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ABSTRACT

THE INTERRELATIONSHIP OF THE LOWER SALINA GROUP AND NIAGARAN REEFS IN ST. CLAIR AND MACOMB COUNTIES, MICHIGAN

By

Kenneth F. Johnson

St. Clair and Macomb counties contain the best known development of Niagaran reefs in Michigan. Because these reefs are related to oil and gas production, the area has been extensively drilled giving good control for reconstructing the geological history of the area. Most of the wells have gamma-ray neutron logs from which formation tops were determined for the construction of structure and isopach maps. This portion of the Michigan Basin, during Middle Silurian time, was represented by a carbonate shelf, with pinnacle reef development, overlain by carbonate-evaporite sequences of Late Silurian age. From the maps and sample descriptions, it was determined that the reflux theory complemented with the barred basin model was a plausible explanation for the environment of deposition of these carbonate-evaporite sequences.

THE INTERRELATIONSHIP OF THE LOWER SALINA GROUP
AND NIAGARAN REEFS IN ST. CLAIR AND
MACOMB COUNTIES, MICHIGAN

By

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A THESIS

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INTRODUCTION

Location

St. Clair and Macomb counties are located in southeastern Michigan (Figure 1). This area contains approximately 1150 square miles and is surveyed on the township and range system. Along the lake fronts of both counties many French colonial claims (Plate 1) predate and overlap the township and range system. Locations within these claims are based on projections of the township and range system. Range 12E is excluded from the study to restrict map width to 42 inches for reproduction purposes.

History of Oil Exploration

The first known production in the area dates back to 1886 when oil was discovered in what was probably a Dundee structural trap (G. D. Ells, personal communication, 1971). This field was located within the city limits of present-day Port Huron and was named the Port Huron oil field. The oil was mainly processed into axle grease until production ceased in 1921. In 1928 gas was discovered in Salina-Niagaran rocks in the Diamond Crystal Salt Company's #13 well in St. Clair Township. Through

GENERALIZED COLUMNAR SECTION OF MICHIGAN

MICHIGAN GEOLOGICAL SURVEY DIVISION

SYSTEM, SERIES	FORMATION, GROUP	THICKNESS
RECENT		
PLEISTOCENE	GLACIAL DRIFT	0-1000
"PERMO-CARBONIFEROUS"	"RED-BEDS"	
PENNSYLVANIAN	GRAND RIVER	80-95
	SAGINAW	20-535
MISSISSIPPIAN	BAY PORT	2-100
	MICHIGAN	0-500
	"MICHIGAN STRAY"	0-80
	MARSHALL	100-400
	COLDWATER	500-1100
	SUNBURY	0-140
	BEREA - BEDFORD	0-325
DEVONIAN	ELLSWORTH - ANTRIM	100-950
	TRAVERSE	100-800
	BELL	0-80
	ROGERS CITY - DUNDEE	0-475
	DETROIT RIVER	150-1400
	SYLVANIA	0-550
	BOIS BLANC	0-1000
SILURIAN	BASS ISLANDS	50-570
	SALINA	50-4000
	NIAGARAN (Guelph - Lockport - Engadine) (Mamistique - Burnt Bluff) (Cataract)	150-800
ORDOVICIAN	CINCINNATIAN (Richmond) (Maysville - Eden)	250-800
	TRENTON-BLACK RIVER	200-1000
	ST PETER	0-150
OZARKIAN OR CANADIAN	PRAIRIE DU CHIEN	0-410
	HERMANSVILLE	15-500
CAMBRIAN	LAKE SUPERIOR (Menominee) (Jacobsville)	500-2000
ALGONKIAN	REWEENAW (Copper formations)	9800-35000
	KILLARNEY GRANITE	
	MURONIAN (Iron formations)	2000+
ARCHEAN	LAURENTIAN	
	KEEWATIN	

"G" UNIT
F UNIT
E UNIT
D UNIT
C UNIT
B EVAPORITE
A-2 CARBONATE
A-2 EVAPORITE
A-1 CARBONATE
A-1 EVAPORITE

Fig. 1 Location of thesis area

the 1930's and 1940's most of the wells drilled were Traverse and Dundee tests until 1952 when the Panhandle-Eastern Pipeline Company discovered gas in a Niagaran reef (Boyd Field) in their #1 Ringle well. In early 1953 Panhandle discovered another reef--the Ira Field (Plate 1), and in late 1955 followed up with the discovery of the Peters Field. All three reefs were discovered by gravity surveys and all produced gas initially. The first Salina-Niagaran oil production was from the Glen Mills No. 1 Waltos well (Peters Reef) in 1958. From 1959 and into the early and mid-1960's exploration was greatly accelerated. Exploration still continues and today there are over 1,600 wells and 40 fields in the area. Most reefs were discovered by a combination of gravity surveys and subsurface geological mapping. Modern seismic methods have been credited with a few discoveries.

Purpose of the Investigation

The purpose of this study is to further the knowledge of reef development, depositional environments, and to aid future reef exploration programs in southeastern Michigan.

This area was chosen for its extensive reef development, distinct carbonate-evaporite sequences, and dense well control. There has been a recent upsurge in exploration for Silurian reefs throughout the Lower Peninsula

of Michigan. Patterns of reef occurrence outlined in this study should contribute to the success of these exploration efforts.

Method of the Investigation and Materials Used

A 1:4000 scale Ammann International map was utilized as a base map and wells located to the nearest $\frac{1}{4}$ - $\frac{1}{4}$ - $\frac{1}{4}$ section were added to it. Only oil, gas, and dry hole symbols appear on the maps. Facility well (gas storage) symbols were not used although gas storage areas appear on the Oil and Gas Field Map (Plate 1).

A total of 932 gamma-ray neutron logs (nuclear logs) were correlated to determine formation tops in constructing the maps. All wells plotted on the maps have nuclear logs. Other wells that were not logged but have formation tops based on samples were not used to insure accuracy of the formation tops.

Nuclear logs are mainly used in Michigan because of the carbonate-evaporite sequences. Salt water used in drilling to prevent dissolving evaporite formations does not adversely effect nuclear logs as it does standard electric logs. Logging through the casing and porosity determinations from neutron logs are other advantages of nuclear logs. The formation tops were picked on gamma-ray log characteristics because the neutron log characteristics may be adversely affected by the fluid level in

the well. A hole that was logged dry would reverse the neutron characteristics (i.e., a carbonate would be more radioactive than an anhydrite).

Logs published by the Michigan Geological Survey were obtained for 50 key wells and were used to double check the accuracy of the formation tops and for their sample and core descriptions. Cores available from the University of Michigan Subsurface Laboratory and samples from the Michigan Geological Survey were also utilized.

STRUCTURE AND STRATIGRAPHY

General Structure of the Michigan Basin

The Michigan Basin (Figure 1) is an intracratonic gravity-sag basin or autogeosyncline that does not have a well-defined hinge line as is found in tectonic basins. It encompasses all of the Southern Peninsula of Michigan and parts of the Northern Peninsula, Wisconsin, Ontario, Ohio, Indiana, and Illinois. Structurally, the basin is flanked on the north by the Canadian Shield, southeast by the Algonquin Arch and Findlay Arch, southwest by the Kankakee Arch and west by the Wisconsin Arch. The basin first developed in middle and late Ordovician time as evidenced by Ordovician rocks thickening slightly in the central basin area (Babb, 1969).

Landes in 1945 calculated the basin to encompass an area of 12,000 square miles and to hold a volume of 108,000 cubic miles of sediments.

