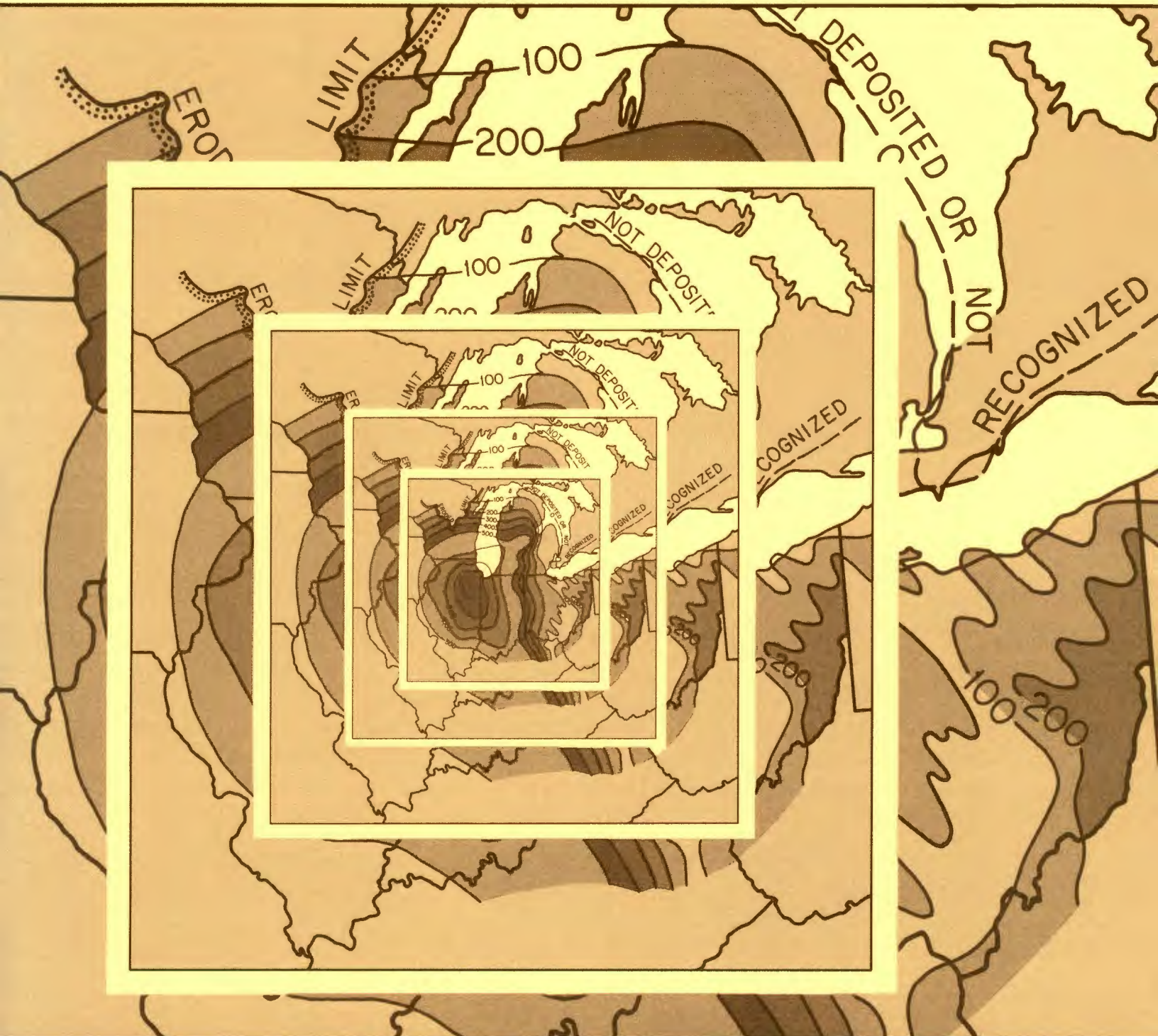


ATLAS OF EARLY AND MIDDLE PALEOZOIC PALEOGEOGRAPHY OF THE SOUTHERN GREAT LAKES AREA

Special Report 32



State of Indiana
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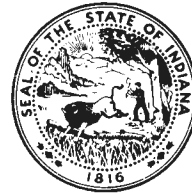
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AUTHORS OF THIS REPORT: John B. Droste, Department of Geology, Indiana University, and Robert H. Shaver, Indiana Geological Survey and Department of Geology, Indiana University, Bloomington, IN 47405.

Atlas of Early and Middle Paleozoic Paleogeography of the Southern Great Lakes Area

By JOHN B. DROSTE *and* ROBERT H. SHAVER

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 32



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Atlas of Early and Middle Paleozoic Paleogeography of the Southern Great Lakes Area

By JOHN B. DROSTE *and* ROBERT H. SHAVER

Introduction

STRATEGY OF THE ATLAS

In earlier presentations (for example, Droste, Shaver, and Lazor, 1975; Droste, Rexroad, and Shaver, 1980) we have stressed that advancement of tectono-sedimentational knowledge of the southern Great Lakes area has been conditioned by (1) the provincialism of most studies and (2) the tendency to think of ancient Paleozoic regional structure too much in terms of present regional structure (fig. 1A).

The first conditioning mentioned above has been a necessary first step in overall study of this area as most individual geologists concentrated in one basin or another or in outcrop geology. As a result, necessarily somewhat independent and contradictory geologic histories have evolved for the Illinois Basin and the two other basins of special concern here, the Michigan and Appalachian Basins. Moreover, some classically generated concepts for the areas of the Cincinnati, Kankakee, Findlay, and Algonquin Arches and the Niagara Escarpment have remained too long uncoordinated with basin-developed knowledge. In this realization we have suggested that regional studies in the Indiana area, extended among three basins and integrating classic outcrop geology, are important keys to improved, integrated regional concepts.

Awareness of the second conditioning mentioned above has resulted in our proposal of such middle Paleozoic paleostructures as the Wabash Platform (Droste, Shaver, and Lazor, 1975) and the Vincennes Basin. (See fig. 1B.) Such ancient features are to be contrasted with or considered as progenitors of present structures.

This new atlas continues this idea, and it takes advantage of several presently enabling circumstances. The first of these is our many years of study of lower and middle Paleozoic rocks extending from subsurface to outcrop areas, which is augmented by the work of many other Indiana-based professional geologists and graduate students. This work has included the collection of many subsurface data that are repositated at several midwestern and southern state surveys. These data form much of the basis for the thickness and paleogeographic maps presented here. Carl B. Rexroad's continuing study of conodont biostratigraphy, which ranges in our study area from Whiterockian (lower Middle Ordovician) rocks into Pennsylvanian rocks, is a vital coordinating key.

Another strategic enabling circumstance has been completion of a comprehensive correlation chart for the midwestern basins and arches region (Shaver and others, 1983) in the project on Correlation of Stratigraphic Units in North America (COSUNA, managed by the American Association of Petroleum Geologists). (See fig. 2.)

EARLIER FACILITATING STUDIES

We have mentioned above our own special interests and facility. These are mutually enforced by and have much of their bases in extant regional summaries of several kinds. The proceedings from two system-scale symposia are noteworthy, one each on the Ordovician (Bassett, 1976) and Devonian (Oswald, 1967). Five very useful examples of regional stratigraphic and partly economic treatments are by Freeman (1951, Silurian and Devonian, and 1953, Cambrian and Ordovician, of Kentucky and vicinity),

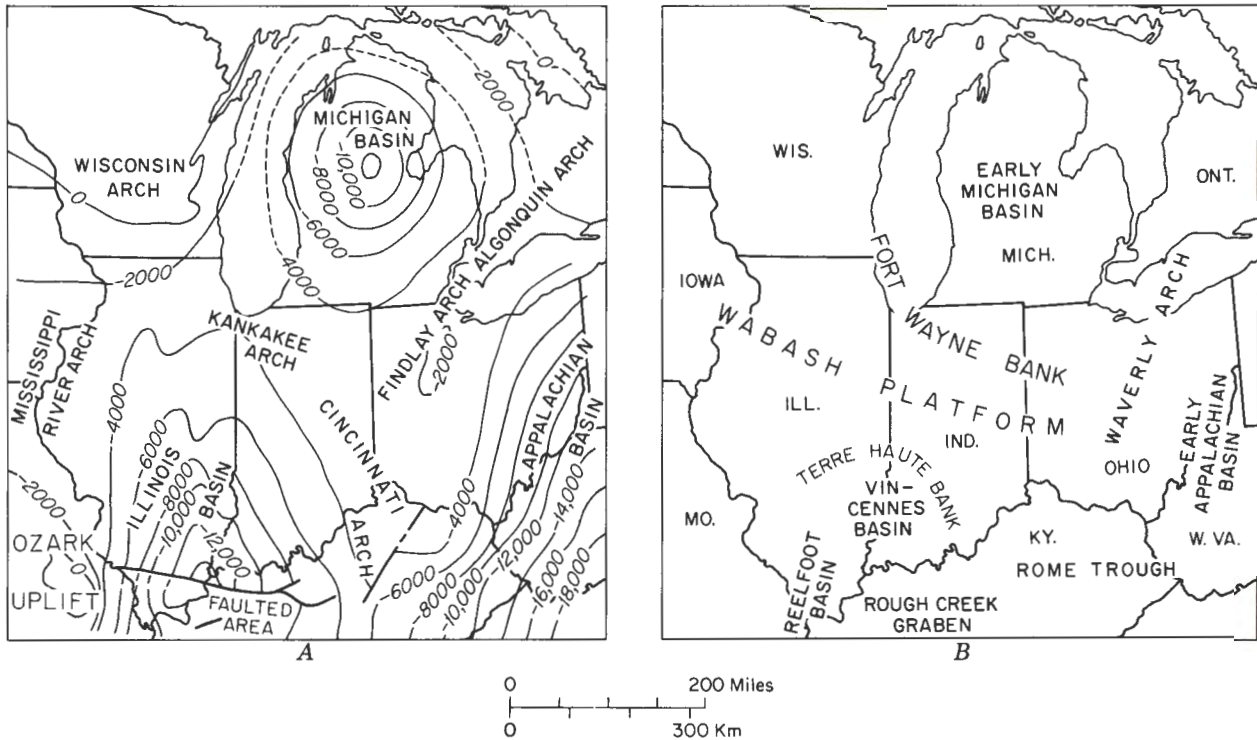


Figure 1. Maps showing area of study and major tectono-sedimental features, including those mentioned in the text. A, Present structure shown by contours drawn on top of Precambrian basement rocks (interval 2,000 feet); adapted from Bond and others (1971), King (1969), and Buschbach (1981). B, Loci of some early and middle Paleozoic features that differed wholly or partly from present structural features.

McGuire and Howell (1963, Cambrian and Ordovician, same area), Rickard (1969, Upper Silurian rocks in the lower Great Lakes area), and Bond and others (1971, general for the Illinois Basin and adjoining areas).

Three state-survey publications provide statewide systematic treatments of rock-unit stratigraphy. Most remarkable is the "Handbook of Illinois Stratigraphy" (Willman and others, 1975), which includes paleogeographic and sedimentologic interpretation. The others are by Lilienthal (1978, a series of interwoven and geophysically coordinated cross sections systematically providing stratigraphic data for the entire column throughout the Southern Peninsula of Michigan) and by Shaver and others (1970, systematic presentation of stratigraphic interpretations and facts for all then-current rock-unit names commonly used in Indiana).

Significant special topics have been pre-

sented by Wones (1980, on the Caledonides in the United States), Ruppel and Walker (1977, on Middle Ordovician ecostratigraphy of the Southern Appalachians), and ORSANCO (1976, on Cambrian sandstones). Paleolatitude data have been adapted from Scotese and others (1979) and Ziegler and others (1979).

Many other significant references are cited in the section presenting the main body of paleogeographic maps. The most recent and most significant are favored, and we regret that a great many pertinent publications are not mentioned specifically. Interpretations and summaries of the type presented here necessarily rest ultimately on a great and long collective effort.

ORGANIZATION OF THE ATLAS

The atlas presents 22 paleogeographic maps ranging in their coverage from Late Cambrian through Middle Devonian settings. (See fig. 2

for representative time intervals.) Dominant kinds of sedimentation as well as interpretative environments of deposition are given. These maps are accompanied by 20 thickness maps and one paleogeologic map chosen to document the interpretations. Most of the maps are arranged four to a page, and facing pages contain pertinent but deliberately brief explanations of the maps. A summary of interpretations drawn selectively from the maps and references concludes the atlas.

EXPLANATION OF TERMS

The interpretive paleoenvironmental maps show sedimentational patterns that are labeled in two sets of rather generalized terms. One set gives the general lithology and grain size of sediment that was accumulating at the indicated time. The other set states the general sedimentary environment especially as it relates to relative depths of water. The latter set includes the terms supratidal, intertidal, peritidal, and subtidal, which commonly are used with characteristic sedimentary structures and biotic features to describe modern environments.

Details of tidal influences in modern environments are easily noted, of course, and although tide-related terms have been used for ancient environments, their applicability is conceded to be much more tenuous. Especially for ancient Paleozoic epicontinental seas, much uncertainty pertains, and some interpreters have emphasized minimal to no tidal effects in some of the environments of concern here. Nevertheless, we use these terms with the following explanations.

The supratidal designation is used for areas of presumed shorelines and for allegedly characteristic lithologies and sedimentary structures. The peritidal designation is intended to include the intertidal zone (in the presumption, if not proof, of at least a minor tidal range) and the very shallow subtidal environment in which modest waves and currents stirred the bottom. The peritidal

setting graded, in our application, into the shallow subtidal zone in which stronger waves and currents stirred the bottom. The deeper subtidal environment label refers to a relatively deep water setting in which the bottom was rarely stirred by the greatest storm energy.

