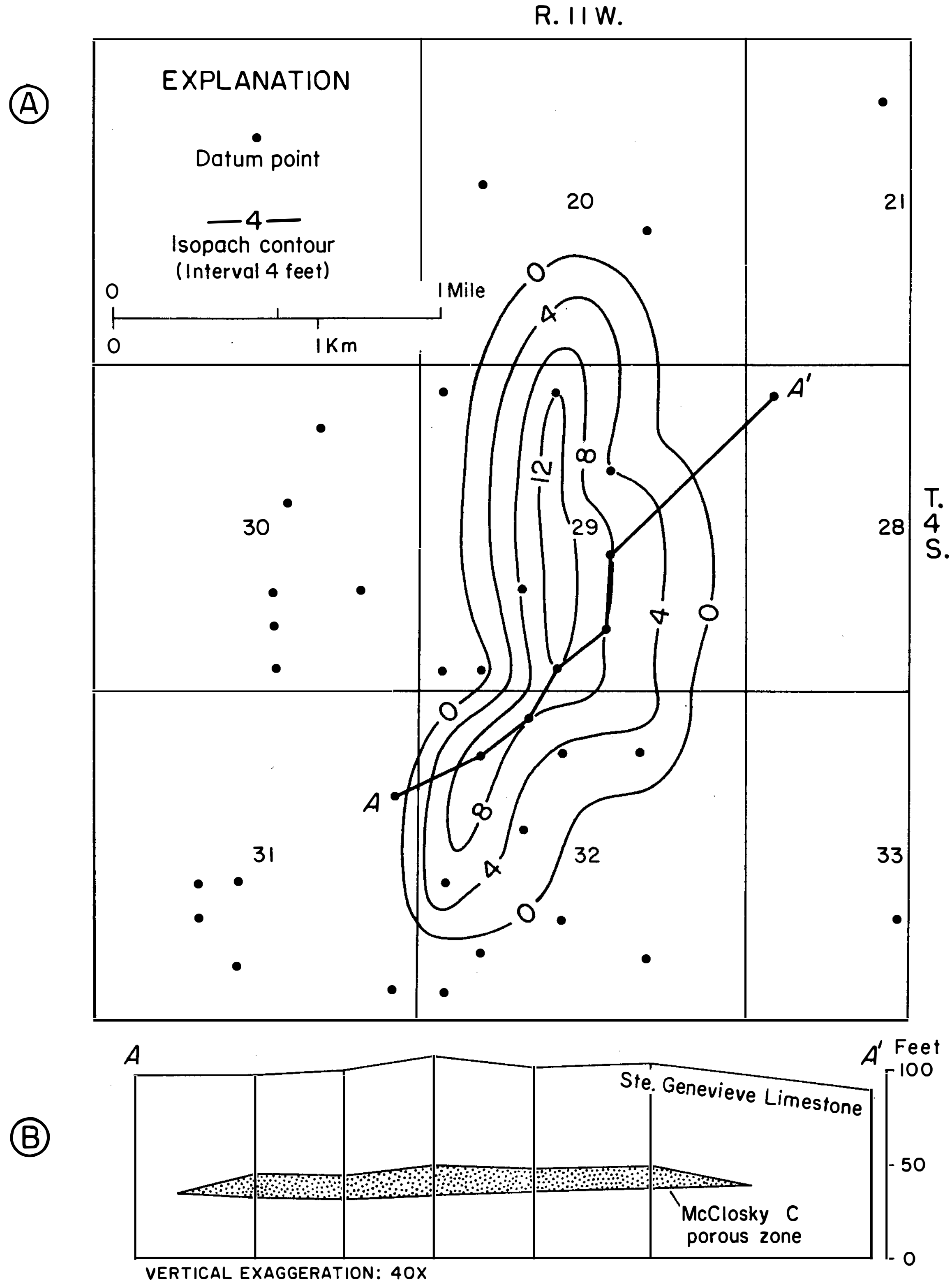


Figure 34. A) Isopach map of McClosky "C" porous zone, Ste. Genevieve Limestone, Martin Field, Vanderburgh County, Indiana. B) Cross section of porous zone. (From Carr, 1973.)

