This is to certify that the

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Niagara Pinnacle Reefs of South Central Michigan

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Frank E. Walles

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James H. Fisher
Major professor

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NIAGARA PINNACLE REEFS OF SOUTH CENTRAL MICHIGAN

by

Frank E. Walles

AN ABSTRACT OF A THESIS

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ABSTRACT

NIAGARA PINNACLE REEFS OF SOUTH CENTRAL MICHIGAN

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Twelve maps were constructed (2 structure, 3 lithofacies and 7 isopach) of the units of the Niagara and Lower Salina. A north-south stratigraphic cross-section was also constructed. Through careful examination of the maps, a number of conclusions were made concerning the depositional history and environments of deposition during the Niagara and Lower Salina in the defined area of study.

In the center of the area of study, a distinct widening of the Niagara isopach contours occurs. Reef debris is likely to have been funneled basinward by several submarine channels in the barrier reef in this area.

The massive barrier reef and the pinnacle reefs grew to their near full height by the end of Niagara time. With the resulting isolation of the Michigan Basin accompanied with arid conditions, the A-1 Evaporite was deposited. Deep water (>50) deposition of the A-1 and later evaporites occurred in the central basin area simultaneously to shallow water ("sabkha") deposition of basin margin evaporites. A rise in sea level during A-1 Carbonate time resulted in minor supratidal algal mat deposition on the pinnacle reefs. Late carbonate (A-2) and evaporite units (A-2 and B) were deposited similarly to the younger A-1 units.

Differential subsidence throughout Niagara and Lower Salina time is well exhibited by the relation of thickness of these units along the Lucas Monroe monocline which enters the eastern half of the study area. The eastern half of the study area is shown to have subsided more rapidly than the western half of the study area.

DEDICATION

I would like to dedicate this study to my entire family, and especially to my Mother and Father (Carrie A. and Wilhelm E. Walles) for all of the support and faith they have given me throughout my life. For without their guidance and love, this study could not have been even begun. I wish to thank my parents for all of the good influence they have exerted on me through the years.

ACKNOWLEDGMENTS

Special thanks and deep appreciation go to Dr. James H. Fisher for his help, his support, and his friendship he has given me in this study. I would also like to express my appreciation to the other committee members, Dr. Duncan F. Sibley and Dr. F. W. Cambray for their time and help.

I am also very grateful to Jack Oswald of Tenneco Oil Company for his generous financial support of my thesis and graduate studies. I would also like to express my thanks to the Michigan Geological Survey for the use of their facilities and data.

Finally, I would also like to thank my fellow graduate students and all those people around the Geology Department (especially Loretta Knutson for her many hours of typing and retyping my thesis).

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INTRODUCTION

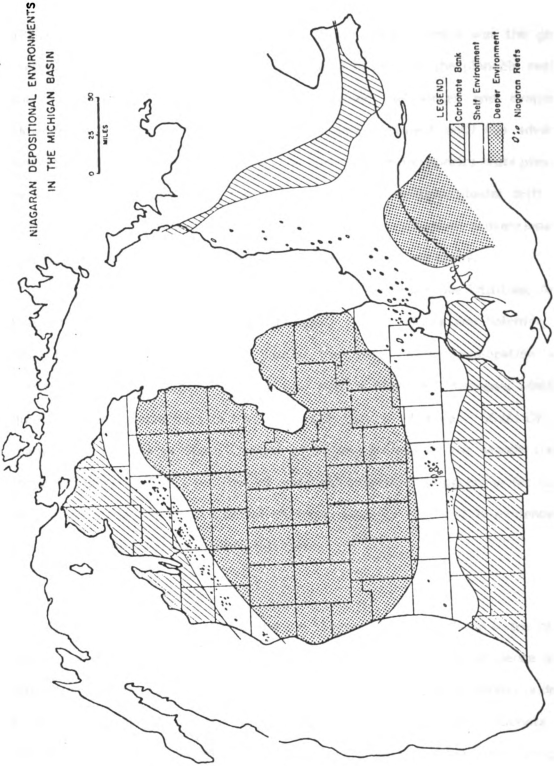
General History

The Niagara pinnacle reefs of South Central Michigan have recently become significant producers of oil and gas. During 1974 total annual production of oil from all zones for the entire state of Michigan was 18,101,812 barrels. The cumulative annual production from the South Central Michigan pinnacle reefs during 1974 was 1,145,000 barrels of oil. By the end of 1978 total cumulative production from the South Central Michigan pinnacle reefs had jumped to 18,667,566 barrels of oil. Comparable increases in the production of natural gas have also occurred.

Presently oil and gas production from the South Central Michigan Niagara pinnacle reefs is obtained from 71 producing reefs. This can be compared to the approximately 400 producing reefs in the Niagara Pinnacle Belt in Northern Michigan.

By comparing the production rise between 1974 and 1978 of the Niagara pinnacle reefs of South Central Michigan it can be seen that this area is being more intensely explored by the petroleum industry. Furthermore, this production rise has shown the great production potential of the Niagara and Lower Salina of the Michigan Basin. The area under study is not only of interest to the petroleum industry, it has attracted the attention of researchers world wide who are concerned with the relationship between cyclic carbonates and evaporites (Figure 1).

The first producing Niagara pinnacle reef in the United States was discovered in St. Clair County, Michigan in 1927. Earlier producing Niagara pinnacle reefs had already been discovered in Canada in the late 1800's. The



(MODIFIED AFTER MANTEK 1973) **FIGURE 1** active search for the pinnacle reefs in Michigan began in the 1950's. During the 1950's the primary prospecting tool for these pinnacle reefs was the gravity meter. This tool was initially fairly successful in locating the pinnacle reefs by the variation in the density contrast between carbonates and evaporites. However, full scale exploration did not become prevalent until the advent of sophisticated seismic investigations. The carbonate and evaporite units proved to be excellent reflectors, once the problems of the Michigan glacial drift were overcome. The combination of both gravity measurements with conventional and vibroseis seismology is the superior exploration method used today.

In the area of study, Mobil Oil along with Michigan Gas Utilities, Amoco Production Company, and other independents such as Kulka and Schmidt, Inc., have been particularly active. During the most intense exploration which occurred along the Niagara pinnacle reef belt in Northern Michigan, Mobil Oil quietly leased up considerable tracts in South Central Michigan. Mobil Oil, with many early failures in South Central Michigan, discovered the Mason field in Ingham County in 1970 - the first of many discoveries. The potential for further production along the South Central Michigan pinnacle reef belt is evidenced by the many recent discoveries along this trend.

Purpose and Scope of Study

The Silurian Cayugan strata and the Niagara are well defined in the central basin area of the Michigan Basin. This well defined stratigraphic sequence occurs along the northern edge of the area of study. Niagara carbonate clearly underlies Lower Salina evaporites in the central basin. Most of the Salina carbonate units are separated by the alternating evaporites. This is not the case along the massive barrier reef trend where the evaporites wedge out. Both non-deposition and/or solution have been postulated to account for the absence of evaporites on the barrier reef.

Niagara carbonates are largely organic framework and detritus associated with reef platform and reef pinnacle growth. A critical question associated with these carbonates is whether reef growth had ceased throughout the Michigan Basin when the deposition of cyclic evaporites began. The age of the pinnacle reefs is important in solving this critical question. Another important question concerns the origin of the pinnacle reefs: Are the pinnacle reefs simply uncoalesced massive barrier reef, or are they associated with Middle Ordovician faulting as suggested by Shaw (1975)?

In trying to solve these problems, many conflicting opinions have been offered. Mesolella et. al. (1974), Huh (1974, 1977), Gill (1975, 1979), Jodry (1969), Sharma (1966), Felber (1964), and Sloss (1964) have suggested solutions based on geologic evidence from separate environmental complexes in the basin. It is crucial to understand, with respect to this study, that it is probable that different parts of the Michigan Basin experienced slightly different histories and that, therefore, each area must be directly studied to determine its structural and depositional history with respect to pinnacle reef growth.

A regional study of Niagara pinnacle reefs by Mesolella et. al. (1974), established the general pinnacle reef belt in Michigan. Later research by Gill (1975, 1979) and Huh (1974, 1977) furnished detailed reef descriptions and a better definition of the reef belts in both northern and southeastern Michigan. However, the productive pinnacle reefs of south-central Michigan (Figure 2) have received little attention as compared to the northern pinnacle reefs, and they are anomalous with reference to the rest of the reef belt. The barrier reef in south-central Michigan has a series of major reentrants which may represent submarine reef channels. The 200 to 300 foot interval on Niagara isopach maps widens considerably opposite the reentrants. The belt of pinnacle reefs swings away from the barrier reef and has a convoluted trend which is unlike the remainder of the reef belt in Michigan.

FIGURE 2 AREA OF STUDY

The primary thrust is to determine how the depositional environment has influenced reef location and petroleum production. In addition this study will hopefully give some indication as to the deep vs. shallow water origin of the marginal Salina evaporites as determined for south-central Michigan

Method of Study

The successful mapping and correlation of seven different stratigraphic and lithologic units of the Niagara and Lower Salina in the area of study was a major goal of this study. Conventional geologic procedures were used in gathering the data. All data were derived from reports of subsurface drilling operations for oil and gas and include information derived from geophysical logs; principally: Compensated Neutron, Formation Density, Borehole Compensated Sonic Log-Gamma Ray, Dual Laterolog, Gamma Ray-Neutron, and Neutron Porosity Logs. Descriptive logs and drillers logs were used to help verify data. The State Survey and the Michigan State University collection of logs was the major source for the geophysical and mechanical logs. The Gamma Ray log, in conjunction with either a Sonic or Density log, was the most consistent and accurate source for picking formational tops. The Sonic and Density logs had as an advantage the distinct separation of carbonates and evaporites. The separation of these evaporites and carbonates was crucial to this study. Another log which gave fairly reliable separation of these cyclic units was the Neutron Porosity log. The Neutron Porosity log is useful for looking for porosity changes which are generally well defined when comparing evaporites and carbonates.

The study was not simply a separation of evaporite and carbonate units. It included the separation of quite comparable carbonate units when the evaporites disappeared as they reached the basin margin. Consistent picking of the Gamma Ray response was a major method of combating this unit separation problem.

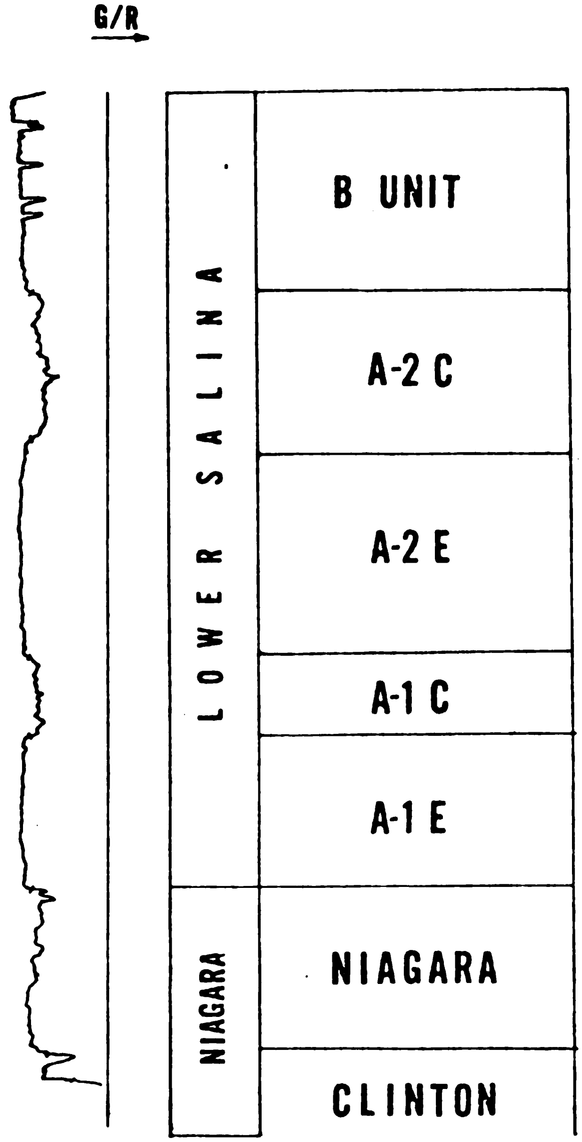


FIGURE 3 STRATIGRAPHIC SECTION WITH TYPICAL GAMMA-RAY OF STUDY AREA

It is important to note that this study is based on lithostratigraphic units, not on time stratigraphic units. Correlations are based on similar lithologies and of gradation of facies which are rock stratigraphic.

The formational tops picked are comparable to those of Lilienthal (1978), Fisher (1973), Autra (1977), and Fincham (1975). Overall these tops were quite consistent in the area of study (Figures 3 & 4).

Over 600 geophysical logs were used in the study. Twelve maps were plotted using the data gathered. The data collection included the measurement of the stratigraphic units by thickness, by elevation and by lithology. An isopach map was constructed of each of the seven units studied. Isopach maps were used in helping to determine the depositional environment and distribution of each unit. Structure maps of the Clinton shale and the A-2 Carbonate were constructed to determine whether any structural control existed on any of the units under study, especially the Niagara pinnacle reefs. Lithofacies maps of the B-Unit, A-2 Evaporite, and the A-1 Evaporite were constructed to determine what control, if any, existed with respect to the pinnacle and barrier reefs of the Niagara. Oil and gas production, with respect to the Niagara pinnacle reefs, was plotted on each map to help determine the trends of production with respect to structure, thickness, and lithofacies of the units. On each map, the 300 foot isopach line of the Niagara barrier reef was plotted. This barrier reef limit is as defined by Fisher (1973). Once all of the maps were contoured and studied, ideas and conclusions were developed as to the different depositional and lithologic trends. An overall view was developed based upon the 12 maps, the stratigraphic cross-section, and related research.

It must be remembered that in a detailed study of such a large area, as in this study, that the best data are obtained from geophysical logs. With geophysical logs, the problems of sample lag, lost samples, sample mixing and lost

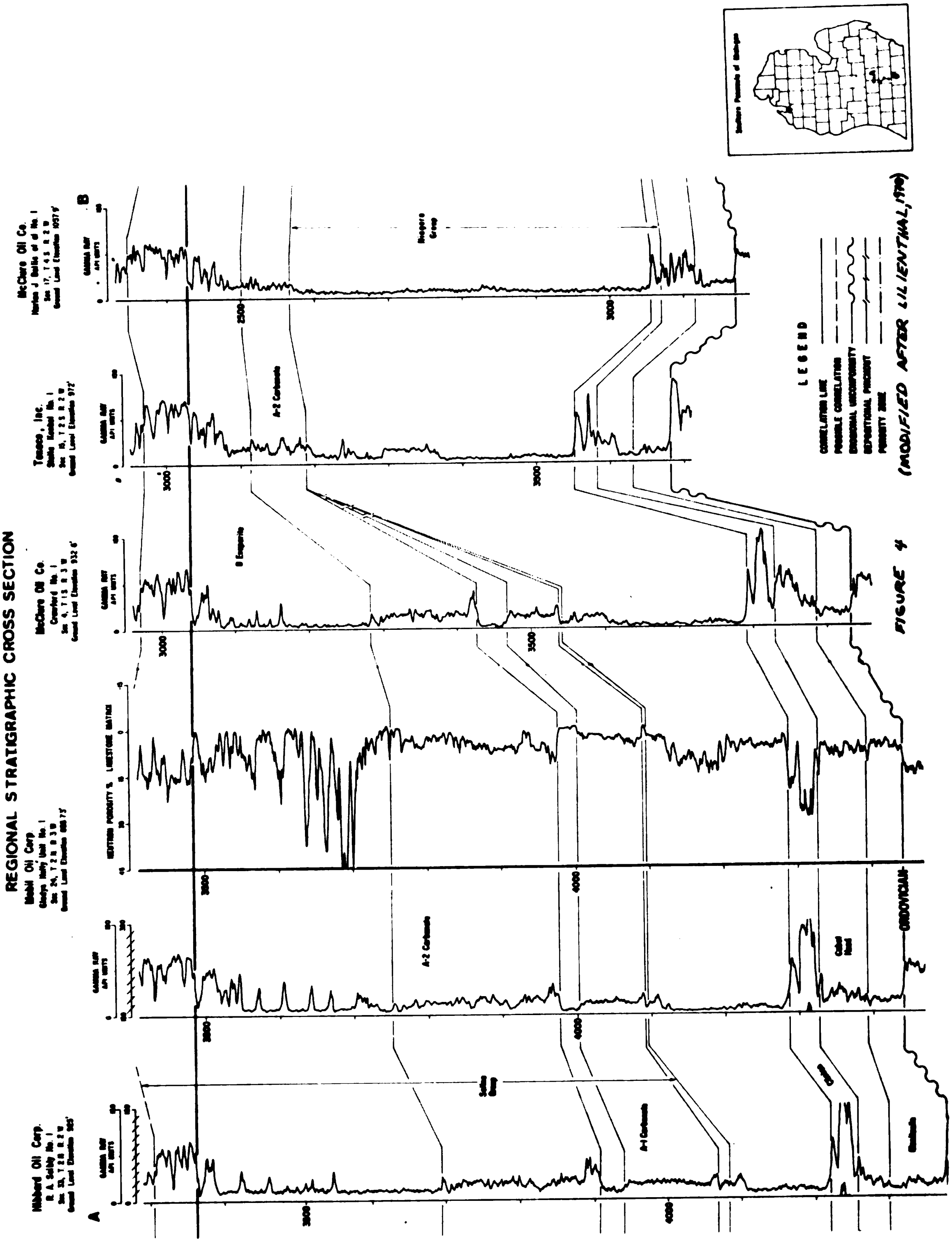


FIGURE 4

(MODIFIED AFTER LILIENTHAL, 1978)

circulation do not occur. Cores are useful in a general standpoint for this study; however, core descriptions were much more available than the cores themselves. In general, systematic core coverage was not available for this study.

A north-to-south stratigraphic cross-section was constructed using Compensated Neutron Formation Density logs. The cross-section gives a detailed type log for each of the environmentally important areas of the study. They include: deep basinal, pinnacle reef, interreef, and barrier reef. The cross-section illustrates the proposed model for the growth sequence of the Niagara pinnacle reefs and the surrounding Lower Salina units of south-central Michigan. The cross-section shows the value that the geophysical logs have for research and petroleum exploration.

