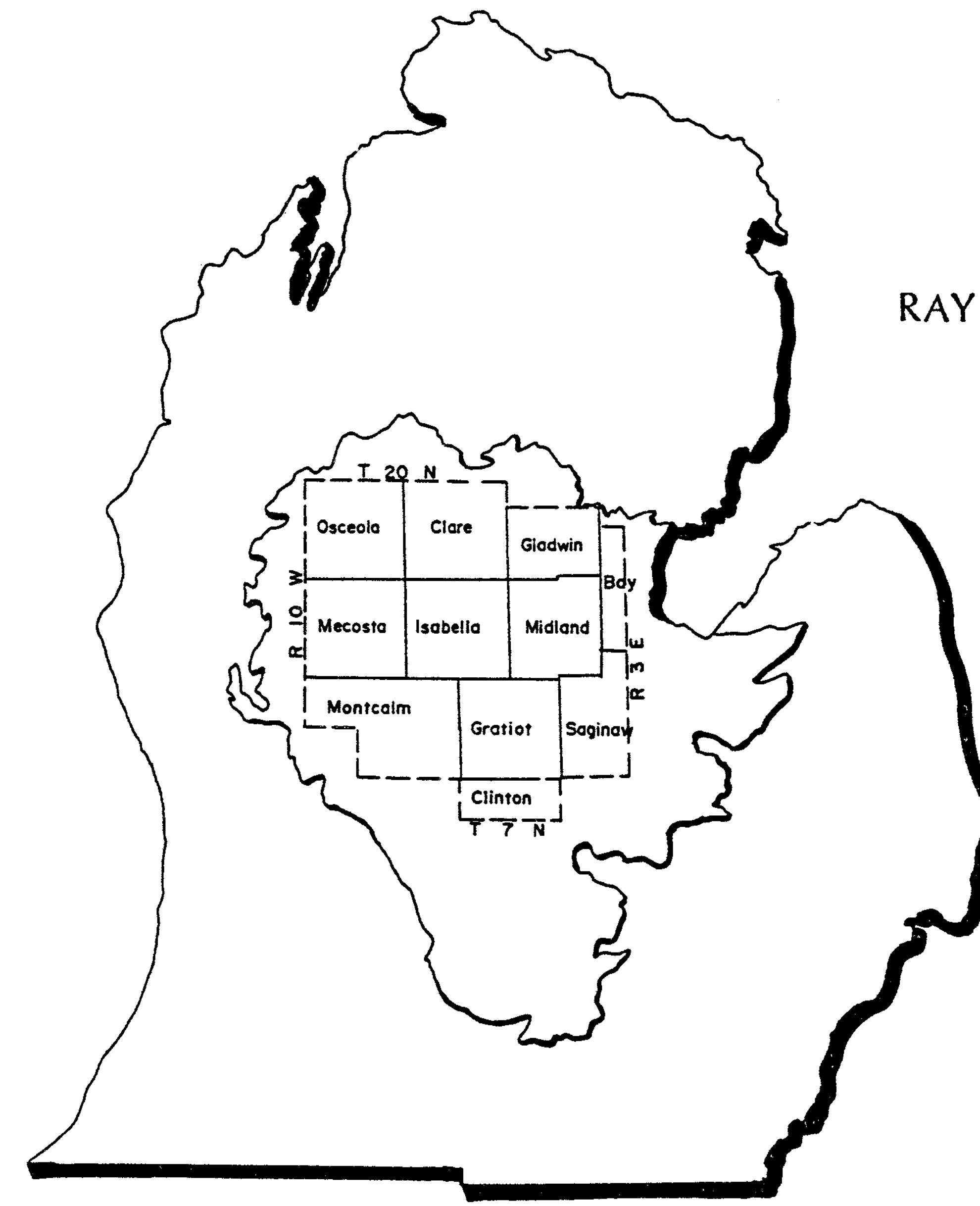
LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE PENNSYLVANIAN ROCKS AND THE BAYPORT FORMATION OF THE MICHIGAN BASIN



by

RAY VUGRINOVICH

1984

Michigan Department of Natural Resources

Geological Survey Division

Report of Investigation 27

Geological Survey Division

REPORT OF INVESTIGATION 27

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GSD

Lansing, Michigan
1984

STATE OF MICHIGAN
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DEPARTMENT OF NATURAL RESOURCES
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GEOLOGICAL SURVEY DIVISION
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CONTENTS

	Page
Illustrations	iv
Charts	v
Abstract	vii
Introduction	1
Previous Investigations	2
Lithostratigraphy and Depositional Environments	3
Bayport Formation	3
Parma Formation	9
Hemlock Lake Formation (new name)	12
Six Lakes Limestone Member (new name)	14
Lake George Formation (new name)	18
Winn Formation (new name)	21
Verne Member	23
Post-Pennsylvanian Deposition	24
Economic Potential	25
Hydrocarbons	25
Natural brines	26
Coal	26
Fresh Water	26
Chronostratigraphy	28
Acknowledgements	30
References	31

ILLUSTRATIONS

		Page
Figure 1	Study area and limit of Pennsylvanian rocks in Michigan	1
Figure 2	Location of geological test wells from which drill cuttings were examined	1
Figure 3	Location of wells from which only driller's logs are available	2
Figure 4	Location of wells from which geophysical logs are available	2
Figure 5	Isopach map of the middle unit of the Bayport Formation	4
Figure 6	Isopach map of the Bayport Formation	5
Figure 7	Location of wells in which the top of the Michigan Formation is marked by an anhydrite bed	6
Figure 8	Structural contours on the top of the Michigan Formation	8
Figure 9	Isopach map of the Parma Formation	10
Figure 10	Structural contours on the top of the Bayport Formation	11
Figure 11	Geophysical logs from the well from which the type section of the Hemlock Lake Formation is taken	12
Figure 12	Geophysical logs showing a thin coal at the base of the Hemlock Lake Formation	13
Figure 13	Geophysical logs from the well from which the type section of the Six Lakes Limestone Member is taken	14
Figure 14	Isopach map of the Six Lakes Limestone Member	15
Figure 15	Isopach map of the Hemlock Lake Formation	16
Figure 16	Structural contours on the base of the Hemlock Lake Formation	18
Figure 17	Geophysical logs from the well from which the type section of the Lake George Formation is taken	19
Figure 18	Isopach map of the Lake George Formation	20
Figure 19	Geophysical logs from the well from which the type section of the Winn Formation is taken	22
Figure 20	Isopach map of the Winn Formation	24
Figure 21	Structural contours on the top of the Pennsylvanian System	25
Figure 22	Location of wells in which coal is indicated by geophysical logs	26
Figure 23	Generalized relationships between Carboniferous rock-stratigraphic and time-stratigraphic units in Michigan	29

CHARTS

Page

Chart 1 Occurrences of coal in the study area indicated by geophysical logs 27

LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE PENNSYLVANIAN ROCKS AND THE BAYPORT FORMATION OF THE MICHIGAN BASIN

by

Ray Vugrinovich

Abstract

Geophysical well logs, drill cuttings, driller's logs, and core material from over 900 wells in an eleven-county area were used to define new stratigraphic units in the Pennsylvanian and Bayport strata of Michigan and to determine depositional environments for those units.