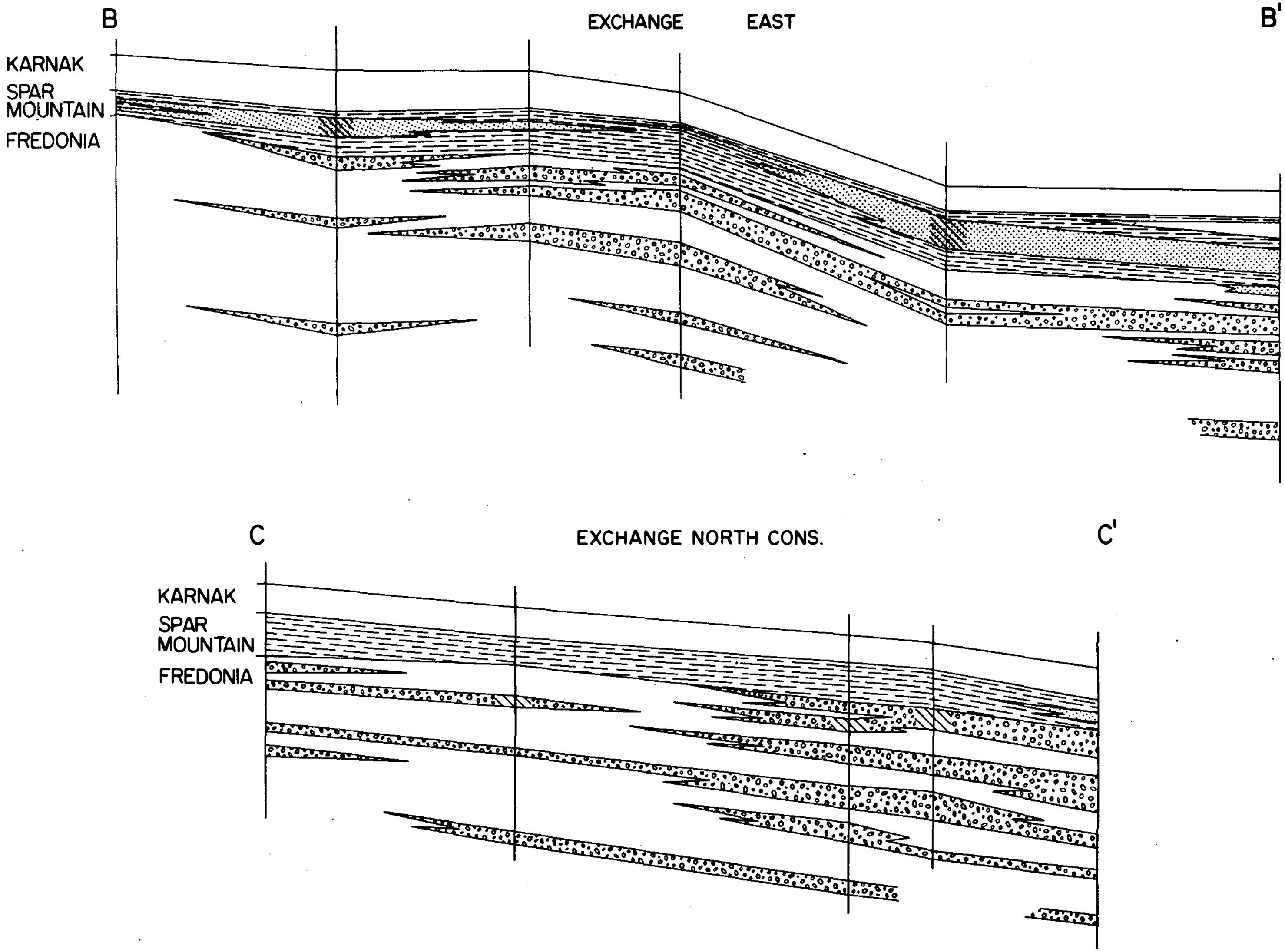


Figure 35. Structural cross sections showing lenticular oolitic limestone bodies in the Ste. Genevieve Limestone, Exchange area, Marion County, Illinois (from Stevenson, 1969).