Previous Work

The Silurian strata of Michigan have been intensely studied over the years. The first definition of Silurian subsurface stratigraphy in the Michigan Basin was by Landes (1945). He divided the Salina into eight units (A-H) and included a regional study of these units. Evans (1950) further subdivided the A unit into four separate units which we presently use in the Michigan Basin. Works by Cummings and Shrock (1928) and Lowenstam (1950) provided early, detailed faunal descriptions of Niagara reefs which created the base for further studies. Further contributions to the general understanding of the regional stratigraphy and paleogeography of the Middle and Upper Silurian were published by Cohee (1948), Alling and Briggs (1961), Melhorn (1958), Ehlers and Kesling (1962), Pounder (1962), Ells (1967, 1969), Burgess and Benson (1969), Huh (1973, 1977), Briggs and Briggs (1974), Shaver (1974), Mesolella et. al. (1974, 1975), Meloy (1974), Mantek (1973), Gill (1975, 1977), Potter (1975), Nurmi (1975), Sears et. al. (1979), and Autra (1977). Stratigraphic relations of carbonate rocks of Niagara reefs and of the strata of the lower Salina Group in southern Michigan were studied by Felber

(1964), Sharma (1961, 1966), Jodry (1969), Ells (1960, 1962, 1969), Gill (1973, 1977), Johnson (1971), Kiddoo (1962), and Fincham (1975). Controversial studies include those by Gill (1973); a detailed study of the Belle River Mils pinnacle reef in southeastern Michigan, and by Huh (1973), who provided an in-depth study of the northern Michigan pinnacle reefs.

Three basic models have been proposed, called Models I, II, and III to try to explain the growth sequence of the Michigan pinnacle reefs. Models I and III are presently the most popular models among geologists today. Good explanations and comparisons of the three models are illustrated in work done by Fincham (1975) and Mesolella et. al. (1974).

Model I proposes that the major growth of the pinnacle reefs occurred during the Niagara and that the alternating carbonates and evaporites occurred after the pinnacle reefs had grown to almost full height. This model proposes that reef growth had stopped during the deposition of evaporites. In-depth studies by Gill (1973) and Huh (1973, 1977) generally support this model. Model I depicts the pinnacle reefs as having been fully developed to a height of several hundred feet during Niagara time. The presence of *Pentamerus* sp. (Wenlockian or older) a well as Ludlow age fossils within the pinnacle reefs is consistent with this model.

Model II proposes that the pinnacle reefs are simply lateral facies changes within the cyclic Lower Salina interreef sequence. Therefore, the carbonates of the pinnacle reef are facies changes of cyclic evaporites and carbonate. This means that while marine organisms were forming the framework pinnacle reefs, extensive halite deposition was taking place in the deeper interreef areas. While Model I depicts hundreds of feet of depositional topography, Model II proposes minimal depositional topography.

Based on earlier work by Jodry (1969) in St. Clair County, Mesolella et. al (1974) proposed a third model (Model III) for the depositional sequence of the

Niagara pinnacle reefs. Model III has been favored in the regional studies performed by Fincham (1975) and Autra (1977). Model III supports the idea that a separate growth stage of the pinnacle reefs occurred during A-1 Carbonate time. Mesolella attributed from 10' to 150' of the pinnacle reefs to A-1 Carbonate sedimentation. An actual rejuvenation of the pinnacle reefs must occur for this model to be accepted. The paleontological evidence mentioned by Mesolella includes the presence of Niagara-Salina brachiopods *(Howellella smith waite)* in the upper algal zone and above that, the later Salina brachiopods *(Howellella corallinensis grabau)*. It is important to understand that these fossils are only in the top portions of the pinnacle reefs and that the exact age relationship has not been determined. The presence of A-1 Carbonate age organisms on the reef crest is not enough evidence to support the idea that a full rejuvenation of the pinnacle reefs occurred. The pinnacle reefs are simply overlain by younger sediments that have been affected by the original pinnacle reefs. Evidence required for the support of model III should include unconformities in the pinnacle reefs associated with A-1 evaporite time.

As shown by this study and the work of Huh et. al. (1977), definite A-1 Carbonate sediments do overlie the pinnacle reefs. But they are primarily tidal flat sediments, and probably not a major organic pinnacle regrowth sequence. The primary growth sequence did occur during the Niagara.

It is highly likely, however, that depending on the local rate of subsidence and local environmental conditions that variations in the pinnacle reef growth sequence do occur. This is demonstrated by the work of Gill (1973) on the Belle River Mils pinnacle reef in Southeastern Michigan. He found thaat there was no A-1 Carbonate on the reef crest and that debris from the reef crest occurred below the A-1 Evaporite on the reef flanks. This proved, in this case, that this pinnacle reef was entirely Niagara in age. Gill also showed that the A-1

Evaporite flanked the lower areas of the pinnacle reef which possibly suggests that exposure of the pinnacle reef during A-1 evaporite time. Mesolella et. al. (1974) allows the lower portions of the pinnacles to be surrounded by A-1 Evaporite in Model III. Huh (1973) found a similar situation as Gill (1973) in the northern pinnacle reefs, but also found that a thin tidal flat section of A-1 Carbonate covered the reef crests.

The evaporite facies relationship of the A-1 and A-2 Evaporites have important effects on the growth and production capabilities of the pinnacle reef belt. Fisher (1973) and Mantek (1973) have described the reef trend and its relationship to the salt zero line of both of these evaporites. In certain areas in the Michigan Basin, this contact determines the type of production and possibility of production.

Many reefs found in North America have a direct application to the Niagara pinnacle reefs of south-central Michigan. Fuller and Porter (1969) and Klingspor (1969) have described a Devonian reef and evaporite sequence in the Williston Basin which is very similar to that of the Michigan Basin. The Michigan Basin reefs have been compared to those in the Illinois Basin where the reefs are believed to be of later Silurian age. Major works on evaporite and carbonate sequences include those by Dellwig and Evans (1969), Goldsmith (1969), Scruton (1953), Kinsman (1969), Raup (1970), King (1947), Schmaltz (1969), and Fisher (ed., 1977).

Studies of the Silurian salt sequence of the Michigan Basin by Dellwig and Evans (1969) and Schmaltz (1969) imply a deep water origin of the evaporites. Salt precipitation is thought to occur when the brine concentration becomes supersaturated with respect to a particular salt. Sloss (1969) and Raup (1970) propose the existence of layered solutions where, if the hypersaline brine underlying a less saline brine becomes suddenly exposed to subaerial evaporation, massive halite deposition can occur. A mechanism for this exposure could involve high winds pushing less saline brines from the dense hypersaline brines underneath. Raup (1970) has shown that the mixing of a bottom layer 94% $MgCl_2$ solution and a top layer of 94% NaCl solution will create rapid salt precipitation.

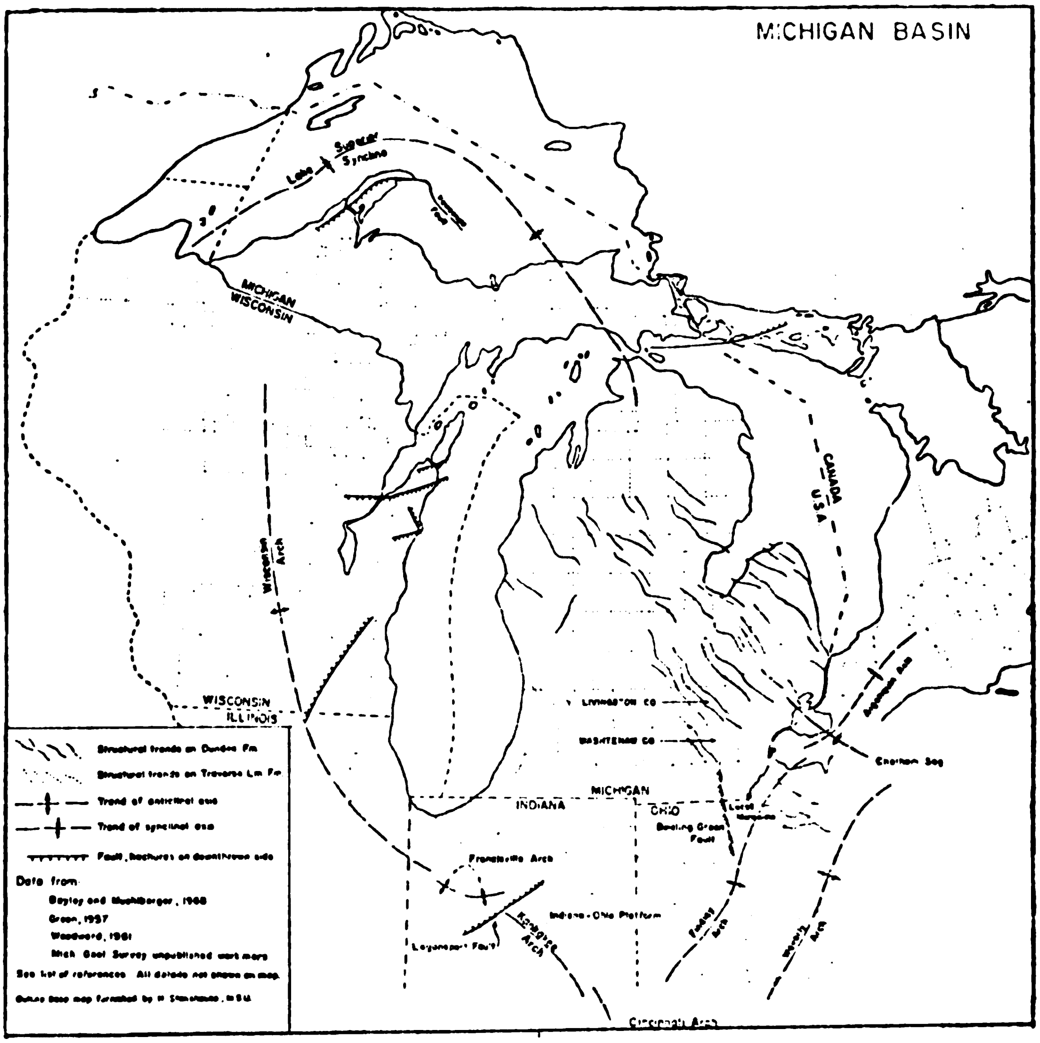
Shallow water deposition of evaporites has often been the most popular model. Simple evaporation concentrates brines in shallow areas with the resulting deposition of evaporites. This has become the most popular model because at the present time no one has identified a locality where large scale deep water precipitation of salts is occurring today. The modern environments of gypsum, anhydrite and halite deposition is in the supra-tidal and "sabkha" environments such as those found in the Persian Gulf (Kinsman, 1969; Shearman, 1971). The shallow water limit for the deposition of evaporites is believed to be in water depths of less than 50 feet. It has been argued that the present day areas of evaporite deposition are very small in comparison to the Michigan Basin and other basins where masive evaporites have been deposited. Nurmi (1974) advocates a sabkha-like environment for the Michigan Basin based on the sedimentary features observed in the Goderich Salt Mine of Ontario, Canada. The sedimentary features observed include ripple marks and many minor unconformities. An important fact is that the mine is located on the basin margin. This does not rule out the possibility of deep water deposition of evaporites in the central basin area. It is possible in a hypersaline basin to have sabkha-like deposition of evaporites on the basin margin along with deep water deposition of evaporites in the deeper central basin area. Important controls of this process are the confinement of the basin and the degree of salinity that is reached. A model is needed to explain thick evaporites in the basin center with contemporary thin evaporites on the basin rim. In the Michigan Basin, the control of evaporite deposition appears to include the rate of subsidence of the basin along with the continuous input of sea water into the basin. High temperatures and high aridity are generally believed to have controlled the deposition of evaporites, whether they are of shallow water or deep water origin.

REGIONAL STRUCTURAL SETTING

The area of study, south-central Michigan, is located in the geologic structure known as the Michigan Basin. The Michigan Basin is defined as an intracratonic or autogeosynclinal basin. The Michigan Basin is centered on the Lower Peninsula of Michigan and includes portions of adjoining states (Fig. 5). The area of the Basin is 122,000 square miles (316,000 square kilometers). The Michigan Basin is surrounded by important positive structures which have influenced its sedimentational history. The basin is bounded on the north and east by the Canadian shield; on the south by the Findlay and Kankakee Arches; and on the west by the Wisconsin Arch and the Wisconsin Dome. During Niagaran and Lower Cayugan time these structures were inactive and of very low relief.

The Michigan Basin includes a number of fault patterns, joint systems and subordinate structures of interest. A strong northwest to southeast trend of these structures suggests a dominant structural control on their origin. In southern Michigan the trends change from a clear north-south trend to a northwest to southeast trend. This could suggest a mechanism of basin faulting related to subsidence of the basin interior. This pattern includes such areas as the Albion-Scipio trend and the Howell-Northville Anticline which are present in southern Michigan. Early researchers believed that the Precambrian basement controlled these structural patterns (Pirtle, 1932). Cohee and Landes (1958) proposed that these structures came from minor folding throughout the Paleozoic with the major diastrophism occurring in the Late Mississippian.

Shaw (1975) believed that Mid-Ordovician faulting had controlled the orientation and geometries of the Niagara reefs. He proposed that local tectonic activity as expressed by the Mid-Ordovician faults controlled the petroleum productivity, the lithologic constituents and the pinnacle reef height by differential subsidence. His conclusions held only for the pinnacle reefs and with



MICHIGAN BASIN AND SURROUNDING STRUCTURAL ELEMENTS

FIGURE 5 (AFTER ELLS 1969)

no reference to the barrier reef. The difference between the northern pinnacle reefs and the southern pinnacle reefs can be due to subregional structural influences (Shaw, 1975).

Newcombe (1933) and Ells (1966) state that southeastern Michigan has been deformed structurally to a greater extent than the rest of Michigan. The Howell Anticline in southeastern Michigan (Newcombe, 1933) and the Washtenaw Anticlinorium, also in southeastern Michigan (Ells, 1966), consist of folds and faults of high amplitude. These folds and faults are said to be of Silurian origin. The Chatham Sag is also believed to have been active at the end of the Silurian.

This Silurian tectonism which was more active in northern Michigan could have created variations in water depth which could, therefore, explain the differences between the northern and southern pinnacle reefs and provide an answer for the cyclical nature of the carbonates and evaporites. It is important to note that both the northern and southern areas have the same cyclical nature of carbonate and evaporites deposition. Differential subsidence of each specific reef tract could control the effective elevations of the pinnacle reefs and thereby control the relationship of the lithologic units with respect to the pinnacle reefs. However, the controls are probably environmental; such as, rate of water influx or local energy conditions. Thus, according to Mesolella et. al. (1974), the A-1 Carbonate would be deposited in the north to a greater extent over the pinnacle reefs as compared to the deposition only around the pinnacle reef edges in the southeastern Michigan area.

Cohee and Landes (1958) proposed that the basin underwent its greatest subsidence during the deposition of the Salina and Bass Islands units (Late Silurian) and during Detroit River time (Middle Devonian). This is evidenced by the great thicknesses of the units. However, because these units are mostly evaporites, the possibility exists that very rapid deposition took place in an already existing deep basin. Evidence for the rapid subsidence theory includes the existence of a pseudohinge line along the northern pinnacle reef trend and of the thinning of the Salina F Salt along the Howell Anticline in southern Michigan (Paris, 1977).

The massive growth of the barrier reefs during Niagara time helped to isolate the Michigan Basin from the surrounding seas. However, several major channels were maintained between the basin and the open sea. In the area of study, the existence of a major reentrant in the barrier reef is proposed. In the southeast, the Chatham Sag and the Midland Trough helped maintain circulation to the Appalachian Basin area. In the southwest, the Battle Creek Trough was a major link to the Illinois Basin (Melhorn, 1958). A major inlet termed the "Artic Seaway" by Briggs (1958) entered through the Georgian Bay area of Ontario, Canada. According to Fisher (1973), another major northern inlet is the Grand Traverse Bay area of Michigan.

GENERAL STRATIGRAPHY AND SEDIMENTATION

The stratigraphic succession in the Michigan Basin includes sedimentary units ranging in age from probable Precambrian sediments through Pleistocene glacial deposits. No Permian, Triassic or Cretaceous sediments are represented in the Michigan Basin. Of the total sedimentary thickness, fully 31% is of Silurian age (Ells, 1969) and one-third of these are evaporites.

Niagaran rocks (Middle Silurian) are exposed in the southern part of the Upper Peninsula of Michigan, in southwestern Ontario, northwestern Ohio, northern Indiana, northeastern Illinois and eastern Wisconsin. Niagaran strata are within 550 feet (165 meters) of the ground surface in the southeastern and southwestern parts of Michigan. In northern Michigan, depth to Niagaran rocks ranges from 3800 feet to more than 7000 feet (Huh et. al., 1977). In south-central Michigan, the depth to Niagaran rocks ranges from 1500 feet to 3700 feet.

The Niagara Group is composed of the Burnt Bluff, Manistique, Lockport, and Guelph formations (the Guelph is considered to be a reef facies of the Lockport). These formations are equivalent to the "Clinton", "White Niagara", "Gray Niagara", and "Brown Niagara" in the informal terminology of the oil industry. For convenience in this study, the "White", "Gray", and "Brown Niagara" are lumped under the term "Niagara." The "Brown" Niagara is equivalent to the Geulph formation. The Geulph formation is composed of the organic skeletal wackestones of the biohermal stage and boundstone of the organic reef stage of the pinnacle reefs. The barrier reef platform bank (Meloy, 1974) is composed of stromatoporoids, coarse-to medium-grained dolomite and arenitic wackestone. The Manistique formation is equivalent to the "Clinton" which consists of about 20 feet of light colored dolomitic carbonates and shales. According to Autra (1977), the Clinton thickens to about 400 feet of clean, cherty dolomite in northern Michigan. The whitish-gray to brownish-gray lower Lockport (White Niagara grades into gray in the Upper Lockport - Gray Niagara). Toward the basin center, the Lockport becomes a hematitic red. Toward the basin margin, the Lockport is more than 300 feet thick in the barrier reef carbonate bank.

The pinnacle reefs are located along a shelf area on the basinward side of the barrier reef. In south-central Michigan, the pinnacle reefs can attain thicknesses of up to 500+ feet.

The Niagara is represented primarily by dolomite in the pinnacle and barrier reef trend and limestone in the more basinward facies. However, some basinward pinnacle reefs are composed of limestone.