Structure of the Study Area

The structural setting of the study area is a carbonate shelf (Plate 2) located on the southeastern periphery of the Michigan Basin. Within the study area the Niagaran varies in depth from 2,000 feet in the

extreme southeast corner to about 4,900 feet in the extreme northwest corner and has a northwest dip of about 1 degree. The Niagaran is thickest on the periphery of the basin and thins toward the central basin area. The Chatham Sag, slightly east of Lake St. Clair, was a structurally low area and was a probable connection between the Michigan and New York Basins.

A paleoslope diagram of the Niagaran was attempted by constructing dip sections and adjusting the tops of the reefs to a horizontal line representing sea level during the end of reef development. It was assumed all reefs grew to sea level and with a trend of reefs attaining greater heights, from the general structural trend of the Brown Niagaran, going down dip. On Plate 2 these heights were plotted next to each reef and it was noted this trend did not occur, therefore, the assumptions are unwarranted (see Depositional Environment for further discussion).

Age and Stratigraphic Nomenclature

This study includes the Niagaran Series of Middle Silurian age and the immediately overlying A-1 evaporite, A-1 carbonate, A-2 evaporite, and A-2 carbonate units of the Salina Group of Upper Silurian age (Figure 2). In 1945 Landes divided the Salina into 7 units (A thru G) and in 1950, Evans further divided the A unit as above.

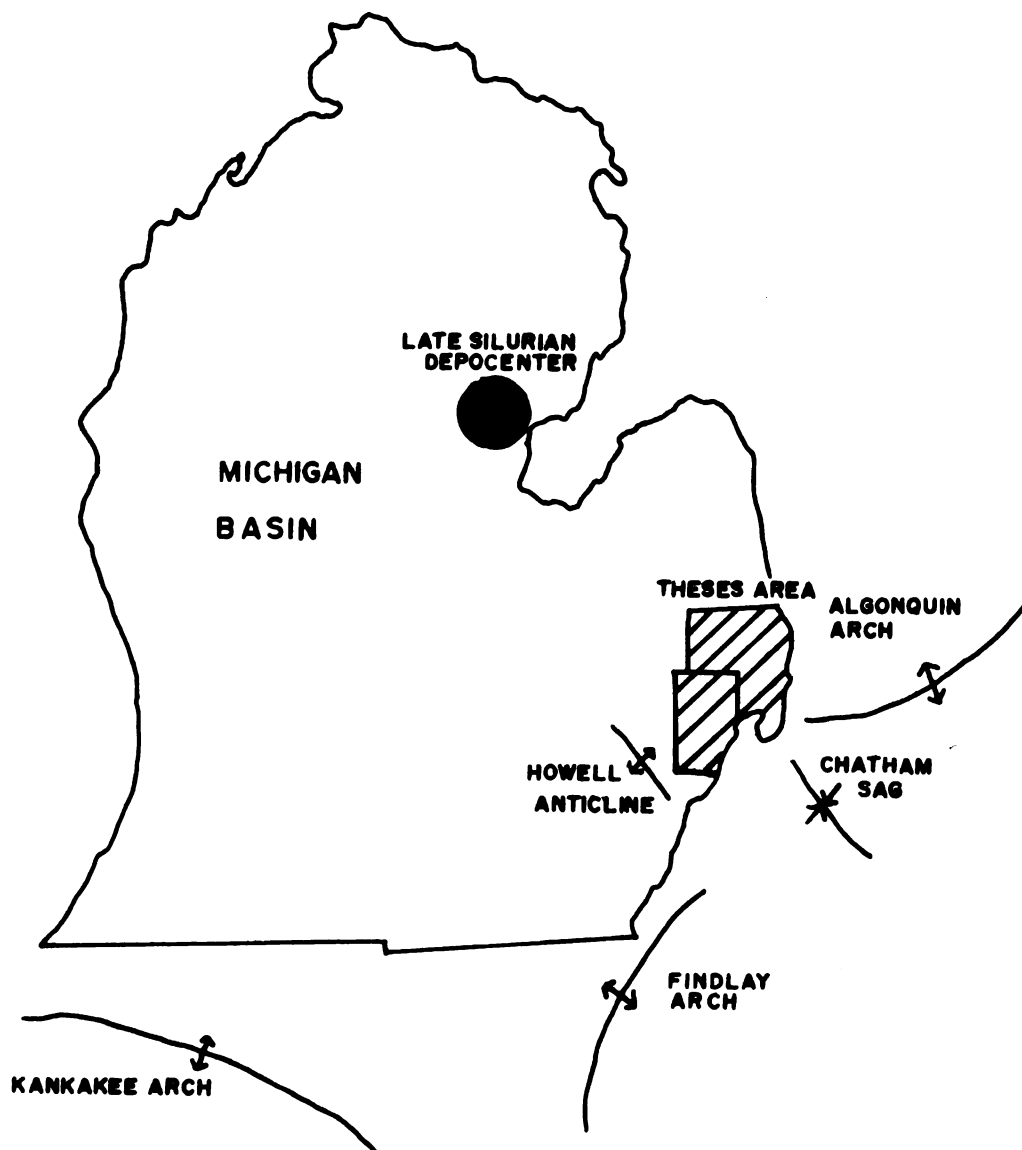


Fig. 2 Stratigraphic Column of Michigan [Modified from Ells, G. D. (1963), Michigan Silurian Oil and Gas Pools, Mich. Dept. of Cons. Pub.]

Unfortunately this division did not reflect the carbonate-anhydrite (or gypsum)-halite sequence as the normal order of precipitation and caused some confusion. Some writers (Sharma, 1966; Gill, 1971) have tried to reorder Evan's stratigraphic divisions but their recommendations have not received wide acceptance.

General Correlation

As previously mentioned, formation tops are based on gamma-ray neutron logs and mainly on the gamma-ray curve characteristics. Figure 3 represents the general characteristics of the gamma-ray neutron curves, with formation tops, in a non-reef well and Figure 4 represents the log characteristics for a reef well. It is difficult to determine the top of the reef on logs and many geologists disagree on this, but, however arbitrary this reef top is, it was picked consistently which is important. The Gray Niagaran characteristic holds up best in Columbus Township, St. Clair County (5N-15E) which is why the Gray Niagaran structure map (Figure 5) covers only this township. The log characteristics for the other formations are about the same throughout the thesis area.

Lithologic Descriptions

Niagaran: The Niagaran is divided into three units on the basis of color. The lowest unit or white