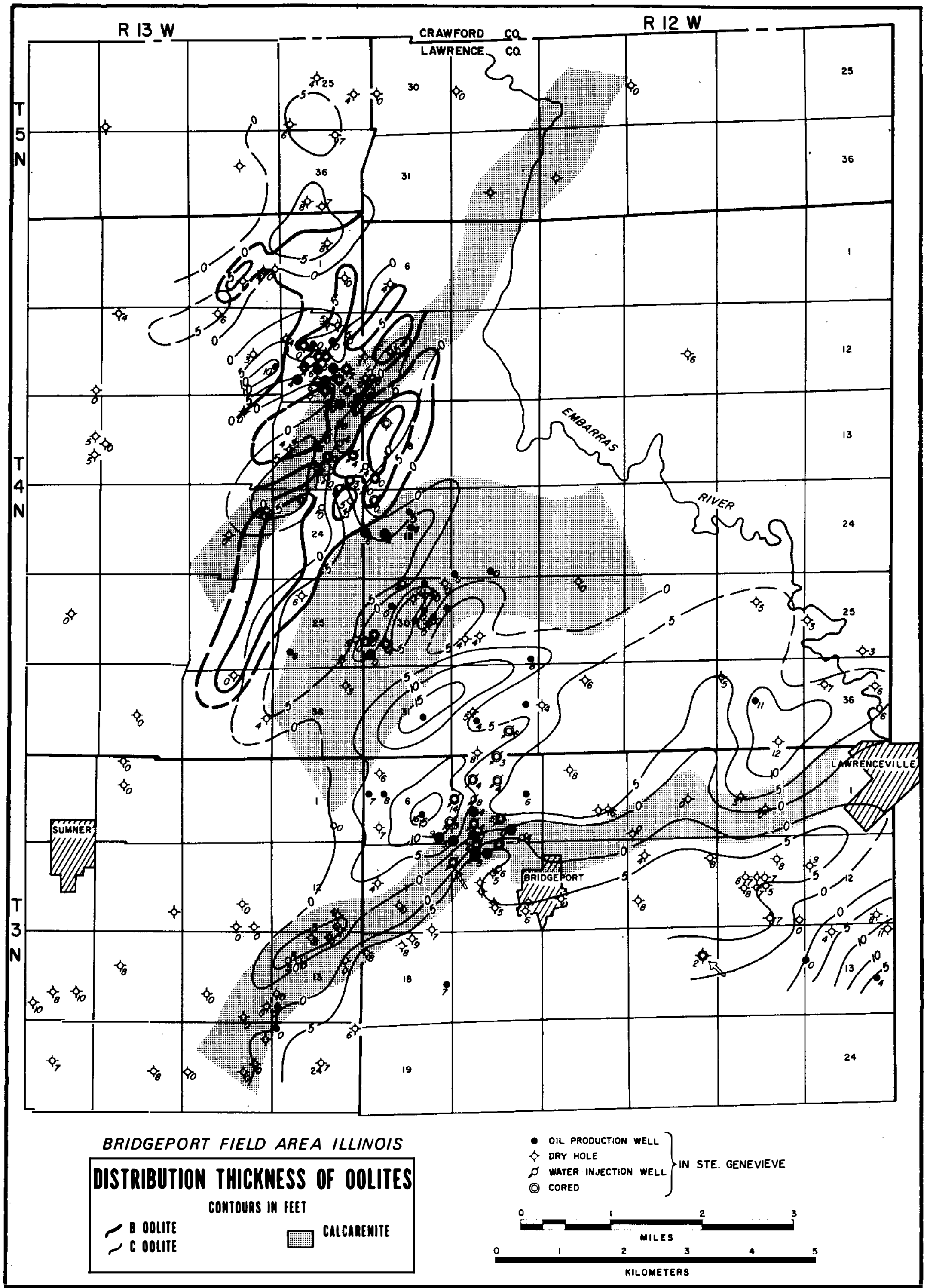


Figure 36. Distribution of "B" and "C" oolite-sand bodies in the Ste. Genevieve Limestone, Bridgeport Field, Lawrence County, Illinois. Oolites are localized along the flank of the LaSalle paleoshoal (from Choquette and Steinen, 1980). (Reprinted with permission of the Society of Economic Paleontologists and Mineralogists.)

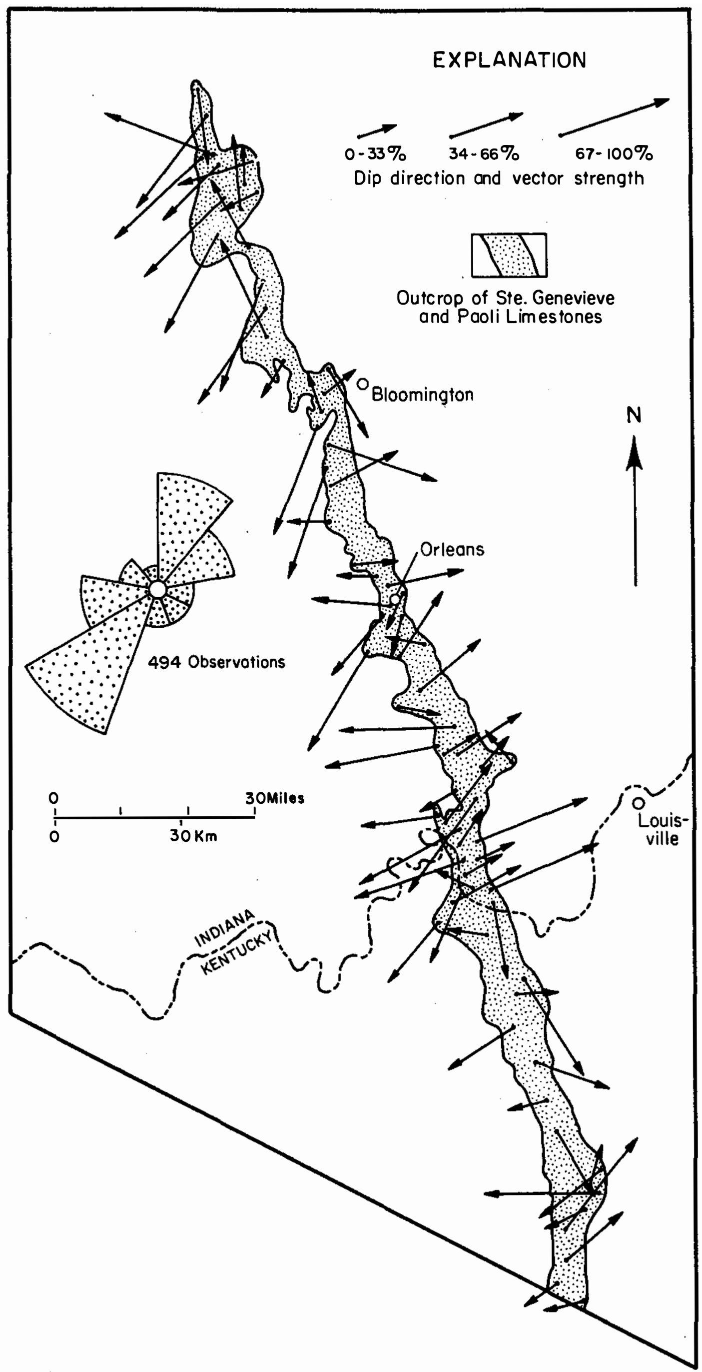


Figure 37. Crossbedding directions in the Ste. Genevieve and Paoli Limestones in Indiana and north-central Kentucky (from Carr, 1973).