Some of the interpretive coastal areas are noted by terms other than "land." Very low coastal areas were probably characterized by high water tables and, depending on climate, may have included marine or continental salinas. Carbonate sediments dominated most of these areas, and vegetative cover was poor or absent except in circumstances of very high water tables. Therefore, soils were mostly very thin and generally not a major source of sediment. Eolian activity may have been a primary mover of sediment in many of these coastal areas.

The term land refers to a general upland with little or no vegetative cover and very thin soils for many of our designations. These regions were major potential source areas for sediments, but for many of these Paleozoic settings in our study area, carbonate rocks dominated the bedrock surface. Therefore, siliciclastic rocks generally had subordinate roles as sources of sediment. Crystalline rocks of the Canadian Shield were part of the sediment source in the northern lands.

Although the thickness maps and the pertinent rocks are documents for the paleoenvironmental maps, these latter maps are reconstructions for rather short intervals of time (see fig. 2), and they need not have a preserved rock record everywhere as support for the indicated environments. This observation obviously applies mostly to those areas that are indicated as coastal environments. Readers may judge for themselves the degree of conservativeness, or its lack, with which we have designated some sedimentary environments in areas without a present rock record representing the stated time.

SYSTEM	SERIES / STAGES		MILLIONS OF YEARS	PALEO GEOGRAPHIC MAP NO.	ROCK					
	GLOBAL	NORTH AMERICA			SOUTHERN AND EASTERN WISCONSIN	SOUTHERN PENINSULA MICHIGAN	ILLINOIS			
DEVONIAN	U.	FRASNIAN	385	47	Milwaukee and Thiensville Fms. ?	Traverse Gr. and equiv. fms.	Lingle Fm.	Cedar Valley Ls.		
	M.	GIVETIAN			ERIAN	Lake Church Fm. ?			Rogers City Ls.	Wapsipinican Ls.
		EIFELIAN	Dundee Ls.	Grand Tower Ls.						
	L.	EMSIAN	ULSTERIAN	390	44	Detroit River Gr.	Lucas and Amherstburg Fms.	Clear Creek Chert to Flat Gap Ls.		
		SIEGENIAN		395	41	Bois Blanc Fm.	Sylvania Ss.			
		GEDINNIAN		405	39	Garden Is. Fm.	St. Ignace Dol. and Pointe aux Chenes Sh.	Bailey Ls.		
SILURIAN	U.	PRIDOLIAN	405	38	Waubakee Dol.	G to C B A Salina and Bass Is. Grs.	Moccasin Springs Fm.	Racine Fm.		
	LUDLOVIAN	CAYUGAN ?			Racine Dol.		Engodine and Niogara Grs.	St. Clair Ls.	Sugar Run Fm.	
	L.	WENLOCKIAN	NIAGARAN	415	36	Manistique Fm. to Byron Dol.	Clinton Gr.	Joliet and Marcus Fms.		
		LLANDOVERIAN		ALEXANDRIAN	420	31	Mayville Dol.	Cotaract Gr.	Kankakee Fm. and Sexton Cr. Ls. to Wilhelmi and Edgewood Fms., etc.	
					425	28	undifferentiated	Maquoketa Gr.	Cape Ls.	
ORDOVICIAN	U.	ASHGILLIAN	CINCINNATIAN	RICHMONDIAN	425	28	Maquoketa Gr.	Neda Fm. to Scales Sh.	Utica Sh.	
		MAYSVILLIAN								
		CARADOCIAN	CHAMPLAINIAN	EDENIAN	455	26	Galena Dol.	Trenton Fm.	Galena Gr.	
				SHERMANIAN	421	21	Decorah Fm.	Black River Gr.	Platteville Gr.	
	KIRKFIELDIAN									
	ROCKLANDIAN	BLACK-RIVERIAN	460	19	Platteville Fm.	Glenwood Fm.	Glenwood Sh.	Joachim Dol.		
	M.	LLANDEILIAN	CHAZYAN	475	17	Ancell Gr.	St. Peter ? Ss.	St. Peter Ss.	Dutchtown Fm.	
		LLANVIRNIAN	WHITEROCKIAN	485	14				Everton	
ARENIGIAN		CANADIAN	490	11	Prairie du Chien Gr.		New Richmond Ss.	Shakopee		
TREMADOCIAN						Gunter Ss.	Oneota			
CAMBRIAN	U.	ST. CROIXAN	TREMPEALEUAN	500	9	Trempealeau Gr.	Trempealeau Fm.	Eminence Dol.		
			FRANCONIAN	7	Tunnell City Gr.	Franconia Fm.	Potosi Dol.			
			DRESBACHIAN	6	Wonewoc Ss.	Galesville Ss. ?	Franconia Fm.	Iron-ton Ss.		
				4	Eau Claire Fm.	Eau Claire Fm.	Galesville Ss.			
	M.		515	4	Mount Simon Ss.	Mt. Simon Ss.	Mount Simon Ss.			
L.							Underlain by older sediments			
pe			570							

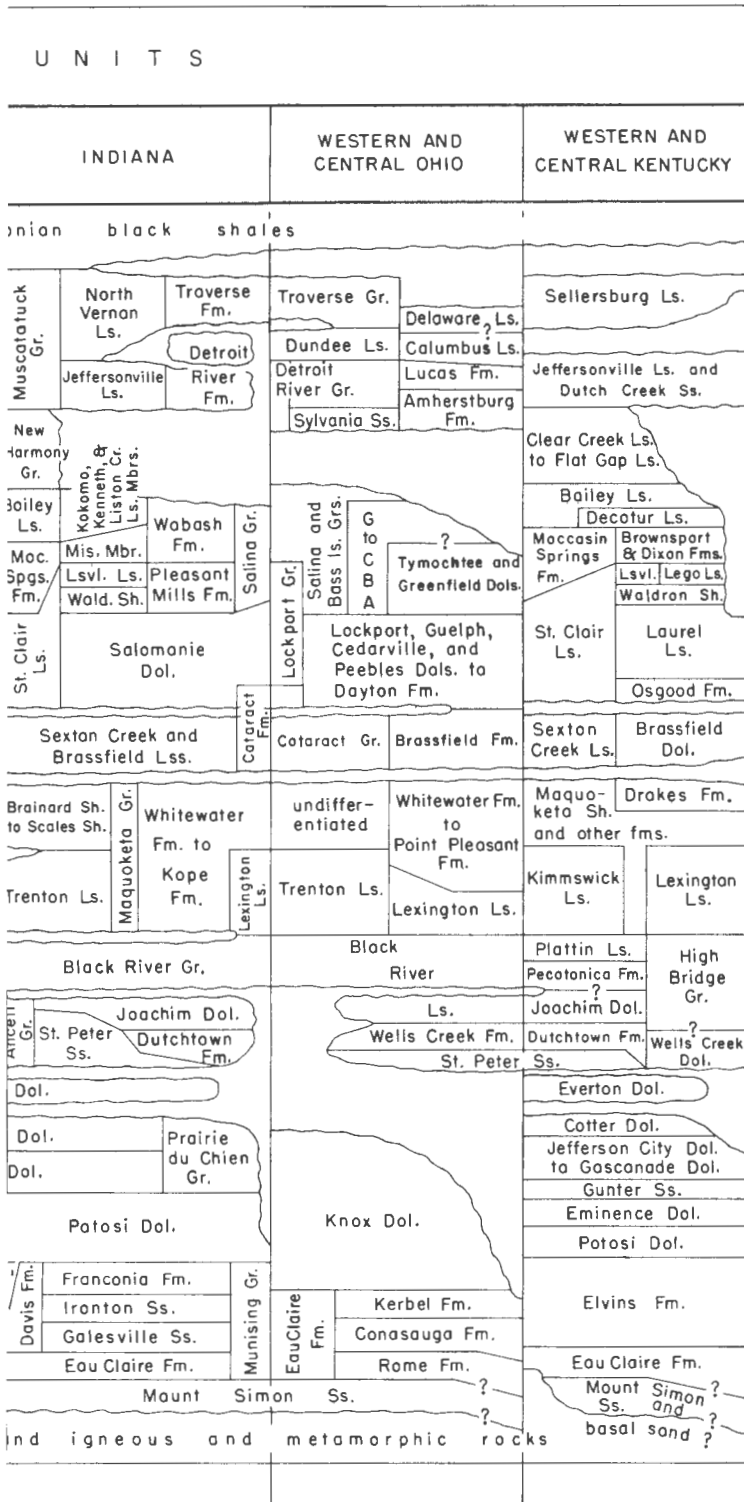
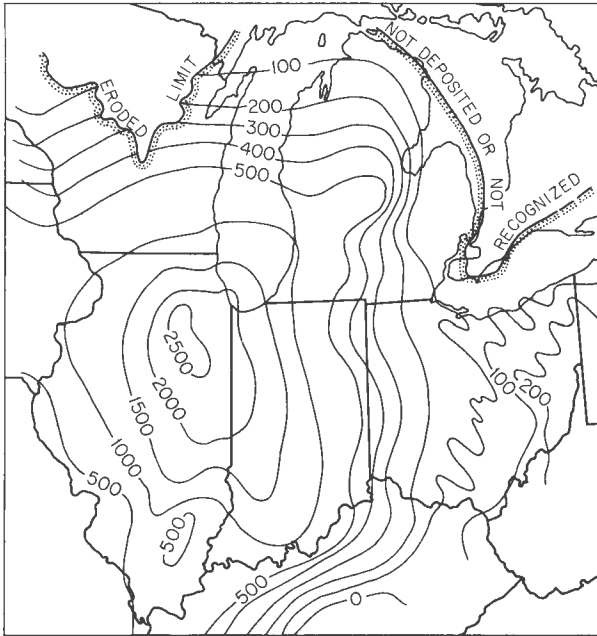
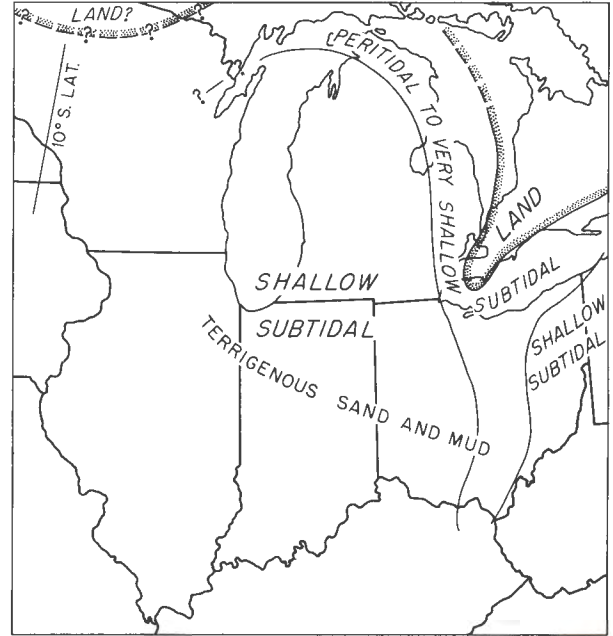


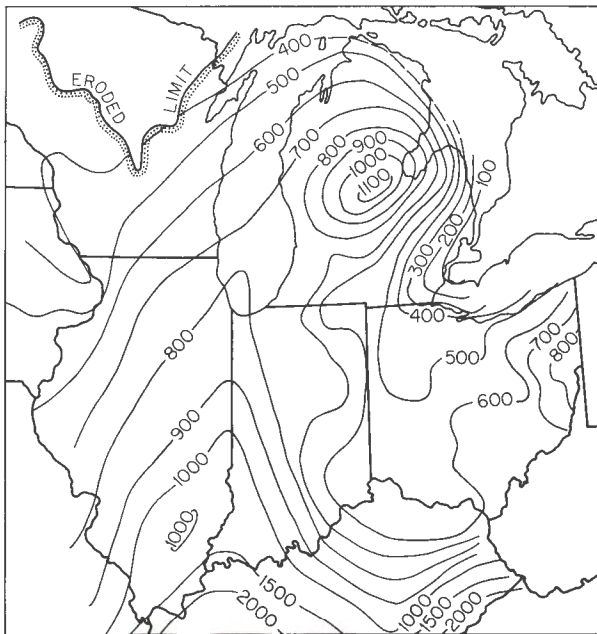
Figure 2. Chart showing correlation of generalized geologic columns for key areas of the western and southern Great Lakes area and approximate times represented by the paleogeographic maps. Modified from Shaver and others (1983). Abbreviations: A B C to G, informal units of the Salina Group; Bass Is., Bass Islands; Liston Cr., Liston Creek; Lsvl., Louisville; and Mis. Mbr., Mississinewa Shale Member.



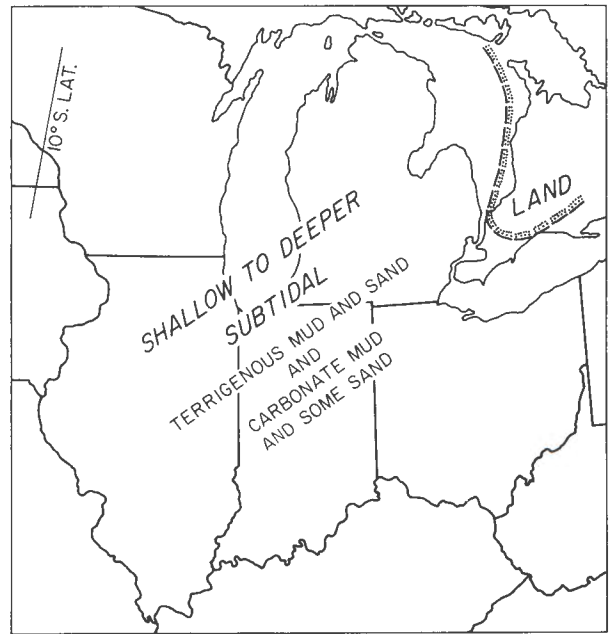
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6



Figures 3-6. Maps respectively showing thickness of the Mount Simon Sandstone and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick), early Dresbachian paleogeography, thickness of the Munising Formation and equivalents (contour interval 100 feet and changing to 500 feet in the Illinois, Indiana, and Kentucky area), and late Dresbachian paleogeography.