The Salina Group overlies the Niagara Group. At the crests of the pinnacle reefs, supra-tidal, island algal stromatolites of the lowermost carbonate unit of the Salina Group is represented (Huh et. al., 1977). In the basinal and interreef areas the Salina Group consists of cyclical evaporites, limestones, and dolomites divided into A-1 Evaporite, A-1 Carbonate (Ruff formation), A-2 Evaporite, A-2 Carbonate, B-Unit evaporite, C-Shale, D-Salt, E-Unit (Marl and Dolomite), F-Salt and G-Unit (Landes, 1945; Evans, 1950; Ells, 1967; Budros and Briggs, 1977). This study is only concerned with the Lower Salina, B-Unit evaporite through A-1 Evaporite.

During the Lower Salina, alternating carbonates and evaporites were deposited with mainly anhydrite and dolomite being found in shelf and pinnacle trend areas and limestone and salt in the central basin areas. The thick barrier reef bank growth during the Niagara set the stage for deposition of the alternating evaporites and carbonates. The restriction and isolation of the basin from surrounding seas is greatest at the end of the Niagara (Dellwig, 1955). Barrier reef growth was important in restricting the basin to the point where thick cyclic evaporites could be deposited.

A general thickening trend of the B-Unit Evaporite, A-2 Evaporite, and the A-1 Evaporite toward the basin center and thinning toward the basin margins are observed. The A-1 Carbonate, A-2 Carbonate, and the Niagara show the opposite trend, thickening toward the basin margin and thinning toward the basin center. The cause for this is believed due to the intense biologic control of the carbonate units.

According to Autra (1977) the total thickness of the units involved in this study (B-Unit through Clinton) varies from less than 600 feet along the basin margins to over 1500 feet in the depocenter of the basin. The thicker basinward sediments include almost 1200 feet of evaporites which are mainly salt. The depocenter for the Upper Silurian is in the Saginaw Bay area of the Lower Peninsula of Michigan.

There are three basic models that try to explain the sequence of sedimentation of the Niagara and Lower Salina Section. Model I makes use of a relatively shallow basin that develops major reef growth along its margins which then becomes rapidly isolated followed by rapid subsidence in the basin interior. During this subsidence, thick evaporites accumulate and fill in the basin.

Model II proposes an existing deep central basin and sea with shallow margins. As the barrier reef belt grows, the isolation of the basin becomes greater, thereby accumulating heavier brines in the central basin. With an arid climate, these hypersaline brines precipitate the evaporites. Deep water origin of evaporites is critical for this model. The evaporites are proposed to be simply lateral facies changes of the carbonates that make up the barrier and pinnacle reefs.

Model III also makes use of a pre-existing deep water basin, with restriction by reefing on the shallow basin margins along with an arid climate at the beginning of the Salina. Importantly, Model III proposes a "sabkha" and desication model for the basin rim evaporites and a deep water origin for the central basin evaporites. It can be seen that all three models have merits and demerits. Models I and III could possibly occur in different environmental sections of the Michigan Basin. An overall important control appears to be the rate of subsidence of the particular area.

For anyone not familiar with the units discussed in this section, it is suggested that a study of the north-south stratigraphic cross-section would be helpful. A standard geophysical log for each environmental section of the Niagara is represented on the cross-section.

DESCRIPTION AND DISCUSSION OF MAPS

Clinton Structure Map

The Clinton structure map (Plate 1) was constructed on a 100 foot contour interval. The Clinton is the lowermost unit mapped. Availability of data was generally good; however, many of the wells drilled into the pinnacle reefs did not test the entire Niagara reef section.

A good understanding of some of the features plotted on the Clinton structure map is important. Standard well symbols were plotted with respect to production from the Niagara pinnacle reefs. The stippled line across the map represents the limit of the Niagara barrier reef as defined by Fisher (1973) and Autra (1977). This barrier reef definition states that the barrier reef begins on or near the 300 foot isopach contour of the Niagara.

The south-central basin outline of the Michigan Basin is well exhibited on the Clinton structure map. The elevation of the central basin area in the area of study is 4300 feet below sea level while the elevation of the basin margin area reaches 1500 feet below sea level. The slope of the basin margin area, which is located along the bottom of the map, averages 46 feet per mile. The slope of the central basin area, which is located near the top of the area of study, averages 66 feet per mile. The overall average slope of the basin in the area of study is 55 feet per mile. The increase in slope moving further into the basin exhibits the greater degree of subsidence in the central basin area. The slope change exhibited on the Clinton structure map is good evidence of differential basin subsidence, but not necessarily during Clinton time.

In the region mapped, the area from R1W to R1E exhibits a fairly consistent basin hinge line oriented north 60° west. However, from R2E to R4E a radical change in the contours occurs. A structure known as the Lucas Monroe monocline is the source of this change. The structure appears to be made up of several left lateral strike slip faults. According to Shaw (1975) the origin of this structure is related to Middle Ordovician faulting which has resulted in the differential subsidence of the overlying beds. The positive and negative areas located in T4N-R4E are likely offset continuations of the Lucas Monroe monocline. It can be postulated that a dip-slip relief fault trending parallel to the Lucas Monroe monocline exists in this area.

Of major importance is the fact that the pinnacle reef belt and the barrier reef presently transect structure. If major subsidence had occurred during the deposition of the barrier reef, the barrier reef outline would follow closer with the structural outline of the present basin. It is well known that a continuous barrier reef grows in a stable depth of water. However, an important trend does exist in the barrier reef belt in T2N-R2E where the barrier reef noses out parallel to the Lucas Monroe monocline. Due to the lower structure surrounding this nose, we can postulate that a slight differential subsidence was occurring during Niagara (Cayugan). If subsidence was occurring during Niagara time, as evidenced by the Clinton structure map, there then could exist a slight age differential along the pinnacle reef belt. The pinnacle reefs higher on structure could be slightly older in age than those lower on structure. This is due to the idea that if the pinnacle reefs are close to the same height, both high and low on structure, the lower on structure pinnacles would have environmentally (deeper water depth) ceased to grow earlier than the structurally higher pinnacles.

Some slight widening of the structure contours does occur along the central area pinnacle reefs. This widening could be the remains of a former stable shelf area meaning that the pinnacle reefs were located on a somewhat broader shelf area as compared to the rest of the basin.

In the center of the area of study, the major pulling back of the barrier reef outline, with respect to the expected trend, appears to parallel structure. The water movement of the postulated reentrant has moved across structure. This gives further evidence for the existence of some structural control during the Clinton and Niagara.

The comparison of the northern pinnacle reef belt to the south-central pinnacle reef belt, with respect to Clinton structure, shows that the northern reef belt lies 2000 to 3000 feet deeper than the south-central reef belt. This difference exhibits the differential basin subsidence that has occurred within the Michigan Baisn. According to Fisher (1977) and Autra (1977) the highest degree of subsidence occurred during the Silurian and Devonian periods.

Clinton Isopach Map

The Clinton isopach map was constructed on a ten foot contour interval. The Clinton is the oldest unit mapped in this study. The Clinton is a shale and carbonate unit that lies directly below the Niagara carbonate reef. The reason for the isopach mapping of the Clinton was to determine whether the Clinton exerted any control on the location and type of production of the Niagara pinnacle reefs.

According to core descriptions, the Clinton, as represented in the area of study, is composed of a thin gray shale and finely crystalline, hematite stained dolomite sequence. According to Autra (1977), the Clinton thickens to over 400 feet in the area of the northern Michigan pinnacle reefs and its lithology changes to a massive cherty dolomite and limestone.

The Clinton, as contoured in the area of study, shows a slight thickening from 20 to 40 feet in thickness toward the central basin area. Along the entire shelf area which includes the pinnacle and barrier reefs, the Clinton appears to have very little meaningful control. No apparent structural control other than a slight thickening basinward occurs during Clinton time. Therefore, it appears that the Clinton exerted no control on the location or production of the pinnacle reefs. In the area of study, Clinton time was a period of stability.

Niagara Isopach Map

The Niagara Isopach Map (Plate 3) was constructed on a 50 foot contour interval. Even with the detailed map that has been constructed, it was impossible to contour each individual pinnacle reef. The Niagara was contoured ignoring the pinnacle reefs; however, each producing pinnacle reef was indicated by standard production symbol employed by the petroleum industry. Where a well penetrated the complete pinnacle reef, the actual thickness of the reef was shown on the map. It can be observed from the map that the pinnacle reef belt occurs between the 150 foot contour and the 300 foot contour interval. The 300 foot contour (stippled line) is defined as the outer limit of the barrier reef (Fisher, 1973).

The Niagara is an intensely biologically controlled sedimentary unit. As can be readily observed on the map, the greatest thickness occurs on the basin margin along with a thinning toward the basin center. The Niagara consists of four basic sedimentologic phases or stages: barrier, interreef, pinnacle and basinal. The barrier reef phase grew in a high energy shallow water environment of the basin margin. With continued consistent subsidence, the barrier reef in south-central Michigan grew to a thickness of over 500 feet. The thickness of the barrier reef is not constant over the area of study. The interreef phase and pinnacle reef phases occur basinward from the barrier reef. The pinnacle reefs are reefs which have grown in a more unstable or more rapidly subsiding area than that of the barrier reef. The pinnacle reefs are steep biohermal growths of carbonate sediments. The interreef sediments are carbonates composed primarily of reef rubble and fine dense unfossiliferous sediments. The fourth phase consists of the basinal Niagara carbonates which are a thin basinal, deeper water facies which covers the central basin area. By studying the north-south stratigraphic section, an example of the relationships between the various units in each separate Niagara phase can be observed.

According to Huh (1973), the massive barrier reef consists of coarse skeletal carbonate, abundant stromatoperoids, corals, and algal units. These units make up most of the massive reef core. Carbonate sands and skeletal allochems have been deposited within and on the slopes of the massive reef. The barrier reef consists of biostromal deposits which are overlain by biohermal deposits. This is compared to the pinnacle reefs which consist primarily of biohermal deposits in their lower sections. Framework organisms common in the barrier reef include Favosites, Halysites and Coenites.

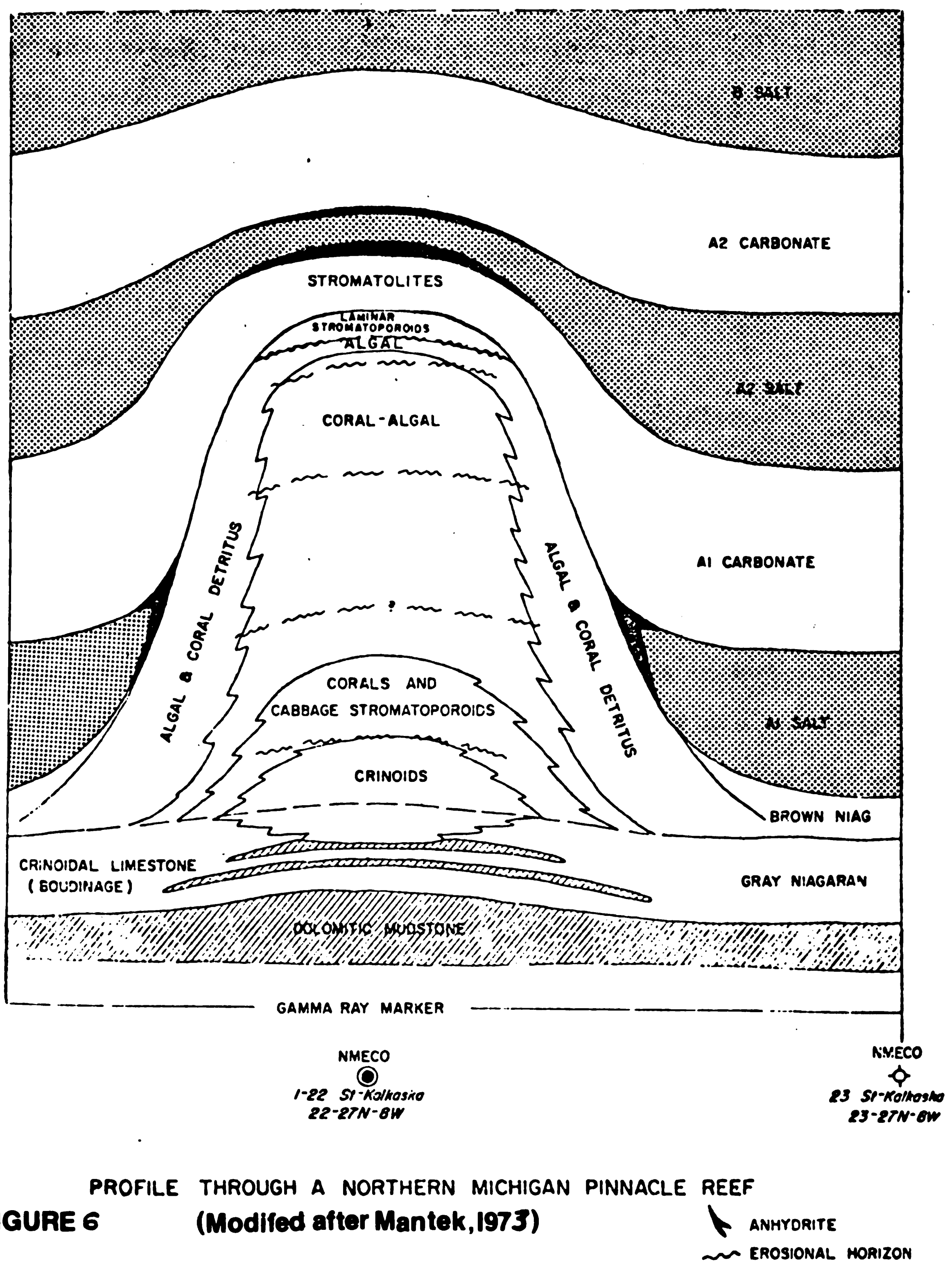
In the southern trend, the barrier reef attains widths of 50 miles (Fisher, 1973). The barrier reef along the southern trend attains, in some places, a thickness of 610 feet. In the area of study, the well control into the barrier reef is quite good due to the many oil fields (i.e., Albion Scipio) of Trenton age, which underlies the Niagara. The barrier reef has proved unproductive so far in southern Michigan.

Mesolella et. al. (1974), Autra (1977) and most other researchers believe that the barrier reef is essentially all Niagara. The Salina A-1 Carbonate is thought by most Michigan geologists to pinch out along the barrier reef slopes and between the interreef passes. Fincham (1975) produced evidence that suggests that erosional unconformities occurred during A-1 Evaporite time on the barrier reef and some of the pinnacle reefs.

The barrier reef in most areas of the Michigan Basin exhibits a steep basinward slope and a gentle backward margin slope. In the center of the area of study a distinct widening of the isopach contours occurs indicating a more gentle slope of the barrier reef. Reef debris is likely to have been funneled basinward by several submarine channels in the barrier reef in this area. The observation of the barrier reef outline in the area of study shows that a major reentrant did exist.

The reentrant in the barrier reef amounts to more than ten miles from the expected barrier reef front. A lack of pinnacle reefs in this zone is further evidence for an area of rapid deposition and turbid waters unfavorable to reef growth. A submarine fan deposit of reef debris may account for this extension of the barrier reef into the basin. Earlier in the discussion, it was mentioned that some structural control occurred along the Lucas Monroe monocline. It is suggested that structural control combined with environmental factors controls the barrier reef trend.

Pinnacle reefs are found between the 150 foot and 300 foot contour interval of the Niagara isopach map. Throughout the area of study, this trend carefully follows the barrier reef outline. Major breaks in the pinnacle reef belt are believed to be controlled by submarine fans and local tectonic stability. The pinnacle reef belt in northern Michigan, in comparison, is within the 200 to 300 foot contour interval, while the pinnacle reefs of the Allegan and St. Clair platforms are generally toward the basin margin from the 140 foot contour (Autra, 1977). The pinnacle reefs are located on the perimeter of the A-1 and A-2 and B-Salt basins, but are still located within the A-1 and A-2 and B-Anhydrite zones. Comparably the northern pinnacle reefs are located within the A-1, A-2 and B-Salt basins (Autra, 1977). As evidenced by the above data, the rate of subsidence within various segments of the basin are of extreme importance with respect to the determination of the depositional environment. Overall, in the area of study, differential subsidence was active in the Middle Niagara. This is based on the assumption that both the barrier and pinnacle reefs are close to the same age. Pinnacle reef growth varies from 300 to 500+ feet in northern Michigan (Figure 6). While pinnacle reefs in the area of study also vary from 300 to 500 feet they are, on the average, not as tall as their northern counter parts. Dips of the steep sides of the pinnacle reefs range between 20° to 40° on the



PROFILE THROUGH A NORTHERN MICHIGAN PINNACLE REEF

FIGURE 6 **(Modified after Mantek, 1973)**

upper flanks (Mantek, 1973; Huh, 1973; Mesolella et. al., 1974; Huh et. al., 1977). The areal extent of the pinnacle reefs ranges from $\frac{1}{4}$ to $\frac{1}{2}$ mile in width and from $\frac{1}{2}$ to $1\frac{1}{2}$ miles in length in northern Michigan. In south-central Michigan, the pinnacle reefs are up to three miles long and one mile wide (Huh et. al., 1977). This increase in size likely means that the area under study was slightly more stable than the northern Michigan pinnacle reef trend and allowed the reefs to broaden.

Four major growth stages characterize most pinnacle reefs. They are in sequence: biohermal, organic reef, supratidal island and tidal flat (Huh et. al., 1977; Huh, 1974; Gill, 1973; and Mantek, 1973).

Initially, a pinnacle reef forms the bioherm. It is composed of skeletal biomicrite, biohermal core, and skeletal-lithoclast facies. Crinoids and bryozoa are especially dominant in the skeletal biomicrite and are believed to be mud dwelling organisms (Huh et. al., 1977). This detail correlates with the fact that the Niagara reef growth overlies the Clinton shale. During the skeletal biomicrite stage, a deeper initial water depth can be considered. Framework building corals and tabular stromatoporoids invaded the biohermal core facies which overlie the skeletal biomicrite. Coarse skeletal fragments and lithoclast allochems, which are termed the skeletal lithoclast facies, developed along the top segments and flanks of the biohermal mounds.

Organic reef stage rocks overlie the biohermal stage rocks. The three primary lithofacies include the reef core, reef dwellers and the reef detritus. Changes are recognized by dominance of specific organisms. Labechiella stromatoporoids are typical of early organic reef deposition. Tabulate corals and the reef dwellers assemblage are important during the middle part of the depositional sequence. Algal boundstone along with massive stromatoporoids are predominant during the last stage of deposition. These three stages exhibit a general shallowing upward sequence.

Vadose deposits do occur within 20 feet of the organic-reef section in some pinnacle reefs. The Belle River Mills reef in southeastern Michigan (Gill, 1972, 1973) and some northern Michigan pinnacle reefs exhibit indications of vadose karstic processes such as fibrous calcite linings, pisoliths, caliche and internal sediment in solution leached vugs.