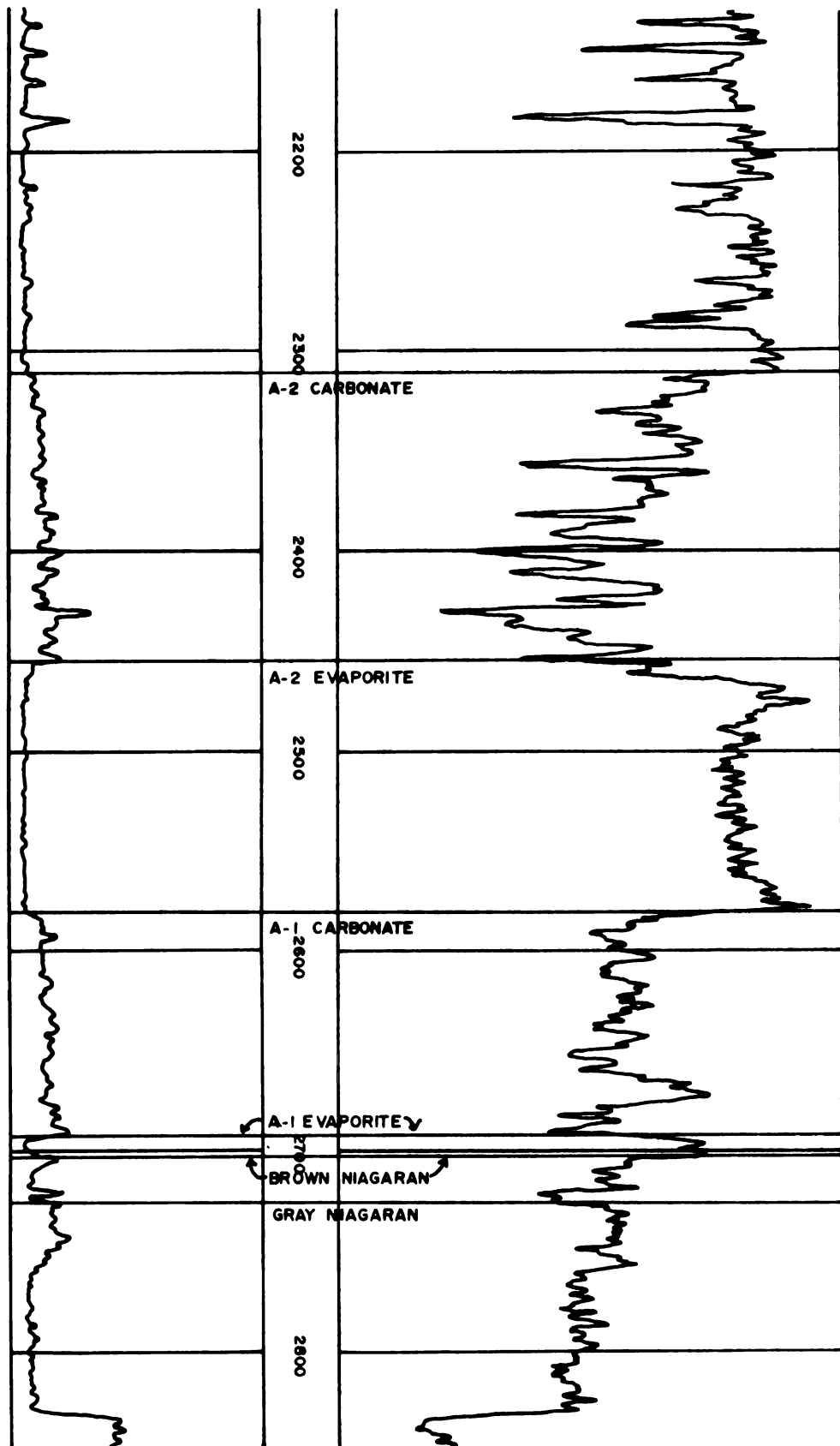


Fig. 3 Characteristic gamma-ray neutron log for an off reef well

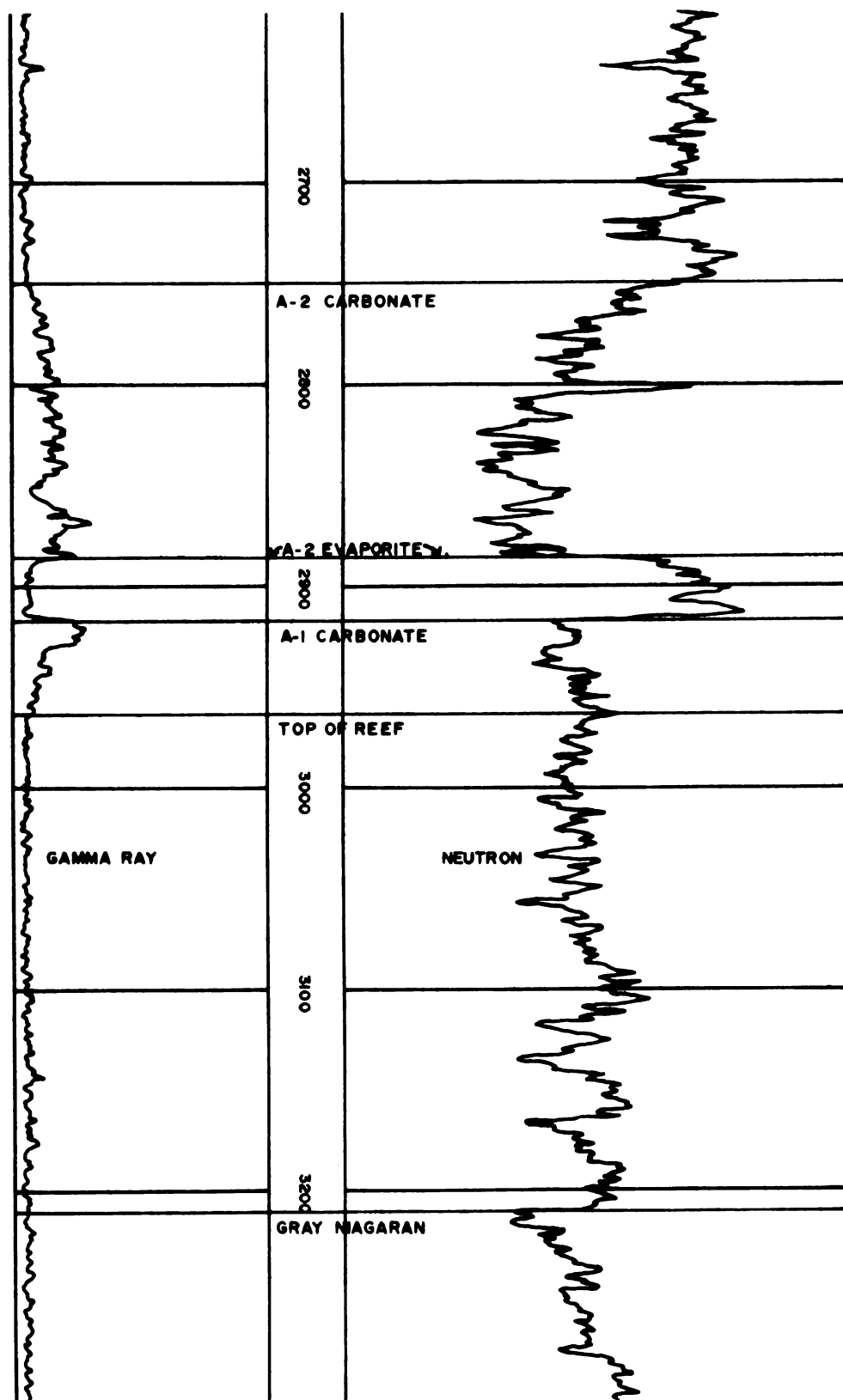
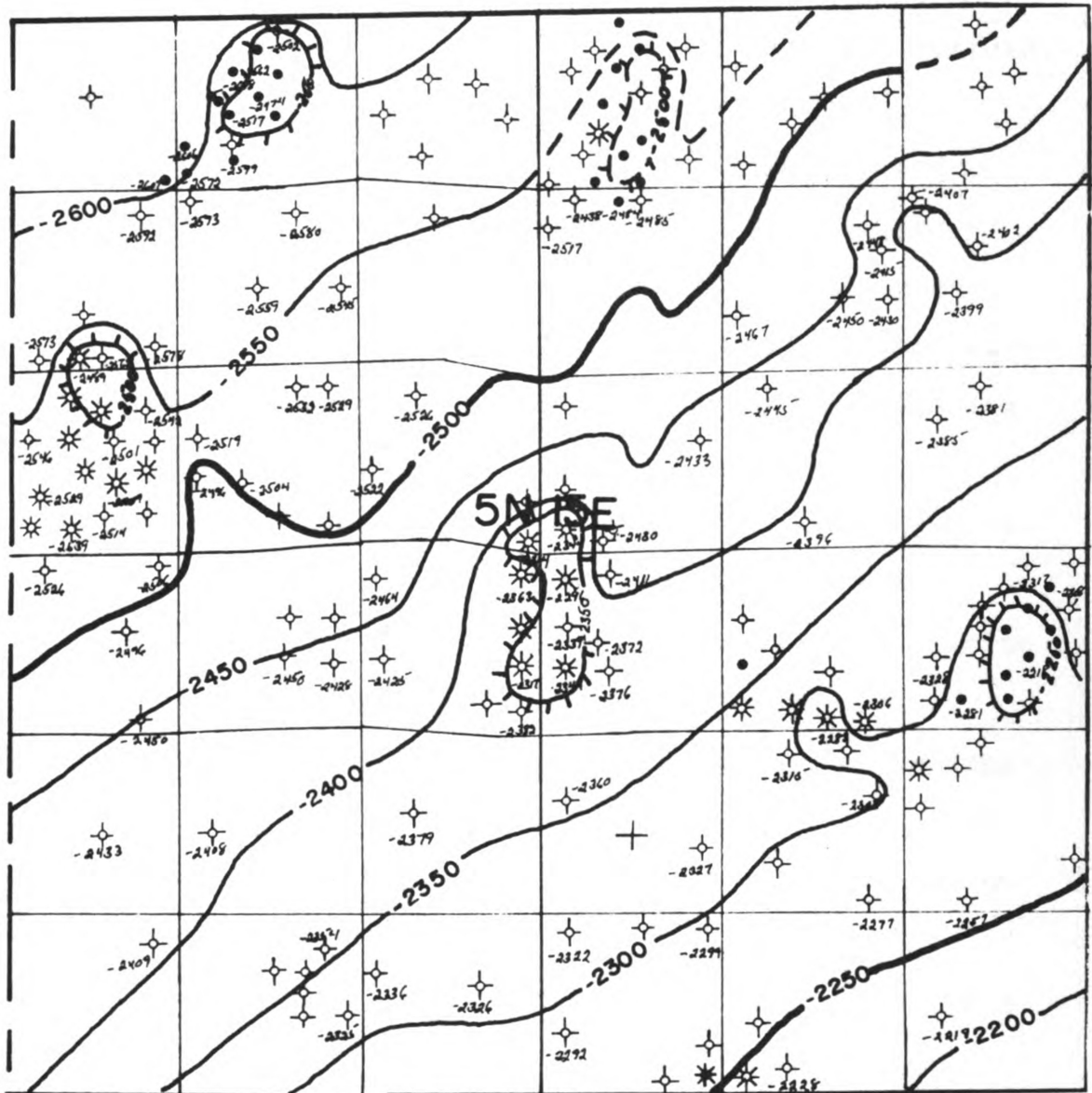