Maps and Discussions

ST. CROIXAN

FIGURES 3 AND 4

The term Mount Simon Sandstone applies in Wisconsin, Michigan, Illinois, Indiana, Ohio, and Kentucky; in addition, part of the unnamed sandstone of pre-St. Croixan age in southwestern Illinois and the so-called basal sand in Kentucky may be included in the thickness mapping where the term Mount Simon is not used. Some of the rocks mapped very likely are pre-St. Croixan in age.

A single basin covering major parts of five states and having a center for Mount Simon deposition in northeastern Illinois was a circumstance never to be repeated during Phanerozoic time.

Our undoubtedly simplistic treatment of Mount Simon and younger Cambrian rocks needs eventual integration with the work of Schwab (1982) in the areas of the paleofeatures called the Reelfoot Basin and the Rough Creek Graben in figure 1*B*. The irregular thickness patterns shown particularly in

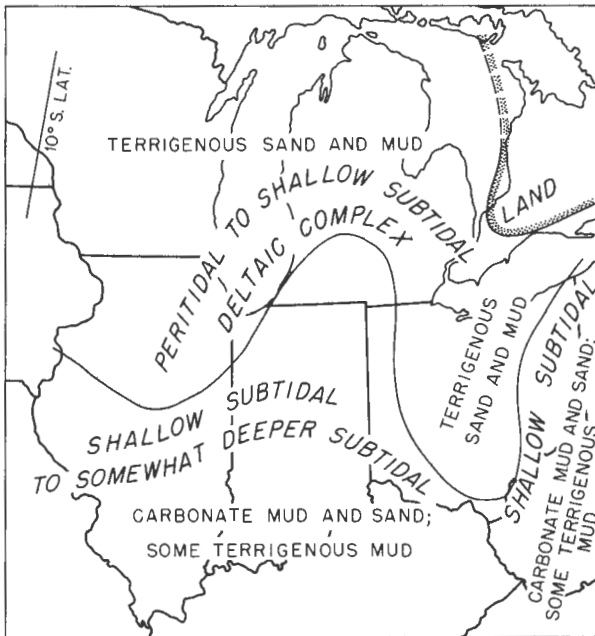
figures 3 and 5 suggest that sedimentation was influenced by growth faults.

References: Becker, Hreha, and Dawson, 1978; Buschbach, 1964; Catacosinos, 1973; Janssens, 1973; Lilienthal, 1978; McGuire and Howell, 1963; Schwab, 1982; and Willman and others, 1975.

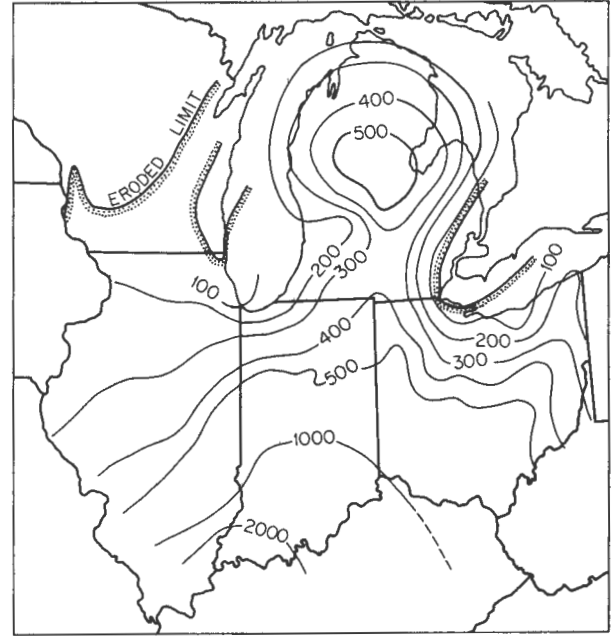
FIGURE 5

Rock units included in the Munising thickness map: Wisconsin—Eau Claire Formation, Wonewoc Sandstone, and Tunnel City Group; Michigan—Munising Formation and Eau Claire Formation through Franconia Formation; Illinois—Eau Claire Formation, Galesville and Ironton Sandstones, and Franconia Formation; Indiana—same as in Illinois but with Davis Formation added in some areas; Ohio—Eau Claire, Rome, Conasauga, and Kerbel Formations; and Kentucky—Eau Claire, Rome, and Conasauga Formations (Rome and Conasauga of Kentucky not shown in fig. 2).

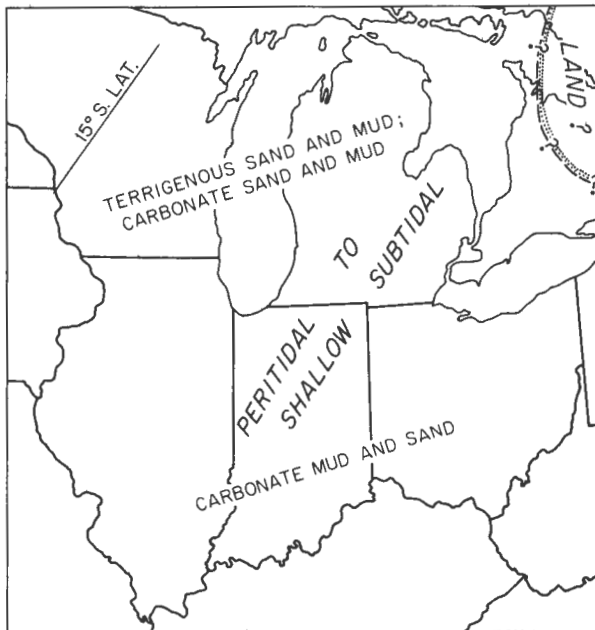
See page 9 for discussion of figure 6.



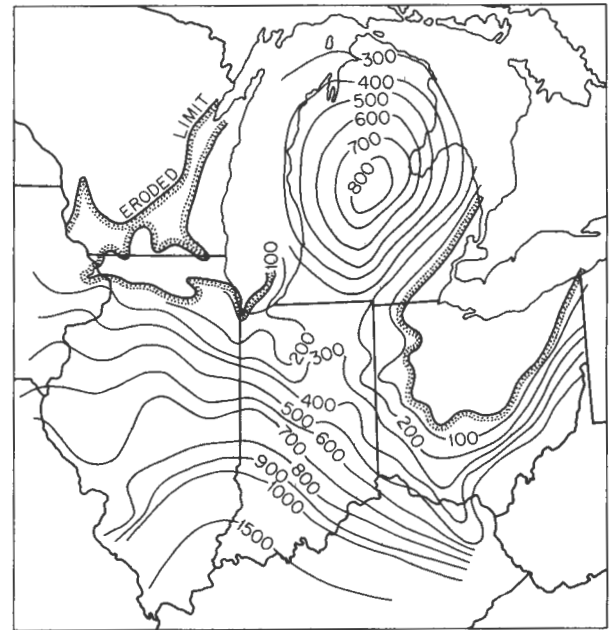
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8



9



10



Figures 7-10. Maps respectively showing Franconian paleogeography, thickness of the Potosi Dolomite and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick), Trempealeuan paleogeography, and thickness of the Prairie du Chien Group and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 1,000 feet thick).

ST. CROIXAN CONTINUED AND CANADIAN

FIGURES 6 AND 7

A depositional center developed in the area of the Michigan Basin during Munising depositional time (fig. 5), and the Reelfoot Basin (see fig. 1*B*) extended northward from the Ouachita Geosyncline into the Great Lakes area.

The Franconian deltaic environment was supplied by terrigenous clastics from northern sources and grades southward into environments where carbonate sediments dominated.

References: Same as for figure 3.

FIGURES 8 AND 9

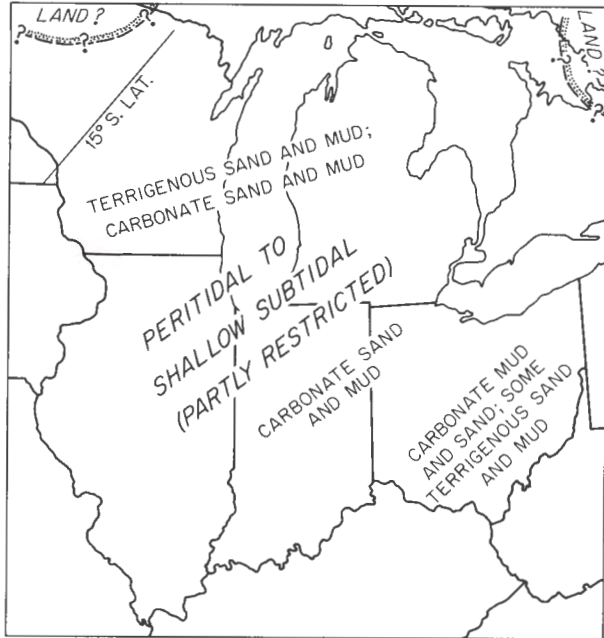
Rock units included in the Potosi thickness map: Wisconsin—Trempealeau Group; Illi-

nois—Potosi Dolomite and Eminence Formation; Indiana—Potosi Dolomite; Ohio—lower part of Knox Dolomite; and Kentucky—Potosi and Eminence Dolomites, Elvins Formation, and Copper Ridge Dolomite (not shown in fig. 2).

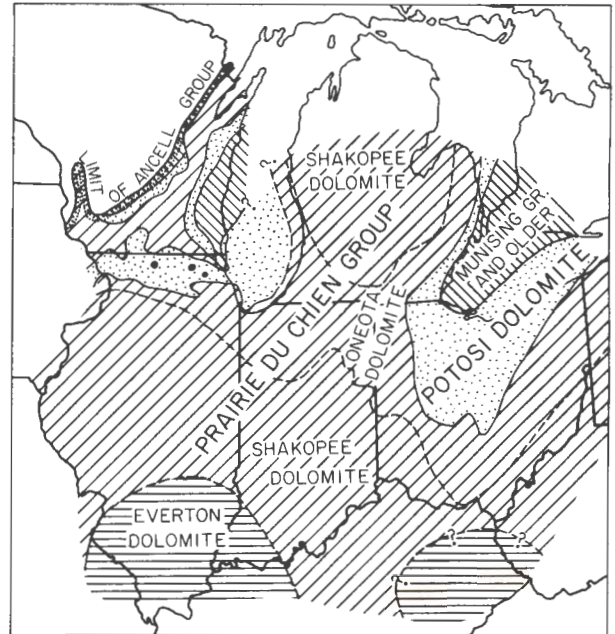
The present Michigan Basin area had a center of deposition during Trempealeauan time, but the south-central area of greatest deposition corresponded to no present basin area.

References: Buschbach, 1964; Droste and Patton, in preparation; Janssens, 1973; Lilienthal, 1978; McGuire and Howell, 1963; Schwalb, 1982; and Willman and others, 1975.

See page 11 for discussion of figure 10.



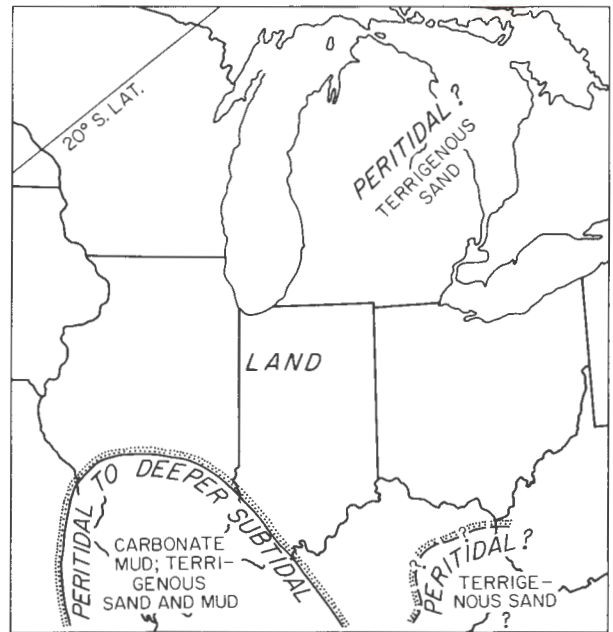
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12



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14



Figures 11-14. Maps respectively showing middle Canadian paleogeography, pre-Ancell paleogeography, thickness of the Everton Dolomite (contour interval 100 feet), and Whiterockian paleogeography.

CANADIAN CONTINUED AND CHAMPLAINIAN

FIGURES 10-11

Rock units included in the Prairie du Chien thickness map: Wisconsin, Michigan, and Indiana—Prairie du Chien Group; Illinois—Gunter Sandstone through Shakopee Dolomite; Ohio—upper part of Knox Dolomite; and Kentucky—Gunter Sandstone through Cotter Dolomite and Beekmantown Dolomite (not shown in fig. 2).

Minor regression and a shoaling event in some areas occurred during early Canadian deposition as represented, for example, by the Gunter Sandstone of northern Illinois and the Rose Run Sandstone of eastern Ohio, but transitional sedimentation across the Cambrian-Ordovician boundary was recorded throughout much of the study area. This episode was punctuated by occasional widespread influxes of mud and sand, possibly from a northern source.