The organic reef stage and the bioherm stage composes the Guelph formation of the Niagara Group. The succeeding supra-tidal island stage could mark the initial deposition of the Salina Group, and the tidal flat stage is represented by the A-1 Carbonate of the Salina Group. The reef rubble conglomerates are deposits from the organic reef of the Guelph formation and from the suptra-tidal, island algal stromatolite of the Lower Salina (continuous sequence). The supra-tidal, island stage unconformably overlies rocks of the organic reef stage. A few diastemic contacts occur in the lower part of the supra-tidal, island section. Persistent stratification of five lithofacies occur in the supra-tidal, island rocks. They are: algal stromatolites, algal detritus wackestone, lagoonal mudstone, finely laminated algal stromatolite and flat pebble conglomerate (Huh et. al., 1977). These five units in sequence indicate a rapid shallowing upward sequence up to the point of arid dessication. Evaporitive drawdown lowered sea level to below the bases of the pinnacle reefs after the accumulation of the supra-tidal, island stromatolites and before deposition of the A-1 Evaporites of the Salina Group.

An interesting side light, which is not covered in this study, is the dolomitization of the Niagara reefs. According to Mantek (1973), Autra (1977) and Fisher (1973), the massive barrier reef is completely dolomitized as well as the pinnacle reefs close to it. This is easily verified by observing the cross-section constructed for this study where the geophysical logs exhibit the standard dolomite response. Some pinnacle reefs and the Lower Salina carbonates basinward of those same

pinnacles are composed of limestones. Both the mixed layer, Dorag Model and the Reflux dolomitization models could account for this dolomitization sequence. It remains to be seen which model of dolomitization actually fits these sediments. The high magnesium to calcium ratios of the brines along with the supra-tidal environments suggest that the Reflux model would be more likely.

Determining the water depth both in the basin center and along the basin rim during Niagara time is quite a controversial problem. Nurmi (1974) and Gill (1973) mentioned water depths of 400 feet or greater along the basin margins. Four-hundred plus feet of Niagara pinnacle reef growth indicates water depths of that order if the pinnacles grew in one stage (Niagara). It is likely that the basin center reached water depths of over 600 feet. Therefore, during A-1 Evaporite time, the pinnacle reefs must have stood several hundred feet above the surrounding interreef carbonates. This would still be the case even if shallow water evaporite deposition along the basin margins and deep water (greater than 50 feet depth) evaporite deposition in the central basin occurred. The thinning of the Niagara basinal facies suggests deeper water depths toward the central basin because of less organic activity. A starved basin could also explain this basinward thinning.

The basin environment during Niagara time consisted of debris of carbonate mudstone washed from the reefs and platform skeletal arenites of the shelf interreef zone which grades into fine argillaceous carbonate mudstone toward the basin center (Huh et. al., 1977). This mudstone is believed to be characteristic of deep water deposition. A general red hematitic staining does occur in the more basinward facies of this thin limestone. Mesolella et. al. (1974) suggests that due to a lack of organics during deposition, the iron was never reduced. The interreef carbonates are very similar to the basinal carbonates. In the area of study, the basinal carbonates thin to as little as 90 feet. In the central basinal area the basinal carbonates do attain thicknesses of 234 feet, but only in a small depocenter north of Saginaw Bay (Autra, 1977). This would indicate that subsidence was occurring in that small depocenter in the central basin area. Over most of the central basin, the Niagara averages 40 to 60 feet in thickness.

In summary, during Niagara deposition, the Michigan Basin did exhibit widespread stability of the marine environments. This stability resulted in the growth of the massive barrier reef. This barrier complex effectively controlled the deposition of the Salina A units.

Salina A-1 Evaporite Isopach and Lithofacies Maps

The A-1 Evaporite isopach map was constructed on a ten foot contour interval. The A-1 Evaporite lithofacies map was constructed by dividing the evaporite facies into three separate lithofacies: primarily anhydrite, salt and anhydrite in combination, and primarily salt. Some dolomite occurs in these facies units. The lithofacies unit was determined by the specific responses exhibited by each lithofacies on the geophysical logs. This was then cross checked with the available drillers logs and core descriptions. One problem that was encountered was the distinguishing of A-1 Evaporite from the "Rabbit Ears" anhydrite. "Rabbit Ears" anhydrite derives its name from the rabbit ear like response on the gamma ray logs. It occurs only in areas proximal to the pinnacle reefs. The "Rabbit Ears" anhydrite is actually part of the A-1 Carbonate and will be discussed in that section.

The A-1 Evaporite isopach map of south-central Michigan shows a unit that thickens rapidly basinward from the pinnacle reefs. The maximum thickness in the area of study is 170 feet. Autra (1977) showed that the maximum central basin thickness is 450 feet. This central basin facies includes halite as the dominant mineral with minor amounts of anhydrite and dolomite. In the northern Michigan pinnacle reefs, the A-1 anhydrite consists of three major textural types: distorted nodular mosaic anhydrite, distorted laminated massive mosaic anhydrite and nodular anhydrite. The A-1 anhydrite deposited along the basin rim is basically nodular anhydrite mixed with brown dolomicrite. Nodular anhydrite is presently being deposited today along the Trucial Coast of the Persian Gulf. It is generally a well known penecontemporaneous diagenetic product of sabkha environments. All lithofacies changes of the A-1 Evaporite are considered to be contemporaneously deposited. Salt is the predominant basin facies while the interfingered anhydrite and salt, and pure anhydrite are considered to be a platform facies. Dellwig and Evans (1969) noted the existence of clear and cloudy halite layers with very thin layers of anhydrite and dolomite. They concluded that this sequence should occur in the shallow water basin margin. The occurrence of sylvite (KCl) mixed with halite (up to 100 feet) in the central parts of the basin indicates supersaline conditions (Hosler, 1966). Sylvite is a very soluble salt associated with brines of very high bromine levels. The sylvite salt section according to Anderson et. al (1973) moves up stratigraphically within the A-1 salt as it approaches the northern basin margin. This is from its normal middle of the section position. No sylvite salts are associated with the section in the south-central Michigan study area. The question of deep water versus shallow water origin of evaporites cannot be answered fully by this study. However, based on the available data it does seem that relatively deep water, hypersaline or supersaline deposition of very thick salt did occur. Studies of Mathews and Egleson (1973), Autra (1977), Schmalz (1969), Dellwig and Evans (1969) and Hosler (1966), do propose a deep water origin of evaporites in the central basin area. These same authors also believe that the basin margin anhydrite and salts have a shallow water origin. Nurmi (1973), Dellwig and Evans (1969), and Mathews (1970) have proven fairly well that sabkha-like environments did occur along the basin margins. Huh et. al. (1977) also observed features which prove a shallow water origin of the A-1 Evaporite along the northern Michigan pinnacle reef trend. These include nodular and enterolithic anhydrite, abundant algal mats and laminations, and evidence of leaching and erosion at the top of the anhydrite.

The A-1 Evaporite in the area of study does occur as an interreef anhydrite. Due to the problem of the stratigraphic closeness to the "Rabbit Ear Anhydrite" of the A-1 Carbonate, it is impossible to prove that the A-1 Evaporite does extend over the tops of the pinnacle reefs. Simply looking at the elevation differences involved, it can be seen that it is not probable that the A-1 Evaporite would cover the pinnacle reefs. There is no question, however, of the existence of a 20 foot or less thickness of A-1 Evaporite in the interreef areas. The zero line of the A-1 Evaporite isopach does define the areas where potential pinnacle reefs have yet to be found. The zero isopach follows a line approximately five to ten miles basinward of the barrier reef belt. Interestingly, a large wedge of anhydrite does occur in the central area where a major submarine fan has been identified by this study. This wedge of anhydrite is evidence for why the normal pinnacle reef belt has been breached. This is due to the concept that the anhydrite would mean that shallow water depth did exist in that area. By the relationship shown by the A-1 Anhydrite, it is clear that three separate groups of pinnacle reefs exist in south-central Michigan. Along the northern extension of the Lucas Monroe anticline, a distinct nosing and widening of the anhydrite lithofacies along with a thinning of the total unit occurs. This is direct evidence for the continued tectonic instability of the Lucas Monroe monocline.

The hinge line of the basin as exhibited by both the A-1 Evaporite lithofacies and isopach maps is oriented north 90^{o} west. This is much different than the original north 60^{o} west shown by the Clinton structure map. In the western half of the area of study, a widening of the anhydrite plus salt facies zones could mean more general stability in those regions.

The northern Michigan pinnacle interreef areas exhibit A-1 Evaporite thicknesses of up to 200 feet. This is compared to the 20 foot thicknesses observed in the area of study. However, even with the greater thickness in the northern trend of Michigan, the A-1 Evaporite does not cap the reefs (Autra, 1977). In northern Michigan, the A-1 Evaporite does overlap the face of the barrier reef in most places. This is not the case in south-central Michigan. The thick A-1 Evaporite deposits along the northern Michigan pinnacle reef trend, along with the overlapping of the front face of the barrier reef, does indicate that greater subsidence occurred in northern Michigan as compared to south-central Michigan. This difference would mean that the pinnacle reefs in south-central Michigan were exposed longer and at a higher elevation with respect to the surrounding sediments. It can also be seen that, in the area of study, A-1 Evaporite time was a period of higher stability than northern Michigan. Slight differential subsidence did occur, but not to as great in extent as in northern Michigan.

Salina A-1 Carbonate (Ruff formation) Isopach Map

The Salina A-1 Carbonate isopach map was constructed on a 20 foot contour interval. In the central area of the study, the A-1 Carbonate tends to thin from the 100 to 120 foot thicknesses which occurs in the interreef areas and pinnacle flanks to a 20 to 40 foot thickness on the pinnacle reef crests. Some thicker crestal A-1 Carbonates do occur on the basinward pinnacle reefs. In the western area of the study area, a 60 foot maximum thickness occurs along the pinnacle reef flanks. Overall, the A-1 Carbonate is thickest along the basin margin and thinner in the central basin area. The basinal A-1 Carbonate reaches an average thickness of 60 feet in the basin center (Autra, 1977).

A-1 Carbonate overlies the A-1 Evaporite and underlies the A-2 Evaporite. Only the algal pelletal wackestone of the upper A-1 Carbonate overlies the

pinnacle reef crests (Huh et. al., 1977). The A-1 Carbonate consists lithologically of dolomite on the carbonate platform and the outer marginal shelf and of limestone in the pinnacle reefs and the interreef areas of the inner marginal shelf and basin (Figure 7). Four lithofacies have been identified in the thickest sections of the A-1 Carbonate. These sections occur along the pinnacle reef flanks.

The lowermost unit is a thinly laminated mudstone. This facies is composed of a lower light-brown dolomicrite covered by a thinly laminated mudstone. The lower light-brown dolomicrite was derived by high energy wave destruction of finely laminated algal stromatolites. The combination of an erosional contact with this facies and the A-1 Evaporite would be supportive of an environment that has occasional high energy periods (storms). Subaerial exposure of the upper dark-gray thinly laminated mudstone (lagoonal) is evidenced by intraformational breccia and mud cracks and which are lacking as one moves up the section. This lithofacies is thought to have been the primary source rock for the petroleum found in the pinnacle reefs due to the high amounts of organic and carbonaceous matter (Huh et. al., 1977).

The second lithofacies deposited was a brownish-tan, thin-bedded, massive dolomicrite (micritic mudstone). Rare algal mats do occur, but generally the facies was deposited in a deeper subtidal environment. The overlying (third) lithofacies is composed of an algal pelletal wackestone. These "pellets" are probably "pseudo" pellets which have formed during diagenesis (Bathurst, 1971). This lithofacies is generally thought to be typical of an intertidal environment (Roehl, 1967). An interfingering of the micritic mudstone and pelletal wackestone lithofacies indicates alternating intertidal and subtidal conditions. This could be due to either fluctuations in sea level or differential subsidence.

The fourth and last lithofacies is a pelletal-stromatolite boundstone which consists of planar algal stromatolites interbedded with enterolithic anhydrite.

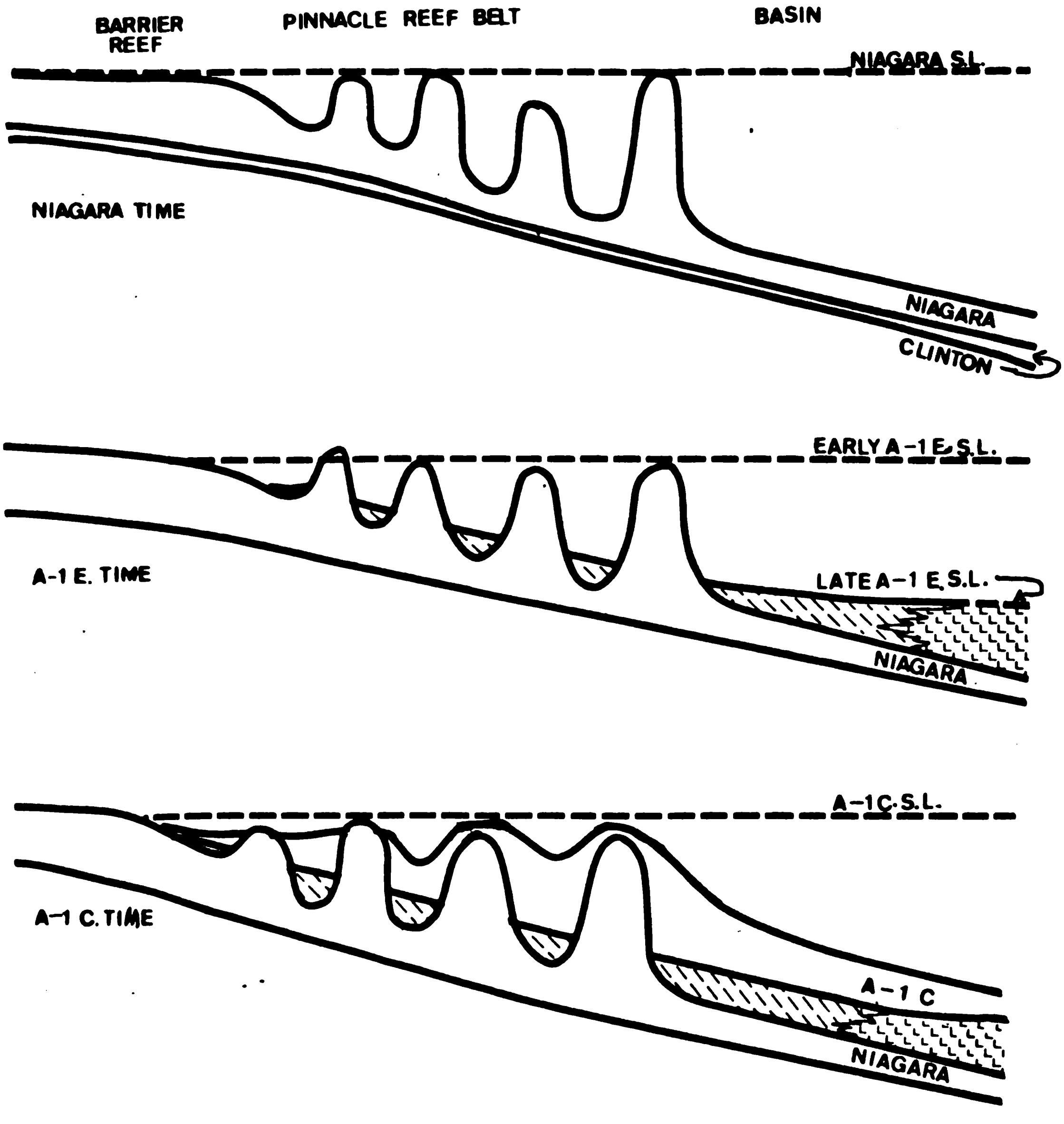


FIGURE 7 DEPOSITIONAL MODEL OF THE NIAGARA, A-1 EVAPORITE, & A-1 CARBONATE IN SOUTH CENTRAL MICHIGAN.

This anhydrite, which has been subjected to changes in volume due to later water influx or change from gypsum, is what has been called "Rabbit Ears" anhydrite. The anhydrite with its nodular textures is typical of a sabkha-like environment. The lowermost section below the "Rabbit Ears" anhydrite was probably deposited in a lower intertidal environment since it lacks evidence of such things as solution leaching and dessication cracks. The interbedding of the algal stromatolites and enterolithic anhydrite indicates a broad tidal flat to supra-tidal zone surrounding the pinnacle reefs. The deposition of algal pelletal wackestone and pelletal stromatolite boundstone in the reef crest and reef flank regions is good proof of the tidal island stage which Huh (1973) proposed as occurring on the pinnacle reef crest during A-1 Carbonate time. Therefore, a full and new pinnacle reef rejuvenation as proposed by Fincham (1975) and Mesolella et. al. (1974) did <u>not</u> occur. The higher saline environment of A-1 Carbonate time as shown by the lithology could not support renewed framework organic reefs. Another explanation as proposed by Autra (1977) is that no other organisms ever became reestablished after A-1 Evaporite dessication of the basin with the resulting destruction of Niagara faunas.

On the A-1 Carbonate isopach map, many interesting features occur. Two broad shelf areas of low slope occur, one on the east side and one on the west side. The central area pinnacle reef belt exhibits a very steep slope on the pinnacle reef flanks. The rapid thickening could mean that the rate of subsidence was somewaht greater than the adjacent stable shelf areas. A slight thinning of the A-1 Carbonate does occur along the area of the Lucas Monroe monocline indicating that a slight positive anomaly did exist.

A most important feature is the close correlation of the zero line of the A-1 Carbonate along the front face of the barrier reef in the western half of the area. The zero line transcends the barrier reef front in the east. This could be simply due to the slightly greater thickness of the barrier reef front in the west as compared to the east. Maximum barrier reef thickness in the west is 500+ feet, while the maximum thickness in the east if 450 feet. This thickness differential, along with a slightly greater rate of subsidence in the east, could explain the variation of the regional extent of the A-1 Carbonate. The earlier identified submarine fan area does show a significant trend in the thickness of the A-1 Carbonate. A thick platform of carbonate sediments occurs in this area. A stable organic active environment best fits as an explanation for this area. The thickness of A-1 Carbonate sediments along the barrier reef front shows that the reef was a significant factor in their deposition.