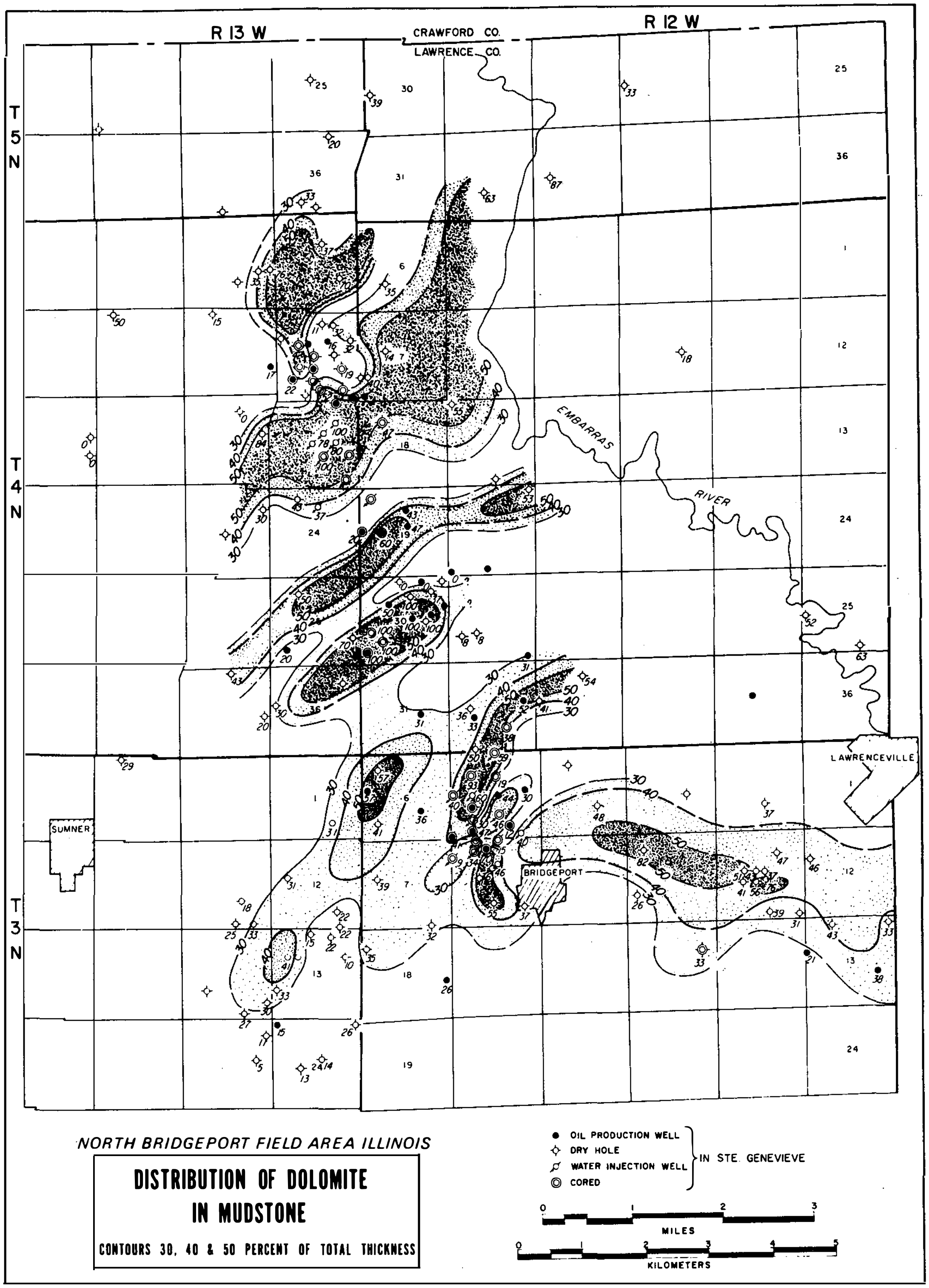


Figure 38. Distribution of dolomite in mudstone facies of the Ste. Genevieve Limestone, Bridgeport Field, Lawrence County, Illinois. Dolomite is most abundant beneath the thick oolite bars shown on figure 36. (From Choquette and Steinen, 1980; reprinted with permission of the Society of Economic Paleontologists and Mineralogists.)

