

THE PALEOGEOGRAPHY OF THE MIDDLE AND UPPER SILURIAN PERIOD  
IN  
SOUTHEASTERN MICHIGAN

by  
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[SENIOR THESIS]

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## INTRODUCTION

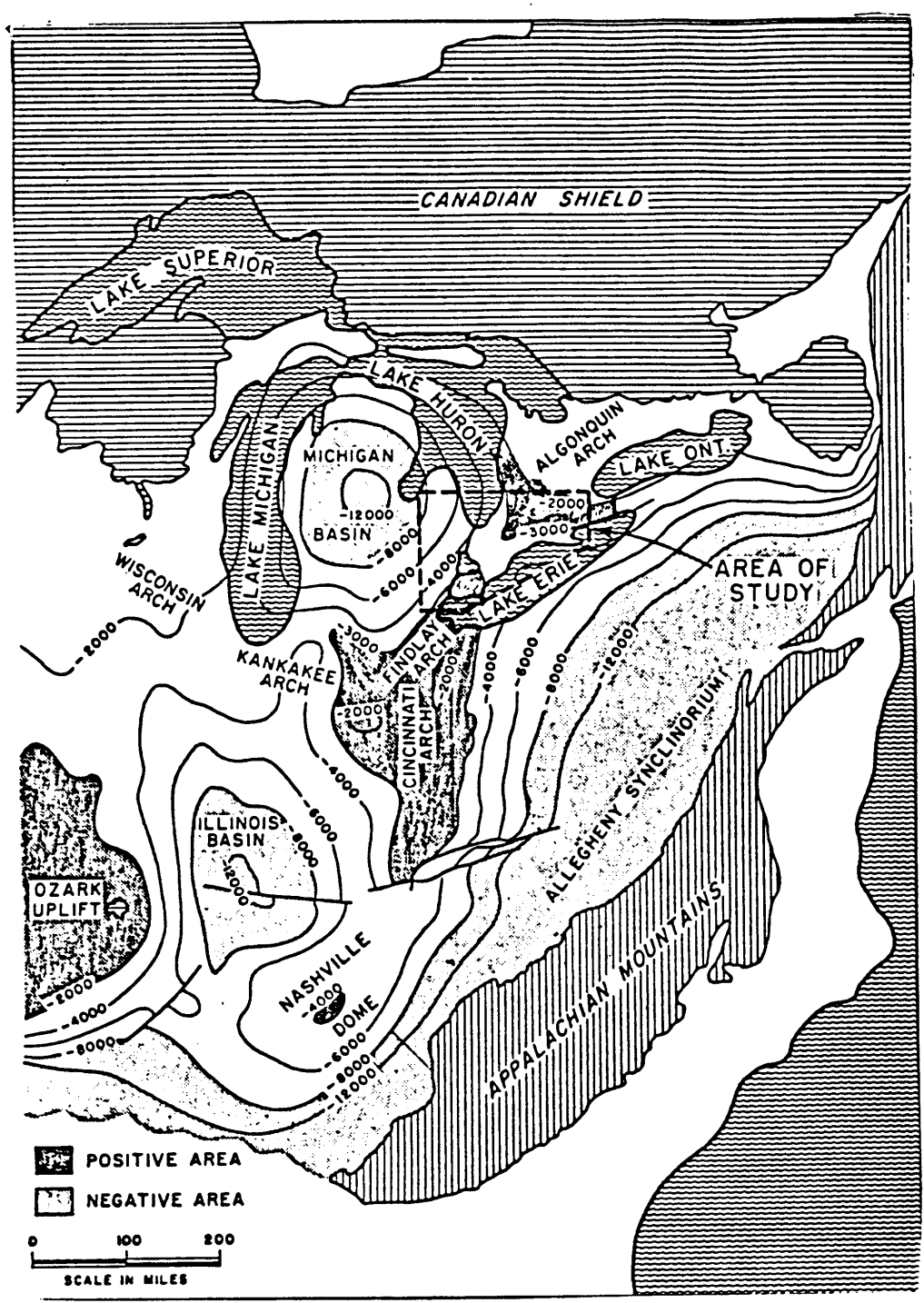
The Michigan basin is a broad, circular, unusually symmetrical structural and sedimentary basin. It is surrounded and limited by tectonic landmasses. To the east, it is bordered by the Algonquin arch in Ontario, and in the southeast by the Findlay arch in northwestern Ohio. The Kankakee arch of northern Indiana forms its southern most boundary and its western rim is formed by the Wisconsin arch. To the north, the Precambrian shield forms its final boundary. (Landes, 1945). Fig. (1).

This unique setting, during late lower, middle, and early upper Silurian times, would provide an ideal environment for several carbonate reef buildings. These reef deposits would in turn greatly influence and affect the sedimentation cycles within the basin. As the upper Silurian progressed, the reef deposits would act to seal off the basinal area from the rest of the shallow continental seas, creating the evaporitic sequences characteristic of the Salina group.

Southeastern Michigan presents an area with an excellent representative stratigraphic sequence of the Silurian period. The area is situated on the northwestern edge of the Findlay arch. The characteristic barrier reef, inter-reef pinnacle, and basin interior facies of the Niagaran series are well represented. The carbonate evaporitic facies of Salina time are present, also.

As a final note, it cannot be emphasized enough that the relationships between landmass and environment, environment and reef, and reef and evaporite, continually influenced the stratigraphic record throughout Silurian time in the Michigan basin.

(Continued)



REGIONAL MAP SHOWING BASIN AND ARCH STRUCTURES OF EASTERN NORTH AMERICA FIG(1)

This paper will discuss the various sedimentary rock occurrences and types of groups, formations, and units found in the southeastern Michigan area. It will, also, attempt to give insight into the probable paleogeography of the region and its influence on the sedimentation and accumulation rates found therein.

Finally, there will be a brief discussion on the makeup and growth patterns of reef structures so common during the middle and upper Silurian in the Michigan basin area.

		Northeastern ILLINOIS	Eastern WISCONSIN	Northern peninsula of MICHIGAN	Southwestern ONTARIO	Southeastern MICHIGAN	Northwestern OHIO	Northern INDIANA
<b>D E V O N I A N</b>								
S I L U R I A N	UPPER			St Ignace dolomite	Bass Island group		Raisin River dolomite Put-in-Bay dolomite	Kenneth limestone
	Cayuga Series		Saline group Waukesha limestone	Saline group Pie aus Chenes shale	Saline group G unit F unit E unit D unit C unit B unit A unit	A <sub>2</sub> unit A <sub>1</sub> unit	Tymachtee shaly dolomite Greenfield dolomite	Kekonsa limestone
MIDDLE	Niagara Series	Port Byron	Guelph	Engadine dolomite	Guelph	Upper Engadine dolo	Engadine dolomite	Huntington dolomite Liston Creek dolomite
		Racine dolomite	Racine dolomite	Engadine dolomite	Albion Lamoine member W. grapt. member Lisport Bay mem Lions Head mem	Engadine dolomite	Cedarville dolomite	
	Waukesha Joliet	Cordell dolomite	Cordell dolomite	Cordell dolomite	Fossil Hill formation	"Clinton"	Clinton (undifferentiated)	Mississinewa shale
		Schoolcraft dolo	Schoolcraft dolo	Schoolcraft dolo	St Edmund formation			
LOWER	Alexandrian Series	Mayville dolomite	Mayville dolomite	Mayville dolomite	Wingfield formation			
		Kankakee limestone Edgewood limestone		Moss Lake formation	Dyer Bay fm Virgane excusosa			
				Cabot Head shale	Cabot Head formation	Cabot Head shale		
<b>O R D O V I C I A N</b>								
				Manitoulin dolomite	Manitoulin formation Whirlpool sandstone	Manitoulin dolomite		Brossfield limestone

DIVISION OF SILURIAN STRATA FOR THE MICHIGAN BASIN & SURROUNDING AREAS FIG(2)

## ROCK IDENTIFICATION

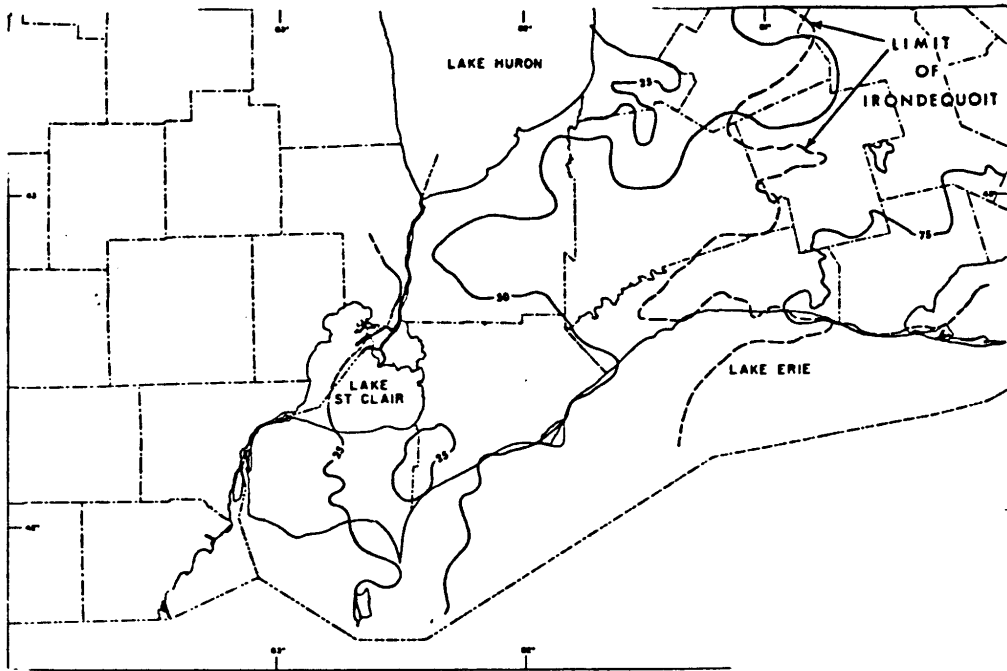
### Niagaran Series

Middle Silurian period strata are referred to as the Niagaran series. In eastern and southeastern Michigan, due to complex reef structures, rapid facies changes and irregular thickness patterns, rocks of the Niagaran series are divided into several local units having more or less provincial names. More commonly, they are divided into a Clinton group and the Engadine dolomite formation.

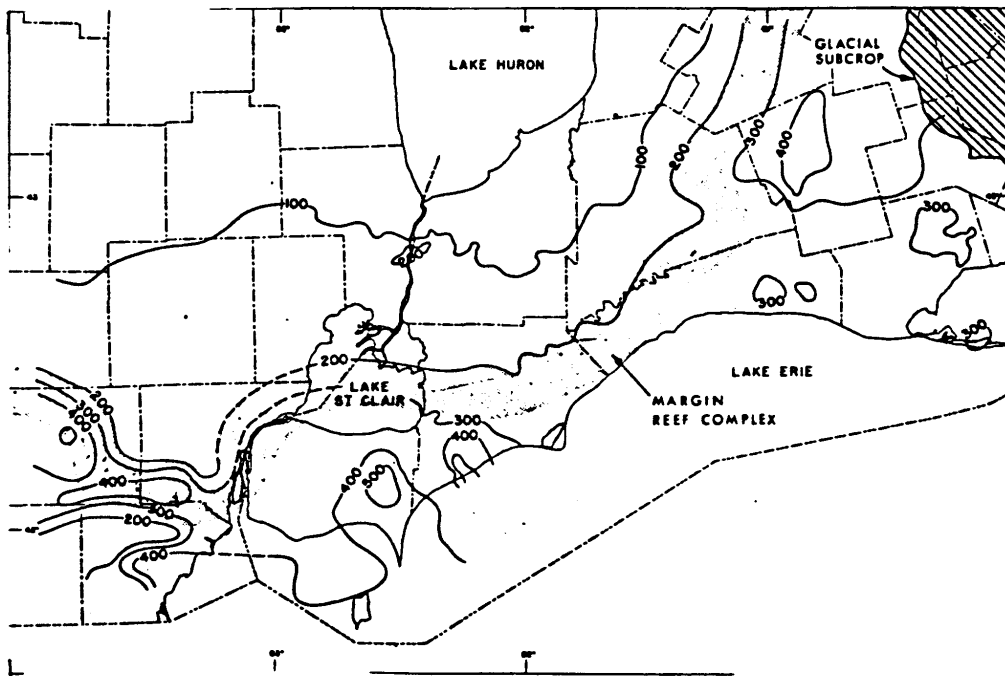
#### Clinton Group

The name "Clinton" is derived from the representative sequence in New York which may be traced westward into Wisconsin and Indiana. The Clinton group has been differentiated outside the eastern and southeastern Michigan area. In southwestern Ontario, extensive field work has resulted in the following divisions: Dyer Bay formation, forming the lower most member; the St. Edmond formation; and the Fossil Hill formation, identifying the upper most member. In northwestern Ohio, the Clinton group also remains essentially undifferentiated being referred to as the Brassfeld formation (lowest member) and the sub-Lockport Silurian. On Michigan's northern peninsula, the Clinton group is extensively subdivided as shown in Fig. (2).

The Clinton, Fig. (3), in southeastern Michigan, is a thin persistent sequence of mainly carbonates with some sandstone and shale interbedding. The shales gradually pinch out from the basin shelf from the east, giving way to the carbonates. Around this basinal shelf, the carbonates,



ISOPACH MAP OF CLINTON SURFACE  
FIG(3) BRIGHAN (1971)



ISOPACH MAP OF ENGADINE SURFACE  
FIG(4) BRIGHAN (1971)



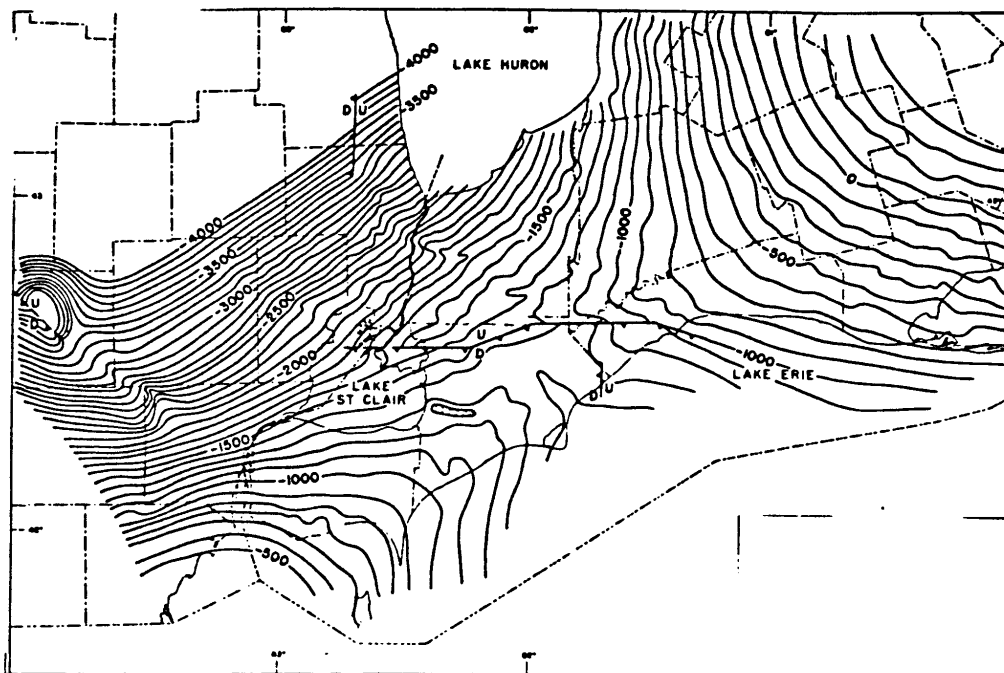
mainly dolomites, are at their thickest point along the reef platform, commonly + 75 feet. Throughout the area, thicknesses will vary markedly depending upon ones location with respect to the basinal rim. Fig. (5). This factor will be discussed later.

The carbonates also vary dramatically in characteristics. Their color commonly range from light browns, buff and brown to a light blue-gray. They are usually coarsely crystalline with vuggy porosity, to very fine grained, depending on their environment of deposition. Generally, they are massive, although in certain areas, such as the Peters Reef area in St. Clair County, they exhibit thick bedding structure. This bedding characteristic becomes more regular as one proceeds northward. Within the reef areas fossil zones are common, mainly consisting of stromatoporoids, corals, pelecypods, brachiopods, ostracods, and bryozoans. Some regions may also contain limited amounts of pyrite. Silicious material is also present in one of three forms: First, as chert nodules replacing matrices and bioclasts alike; Second, as quartz spar filling primary voids in fossils which have not been occupied with calcite mud or spar. The Third type of authigenic silica is chalcedony, usually found as a replacement in some brachiopoda shells.

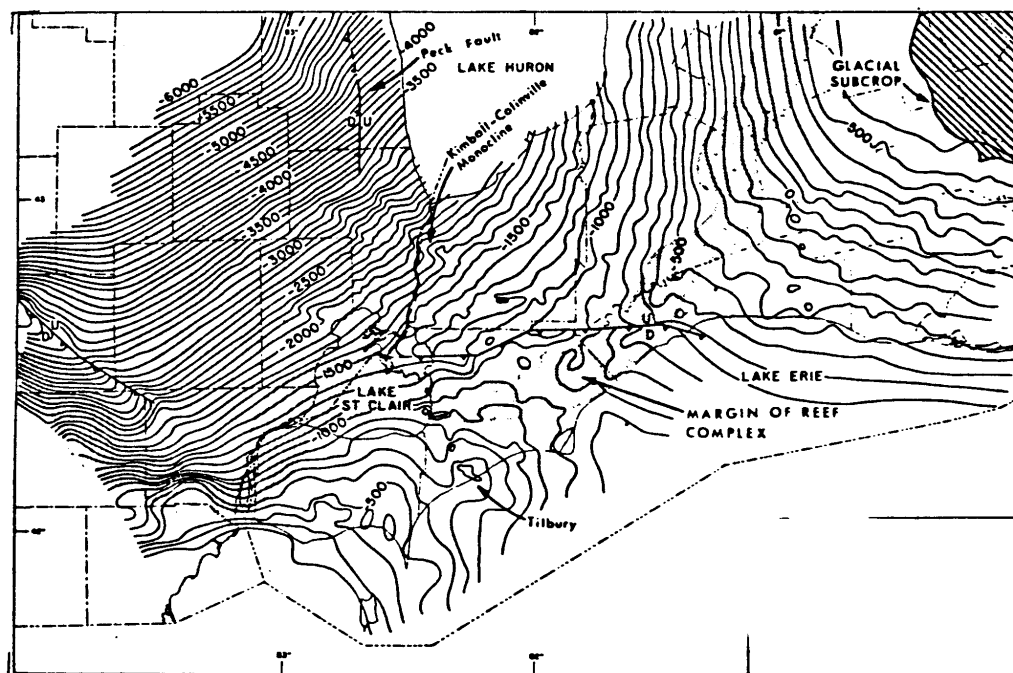
The shales are thinly laminated, finely textured, gray to gray-brown, and dolomitic.

#### Engadine Dolomite Formation

The contact between the underlying Clinton group of early and middle Niagaran age is sharply overlain by the youngest member of the Niagaran, the Engadine Dolomite. Fig. (4). The name Engadine was first used in the northern peninsula of Michigan by R. A. Smith.



STRUCTURAL CONTOUR MAP OF THE CLINTON GROUP FIG(5)  
BRIGHAN (1971)



STRUCTURAL CONTOUR MAP ON THE ENGADINE FORMATION FIG(6)  
BRIGHAN (1971)

Outside of the southeastern Michigan area, the Engadine is recognized by several different members. See Fig. (2). Southwestern Ontario refers to this as the Albermarle group, consisting of four members and the Guelph formation. In northwestern Ohio, the Cedarville and Woodville dolomites are called the familiar Lockport-Guelph group. Finally, on the northern Peninsula, the Engadine nomenclature is used, although a controversy remains over the possibility of Guelph fauna being present.