Fig. 4 Characteristic gamma-ray neutron log for a reef well



Legend

Positive Areas



Contour Interval = 50 ft
Datum = Sea Level

Fig. 5 Gray Niagaran structure map of Columbus Township

Niagaran is a dolomite, light to dark bluish-gray, fine to coarsely-crystalline with some small vugs and disseminated pyrite along partings. The middle unit, or Gray Niagaran, is also a dolomite, gray with dark-gray streaks, finely-crystalline with some argillaceous zones. The upper unit, or Brown Niagaran, is a limestone in non-reef areas and a dolomite in reef areas, gray to gray-brown and dark-brown, fine to coarsely-crystalline and vugular in reef areas. The reefs are the equivalent of the Brown Niagaran with the overlying sediments thinning and draping over the reefs.

A-1 Evaporite: The A-1 evaporite immediately overlies the Brown Niagaran (Figure 3, Plate 3). In the inter-reef areas it is an anhydrite, bluish-gray to white with dolomite stringers and some disseminated pyrite. Salt is deposited and overlies the anhydrite in the area of the 35-foot isopach line in the northwest portion of the map and the salt rapidly thickens towards the northwest.

A-1 Carbonate: The A-1 carbonate lies immediately above the A-1 evaporite. It is mainly a limestone in non-reef areas and a dolomite in reef areas. It is gray, light-brown, dark-brown, finely-crystalline with pinpoint porosity in reef areas and is argillaceous and carbonaceous in the lower part. There is some salt filling of the porosity especially in reef areas. The thickness

varies, generally, from 120 feet regionally to as little as 15 feet over large reefs, but is never absent.

A-2 Evaporite: The A-2 evaporite immediately overlies the A-1 carbonate. It is mainly a salt, clear to white, capped by a thin (10-15-foot) anhydrite. In some places there is an anhydrite layer at the base and again within the salt but there is no consistent pattern. Usually over a reef only an anhydrite is found. This will be discussed more fully under Depositional Environments. The thickness varies (Plate 5) from 50 feet in the extreme southeast portions of the area to over 370 feet in the extreme northwest portion.

A-2 Carbonate: The A-2 carbonate immediately overlies the A-2 evaporite. In off-reef areas it is a dolomite in the upper and lower portions, tan to buff and fine-grained to cryptocrystalline. Over the reefs it is all dolomite, gray to brown and dense to porous. The thickness is generally 150 feet, thinning to less than 100 feet over large reefs.

DEPOSITIONAL ENVIRONMENTS

Introduction

This area during Niagaran time was a carbonate shelf with a water depth conducive to the growth of pinnacle reefs. These reefs along with the barrier reefs, acted as restricting features to the influx and reflux of sea water between the Michigan Basin and the New York Basin via the Chatham Sag. Because of this restriction and the possibly arid climate, the area became a supratidal zone or sabkha¹ conducive to evaporite deposition.

The reflux theory complemented with the barred basin model is a plausible explanation for the evaporite sequences found in this area. The reflux theory was first proposed by Ochsenius in 1877 to explain imbalances in evaporite sequences. It did not receive widespread acceptance until King (1947) utilized the theory to explain evaporite deposits in the Delaware Basin. Some of the reflux theory principles which are applicable to this area are review by Hite (1970):

¹Kinsman (1969) defines sabkha as a salt or evaporite plain formed by slow regression of the sea.

- (1) All evaporite basins undergo some degree of reflux.
- (2) Rate of reflux is primarily controlled by sea level. If the sea level is high, then the rate of reflux will be great; if, however, the sea level is low, reflux is absent or minimal.
- (3) Every marine evaporite facies must have a contemporaneous carbonate facies unless the evaporities are the result of solution and redeposition of pre-existing deposits.
- (4) The contemporaneous carbonate facies will be deposited in the area of sea water ingress, and thus will also be in the path of refluxing brines from the basin.
- (5) Contrary to popular opinion, biogenic carbonates should develop during a low sea level or regressive phase when reflux is minimal.

Niagaran

The Brown Niagaran structure map (Plate 2) shows the present known reef buildup. These reefs are generally outlined on the map by a symbol for positive areas. The numbers adjacent to the reefs are the reef height above the regional structure trends of the Brown Niagaran. It will be noticed that these reef heights fall into no particular pattern. Lowenstam (1949) found small biohermal mounds adjacent to large pinnacle reefs in outcrops in Illinois. Apparently that is the case here. For example the Columbus 23 field (23-5N-15E) has a reef buildup of 72 feet whereas the Big Hand Reef in the next section (24-5N-15E) has a buildup of 352 feet.

The Gray Niagaran structure map for Columbus Township (Figure 5) indicates definite positive areas directly below known reefs indicating that reefs either grew on

already positive areas or there was incipient reefing¹ in the Gray Niagaran.