References: Buschbach, 1964; Droste and Patton, in preparation; Janssens, 1973; Lilienthal, 1978; McGuire and Howell, 1963; Schwab, 1982; and Willman and others, 1975.

FIGURE 12

Very extensive post-Prairie du Chien, pre-Ancell erosion truncated Prairie du Chien, Trempealeau, Munising, and older strata. The Waverly Arch (see fig. 1B) extended from Ontario across Ohio.

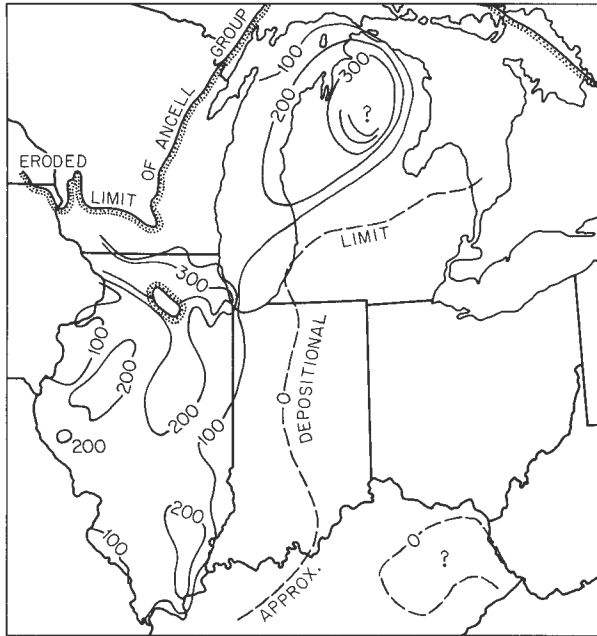
FIGURES 13 AND 14

Rock units included in the Everton thickness

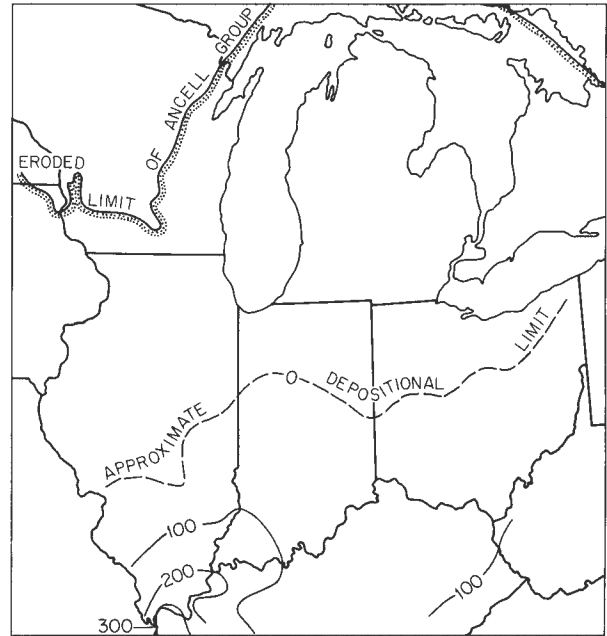
map: Illinois, Indiana, and Missouri—Everton Dolomite; Kentucky and Michigan—unnamed sands or sands commonly assigned to St. Peter Sandstone that are older than the St. Peter proper.

The areal extent shown for Everton (Whiterockian) deposition is probably conservative because it is based on sparse data, but the thickness pattern clearly suggests the continued existence of the southern basin in the tristate area of Illinois, Indiana, and Kentucky that is depicted for earlier times in figures 5, 8, and 10. Relief on the post-Canadian erosion surface could have resulted in shallow embayments elsewhere in the study area in which quartz sand accumulated northward from the recognized extent of the predominantly carbonate rocks of the Everton. In places these sands may be overlain by the main body of the St. Peter Sandstone without being so recognized, or, for example, the undifferentiated Prairie du Chien rocks in the Michigan Basin area may be partly Whiterockian in age. Also, the transgressive Whiterockian sea in eastern Kentucky and eastern Tennessee may have been represented shelfward in eastern Kentucky by thin accumulations of sand.

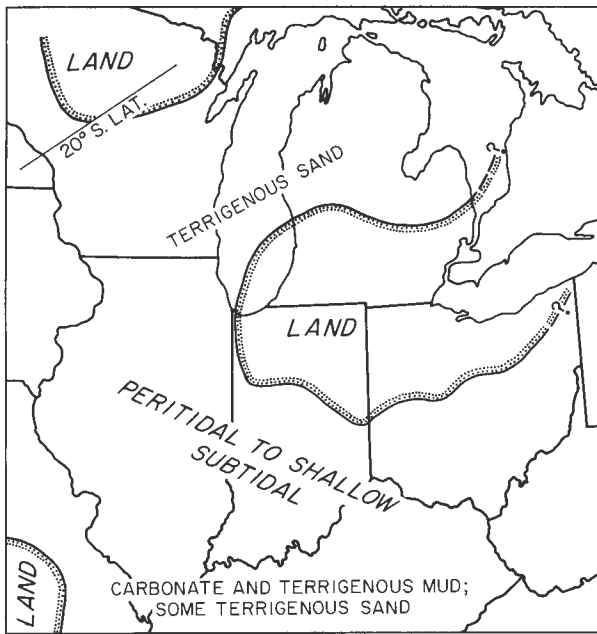
References: Droste, Abdulkareem, and Patton, 1982; Lilienthal, 1978; McGuire and Howell, 1963; Rexroad, Droste, and Ethington, 1982; Ruppel and Walker, 1977; Schwab, 1982; and Willman and others, 1975.



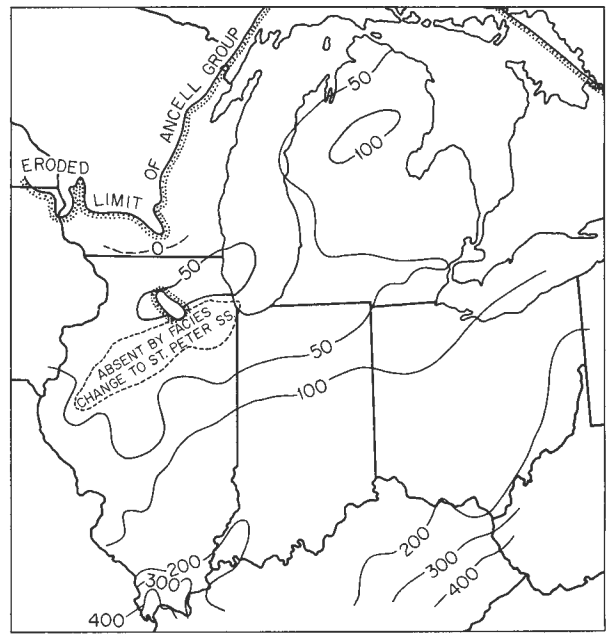
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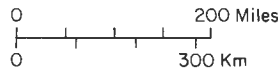
16



17



18



Figures 15-18. Maps respectively showing thickness of the St. Peter Sandstone and thickness of the Dutchtown Formation and equivalents (both maps using a 100-foot contour interval), Chazyan paleogeography, and thickness of the Joachim Dolomite (contour interval 50 feet and changing to 100 feet where unit is more than 100 feet thick).

CHAMPLAINIAN CONTINUED

FIGURES 15-17

Rock units included in the St. Peter thickness map: Wisconsin, Illinois, Indiana, Ohio, and Kentucky—St. Peter Sandstone; and Michigan—St. Peter Sandstone and probably an undifferentiated part of Prairie du Chien Group.

Rock units included in the Dutchtown thickness map: Illinois and Indiana—Dutchtown Formation; Ohio—Wells Creek Formation; and Kentucky—Wells Creek Formation and possibly a lowest part of High Bridge Group.

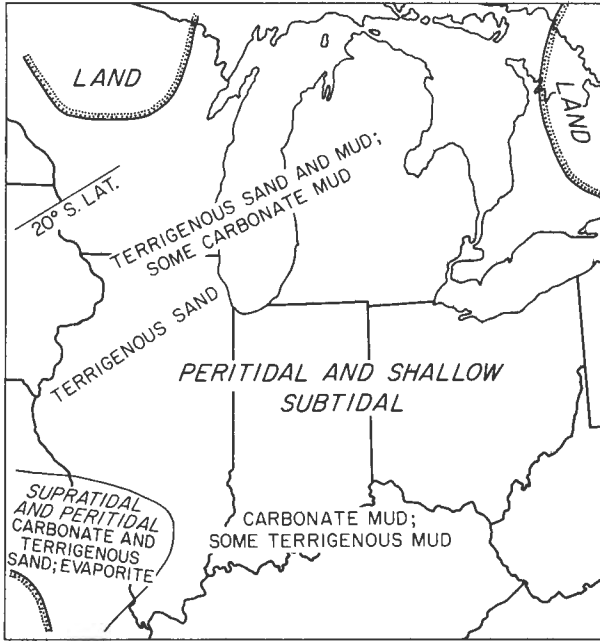
St. Peter distribution is much more irregular than is shown in figure 15. For example, the 300-foot-contour area in northern Illinois includes places where the St. Peter is much less than 300 feet thick and where it is as thick as 600 feet. In various isolated places in Illinois and Indiana, single wells record thicknesses exceeding the regional thickness by hundreds of feet. In eastern Indiana, southeastern Michigan, and Ohio, many large to small patches of questionably identified sandstone are referred to the St. Peter. Many of these assignments would be better if made to the Dutchtown Formation or to still older rocks, such as the Everton Dolomite or Prairie du Chien Group.

The sandy argillaceous carbonate rocks of the Dutchtown are in facies relationship with the lower St. Peter, and the aforementioned southern basin is represented by southward-thickening Dutchtown sediments. The Dutchtown zero contour (fig. 16) is generalized to include most of the isolated patches of Dutchtown rocks that accumulated in low areas on the post-Prairie du Chien erosion surface (fig. 12).

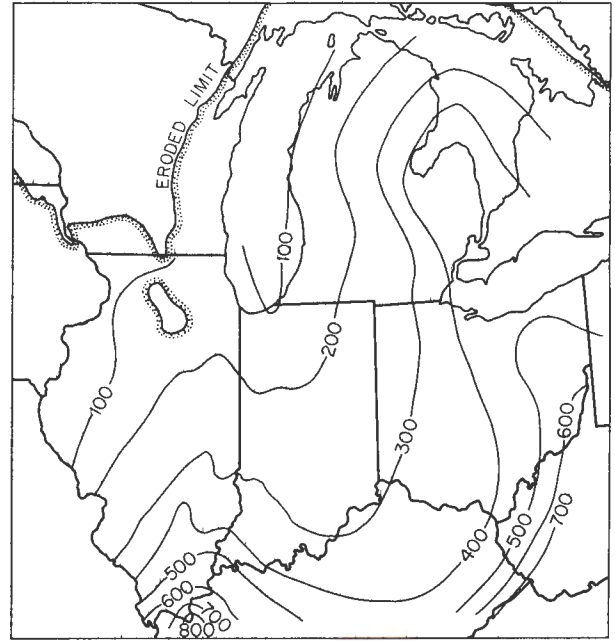
The Chazyan paleogeographic map (fig. 17) depicts the events concomitant with the beginning of a period of major Middle Ordovician submergence. Sands deposited in the northern part of the study area were derived from northern sources, and some sand was transported beyond the major locus of St. Peter deposition to become part of the predominately carbonate rocks of the Dutchtown. Much of the terrigenous mud component of the Dutchtown was derived from southern sources, although some could have had a northern source or could have been reworked residuum that had been developed on the subjacent erosion surface.

References: Droste, Abdulkareem, and Patton, 1982; McGuire and Howell, 1963; Schwalb, 1982; Stith, 1979; and Willman and others, 1975.

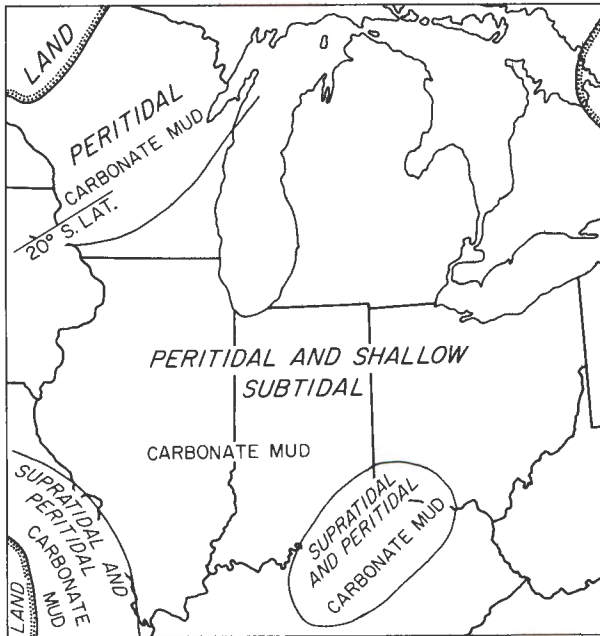
See page 15 for discussion of figure 18.