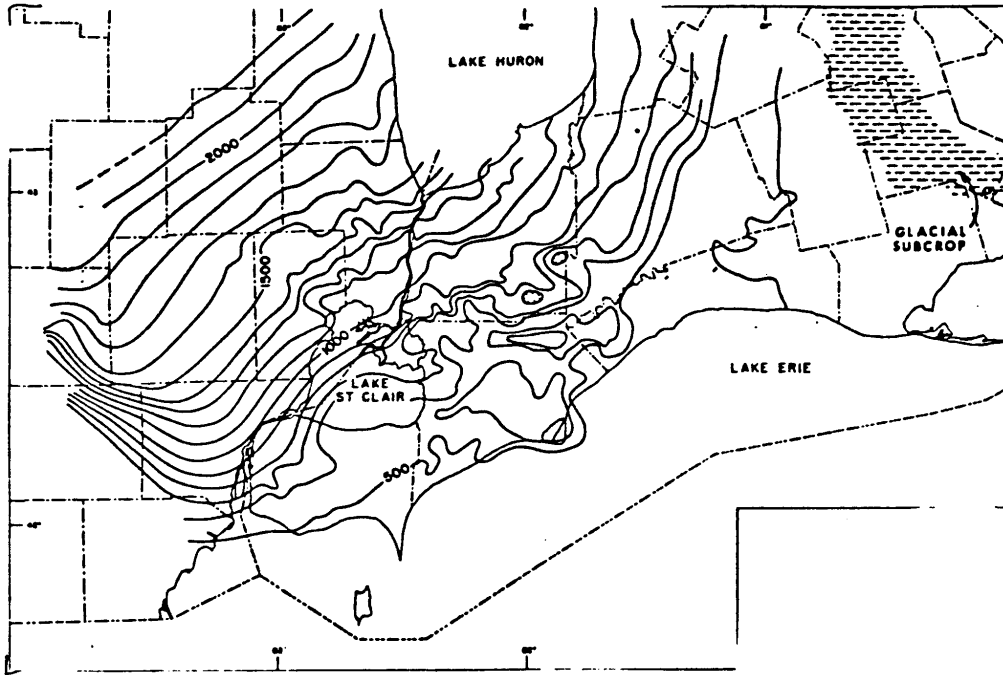
The Engadine dolomite consists of bioconstructed limestone and sediments which have originated from organic activity. It is a recrystallized dolomite with thicknesses varying somewhat from 60 to 400 feet. The maximum thicknesses have been interpreted as reef banks or complexes that developed on the platform areas which were present along the southeastern edge of the basin, or on structurally high areas basinward of the platform region. The minimum thicknesses would have occurred in the form of inter-reef deposits. This type of thickness pattern has proven true in other platform areas of the basin, as well as in the Illinois basin. The Engadine will show thinning in a basinward direction, although along the strike of the reef platform thicknesses are fairly uniform. Fig. (6). It is postulated that different rates of subsidence were an important factor in basinward reef development. Rapid subsidence basinward would prevent extensive carbonate production due to low sunlight conditions and low wave energy. In southeastern Michigan, the situation was the exact opposite. The area lay on the very edge of the Findlay Arch which would practically guarantee a slow subsidence rate and the right conditions. Within the basinal area, only synchronous highs would permit the growth of pinnacle reefs. These were the only areas where carbonate production could keep up with subsidence.

The lithological characteristics of the Engadine are commonly divided into three different zones in southeastern Michigan. Each zone is representative of one of the distinct environments in which reef growth occurred. These strata consist principally of carbonates mixed with different proportions of anhydrite. Extensive alteration has occurred since deposition and quantities of foreign material such as carbonate silt and shell fragments have been added. This alteration considerably hinders recognition of both fauna and the environment of deposition.

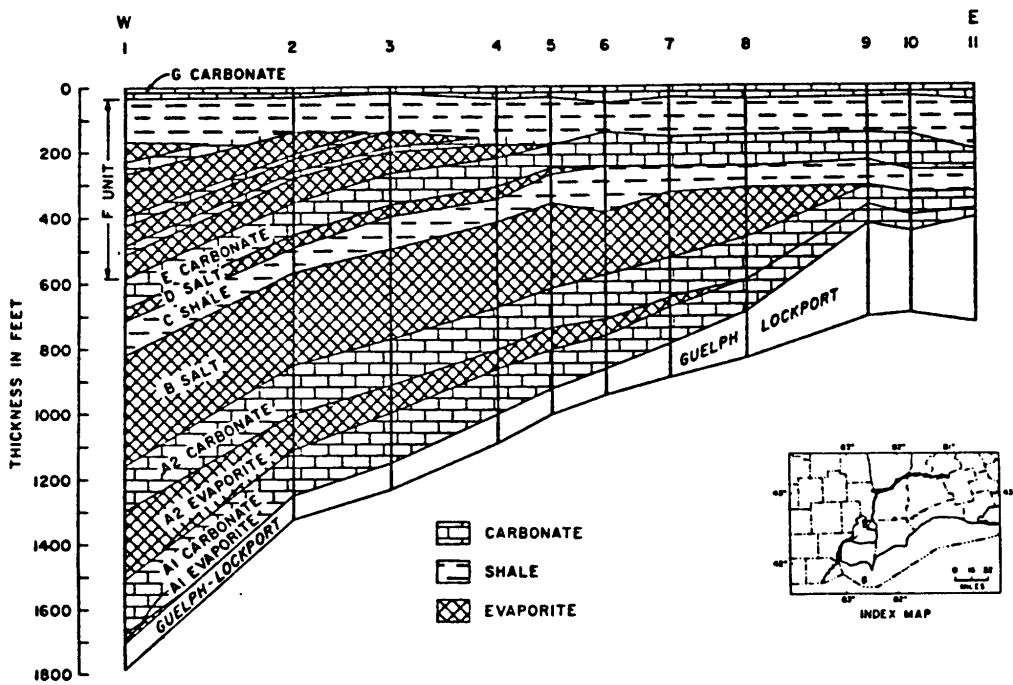
Zone One consists of a brown-buff to blue-gray, fine to medium grained grainoblastic, fossiliferous, well cemented dolomite. In places, it has thin laminate with stylitic partings, interskeletal and intergranular porosity. Since this Zone represents early reef development, stromatoporoids are found in large numbers. This Zone is commonly called the "White Niagaran" by well drillers.

Zone Two will vary in thickness, generally 30 to 50 feet. It consists of a buff to gray-buff, very fine grained (almost lithographic) texture and detrital dolomite. Fossils are very scarce, it exhibits intergranular porosity with granoblastic texture, and is usually well cemented. In some places, thinly laminated stylitic partings occur with black bituminous matter. This Zone is commonly leached and recrystallized, also. Thin dark gray streaks and patches mottle this Zone and are one of its outstanding characteristics in well cores. Drillers often refer to this as the "Gray Niagaran."

Zone Three is the "Brown Niagaran." It consists of a dark brown to tan, fine to medium grained, crystalline dolomite. It tends to be grainoblastic and brecciated. The breccia are fossil fragments which exhibit good interskeletal porosity.



ISOPACH MAP OF THE TOTAL SALINA GROUP FIG(7)  
BRIGHAM (1971)



EAST - WEST CROSS-SECTION FOR THE SALINA GROUP  
FIG(8) BRIGHAM (1971)

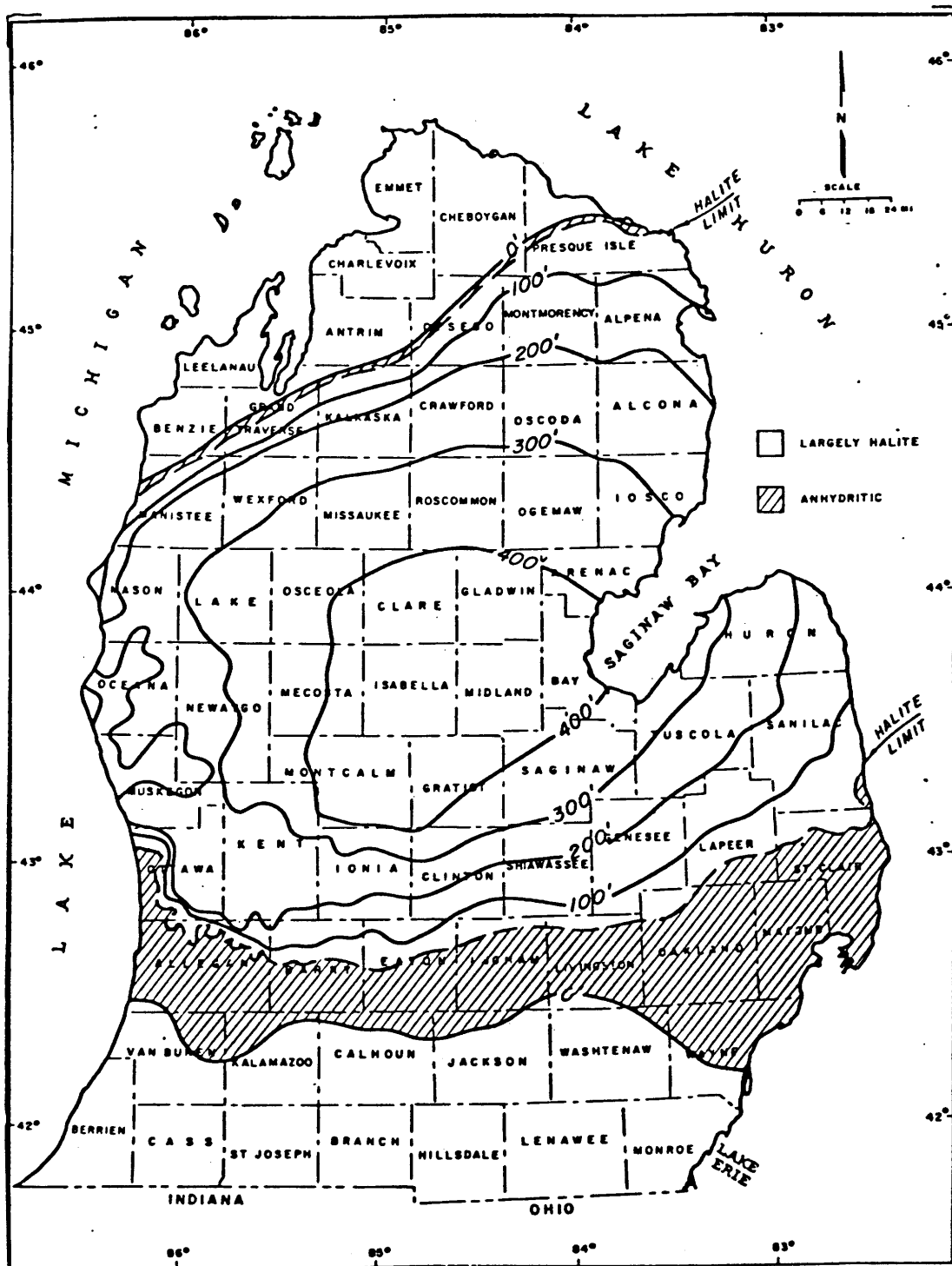
There has been some difficulty in defining the relationship of middle Silurian Niagaran rocks and upper Silurian Salina rocks. Problems of stratigraphic placement outside the Michigan basinal area remain. Salina strata began to be deposited earlier within the basin than in the Appalachian basin. The meanings of the terms Niagaran and Salina in terms of their stratigraphic boundaries, as well as the place of occurrence, continue to cause correlation problems.

### Cayugan Series

The Cayugan rocks of late Silurian age constitute the largest volume of Silurian sediments within the Michigan basin. Fig. (7) & (8). They are generally divided into two groups, the Salina and the Bass Islands. The lower most group, the Salina, is subdivided into various units approximately equivalent to formations. Upper Silurian rocks of the basin area are exposed along the Mackinac Straits Region to the north and on the southeastern edge of the Ontario Peninsula, along the Niagaran escarpment, to the east. To the south, along the Cincinnati arch, and in west central Ohio, Cayugan rocks are widely exposed.

### Salina Group

On the Northern Peninsula of Michigan, the Salina group embraces the entire Upper Silurian age; and it is subdivided only into two formations, the Pte. Aux Chenes shale and the St. Ignace dolomite. Northwestern Ohio divides the Upper Silurian into the Greenfield formation and Tymochtee formation which correlates with the Salina group and the Put-in-Bay and Raisin River formations, which are equivalent



THICKNESS VARIATIONS ON THE A-1 EVAPORITE SURFACE  
 CONTOUR INTERVAL, 100' FIG(9)  
 GILL (1975)

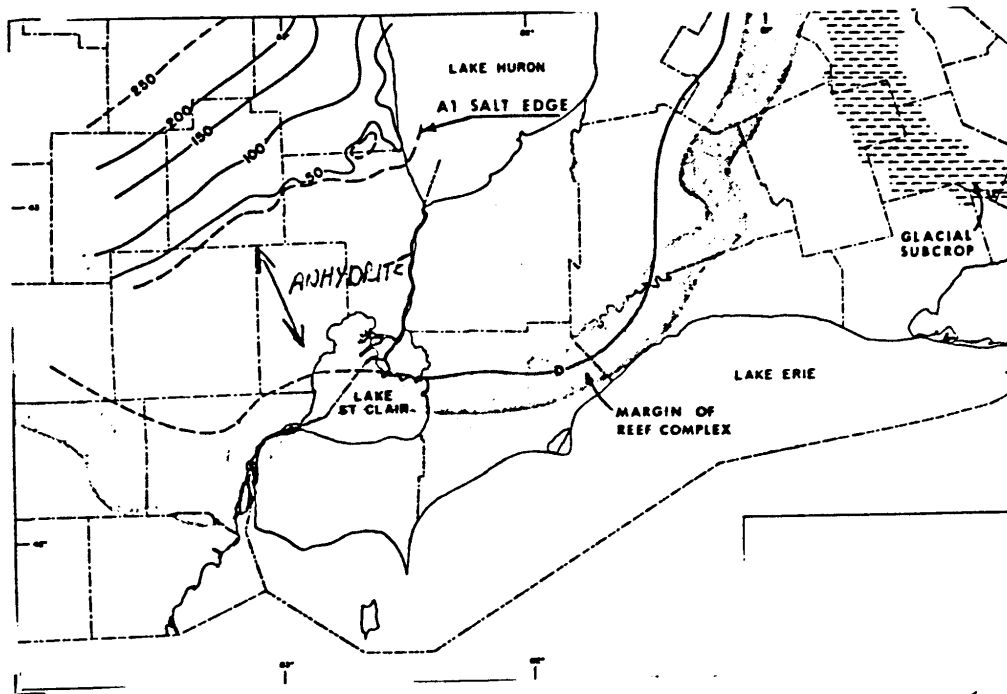
to the Bass Islands group. Southwestern Ontario recognizes basically the same nomenclature that is used within the basinal area, except that one final subdivision within the Salina group is used to denote the Bass Islands group. To the west, the State of Wisconsin doesn't generally subdivide the Cayugan series. Fig. (2).

The terminology and general rock divisions currently being used are mainly the result of many years of work on the part of two men, Landes (1948) and Evans (1950). Landes divided Upper Silurian rock, in ascending order, into units A through H. The "H" unit is now considered as the Bass Islands group. Evans has subdivided the "A" unit even further.

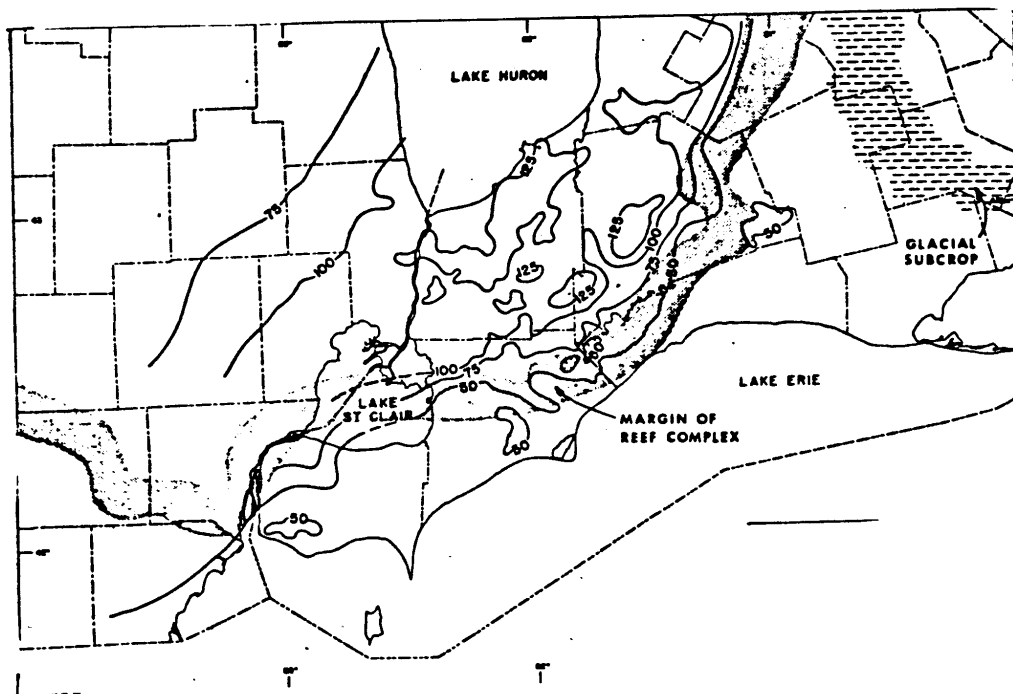
The Salina group is more extensively developed within the Michigan Basin than in any other region. The group was first named by Dana (1864) in New York. Niagaran reef and reef complexes have, in general, influenced the deposition and structural aspects of Salina rocks in the southeastern Michigan area.

**A-1 Evaporite:** This is the lowest stratigraphic formation, and it will include the A-1 salt and the overlying A-1 anhydrite. The salt unit is very clean and occurs over most of the interior area within the basin. Beyond the southeastern area, some shale lens will occur within this unit. This very clean salt will vary in thickness from basin to platform area. Fig. (9). It is generally restricted to the north and west of the Niagaran reef structures. As one approaches the reef complex, a facies change occurs. Fig. (10). The A-1 salt will grade laterally into the A-1 anhydrite. Along the basinal shelf, only the A-1 anhydrite occurs, varying without observable regional patterns, from a few feet to so much as 35 feet near the reef margin.