Both Gill (1971), who studied the Belle River Mills reef, and Sharma (1966), who studied the Peters reef, found three stages of reef growth. The first stage, found at the basal part of the reef was characterized by large numbers of stromatoporoids. The second stage represents the greatest acceleration of organic development and contains the greatest variety of fossils--corals, brachiopods, crinoids, stromatoporoids, and bryozoans. The third stage or upper zone contained few reef fossils. Sharma mentioned that secondary dolomitization and recrystallization of the reef destroyed characteristic features of the fossils but could identify the following:

Class Anthozoa	Class Hydrozoa
1. <u>Farosites</u>	Class stromatoporoidea
2. <u>Halysites</u>	Class Bryozoa
3. <u>Alreolites</u>	Class Brachiopoda
4. <u>Catenipora</u>	1. <u>Atrypa</u>
5. <u>Pycnostylus</u>	2. <u>Pentamerus</u>
	Class Crinoidea
	Family Algae

Most of the larger reefs are elongated in a north-east-southwest direction. It appears from the Niagaran structure map (PLATE 2) that some of these longer reefs such as the Columbus 3 and Ray Fields could be more than one reef with one reef growing on the flanks of the other.

¹Since the data were collected for this study McClure Oil Company discovered production in the Gray Niagaran from a reef in Columbus Township. Until this time all production was from the Brown Niagaran or A-1 carbonate.

Many of the reefs have been discovered by gravity techniques. The reefs appear as positive gravity anomalies of about +.2 to +.5 mgls. on residual gravity maps. The anomalies are probably due to a density contrast of the reefs with a density of 2.5 to 2.7 and the surrounding salts with a density of 2.0. The anhydrite with a density of 3.0 would not be thick enough to offset this contrast. The high density of the reef is probably due to its high dolomite content. Some of the magnesium content could have been inherent in the reef and not entirely due to dolomitization. The lower the level of organization of marine invertebrates the higher the magnesium content they contain plus the fact the magnesium content of sea water is a function of temperature and is higher with higher temperatures (Pettijohn, 1957).

The Brown Niagaran lime muds were deposited from the denser (salinity 72,000 p.p.m.) refluxing current while the reefs flourished in the upper more normally saline (35,000 p.p.m.) influxing current depositing biogenic carbonates (Adams and Rhodes, 1960). Since modern reefs are formed in waters no more than about 100 feet deep and at temperatures greater than 60 F., these conditions probably prevailed for ancient reef development.

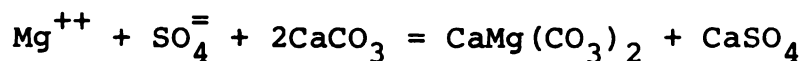
Reef development ceased either near the end of Niagaran time or at the beginning of A-1 evaporite time because of the lowering of sea level exposing the upper

living portions of the reefs to subaerial erosion. This is evidenced by leaching in the upper portions of the Peters reef (Sharma, 1966) and Belle River Mills reef (Gill, 1971) with a conglomerate of reef material found around the periphery of both.

All petroleum production in the area is from the reefs or the A-1 carbonate directly above and flanking the reefs, except for the Capac gas field in the northwest portion of the area (Plate 1). Capac produces from the Brown Niagaran and could be a porosity-permeability wedgeout. The Mt. Clemens and Chesterfield fields in the southwest portion do not appear to be large reef build-ups but possibly small biohermal mounds.

A-1 Evaporite

With the lowering of sea level the refluxing current was cut off and a rise in temperature and increase in concentration of total dissolved solids from 72 to 190 parts per million caused expulsion of the CO_2 from solution into the atmosphere terminating carbonate deposition (Adams and Rhodes, 1960). The remaining concentrated brine reacted slowly with the deposited CaCO_3 forming penecontemporaneous dolomite and precipitating CaSO_4 from solution (Krauskopf, 1967);



It is not known whether the anhydrite was originally deposited as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). If it was there must have been avenues of escape for the water during dehydration. There was no evidence of gypsum in the wells checked.

The reefs probably acted as sediment traps for the refluxing brines causing a thickening of anhydrite deposits around the reefs such as the Belle River Mills area in 4N-14E (Plate 3). The anhydrite wedges out and drapes up on the flanks of the reefs. This is probably due to: (1) initial slope of the reef, (2) compaction of the reefs into the lime muds, and (3) later compaction of the anhydrite due to depth of burial.

The sea level was further lowered, concentrating the brine to 353 ppm (Adams and Rhodes, 1960) causing precipitation of anhydrite and halite together. On the A-1 evaporite isopach (Plate 3) the halite facies begins at about the 35-foot contour and rapidly thickens to the northwest, attaining its greatest thickness in the central basin area. The wells south of the 35-foot contour line showed no evidence of salt deposition, therefore, the salt was probably not deposited there and later redissolved.

A-1 Carbonate

The A-1 carbonate reflects either a downwarping of the basin or a rise in sea level. The refluxing waters

from the basin were concentrated to a minimum of 72,000 ppm of total dissolved solids to precipitate calcium carbonate but the refluxing salt brine was balanced by the influx-
ing less saline waters preventing salt deposition.

No bioherms are based in the A-1 carbonate but Niagaran bioherms were still positive features during A-1 carbonate deposition and probably restricted influxing and refluxing currents. The A-1 carbonate is 110-120 feet thick in interreef areas but thins (15-20 feet over large reefs) and drapes over the reefs (Figures 6, 7, and 8). The reasoning for the thinning and draping of the A-1 evaporite outlined in the preceding section applies here. There is usually a porosity halo in the A-1 carbonate surrounding the reef flanks (Alguire, 1962) probably caused by a shrinkage of the limestone during dolomitization. This porosity zone often serves as a petroleum reservoir.

A-2 Evaporite

The conditions for A-2 evaporite deposition were essentially the same as the A-1 evaporite except the A-2, due to its halite thickness, reflects a deeper water deposit. The shallow water zone of the basin was farther to the southeast than previously with the A-2 salt pinching out into Ontario (Alguire, 1962). The salt is structurally controlled (Plate 5) becoming thicker from the southeast to the northwest (down the dip--see Plate 2)

but does not attain full thickness until the central basin area (Figure 1) is reached.

In most wells the salt is overlain by an anhydrite cap possibly reflecting less saline conditions and a shallowing of the water but in some wells an anhydrite is at the base. It is possible that an anhydrite was deposited, before the salt, over the entire area but was redissolved and reprecipitated contemporaneously with the salt. In most wells there is an anhydrite within the salt.

The A-2 evaporite thins and drapes over the reefs similar to the A-1 carbonate and is due to the same factors affecting the A-1 carbonate plus possible salt flowage and solution over the reefs.

Over most reefs the A-2 evaporite thins and changes from salt to anhydrite (Figure 6). If the salt was originally deposited on the reefs it may have been redissolved due to turbulence, changes in salinity, etc. Over some reefs, such as the Ray Field, the A-2 evaporite thins to a salt capped by an anhydrite (Figure 7) and others, such as the Peters Field, there is an anhydrite cap, salt in the middle and anhydrite at the base (Figure 8).

During early A-2 evaporite deposition, the magnesium rich brines percolated through and dolomitized (see Depositional Environment for A-1 Evaporite for dolomitization process) the A-1 carbonate and Niagaran reefs.