The Bayport Formation was the lowest formation studied. The Bayport is divided into three unnamed units. The lowest unit consists of sandstones, carbonate rocks, siltstones, and shales which were deposited in nearshore environments following a transgression of the seas which began in Late Mississippian time. The next unit is composed of limestone deposited in a shallow marine environment. Following stabilization of sea levels, sediments deposited in nearshore environments began to prograde into the basin, covering the marine sediments. Uplift in the early stages of the Bayport deposition resulted in localized topographic highs which were the preferred sites of growth for reef-forming organisms, resulting in patch reefs, detectable today as slight thickenings of the middle unit of the Bayport. The reefs were not all completely buried by the prograding tidal flat sediments.

The reefs remaining exposed were buried by barrier beach sands of the Parma Formation. The Parma barrier advanced to a line running from northeast to southwest through the approximate center of the study area. To the east and southeast of this line, sands were deposited in a shallow marine environment.

Behind the Parma barrier fine grained sediments of the lower part of the Hemlock Lake Formation (new name) were being deposited in back-barrier environments. A second marine transgression is recorded by rocks of the Six Lakes Limestone Member (new name). After stabilization of the sea levels, interbedded red and gray siltstones and sandstones of the middle part of the Hemlock Lake were deposited over much of the northern and northwestern portions of the study area. These sediments were laid down in an alluvial plain environment. Elsewhere dark shales were deposited in low-energy environments which may have had marine affinities.

Rivers began to erode the Hemlock Lake sediments, depositing the massive channel sands and dark shale channel fill deposits of the Lake George Formation (new name) and nearly filling in the depositional areas in the eastern and southeastern portions of the study area. Channel fill sediments and sediments deposited in swamps and by sluggish streams make up the overlying Winn Formation (new name). The Verne Member of the Winn records a third and much more limited incursion of marine water into the Michigan Basin.

Coal and fresh water are the only substances likely to be economically recoverable from rocks of the interval studied. Geophysical logs indicate that coal occurs in many places near the top of the Hemlock Lake Formation. Some of the coal deposits may approach ten feet in thickness. Water occurs in the channel sands of the Lake George and resistivity logs indicate that it may be fresh in places.

Paleontological evidence indicates that the Winn Formation ranges in age from late Morrowan to late Desmoinesian. Most of the Pennsylvanian sediments are Morrowan in age. Similarities to Chesterian sediments of Illinois suggest that the upper unit of the Bayport and the lower part of the Parma should be assigned a Chesterian age.

INTRODUCTION

The present study was begun in 1979 and was prompted by a statement in Lilienthal (1978, p.4) that:

> Very little work has been done previously on correlation of Pennsylvanian strata based on gamma ray log information ... Some lithologic studies have been done but none have been integrated with radiation logs and gamma ray response.

From an attempt simply to correlate the Pennsylvanian strata over their entire subcrop area, the study was modified into an attempt to decipher the lithostratigraphy and depositional environments of the Pennsylvanian rocks and the underlying Bayport Limestone in a somewhat more limited area (Figure 1). During the course of this study three things became apparent: first, the rocks studied are exceedingly complex -- possibly more so than other Paleozoic rocks in Michigan; second, the rocks are not hopelessly chaotic; and third, the present system of stratigraphic nomenclature of the Pennsylvanian rocks could be usefully modified to more accurately reflect the stratigraphy.

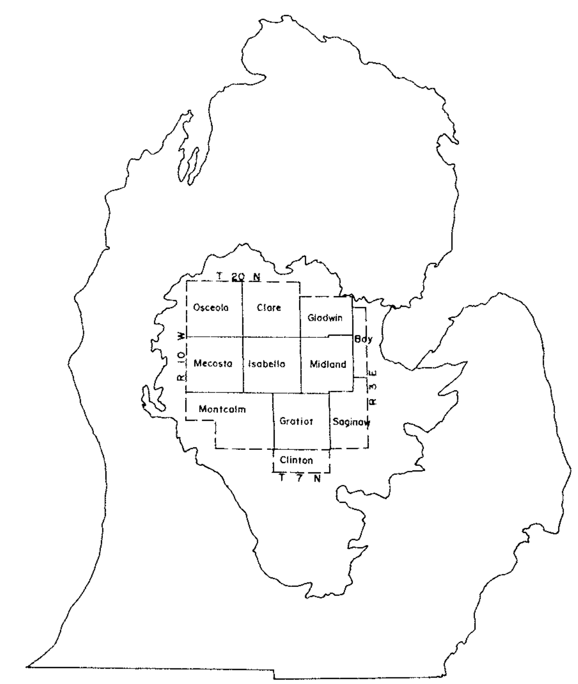


Figure 1 Study area and limit of Pennsylvanian rocks in Michigan

Four sources of information have been used in this study: drill cuttings examined by the author or written records of drill cuttings examined by personnel of the Geological Survey Division of the Michigan Department of Natural Resources or by petroleum industry personnel, driller's logs, cores, and borehole geophysical logs. All of the information used in this study is in the possession of the Geological Survey Division.