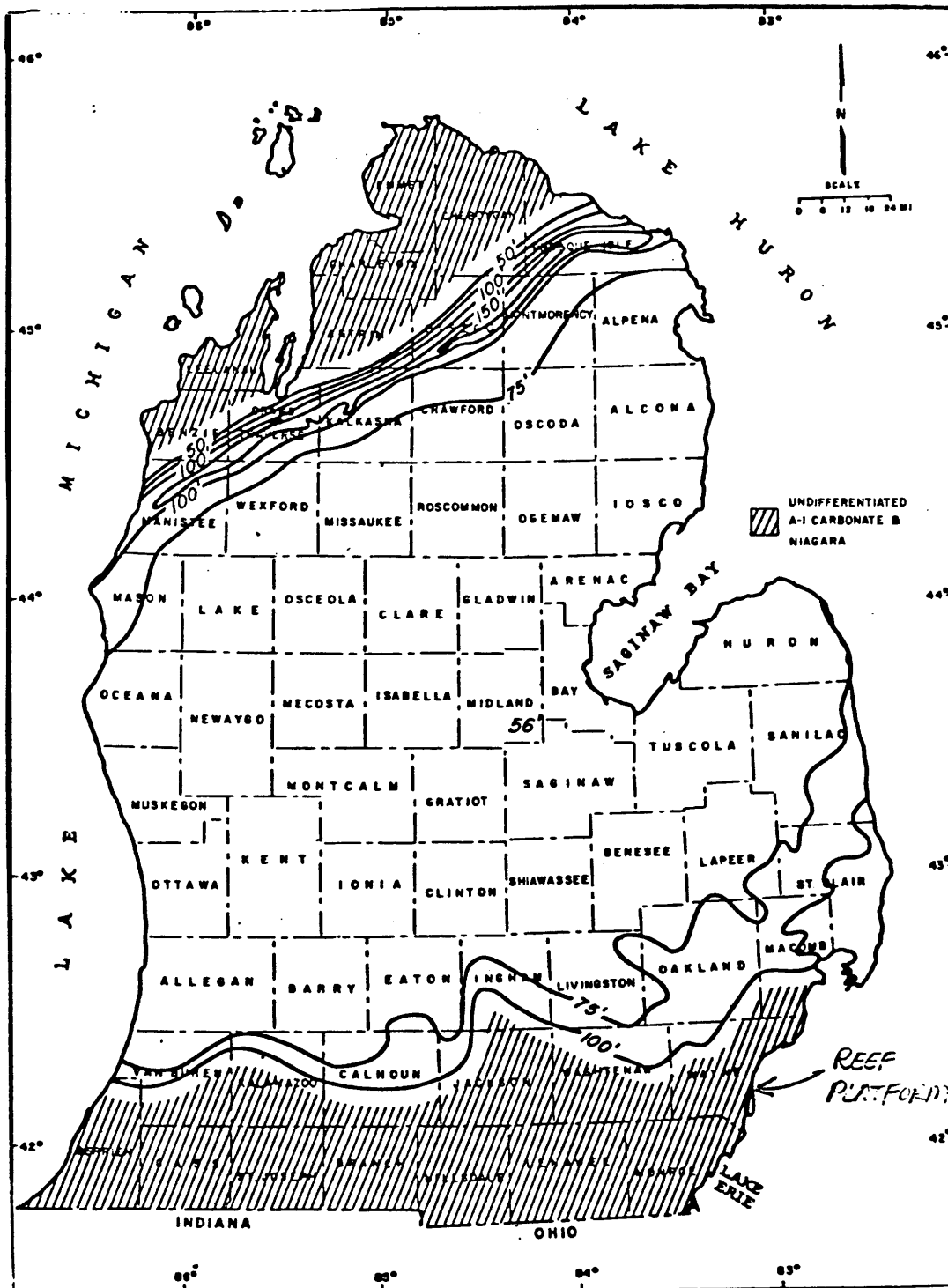




ISOPACH MAP OF THE A-1 EVAPORITE UNIT FIG (10)  
BRIGHAN (1971)



ISOPACH MAP OF THE A-1 CARBONATE UNIT FIG (11)  
BRIGHAN (1971)

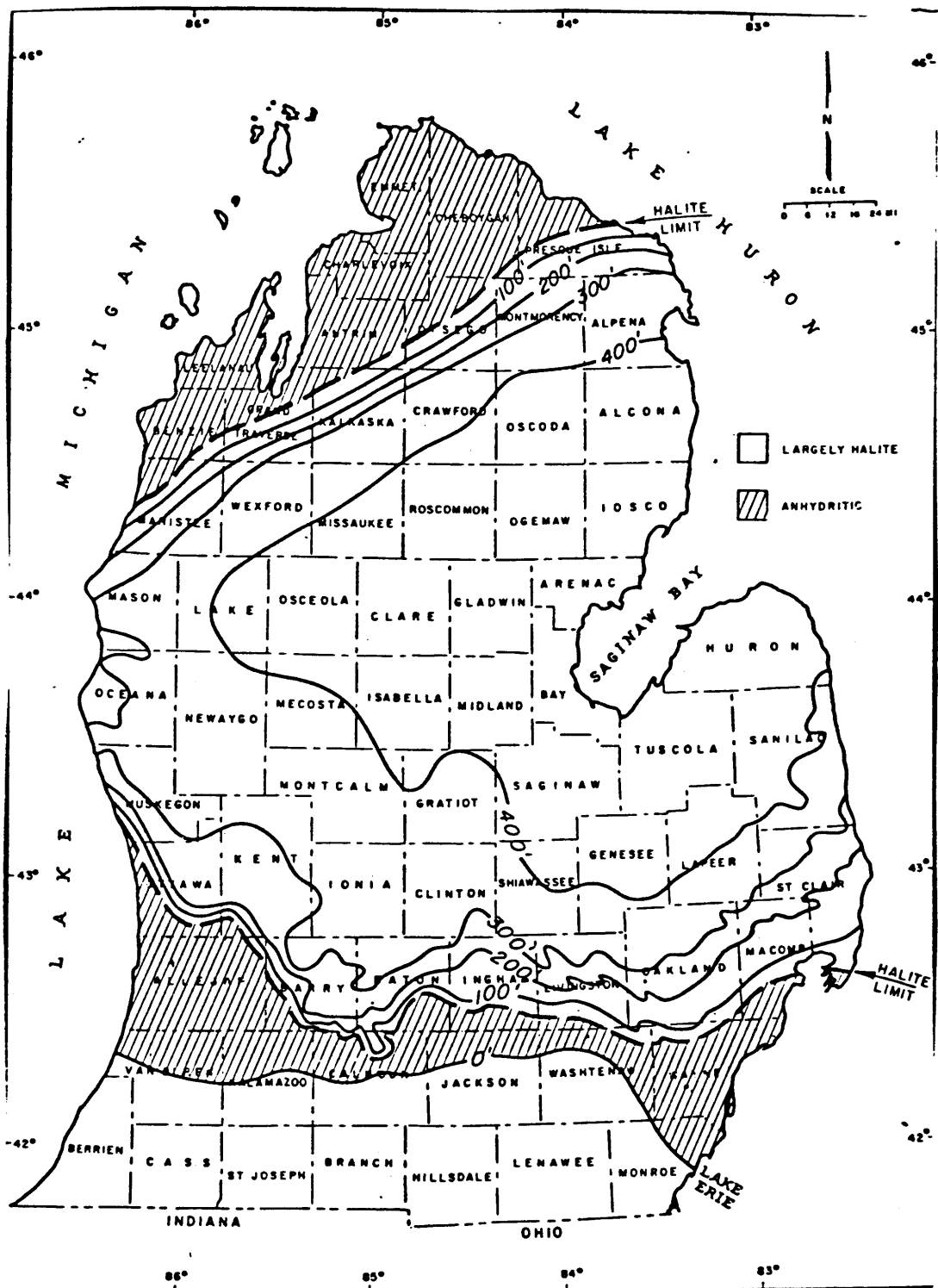


THICKNESS VARIATIONS ON THE A-1 CARBONATE SURFACE, CONTOUR INTERVAL, 25' FIG(12) GIL (1975)

The A-1 anhydrite may also show thin shale and carbonate bands, but this occurs very locally. In the area of southeastern Michigan, neither the A-1 salt or A-1 anhydrite are present on the higher flanks or crests of the reef platform.

**A-1 Carbonate:** This unit changes laterally from a dark gray, thinly bedded, argillaceous limestone to the north and west, to a light brown sucrosic dolostone to the south; and vertically it changes to a dark gray argillaceous limestone toward the base. Its lithologic character has been observed to change laterally as well as vertically. Near the basinal shelf it is mainly a dolomite, but toward the interior it will contain limestone. The darker colors may be caused by the presence of heavy hydrocarbons. The thin bedding arrangement may represent a seasonal or possibly a yearly cycle change. It is generally unfossiliferous. Greatest thicknesses occur near the reefs and interreef areas, approximately 100 - 130 feet. Fig. (11). Over the pinnacle reefs the unit will be thin or missing entirely. Along the reef crests of the Niagaran platform, thicknesses are commonly 20 to 50 feet. Fig. (12). As with the A-1 evaporites, the carbonates appear to have been deposited entirely within the basinal area.

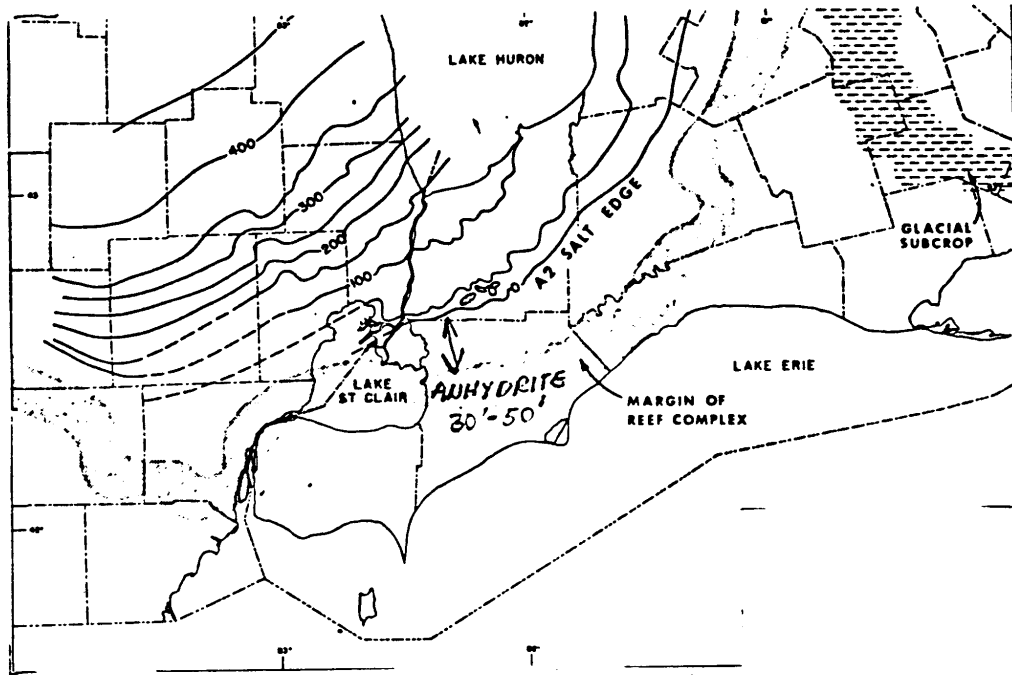
**A-2 Unit:** This unit contains the same sequence as the A-1 unit, but it varies lithologically. The A-2 evaporite is primarily salt with minor anhydrite beds at the top and bottom of the section which coalesce and extend shelfward beyond the edge of the salt. The salt is relatively pure and the anhydrite is characteristically gray to white in color and in some areas it may become a dolomitic anhydrite. The salt section is more than 400 feet thick in the deeper basinal areas,



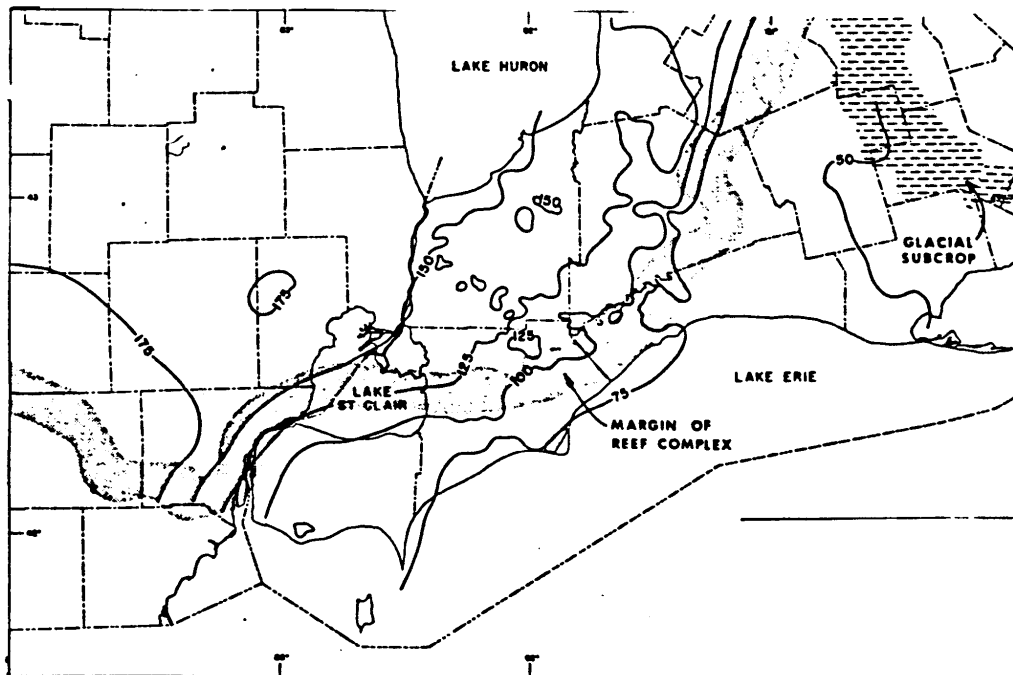
THICKNESS VARIATIONS FOR THE A-2 EVAPORITE SURFACE, CONTOUR INTERVAL, 100' FIG. (13) GILL (1975)

but will thin and grade laterally into an anhydrite equivalent on the basinal margins. Fig. (13). The salt unit may vary greatly in thickness due to leaching. Again, it will be absent over reef margins and over the pinnacle reefs. The thickness of the A-2 anhydrite may vary from approximately 30 - 50 feet at the reef crest, to less than 10 feet near the flanks of the reef complex. Fig. (14). These anhydrite beds lie unconformably on the A-1 carbonate over the reef structures. Interestingly enough, the anhydrite thickens on the reef crest. Briggs (1961) proposed an explanation for this in one of two ways, or both: (1) result of lateral facies gradation, the anhydrite on the reef is the facies equivalent of the A-2 salt off the reef, or (2) differential flowage of the salt toward the basin and the anhydrite toward the reef crests.

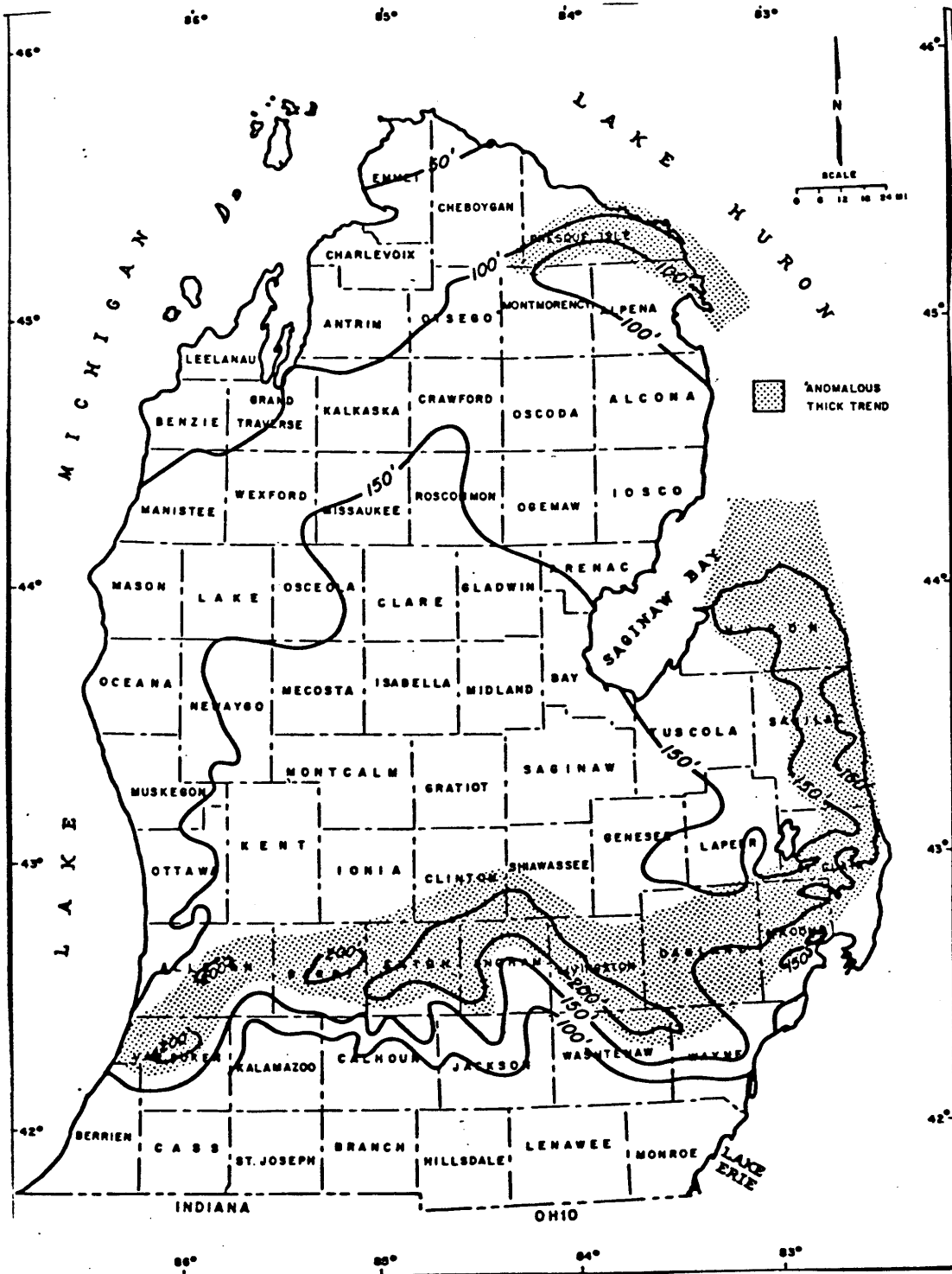
A-2 Carbonate: This carbonate is a widespread formation whose lithologic characteristics are very similar to those of the A-1 carbonate unit. It is underlain by A-2 anhydrites on the shelf margin and can be found over the A-2 salt toward the basin interior, due to a facies change from anhydrite to salt. The A-2 carbonate has been subject to separation into two zones, the A-2 limestone and A-2 dolomite on the same crest. The dolomite occurs above the limestone with a gradational contact. This is a brown-buff dolomite with thin laminae, and it is finely crystalline. The limestone is commonly gray-brown, shaly, and argillaceous. They will range in thickness from 50 - 90 feet over the reef complex and pinnacle reefs to approximately 100 - 160 feet over the reef flanks. Fig. (15). This carbonate (unlike the A-1 carbonate) remains fairly constant in thickness along the strike of the reef platform. Fig. (16).