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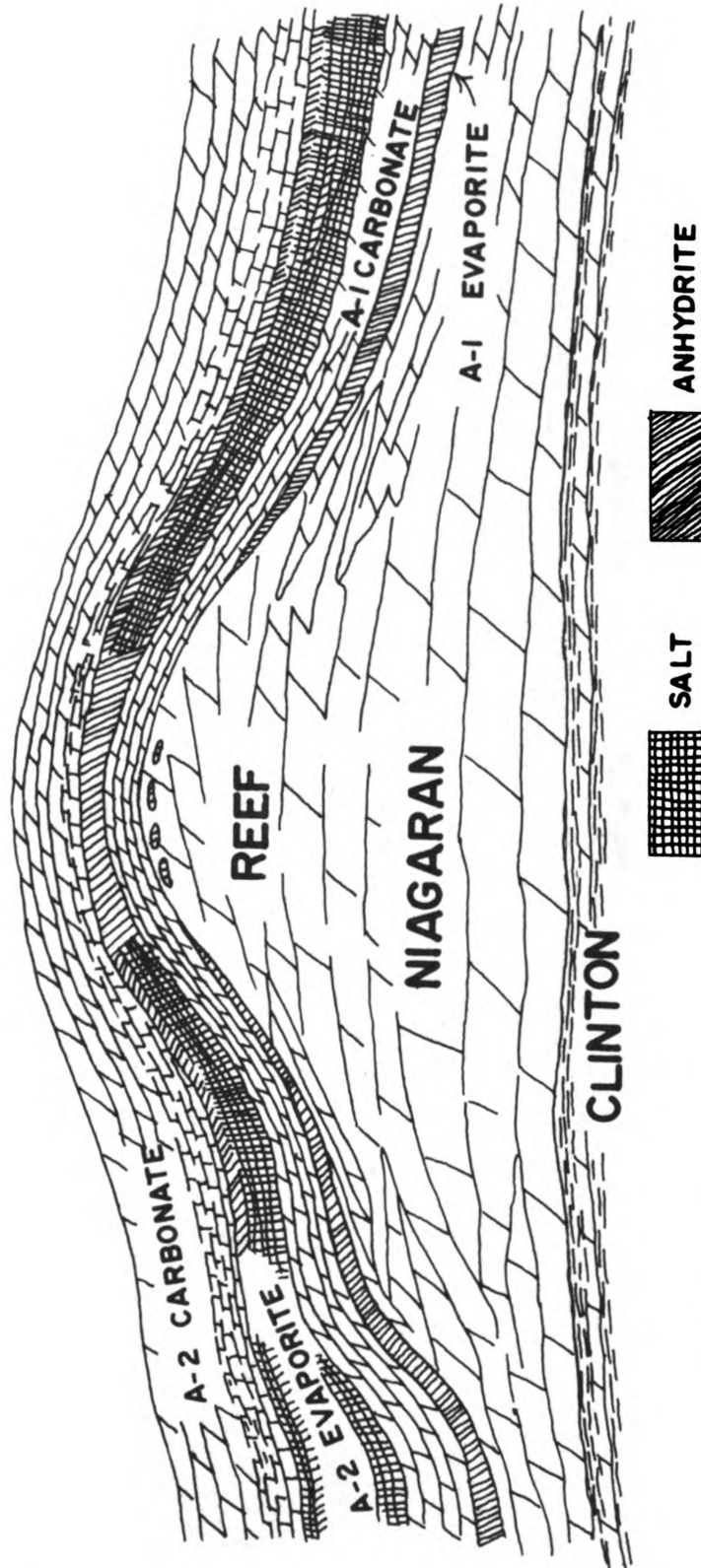


Fig. 6 Diagrammatic cross-section of a typical reef with the A-2 evaporite thinning to an anhydrite over the reefs. [Modified from Ellis, G. D. (1963)]

TYPE 2 CROSS SECTION

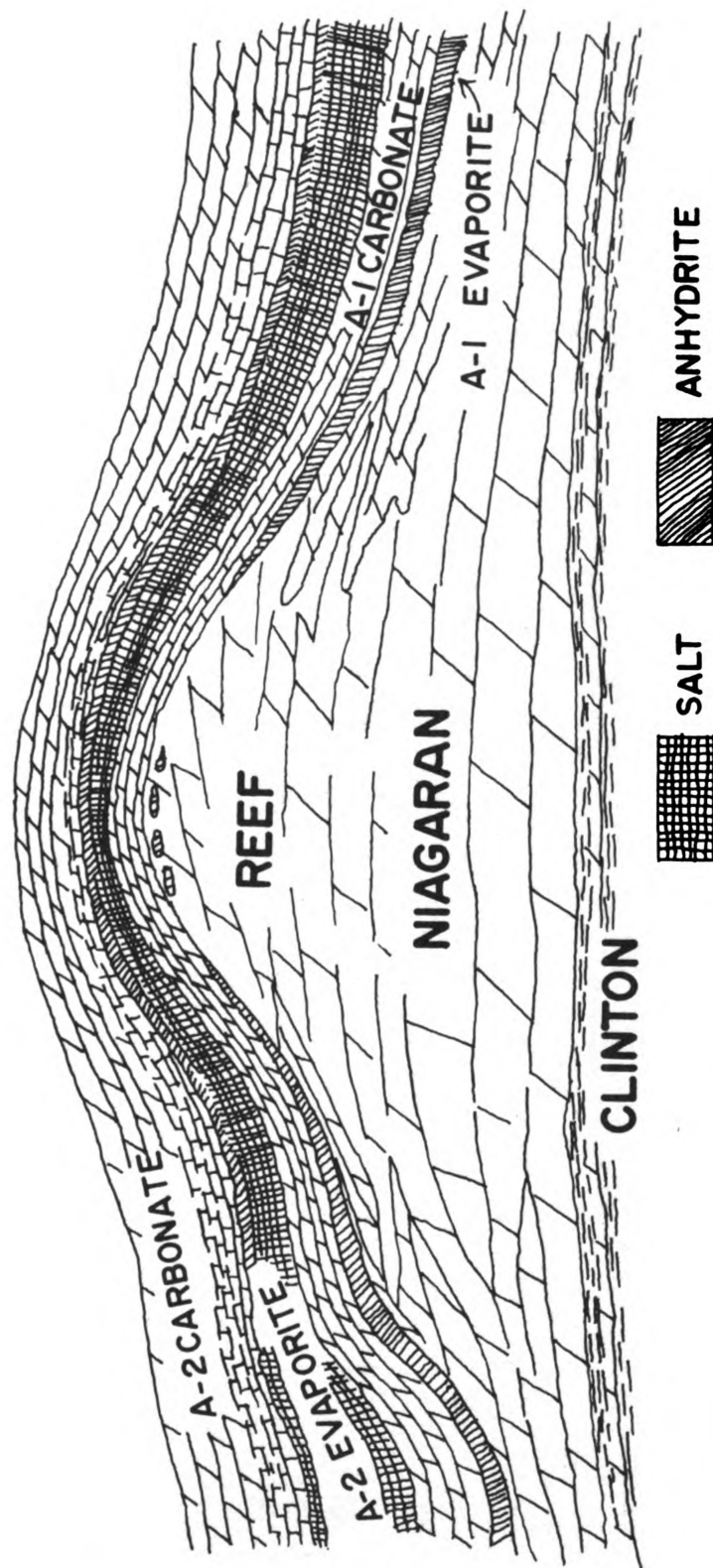


Fig. 7 Diagrammatic cross-section of a typical reef with the A-2 evaporite thinning to a salt overlain by an anhydrite. [Modified from Ellis, G. D. (1963)]