Due to the lack of economic targets in the rocks studied, drill cuttings are not usually collected from oil and gas boreholes with all the care which could be taken. In addition some of the formations are poorly consolidated; caliper logs show that severe caving, with resultant contamination of the drill cuttings, is the rule rather than the exception. For these reasons drill cuttings collected from wells drilled with rotary tools to deeper horizons have not been examined by the author. Fortunately, to compensate for this lack of information, the Geological Survey Division has in its possession drill cuttings from shallow (total depth of 2,000 feet or less) geological test holes drilled by the Sohio Petroleum Company in the 1940's. The cuttings from 19 of these wells (Figure 2) were examined in detail and were used to compare geophysical log responses with lithology. Mr. Thomas Knapp, formerly employed by Sohio Petroleum, was involved with the drilling of these wells and has advised that the cuttings are probably as

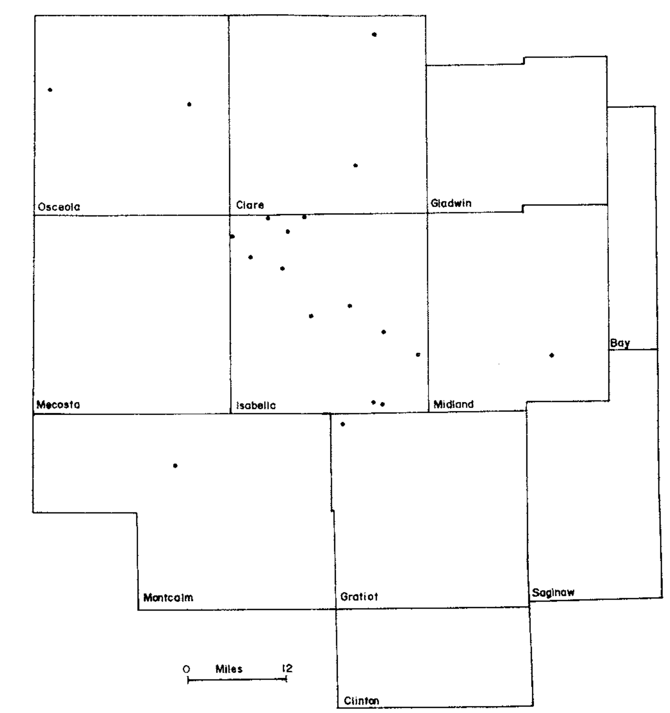


Figure 2 Location of geological test wells from which drill cuttings were examined

good as can be obtained. The sample descriptions prepared from these cuttings are available from the Geological Survey Division, Michigan Department of Natural Resources.

Driller's logs are made on site by the person or persons actually drilling the well, on the basis of a naked-eye examination of the cuttings at the wellsite. They are available in abundance for the interval under study and range in quality from very poor to very good. Insofar as possible, driller's logs were not used unless they could meet three criteria. First, they must have been made from cuttings recovered from wells drilled with cable tools. Second, the overburden must have been described as something other than "drift". Third, the driller's logs should mention only one lithology in each interval and should not include such terms as "shale and sand" or "shale and shells" and so forth. This set of conditions could not always be met, particularly in areas where only one or two wells have been drilled. Nevertheless, it was possible to utilize many of the driller's logs in the files of the Michigan Geological Survey (Figure 3).

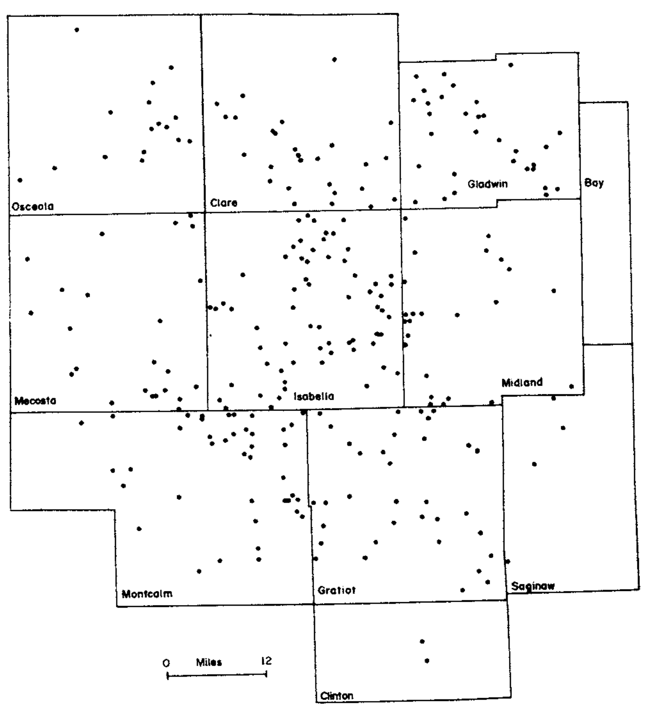


Figure 3 Location of wells from which only driller's logs are available

Borehole geophysical logs are recordings of a property or properties of the rocks surrounding a borehole or of the fluids in the rocks, versus depth. They are perhaps the most reliable records available for any well. In many instances they are the only records available for the interval under study. A large number of borehole geophysical logs was used in this study (Figure 4).

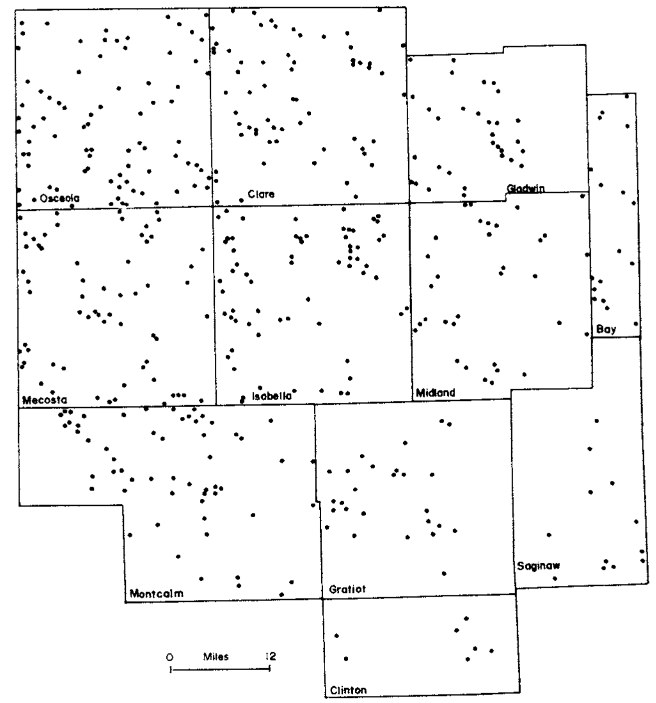


Figure 4 Location of wells from which geophysical logs are available

A single core of a portion of the Pennsylvanian interval in the study area was available. This core was cut by the Dart Oil and Gas Corporation in Montcalm County. Because core information is essentially non-existent, the small-scale sedimentary structures which would aid in environmental interpretation could not be observed. Paleontological evidence is similarly scarce, although use has been made of the available published information.