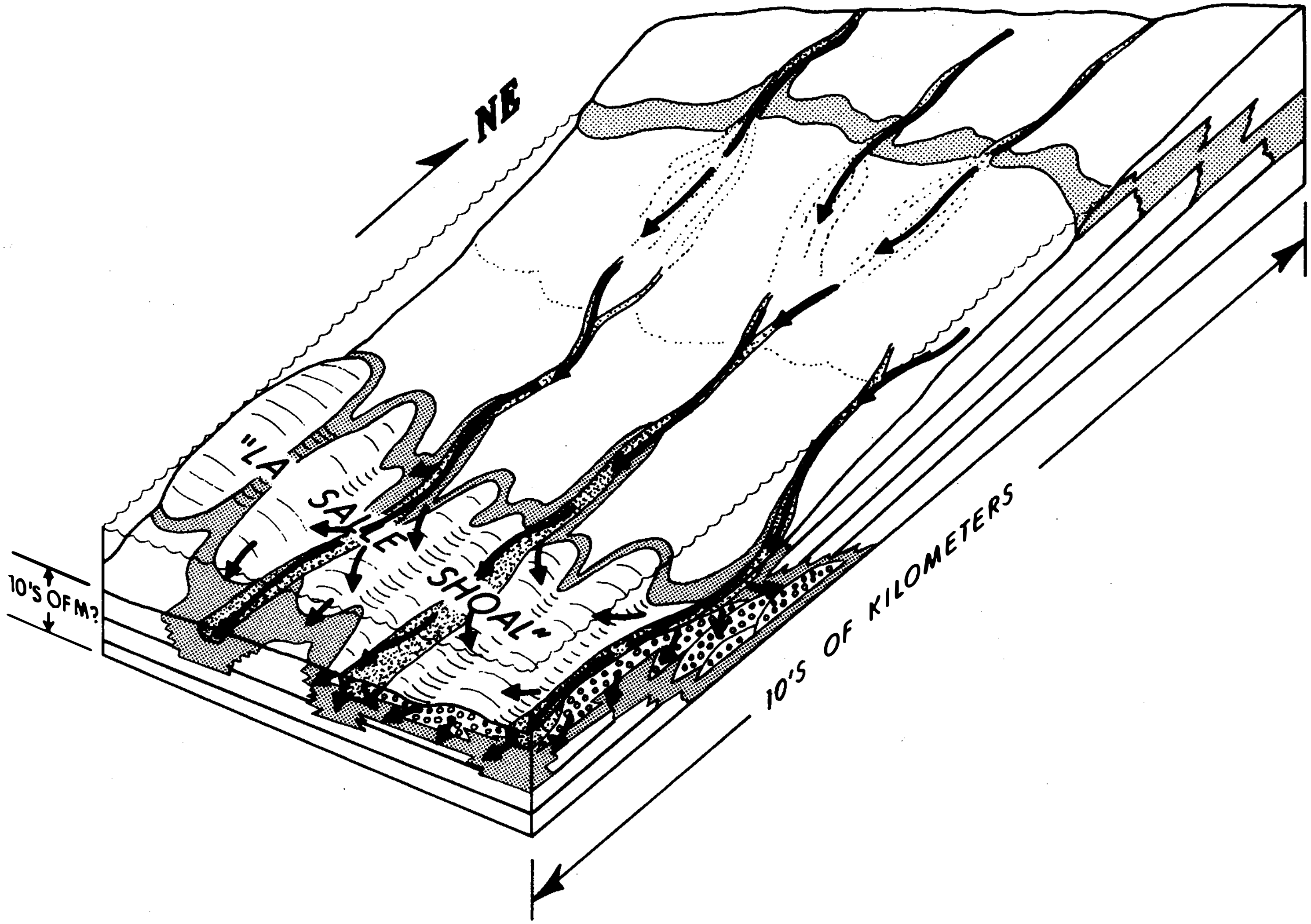


Figure 39. Possible model for dolomitization of lime mud sediments in the upper part of the Ste. Genevieve Limestone. Groundwater of mixed marine and meteoric origin is fed from a subaerial recharge area to the northeast and gains access to buried lime muds via carbonate sand conduits. Most dolomitization occurs beneath these porous sand bodies. (From Choquette and Steinen, 1980; reprinted with permission of the Society of Economic Paleontologists and Mineralogists.)

studies of cross-bedding dip directions still reveal a strong basinward (south and southwestward) trend (fig. 37). Local variations can be expected that are due to the influence of basin anticlines which were well expressed by this time.

Sucrosic dolomite beds similar to those in the St. Louis Limestone also occur in the Ste. Genevieve. Choquette and Steinen (1980) observed that the thickest dolomite beds underlie the axes of oolite bodies (figs. 36 and 38). They suggested a model for dolomitization of lime mud sediments in the Ste. Genevieve Limestone based on this relationship and postulated that meteoric waters gained access to the lime muds by movement through porous carbonate sand aquifers (fig. 39). Dolomitization occurred in the zone of mixing between fresh meteoric waters and connate marine waters beneath the oolite bodies. If this model is correct, it suggests considerable potential for discovery of deeper pay zones in porous dolomites beneath known Ste. Genevieve oil pools.

Grainstone cycles in the Ste. Genevieve are thinner and less clearly developed than similar cycles in the Salem Limestone. The differences between the fore-bar (open marine) and back-bar (lagoonal) facies, which are so apparent in the Salem, are not clearly developed in the Ste. Genevieve. Perhaps a more detailed study than we have undertaken will reveal significant differences. In our estimation, however, environments in the Ste. Genevieve probably were more variable over short distances than in the Salem. Oolitic sand bodies in the Ste. Genevieve were smaller, shorter lived, more closely spaced to one another, and migrated across much shorter distances than their counterparts in the Salem. Scattered, isolated bars may have formed over wide areas of the Ste. Genevieve sea, rather than in well-defined linear belts like typical, modern oolite shoals. Despite these differences, the Ste. Genevieve reflects a depositional setting that is fundamentally similar to the Salem; that is, a complex of shallow, high energy carbonate sand shoals surrounded by low energy open marine and lagoonal areas where lime muds were deposited.

THE TRANSITION TO CLASTIC DEPOSITION: AUX VASES AND SPAR MOUNTAIN SANDSTONES

Despite the vast quantities of oil that have been produced from these sandstones, remarkably little work has been published on their origin, characteristics, or stratigraphic relationship to the underlying carbonates. Because of the lack of detailed investigations, many stratigraphers consider the Aux Vases-Ste. Genevieve relationship to be one of the greatest unsolved stratigraphic problems in the Illinois Basin.