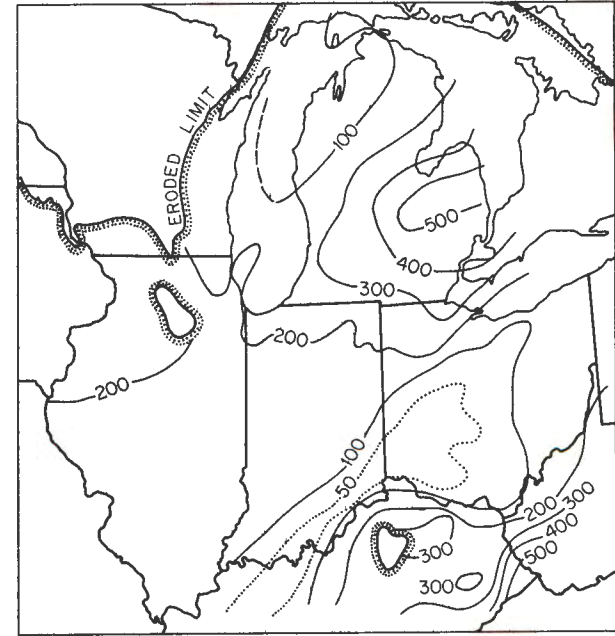
19



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22



Figures 19-22. Maps respectively showing early Blackriverian paleogeography, thickness of the Black River Group and equivalents (contour interval 100 feet), late Blackriverian paleogeography, and thickness of the Trenton and Lexington Limestones and equivalents (contour interval 100 feet and changing to 50 feet where unit is less than 100 feet thick).

FIGURES 18 AND 19

Rock units included in the Joachim thickness map: Wisconsin and Michigan—Glenwood Formation (Shale); Illinois—Glenwood Formation and Joachim Dolomite; Indiana—Joachim Dolomite; Ohio—lower part of Black River Group including lower-argillaceous, Carntown, and upper-argillaceous units of Stith (1979); and Kentucky—Joachim Dolomite and lower part of High Bridge Group.

The Joachim carbonate muds graded northwestward into the contemporaneously deposited upper St. Peter sands (zero-thickness area of fig. 18), which in turn graded into the Glenwood terrigenous sands and muds. The Joachim depositional centers record the continued existence of a somewhat modified Reelfoot Basin and the expansion of the Appalachian Basin into eastern Kentucky.

References: Droste, Abdulkareem, and Patton, 1982; Lilienthal, 1978; McGuire and Howell, 1963; Schwalb, 1982; Stith, 1979; and Willman and others, 1975.

FIGURES 20 AND 21

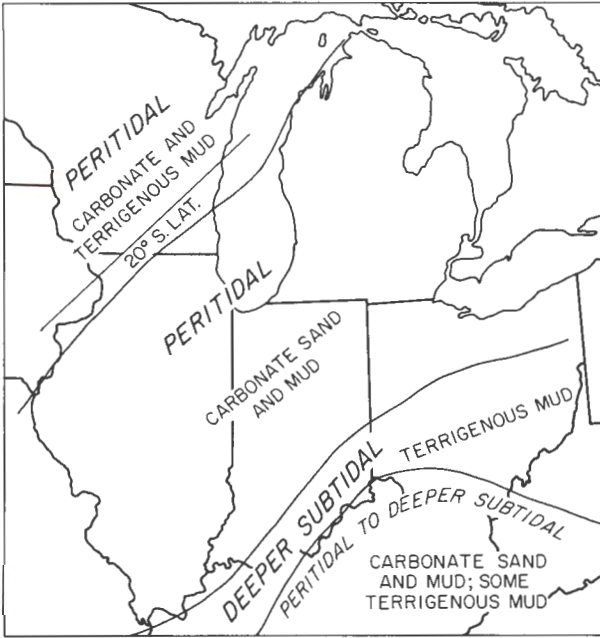
Rock units included in the Black River

thickness map: Wisconsin and Illinois—Platteville Formation (Group); Michigan and Indiana—Black River Group; Ohio—middle and upper parts of Black River Limestone; and Kentucky—Pecatonica Formation and Plattin Limestone and middle and upper parts of High Bridge Group.

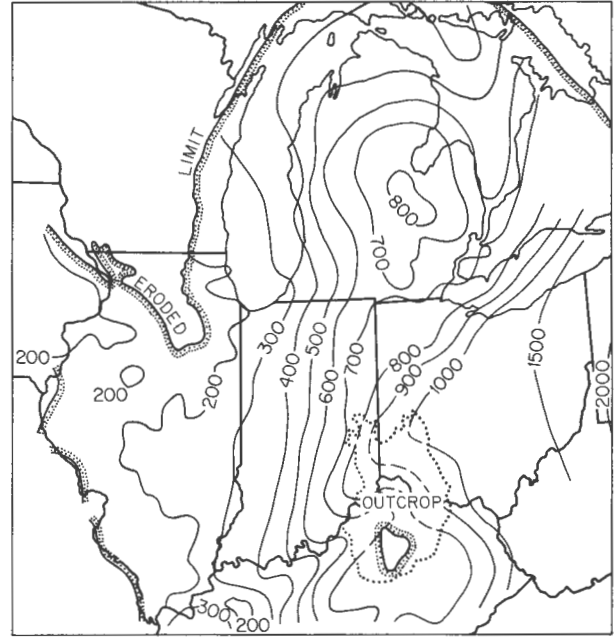
During late Blackriverian time, a part of the Appalachian Basin expanded and apparently included the eastern part of the present Michigan Basin area. The southern depositional center continued very much in evidence. Carbonate-mud sediments were pervasive, almost to the exclusion of terrigenous clastics, in a far-ranging peritidal to shallow subtidal environment.

References: Cressman and Noger, 1976; Droste, Abdulkareem, and Patton, 1982; Lilienthal, 1978; McGuire and Howell, 1963; Schwalb, 1982; Stith, 1979; and Willman and others, 1975.

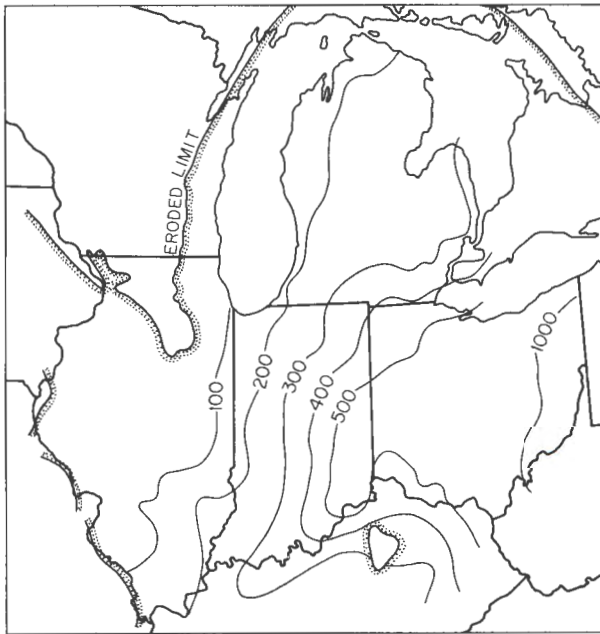
See page 17 for discussion of figure 22.



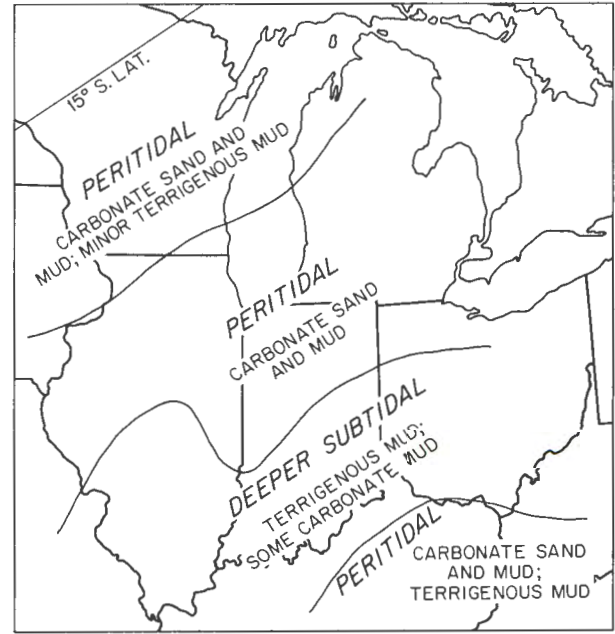
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Figures 23-26. Maps respectively showing Kirkfieldian paleogeography, thickness of the Maquoketa Group and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 1,000 feet thick), thickness of the lower part of the Maquoketa Group and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick), and Edenian paleogeography.

CHAMPLAINIAN CONTINUED
AND CINCIANNATIAN

FIGURES 22 AND 23

Rock units included in the Trenton thickness map: Wisconsin—Decorah Formation and Galena Dolomite; Michigan—Trenton Formation; Illinois—Galena Group; Indiana—Trenton and Lexington Limestones; Ohio—Trenton and Lexington Limestones; and Kentucky—Lexington and Kimmswick Limestones.

Two thick sections of Trenton carbonate rocks, one in the north and one in the south, thin toward the central area in the tristate area of Indiana, Ohio, and Kentucky. Although a minor discontinuity in Trenton sedimentation has been reported in northern Illinois and southern Wisconsin, most of the thinning in Trenton carbonate rocks is complemented by thickening in shale and siltstone in the lower part of the Maquoketa Group (fig. 25). In some places in southern Indiana, the lower Maquoketa shales nearly lie on Black River carbonate rocks (fig. 2).

During Kirkfieldian time, shallow carbonate-banklike areas lay to the northwest and the southeast and were separated by a narrow, relatively deep basin in which mostly terrigenous muds accumulated.

References: Coogan and Maxey, in preparation; Cressman, 1973; Lilienthal, 1978; Willman and Kolata, 1978; and Willman and others, 1975.

FIGURES 24-26

Rock units included in the Maquoketa

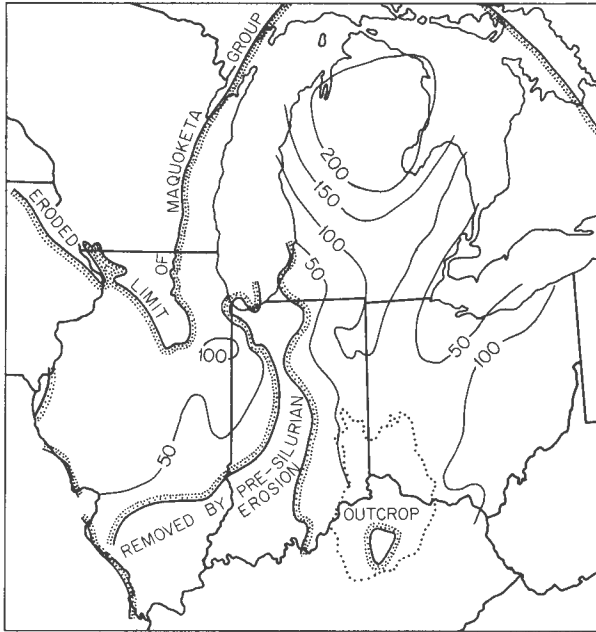
thickness map: Wisconsin, Illinois, and Indiana—Maquoketa Group (in Illinois, Cape Limestone also included); Michigan—Utica Shale and undifferentiated upper Cincinnati rocks; Ohio—Point Pleasant Formation to Whitewater Formation and undifferentiated Cincinnati rocks; and Kentucky—Maquoketa Shale, Drakes Formation, and other formations.

Rock units included in the lower Maquoketa thickness map: Iowa, Wisconsin, and Illinois—Scales Shale; Michigan—Utica Shale; Indiana—Scales Shale and Kope Formation; Ohio—lower undifferentiated Cincinnati rocks and Kope Formation; and Kentucky—lower part of Maquoketa Shale.

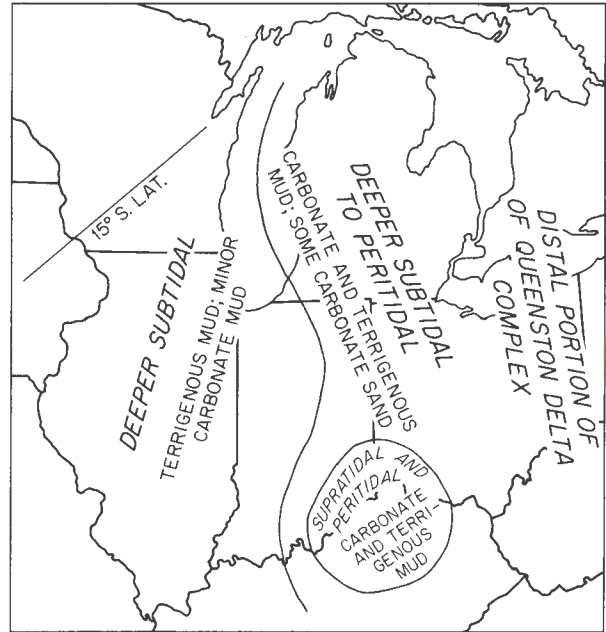
The Maquoketa Group thickens rather regularly eastward in the central part of the map area. The southern irregularity is owed both to erosion and to a complementary relationship with the underlying Trenton carbonate rocks (compare especially figs. 22 and 25), and the northern thickening reveals a distinct depositional center in the Michigan Basin area during Cincinnati time.

During the Edenian part of Cincinnati time, the preexisting Kirkfieldian shale basin of the southern part of the map area (fig. 23) expanded in two directions as the adjacent carbonate-bank areas contracted.

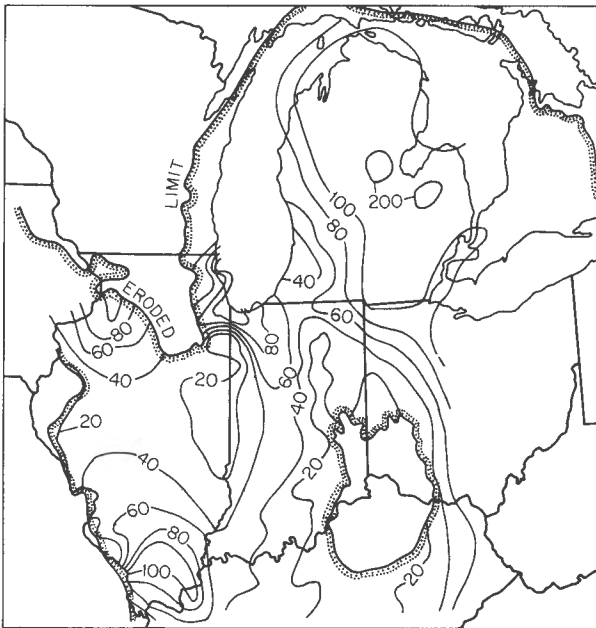
References: Bond and others, 1971; Gray, 1972; Kolata and Graese, 1983; Lilienthal, 1978; and Willman and others, 1975.