The results of this study are an interpretation of the lithostratigraphy of the Pennsylvanian and Bayport rocks and of the depositional environments in which those rocks originated. Short discussions of the late Paleozoic structural evolution of the Michigan Basin, the economic geology of the interval studied, and a review of the published information bearing on the chronostratigraphy of these rocks are also included.

PREVIOUS INVESTIGATIONS

Bayport strata were first described by Douglass (1841) who gave the name Pointe au Gres to limestones exposed in eastern Arenac County. The name Bayport was subsequently proposed for correlative rocks in Huron County and this name has supplanted the name Pointe au Gres. Lane (1906) placed the Bayport in the Grand Rapids Group along with the Michigan Formation.

Cohee (1951) and Lilienthal (1978) provided correlation charts showing the Bayport along with short discussions of the lithology. Newcombe (1932) discussed variations in Bayport lithology and thickness on a regional basis utilizing data from oil and gas boreholes. Bacon (1971) described depositional environments from a study of the type section. Lasemi (1975) utilized drill cuttings from 200 boreholes to prepare lithofacies, clastic/carbonate ratio, structural, and isopach maps of the Bayport. He further divided the formation into three informal units and inferred depositional histories for the units.

Other studies dealing with the Bayport have considered only limited areas of Michigan, have provided only summaries of information and conclusions reached by previous workers, or have not treated the Bayport separately from other Mississippian rocks.

Rocks of the Pennsylvanian system have been the objects of more detailed studies primarily because of the occurrence of coal in these rocks. Coal was first discovered near Jackson in 1835 and Houghton (1838) provided the first published treatment of the Jackson strata, assigning the rocks to the "Coal Measures". Winchell (1861) proposed a threefold division of Pennsylvanian strata and their separation from underlying rocks. Rominger (1876) considered the lithostratigraphy of the Pennsylvanian rocks and discussed the rapid lateral facies changes characteristic of the interval. Studies making extensive use of data obtained from boreholes drilled during coal exploration programs were published by Lane (1902), Cooper (1906), and Smith (1912). Lane's was the most comprehensive study, dealing with stratigraphy, correlation and nomenclature of the individual coal beds, and depositional environments of the coals.

Other studies which were published in the annual reports of the State Geologist prior to the 1930's added little new information concerning the Pennsylvanian strata. Newcombe (1932) provided the first study to utilize much information from oil and gas boreholes and provided much regional information about the Pennsylvanian rocks. Kelly (1930, 1931, 1933, 1936) produced several studies of the Pennsylvanian system based principally on outcrops in Ingham, Eaton, Shiawassee, Genessee, Tuscola, and Arenac counties, other widely scattered outcrops, and fossil material collected from coal mines in Bay and Saginaw counties. Kelly discussed the lithostratigraphy, correlation, and depositional environments of the Pennsylvanian strata and explained the rapid lateral variations in lithology by the cyclothem hypothesis. Until recently, Kelly's were the only modern studies dealing with the stratigraphy and depositional environments of Pennsylvanian strata in Michigan.

In 1949 Arnold prepared a study of the fossil flora of the Pennsylvanian rocks of Michigan. Arnold's conclusions are discussed further below. Recently Shideler (1963) and Wanless and Shideler (1975) presented the results of regional studies of the Pennsylvanian system based on drill cuttings from oil and gas boreholes. Depositional environments were inferred from patterns of clastic deposition, isopach maps, and sand/shale ratio maps. Tyler (1980) discussed depositional environments inferred from a study of drill cuttings and borehole geophysical logs obtained from wells drilled into the Six Lakes gas storage field in Montcalm and Mecosta counties.

LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

BAYPORT FORMATION

Bayport Formation is the name proposed for the sequence of sediments which occurs between the top of the Michigan Formation and the base of the Parma Formation. The dominant lithologies in this interval are carbonate rocks and sandstones. Shales and siltstones may be locally abundant. Evaporites occur only rarely. Drill cuttings and geophysical logs suggest a threefold division of the Bayport.

The lower part of the Bayport consists of sandy carbonate rocks and calcareous or gypsiferous sandstones with lesser amounts of shales and siltstones. These lithologies appear to be randomly interbedded and to vary considerably in thickness over short distances.

The carbonate rocks of the lower part of the Bayport are finely crystalline to microcrystalline limestones that are dolomitic in some parts of the section. These rocks are predominantly light gray to yellowish gray but range to dark gray and dark olive gray. The darker-colored carbonate rocks are commonly dolomitic. A residue of fine, silt-sized material remains when the limestones are dissolved in acid. Acid etching leaves a dull opaque surface; rarely, thin silt laminae are visible after acid etching. Fine-grained quartz sand occurs frequently as lenses or thin laminae. Isolated rounded fine to coarse quartz grains are common and may compose a significant proportion of the rocks.