A-2 Evaporite Isopach and Lithofacies Maps

The A-2 Evaporite isopach map was constructed on a 40 foot contour interval. The A-2 Evaporite lithofacies map was constructed on the identical facies changes as constructed for the A-1 Evaporite lithofacies maps. The A-2 Evaporite is generally very similar to the A-1 Evaporite. The primary difference is that the A-2 Evaporite occurred over a greater areal extent and is thicker in the area of study. In the northern portion of the area of study, the A-2 Evaporite reaches thicknesses of 360 feet. In comparison, the A-1 Evaporite deposited 170 feet of salts in the same area. The main portion of the A-2 Evaporite deposition is a thick sequence of halite. The formation thins gradually from 500 feet in the basin interior to about 200 feet along the margins of the pinnacle reef belt. In northen Michigan, the thickness along the pinnacle reef belt is 300 feet (Mesolella et. al., 1974). Very rapid thinning occurs along the southern pinnacle reef belt. Over the pinnacle reefs, thicknesses very from 40 to 60 feet in the area of study. Along the entire pinnacle reef belt, the facies of the A-2 Evaporite is anhydrite. Three pinnacle reefs in the area of study are capped by a mixture of thin salt beds in the center of the dominantly anhydrite unit. This only occurs in the basinward pinnacle reefs both in northern and southern Michigan. Northern pinnacle reefs can have up to a 250 foot thicknesses of A-2 Evaporite covering them (Autra, 1977).

In northern Michigan, the A-2 Evaporite thins to 40 feet or less and undergoes a facies change to a dense anhydrite which covers much of the area over the barrier reef (Mesolella et. al., 1974). This is not entirely the case in south-central Michigan. Along the western half of the barrier reef trend, the A-2 anhydrite abuts the barrier reef in the same fashion as the deposition of the A-1 Carbonate. This same relationship of overlapping in the east could be related to the A-1 Carbonate which is in turn controlled by the Niagara barrier reef. The elevation of the barrier reef had to be lower in the east. This can either be explained by a higher rate of subsidence in the east or possibly by the original height of the barrier reef in each specific area, or a combination of the two. The overlapping of the barrier reef in both southern and northern Michigan is important for the formation of an evaporite seal of the pinnacle reefs for hydrocarbons.

The A-2 Evaporite in the area of the Lucas Monroe monocline shows a distinct pattern of thinning. Thinning of the A-2 Evaporite occurs along the crest of this positive structure. Where the lithology of the A-2 Evaporite should be salt, a combination of salt and anhydrite occurs. The zero isopach line of the A-2 Anhydrite also makes a broad basinward loop along the Lucas Monroe monocline. Either the structure was rising or more probably the surrounding areas were subsiding faster.

Along the northwest quarter of south-central Michigan, the A-2 Evaporite indicates deposition on a flat platform. This area has remained very stable compared to the marginal areas along the pinnacle reefs. Many random wells have been drilled on this platform in search of pinnacle reefs with little success. The pinnacle reef trend is located south of this platform area.

A major difference between the A-1 and A-2 Evaporite units is that the A-2 Evaporite contains no sylvite (KCl). The A-2 Evaporite also has relatively low bromine levels (Hosler, 1966) which explains the nondeposition of sylvite. This gives evidence for an increase in flow of water into the basin to account for the greater thickness of evaporites. The rate of subsidence at the same time must also have been greater than that during A-1 Evaporite time. It is likely that extreme dessication did not occur. The evidence for deep water origin of evaporites is stronger for the A-2 Evaporite. The rate of subsidence, however, seems to be the overriding factor controlling deposition.

Salina A-2 Carbonate Isopach Map

The Saline A-2 Carbonate map was constructed on a 40 foot contour interval. Over the study area the thickness ranges vary from 60 feet to 260 feet. The A-2 Carbonate is generally thinnest along the barrier and pinnacle reefs. The A-2 Carbonate is thickest in the interreef areas of the pinnacle reefs. It often appears to fill in the channel ways between individual pinnacles. The A-2 Carbonate is approximately 160 feet in the basin center. In the interreef and basinal areas, the thickness ranges from 120 feet to 160 feet. The barrier reef has A-2 Carbonate thicknesses of 60 to 100 feet in the west and 60 to 180 feet in the east. Where the A-2 Evaporite pinches out along the barrier reef, it is difficult to distinguish between the Niagara and the A-2 Carbonate.

Major anomalous thickenings of the A-2 Carbonate do occur in three groups of pinnacle reefs. Thicknesses of up to 260 feet do occur on the two basinward pinnacle reef groups. These two groups can be explained by a higher rate of subsidence along the basinward segment of the pinnacle reef belt. The third group of pinnacle reefs located in T1S-R7W are more difficult to explain. Thicknesses of up to 220 feet occur in this third group. This third group could be

a bonafide rejuvenation of pinnacle reef growth. On the southern border of this section of interest, the A-2 Carbonate thin rapidly to 100 feet in thickness. This rapid thinning does not occur on the basinward side of the "pinnacle." This difference could mean that more rapid subsidence occurred along the basin margin area. Anomalous thinnings do occur elsewhere along the pinnacle reef belt. In T1S-R5W, a thinning to less than 100 feet occurs on the pinnacle reef crests and interreef areas. There appears to be a random regeneration of organic reef growth during A-2 Carbonate time which may or may not be controlled by the Niagara pinnacle reefs. According to Mesolella et. al. (1974), A-2 Carbonate is nonfossiliferous. However, it is believed that algal reefing did occur. Diagenetic alteration seems to have altered the rock leaving little skeletal evidence of organic reef growth.

The A-2 Carbonate has been most often described in core descriptions as a finely crystalline dolomite ranging in color from light-brown to gray and containing varying amounts of argillaceous silty layers. Dolomite is the general lithology of the A-2 Carbonate throughout the area of study.

According to Mesolella et. al. (1974), the thickness trend observed in southern Michigan coincides with the rapid marginward thinning and wedgeout of the halite beds of the underlying A-2 Evaporite which suggests mass solution of the A-2 Evaporite prior to, or during, deposition of the A-2 Carbonate. Core data of south-central Michigan wells exhibit many small scale structures suggestive of soft sediment deformation. The base of the A-2 Carbonate is said to consist of several feet of carbonate rubble which possibly formed by collapse during solution of the underlying A-2 Evaporite.

The extension of the Lucas Monroe monocline does exhibit a position of positive elevation during A-2 Carbonate deposition. This is evidenced by thinning of the A-2 Carbonate over this fault related structure. Again in the northwest quarter of the area of study, there exits a stable platform much like that which existed during A-1 Carbonate time. In northern Ingham County, the deepest water is believed to have existed.

There is general agreement that the A-2 Carbonate resulted from a general rise in sea level (Mesolella et. al., 1974; Huh, 1973). With the lowering of the sea level during B-Evaporite time, a cap was formed over the A-2 Carbonate within the central basin areas. Therefore, production possibilities still exist for the A-2 Carbonate.

Salina A-2 Carbonate Structure Map

The Salina A-2 Carbonate structure map was constructed for the purpose of having a structural view of both the upper and lower units under study. Another purpose was to find out if structure affected the deposition of the Salina A and B units. It is important to remember that the structure map represents the present day structure of the area of study. An indication of the history to this area is shown by the structure map. A close correlation exists between the Clinton structure map and the A-2 Carbonate structure.

The A-2 Carbonate map was constructed on a 100 foot contour interval which was identical to the Clinton structure map. The elevation, with respect to sea level of the A-2 Carbonate, varies from -1100 feet along the basin margin to over -3600 feet toward the central basin. The average slope is very close to that observed on the Clinton structure map. An average 2500 foot drop occurs from the basin margin to the central basin area on both structure maps.

The obvious difference between the two structure maps is the convoluted nature of the A-2 Carbonate structure contours. The stable platform area in the northwest quarter of the map, which existed during A-1 and A-2 Carbonate time, is well represented on the A-2 Carbonate structure map by a general decrease in slope and in the widening of the contour intervals.

Another important feature exhibited by both structure maps is that the barrier reef and the pinnacle reef belt transect structure. The barrier and pinnacle reefs in the west are again structurally higher. Due to this structural elevation difference, it means that the western area has undergone less subsidence that the east. If this was true during Niagara time, it could mean that subsidence accounts for the thicker barrier reef growth and the semi-stable northwestern platform area.

The contorted trend of the A-2 Carbonate structure contour lines is likely due to the pinnacle reefs. Their existence as separate lithologic units could mean that they behaved as separate subsiding units. A good structural low occurs in the T1N-R3W collection of pinnacle reefs.

The Lucas Monroe monocline extension exhibits an identical relationship as discussed in the Clinton structure section. The structure still exhibits the left lateral strike slip faults and the dip slip normal fault in the northeastern area of the study.

B-Unit Isopach and Lithofacies Map

The Salina B subdivision is composed of two different lithologies - a lower evaporite and an upper dolomite section. The anhydrite evaporite varies from zero to four hundred feet in the Michigan Basin. The upper section of the Salina B varies from 20 to 60 feet in the Michigan Basin. For convenience, these two lithologies were combined into a single unit called the B-Unit.

The B-Unit mapped, in its upper section, is composed of minor amounts of shale interbedded with primarily four different facies units depending on its location with respect to the basin margin. The lithofacies map was constructed on these four lithofacies units: dolomite, anhydrite, anhydrite interbedded with thick salt and salt. The salt interbedded with anhydrite lithofacies usually has the thick salt in the center of the unit. This does exhibit the model of a gradual lowering of sea level followed by a rising sea. This gradation of salt to anhydrite both on the top and bottom of the B-Unit is especially common in the pinnacle reef and interreef trend. The lithofacies trends were again primarily determined by geophysical log means.

The B-Unit isopach map was constructed on a 50 foot contour interval. The thicknesses of the B-Unit mapped ranges from 90 feet along the basin margin to 450 feet toward the central basin area. A primary difference between the B-Unit and the earlier Salina A Evaporites is that the B-Unit continues beyond the basin margin as dolomite. All other A Evaporite units terminate once they have reached the massive barrier reef. A special feature of the B-Unit is that it covers the Niagara barrier reef with an average thickness of 100 feet. These relationships are well displayed by the stratigraphic cross-section (Plate).

The thickness trends, with respect to the barrier reef, are close to that of the A-2 Evaporite and A-1 Carbonate. What was observed earlier, with respect to these units, is that the barrier reef in the eastern half of the area of study was overlapped with thicker sections than that of the western half. This is still the case with the B-Unit. The B-Unit over the barrier reef in the west has an average thickness of 100 feet, which in the east the B-Unit over the barrier reef has thicknesses in some places exceeding 300 feet. A feature exhibited by the lithofacies map is that the barrier reef in the western half coincides with the beginning of the dolomite facies. The eastern barrier reef shows an overlapping affect of the anhydrite and anhydrite plus salt lithofacies. This evidence does show that the eastern half of the area of study was subsiding more rapidly than the west and that the original Niagara barrier reef did exert control of the B-Unit lithology in the west.

The pinnacle reef belt does show corroborating evidence for this differential subsidence. The pinnacle reef belt in the west is covered by a B-Unit thickness of

100 to 130 feet of anhydrite. Various patches of pinnacle reefs, both in the east and the west, show greater thinning than other patches. This could mean that the pinnacle reefs did exert control on B-Unit deposition. The eastern pinnacle reef trend had B-Unit thicknesses of over 300 feet and the lithology is primarily anhydrite plus salt (halite). This again shows that active differential subsidence was occurring during B-Unit time. An alternative explanation is that an influx of marine water was occurring along the submarine fan area identified earlier in the study. A northwesterly flow of water could have diluted the hypersaline brines so that halite deposition did not occur in the area in question. Evidence for this is the platform of 100 foot isopach thickness of the B-Unit sediments which occurs beyond the western pinnacle reef belt. The rapid thickening of the B-Unit along the eastern pinnacle reefs cannot be explained by an influx of marine diluting waters. The evidence overall leads to the conclusion that differential subsidence was active during B-Unit deposition.

Along the southern edge of the western area of study a slight thickening of the B-Unit does occur. This is evidence for a lagoonal area much like that of Niagara time (Fisher, 1973; Autra, 1977).

The Lucas Monroe monocline does show active positive movement in the northeastern quarter of the study area. A thinning from an expected 300 feet to a thickness of less than 150 feet occurs. Also, a slight thickening of the B-Unit with no associated lithologic change does occur along the eastern edge of the study area. This evidence, though meager, does suggest some slight differential movement along the eastern edge of the fault related Lucas Monroe monocline.

PETROLEUM PRODUCTION

A goal of this study was to determine if any control could be found on the type and capability of petroleum production. Gill (1979) observed a distinct succession of production type (oil, gas, oil and gas, and water) with respect to pinnacle position on the basin margin in the northern Michigan pinnacle reef belt. Reef height, pay thickness, burial depth, reservoir pressure, and extent of salt plugging were observed to increase progressively in a basinward direction across the belt, whereas oil gravity and degree of dolomitization increase in the opposite direction. The belt in northern Michigan is distinctly partitioned in an updip direction into three parallel bands of gas, oil and water saturated zones. The pinnacles structurally deeper in northern Michigan produce gas, while moving up structurally production type switches to oil and then to water. The oil in the downdip direction was shown to become progressively lighter (higher degree API).

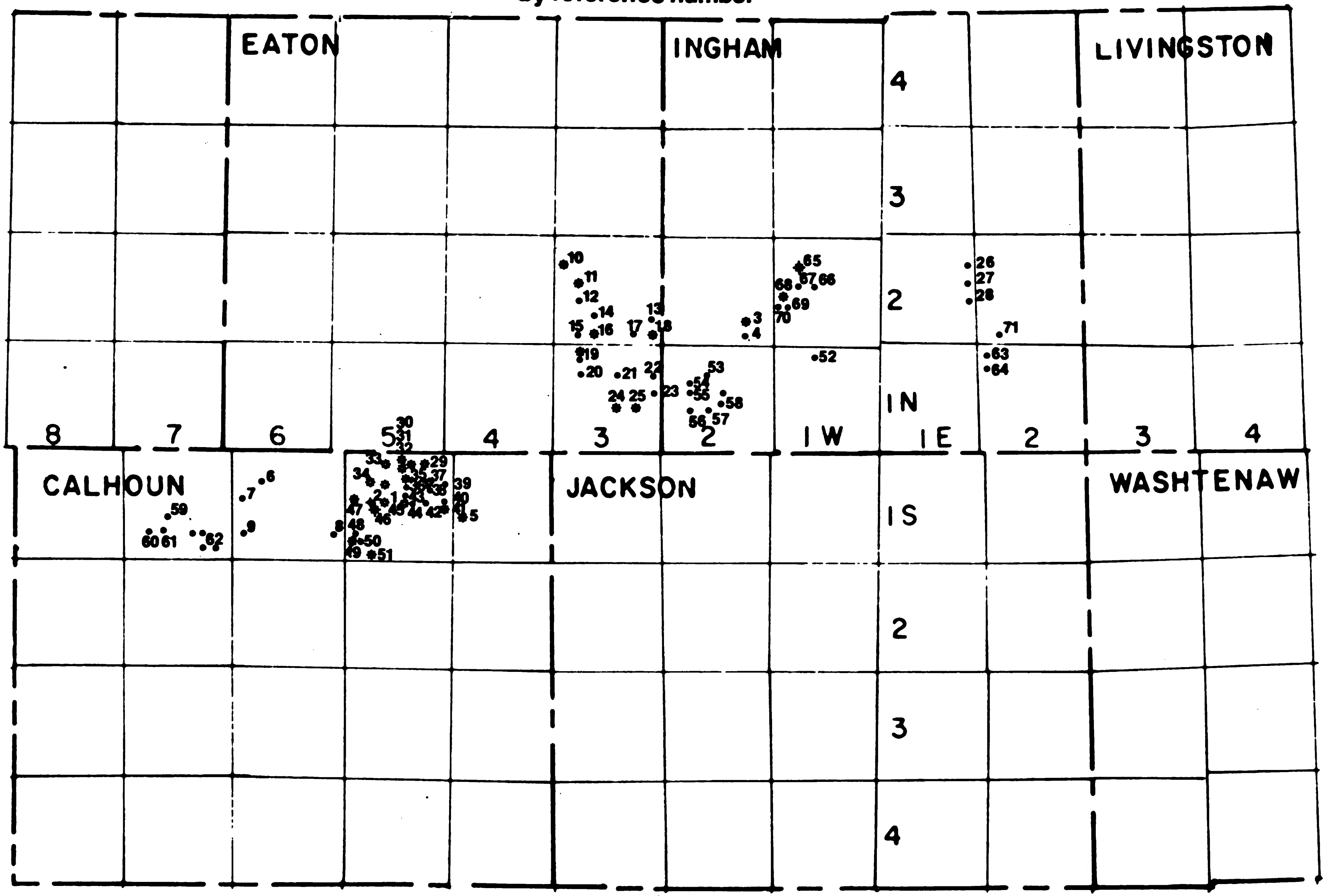
No such trend was observed in South Central Michigan. Type of production appears random. This could likely be due to the depositionally flat shelf area where the pinnacle reefs are located. Reef height does not progressively or consistently increase basinward. However, scattered trends where the gas producers are more basinward with respect to the barrier reef do occur. With respect to the present A-2 Carbonate and Clinton structure map, production trends are not related to present structure. The only possible answer to this problem is to propose that different depositional and oil migrational histories have occurred in the two areas. Possibly the oil migration from the source rock occurred earlier in the study than in northern Michigan. Random production would occur if no structural control existed between the pinnacle reefs. The different geometries (larger) of the reefs in the area of study could have had some effect on production type. Often in South Central Michigan, both oil and gas are produced. Production type has been distinguished only on which type is more prolific. Due to lack of data on reservoir pressure, trends could not be observed. However, we would expect the trend to parallel the present random-like production trend.

Oil production is observed to be restricted between the Niagara Barrier reef outline and the zero line of the A-1 Evaporite. A-1 Anhydrite is found on the basinward side of oil producing pinnacle reefs but not on the basin margin side of these same pinnacle reefs. This is not comparable to Northern Michigan pinnacle reefs because those reefs have thick A-1 salt surrounding oil producing pinnacle reefs. Presently no explanation can be offered for this observation

Presently, when drilling for the pinnacle reefs in South Central Michigan, type of production can not be determined before the actual penetration of the pinnacle reef.

The source for the petroleum is likely from basinal Niagara carbonates. Also, Gill (1979) has proposed that some hydrocarbons could have come from the lowermost thinly laminated mudstone of the A-1 Carbonate. Methods to solve this problem in the future could possibly rely on trace element analysis and geochemical studies of both the reservoir rock and likely source rocks.