Correlations by Swann and Atherton (1948) and Swann (1963) have shown that much of the type Aux Vases Sandstone of the Mississippi River Valley is equivalent in age to the upper part of the Ste. Genevieve Limestone in the central and eastern portions of the Illinois Basin (fig. 40). The contact between the Ste. Genevieve and the Aux Vases is conformable, but is marked by a series of downward steps to the west as the upper limestone beds grade westward into sandstone. Most of this facies relationship occurs between the Aux Vases and the Joppa Member of the Ste. Genevieve, a sandy limestone often referred to as the "Aux Vases lime." The underlying Karnak Member of the Ste. Genevieve, however, also grades into the Aux Vases in western Washington County, Illinois, and nearby areas. The Spar Mountain Sandstone

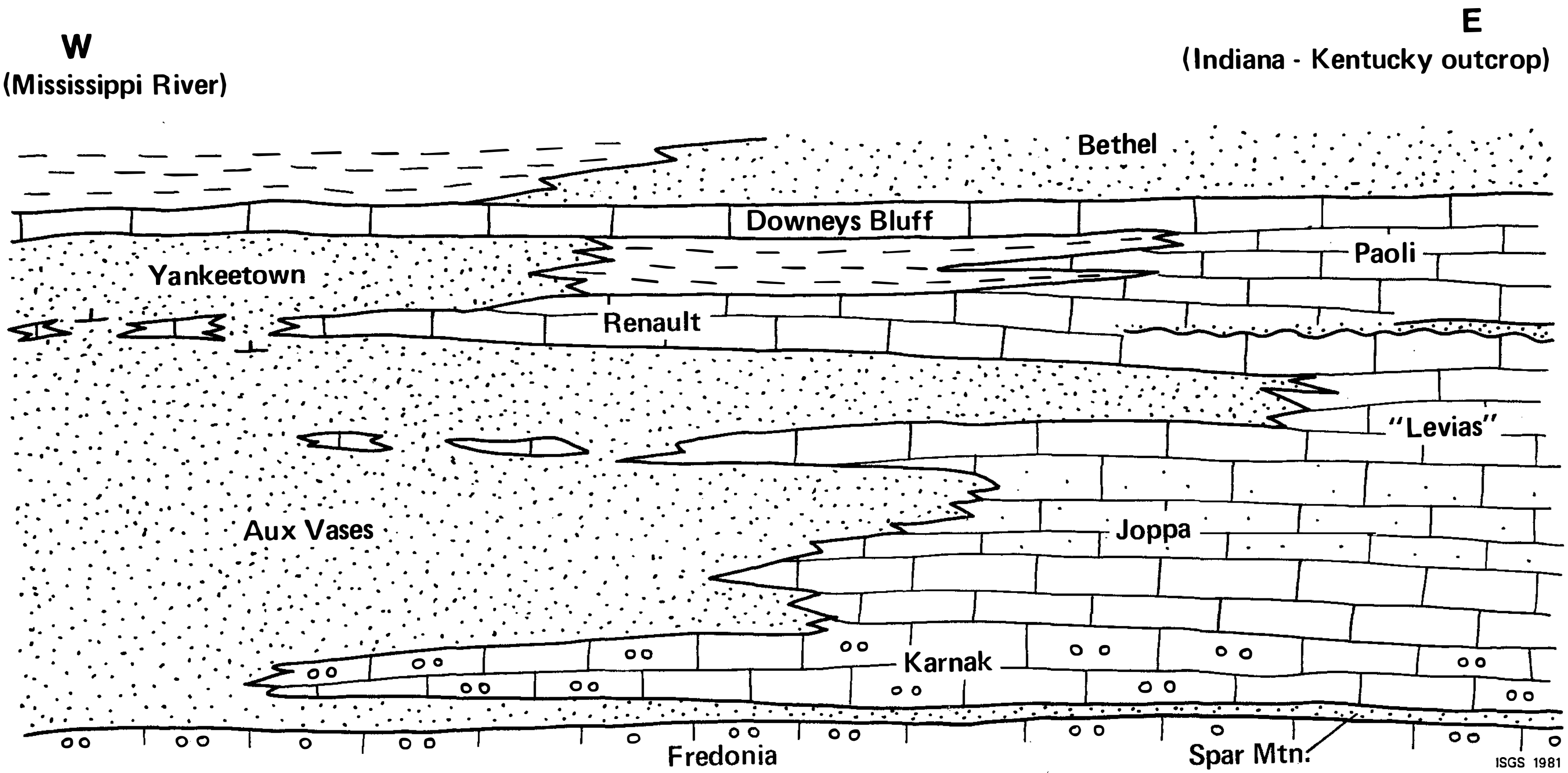


Figure 40. Schematic stratigraphic cross section of lowermost Chesterian and uppermost Valmeyeran strata across the Illinois Basin. On the southwestern shelf of the basin this section is an almost unbroken sequence of sandstone, containing only minor limestone and calcareous intervals. The sands thin basinward and interfinger with marine limestones assigned to the Ste. Genevieve and Renault formations. On the eastern flank of the basin marine carbonate deposition was essentially uninterrupted and only a few sandy limestone intervals reflect the influence of clastic deposition to the west.

(commonly referred to as the "Rosiclare sand") persists across most of the Illinois Basin to the Indiana outcrop. In a north-south trending area of southwestern Illinois the Spar Mountain is apparently absent (see plate 1, Bristol and Howard, 1976), and in a few small areas the Spar Mountain thickens abruptly at the expense of the underlying Fredonia Member of the Ste. Genevieve. The Spar Mountain is essentially an early, eastward-extending tongue of the Aux Vases and merges with it in extreme western Illinois (fig. 40).

Few authors have ventured opinions on the depositional environment of the Aux Vases-Spar Mountain sequence. Apparently no one has attempted to explain the large-scale carbonate-clastic transition across the basin. Most geologists have assumed the Aux Vases was deposited in a fluvial-deltaic environment that was similar to the situation inferred for higher Chesterian sandstones (Potter, 1962; 1963). Comparison of the Aux Vases-Ste. Genevieve transition with the modern Persian Gulf, however, suggests a strikingly different interpretation.