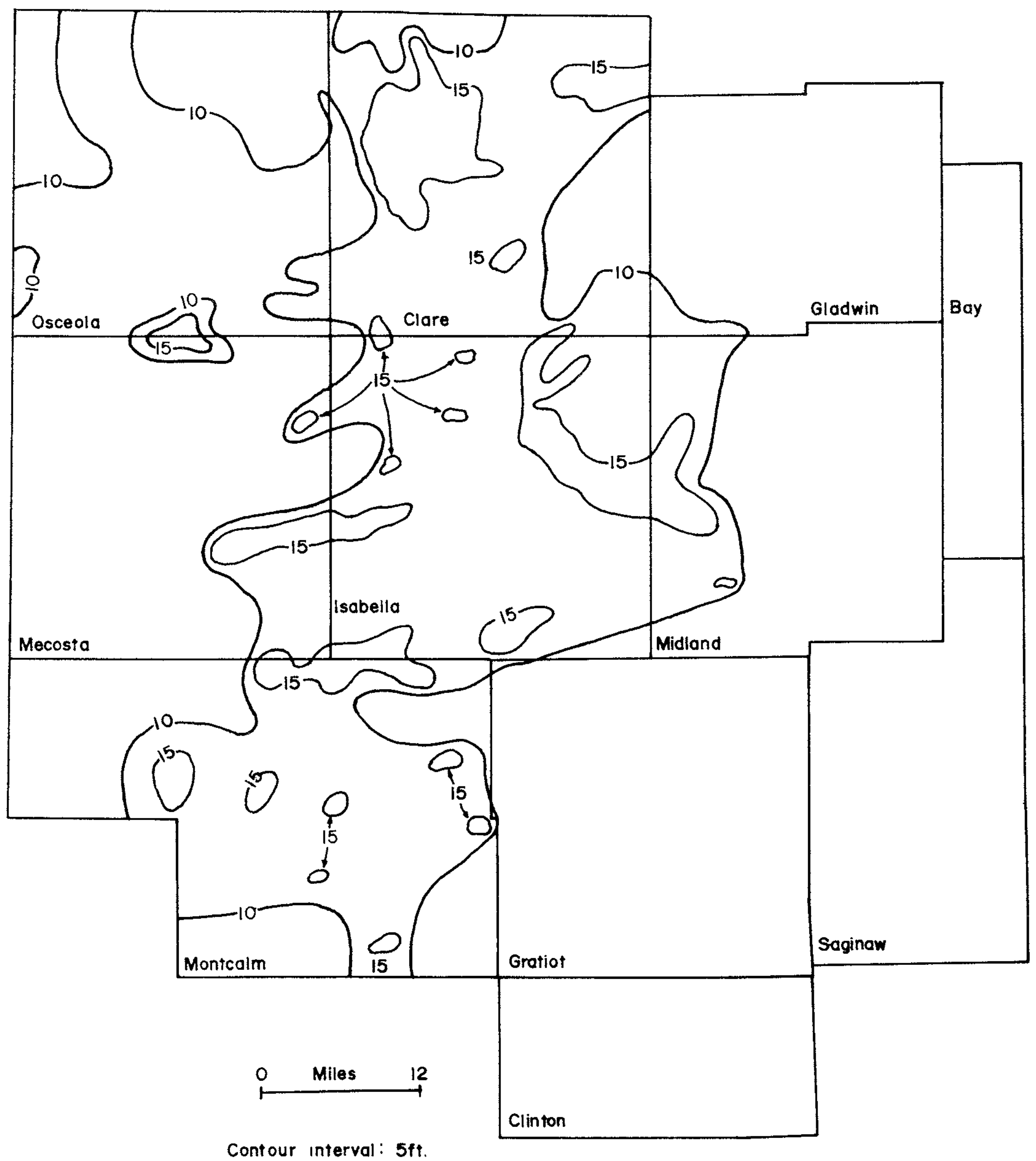
Nodules of gypsum are found in the limestones and dolomites in some instances. Metallic sulfides, usually in the form of minute euhedral crystals, occur rarely.

Shales and siltstones of the lower part of the Bayport Formation are typically shades of reddish gray or reddish brown and greenish gray or medium gray. These shales are calcareous or dolomitic and occasionally have minute euhedral crystals of metallic sulfides. Rarely, fine rounded transparent quartz grains are present. The reddish shales may have minute mica flakes. Some of the gray shales have the property of swelling and disintegrating in fresh water. The reddish and grayish shales appear to be intimately interbedded.

A small proportion of the shales of the lower part of the Bayport are light green (5GY 6/1), slightly calcareous, and have a waxy appearance. Very rarely, dark, possibly carbonaceous patches and streaks are observed in this shale. The light green shales are associated with the reddish and grayish shales, but whether they occur as thin discrete beds or as isolate lenses is not known.

A brownish-black, noncalcareous, fissile shale, having a flinty appearance, occurs in the lower part of the Bayport Formation in some wells. It is more common near the base of the formation and seems to be associated with the carbonate rocks.

The sandstones of the lower part of



-ure 5 Isopach map of the middle unit of the Bayport Formation

the Bayport are white or yellowish gray, moderately well sorted to very well sorted, fine- to coarse-grained and poorly cemented. The cement is commonly calcareous but calcareous cement may be replaced by gypsum cement in the sandstones near the base of the Bayport. The quartz grains are commonly frosted and. Iron staining, which may be quite intense, occurs frequently. Accessory non-quartz minerals are not common.

Geophysical logs indicate that the contacts between individual beds in the lower part of the Bayport are well defined. None of the individual beds can be traced for any distance.

The middle part of the Bayport Formation is composed of a very finely crystalline to microcrystalline, light gray to very light gray limestone. Thin laminae of fine grained to very fine grained, well sorted, transparent quartz grains occur in many of the cuttings. Metallic sulfides are rare, occurring as minute, euhedral crystals. A cloud of fine-silt-sized to clay-sized debris is released when the limestone is dissolved in acid. The only fossils observed in the cuttings are worn crinoid columnals and what are probably fragments of brachiopod shells. Both varieties of fossils are uncommon.

The middle unit of the Bayport can be traced across the entire study area (Figure 5). Geophysical log responses indicate that both the upper and lower contacts are sharp.