PRODUCING NIAGARAN PINNACLE REEFS OF SOUTH-
-CENTRAL MICHIGAN
- by reference number -



Scale: 1" = 8 miles

TABLE 1. Reference Key to Producing Niagaran Pinnacle Reefs of South Central Michigan.

Ref. #	County	Field Name & Location	Discovery	Production	#Wells To End	#Wells Active
1	Calhoun	Cal Lee 9, 15, 16, 22-1S-5W	1962	Gas	1	1
2	Calhoun	Lee Twp. 17-1S-5W	1961	Oil	1	1
3	Ingham	Aurelius 26-2N-2W	1974	Gas	2	2
4	Ingham	Aurelius 26, 35, 36-2N-2W	1971	Oil	5	5
5	Calhoun	Clarence 19-1S-4W (Pool A)	1977	Gas	1	1
6	Calhoun	Convis 8-1S-6W	1975	Oil	3	3
7	Calhoun	Convis 7, 18-1S-6W	1975	Oil	7	7
8	Calhoun	Convis 25-1S-6W	1975	Oil	1	1
9	Calhoun	Convis 30-1S-6W	1975	Oil	6	6
10	Eaton	Eaton Rapids 7-2N-3W	1977	Gas	1	1
11	Eaton	Eaton Rapids 17-2N-3W	1973	Gas	4	4
12	Eaton	Eaton Rapids 20-2N-3W	1974	Oil	5	5
13	Eaton	Eaton Rapids 25-2N-3W	1976	Oil	1	1
14	Eaton	Eaton Rapids 28-2N-3W	1974	Oil	1	1
15	Eaton	Eaton Rapids 32-2N-3W	1975	Oil	2	2
16	Eaton	Eaton Rapids 33-2N-3W	1976	Gas	1	1
17	Eaton	Eaton Rapids 35-2N-3W	1976	Oil	2	2
18	Eaton	Eaton Rapids 36-2N-3W	1971	Gas	7	7

TABLE 1. (cont'd)

Ref. #	County	Field Name & Location	Discovery	Production	#Wells To End	#Wells Active
19	Eaton	Hamlin 5-1N-3W	1975	Oil	2	2
				Gas	1	1
20	Eaton	Hamlin 8-1N-3W	1972	Oil	3	3
21	Eaton	Hamlin 10-1N-3W	1974	Oil	3	3
22	Eaton	Hamlin 12-1N-3W	1977	Oil	1	1
23	Eaton	Hamlin 13-1N-3W	1977	Oil	1	1
24	Eaton	Hamlin 22-1N-3W	1977	Gas	1	1
25	Eaton	Hamlin 23-1N-3W	1974	Gas	2	2
26	Ingham	Ingham 12-2N-1E	1973	Oil	4	4
27	Ingham	Ingham 13-2N-1E	1972	Oil	5	5
28	Ingham	Ingham 25-2N-1E	1973	Oil	3	3
29	Calhoun	Lee 2-1S-5W	1973	Gas	4	4
30	Calhoun	Lee 3-1S-5W	1972	Gas	4	4
31	Calhoun	Lee 3-1S-5W (Pool A)	1975	Gas	3	3
32	Calhoun	Lee 3-1S-5W (Pool B)	1976	Gas	1	1
33	Calhoun	Lee 4-1S-5W	1972	Gas	2	2
34	Calhoun	Lee 8-1S-5W	1974	Gas	2	2
35	Calhoun	Lee 10-1S-5W	1973	Gas	1	1

TABLE 1. (cont'd)

Ref. #	County	Field Name & Location	Discovery	Production	#Wells To End	#Wells Active
36	Calhoun	Lee 10-1S-5W (Pool A)	1974	Oil	1	1
37	Calhoun	Lee 11-1S-5W	1976	Gas	1	1
38	Calhoun	Lee 11-1S-5W (Pool A)	1977	Oil	1	1
39	Calhoun	Lee 12-1S-5W	1972	Gas	1	1
40	Calhoun	Lee 13-1S-5W	1973	Oil	5	5
41	Calhoun	Lee 13-1S-5W (Pool A)	1973	Gas	3	3
42	Calhoun	Lee 14-1S-5W	1974	Oil	2	2
43	Calhoun	Lee 15-1S-5W	1974	Gas	1	1
44	Calhoun	Lee 15-1S-5W (Pool A)	1977	Oil	1	1
45	Calhoun	Lee 15-1S-5W (Pool B)	1977	Oil	2	2
46	Calhoun	Lee 17-1S-5W	1972	Abnd.Gas	1	0
47	Calhoun	Lee 18-1S-5W	1976	Gas	1	1
48	Calhoun	Lee 30-1S-5W	1975	Oil	3	2
49	Calhoun	Lee 30-1S-5W (Pool A)	1977	Gas	1	1
50	Calhoun	Lee 30-1S-5W (Pool B)	1977	Oil	2	2
51	Calhoun	Lee 32-1S-5W	1975	Gas	2	2
52	Ingham	Leslie 4-1N-1W	1973	Oil	1	1
53	Ingham	Onondaga 10-1N-2W	1971	Oil	16	15

TABLE 1. (cont'd)

Ref. #	County	Field Name & Location	Discovery	Production	#Wells To End	#Wells Active
54	Ingham	Onondaga 17-1N-2W	1973	Oil	1	1
55	Ingham	Onondaga 17-1N-2W (Pool A)	1975	Oil	1	1
56	Ingham	Onondaga 20-1N-2W	1976	Oil	1	1
57	Ingham	Onondaga 16, 17, 21-1N-2W (Unit A)	1971	Oil	18	18
58	Ingham	Onondaga 15, 21, 22-1N-2W (Unit B)	1972	Oil	6	6
59	Calhoun	Pennfield 21-1S-7W	1975	Oil	1	1
60	Calhoun	Pennfield 28, 29-1S-7W	1973	Oil	2	2
61	Calhoun	Pennfield 29-1S-7W (Pool A)	1976	Oil	1	1
62	Calhoun	Pennfield 26, 27, 35, 36-1S-7W	1974	Oil	12	10
63	Ingham	Stockbridge 6-1N-2E	1972	Oil	3	2
64	Ingham	Stockbridge 7-1N-2E	1974	Oil	1	1
65	Ingham	Vevay 8-2N-1W	1975	Abnd.Gas	1	0
66	Ingham	Vevay 16-2N-1W (Muson)	1970	Oil	2	2
67	Ingham	Vevay 17-2N-1W	1972	Oil	3	3
68	Ingham	Vevay 19-2N-1W (Pool A)	1971	Gas	2	2
69	Ingham	Vevay 19-2N-1W (Pool B)	1971	Oil	4	4
70	Ingham	Vevay 19-2N-1W (Pool C)	1971	Oil	1	1
71	Ingham	White Oak 29, 31, 32-2N-2E	1973	Oil	5	5

CONCLUSION

It is crucial to have understood, with respect to this study, that is is likely that different parts of the Michigan Basin have experienced slightly different histories and that, therefore, each area must be individually studied to determine its structural and depositional history with respect to pinnacle reef growth. This study has shown that the Niagara and Lower Salina of South Central Michigan has its own distinct depositional and structural history as compared to other separate pinnacle reef groups around the Michigan Basin margin. Local structural control as exhibited by the local rate of subsidence in combination with environmental controls such as basin reentrants determines the unique local depositional history of each particular pinnacle reef group.

The barrier reef in South Central Michigan has a series of major reentrants which may represent submarine channels. In the center of the area of study, a distinct widening of the Niagara isopach contours occurs. Reef debris is likely to have been funneled basinward by several submarine channels in the barrier reef in this area. The reentrant in the barrier reef amounts to more than ten miles from the expected barrier reef front. A lack of pinnacle reefs in this zone is further evidence for an area of rapid deposition and turbid waters unfavorable to reef growth.

Environmentally, the Niagara has been divided into four distinct zones: Basinal, Interreef, Pinnacle reef and Barrier reef. These environmental zones are exhibited in the north-south stratigraphic cross section. This cross section illustrates the proposed model for the growth sequence observed of the Niagara pinnacle reefs and surrounding Lower Salina units of South Central Michigan. The model for the growth sequence of the Niagara pinnacle reefs is basically Model I, but with major modifications. The major pinnacle and barrier reef growth occurred during the Niagara. High depositionaltopography did exist near the end of the Niagara. The alternating Lower Salina carbonates and evaporites occurred after the pinnacle reefs had grown to almost their full height. Deep water evaporites of the central basin area occurred simultaneously with shallow water deposition of evaporites along the barrier reef margins. The A-1 Carbonate did add to the pinnacle reefs crests, but not as a major reef regrowth sequence as proposed by Model III. Tidal flat algal mats do not constitute renewed framework pinnacle reef growth. A maximum of 60 feet of tidal flat algal mats of A-1 Carbonate age do occur on the more basinward pinnacle reef crests in the area of study. Evaporites do not transect the pinnacle reefs.

Evidence for deep water origin of the basinal evaporites includes the existence of very thick basinal salt which lacks sabkha sedimentary structures. High temperature and high aridity in combination with the restriction of the basin by the Niagara barrier reef was the primary mechanism for the deposition of the Lower Salina evaporites. A promising mechanism for evaporite deposition is where a hypersaline brine underlying a less saline brine becomes suddenly exposed to subaerial evaporation; through winds pushing the less saline brines from the dense hypersaline brines underneath.

Little evidence of deep basement control of Niagara reefs has been found. However, mid-Ordovician faults could have been responsible for some pinnacle reef locations. Movement along the fault controlled Lucas Monroe monocline did occur throughout the Niagara and Lower Salina as evidenced by the thinning of the units studied.

The Clinton structure and A-2 Carbonate structure maps have shown that extreme subsidence has occurred since Clinton and Niagaran deposition. This is illustrated by the Niagara barrier reef transcending structurally deeper into the basin. If no subsidence had occurred, it would have been expected that the barrier reef outline would follow lateral structure contours. The rapid increase in slope basinward also exhibits the higher rate of subsidence that has occurred in the central basin area. It is proposed that subsidence did occur during the Niagara and that the origin of the pinnacle reefs are tied to this more rapidly subsiding interior.

Differential subsidence of each specific reef tract did control the effective elevations of the pinnacle reefs with respect to sea level. This is reflected by the relationship of the lithofacies units of the evaporites positionwise with respect to the barrier reef. Due to the barrier reef outline transecting structure and the Lower Salina units overlapping the eastern barrier reef, it has been concluded that the western pinnacle reefs are therefore slightly older. This is due to the possibility that a lower rate of subsidence occurred in the western half of the area of study.

The Clinton isopach map has effectively shown that the Clinton exerted no control on the location or production of the pinnacle or barrier reefs. No apparent stratigraphic control other than a slight thickening basinward occurred during Clinton time.

The basinward thickening of the A-1 Evaporite and its progressive facies changes which require higher brine concentrations basinward does show that subsidence did occur during A-1 Evaporite time. A-1 Evaporite does occur in the interreef areas, but due to elevational differences, the A-1 Evaporite was unable to cover the pinnacle reef crests.

Only the upper facies unit of the A-1 Carbonate overlies the pinnacle reef crests. This distinction shows that the A-1 Carbonate had to fill in between the pinnacle reefs until it was finally able to deposit tidal flat sediments on the pinnacle reef crests. The greatest thicknesses of the A-1 Carbonate occur on the flanks of the pinnacle reefs. Importantly, the A-1 Carbonate sea did not reconnect to the Illinois or Appalachian basins. This is contrary to the suggestion of some geologists that the A-1 Carbonate covers the barrier reef and connects to the southern basins.

The A-2 Evaporite resulted environmentally from the lowering of the sea level after A-1 Carbonate time. The rate of subsidence was slightly faster than that of A-1 Evaporite time as evidenced by the thicker evaporites and the lack of sylvite deposition. This thickness could also be explained by a deposition of the evaporites over a longer period of time and by a less dense brine concentration than was characteristic of the A-1 Evaporite.

The A-2 Carbonate was again biologically controlled. This is evidenced by the thickest carbonates occurring in the interreef areas. Algal reef growth did occur during the A-2 Carbonate in the interreef areas as shown by the random thickening of the unit. A-2 Carbonate time included the rising of the sea level up and over the Niagara barrier reef. For the first time since Clinton time, the Michigan, Illinois and Appalachian basins were fully reconnected. Niagara pinnacle reefs are reflected in the A-2 Carbonate structure map as convoluted contours. This shows that during later differential subsidence, the pinnacle reefs behave as independently subsiding structural units. Thinning of the A-2 Carbonate over the Lucas Monroe monocline suggests positive movement along this structure.

With the renewed lowering of the sea level, B-Unit evaporites were deposited. The B-Unit exhibits a unique lithofacies pattern. In contrast to the A-Evaporites, the B-Unit has its own basin margin dolomite equivalent. The B-Unit has a thickness pattern very close to that of the A-2 Evaporite and A-1 Carbonate. This pattern is that of thicker deposition in the east and thinner in the west. In the east, the Niagara barrier reef did control the lithofacies of the B-Unit so that only dolomite was deposited. This reflects the higher structural position of the eastern part of the area of study. All of the units of the Lower

Salina, including the B-Unit, show a progressive overlapping of the younger units toward the basin margin. This represents active basin subsidence throughout the time interval studied.

Petroleum production, whether oil or gas or mixed has shown no observable depositional (other than A-1 Evapi) and structural control. The random pattern of the type of production has at present no reasonable explanation. No such trend as observed in the northern Michigan pinnacle reef belt is found in South Central Michigan. Different depositional histories between these two areas offer the only explanation. The different geometries of the reefs in the area of study could have affected the type of production.

It is hoped that a better understanding of the depositional and structural history of the Niagara pinnacle reefs of South Central Michigan has been accomplished by this study. With this study in hand, the location of promising areas for future exploration can be determined. The effective use of seismic in these promising areas should help narrow the search for potential pinnacle reefs.

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APPENDIX

APPENDIX 1. GEOPHYSICAL WELL DATA BY COUNTIES.

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						BARRY COUNTY								
28802	23-3N-7W	949	208	190	291	62	36			A+S	S	A+S		3470
	24-3N-7W	950	233	189	290	60	56	98	30	S	S	A+S	4210	3515
21987	22	908	204	195	291	67	59	97	29	S	S	S	4137	3428
30137	14-3N-8W	927	194	188	292	61	70	90	15	S	S	A+S	4040	3330
23572	20-4N-7W	882	211	173	308	56	110	92	30	S	S	S	4330	3583
	3-4N-8W	882	203	181	323	56	160	72	24	S	S	S	4330	3551
23573	20	864	181	196	296	56	124	86	28	S	S	S	4132	3374
28728	11-1N-7W	955	106	156	254	44	12	150		A	A	A	3678	3062
	19	950	94	176	224	58	6	146	22	A+S	S	S	3520	2910
29251	32-1N-8W	931	95	145	38	53	12	130	22	A	A	A+S	3323	2945
30153	14	942	138	149	234	35	36	96	22	A+S	S	A	3520	2968
28494	11-2N-7W	844		188	280	72	14	128	12	A+S	S	S	3828	3146
28493	13	917		186	280	66	12	134	10	A+S	S	S	3862	3184
21999	22	979	189	184	266	72	14	138	10	A+S	S	A+S	3870	3197
29092	36	959	208	186	240	60	9	147	10	A	S	A+S	3796	3154
27951	15-2N-8W	956	186	175	270	66	8	144	8	A	S	S	3752	3089
24782	30-1N-7W	900	96	162	90	58	14	146	29	A	S	S	3468	3098
25775	23	858	96	173	167	44	15	147		A	S	S	3480	2998
23401	17-1N-8W	992	91	165	199	60	16	121	22	A	S	S	3506	2945

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						JACKSON COUNTY (Cont'd)								
	33-4S-3W	1099	96	48	0	0	0	499	14			D	2915	2368
22663	33	1036	95	53	0	0	0	508	14			D	2834	2273
22951	34	1097	95	49	0	0	0	495	14			D	2877	2333
23197	34	1115	84	58	0	0	0	483	15			D	2892	2350
	34	1105	85	51	0	0	0	541	15			D	2929	2337
22425	34	1100	91	53	0	0	0	478	16			D	2902	2371
	34	1111	97	50	0	0	0	494	12			D	2896	2352
22252	32-3S-1W	988	76	60	0	0	0	521	20			D	3121	2541
22442	28-3S-1W	968	79	88	0	0	0	390	23			D	3196	2718
27708	2-3S-3W	1000	82	89	0	0	0	516	20			D	3306	2790
28705	8-4S-2E	987	76	62	0	0	0	453	14			D	3103	2588
28305	10-4S-1E	996	87	36	0	0	0	454	18			D	3122	2632
22483	10-2S-1W	961	82	72	0	0	0	358	22			D	3648	3216
22742	5-3S-3W	1012	85	100	0	0	0	392	25			D	3285	2792
21778	17	1043	81	79	0	0	0	422	24			D	3170	2664
24449	19	1042	80	66	0	0	0	466				D	3126	2594
22674	22	1035	83	83	0	0	0	582	20			D	3164	2599
28690	24	1005	91	82	0	0	0	430	19			D	3170	2658
21601	25	1028	83	89	0	0	0	480	20			D	3130	2561
29944	4-3S-2E	1032	73	89	0	0	0	488+				D		2913
23399	22	962	62	50	0	0	0	468	18			D	3290	2772
28272	3-4S-2W	1022	91	76	0	0	0	473	15			D	3087	2538

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
JACKSON COUNTY (Cont'd)														
23828	18	1011	93	68	0	0	0	472	20			D	2936	2464
	18	1019	96	74	0	0	0	387	20			D	2945	2484
	17	1036	100	62	0	0	0	382	22			D	2972	2528
22934	17	1020	99	71	0	0	0	420	18			D	2920	2429
22955	8	1033	86	54	0	0	0	515	12			D	3035	2466
23789	6	1066	84	57	0	0	0	433	18			D	3076	2586
	6	1073	76	71	0	0	0	414	22			D	3068	2584
	6	1057	87	60	0	0	0	427	19			D	3073	2586
22908	6	1028	88	57	0	0	0	415	23			D	3004	2532
	6	1030	87	59	0	0	0	417	20			D	3027	2551
	9	1095	90	56	0	0	0	479	21			D	3085	2550
	19-4S-1W	1137	82	62	0	0	0	473				D	2984	2448
22469	33-4S-3W	1077	89	52	0	0	0	518	14			D	2902	2332
	33	1094	83	54	0	0	0	529	14			D	2925	2352
22503	33	1093	94	52	0	0	0	479	13			D	2905	2374
	33	1097	99	52	0	0	0	514	14			D	2940	2374
22660	33	1103	95	52	0	0	0	537	13			D	2931	2394
	33	1101	92	49	0	0	0	511	13			D	2929	2369
22391	33	1057	94	50	0	0	0	525	12			D	1893	2318
	33	1055	98	54	0	0	0	487	16			D	2893	2352
	33	1094	88	47	0	0	0	520	17			D	2913	2346
23831	33	992	88	46	0	0	0	539	16			D	2919	2344