TYPE 3 CROSS SECTION

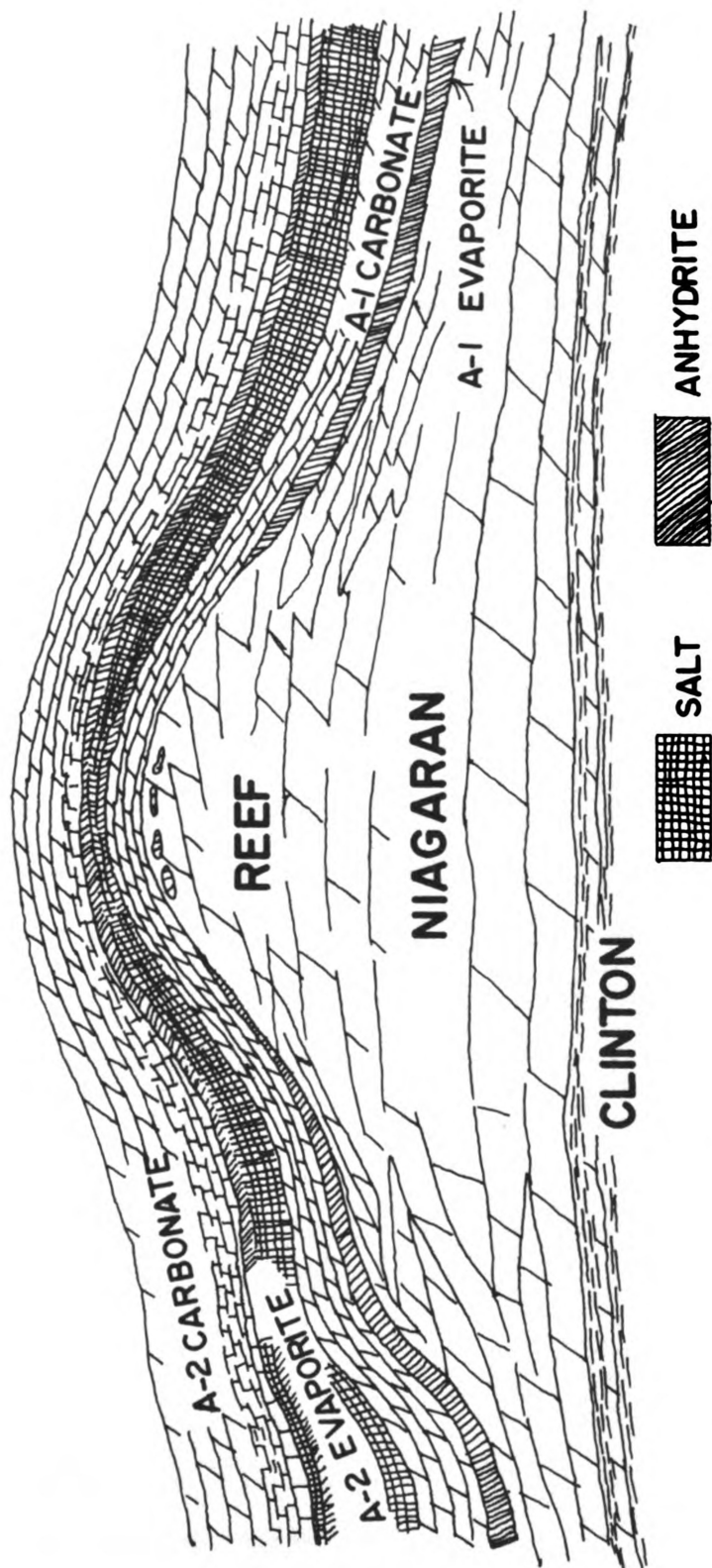


Fig. 8 Diagrammatic cross-section of a typical reef with the A-2 evaporite thinning to a salt overlain and underlain by an anhydrite. [Modified from Ells, G. D. (1963)]

With the onset of salt deposition some of the salt was dissolved and redeposited in the reefs. Almost all reefs have salt and anhydrite in the upper part which acts as a cap rock or partial cap rock sealing in the gas and oil. Over all salt filled reefs (Plates 1, 5, and 6), the A-1 carbonate porosity is salt filled with the A-2 evaporite greatly thinned and A-2 carbonate much thicker than regionally. The salt filled reefs show the most direct connection of the reef salt and A-2 salt. Soon after the onset of A-2 salt deposition some of the salt was redissolved and percolated through the A-1 carbonate dolomitized porosity zone and down into the permeable reef. The low areas in the A-2 evaporite over the reefs were filled in by A-2 carbonate deposition. The only difference between salt filled reefs and those with only some salt near their top was due to the amount of overlying A-2 salt originally dissolved because the A-2 carbonate does not thicken over non-salt filled reefs.

A-2 Carbonate

The A-2 carbonate reflects another rise in sea level with the controlling factors of deposition essentially the same as the A-1 carbonate. Niagaran reef areas were still positive topographic features during the onset of A-2 carbonate deposition and still could have controlled refluxing currents. There is some thickening in near-reef areas possibly because of compaction of the

reefs into the Niagaran lime muds causing a depression around the reefs that were filled in by carbonate deposition from the refluxing brines.

This unit also thins and drapes over the reefs (Figure 5) changing from a regional average of 150 feet to less than 100 feet over large reefs.

Figure 9 summarizes the above depositional phases.