ISOPACH MAP OF THE A-2 EVAPORITE UNIT FIG (14)  
BRIGHAN (1971)



ISOPACH MAP OF THE A-2 CARBONATE UNIT FIG(15)  
BRIGHAN (1971)



THICKNESS VARIATIONS FOR THE N-Q CARBONATE SURFACE, CONTOUR INTERVAL, 50'

(NOT THE RESULT OF REEF BUILDING) FIG. (16)  
GILL (1975)

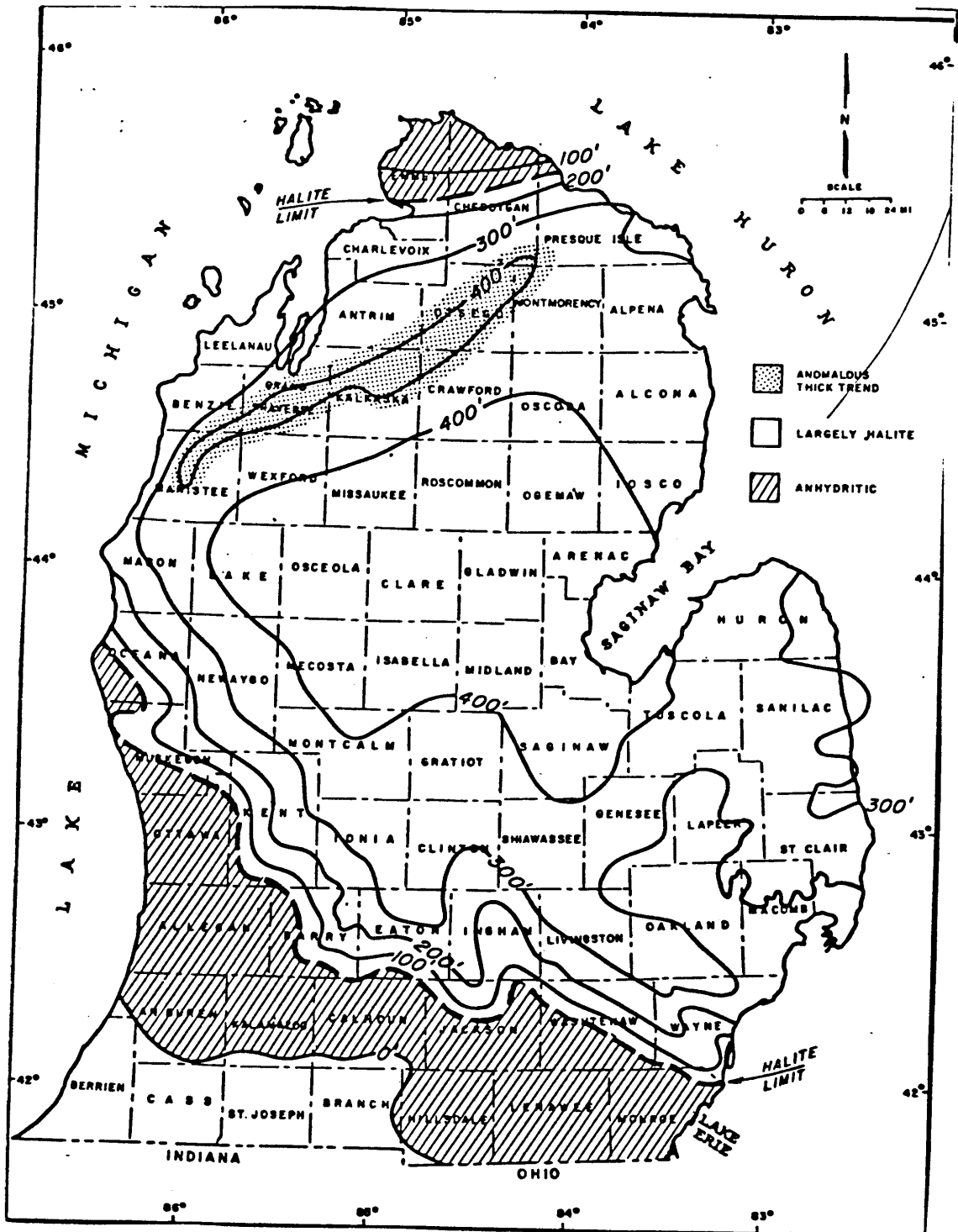
B Evaporite Unit: This unit is mainly a salt unit, with a fairly uniform thickness in the basinal area of about 245 - 400 feet. Fig. (17). As you approach the reef platform, it can be as little as 50 feet thick over the crest.

Along the extreme southern end of southeastern Michigan, the salt distribution is irregular, presumably due to solution. Fig. (18). It is not even present in the southwestern basin area due to removal by erosion.

The lower part of this unit is a relatively pure salt with a very high sodium chloride content. The upper part of the unit is a series of salt, shale, anhydrite, and dolomite. These are due to facies changes that occur from basin to shelf boundaries. This salt is the only salt which extends over the reef complex and will usually be the thickest salt found in a core sample or by induction log. The presence of a thick salt does not indicate a considerable span of geologic time. Halite has been observed to accumulate faster than three feet per year under optimum conditions (Briggs 1958). In general, evaporite minerals will accumulate at a higher rate than carbonate minerals.

C Unit: The "C Unit" has been observed to be one of the most persistent of the Salina group, in this area. It consists of a gray to greenish-gray, dolomitic shale containing rounded quartz sand grains. The unit won't contain salt beds, but a thin bed of pink to light green nodular anhydrite appears to be persistent throughout the basin. The thickness of this unit has been observed to change abruptly and is not conformable with the reef structures. Some reef crests contain a red shale bed near the top of the formation suggesting an





THICKNESS VARIATIONS FOR THE B EVAPORITE SURFACE, CONTOUR INTERVAL 100' FIG (17) GILL (1975)

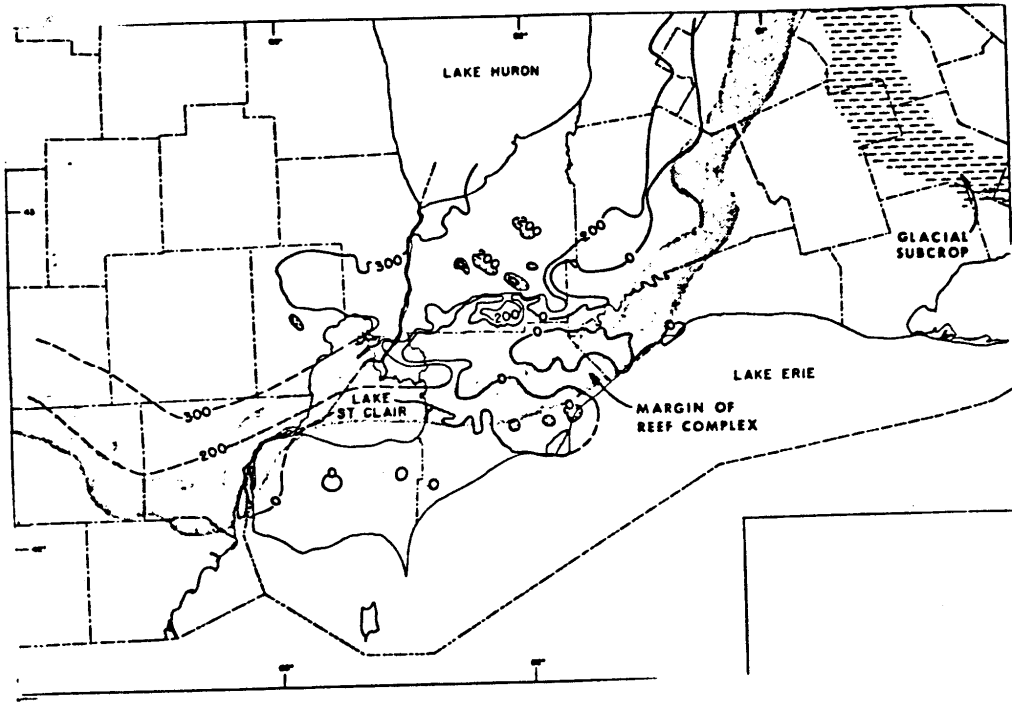
oxidizing environment and indicates an erosional unconformity.

General thicknesses would range from 60 - 120 feet. This C unit carbonate has been traced, in the subsurface, from the basinal area into the Ohio and New York areas.

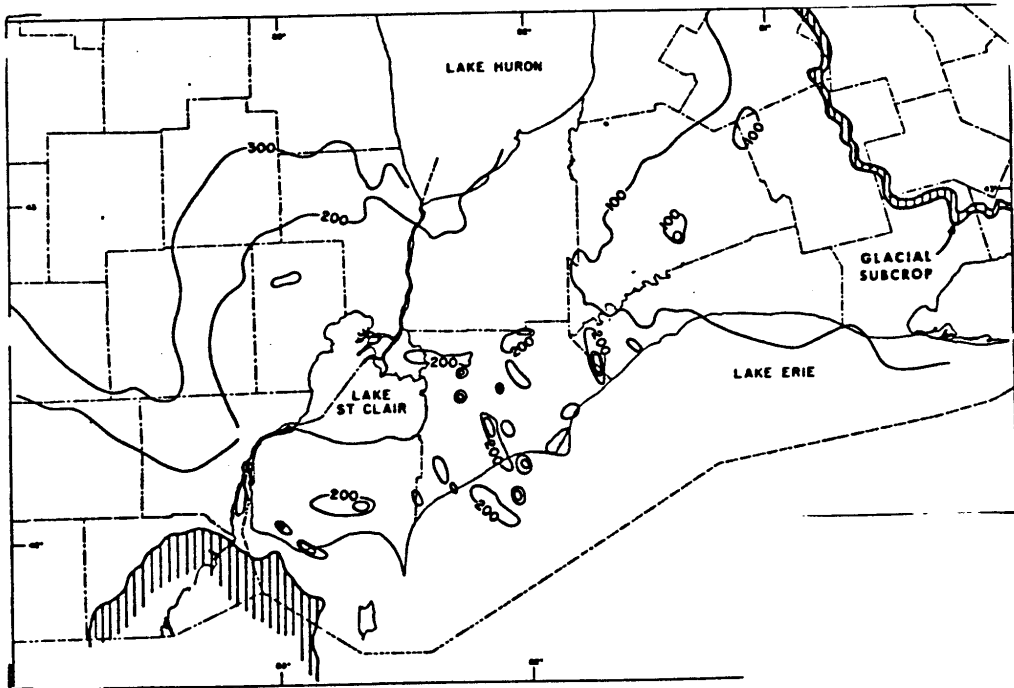
**D Evaporite:** This evaporite is defined by the presence of overlying E Unit and underlain by the C Unit carbonate. In most of the study area it consists of two relatively pure salts with a light brown dolomite dividing them. The unit is lenticular and occurs within the inner margins of the Niagaran reef complex. It is generally present over the reef complex, also. Where leaching has not removed it, the salt will vary from approximately 30 - 60 feet. Unlike the A-2 salt, the D salt doesn't exhibit any regional thickening.

**E Unit:** The "E Unit" carbonate is present throughout the study area and has a relatively uniform thickness ranging from 80 - 120 feet. Although it is termed a carbonate unit, the unit consists mainly of gray, greenish-gray, and red shales with a thin bed of dolomite inbetween. The unit is not present at all in the southwestern basinal area due to removal by erosion.

**F Unit:** This unit contains thin successions of pure and impure salt beds, thin anhydrite, anhydritic shale beds, and shaly dolomites. The dolomites are characteristically gray, buff, and brown, medium grained, and exhibits vuggy porosity. The shales are gray, greenish-gray, and red-gray in color. Salts occur as pink to red tinged depending on the amount of impurities. These salts occur in as many as six beds in the northern part of the study area. The sequence is generally uniform in thickness, approximately 100 feet; although in some areas where the six salt beds occur, the thicknesses may exceed 500 feet. The section



ISOPACH MAP OF THE B EVAPORITE UNIT FIG(18)  
BRIGHAN (1971)



ISOPACH MAP OF THE BASS ISLAND GROUP FIG(19)  
BRIGHAN (1971)

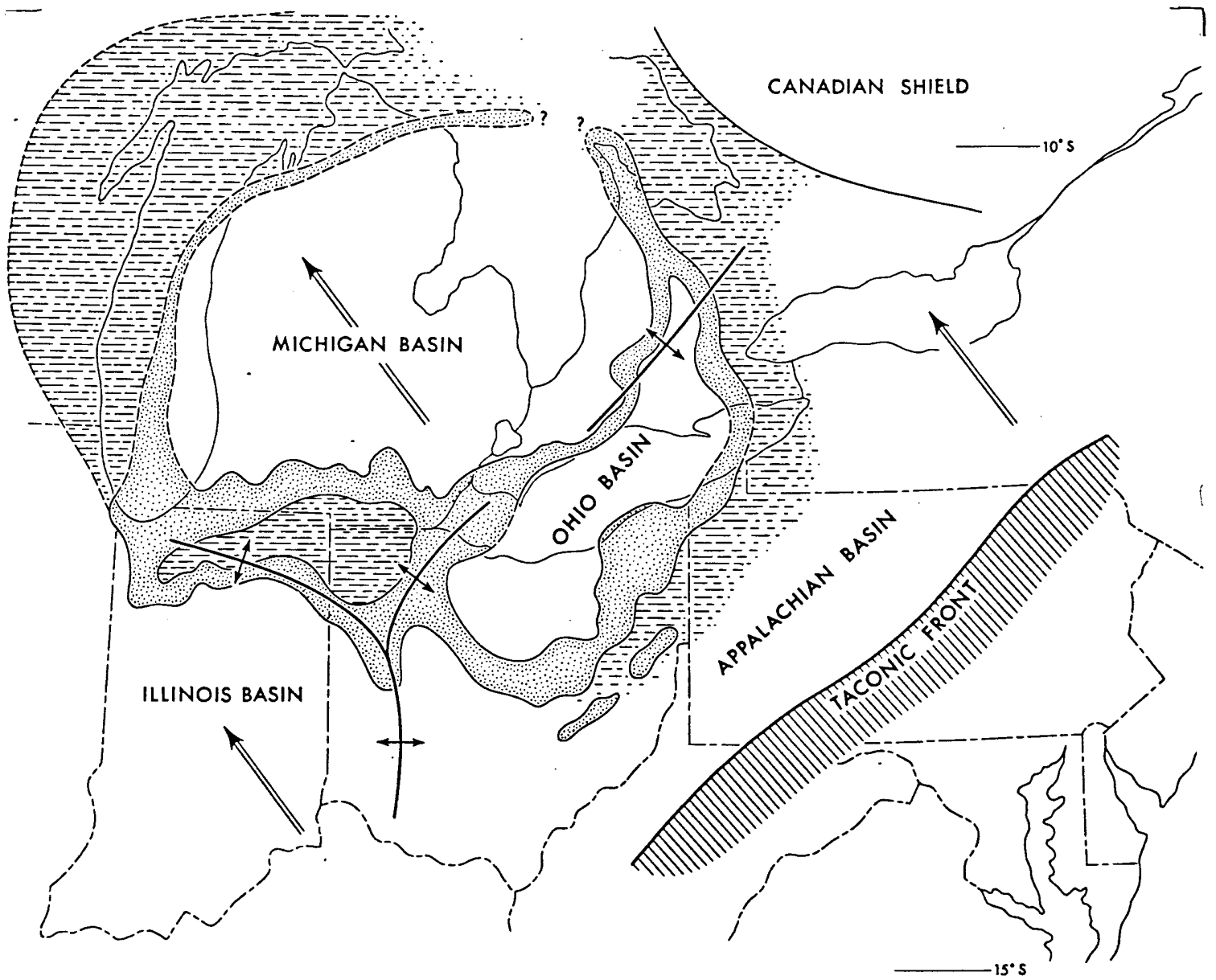
characteristically thins toward the basinal margin; most of this is due to depositional thinning of the salt beds. In certain areas of the basin, the F unit has been entirely removed by erosion.

**G Unit:** This is the uppermost unit of the Salina group in this area. It is composed of a buff colored, fairly dense dolomite overlain by a gray, to dark gray shaly argillaceous dolomite. The thicknesses vary considerably from 10 - 80 feet. The main problem exists when the G unit is picked up in the margins of the basin. When traced into the basin interior, the unit can be shown to grade into F evaporite unit. Due to a difference in stratigraphic section from basin to basin margin, the top of the Salina will be placed at different levels, with devonian rocks overlying the G unit along the margin and overlying the F unit evaporite in the basin interior. These differences are well documented in the well records.

#### Bass Island Group

The topmost formation of the Silurian in the basinal area, and also in the study area, is the Bass Island Group. Although this formation is usually divided into two distinct formations at outcrop, they are seldom divided in the subsurface. There is a general lack of agreement among geologists as to the contact between the Bass Island and the uppermost Salina unit. Due to the similar lithologic characteristics of both formations, there may be discrepancies of as much as 60 feet in thickness accredited to the Bass Islands. The common identification being a difference in the color of the dolomite. The Bass Island rocks are commonly buff to a gray-buff dolomite. The upper unit exhibits oolitic character at several horizons. In the lower areas of the section, gray argillaceous to shaly dolomites dominate

the stratigraphic column. As the formation proceeds basinward, thin anhydrites and several thin salt beds are found. Thicknesses range from 50 - 100 feet near the basin margin to approximately 750 feet in the deeper parts of the basin. Fig. (19). In the study area, the thicknesses are extremely variable, locally as much as 450 feet, in some structurally low areas. An unconformity exists at the uppermost portion where the Devonian occurs. This unconformity is most acute at the southern edge of the study area where a great portion of the Bass Island and some of the Salina are absent. This is an indication of possibly several periods of erosion during lower Devonian times. As one moves basinward, this unconformity is not apparent suggesting that erosional forces were confined to the marginal edges.



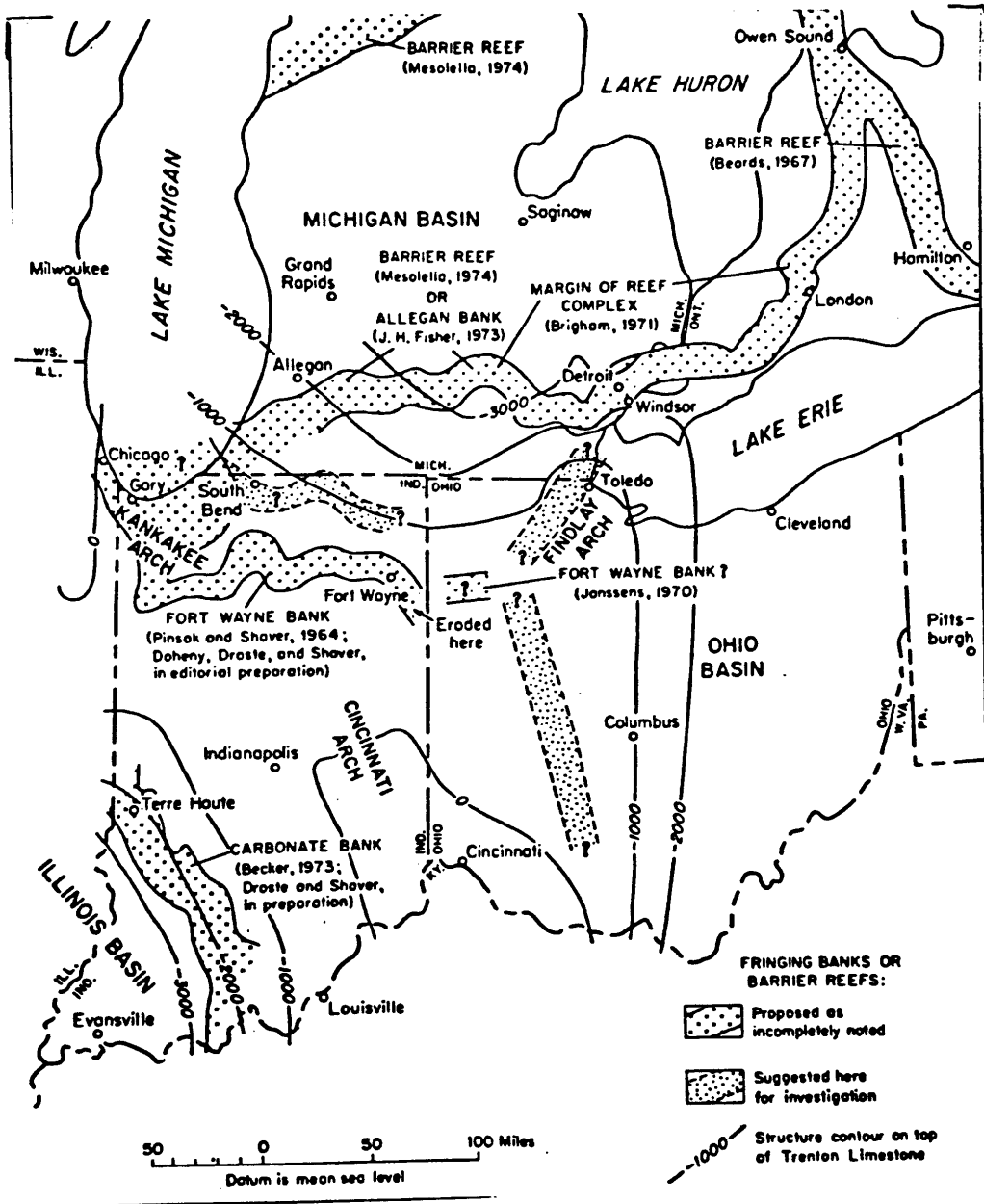
*PALEOGEOGRAPHY OF THE NIAGARA-CAYUGA SHOWING THE  
SETTING OF THE REEF PLATFORMS AND BASINS (LOUIS & DARDENKA 1963)*

... FIG(20)

## PALEOGEOGRAPHY

The Silurian history of the eastern North American continent represents a unique climatic, biologic, sedimentological and tectonic setting that produced a stratigraphic complex of tectonic malasse, carbonate reefs and evaporites in the Appalachian trough, Michigan basin and adjacent continental platform areas. Fig. (20). Interpretation of the events of this history necessitates defining effects of cyclic deposition, climatology, biologic types and communities, that are recorded in the sedimentary rocks of these regions. The present regional stratigraphic setting for the Silurian, portrays the nature and distribution of the middle and late Silurian arches, basins and Taconic Front; the paleoclimatological setting, paleogeography and expected prevailing wind pattern, and the distribution of the extensive platform reef complexes. As our knowledge and concepts develop and evolve, the stratigraphic and paleogeographic framework becomes better defined and refined, and is able to encompass more of the specific details derived from the studies of parts of the stratigraphic records in local areas. (Louis L. and Darinka Briggs, 1974). Fig. (21).