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
LIVINGSTON COUNTY (Cont'd)														
26818	1	221	360	179	188	47	15			A	A+S	A+S		3428
26817	2	915	350	187	182	54	13			A	A+S	A+S		3373
WASHTENAW COUNTY														
24161	22-1S-3E	961	124	80	0	21	0	420	22		A	A	3454	2934
24396	25-2S-3E	939	54	71	0	15	0	461	22			D	3090	2540
	14	993	118	77	0	14	0	460	27			D	3214	2665
27472	8-3S-4E	957	75	58	0	12	0	446	23			D	2954	2438
25607	16	974	115	83	0	14	0	372	22			D	2876	2406
28596	18	NA	66	60	0	0	0	402	25			D	3236	2776
21903	6	968	60	72	0	14	0	438	20			D	2974	2460
	8	942	87	76	0	9	0	419	24			D	3054	2550
32841	15-1S-4E	899	123	93	38	18	0	390	16		A	A	3557	3018
32581	26	917	126	44	0	0	0	450+			A+D	A+D		2880
28534	17-3S-4E	933	67	53	0	0	0	401	7			D	3237	2783
27049	21	1002	79	60	0	0	0	502	7			D	2864	2362

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						LIVINGSTON COUNTY (Cont'd)								
25868	14-2N-4E	938	336	210	122	58	10	180	31		A	A	4518	3938
28405	12-3N-3E	921	179	192	122	48	17			A	A	S		3570
29675	34	922	372	196	186	58	14	157	24	A	A+S	A+S	4429	3818
29051	1	920	266	154	288	130	23	145	30	A	S	S	3952	3212
23374	2	939		184	284	56	26	122	26	A	A+S		3952	3280
31900	30	927	132	240	252	0	0	190	14	A	A+S	A	4913	
22642	28-4N-3E	900	271	162	239	58	24	118	46	A	A+S	S	4290	3689
32078	6	918	310	174	358	64	58	98		A+S	A+S	S	4520	3768
29296	7-3N-4E	928	318	190	248	55	8			A	A+S	A+S		3548
28949	6	925	306	209	282	52	19			A	A+S	S		3446
31973	32-3N-3E	731	252	262	134	180	57	250	14	A+S	S	S	4376	3492
31821	21	918	156	274	59	64	122	170	11	A	A	A+S	4511	3955
29021	36-4N-3E	945	325	185	283	57	18			A	S	S		3364
24324	35-4N-3E	906	328	179	295	58	17	126		A	A+S	A+S	4185	3510
28255	27	932	322	176	314	61	14			A	S	S		3588
29089	22	940	322	185	309	62	21			A	A+S	S		3668
26623	21	915	316	182	345	69	22	144	14	A	S	S	5080	4318
26760	35-3N-4E	950	357	173	190	48	13			A	A+S	A+S		3453
26775	34	897	370	177	183	55	5			A	A+S	S		3433
26816	27	907	379	178	209	53	28			A	A+S	S		3483
28482	18	928	324	200	280	54	13			A	A+S	S		3479
26109	12-2N-4E	932	298	175	152	53	14			A	A+S	A+S		3433

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
JACKSON COUNTY (Cont'd)														
21226	9	1027	74	86	0	0	0	403	18			D	2991	2502
22649	19	1101	94	56	0	0	0	490	16			D	3010	2464
24548	16	1033	106	66	0	0	0	430	20			D	2945	2448
	21	1045	86	57	0	0	0	517	16			D	2909	2335
22664	27	1123	93	51	0	0	0	508	16			D	2962	2403
28838	28	1093	88	50	0	0	0	516	17			D	2939	2373
26427	31	1028	85	57	0	0	0	540	16			D	2822	2226
24098	32	1016	90	49	0	0	0	532	12			D	2808	2227
26456	10-1S-3W	935	241	153	41	62	0	258	23		A	A+S	3754	3240
26549	10-2S-2W	974	82	72	0	0	0	326	22			D	3576	3138
26548	16	940	90	86	0	0	0	323	19			D	3473	3023
27478	21	990	77	74	0	0	0	407	22			D	3475	2994
22110	27	987	90	94	0	0	0	338	16			D	3442	2962
21723	1-3S-2W	1023	86	77	0	0	0	120+				D		2805
22950	31	1044	107	76	0	0	0	441	13			D	3133	2616
27672	36	1039	80	71	0	0	0	487	20			D	3202	2634
21736	35	1041	72	78	0	0	0	500	17			D	3175	2634
LIVINGSTON COUNTY														
28752	17-2N-3E	960	340	230	56	60	4	209	24	A	A+S	A+S	4253	3694
32427	28	936	188	170	43	14	0	430	22		A	A+S	4186	3540

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
JACKSON COUNTY (Cont'd)														
25190	34	1111	70	74	0	0	0	448	20			D	2950	2428
21714	33	1073	78	61	0	0	0	505	13			D	2938	2372
26004	23	1067	82	64	0	0	0	488	12			D	3014	2452
21740	22	1093	89	60	0	0	0	500	18			D	3050	2490
24251	21-4S-2W	1165	88	62	0	0	0	444	20			D	3086	2572
22984	16	1069	90	56	0	0	0	479	11			D	3053	2518
21976	11	1033	82	61	0	0	0	509	18			D	3059	2489
30720	7	1076	82	69	0	0	0	508	12			D	3058	2481
21932	5	1027	77	51	0	0	0	534	20			D	3096	2511
33091	7-1S-1E	957	94	41	28	18	0	383	27		A	D	4001	3531
21898	26-3S-1E	959	84	67	0	0	0	443	18			D	3256	2746
27633	8-2S-3W	981	61	54	0	0	0	380	27			D	3460	3027
22808	9	1014	89	51	54	0	0	349	25		A	D	3523	3079
28394	13	1016	85	86	0	0	0	348	25			D	3484	3050
21963	15	1020	90	119	0	0	0	323	25			D	3487	3055
21905	26	971	93	66	0	0	0	437	23			D	3342	2839
27882	27	1010	89	91	0	0	0	374	30			D	3364	2899
21161	29	1002	78	96	0	0	0	377				D	3366	2893
27565	2-4S-3W	1084	96	64	0	0	0	453	25			D	3107	2590
25610	3	1053	90	62	0	0	0	436	22			D	3036	2538
28740	5	1012	89	70	0	0	0	402	19			D	2987	2515
22461	7	1002	83	88	0	0	0	391	22			D	2958	2479

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
JACKSON COUNTY (Cont'd)														
33119	34	1005	132	115	38	59	0	150+			A	A+S		3156
27903	36	1024	120	112	46	68	0	266	24		A	A+S	3680	3188
31337	2	950	244	156	43	53					A	A+S		3298
33081	7-1S-1E	957	94	41	28	18	0	383	27		A	D	4001	3531
33028	17	975	98	90	0	0	0	378	25			D	3990	3527
21992	26	924	75	73	0	0	0	384	26			D	3838	3381
26541	15-2S-2W	986	82	106	16	6	4	306	22	A	A	D	3550	3112
28617	24-2S-3W	1002	86	49	0	18	0	414	30			A	3432	2951
23656	24-4S-2E	1051	89	92	0	22	0	330	26			D	3068	2624
29558	32-1S-2W	937	128	93	59	71	0	244	20		A	A+S	3592	3126
22107	14-3S-3W	995	80	56	0	3	0	503	21			D	3190	2628
24840	35-3S-3W	1079	90	65	0	0	0	467	14			D	3130	2598
22275	29-3S-1W	997	82	80	0	0	0	498	10			D	3172	2594
23013	17-4S-2W	1072	73	54	0	0	0	484	22			D	3056	2518
	33-3S-3W	1032						421	21			D	3063	
	33	1025	68	96	0	0	0	422				D	3058	2550
22351	30-3S-3W	999	83	68	0	0	0	453	24			D	3058	2547
	20	1030	82	70	0	0	0					D		2598
23022	19-4S-3W	1011	102	66	0	0	0	406	20			D	2888	2416
	24	1138	90	56	0	0	0	500	6			D	3012	2456
22931	29	1073	88	50	0	0	0	510	16			D	1932	2372
22504	18	1021	96	66	0	0	0	404	18			D	2960	2490

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
26689	17-2S-6W	957	97	91	0	0	0	367	22			D	3177	2719
24508	26-2S-7W	893	93	105	0	0	0	363	22			D	2998	2530
27862	7-3S-8W	982	91	71	0	0	0	513	18			D	2856	2272
19880	24	931	98	72	0	0	0	441	22			D	2805	2292
28044	17-3S-8W	992	88	84	0	0	0	440	16			D	2818	2294
23038	16	958	79	62	0	0	0	570	20			D	2786	2154
23292	23-3S-7W	925	93	100	0	0	0	385	21			D	2825	2340
23635	26	946	90	74	0	0	0	410	20			D	2804	2320
JACKSON COUNTY														
28733	2-1S-1W	971	114	93	45	15	0	373	25		A	A	3973	3447
29501	5	986	119	104	46	14	0	374			A	A	4040	3502
32579	11	928	109	93	46	16	0	373	25		A	A	3891	3369
32951	12	962	103	84	48	17	0	374	24		A	A	3987	3464
30415	27-1S-2W	974	68	102	52	64	0	268	14		A	A	3716	3216
30757	2-1S-3W	952	248	151	38	68	30			A	A	A+S		3304
26481	4	946	240	145	41	71	4	250	27	A	A	A+S	3791	3280
22719	14	945	234	132	39	75	0	252	19		A	A+S	3720	3220
23269	11	944	242	147	43	60	0	259	28		A	A+S	3777	3218
33080	15	957	138	134	40	64	0	237			A	A+S	3703	3228
33080	27		120	119	37	65	0	260			A	A	3628	3197

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
30574	18	930	128	132	66	34	0	100+			A	A		2968
31607	19	936	107	95	54	24	0	80+			A	A		2851
32492	21	936	103	98	40	29	0	230+			A	A		2899
33160	24	962	102	104	38	21	0	150+			A	A		2979
32294	25	959	98	102	43	21	0	150+			A	A		2926
26506	27	964	113	137	36	72	0	276			A	A	3457	2946
31893	30	938	108	94	45	24	0	100+			A	A		2845
30434	31	935	111	83	47	20	0	432			A	A	3372	1770
30435	32	952	97	87	46	24	0	448			A	A	3376	2771
32380	34	952	104	94	45	27	0	150+			A	A		2834
22835	35	961	92	95	5	49	0	358	18		A	A	3436	2974
30678	36	976	110	142	32	80	0	244	24	A	A	A	3482	2976
30394	7-1S-6W	858	110	112	36	24	0	150+			A	A		2748
30539	9	894	104	109	37	16	0	50+			A	A		2880
30802	16	945	104	92	43	25	0	50+			A	A		2844
30484	17	907	110	100	40	18	0	150+			A	A		2790
30819	19	955	111	185	28	34	0	50+			A	A		2845
31129	22	956	105	86	47	23	0	150+			A	A		2848
32097	25	947	97	90	50	24	0	50+			A	A		2764
31998	26	947	110	94	47	23	0	50+			A	A		2780
30505	30	908	106	94	36	18	0	472			A	A	3306	2686
30782	36	951	102	95	50	18	0	50+			A	A		2765

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
30249	35	967	106	90	48	20	0	150+			A	A		2662
30180	36	974	128	92	38	22	0	150+			A	A		2658
22706	12	859	108	212	17	89	0	154	20		A	A	3342	2871
30990	13	859	128	234	36	56	9	100+			A	A		2872
31587	22	846	112	233	21	68	10	20+			A	A		2738
30658	23	886	108	217	21	63	11	201			A	A	3276	2763
32873	24	937	104	185	28	0	0	100+			A	A		2791
30399	25-1S-7W	968	114	132	66	36	0	50+			A	A		2751
30157	26	981	100	87	52	27	0	130+			A	A		2677
29709	2-1S-5W	939	112	202	35	47	0	50+		A	A	A		3102
30710	3	977	103	127	60	34	0	150+			A	A		3109
26737	5	944	115	211	28	36	0	219	17		A	A	3606	3112
22489	6	922	114	217	20	68	0	181	24		A	A	3624	3138
30479	7	952	117	209	28	18	7	50+		A	A	A		3061
29726	8	949	99	96	42	22	0	450+			A	A		2951
29082	9	957	93	98	36	28	0	200+			A	A		3034
29642	10	974	104	97	39	17	0	200+			A	A		3033
31432	11	951	108	150	67	43	0	80+			A	A		3082
32328	13	967	131	100	47	30	0	180+			A	A		3019
31867	14	952	99	97	43	23	0	100+			A	A		2969
31950	15	974	98	95	40	19	0	100+			A	A		1978
31001	17	930	128	179	30	41	0	50+		A	A	A		2989

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
23563	17-4S-6W	990	95	61	0	0	0	464	24			D	2756	2231
23753	17	1004	99	61	0	0	0	506	23			D	2780	2213
30731	19	962	108	84	0	0	0	376	20			D	2676	2216
29975	21	949	93	69	0	0	0	464	22			D	2698	2165
23065	32-4S-4W	1010	99	70	0	0	0	369	20			D	2751	2312
22789	3-4S-7W	961	95	94	0	0	0	404	20			D	2774	2276
27758	4	920	88	70	0	0	0	516	18			D	2702	1197
28321	33	904	104	96	0	0	0	309	17			D	2559	2134
26902	8-4S-6W	975	94	66	0	0	0	437	23			D	2769	2266
29737	7-1S-4W	958	110	190	28	26	12	50		A	A	A		3122
32034	15	956	106	188	25	78	17	195		A+S	A	A	3624	3120
23770	8	987	114	183	30						A	A		3120
33128	27	956	97	106	40	26					A	A		2940
31871	28	931	106	192	27	0	14	200	16	A	A	A	3506	3012
29148	11-4S-5W	NA	93	54	0	0	0	400	17			D	2886	2412
24556	20	1018	103	88	0	0	0	386	14			D	1812	1248
29630	31	975	104	62	0	0	0	380	14			D	2658	2216
31584	4-1S-6W	879	84	226	26	42	0	234	16		A	D	3478	2972
24536	5	866	104	214	26	44	0	177	12		A	D	3461	3000
31315	27-1S-7W	1013	110	117	93	23	0	100+			A	A		2757
29156	29	852	90	94	36	25	0	484	26		A	A	3202	2558
29670	28	851	88	100	40	22	0	100+			A	A		2558

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						CALHOUN COUNTY (Cont'd)								
23547	11	1030	82	63	0	0	0	486	22			D	3196	2647
21739	12	994	92	72	0	0	0	452	28			D	3206	2682
23950	27	1035	87	78	0	0	0	416	17			D	3140	2646
26184	34	1009	90	74	0	0	0	403	14			D	3017	2540
22151	3	981	85	73	0	0	0	414	18			D	3234	2747
24353	30-3S-5W	982	83	65	0	0	0	468	17			D	2919	2386
32682	34	991	78	70	0	0	0	504	19			D	2922	2348
23031	9-3S-6W	961	85	70	0	0	0	412	26			D	2968	2486
23389	15	963	86	71	0	0	0	414	21			D	2954	2469
	1-4S-4W	1052	88	80	0	0	0	380	23			D	3070	2610
	1	1044	88	82	0	0	0	381	24			D	3077	2614
23608	1	1038	91	81	0	0	0	385	22			D	3033	2567
	1	1046	89	79	0	0	0	392	23			D	3070	2599
	1	1034	93	78	0	0	0	387	22			D	3057	2592
23280	1	1070	86	83	0	0	0	387	20			D	3077	2607
	1	1047	90	80	0	0	0	384	20			D	3086	2622
26274	3	1014	88	78	0	0	0	397	20			D	3013	2538
22007	13	999	86	80	0	0	0	387	20			D	2913	2456
24310	20	1049	98	76	0	0	0	363	19			D	2887	2448
	22	1026	102	65	0	0	0	403	16			D	2867	2399
31634	26	1018	114	60	0	0	0	404	17			D	2804	2340
29151	31	NA	101	68	0	0	0	369	17			D	2755	2308

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	Cl	A_1E	A_2E	Bu	Cl	A_2C
CALHOUN COUNTY (Cont'd)														
23305	36	1026	82	78	0	0	0	386	23			D	3065	2600
	3	971	106	95	0	0	0	380	23			D	3220	2755
	3	973	87	73	0	0	0	427	20			D	3228	2728
	3	967	93	70	0	0	0	422	20			D	3222	2730
	3	966	86	70	0	0	0	427	19			D	3215	2718
	3	997	85	89	0	0	0	435	19			D	3239	2715
	16	953	83	114	0	0	0	400	21			D	3104	2507
23368	22	1002	83	94	0	0	0	407	20			D	3147	2646
	23	1008	90	70	0	0	0	446	22			D	3134	2618
	15	1042	83	67	0	0	0	484	22			D	3214	2663
22523	15	1051	85	56	0	0	0	492	20			D	3228	2680
	15	1035	87	65	0	0	0	478	18			D	3212	2669
	15	1013	86	82	0	0	0	408	20			D	3176	2688
	15	1029	79	57	0	0	0	505	21			D	3203	2641
	15	1097	82	72	0	0	0	446	19			D	3200	2682
22457	15	1027	79	66	0	0	0	499	21			D	3187	2622
22422	14-3S-4W	1032	80	70	0	0	0	487	20			D	3185	2618
	10-3S-4W	972							21				3181	
	10	958	85	65	0	0	0	463	20			D	3140	2612
22209	10	970	83	71	0	0	0	487	22			D	3176	2618
	10	957	87	60	0	0	0	545	20			D	3187	2582
24451	9	960	83	61	0	0	0	501	19			D	3161	2599