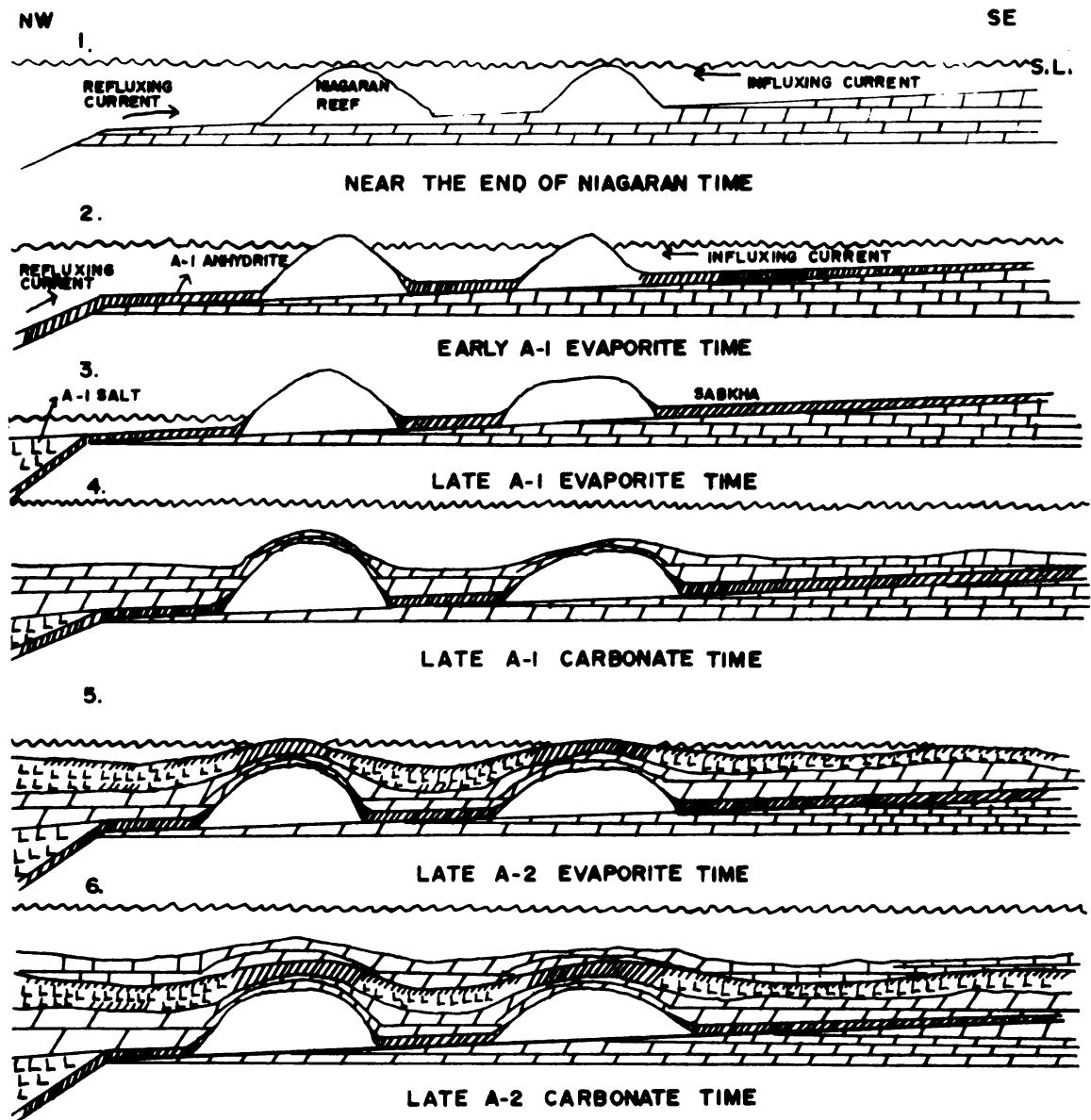


Fig. 9 Diagrammatic sketches of each sedimentation phase

SOURCE ROCK

Many geologists (Sharma, 1966; Gill, 1971; Ells, oral communication, 1971) agree that the source rock for the petroleum is the A-1 carbonate with the oil and gas migrating to and being trapped in the reef areas because of high porosity. The A-1 carbonate does contain some carbonaceous shale and is in close proximity to the reefs. However, it is possible the reefs could have been their own source rock. Bergmann and Lester (1940) studied 28 species of corals and found the organic matter was not confined to the thin living layer but was spread throughout the inorganic structure. This organic matter amounted to 4-8% of the total. Many geologists condemn reefs as source rocks because the outer, thin, living layer would not be buried quickly enough for organic preservation. But, if the organic matter was spread throughout the inorganic structure of the organisms which formed the ancient Niagaran reefs as Bergmann and Lester found in modern corals, then the reefs could have been their own source rock.

PETROLEUM POTENTIAL

The Brown Niagaran structure map (Plate 2) shows present known reef buildups but the isopachs of the overlying units (Plates 3, 4, 5, and 6), because of their thinning over known reefs, could reflect unknown reefs. The A-1 evaporite (Plate 3) is particularly sensitive to positive Niagaran areas because (1) it directly overlies the Niagaran and (2) its thin nature. Wells that could be in close proximity to unknown reefs occur in section 28-5N-14E and section 15-3N-16E. Other such areas can be found on all maps contained in this study. Detailed gravity and seismic surveys in these areas could further substantiate the presence of reefs.

Other people apparently believe there are more reefs in the area because exploration is still active. There are few wells in the northern portion and this could be the main area where new discoveries might occur.

CONCLUSIONS

The Niagaran sequence was formed on a carbonate shelf, on the periphery of the Michigan Basin, during Middle Silurian time. Sea level fluctuation and the Niagaran reefs on the periphery of the basin controlled the influx and reflux of brine currents to this portion of the basin and in turn influenced the carbonate-evaporite sequences overlying the Niagaran. All of these overlying units thin and drape over the reefs due to: (1) initial slope of the reefs, (2) compaction of the reefs into the Niagaran lime muds, (3) compaction of the overlying sequences due to depth of burial, and (4) salt solution and flowage.

The reefs were dolomitized possibly during A-2 salt deposition with magnesium rich brines percolating through the A-1 carbonate and into the reefs causing porosity and salt precipitation. Petroleum later migrated into these porosity zones forming Silurian oil and gas pools.

REFERENCES

- Adams, J. E., and Rhodes, M. L. (1960), Dolomitization by seepage refluxion, Amer. Assoc. Petroleum. Geol. Bull., V. 44, pp. 1912-1920.
- Alguire, S. L. (1962), Some geologic and economic aspects of Niagaran reefs in eastern Michigan, Mich. Basin Geol. Soc. Annual Field Conf., pp. 30-38.
- Alling, H. L. and Briggs, L. (1961), Stratigraphy of upper Silurian Cayugan Eraporites, Amer. Assoc. Petroleum Geol. Bull., V. 45, pp. 515-547.
- Babb, C. S. (1969), Geologic interpretative study and data resource evaluation of the St. Clair and Macomb counties, Michigan subsurface, unpublished Masters Thesis, Michigan State University.
- Bates, E. R. (1970), The Niagaran reefs and overlying carbonate evaporite sequence in southeastern Michigan, unpublished Masters Thesis, Michigan State University.
- Bergmann, W. and Lester, D. (1940), Coral reefs and the formation of petroleum, Science, V. 92, No. 2394, pp. 452-453.
- Braitsch, O. (1971), Salt deposits; their origin and composition, New York, Springer-Verlag-New York.
- Briggs, L. L. (1958), Evaporite facies, Jour. Sedim. Petrol., V. 28, pp. 46-56.
- , (1962), Niagaran-Cayugan Sedimentation in the Michigan Basin, Mich. Basin Geol. Soc. Annual Field Conf., pp. 58-60.
- Dellwig, L. F. (1955), Origin of the Salina salt of Michigan, Jour. Sedim. Petrol., V. 25, pp. 83-110.

- Dellwig, L. F. and Evans, R. (1969), Depositional processes in Salina Salt of Mich., Ohio and New York, Amer. Assoc. Petroleum Geol. Bull., V. 53, No. 4, pp. 949-956.
- Dorr, J. A. and Eschman, D. F. (1970), Geology of Michigan, Ann Arbor, Mich., Univ. of Mich. Press, pp. 102-113, 228-244, 285-350.
- Ells, G. D. (1962), Silurian rocks in the subsurface of southern Michigan, Mich. Basin Geol. Soc. Annual Field Conf., pp. 39-49.
- _____. (1963), Michigan Silurian oil and gas pools, Mich. Geol. Surv. Pub.
- _____. (1967), Michigan Silurian oil and gas pools, Mich. Geol. Surv. Report of Investigation, No. 2.
- Gill, D. (1971), Belle River Mills: Study of a producing Niagaran reef in Michigan, Ph.D. Dissertation, Univ. of Michigan.
- Hite, R. J. (1966), Sheif carbonate sedimentation controlled salinity in the Paradox Basin, southeast Utah, the N. Ohio Geol. Soc., Inc., Third Symp. on Salt, pp. 48-66.
- Jodry, R. L. (1969), Growth and dolomitization of Silurian reefs, St. Clair County, Mich., Amer. Assoc. Petroleum Geol. Bull., V. 53, No. 4, pp. 957-981.
- King, R. H. (1947), Sedimentation in Permian Castile Sea, Am. Assoc. Petroleum Geol. Bull., V. 31, pp. 470-477.
- Kinsman, D. J. J. (1969), Modes of formation, sedimentary associations, and diagnostic features of shallow water and supratidal evaporites, Amer. Assoc. Petroleum Geol. Bull., V. 53, No. 4, pp. 830-840.
- Krauskopf, K. B. (1967), Introduction to geochemistry, New York, McGraw Hill, pp. 318-354.
- Krumbein, W. C. (1951), Occurrence and lithologic associations of evaporites in the United States, Jour. Sedim. Petrol., V. 21, pp. 63-81.
- Lowenstam, H. A. (1949), Niagaran reefs in Illinois and their relation to oil accumulation, Ill. State Geol. Surv. Report of Investigations No. 145.

- Oschenius, K. (1877), Die bildung der steinsalzlager und ihrer mutterlaugensalze, Halle, C.E.M. Pfeffer, 172 p.
- Pettijohn, F. J. (1957), Sedimentary rocks, New York, Harper and Brothers, pp. 381-427, 478-485.
- Scruton, L. P. (1953), Deposition of evaporites, Amer. Assoc. Petroleum Geol., V. 37, pp. 2498-2512.
- Sharma, G. D. (1966), Geology of the Peters Reef, St. Clair county, Mich., Amer. Assoc. Petroleum Geol. Bull., V. 50, No. 2, pp. 327-350.
- Sloss, L. L. (1953), The significance of evaporites, Jour. Sedim. Petroleum, V. 23, pp. 143-151.
- _____. (1969), Evaporite deposition from layered solutions, Amer. Assoc. Petroleum Geol. Bull., V. 53, No. 4, pp. 776-789.

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