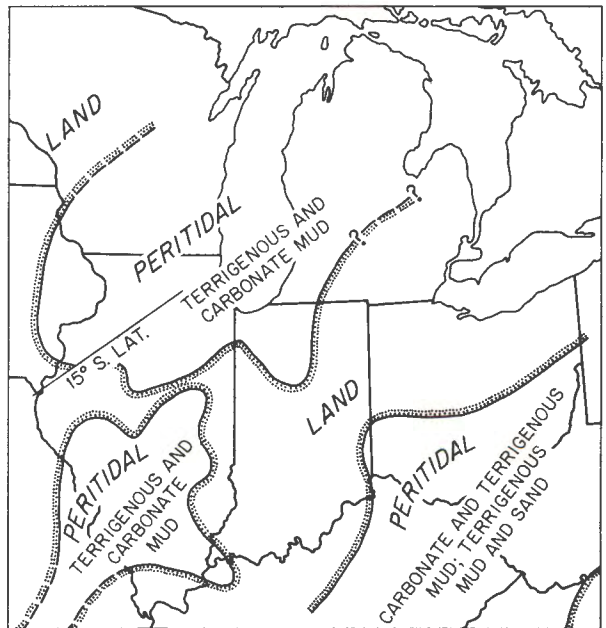
27



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Figures 27-30. Maps respectively showing thickness of the uppermost part of the Maquoketa Group and equivalents (contour interval 50 feet), late Richmondian paleogeography, thickness of the Sexton Creek Limestone and equivalents (contour interval 20 feet and changing to 100 feet where unit is more than 100 feet thick), and middle Alexandrian paleogeography.

CINCINNATIAN CONTINUED
AND ALEXANDRIAN

FIGURES 27 AND 28

Rock units included in the uppermost Maquoketa thickness map: Wisconsin and Illinois—Brainard Shale and Neda Formation; Michigan—upper part of undifferentiated Cincinnati rocks; Indiana—Brainard Shale and Whitewater Formation; Ohio—Whitewater Formation and upper part of undifferentiated Cincinnati rocks; and Kentucky—upper part of Drakes Formation.

The thickness of the Whitewater and its equivalents was affected significantly by pre-Sexton Creek (pre-Brassfield) erosion during Late Ordovician and Early Silurian time. This effect extends especially from southern Illinois, through Indiana, and into the northwestern Ohio-southwestern Ontario area, and it explains much of the western absence of typical redbeds of the Queenston delta (Ordovician) that are so prevalent in eastern Ohio and in the central Michigan Basin.

The gross pattern of sedimentation prevalent during late Richmondian time shows a distinctly linear north-south orientation and therefore contrasts with the pattern interpreted for Edenian time (fig. 26). This pattern, however, appears to be affected by a proto-Cincinnati Arch. Terrigenous muds dominated the distal part of the Queenston delta complex in the east; carbonate sediments became more prevalent westward and

were mixed with terrigenous components in shallow environments, including supratidal in part of the central area and somewhat deeper subtidal still farther westward.

References: Bond and others, 1971; Gray, 1972; Kolata and Graese, 1983; Lilienthal, 1978; and Willman and others, 1975.

FIGURES 29 AND 30

Rock units included in the Sexton Creek thickness map: Wisconsin—Mayville Dolomite; Michigan—Cataract Group; Illinois—Edgewood Formation (Silurian part) to Sexton Creek Limestone, Wilhelmi Formation to Kankakee Formation, and equivalents; Indiana—Sexton Creek and Brassfield Limestones and Cataract Formation; Ohio—Brassfield Formation and Cataract Group; and Kentucky—Sexton Creek Limestone and Brassfield Dolomite.

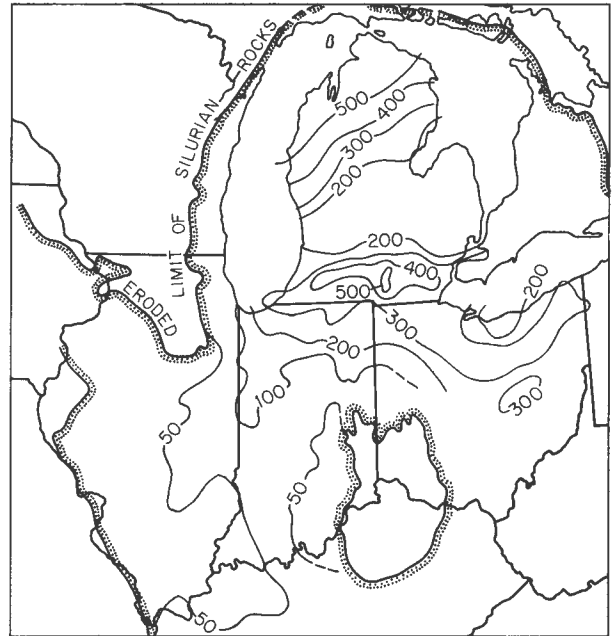
Part of the irregular regional thickness pattern is due to erosional relief on the Ordovician surface. (Compare fig. 27.)

During middle Alexandrian time, land separated the sea in the Appalachian Basin area from shallow seas westward. Initially, land also separated the two western seas.

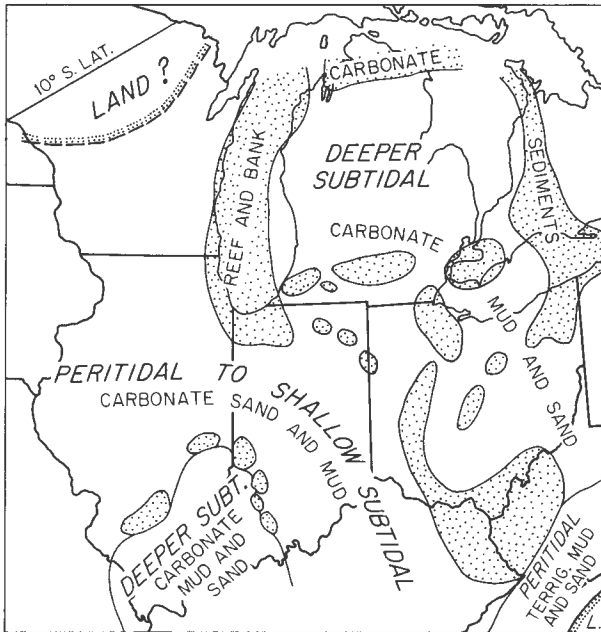
References: Becker, 1974; Janssens, 1977; Lilienthal, 1978; Rexroad, 1967, 1980; Rexroad and Droste, 1982; Rexroad and others, 1965; Stith and Stieglitz, 1979; Smosna and Patchen, 1978; and Willman and others, 1975.



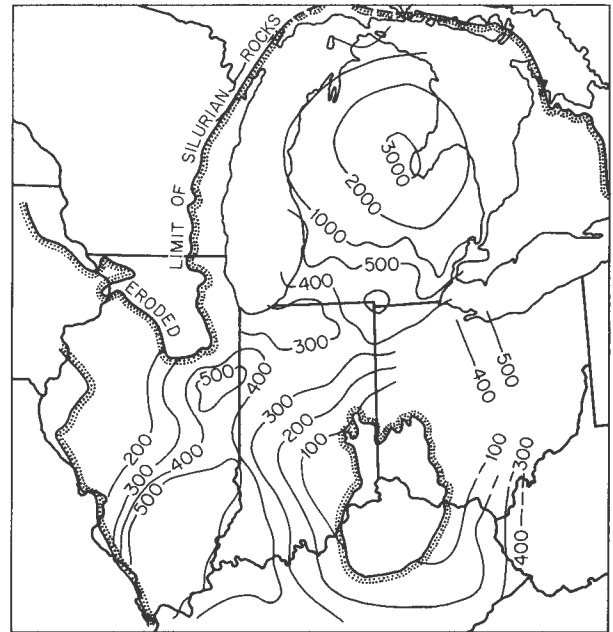
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Figures 31-34. Maps respectively showing late Alexandrian paleogeography, thickness of the Salomie Dolomite and equivalents (contour interval 100 feet and changing to 50 feet where unit is less than 100 feet thick), middle Niagaran (middle Wenlockian) paleogeography, and thickness of the Salina Group and equivalents (contour interval 100 feet and changing to 500 and 1,000 feet where unit is more than 500 feet thick).

ALEXANDRIAN CONTINUED, NIAGARAN,
AND CAYUGAN

FIGURE 31

During late Alexandrian time, widespread submergence established a shallow-water sea in which carbonate sediments dominated terrigenous sediments in the central and western areas, but the earlier formed quartz-sand regime associated with the deltaic complex in the Appalachian Basin area expanded.

References: Same as those cited for figures 29 and 30.

FIGURES 32 AND 33

Rock units included in the Salamonie thickness map: Wisconsin—Byron Dolomite through Manistique Formation and equivalent of Joliet Formation, possibly including some lower Racine rocks; Michigan—Engadine, Clinton, and Niagara Groups; Illinois—lower and middle parts of St. Clair Limestone and Marcus and Joliet Formations; Indiana—Salamonie Dolomite and lower part of St. Clair Limestone; Ohio—Dayton Formation through Peebles, Cedarville, Guelph, and Lockport Dolomites and Lockport Group (excludes Clinton rocks in northeastern Ohio); and Kentucky—lower part of St. Clair Limestone, Laurel Limestone, and Osgood Formation.

The three areas of marked thickening of the Salamonie, Lockport, and equivalent rocks in the Indiana-Michigan-Ohio tristate area, northern Michigan, and central Ohio result from the development of reef-dominated carbonate banks, which continued to accumulate into late Niagaran time in peripheral areas of the Michigan Basin and the Appalachian Basin. The upper parts of these thickened bodies are about the same age as the lower Salina rocks included in the

Pleasant Mills thickness map (figs. 2 and 5).

Middle Niagaran (middle Wenlockian) time was characterized by the first major Silurian development of extensive carbonate banks that virtually surrounded the Michigan Basin and extended into the Appalachian Basin but that had lesser development peripheral to the Illinois Basin. Such reef-dominated banks were interrupted by passes, which are partly generalized in figure 33 because of sparse data. Numerous reefs began to form on the Wabash Platform (see fig. 1B) in Indiana and Illinois, and a delta complex continued to form in the southeast and was dominated by terrigenous sediments.

References: Becker, 1974; Droste and Shaver, 1977, 1980, and 1982; Janssens, 1977; Patchen and Smosna, 1975; Shaver and others, 1978; Smosna and Patchen, 1978; Ulteig, 1964; and Willman and others, 1975.

FIGURE 34

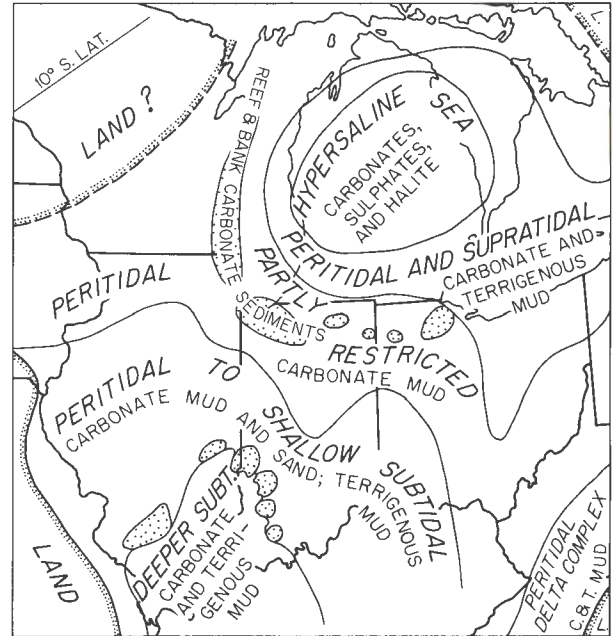
Rock units included in the Salina thickness map: Wisconsin—most of Racine Dolomite and Waubakee Dolomite; Michigan and Ohio—Salina and Bass Islands Groups; Illinois—Sugar Run and Racine Formations and upper part of St. Clair Limestone, Moccasin Springs Formation, and Silurian part of Bailey Limestone; Indiana—Salina Group, upper part of St. Clair Limestone, Moccasin Springs Formation, Bailey Limestone, and Waldron Shale through Wabash Formation; and Kentucky—Waldron Shale and upper part of St. Clair Limestone through Bailey Limestone.

The Salina rocks and their equivalents have partly complementary thicknesses with the Niagara and Lockport Groups, the Salamonie Dolomite, and the Engadine Group.