The Michigan Basin presents an area of unique geology. There are formations within this area that remain confined to only the basin and others that commonly occur from as far east as New York State. Rocks of the Early, Middle, and Late Silurian system occur throughout most of the Basin. They account for over thirty percent of the estimated 108,000 cubic miles of sediments deposited here. (Cohee and Landes, 1958). The paleogeography of southeastern Michigan was, of course, largely determined by major tectonic, transgressive and regressive events on the North American Continent. However, during different intervals, local activities helped to mold the present day and subsur



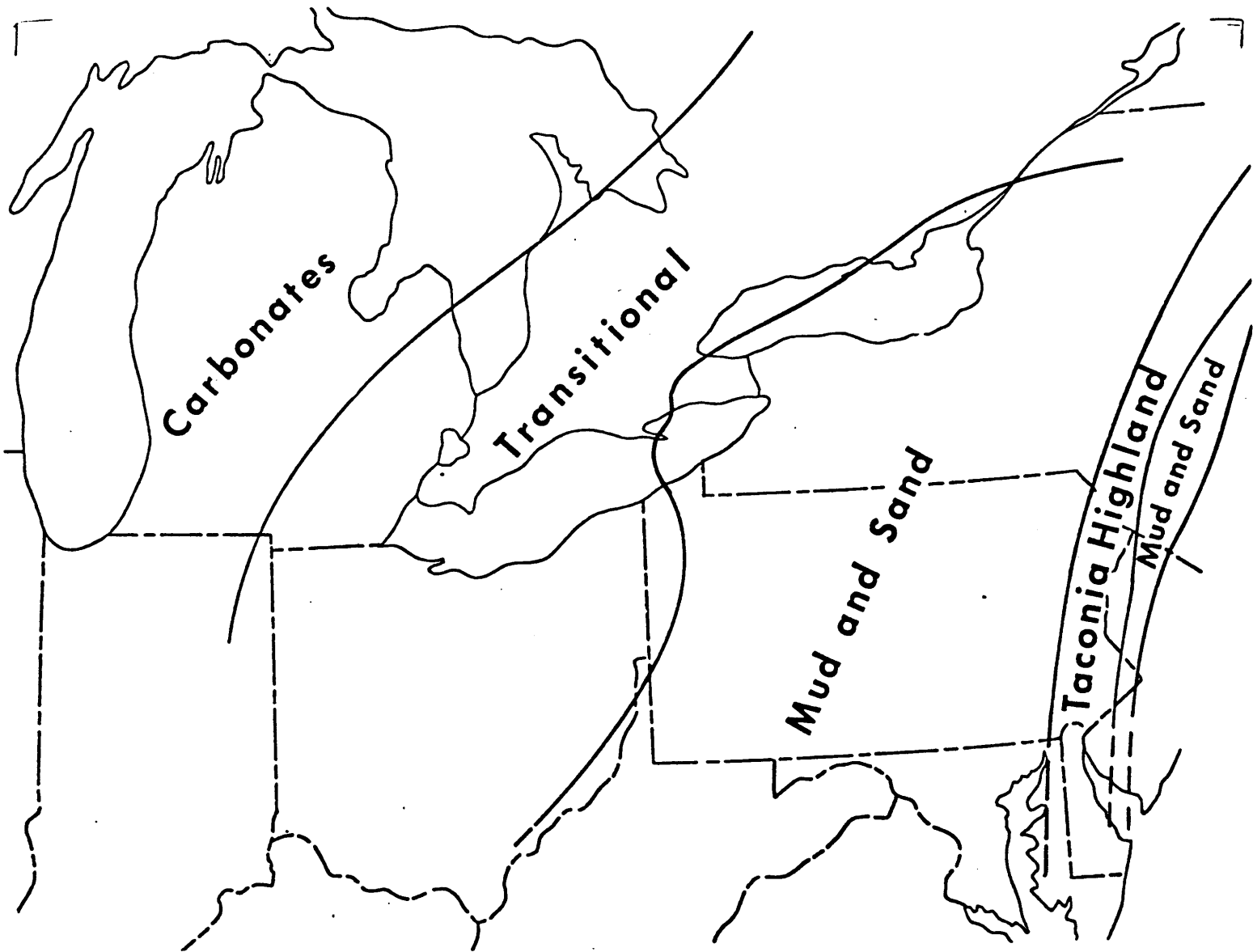
MAP SHOWING BARRIER REEFS FRINGING MICHIGAN BASIN + OTHER BASINS AND TECTONIC ARCHES. FIG. 21) MESOLELLA, ROBINSON, Mc CORNICK, ORMISTON (1974)



face structures in evidence here. The following is a general overview of both regional and local paleogeography from the Lower thru the Upper Silurian period with emphasis to be placed upon the Middle and the Upper periods in southeastern Michigan.

#### Upper Ordovician

As the Late Ordovician period came to a close, a major tectonic event occurred that would influence most of the area to the east of the present day Mississippi River. The orogenic intensity was locally centered in the area of New England, although the Michigan Basin did feel the effects somewhat. These effects were felt in the form of a clastic wedge of detrital materials that would result from erosion of the high topography. The orogeny did not elevate the basinal area, which at the time was still covered by a shallow continental sea that covered much of the midwest. There was a westward migration of shorelines. This was probably the end product of the filling in by the clastic wedge. The high areas within the southeastern basinal area during this period were the Findlay Arch to the southeast and the Algonquin Arch to the northeast. Both would become important during the mid to late Silurian periods as reef building areas. The climate was temperate and marine organisms thrived. There was good circulation into the basin area as evidenced by floating faunal forms from as far east as New York State. Current ripple marks and cross-bedding seem to indicate current direction was from the east, also.



DEPOSITIONAL FACIES OF LOWER AND MIDDLE SILURIAN  
A REGIONAL OVERVIEW, RODGERS (1971). FIG (22)

## Lower Silurian

The Lower Silurian age began with an extensive transgression of the sea in the basinal area. Fig. (22). The clastics of the Queenston Delta from the east were still apparent during this time but generally only locally. This would tend to suggest certain landforms on the eastern edge of the basin prevented subsequent deposition in certain area. The continental sea, still widespread, deepened and slightly extended its boundaries. Deposition was characteristically clastic, shallow water sequences that began as pure sandstones on the basinal margin along the Findlay Arch, to shales and siltstones deposited in the deep, quiet waters of the basin interior. Later during this time, the Manitoulin dolomite was deposited within the area and its remarkably consistent thickness suggests a constant uniform depth for the continental sea. In the southeastern Michigan area, clean sandstone, low carbonate content and a lack of fossilized material indicate an environment of low depositional topography such as that which would be found at a shelf margin. As one proceeds a few miles west, a facies change occurs, the clastics wedge out into dolomites indicating clear deeper water adjacent to the shelf margin. Minor transgressions and regressions marked the next time period within the lower Silurian. This is evidenced by the interfingering of sandstones and shales with carbonates. The source rock, for these being the Taconic Mountains, the Adirondack dome, and the continental platform in the eastern provinces. The carbonates deposited at this time were formed in the shallow warm marine water of the basin where a more intense subsidence rate favored deposition of a thick, uniform stratigraphic sequence.

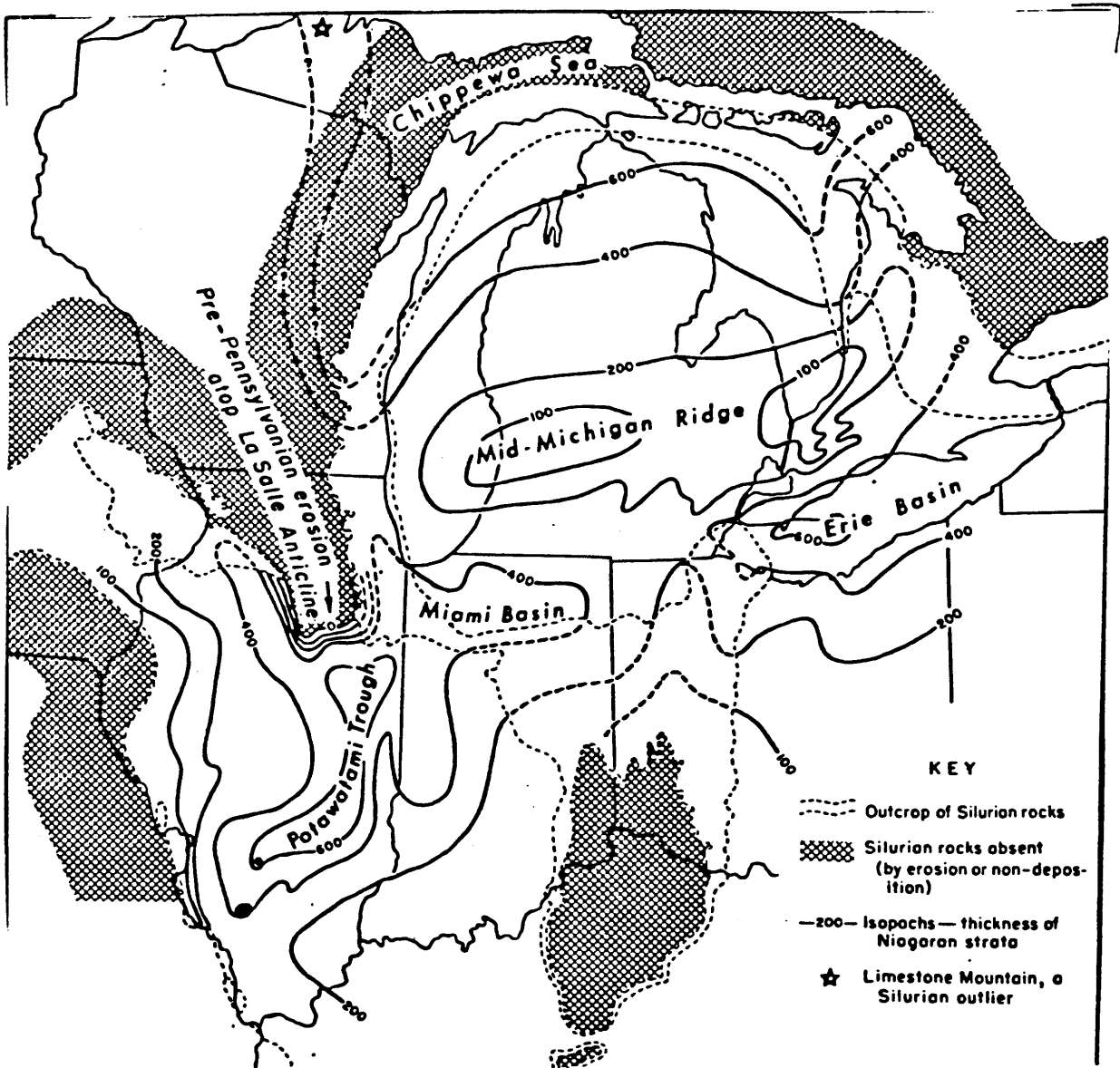
As the lower Silurian came to a close, there is evidence of more uplift to the east. Sedimentation within the basin and subsequently

the southeastern Michigan area, began with much the same conditions as previously noted during the occurrence of deltaic clastics as the result of intense erosion in the east. Near the platform, clastics showed lateral facies changes into basinal carbonate sequences. The end of the lower Silurian also marks the beginning of a controversy surrounding a theory that a mid-basinal ridge was beginning to form at this time. Arguments for both sides will be reviewed further on in this section.

### Middle Silurian

The middle and upper Silurian interval represents the transition between the Taconic and Acadian orogenic cycles. Orogenically stable conditions prevailed during the deposition of middle Silurian sediments without radical environmental changes. Marine sedimentation was continuous throughout all of the middle and upper Silurian on the Midcontinent and Appalachian regions. (Berry and Boucat, 1970). A major transgressive sequence marks the opening of middle Silurian time. The Clinton group shows both lateral and vertical facies changes. This represents a complex sequence of clastic and carbonate sedimentation related to continuous shifting of strandlines during the final phases of clastic influx from the Taconic Highlands into the carbonate depositing basin area. Shallows must have existed, at least temporarily, during formation of the Clinton group, because the shaly beds are locally argillaceous and are observed to have some mud cracks and ripple marks. The transgression during this time probably came from the north and northeast as indicated by strata thicknesses. The lower portion of middle Silurian time had been postulated by some: Schuchert, 1911; Cummings, 1939; Kay, 1942; Freeman, 1951; Ehlers, 1962, to be the

time of maximum influence by the Mid Basinal Arch which occurred across the southern edge of the Michigan Peninsula. Fig. (23). This theory divides the regional area into several basins; to the north, the basin was called the Chippewa Sea, which extended over much of Canada, northern Michigan, Wisconsin, and into present day Iowa. To the southeast lay the Erie basin; this was part of a large trough that extended into present day New York. To the south in Indiana lay the Miami basin; and to the southwest lay the Potawatami trough. A difficulty arises in the west where the formation of the Pennsylvanian age, Lasalle Anticline has caused erosion of the entire Silurian section. This Mid-Michigan ridge theory is countered with different arguments, the strongest being presented by several others: Cohee, 1948; Slost, 1954; Liberty, 1956, and Brigham, 1971. Their arguments are based upon the following. The word "arch" denotes an elongate structure that slopes downward on two sides from a central axis, but evidence of uniform formation thicknesses for both the lower Silurian cataract group and the middle Silurian Clinton group does not suggest such a structure is possible. Rather distance from source seems a more plausible explanation for the observed facies changes in these sections. Thinning of middle Silurian Engadine dolomite lead Cohee (1945) to theorize uplift in the central Michigan basin, either during the time that carbonates were being deposited in the surrounding area resulting in nondeposition over the arch, or at a later time which would have resulted in erosion. However, rapid thinning of the Engadine Dolomite over a distance of a few miles is inconsistent with thinning due to uplift on a regional scale. Also, lack of evidence of an erosional surface within the Engadine lends credit to those opposing the mid Michigan arch theory.



PALEOGEOGRAPHIC SETTING OF THE MID-MICHIGAN RIDGE DURING NIAGARAN TIME FROM COHEE (1946), LOWENSTAM (1949) + ROLIFF (1949) FIG (23)

The writer was unable to uncover conclusive evidence from either arguments but tends to lean towards the "con" version.

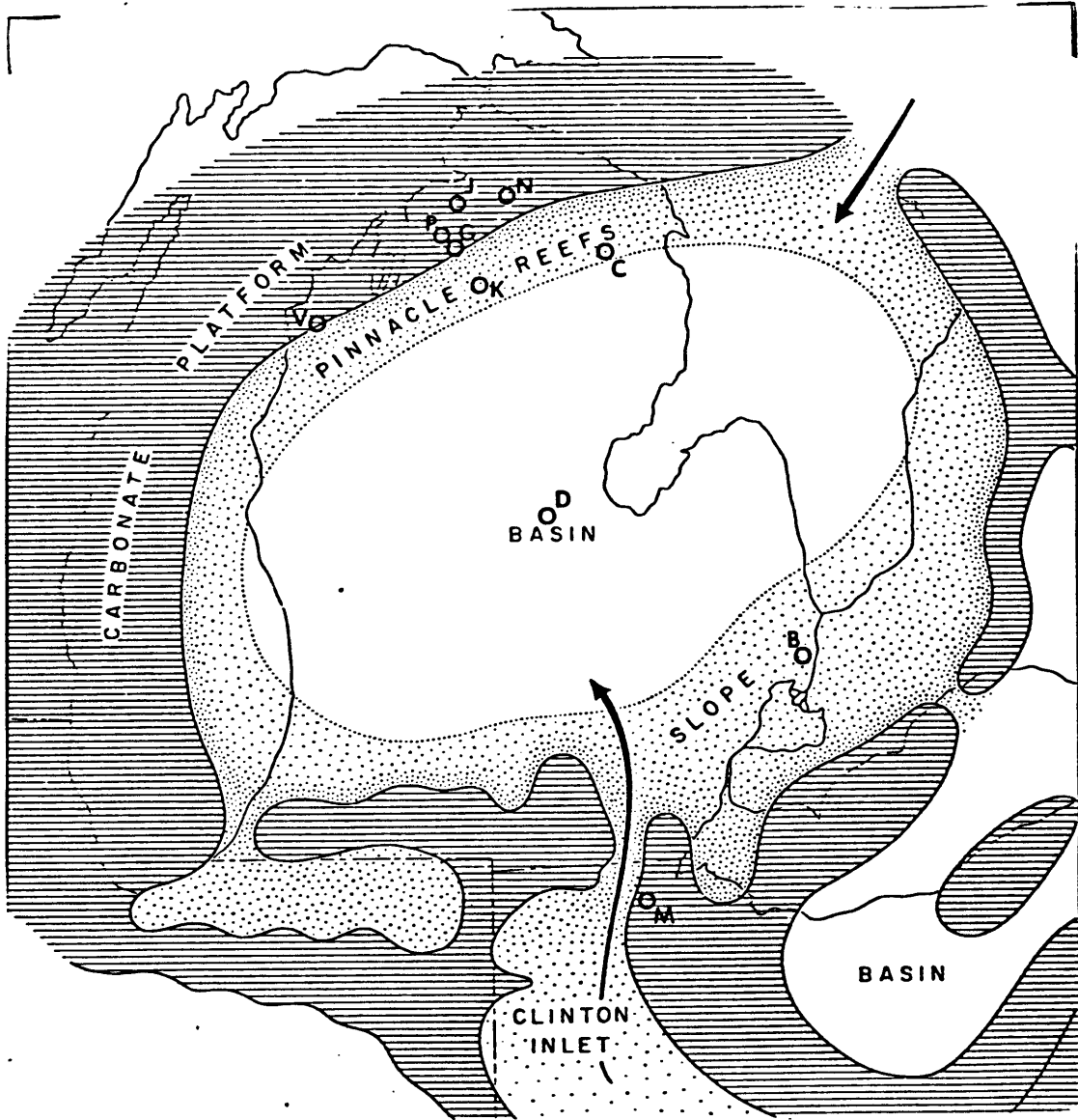
A reef platform began developing along the borders of the Michigan basin and subdivided the Ohio basin from the western Appalachian trough. This inner basinal shelf zone became an ideal site for the growth of pinnacle reef complexes. Fig. (24). The area between the two reef zones was an area of great faunal growth.