In several areas along the western side of the Persian Gulf "shamal" winds have transported terrigenous quartz sand (in the form of large sand dunes) from the Saudi Arabian mainland across shallow subtidal carbonate environments (Shinn, 1973). Interdune ares near the coastline form a supratidal sabkha environment that is occasionally flooded by storm tides. Shallow ponds form in minor depressions and subsequently dry up to produce crusts of salt, gypsum, and dried algal mat. Aeolian transport of quartz sand occurs under the influence of northwestern "shamal" winds that prograde the quartz sand dunes and supratidal flat environment eastward over marine carbonate sediments. Shinn (1973) suggested seven criteria that might be useful to distinguish analogous quartz sands in ancient rocks from deltaic sands or tidal-bar complexes. These are:

(1) Absence of clay layers (very common in river deltas).

(2) Absence of freshwater fauna (also common in deltas).

(3) Open marine fauna in adjacent marine carbonates having little or no evidence for the brackish or fresh-water influence expected around river mouths.

(4) Steep planar accretion bedding showing uniform dip directions.

(5) Upward increase in grain size.

(6) Lack of fining-upward channel sandstones.

(7) Presence of pore-filling dolomite or evaporite minerals in sand.

The Aux Vases Sandstone meets most of the above criteria, and the Aux Vases-Ste. Genevieve facies relationship is certainly similar to the Persian Gulf situation. If this analogy is correct, then most of the Aux Vases through Yankeetown interval in the Mississippi River Valley area (fig. 40) probably represents eolian dune sands transported from the north and west. Potter

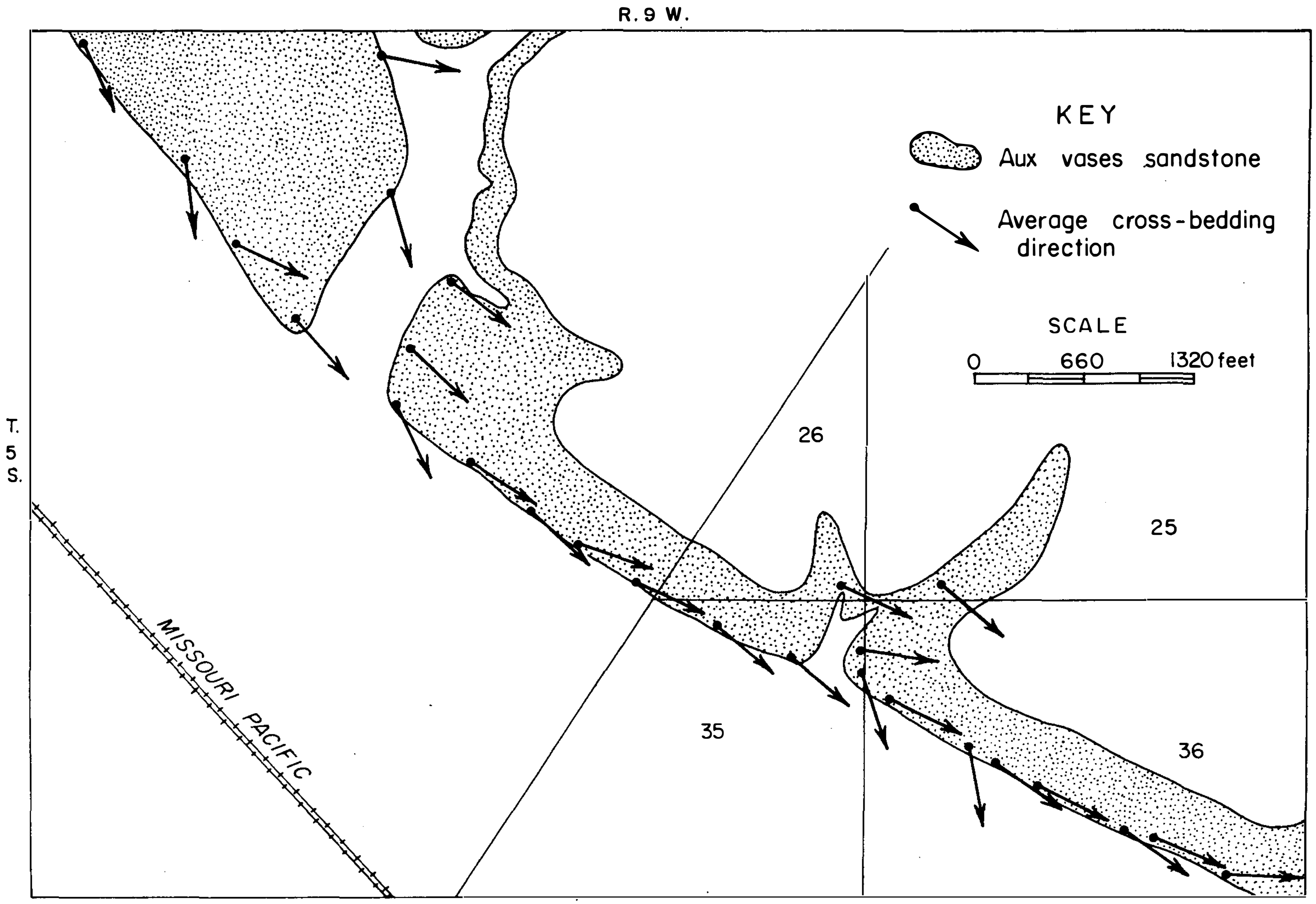


Figure 41. Cross-bedding in the Aux Vases Sandstone, Randolph County, Illinois (from Potter, 1962).