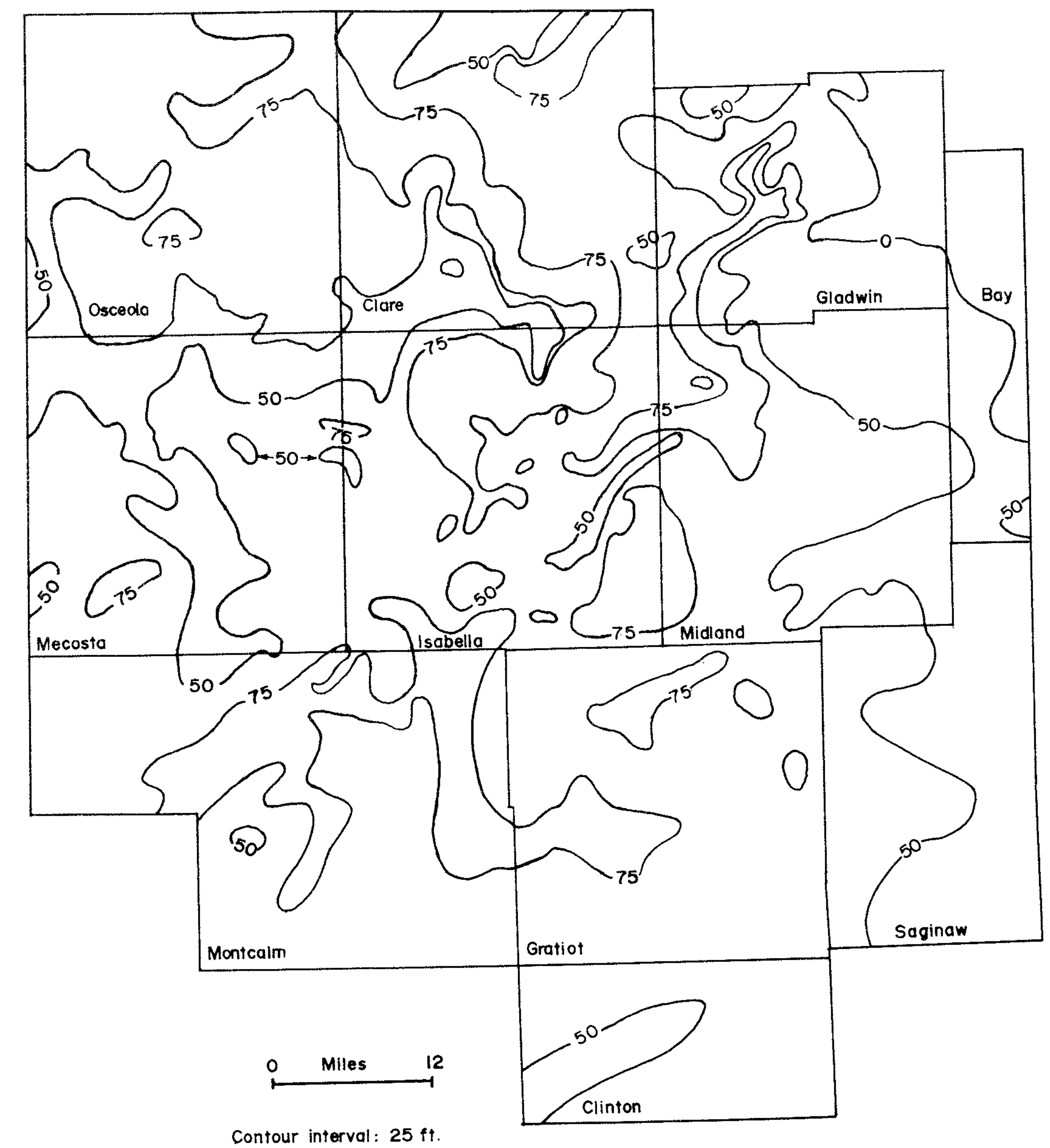


Figure 6 Isopach map of the Bayport Formation

In many wells the middle unit of the Bayport is overlain by rocks of the Parma Formation. Frequently, however, the limestone is overlain by a sequence of rocks similar to those in the lower part of the Bayport. The major difference between the uppermost and the lowermost portions is the rare occurrence of discrete gypsum beds in the uppermost portion. Contacts between individual beds in the uppermost portion are well defined on geophysical logs.

As previous investigators have noted, the thickness of the Bayport Formation is highly variable (Figure 6). In the northern third of Bay County and most of eastern Gladwin County, geophysical logs do not show the distinctive responses of the middle unit of the Bayport. The entire formation may be absent, or it may be composed predominantly of sandstone. The available data do not allow a definitive statement to be made. Figure 6 has been constructed as though the entire Bayport is absent from northern Bay County and northeastern Gladwin County.

In the study area the Bayport shows regions of thickening which trend predominantly northeast to southwest. Away from these regions Bayport thicknesses in excess of 75 feet are not common. A sinuous thinning trend occurs in the western part of the syudy area. The thinning trend divides in central northwestern Mecosta County; the northern branch continues east into southern Clare County before bending sharply to the south and terminating abruptly. The southern branch wanders through Mecosta County in a southerly direction; at the southern boundary of Mecosta County this branch appears to curve to the northeast before terminating. Scattered areas of thinning in southern and eastern Isabella County may be related to the southern thinning trend.

The lower contact of the Bayport with the Michigan Formation is easily denoted in many wells by the occurrence in the drill cuttings of a sucrosic, white to yellowish gray, somewhat silty anhydrite, rarely more than 5 feet thick (Figure 7). Where the anhydrite is absent a basal sandstone commonly marks the contact. Where neither of these lithologies is present the contact is placed at the first appearance of the dark gray shales of the Michigan Formation. The lower contact is easy to identify on geophysical logs, although the anhydrite bed cannot be detected if only a gamma-ray log is available.

The upper contact of the Bayport is normally sharp. It is marked in cuttings by the appearance of the distinctive sandstones of the Parma Formation. The upper contact may be difficult to identify on geophysical logs, even if a gamma-ray-formation density-neutron porosity combination log is available. Throughout the study area the top of the Bayport is frequently marked by

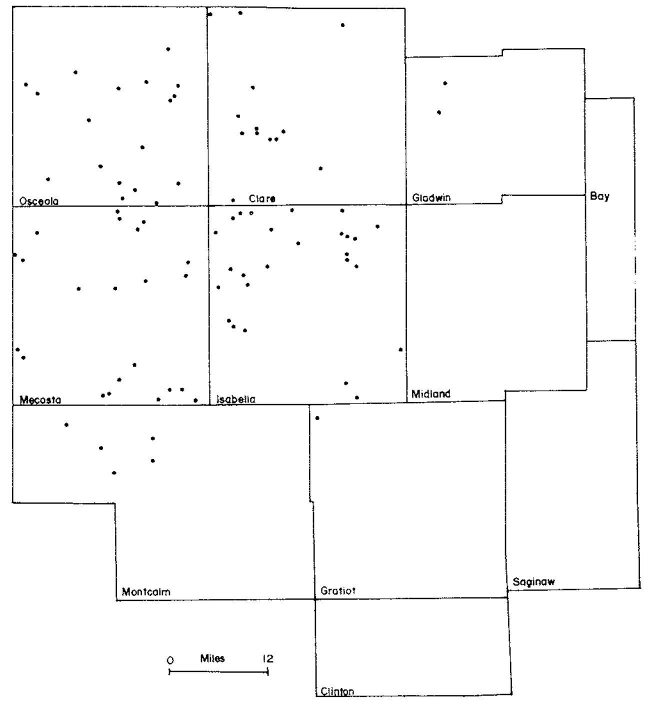


Figure 7 Location of wells in which the top of the Michigan Formation is marked by an anhydrite bed

an increase in gamma-ray count of 5 to 10 API units above the gamma-ray count in the overlying Parma Formation. In wells which were not logged with a neutron porosity-formation density combination tool, the top of the Bayport was picked at this gamma-ray increase.