Paleomagnetic data (Roy, 1967) placed the Michigan Basin approximately at its present azimuth. Fig. (25). The wind direction came from an easterly-south-easterly direction bringing warm equatorial air.

The epicontinental sea extended throughout much of the central part of the continent. There may have also been a landmass called the Wisconsin Highlands to the northwest. During mid Silurian, the basin evolved from one of a poorly defined basin between the Kanakee, Cincinnati, Findlay, and Algonquin arches to a more definite pattern, which evolved from extensive carbonate buildups along the shallow waters immediately seaward of the arches. A reef platform began developing throughout southeastern Michigan that would effectively seal off most of this area from the Ohio Basin except through a few passes.

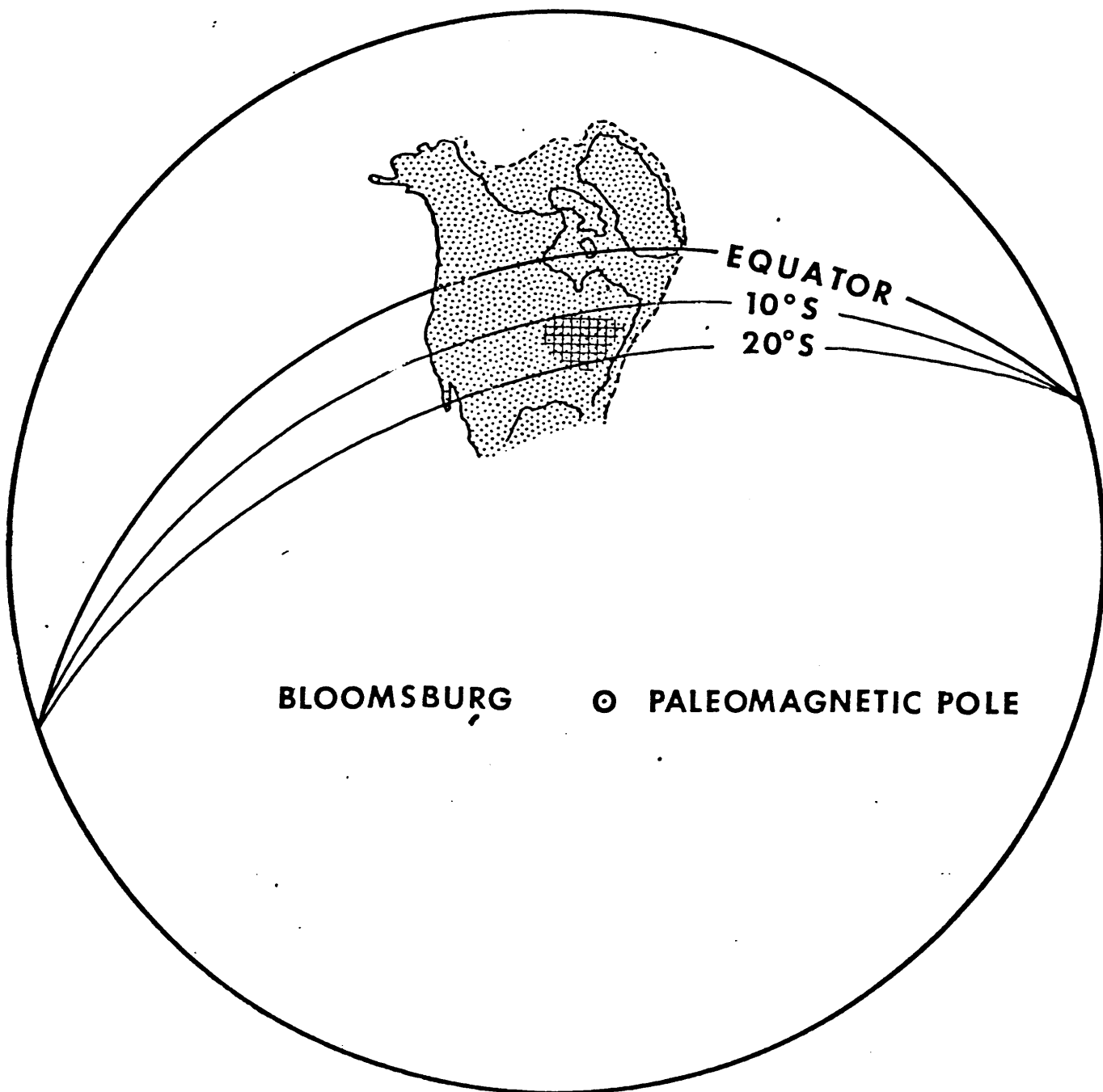
#### Niagaran Period

This Niagaran period was envisioned as a period of normal salinity and good circulation throughout the basinal area. The waters were relatively warm as indicated by Paleomagnetic data and coral beds were abundant, conditions were generally favorable to the preservation of marine fauna. The deposition of the Engadine dolomite evidently marked



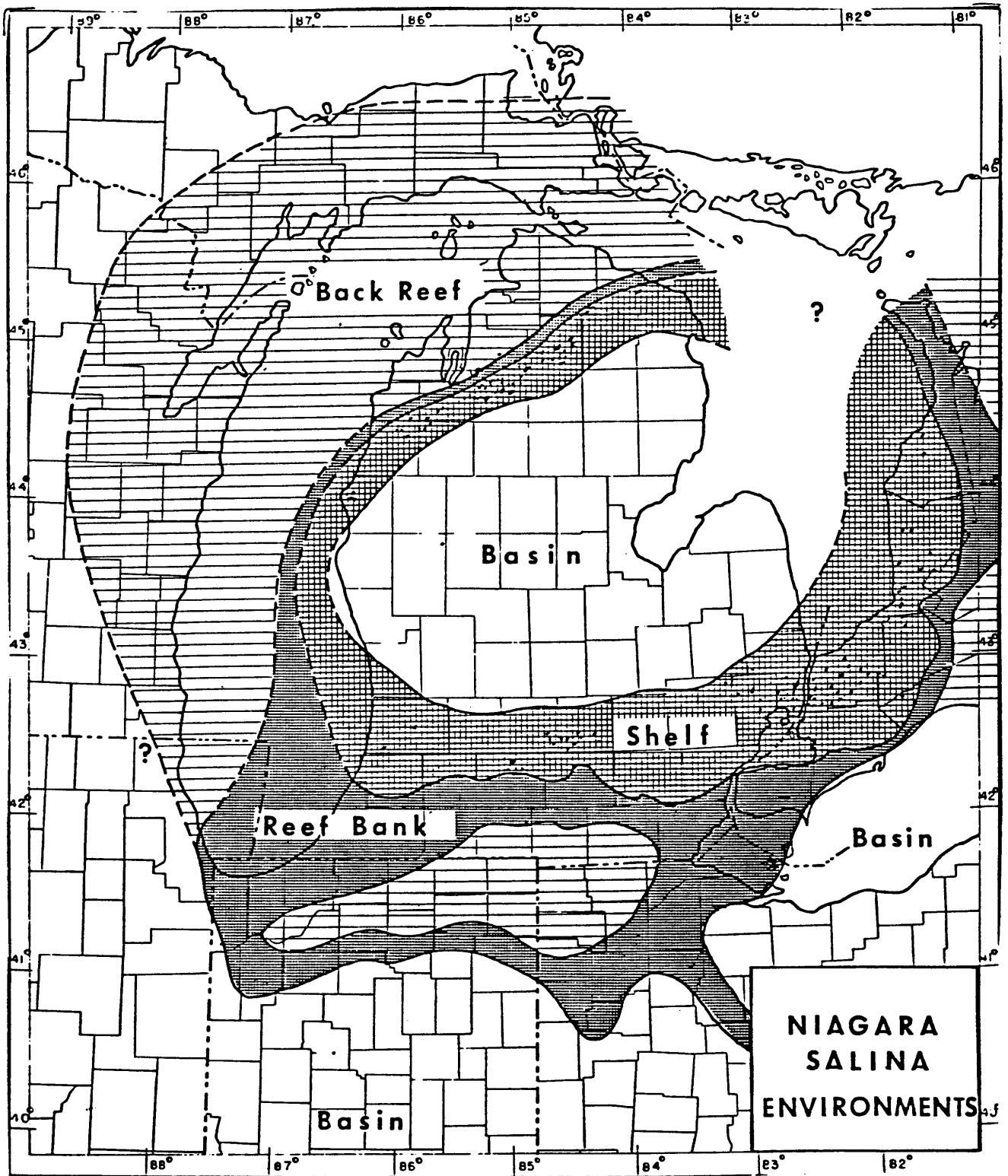
MAP OF LOWER NIAGARAN TIME, SHOWING FIG(24)  
 THE POSITIONS OF CARBONATE PLATFORM & PINNACLE  
 REEF AREA. ELS (1968)





*MAGNETIC DECLINATION OF THE MICHIGAN BASIN  
DURING SKURIAN TIME, RELATIVE TO THE SILURIAN  
EQUATOR (ROY, 1967) FIG (25)*

a shallowing of the basin because of the intensive organism growth. Prograding barrier reef systems thrived, in coincidence with this deposition, along the basin rim. Fig. (26). They enjoyed a period of rapid growth. Shallow water high energy environmental conditions are varified by the large amounts of carbonate sands found adjacent to the barrier reef complex in southeastern Michigan. Beyond this barrier reef complex lay yet another belt, one of the pinnacle reefs, some of which occupied several hundred acres and stood tens of feet above the interreef zones. Also, the steepness of dip on many of the reef fronts indicate intense wave action that would tend to indicate shallow water. An example of this type of reef, the Peters reef in St. Clair Co., and others like it grew off the soft bottom of the basin immediately in front on the barrier complex and hence laid their own foundations generally on a base of stomatoporids. Further basinward, reef buildup was retarded due to depth and wave energy restrictions. The thickness variations observed in the Niagaran sequence, as shown in southeastern Michigan, are a direct reflection of the different carbonate sedimentation rates from one of high near the platform, decreasing rapidly basinward. This is in direct conflict with most of the other stratagraphic sections within the basin which are more commonly observed to thicken basinward. "One can think of the many barrier and pinnacle reef complexes that surrounded the basin during Niagaran time as carbonate generating machines." (J. D. Robinson, 1974). This is especially true for the southern and northern Michigan portions. The area researched is situated directly in the center of the barrier reef, inter reef and pinnacle reef zone. Another interesting characteristic of these Niagaran beds is that the



MAP OF NIAGARA & EARLY SALINA, IN THE MICHIGAN  
 SHOWING THE RELATIONSHIPS OF REEF PLATFORM, BANK & BASIN  
 INTERIOR.

thinner basin sediments are heavily stained with iron oxide. This phenomena is attributed to bacterial action within the basinal interior. The Niagaran carbonate deposition was terminated by a gradual regression of the entire sub-continental sea. As the sea level within the basin declined, sub aerial exposure and subsequent erosion of the barrier and pinnacle reefs occurred. This regression was directly responsible for an increase of the salinity within the basin which intern severely handicapped both reef and abundant organism growth.

In review, the middle Silurian strata of the southeastern Michigan area are a typical sequence of the Niagaran reef building period. It supports all of the theories about the geography and environments of the platform area that surrounded the Michigan basin during these times. (This will be discussed in greater detail in the reef building section.)

The middle Silurian period was marked by the rapid development of the carbonate reef barriers, the offshore pinnacle reef complexes, and the gradual definition of the Michigan Basin which would be effectively sealed off from the rest of the continental sea area during upper Silurian time. Through paleomagnetic data, fossils, and the relative size of the reef zones, all evidence points to an environment ideally suited for rapid reef development.

#### Upper Silurian

Upper Silurian strata within the Michigan Basin are probably the most extensively studied and probably the most controversial sequence in the entire geologic history of the area. There are a number of problems and opposing viewpoints, such as; to what extent are Silurian reefs in the basinal area entirely Niagaran or partly Niagaran and

partly Cayugan? Was the growth of these reef complexes and the depositional period of evaporitic sequences contemporaneous or separate occurrences? Is the theory of sub-aereal exposure to the reef complexes valid; and, if so, was this occurrence cyclic or purely random? To what extent did sedimentation rates and areas of deposition, like the shelf margin, interreef, pinnacle reef, and basin zones, effect the presence and thicknesses of strata? After reviewing several theories on the area, this portion contains what the writer believes to be a plausible explanation for the occurrence of upper Silurian strata in the southeastern portion of the basin.

#### Cayugan Period

Upper Silurian strata is referred to as the Cayugan series; and it is defined by the Salina group, which consists of several units and the Bass Island group. The strata were deposited during a period of maximum basin subsidence; and assuming that deposition kept pace with subsidence, the basin area subsided at least 1,600 feet during deposition of the Salina group. This subsidence was caused by sedimentation from the center of the basin outward rather than margin inward sequences that had characterized the Niagaran. This subsidence was also directly responsible to depression of the northwestern flanks of the Findlay and Algonquin arches.

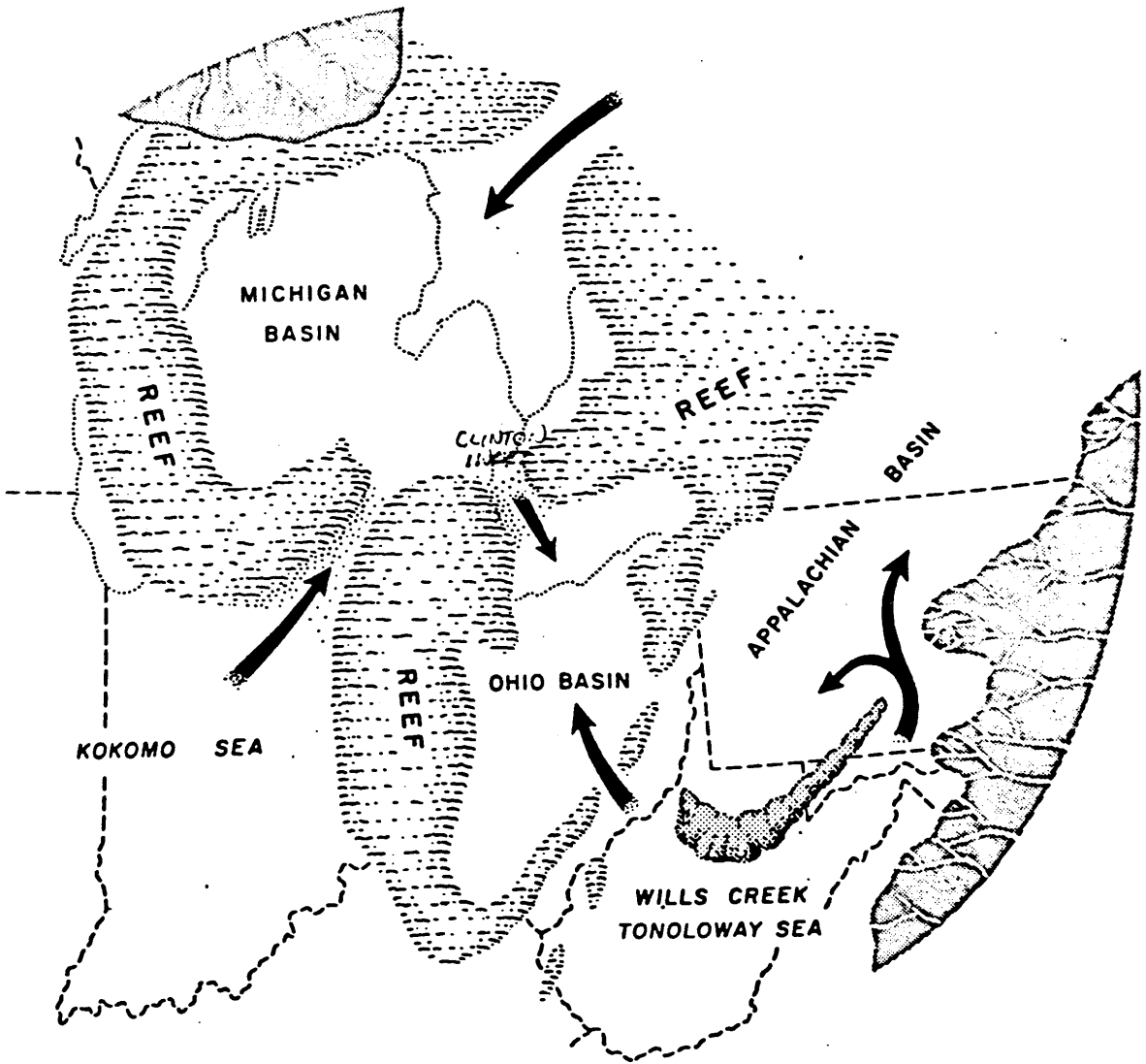
The Salina group was formed in a time period of large and small scale transgressions and regressions of the continental seas.

The position of Niagaran strata was terminated with the first regressive sequence. The vast continental seas that covered most of eastern United States and southern Canada began receding from the

basinal area. With the regression came subaereal exposure of the barrier reef complexes and the upper portions of the pinnacle reef areas, extensive vadose carbonate alteration began to develop in these areas. The gradual emergence led to a partial to complete isolation of the basin. The sea level within the basin was also lowered considerably, possibly to the edge of the shelf margin, thus effectively restricting flow from the inlets that would allow free circulation with the surrounding seas. Fig. (27). Evidence along the reef bank in Macomb and St. Clair Counties of carbonate rubble suggest that the sea level was lowered some 430 feet. (Gill, 1977).

During the initial phase, a change in climatic conditions from tropical, humid to a tendency toward greater aridity and higher evaporation occurred. This factor along with the restricted circulation helped increase the salinity of the basinal brine to cause a hypersaline condition. This condition completely terminated the stromatolite reef deposition and restricted the biota largely only to algae in the last stage of reef evolution. These conditions are strongly supported by a few inches of supersaline, nonfossiliferous shales on the immediate basin rim and dark gray to black argillaceous limestones that represent esexinic penesaline, but nonevaporitic conditions in the interreef and basinal areas of southeastern Michigan. It should again be emphasized that evaporitic conditions did not yet exist. The continued restricted sea water flow combined with a high evaporation rate would eventually yield conditions favorable for evaporite deposition.

As the continental wide regression of the sea continued and reef banks and pinnacle complexes were no longer actively building up as before, their effects on basin sedimentation were negated; an evaporitic



REGIONAL AREA AT THE TIME OF EARLY CAYUGAN FIG.(27)

sequence began forming. This sequence was largely responsible for the filling in and smoothing out of the topography between the reef bank and the pinnacle reef zone. In southeastern Michigan, the sequence is found between and in conformable contact with the reef bank and pinnacle reef masses. Due to continued sub-aereal exposure, the sequence could not cover the reef structures. Although, it would set the stage for later deposition that would eventually cover the great Niagaran reef zones.

An interesting aspect of the paleogeography of southeastern Michigan at this time was the effects on sedimentation dictated by the Clinton inlet. Fig. (27). Even though restrictions of marine water influx over the reef complex was accomplished by the regression, marine water, from time to time, was allowed to enter the basin in several places through inlets like the Clinton. The open sea water that did manage to find its way through these inlets maintained its identity as a narrowly confined current or stream that could extend well into the basins interior. The normally saline water being less dense, therefore, traveled on top of the more dense hypersaline waters of the basin. Evidence to prove such a theory is found in southeastern Michigan in the form of a sequence of normal marine limestone that is surrounded by markedly different areas of anhydrite on the basin edge, to halite sequences in the basinal interior. This theory was proposed by Briggs, 1958, and again by Ellis in 1962.