(1962) documented a strong southeastward cross-bedding orientation for the Aux Vases sands in Randolph County, Illinois (fig. 41). This trend is virtually perpendicular to the dominant southwestward transport of most Chesterian sands. In Randolph County, the Aux Vases is characterized by thick, high-angle cross-bedded units having few ripple marks or other sedimentary structures. This is fully consistent with an eolian origin.

The Aux Vases is believed to grade eastward from an eolian sandstone into a shallow subtidal, marine sandstone. Sand transported into the marine carbonate environment could have been widely redistributed by currents, apparently toward the east for the most part. Because the supply of quartz sand probably was limited, the sands thin eastward and eventually grade into sandy marine limestone (Joppa and equivalents). Cores from the central portion of the Illinois Basin indicate that sandstone of the Aux Vases is mostly massive to bioturbated, with many thin beds of low angle cross-bedded and ripple marked sandstone (fig. 42).

This interpretation is both speculative and highly simplified. However, in the absence of any published alternatives we offer it as a thought-provoking incentive to new studies of these rocks and their place in the sedimentologic history of the Illinois Basin.

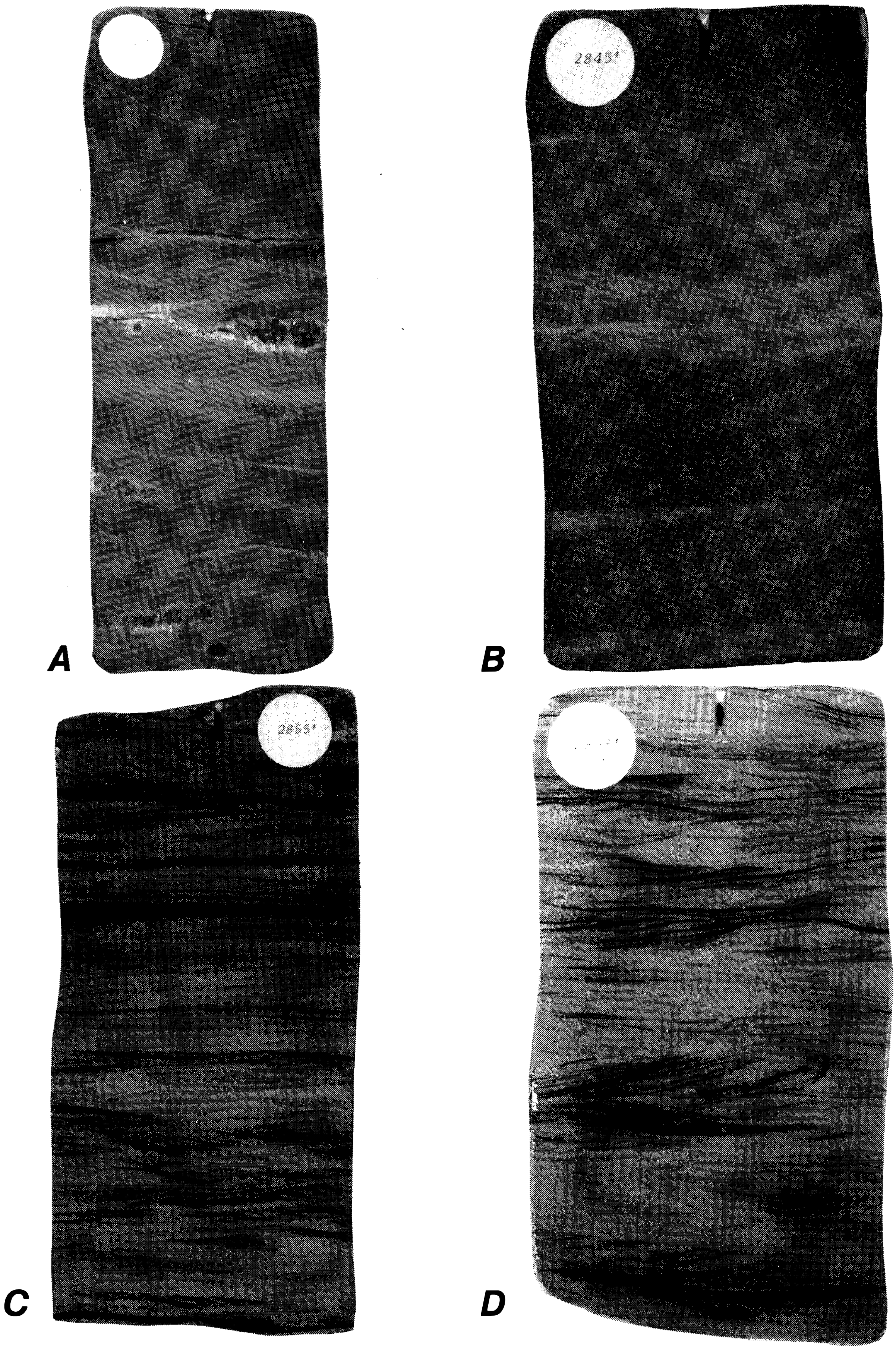
Figure 42. Common Aux Vases Sandstone facies from the deep part of the Illinois Basin. All samples are from the Superior Oil #33 E.S. Greathouse core, 4-5S-14W, White Co., Illinois. Spot in upper left corner of each slab is 2 cm across.

A) Bioturbated sandstone. 2841 ft.

B) Massive to faintly laminated sandstone. 2845 ft.

C) Small scale cross laminated sandstone, with possible climbing ripple lamination in lower part. 2855 ft.

D) Small scale cross laminated sandstone. 2858 ft.


2845'
2855'
A
B
C
D

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