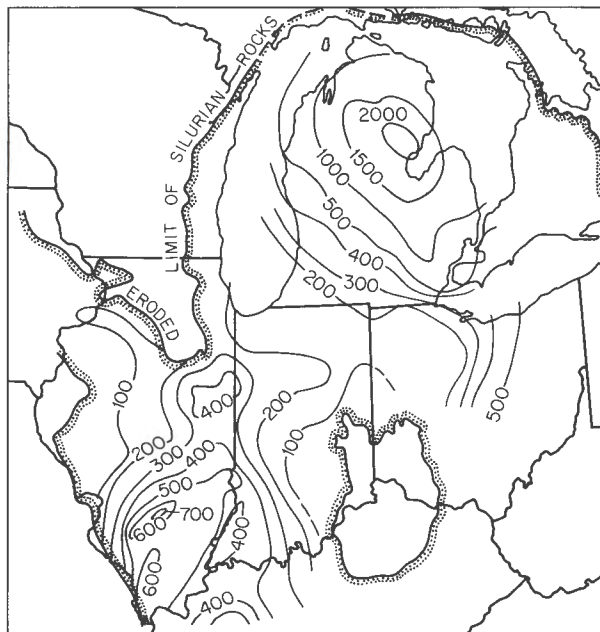
References: Same as those for figures 32, 33, 35, and 36.



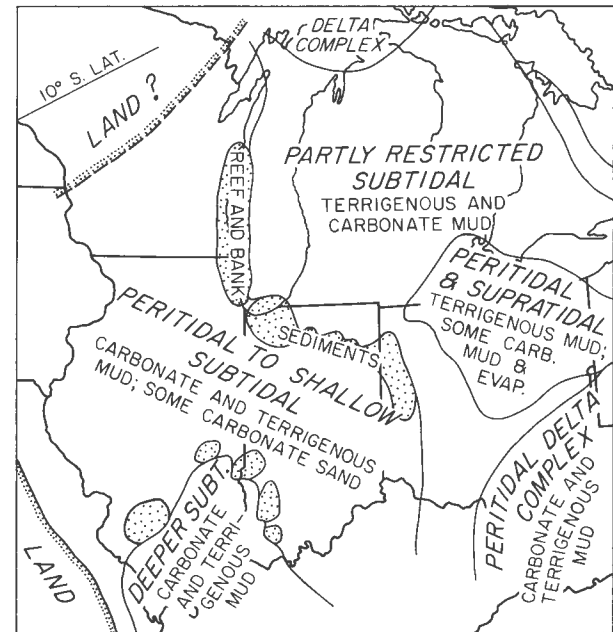
35



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Figures 35-38. Maps respectively showing thickness of the Pleasant Mills Formation and equivalents (contour interval 100 feet and changing to 50 feet where unit is less than 100 feet thick and to 500 and 250 feet where unit is more than 500 feet thick), late Niagaran (late Wenlockian) paleogeography, thickness of the Wabash Formation and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick), and early Cayugan (latest Niagaran?; Ludlovian) paleogeography.

NIAGARAN CONTINUED AND CAYUGAN
CONTINUED

FIGURES 35 AND 36

Rock units included in the Pleasant Mills thickness map: Wisconsin—lower part of Racine Formation; Michigan—lower part of Salina Group (A unit through B unit); Illinois—upper part of St. Clair Limestone, Sugar Run Formation, and lower part of Racine Formation; Indiana—upper part of St. Clair Limestone, Waldron Shale and Louisville Limestone, and Pleasant Mills Formation; Ohio—lower part of Salina Group (A unit to, but not including, C unit and Greenfield and Tymochtee Dolomites); and Kentucky—upper part of St. Clair Limestone, Waldron Shale, and Louisville and Lego Limestones.

The disproportionately great thickness in the Michigan Basin is owed to extensive evaporite sedimentation. (See also fig. 34 for the entire Salina thickness and fig. 37 for upper Salina thickness.)

The evaporite seas in the Michigan Basin and, to a lesser extent, in the Appalachian Basin brought about cessation of reef growth in proximal basin areas, but reef and bank sediments continued to accumulate in the most peripheral basin areas. The Fort Wayne Bank (see fig. 1*B*), extending from Wisconsin to Ohio, formed a new margin along the southwest side of the Michigan Basin. Early development of the Illinois Basin-fringing reef and bank system (Terre Haute Bank) continued, and the delta complex continued to grow in the southeast. Some of the previously mentioned reefs on the Wabash Platform experienced interruptions in growth.

References: Droste and Shaver, 1976, 1977, 1980, and 1982; Janssens, 1977; Lilienthal, 1978; Rickard, 1969; Shaver and others, 1978; Smosna and Patchen, 1978; Ulteig, 1964; and Willman and others, 1975.

FIGURES 37 AND 38

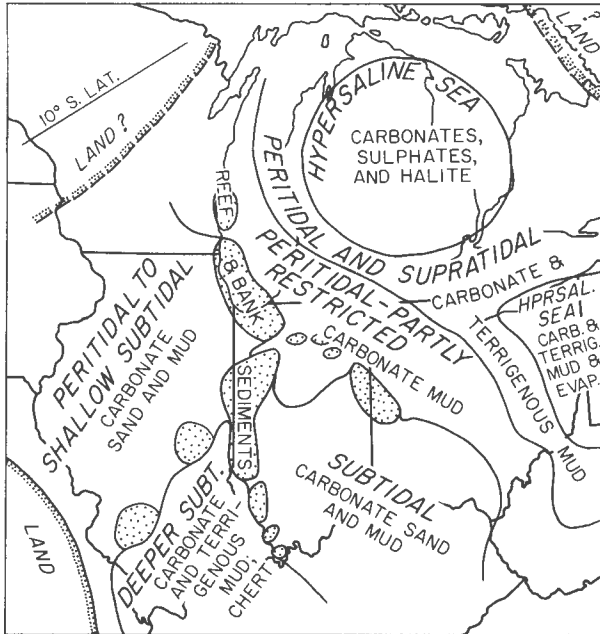
Rock units included in the Wabash thickness

map: Wisconsin—upper part of Racine Formation and Waubakee Dolomite; Michigan—Pointe aux Chenes Shale, upper part of Salina Group (C unit through G unit), and Bass Islands Group; Illinois—Moccasin Springs Formation and most of Bailey Limestone and upper part of Racine Formation; Indiana—Wabash and Moccasin Springs Formations and Bailey Limestone; Ohio—upper part of Salina Group (C unit through G unit) and Bass Islands Group; and Kentucky—Moccasin Springs Formation and Dixon Formation through Bailey Limestone.

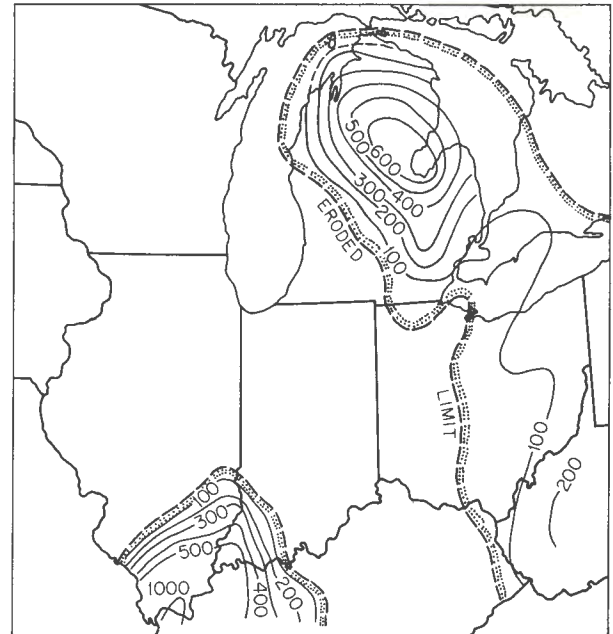
The thickness distribution of Wabash and equivalent rocks is strongly affected by post-Silurian and pre-Middle Devonian erosion as well as by later erosion. In some parts of the platform area, Middle Devonian rocks lie directly on early Niagaran rocks. Nevertheless, upper Salina (Wabash) rocks as young as the F unit are preserved in northernmost Indiana, and probably youngest Silurian rocks are preserved in the deeper part of the Illinois Basin area.

During latest Niagaran and earliest Cayugan (middle Ludlovian) time, a general deepening of the seas brought about cessation of evaporite deposition and permitted far-traveled fine terrigenous sediments to be deposited in the basins and on the platform. Some of these terrigenous sediments evidently were generated from growing delta complexes in the north and the southeast. Preexisting reef and bank systems in the central and western areas flourished anew, and many new reefs were generated on the Wabash Platform.

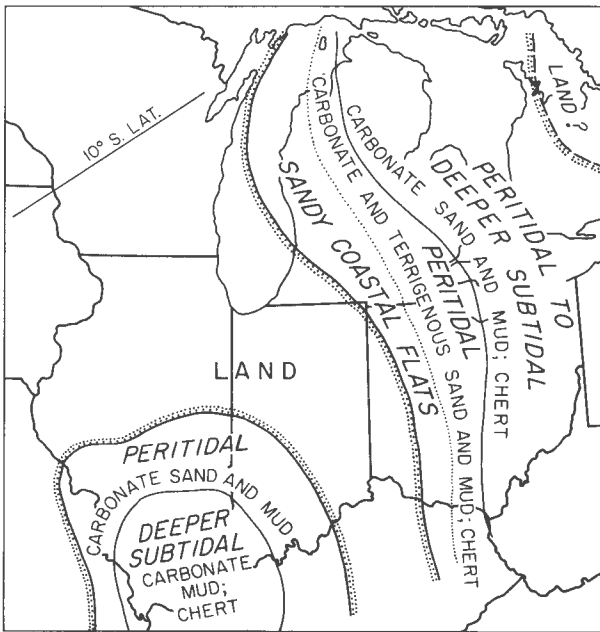
References: Becker, 1974; Becker and Droste, 1978; Droste and Shaver, 1977, 1980, and 1982; Janssens, 1977; Lilienthal, 1978; Rickard, 1969; Shaver and others, 1978; Smosna and Patchen, 1978; and Ulteig, 1964.



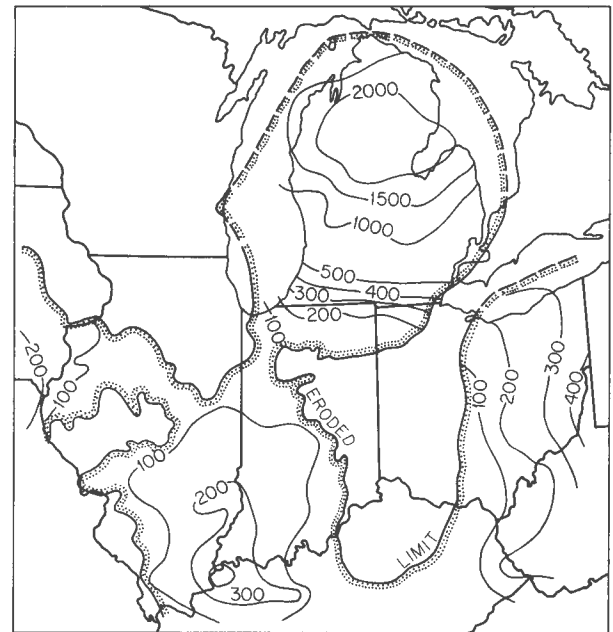
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Figures 39-42. Maps respectively showing late Cayugan (Pridolian) paleogeography, thickness of the New Harmony Group and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick in the Illinois Basin), late Ulsterian (Emsian) paleogeography, and thickness of the Muscatatuck Group and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick).

CAYUGAN CONTINUED, ULSTERIAN,
AND ERIAN

FIGURE 39

The Silurian sea remained widespread in late Cayugan (Pridolian) time, but the earlier established Early to Late Silurian environmental cyclicity was superimposed. The time of F-unit (upper Salina) deposition, for example, was characterized by widespread very shallow and otherwise partly restricted to restricted seas in the northeast, in which evaporites and carbonate muds (evaporitic in part?) accumulated. Nevertheless, toward the southwest the Fort Wayne Bank and other reef systems, both on the platform and peripheral to the proto-Illinois Basin, reached their grandest proportions during the whole of Pridolian (late Cayugan) time.

References: Droste and Shaver, 1982; Janssens, 1977; Rickard, 1969; Smosna and Patchen, 1978; and Ulteig, 1964.

FIGURES 40 AND 41

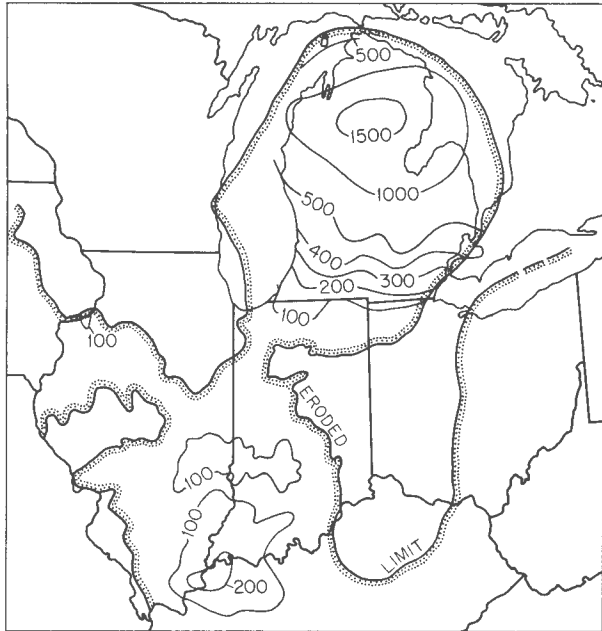
Rock units included in the New Harmony

thickness map: Michigan—Garden Island Formation through Sylvania Sandstone; Illinois—uppermost part of Bailey Limestone through Clear Creek Chert; Indiana—New Harmony Group; Ohio—Sylvania Sandstone of Detroit River Group; and Kentucky—Flat Gap Limestone through Clear Creek Limestone.