Following this period of hypersalinity, a slight period of sea level transgression and the return of carbonate production occurred. The areas of former exposure now became resubmerged and carbonate production was largely the result of algal fauna. In the areas



between the reef bank and pinnacle zones, argillaceous carbonate muds were deposited once again. Normal marine conditions, when compared with those of Niagaran times, were not achieved though. A general absence of corals and many brachiopods, ostracods, and bryozoans indicate that marine conditions were still in the higher saline stages. The thickness of the carbonates give an indication that the transgression was short lived. Also, the limited growth, topographically speaking, of the reef complexes lends credibility to this theory. Through this interval of time and the carbonate sedimentations periods that followed, it seems as though physical factors become the dominate force replacing biological factors.

The carbonate production period came to a close with perhaps another event of relative sea level lowering and exposures of the reef complexes. From this point onward in the Salina group, the progressive deterioration of basin-margin reefing during the carbonate phases and the reduction in associated depositional topography would allow each successive, regressive evaporite sequence to become more widespread and influential in the stratigraphic sequence. Thicknesses in the next evaporitic sequence are shown in southeastern Michigan, to be less varied than the previous phase, suggesting that there was less depositional topography to overcome.

The evaporitic sequence was again followed by a carbonate producing period. Although it was a period of carbonate build-up, it is held in stark contrast with the previous one. This sequence is generally devoid of the reefing common to the latter. In southeastern Michigan, its thickness, although still increasing from basin to margin, is fairly uniform. In this area, the underlying evaporitic sequence is almost wedged out. This was probably due to the combination of the still

present topographical high that marked the now buried Niagaran reef complex and the mass transport in solution to the subsiding basinal interior. The presence of deformation structures within this carbonate sequence and not in the underlying evaporite, lend proof to the mass solution idea.

Another regressive cycle within the Michigan basin heavily influenced the now familiar evaporite sequence. This evaporite was shown to have the furthest distribution thus far from the hypersaline conditions present in the basin at this time. Intense evaporation of the almost stagnant area caused an exceptionally thick deposit to form. The thickness of the deposit does not necessarily indicate longevity though, as previously mentioned in the rock description portion, salt has been observed to accumulate extremely rapidly under favorable conditions. Along the basinal margin at this time dolomitic shales and finely laminated shales were being deposited in scattered lenses suggesting clastic influx from a distant, exposed landmass. This phenomenon, while present in southeastern Michigan, is very local. On a larger scale, the occurrence of agillaceous clastics are not abundant and this indicates that the basin was largely surrounded by limestone remnants and climatic conditions weren't favorable for complete disintegration into clay soils. Also present are lime muds near the basin margin suggesting erosion of limestones and dolomites laid down during previous periods. This can be shown as erosional unconformities on the reef crest. The evaporites again wedge near the basinal margin suggesting more mass solution, although thickness variations suggest that it was not as intense as during the previous evaporite stage.

This shelf-ward advancement of the evaporite bodies is related directly to a biologic deterioration of the basin-margin organic communities from Niagaran time through this point in the Cayugan cyclic evaporite, carbonate unit. The basin-margin organics, being for the most part controlled by organic production, were phasing out. As each ensuing carbonate phase became less, the marginal topography would suffer accordingly. This continual reduction in the carbonate production cycle now allowed each successive evaporitic cycle to spread further and further out onto the basinal margin. This fact is upheld by the stratigraphic sequence presently found in southeastern Michigan. (K. J. Mesiella, J. D. Robinson, L. M. McCormick, and A. R. Ormiston; 1974).

The previous carbonate sequences suggested transgressions on a regional scale, but the next carbonate unit has been traced in the subsurface through Ohio and on into New York. This evidence points rather strongly to a continental wide transgression and major flooding even into southwestern Canada. The unit contains shaly lenses in southeastern Michigan which indicates clastic influx from some outside source, in this case from the east. From the red shales noted in the rock description, one can hypothesize an oxidizing environment. The partially uniform thickness of this sequence suggests a period of stable environmental conditions but still abnormal salinity conditions. The proof being the complete lack of fossiliferous material.

The next evaporite sequence is a small one, and due to the fact that it is present over much of the former reef structures, it suggests that there was some sub-aereal exposure during this period and dolomitic muds bear this out. It also thins marginward due to mass solution into the subsiding basin.

During the Salina period, deposition subsidence within the basin was gradual. This sinking was directly proportional to the pace maintained by evaporation. Flooding of salt flats that lay near the margin very likely accounted for the transitional period between evaporitic and carbonate phases. Due to the aridity that probably existed throughout this period, and dry seasonal winds, concentration of salt on broad flats, as indicated in the rock record, would occur. The local occurrence in southeastern Michigan of red shale also lends evidence to the extreme aridity. The major paleogeographic influence though came from the effective sealing off of the basin by the regression of the sea and the exposure of the reef bank which prohibited any influx of fresh marine water.

The final phase of upper Silurian record is represented by the Bass Island group. During this time, conditions were about the same, climate wise, as the Salina period. But basinal circulation was restored although evaporation was still in progress. Fresh water resources gradually began to influence the basin, and there is fossilized evidence of abundant flora and fauna. Climatic changes began to occur to a more humid climate, thus preventing intense evaporation and concentration of the now familiar evaporitic sequences present through most of the Cayugan Series. There is some evidence that during the later phase of the Cayugan sedimentation the basin was shrinking. Southeastern Michigan strata show Bass Island limestones and dolomites occur further basinward than previous formations. During the deposition of the Bass Island groups, there is evidence to suggest that basinal subsidence so prominent during Salina time, was not as extensive. A fairly constant thickness throughout the study area and proceeding basinward is shown

in the rock record. As the Upper Silurian period came to a close, a large westward transgression of the continental sea took place.

Southeastern Michigan's rock record shows this as a band of dolomite with several forms of algeal fauna. The fact that the algae is present suggests that the waters were relatively shallow with flats running several miles out into the basin. Ripple marks and mud cracks are also present in areas where channel influx occurred.

Overall, the Salina represents marine regression during widespread evaporite deposition, with a minor transgression during the uppermost Cayugan Bass Island stage. Afterward, there was to be a final draining of the sea from the continental platform into the Appalachian seaway during the erosion which would be represented by the Silurian-Devonian unconformity.

The Silurian period began with a plate collision and tectonic unrest, with mountain building followed by quiescence and mountain denudation. The sedimentation cycle began with clastics formed from erosion of the uplifted strata, followed by a carbonate sequence that would dominate the Middle Silurian and ending finally with evaporites, paralleling low sea level conditions during the initial clastic phase of sedimentation; transgression which would reach its maximum during the carbonate phase and regression during the evaporite phase.

(Louis I. and Darinka Briggs, 1974).

## REEFS

Reef, commonly cited as a standard definition is that of Lowenstam (1950) who said, "a reef, in terms of ecologic principles, is the product of the activity building and sediment-binding biotic constituents, which because of their potential wave resistance, have the ability to erect rigid, wave-resistant topographic structures."

Much of the carbonate deposits in the southeastern Michigan area are attributed to reef building, most of which occurred under the ideal conditions provided during the latter part of the Early Silurian and throughout the Middle Silurian only to be terminated about the time of the Upper Silurian.

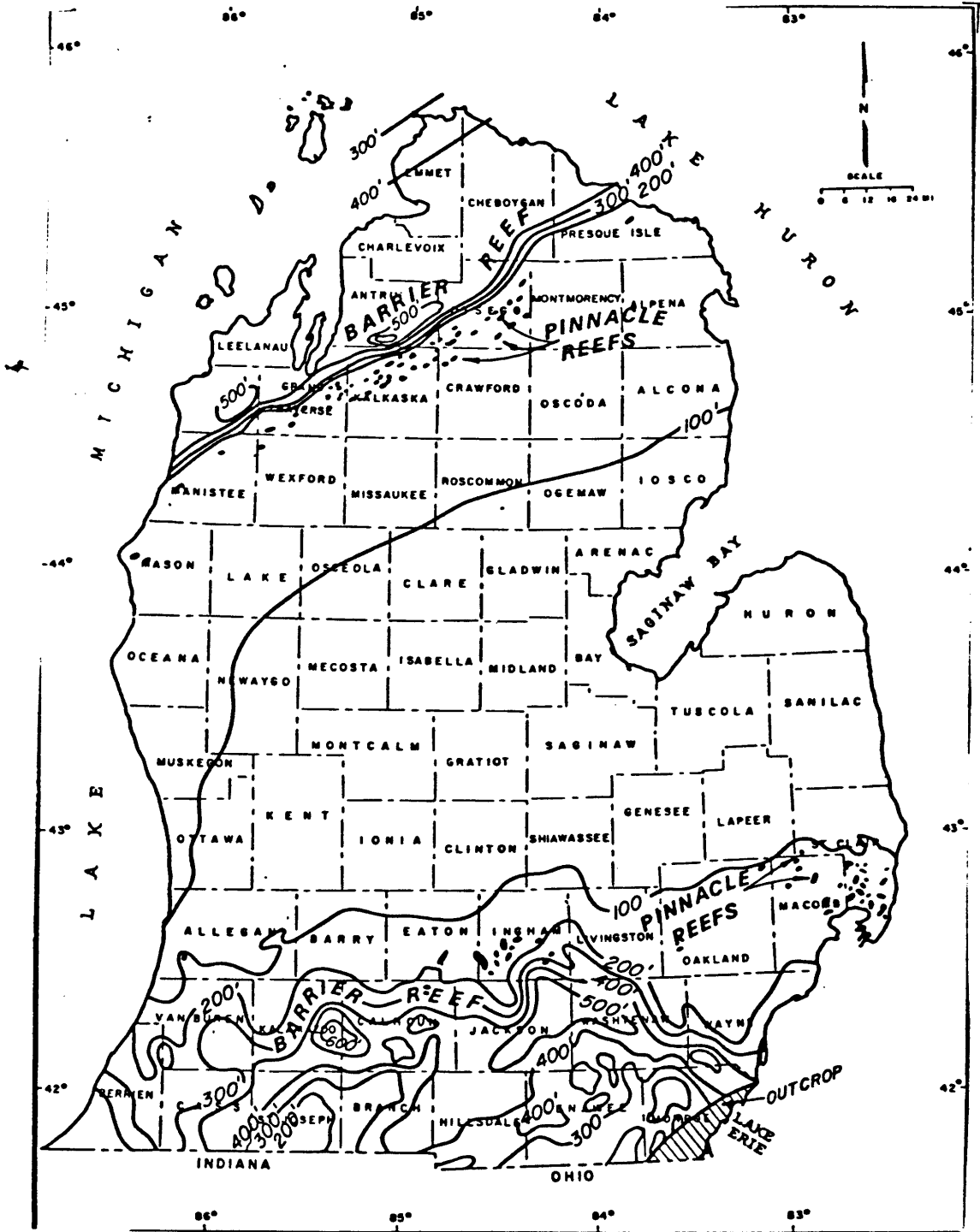
These reef structures were developed along the shelf margin or platform area made possible by the presence of tectonic landmasses. They would also occur just basinward along the relatively shallow waters immediately adjacent to the deeper interior areas. These were the pinnacle or patch reefs so named due to their infrequent occurrences

### Reef Framework

In southeastern Michigan, the reef deposits are represented in the form of two distinctly different structures; the reef bank, which formed the barrier between the basin and the open seas, and the pinnacle reef, which occurred in patches immediately adjacent to the reef

. Fig. (28).

The framework of these two types will vary somewhat. Although almost universally, the reef substrate will consist of crinoidal, bryozoan bioherms, and biostromes or stromatoporoids. Stromatoporoids are commonly defined as; laminated organic bodies made of calcium



*BARRIER REEF + PINNACLE REEF OCCURENCES  
 WITHIN THE MICHIGAN BASIN AREA DURING NIAGARAN  
 CARBONATE SEDIMENTATION , CONTOUR INTERVAL 100'  
 FIG (26) MESOLELA , ROBINSON , McCORMICK , ORMISTON (1974)*

carbonate; commonly hydrozoans. The reef banks and pinnacle reefs would usually contain this as basal material, although in some areas pinnacle reefs did not develop beyond this initial stage. Exactly how these biohermal masses were initiated is uncertain. The bases of most bioherms have been found resting upon dolomite containing variable amounts of echinoderm debris, and mounds of such debris may have served to localize the development of bioherms. Several theories now being examined suggest that these bioherms did not form wave resistant frameworks. It has been postulated that the bioherms gradually evolved in a more quiet water marine environment below the wave base.

The reef banks began their development on the platform side provided by the Findlay arch. The ideal environmental conditions assumed command from that point and the reef bank extended its boundaries. In the reef bank, vertical cross-sections of southeastern Michigan characteristically contained the following:

1. Crinoidal wackstone - This is the lower most unit with its contents varying from fragmental debris of stromatoporoids, brachiopods, and crinoids to some types, in lesser amounts, of corals and bryozoan debris.
2. This intermediate zone has been observed to contain coral-bryozoan packstone. Coral and bryozoans occur in great abundance, though crinoids and brachiopods, both whole and fragmental, are also present.
3. The upper zone consists of Stromatoporoid wackstone and fossiliferous grainstone. These types are commonly found to become interbedded with solitary rugose corals, gastropods, and stromatoporoids.

Most of the reef bank complexes observed today are found to be highly dolomitized. This dolomitization according to Sharma (1966) is attributed to **refluxion on** pickling of the exposed reef by high magnesium brines.



The pinnacle reefs framework began with the accumulation and concentration of crinoids and bryozoans on the broad slope areas on the basinward side of the reef bank which was already developing at this time. These small biota are envisioned as trapping the argillaceous carbonate muds that were constantly being eroded away from the main reef bank due to wave action. As this capturing process continued, biohermal mounds began forming. The stages of pinnacle reef growth are as follows: Biohermal stage, this is primarily wackstone, derived from crinoidal and bryozoan allachems, developed below the wave base; and the Organic stage. The dominant frame builders (stromatoporoids and tabulate corals), form the reef-core lithofacies which is associated with various types of reef dwellers such as brachiopods, gastropods, rugose corals, crinoids, and bryozoa. The pinnacle framework would extend as high as 300 feet to 600 feet. Debris and other material would accumulate due to storm action about the base of the reef allowing it to build laterally somewhat.

#### Growth Stages

Correlations in the growth patterns of the reef bank and the pinnacle reef zone are difficult to determine due to a general lack of any marker horizons. Suggestions as to the contemporaneous growth of both can be found based on the faunal evidence and similarity of sequences in certain areas of the basin. The main reef bank development on the platform probably correlates with the Organic-reef stage of the pinnacle reefs (Mesolella, 1977; Gill, 1977). The reef bank growth is even more difficult to correlate because of the sparsity of any distinct lithologic markers. Dolomitization has successfully obliterated the rock record throughout most of the reef bank area.

The growth stages within the reef area remain curiously constant throughout most of the Michigan basin with the organic contribution to the construction of these bank and pinnacle reefs being highly dependent of environmental conditions and visa versa as the reef matured.

Following this idea, Shaver, in 1974, stated these six observations:

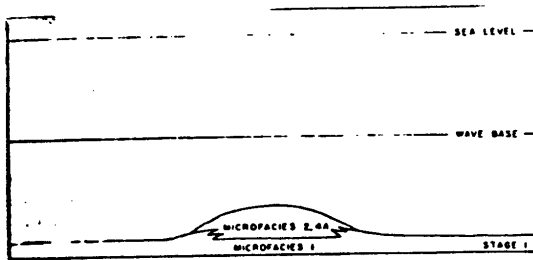
1. Frame builders and sediment binders were responsible particularly for construction of the core, where as the reef dwellers contributed especially to flanking reef portions.
2. The stages of reef growth and structure were mutually interdependent with evolution of the faunal community and with some organic evolution.
3. As the wave level was approached or reached, environmental complexity greatly increased so that many niches prompted increasing species diversity and concomitantly increased organic productivity resulted in accelerated rates of supply of skeletal material.
4. During a late period of growth, the activity of reef dwellers had so increased and other causative processes had become so involved that the volume of flank beds surpassed that of the reef core.
5. The attainment of wave base and surf level was the basic condition to cause lateral growth of both core and reef flank-facies.
6. In this concept a reef in an early growth stage was a product of the environment but had very little influence on the environment, whereas a mature reef, although being a product, greatly influenced the environment, and thus exercised considerable contact over sedimentation in the surrounding basinal area.

#### Reef Bank

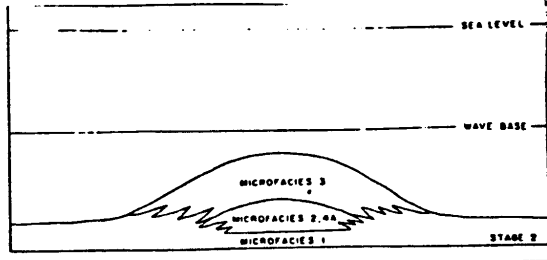
The reef began its growth in southeastern Michigan during late Alexandrian time and reached a mature stage during Niagaran time, and it is generally divided into five or six growth stages. Fig. (29).

The first stage consists of bioclastic accumulation, mostly crinoids, which dilutes the calcareous mud and subsequently forms a

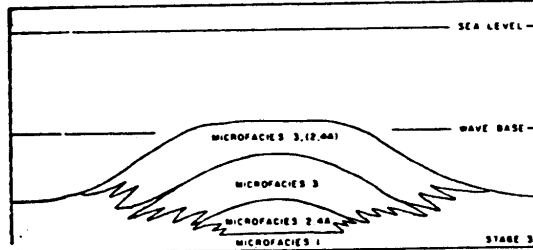
STAGE 1



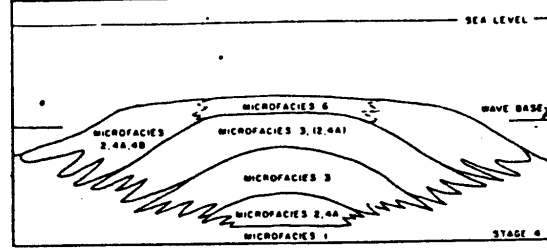
STAGE 2



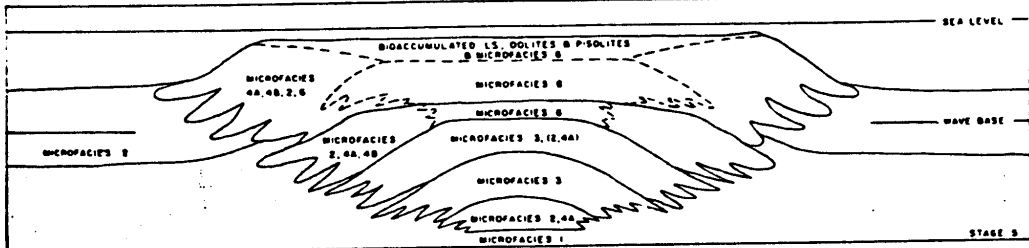
STAGE 3



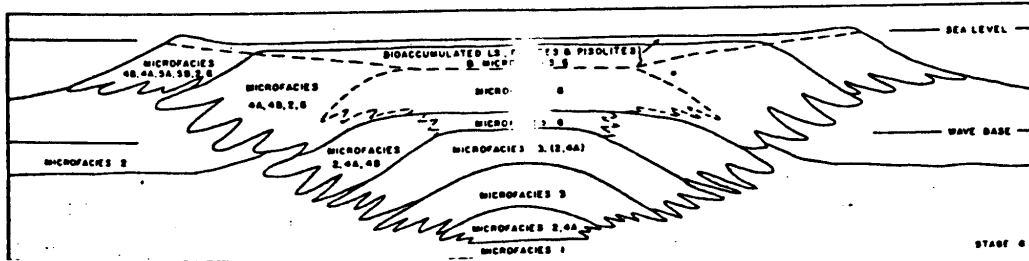
STAGE 4



STAGE 5



STAGE 6



6 DEVELOPMENTAL STAGES OF THE NIAGARAN BARRIER REEF COMPLEX DURING THE MIDDLE SILURIAN, (SHAVER, 1974) FIG(29)

biohermal mound. This is the foundation for later reef building organisms. These deposits suggest a broad bank like accumulation, deposited in shallow waters where there was probably wave action, but the mound was below the wave base.