At the present time, structure contours on the top of the Michigan Formation show an assymetric basin with a gentle slope to the east (Figure 8). Two structurally low areas exist. The larger is located in central and northern Midland County and includes portions of Gladwin, Isabella, Bay, and Clare Counties. The smaller is centered over central Isabella County. Both low areas are oriented northwest to southeast and are separated by a higher area with a relief of 50 to 100 feet. This elevated area is the surface expression of the structure in which are located the Porter, Mt. Pleasant, Leaton, Rosebush, Vernon, Wise, and Clare City hydrocarbon fields. As is discussed below, this author believes that the structure was not in existence at the beginning of Bayport depositional time.

The physical characteristics of the lower part of the Bayport indicate that the sediments were deposited in a number of different environments. Rivers and streams deposited large amounts of fine terrigenous sediments into environments that ranged from highly oxidizing to slightly reducing. Fluctuations in terrigenous sediment supply or localized transgressions of marine water

resulted in the deposition of carbonate rocks. Locally hypersaline brines were formed resulting in evaporite deposition or dolomitization of the limestones. Offshore bars, barrier beaches, and spits undoubtedly existed. The complex lateral and vertical interbedding of lithologies indicate that environmental conditions changed repeatedly and perhaps rapidly. A transitional marine environment, in which terrigenous mudflats cut by sluggish streams alternated with carbonate/evaporite tidal flats along a coastline of low relief is suggested as the depositional system for the lower part of the Bayport Formation.

The middle part of the Bayport is marked by an almost complete absence of terrigenous sediments coarser than fine sand. A certain amount of clay-sized and silt-sized material was deposited, but it was not concentrated in discrete bodies of silt or clay. The few fossils are from marine organisms. An open marine environment is the setting in which the limestones of the middle part of the Bayport were deposited. Lime muds were deposited in shallow water. Terrigenous sediments were being introduced, but not in such large quantities that filter-feeding marine organisms could not survive. Small amounts of fine sand were introduced from time to time, probably by storm surges.

The upper part of the Bayport records a return to a transitional marine shoreline environment. Sea levels stabilized while the supply of terrigenous sediment remained constant or increased. The result of this combination was that mudflats began to prograde over the shallow marine sediments deposited in the Bayport sea. Small bodies of water were trapped by the advancing tidal flats and mudflats, resulting in the deposition of discrete anhydrite beds of limited areal extent and thickness. Fluctuations in sediment supply again caused a complex sequence of sediments to be deposited; the rocks reflect unstable, shifting environmental conditions.

It was probably during deposition of the upper part of the Bayport that the thinning trend discussed above began to form. Cross sections based on geophysical logs show that the thinning trend corresponds to a trough which was eroded into pre-existing sediments, but not so deeply as to remove sediments of the Michigan Formation. The sediments from within the thinning trend are marked by an abundance of clastic rocks (predominantly sandstones) or by interbedded clastics and carbonate rocks. These sediments were probably deposited by streams that meandered across the tidal flats, eroding the tidal flat sediments and depositing alluvial sediments. After a channel had shifted, tidal flat sedimentation began again. The streams probably entered an open sea located in the southern and eastern portions of the study area. The point of entry into this sea was in southeastern Isabella County.

The location of the inlet of the Bayport seas into the Michigan Basin has been much debated. An answer to the question "From which direction did the seas come?" can be provided by considering the sediments immediately underlying the Bayport. The anhydrite bed which marks the top of the Michigan Formation is restricted to the western and northern portions of the study area (Figure 7). The presence of anhydrite indicates that hypersaline water existed in this area of the Michigan Basin at the close of Michigan depositional time. By applying the model of carbonate and evaporite deposition in a restricted basin discussed by Briggs (1957, 1958), it can be determined that the inlet to the Michigan basin at the close of Michigan depositional time was located to the east or southeast of the study area. No definite statement can be made regarding connections with the Appalachian Basin or the Illinois Basin.

The contact between the Bayport and Parma Formations has been considered to be a disconformity since Lane and Seaman (1909) so labeled it. Newcombe (1933) also determined that the Bayport and the overlying Parma were in unconformable contact. His conclusion was apparently greatly influenced by studies in the eastern United States indicating that considerable erosional relief existed between the Mississippian and Pennsylvanian rocks in that area. Newcombe further supported his thesis by noting that ". . . locally the Parma sandstone rests directly on the Upper Marshall (Napoleon) sandstone . . ." and further ". . . that average sized anticlines in the Pennsylvanian rocks do not persist with like characteristics to any depth in the underlying beds."

Each of Newcombe's observations is undoubtedly true. However they do not prove the existence of a regional unconformity. In certain portions of the study area carbonate rocks typical of the Bayport are absent. This absence could be explained by local uplift and erosion. Overall, however, the architecture of the study area remained essentially unchanged between the end of Michigan depositional time and the end of Parma depositional time (Figures 8 and 15). The only change noted is a shallowing of the entire basin, which would be expected during an episode of basin infilling undisturbed by regional uplift.

A further argument against the theory of regional uplift and the occurrence of a regional disconformity at the top of the Bayport is offered by the regional variations in thickness of the middle part of the Bayport (Figure 5). The middle limestone unit is actually thicker over known hydrocarbon fields, many of which show