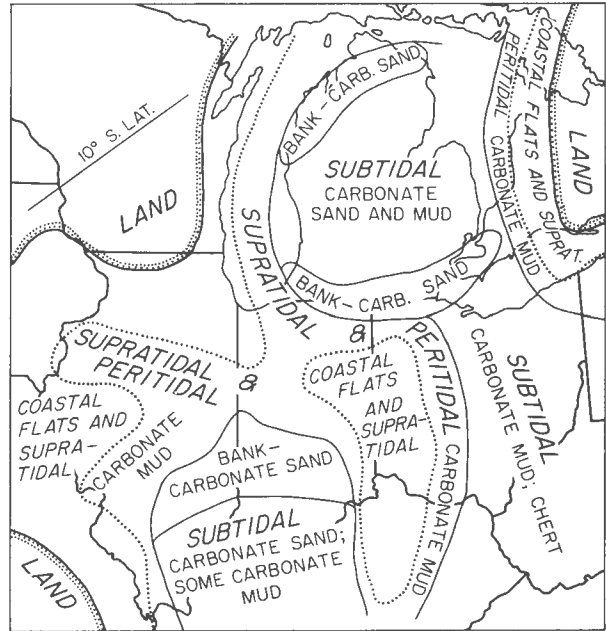
The areas of the present Illinois and Michigan Basins appear to have deepened and become pronounced depositional centers during Early Devonian time, their deepest parts possibly receiving sediments continuously from Silurian to Devonian time. Cherty carbonate sediments dominated in the two principal seaways that were separated by a broad land area that underwent profound erosion in some places. The northern limit of the Reelfoot Basin was in southern Illinois and Indiana.

References: Becker and Droste, 1978; Dow, 1962; Gardner, 1974; and Willman and others, 1975.

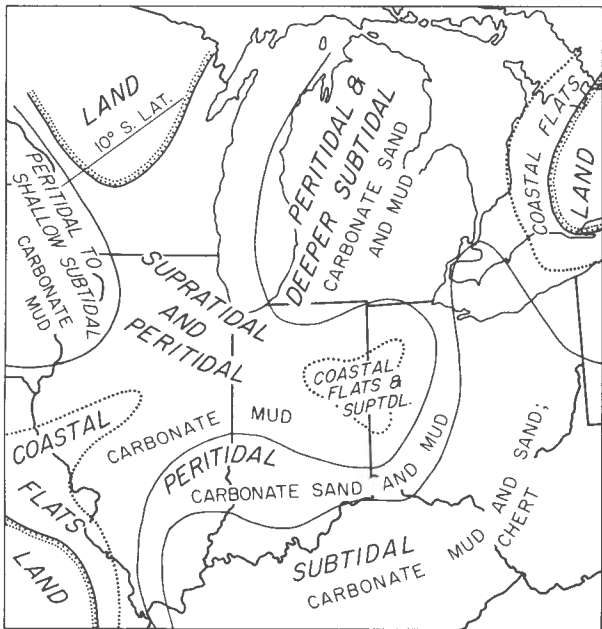
See page 27 for discussion of figure 42.



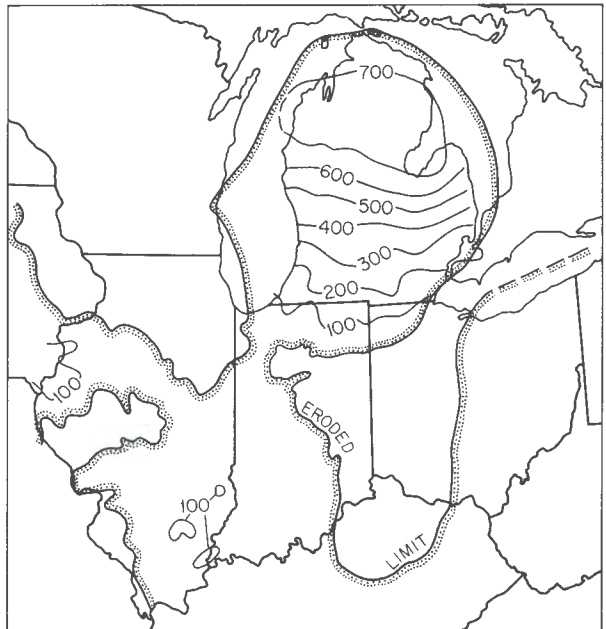
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Figures 43-46. Maps respectively showing thickness of lower Muscatatuck rocks and equivalents (contour interval 100 feet and changing to 500 feet where unit is more than 500 feet thick), early Erian (early Eifelian) paleogeography, late early Erian (late Eifelian) paleogeography, and thickness of upper Muscatatuck rocks and equivalents (contour interval 100 feet).

ERIAN CONTINUED

FIGURE 42

Rock units included in the Muscatatuck thickness map: See statements for lower and upper Muscatatuck maps (figs. 43-46).

By Eifelian (early Erian) time, a modest depositional center had developed in the tristate area of Illinois, Indiana, and Kentucky, apparently with some independence of the Reelfoot Basin and as a feature bordering the aforementioned Wabash Platform. Therefore the forerunners of three prominent modern basins were present. The Michigan Basin received by far the greatest amount of sediments owing in part to extensive evaporite deposition especially during middle Eifelian time.

References: Same as those cited for figures 43-47.

FIGURES 43-45

Rock units included in the lower Muscatatuck thickness map: Michigan—Detroit River Group (except for Sylvania Sandstone) and Dundee Limestone; Illinois—Ground Tower Limestone and a lowest part of Wapsipinicon

Limestone; Indiana—Jeffersonville Limestone and Detroit River Formation; Ohio—Detroit River Group (except for Sylvania) and Columbus and Dundee Limestones; and Kentucky—Dutch Creek Sandstone and Jeffersonville Limestone.

A widespread transgressive event began during early Eifelian time (fig. 44), when dominantly carbonate sediments were deposited in subtidal to supratidal conditions. Banklike skeletal deposits characterized parts of the Illinois Basin area (Geneva Dolomite Member of the Jeffersonville Limestone) and parts of the Michigan Basin (Amherstburg Formation). Evaporite deposition followed in the Michigan Basin area principally during middle Eifelian time (not depicted in figs. 44 and 45) and in turn was succeeded by a return to more normal marine conditions in late Eifelian time (fig. 45), which completed the overall Eifelian transgressive event.

References: Becker, 1974; Doheny, Droste, and Shaver, 1975; Dow, 1962; Droste and Shaver, 1975; Gardner, 1974; Janssens, 1970; and Willman and others, 1975.

See page 28 for discussion of figure 46.

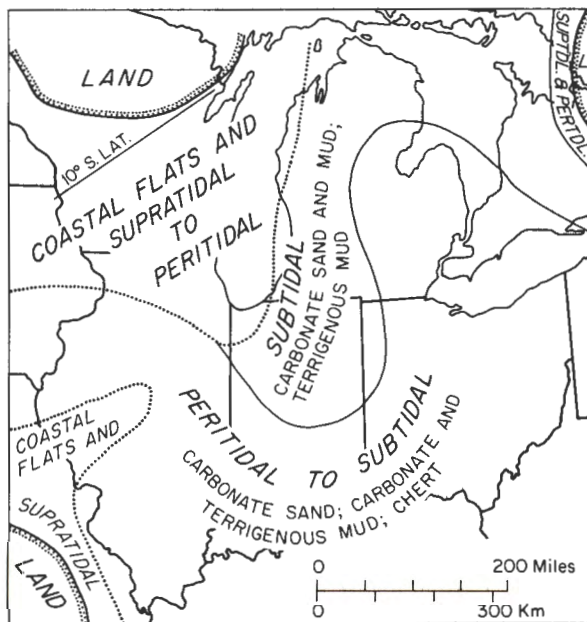


Figure 47. Map showing late Erian (middle to late Givetian) paleogeography.

FIGURES 46 AND 47

Rock units included in the upper Muscatatuck thickness map: Michigan—Rogers City Limestone and Traverse Group and equivalents; Illinois—middle and upper parts of Wapsipincon Limestone, Cedar Valley Limestone, and Lingle Formation; Indiana—North Vernon Limestone and Traverse Formation; Ohio—Delaware Limestone and Traverse Group; and Kentucky—Sellersburg Limestone.

Widespread submergence continued from Eifelian into Givetian time (early to late Erian), and the Michigan Basin continued as the major depositional center. Terrigenous muds were increasingly introduced and became dominant over carbonate sediments in the east. Very shallow marine conditions prevailed over much of the western area, so that local erosion (submarine?) and sediment bypassing gave rise to many discontinuities in the sedimentational record and to quickly shifting subenvironments. (Fig. 47 greatly generalizes this dynamic overall Givetian history.)

References: Becker, 1974; Doheny, Droste, and Shaver, 1975; Dow, 1962; Gardner, 1974; Janssens, 1970; and Willman and others, 1975.

An even more widespread sea followed the Givetian submergences and resulted in Late Devonian deposition of black shales (New Albany and Antrim Shales and equivalents).

Summary

1. The loci of maximum preserved thicknesses shown in the thickness maps indicate that the depocenters changed positions from Late Cambrian to Middle Devonian time. Even though erosion has reduced the original record, the thickness patterns also indicate that the rates of subsidence varied throughout the area. These variations attest both to the dynamics of basin tectonics and to controls on thicknesses that relate to the kind of sedimentation in itself. Most important is the idea that basement mechanics controlled subsidence and its rates and, therefore, are the prime reason for thickness of the preserved record. In many examples presented here, basin development is revealed in the thickness-distribution patterns. Eustatic sea-level controls, however, left secondary imprints in the sedimentary record as also did such controls as were exerted by the kinds of sedimentation. Especially carbonate and evaporite buildups were in some places so rapid and localized as to control water depths and influence further the kind of sedimentation. Their thickness-distribution patterns may or may not accord directly with given tectonic episodes as generally expectable with other kinds of sediments.
2. What appears to be a Mount Simon depositional basin during early Late Cambrian time (figs. 3 and 4) is unique with respect to its position. After Mount Simon deposition, most of the thick depositional centers lay to the south, northeast, and southeast in areas approximating the whole or parts of the present proximal Illinois, Michigan, and Appalachian Basins. These areas did not serve continuously as major depositional centers, however.

3. In Franconian, Trempealeuan, and Canadian time, the Michigan Basin area took on the appearance of a structurally closed basin, but the Reelfoot Basin remained open southward. In this time carbonate sedimentation became dominant over terrigenous clastic deposition.
4. During a period of profound Early to Middle Ordovician erosion, only the Reelfoot Basin remained important as a depositional locus (figs. 13 and 14). The presence of such a center in Michigan is questionable.
5. Thickness and facies patterns representing Chazyan and early Blackriverian time (figs. 15-19) are complex. At least the present Illinois Basin area had some semblance of a basin but only as a part of the Reelfoot Basin that extended northward from the Ouachita Geosyncline.
6. During Black River deposition (middle Champlainian), the Michigan Basin area and the Appalachian Basin area appear to have been joined, while the Illinois Basin area continued as an area of thick sedimentation in the northern part of the Reelfoot Basin.
7. In late Champlainian time, a northeastward-trending shale-dominated extension from the Reelfoot Basin covered part of southern Indiana and southwestern Ohio (figs. 22 and 23). It divided carbonate-shelf sedimentation to the northwest (Galena and Trenton) and the southeast (figs. 22 and 23).
8. The Appalachian Basin area became the main locus of terrigenous clastic deposition during Cincinnati time and was apparently open to the Michigan Basin area, although the latter had its own localized depositional center (figs. 24-28). In contrast, the Illinois Basin had not yet developed a structurally closed appearance.
9. The tectonism that had greatly influenced changing patterns of Ordovician terrigenous clastic and carbonate sedimentation and culminated in great erosion during Late Ordovician and Early Silurian time became largely ineffectual by middle Early Silurian time. Therefore, somewhat ephemeral early and middle Alexandrian seas became mostly widespread carbonate-dominated seas by early Niagaran time (figs. 29-31).
10. During Niagaran time, the gross structural configurations of the area of study took on such proportions and stability of position as to be clearly recognizable as forerunners of modern structure. The Illinois Basin assumed a somewhat structurally closed appearance as a depositional center in its own right (figs. 32-36). The elements of the present arches in northern Illinois, Indiana, Kentucky, western Ohio, and southeastern Michigan and adjacent Ontario were in place but were so broad (in contrast with relatively small basins) as to be appropriately termed the Wabash Platform.
11. Middle Niagaran and Cayugan time was characterized by dominant carbonate and evaporite sedimentation, including large organic reef tracts (figs. 32-39). Although basement mechanics, especially toward basin development, ultimately controlled the depositional patterns, the thickness distributions do not all relate directly to subsidence (tectonism) as such. Great carbonate thicknesses relate more directly to organic activity than to greater rates of subsidence (figs. 32, 33, 34, and 37-39) in the thickened areas. Furthermore, great evaporite thicknesses in the central Michigan Basin, and to a lesser extent in the Appalachian Basin, relate to closed circulation in those areas. In contrast, although the Illinois Basin may have been nearly as deep (subsided as much), it was not completely closed to the south, and its circulation was not sufficiently restricted as to result in sulfate and halite deposition.
12. Profound Late Silurian and Early Devonian erosion affected both the Silurian and Devonian thickness distributions, but the Early Devonian pattern (fig. 40) suggests the continued development of the three principal basins. Great quantities of chert characterize

- particularly the Illinois Basin area, which apparently was open into the southern midcontinent region and was one and the same with that great chert province.
13. Middle Devonian thickness and facies patterns (figs. 42-47) have much the same general appearances as do the Early to Late Silurian patterns. This circumstance extends to evaporite deposition in the closed northern basin in contrast with none in the more open southern basin.
 14. These abbreviated interpretations treat about 130 million years of tectono-sedimentational history in a locale that is predominantly within the North American craton. These interpretations now need to be integrated with events related more directly to continental margins and with the emerging general understanding of plate tectonics.

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