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						CALHOUN COUNTY (Cont'd)								
19591	5-4S-7W	943						24				2735	1778	
22352	13-3S-8W	952	103	70	0	0	0	418	20			D	2826	2338
29923	29-1S-7W	928	112	238	16	46	0	206	22		A	A	3240	2734
30688	29	939	108	126	44	20	0				A	A		2594
29389	29	852	90	94	43	8	0				A	A		2538
29857	21	853	114	196	54	25	6			A	A	A		2656
31121	21	857	118	210	56	16	15			A	A	A		2712
25760	16-1S-5W	984	122	108	36	14	0	424	26		A	A	3604	3022
21772	16	999	124	154	50	12	0	318	20		A	A	3606	3072
	22-3S-4W	1011	88	30	0	12	0	455	18			D	3151	2654
21998	4	979	88	74	0	0	0	378	23			D	3240	2778
	4	933	90	68	0	0	0	514	20			D	3212	2630
	10	993	86	98	0	0	0	459	19			D	3177	2620
21502	10-3S-4W	998	82	104	0	0	0	478	20			D	3186	2604
	10	962	79	110	0	0	0	422	24			D	3126	2594
22460	10	990	83	90	0	10	0	483	20			D	3181	2598
21696	23	1008	90	54	0	14	0	450	21			D	3136	2618
	23	1021	84	26	0	13	0	451	20			D	3158	2668
23300	35	1038	88	65	0	0	0	409	23			D	3101	2627
23942	36	1034	82	76	0	0	0	392	23			D	3082	2614
22456	36	1032	86	76	0	0	0	394	22			D	3058	2614
23560	36	1029	91	70	0	0	0	401	23			D	3051	2590

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	Cl	A_1E	A_2E	Bu	Cl	A_2C
CALHOUN COUNTY (Cont'd)														
28328	5	932	103	128	38	68	0	258	13		A	A	3388	2896
32720	12	1000	75	134	36	82	13	225	26	A	A	A	3476	2986
27211	17	935	95	92	0	0	0	348	16			A	3326	2896
23032	28	969	86	79	0	24	0	383	16		A	D	3271	2809
22584	29	964	79	82	0	0	0	382	18			D	3270	2806
23370	34	947	64	82	0	0	0	382	18			D	3200	2770
30381	2-2S-6W	961	112	97	39	19	0	409			A	A	3282	2718
30339	10-2S-6W	956	116	94	60	29	0	352			A	A	3214	2679
22996	14-3S-4W	1028	81	50	0	10	0	500	22			D	3168	2601
23017	15	1019	83	65	0	6	0	432	21			D	3178	2668
	22	1000	84	99	0	0	0	380	20			D	3090	2605
	26	1042	80	67	0	7	0	424	22			D	3136	2638
23576	26	1042	84	77	0	0	0	454	22			D	3108	2588
	3	967	93	70	0	0	0	421	21			D	3221	2730
	3	998	86	73	0	0	0	451	17			D	3240	2716
	10	959	86	64	0	0	0	523	20			D	3182	2594
	10	1021	78	66	0	0	0	537	19			D	3203	2600
23114	1-4S-4W	1030	94	57	0	0	0	401	18			D	3022	2564
22895	1	1053	75	80	0	0	0	389	24			D	3070	2601
22946	12	1012	84	87	0	0	0	394	22			D	2986	2505
23551	22	1026	95	73	0	0	0	401	20			D	2866	2392
23563	17-4S-6W	990	96	59	0	0	0	465	24			D	2756	2232

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
24001	12	934	157	115	21	49	11	155		A	A	A+S	3350	2999
23553	7-2S-4W	932	83	64	13	12	0	349	17	A	A	A	3357	2919
22592	18-2S-4W	935	79	60	0	20	0	386	16			A	3310	2844
23757	19	985		60	0	23	0	385	18				3334	2866
	19	980	86	49	12	24	0	398	19	A	A	D	3343	2870
	19	989	84	54	0	24	0	390	17		A	D	3367	2900
24269	209	994	82	55	0	30	0	372	17			A	3361	2904
25096	20	979	81	49	4	20	0	408	15		A	D	3360	2879
	21	983	86	44	18	34	0	346	16		A	A	3302	2860
22748	33	976	87	53	0	17	0	371	16			D	3263	2823
22837	33	975	85	44	3	34	0	358	20		A	D	3265	2772
23457	33	961	85	55	0	30	0	365	17			D	3257	2807
22723	1-2S-5W	984	86	92	42	53	0	283	20		A	D	3448	2973
23680	12	923	83	58	0	24	0	389	18			D	3326	2855
23746	12	962	80	82	0	0	0	380	12			D	3368	2906
23983	13	933	86	80	0	0	0	394	20			D	3296	2822
22415	13	954	88	72	0	0	0	378	20			D	3304	2854
22096	27	972	89	62	0	0	0	450	20			D	3214	2702
23807	30	936	80	62	0	0	0	465	23			D	3145	2618
	6	963	82	56	0	26	0	384	19			D	3318	2852
22683	11	970	80	62	0	24	0	420	16			D	3374	2868
	27-2S-4W	1009	92	51	0	21	0	380	18			D	3304	2852

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
CALHOUN COUNTY (Cont'd)														
23427	33	986	103	150	34	72	0	238	12		A	A	3492	2998
30227	4-1S-5W	942	108	206	26	63	9			A	A	A		3154
27816	1	971	114	224	24	44	8	190	24	A	A	A	3708	3220
22484	6	922	124	207	20	60	6	175	23	A	A	A	3625	3148
27387	12	971	108	92	52						A	A		3006
22963	12	973	116	192	22	39	0	261	21		A	A	3605	3090
23637	16	969	114	154	42	40	0	304	18		A	A	3566	3026
29379	22	934	130	143	47	50	0	300			A	A	3484	2944
22903	23	943	111	149	41	57	0	274	22		A	A	3514	2993
23020	26	948	140	156	32	54	0	278	27		A	A	3464	2944
30939	28	962	112	96	42	24	0	408			A	A	3466	2896
30808	8-1S-6W	875	100	96	40	18	0	534			A	A	3440	2752
30982	8	860	112	182	30	34	5	289		A	A	A	3406	2866
30587	18	877	100	92	40	14					A	A		2706
30511	20	911	102	86	41	11					A	A		2732
30968	23	948	107	89	52	16	0	460			A	A	3420	2803
30783	32	990	118	136	36	16	0	301	20		A	A	3307	2766
30351	21-1S-7W	854	98	100	43	14					A	A		2598
30080	21	854	112	186	66	20	4			A	A	A		2664
30894	29	854	87	102	39	13					A	A		2537
29156	29	852	90	96	40	12	0	498	24		A	A	3204	2558
29214	4-1S-8W	907	154	108	26	54	10	136	20	A	A	A+S	3268	2934

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
INGHAM COUNTY (Cont'd)														
28858	6	971	256	117	46	24	0	439	10		A	A+S	4420	3794
29748	7	967	238	112	54	46	0	418	80		A	A+S	4361	3730
28913	9	968	327	135	45	25	0	337	15		A	A+S	4412	3861
32067	8	958	254	118	50	22	0	100+			A	A+S		3768
30247	24-2N-2E	945	360	197	40						A	A+S		3513
30288	25	970	294	124	50	22	0	409	5		A	A+S	3919	3314
30926	29	955	296	121	64	22	0	100+			A	A+S		3941
32054	36	954	265	118	52	20	0	428	20		A	A+S	3856	3238
32066	32	962	316	120	54	20	0	100+			A	A+S		3970
29727	31	970	252	126	50	24	0	100+			A	A+S		3804
32047	30	964	264	124	50	22	0	100+			A	A+S		3864
28999	31-2N-2W	934	232	120	54	34	0	480	22		A	A+S	4196	3262
30803	26	988	261	134	45	18	0	250+			A	A+S		3708
29118	25	976	350	197	34	22	4	292	20	A	A	A+S	4366	3807
28991	24	939	294	151	70	32					A	A+S		3786
29174	6	871	301	204	164	100	18			A+S	A+S	A+S		3800
28816	36	974	322	131	43	42	0	200+			A	A+S		3770
28955	16-1N-1E	958	222	103	51	19	0	393	22		A	A+S	4307	3741
CALHOUN COUNTY														
28680	19-1S-4W	945	111	160	38						A	A		3008
	32	957	116	145	41	50	0	253	19	A	A	A	3457	2968

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
INGHAM COUNTY (Cont'd)														
29420	32	972	141	105	47	15	0	70+			A	A+S		3684
29253	34-3N-1E	942	332	260	31	67	25	187	14	A	A	S	4770	4200
30134	3-2N-2E	944	260	210	44	8	14	314	10	A	A	A+S	4770	4180
29338	7	935	284	127	53	20	0	150+			A	A+S		3991
29334	18	965	264	142	54	22	0	100+			A	A+S		4004
31976	21	969	374	194	37						A	A+S		4056
29498	1-1N-2W	1004	109	171	37	109	40	173	12	A	A	A	4331	3801
31069	2	934	240	110	52	39	0	200			A	A+S		3528
28455	9-1N-1W	1026		83	36	37	0	490	13		A	A	4323	3650
29398	5	977	212	106	43	22	0	100			A	A+S		3650
29292	4	972	189	101	10	32	0	529	12		A	A+S	4335	3663
28145	29-3N-2E	931	182	178	155	61	18	192	11	A	A+S	A+S	4901	4298
27910	21-3N-2E	928	121	175	72	63	22	150+		A	A	A		4469
	25-2N-1E	963	272	122	52	21	0	100+			A	A+S		3883
28961	6-1N-2W	931	224	112	51	19	0	516			A	A+S	4186	3488
28389	11	935	241	110	56	15	0	200+			A	A+S		3514
28839	14	972	252	112	45	19	0	254			A	A+S	4000	3570
30615	17-1N-2W	915	252	104	42	12	0	200+			A	A+S		3454
28791	22	939			54	14	0	200+			A			
31040	32	1002	248	144	40						A	A+S		3420
30715	31	964	252	160	35	23	19				A	A+S		3416
29973	5-1N-2E	964	239	115	46	18	0	100+			A	A+S		3751

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
INGHAM COUNTY (Cont'd)														
29502	8-1N-1E	980		108	44	15	0	434			A	S	4362	3761
29665	34	971	100	90	51	15	0	397	28		A	A	4140	3585
30182	27-2N-1E	967	326	194	34	103	19	179		A	A	A+S	4550	4023
30338	32	984	206	218	27						A	S	4442	3950
29557	12	905	316	136	54						A	A+S		4000
29055	13	925	305	124	57	13	0	472			A	A+S	4620	3952
28739	15-3N-2E	905	96	118	222	59	4	181		A	A	A+S	5000	4416
28910	11-1N-1W	975	90	86	6	20	0	500+			A	A		3700
22607	13-1N-2E	972	286	124	46	28	0	355	42		A	A+S	3758	3206
29415	17	966	293	140	38	25	0	350			A	A+S	4328	3776
24470	31	944	106	170	34	12	0	444	40		A	A+S	4166	3606
29292	4-1N-1W	972	189	103	8	32	0				A	A+S	4334	3663
29672	36-1N-1W	977	168	93	55	17	0	376	30		A	A+S	4093	3552
29080	15-1N-2W	939	256	125	53	12	0				A	A+S		3508
32367	18	930	228	114	47	11	0				A	A+S		3418
28894	19-2N-1W	940	234	128	58	14	0	200+			A	A+S		3762
28807	18	916	223	122	50	14	0	250+			A	A+S		3734
29636	17	916	263	130	54	23	0	330+			A	A+S		3924
28304	15	933	349	229	35	151	0	168			A	A+S	4518	3970
28834	7	915	312	226	132						A	A+S		3936
30441	8	918	294	111	54	14	0	250+			A	A+S		3872
28696	27	948	313	176	40	67	38	213	13	A	A	A+S	4453	3918

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
						INGHAM COUNTY								
29416	35-1N-1W	984	130	104	46	16	0	378	34		A	A+S	4080	3536
28920	7-1N-2W	908	224	112	52	12	0	492			A	A+S	4092	3416
29521	16	956	246	110	48	12					A	A+S		3494
28377	3	939	246	108	76	20	0	452			A	A+S	4194	3533
28355	10	934	264	119	49	16	0	444	27		A	A+S	4178	3550
29669	15	954	277	158	32	58					A	A+S		3572
29358	15	943	244	96	70	10	0	462			A	A+S	4132	3494
31505	18	929	246	119	48	12					A	A+S		3441
32024	18-1N-2W	929	246	119	48	12					A	A+S		3426
30645	20	919	225	106	57	11					A	A+S		3434
29753	21	961	288	166	38	44	7	173	30	A	A	A+S	4068	3540
29581	26	969	280	154	34	16	0	304	27		A	A+S	4028	3520
28929	33-2N-2W	937	282	212	34	128	14	136	31	A	A	A+S	4218	3694
29656	35	990	357	219	42						A	A		3834
24518	16	916	324	213	132	98	27	122	40	A	A+S	S	4422	3830
28842	11	917	317	216	128	111	24	119		A	A+S	A+S	4468	3872
28607	29-2N-1W	939	216	124	46	17	0	510	34		A	A+S	4400	3704
28266	29	972	220	110	52	10	0	496	34		A	A+S	4402	3736
28801-A	20	926	231	124	49	12	0	490	33		A	A+S	4415	3744
29500	36	943	242	145	45	14	0	414+			A	A+S	4434	3817
	16	936	232	231	40	88	14	173		A	A	A+S	4520	3974
28953	21	920	260	203	43	107	9	183		A	A	A+S	4475	3927

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
EATON COUNTY (Cont'd)														
32458	15	922	265	116	47	10	0	200+			A	A+S		3413
30110	14	946	262	123	57	16	0	100+			A	A+S		3456
29293	13	950	252	123	48	11	0	160+			A	A+S		3468
32056	12	914	269	123	48	12	0	100+			A	A+S		3473
29625	11	923	286	132	40	15	0	200+			A	A+S		3500
29613	10	928	247	117	57	19	0	150+			A	A+S		3440
30081	8-1N-3W	912	230	130	39	14	0	453			A	A+S	4018	3382
30466	5	908	232	127	46	14	0	300+			A	A+S		3384
32548	1	923	280	128	42	18	0	426	24		A	A+S	4156	3542
29787	36-1N-5W	915	114	203	26	56	20	160	22	A+S	A	A	3718	3248
30308	35	977	140	208	25	67	18	100+		A+S	A	A		3278
27309	19	886	99	168	22	92	16	160	20	A+S	A	A	3684	3264
27845	12	956	117	174	15	76	13	153	21	A	A	A	3899	3483
33065	36-2N-4W	907	279	234	33	47	32	100+		A+S	A	A+S		3500
33131	35	913	172	131	39	20	0	417			A	A+S	4038	3431
32428	33	936	148	226	24	52	22	160		A	A	A+S	4016	3532
32043	31	946	75	275	20		0				A+S	A		3561
31839	4-1N-4W	956	130	212	26	54	24	184		A+S	A	A+S	3994	3518
32990	2	923	164	120	46	17	0	432	10		A	A+S	4030	3415
29530	36-1N-6W	915	100	180	12	77	4			A	A	A		3205

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
EATON COUNTY (Cont'd)														
	18	901	97	163	190	76	18	138	26	A	S	A	3752	3167
	30-1N-5W	885	98	178	22	70	14	146	22	A	A	A	3752	3167
	2-1N-6W	948	182	183	212	70	10	145	26	A	S	A+S	3840	3220
29891	13	952							30				3770	
27898	24	875			24	66	8	150	26	A	A		3660	
28372	25	882	107	163	22	68	8	152	24	A	A	A	3668	3257
22541	17	954	120	176	217	62	8	148	20	A	S	A+S	3702	3092
29860	24-2N-4W	916	136	208	26	70	14	172		A+S	A	A+S	4204	3714
28715	22-2N-5W	923	95	191	218	50	15	151		A	S	A+S	4052	3428
	22	914	96	182	224	42	23	150	22	A+S	S	A	4082	3464
22672	18	925	244	178	254	61	20	129	20	A+S	S	A+S	4032	3390
22516	9-2N-6W	937	210	194	254	80	16	120	22	A+S	S	A+S	4018	3354
30214	25	926	224	182	240	66	18	136	14	A+S	S	A+S	3974	3332
30513	20-2N-3W	943	300	232	32	50	16			A	A	A+S		3740
29000	35	896	258	123	43	12	0	400+			A	A+S		3512
30993	33	893	317	222	34	52	23			A+S	A	A+S		3554
32457	32	910	246	119	55	12	0	300+			A	A+S		3486
	28	936	290	180	64	16	14	200+			A	A+S		3612
	25	916	258	123	55	19	0	450+			A	A+S		3569
32443	21	927	340	238	54	50	20	200+		A	A+S	A+S		3724
31559	28-1N-3W	946	286	170	38	52	6	100+		A	A	A+S		3374
29331	23	951	245	117	49	13	0	200+			A	A+S		3423

APPENDIX 1. (Cont'd)

Location			Isopach							Lithofacies			Structure	
Permit #	Sec. T/R	Datum	Bu	A_2C	A_2E	A_1C	A_1E	NIAG	CI	A_1E	A_2E	Bu	CI	A_2C
EATON COUNTY														
29509	4-1N-3W	906	302	202	40	14	0	284	28		A	A+S	4048	3508
30317	9	901	290	202	32	50	6	242	26	A	A	A+S	3990	3458
27766	3	917	310	108	30	48	0	242	30		A	A+S	4070	3542
31525	22	926	228	110	56	10	0	468			A	A+S	3948	3304
28363	5-1N-4W	917	94	226	22	82	18				A	A		3440
29059	19	945	114	176	28	72	10	152	18	A	A	A	3802	3568
28163	17-1N-5W	883	118	168	189	76	12	138	28	A	S	A+S	3772	3190
30732	30	890	99	181	22	70	6	153	20	A	A	A	3676	3254
29863	34	965	99	95	42	11				A	A	3093		
30291	28	910	106	197	26	59	10	160	16	A	A	A	3678	3226
30202	25	940	105	209	30	52	16	162		A	A	A	3776	3306
29007	36-2N-3W	930	254	127	53	10	0	474	34		A	A+S	4072	3561
29225	17-2N-3W	894	265	229	54	16	0	304+			A	A+S		3696
31990	7	882	90	194	70						A	A		3920
32291	7	889	108	216	42						A	A		4010
30432	10-3N-5W	866	265	190	291	69	42	100	31	S	S	A+S	4382	3692
29546	32-3N-3W	936	271	226	178	58	47			A	A+S	A+S		3824
29160	16-4N-6W	840	249	181	322	59	147	85	42	S	S	S	4562	3747
28902	15-2N-4W	943	130	171	12	112	17	153	32	A	S	S	4235	3772
29117	24-2N-3W	870	219	272	24	88	5	192	34	A	A	A+S	4286	3704
29785	13	911	204	266	7	130	16	156		S	A+S	A	4344	3774
28263	27-1N-5W	920	100	194	22	74	10	158	24	A	A	A	3741	3296