Stage two, with the addition of stromatoporoids, brachiopods, and crinoids, and lesser degrees of other marine flora and fauna, starts the development of the reef core. The core is massive and composed of stromatactis calcite (stromatoporoid constructed limestone) and originated below the wave base.

In stage three, the mound continues to enlarge and is now being built up to a height near the wave base and forms a transitional core. This portion shows well developed bedding planes of stromatactis calcite alternating with fossiliferous beds of frame building organisms and reef dwellers such as rugosa corals and bryozoans; others include brachiopods, crinoids, and echinoderms. This layering of the beds is observed to parallel the dipping flanks.

Stage four is a mature stage, probably mid to late Niagaran in age. The mound is now mostly into and above the wave front. Stromatoporoids become abundant enough to form smaller bioconstructed cores on the reef forefront and leeward sides thus allowing the reef to expand laterally and continue to enlarge the original structure. Well bedded crinoidal flank beds begin to accumulate against the sides of the core. It is during this stage that the previously common stromatactis becomes practically nonexistent.

In stage five, the core of stromatoporoid material will continue to remain active but the main growth regions on the reef will be the flank area. Reef dwellers are very abundant, and their skeletal contributions will help the reef continue to expand. A current swept

platform begins to develop on the top of the now mature reef structure. It now fulfills Lowenstams definition and becomes a true wave resistant structure. The flank beds consist of fossiliferous material and some eroded carbonate material from the reef itself.

In stage six, the platform and reef flanks become ecologically zoned and support great throngs of marine flora and fauna. The reef will continue to enlarge laterally; it has reached its summit under the present water depth conditions. The flanks continue to be built up with fossiliferous skeletal material and eroded platform material, with the eroded material becoming increasingly abundant.

The most important factor in the developmental stages of the barrier reef zone appears to be the relationship between reef building and the sea environment. This relationship has been shown to reverse itself from one of the reef being totally dependent on the environment to the reef greatly influencing the environment.

#### Pinnacle Reefs

The pinnacle reef area in southeastern Michigan has long been known for its oil producing attributes. They developed in much the same manner as the barrier reef. The growth pattern for all or most all of the southeastern Michigan area was devised by Gill and Briggs (1970); their model was the Belle River Mills Reef. But through subsequent study of the pinnacle reefs throughout St. Clair and Macomb counties, the following pattern has emerged. It should be mentioned at this time that this is by no means the only theory on this subject; but for this study area, this theory seems to maintain its credibility.

The three stage pinnacle reef development will also coincide with the six stages of barrier reef development mentioned before. The lowermost stage is observed to be underlain by the same engadine dolomite found under the barrier sequence.

The Biohermal stage (Fig. (30)) is composed of approximately seventy percent crinoids (Fig. (30a)) and bryozoans (Fig. (30b)). With the diminishing flow of argillaceous clastics from the tectonic highlands in the East, a favorable growth environment began forming. The Biohermal mounds would now begin to grow, increasing in both height and width, in response to favorable environmental conditions of clear relatively shallow water, warm climate, and plenty of sunlight. The upward growth would be strengthened by colonization of tabular stromatoporoids, tabulate corals, and branching and encrusting bryozoans as the structure approached the high energy area above the wave base. Frequent occurrences of skeletal mudstones are found in this lower phase (Fig. (30c)); these are the result of erosion of the barrier reef buildup.

As the mound approaches the wave zone, the marine community also begins a change toward frame building organisms.

Stage two (Fig. (31)), the reef framework, is what comprises the majority of the pinnacle reef (Fig. (31a)). This framework reflects a time of intense vertical growth. The period occurred during a time of large scale continental sea transgressive sequence during a time of active basinal subsidence. Again, environmental factors would now greatly influence growth trends (Fig. (31b)). As this particular stage neared its climax, the pinnacle reefs in southeastern Michigan took on an atoll-like configuration, with carbonate barriers

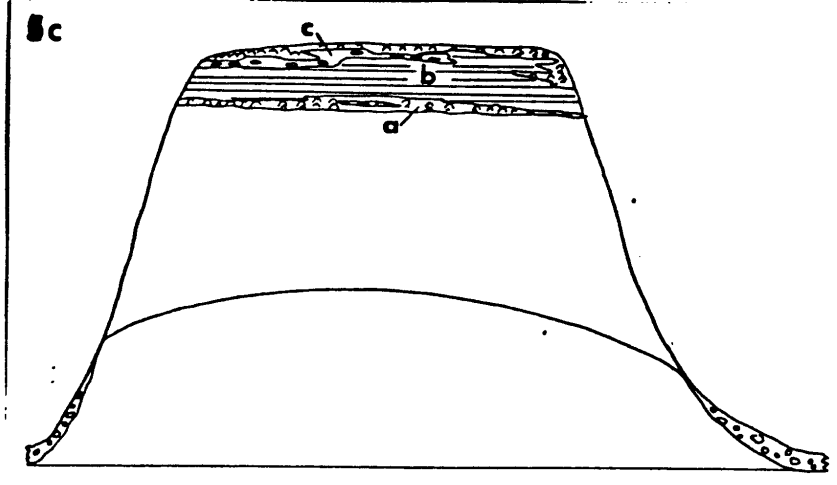


FIG.(31)

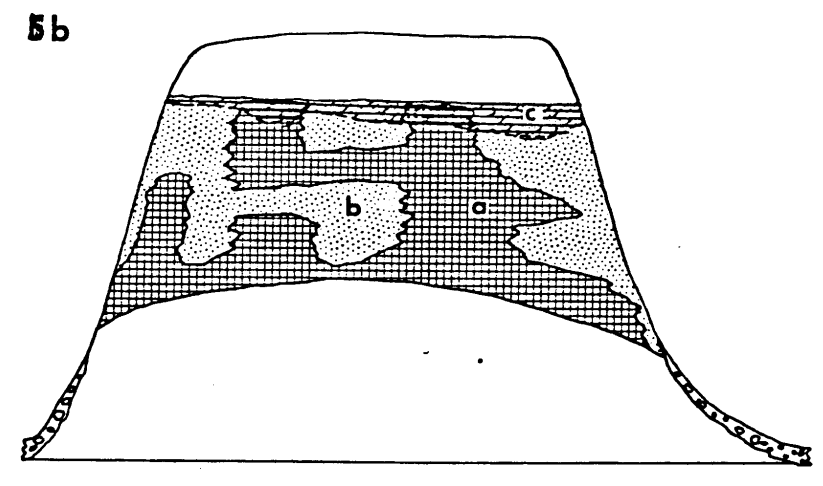
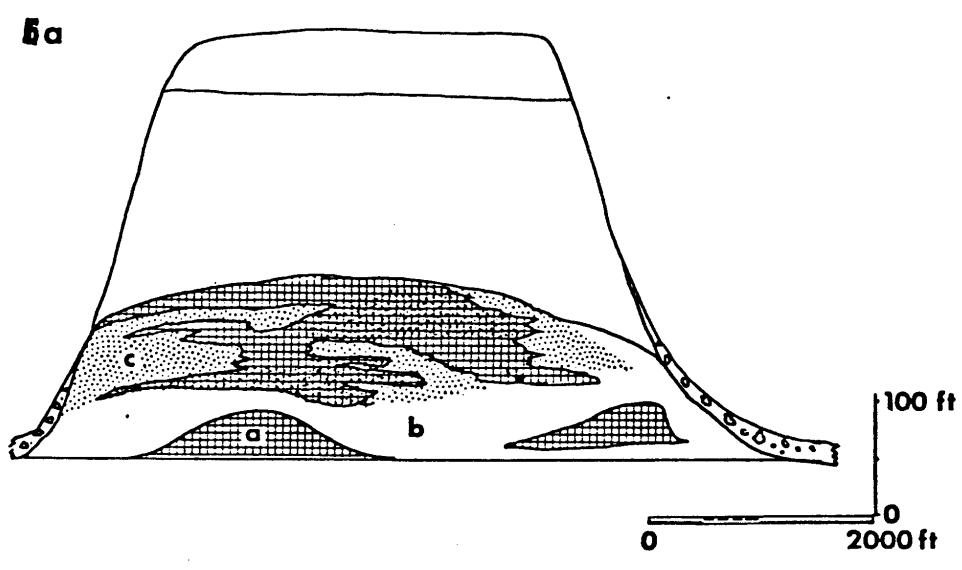


FIG.(30)



EVOLUTION OF A TYPICAL PINNACLE REEF

FIG. (30) BIOHERMAL STAGE

FIG. (31) ORGANIC REEF STAGE

FIG.(32) SUPRATIDAL STAGE

ringing the outer portion and a lagoonal inner core. This pattern is confirmed by the presence of fine granular lime mudstone found in the middle of the reef (Fig. (31c)).

High energy biolithites are the dominant lithofacies during stage two. The more common types include frame building, massive and encrusting stromatoporoids, encrusting tabulate, head corals, and a host of algal forms and crinoid-bryozoan bioherms. Reef dwellers abound during this stage. They were characterized by colonized crinoids, brachiopods, gastropods, and echinoderms. In southeastern Michigan localized beds of coquina are abundant sometimes as great as fifty feet in thickness. They are extremely common at the very top of this particular stage.

The third and final pattern is termed the supratidal island stage (Gill, 1972; Noh, 1973). Fig. (32). It is characterized by the presence of massive cones of algae stromatolites and carbonate detritus. This unit is believed by some to be the transition between the Niagaran and Salina series. This theory is founded on the basis that in northern Michigan this phase is still important to the continued growth of the reef whereas in certain areas it is missing entirely. This phase, in southeastern Michigan, followed a period of sea regression and vadose karstic leaching in some areas as much as thirty feet. During this stage, four principle lithofacies have been observed to develop: algal stromatolite (Fig. (32a)), some attaining sizes of ten feet in diameter; flat pebble conglomerate consisting of stromatolite debris (Fig. (32c)); burrowed mudstone massive dolomicritic; and pelletal mudstone with its elliptical pellets and minor algal limestones. Fig. (32b). After these beds were laid down, the effect of a major sea level regression and the subsequent sealing off of the basinal area



caused the ideal environmental conditions within the Michigan basin to deteriorate and consequently ended pinnacle reef growth.

The reef complexes of middle, early, and late Silurian time enjoyed conditions favorable to their rapid growth and development. Their influence on later events cannot be emphasized enough. As the exploration of the basin continues, a greater knowledge and understanding of the relationship between the barrier reef complex and pinnacle reefs and their impact on paleogeography and sedimentation can only be expanded.

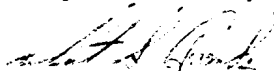
## CONCLUSION

Before the middle Silurian, the Michigan basin was not actually very well defined. But due to ideal environmental conditions that occurred during this time, large reef complexes were able to form. These reefs would serve to build an effective barrier that would successfully create a true basinal environment in the present day Michigan area. The Niagaran stratigraphic section reviewed in this paper is the direct remnant of this reef building period. This barrier reef complex would in turn be directly responsible for the Salina and Bass Island sequence also reviewed in this paper. The reason for choosing the Southeastern Michigan area was due to the fact that it represents one of the most complete preservations of middle and late Silurian history in the entire basinal area.

This paper was never intended to be the standard by which others were judged; and, granted, there will probably be those who would disagree with what has been stated previously.

The writer has compiled evidence, along with his own interpretation and ideas, and has arrived at a logical explanation for the stratigraphic sequence found in the southeastern Michigan area.

Respectfully Submitted,

A handwritten signature in cursive script, appearing to read "H. S. G. 1922".

# STRATIGRAPHIC SUCCESSION IN MICHIGAN

PALEOZOIC THROUGH RECENT



MICHIGAN DEPARTMENT OF CONSERVATION

Richard A. Muesel, Director

GEOLOGICAL SURVEY

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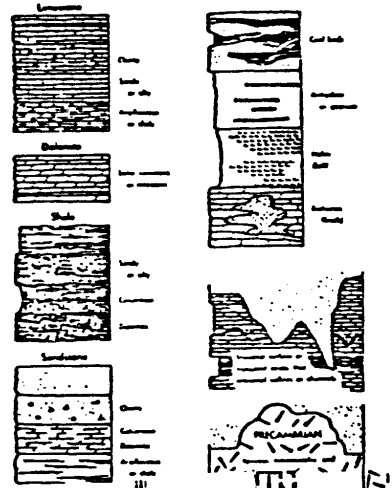
Richard A. Muesel, Chairman; Robert H. Dott, Jr., Secretary; James H. MacGowan, Jr., Robert S. Anderson, Members

## INFORMAL TERMS

Described and given names and informal terms used in previous explanation and applied as parts of formations or groups in the subsurface.

STRATIGRAPHIC POSITION	INFORMAL TERMS	PAYS
Base of Cambrian	None	
In lower part of	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> <li>None</li> </ul>	
Marshall Sh.	None	Gr & G
Calderwood Sh.	None	Gr & G
In upper part of	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> </ul>	
Marshall Sh.	None	Gr & G
Marshall Sh.	None	Gr & G
Saginaw Bay Ls.	None	Gr & G
Upper part of	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> </ul>	
Traverse Group in Western Michigan	None	Gr & G
Saginaw Bay Ls.	None	Gr & G
Upper part of	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> </ul>	
Dundee Ls. (Upper part of Loran Fm.?)	None	Gr & G
In Loran Fm.	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> </ul>	
Anderson Fm.	None	Gr
Part of Unit	None	Gr
Group 1 below	None	Gr
Division of A-7	None	Gr
Carboniferous in Western Michigan	None	Gr
A-1 Carboniferous	None	Gr & G
Upper part of	<ul style="list-style-type: none"> <li>None</li> <li>None</li> <li>None</li> </ul>	
Maquoket Series	None	Gr & G
Part of Maquoket Series	None	Gr & G
Traverse Group	None	Gr & G
Black River Group	None	Gr & G
Onondaga Dal.	None	Gr

## EXPLANATION



63

### PLEISTOCENE NOMENCLATURE

ERA	SYSTEM	SERIES	STAGE
CENOZOIC	QUATERNARY	PLEISTOCENE	Wisconsin
			Illinoian

### OUTCROP NOMENCLATURE

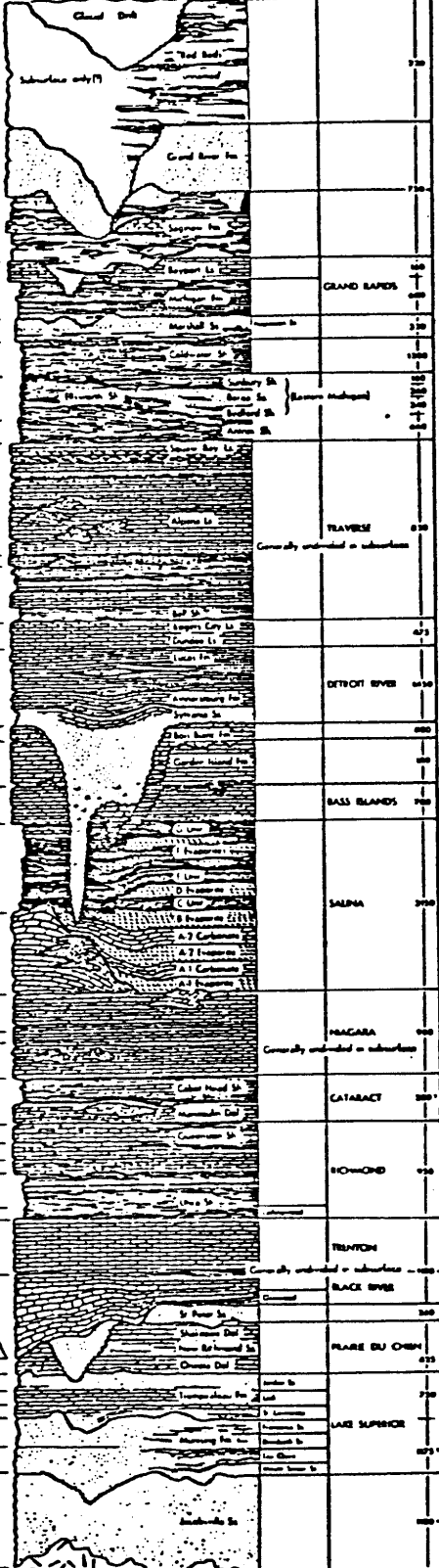
GEOLOGIC TIME	TIME STRATIGRAPHIC	ROCK STRATIGRAPHIC	
		SERIES	GROUP
ERA	PERIOD	FORMATION	MEMBER

### SUBSURFACE NOMENCLATURE

ROCK STRATIGRAPHIC		
FORMATION	MEMBER	GROUP
Approximate maximum thickness, in feet, of rock units in the subsurface. 100 SCALE		

### MEZOZOIC

ERA	PERIOD	EPOCH	SYSTEM	SERIES	GROUP	FORMATION	MEMBER																							
MEZOZOIC	JURASSIC	LATE	JURASSIC	EMERSONIAN																										
				CONEMAUGH	Grand River Fm.	None																								
	PENNSYLVANIAN	LATE	PENNSYLVANIAN	POITTSVILLE	Saginaw Fm.	None																								
				MERAMECIAN	GRAND RAPIDS	Beyers Ls.																								
	PENNSYLVANIAN	EARLY	PENNSYLVANIAN	OSAGIAN	Marshall Sh.	None																								
				KINDERHOOKIAN	Calderwood Sh.	None																								
	DEVONIAN	LATE	DEVONIAN	CHAUTAUGUAN	Blivens Sh.	None																								
				SILURIAN	LATE	SILURIAN	TRAVELLE	Albion Ls.	TRAVELLE	Generally undisturbed in subsurface																				
							MIDDLE	DEVONIAN	MIDDLE	DETROIT RIVER	Loran Fm.	DETROIT RIVER																		
										EARLY	DEVONIAN	EARLY	MAQUOKET BRACCA	Maquoket Fm.																
DEVONIAN													EARLY	DEVONIAN	BASS ISLANDS	Bass Island Fm.	BASS ISLANDS													
															LATE	SILURIAN	LATE	CAYUGAN	Salina Fm.	SALINA										
																		EARLY	SILURIAN	EARLY	NIAGARAN	Carroll Dal.	NIAGARA	Generally undisturbed in subsurface						
																					SILURIAN	EARLY	SILURIAN	ALEXANDRIAN	Cataract Sh.	CATARACT				
																								LATE	ORDOVICIAN	LATE	CINCINNATIAN	Richmond Fm.	CHICHOND	
																											MIDDLE	ORDOVICIAN	MIDDLE	MOHAWELIAN
	EARLY	ORDOVICIAN	EARLY																											CHAZYAN
				EARLY	CAMBRIAN	EARLY																								CANADIAN
							LATE	CAMBRIAN	LATE																					ST. CROIXAN



PRECAMBRIAN

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2. Briggs, L. I., Niagaran - Cayugan Sedimentation in the Michigan Basin.
3. Ehlers, G. M. and Kesling, R. V., Silurian - Rocks of Michigan and Their Correlation.
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