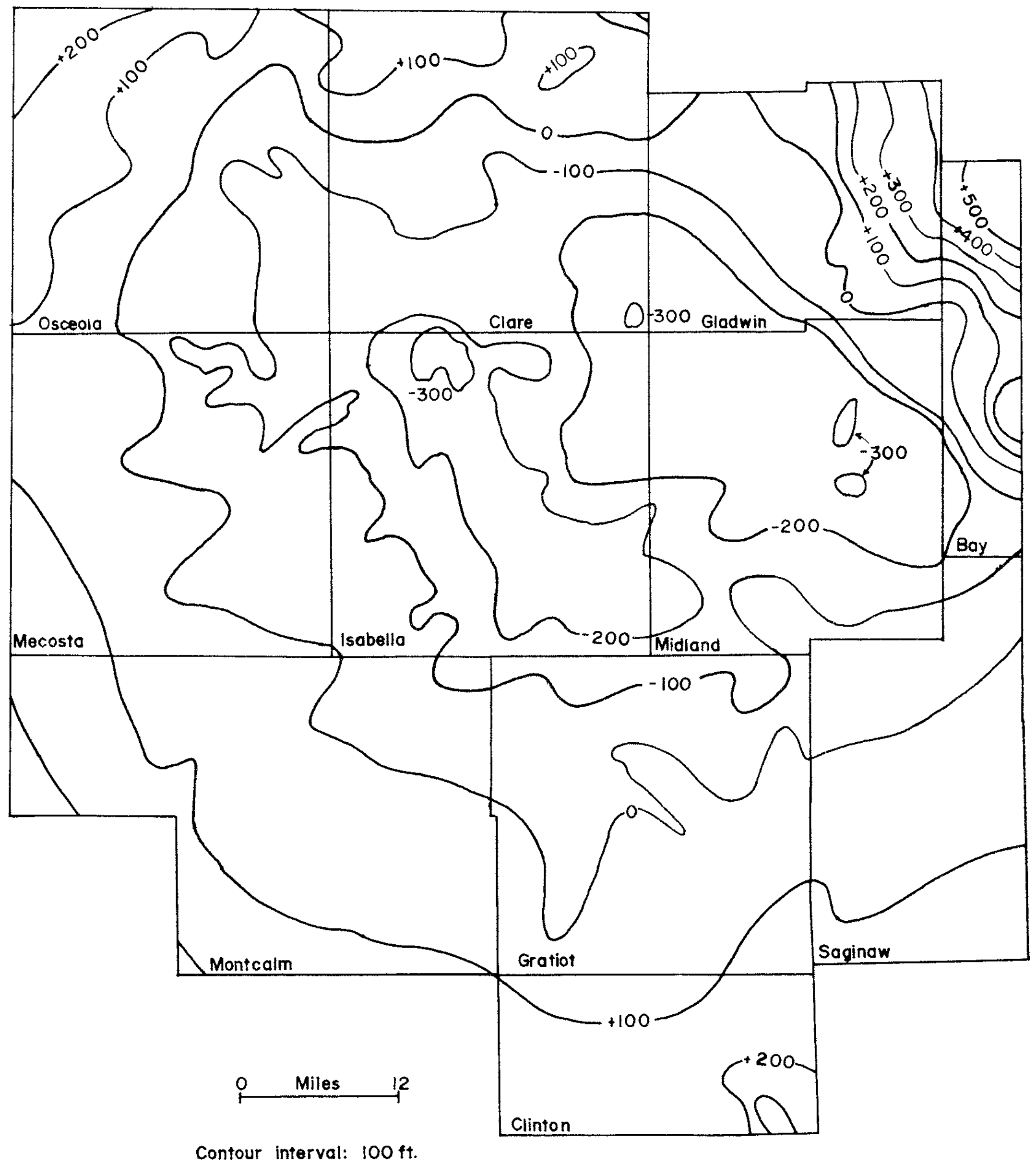


Figure 8 Structural contours on the top of the Michigan Formation

evidence of uplift. Freeman-Lincoln, Hamilton, Coldwater, Vernon, Leaton, Mt. Pleasant, and Broomfield fields, as well as many of the fields in Montcalm County, have more than 15 feet of the middle unit, compared with less than 15 feet in much of the remainder of the study area.

The occurrence of anomalous thickening of the middle Bayport unit has a direct bearing on the timing and extent of any post-Michigan uplift. That an uplift did occur is shown by the fact that the easily traceable, so-called triple gypsum marker bed is structurally high over many of the hydrocarbon fields in the study area. However, the interval between the top of the triple gypsum and the top of the Michigan Formation is quite uniform in thickness, indicating that the uplift postdates Michigan depositional time and that significant erosion of the upper part of the Michigan Formation following uplift did not occur. The upper unit of the Bayport thins or pinches out over many of the hydrocarbon fields in the study area, suggesting that the uplift had occurred by the time deposition of the upper unit began. In addition the upper part of the Bayport is commonly well-developed in the western and northwestern portions of the study area, from which it should have been removed by post-uplift erosion.

This author believes that the items discussed in the preceding paragraphs can be

explained by postulating an episode of localized uplift beginning near the end of Michigan depositional time and lasting no longer than the end of the time period marked by the middle unit of the Bayport Formation. The result of this uplift was a series of localized topographic highs that were drowned during the marine transgression in middle Bayport depositional time. The highs then served as preferred growth sites for marine organisms, resulting in the formation of patch reefs similar to the patch reefs found in the Devonian of Michigan and discussed by Cloud (1952). None of the Bayport patch reefs is more than about 30 feet thick, indicating that they grew in shallow seas. Following the end of the marine transgression, these high areas in many instances were not buried by the sediments of the advancing tidal flats and mudflats, thus explaining the absence of the upper part of the Bayport Formation over many of the hydrocarbon fields in the study area. Final burial of the remains of the patch reefs did not occur until the deposition of the Parma sediments.

PARMA FORMATION

The name Parma was applied by Winchell (1861) to the sandstones that outcrop in Parma Township, Jackson County, Michigan. Kelly (1936) treated the Parma separately from the overlying sedimentary rocks of Pennsylvanian age, and noted that correlative rocks might be restricted to the southern area of the Pennsylvanian subcrop.

Correlation between the outcrops in Jackson County and Calhoun County and the sequence of sandstone above the Bayport Formation in the study area and the remainder of the Michigan Basin is difficult at best. The known exposures of the Parma are small, of poor quality, and discontinuous. Lateral and vertical contact relationships are not visible at the outcrops. Additionally, the detailed stratigraphy of the Pennsylvanian rocks in the vicinity of the type section is poorly understood. For these reasons, the name Parma was dropped from formational status on the chart entitled "Stratigraphic Succession in Michigan" published in 1964 by the Geological Survey Division of the Michigan Department of Natural Resources.

Geophysical logs from Parma Township, Jackson County, show that along the eastern edge of the township the Michigan Formation is encountered at a depth of 50 to 100 feet. Sandstones occurring at the surface could be placed in the Bayport. However Bayport thicknesses in excess of 50 feet would not be expected so close to the present-day edge of the formation, making it unlikely that the type Parma section actually belongs in the Bayport. The area in which the type section is located has not undergone any unusual uplift which might have exposed Bayport strata. Finally the lithology of the rocks at the type section and at exposures in Jackson and Calhoun Counties is very similar to the lithology of the sandstones in the study area. For these reasons this author believes that the name Parma should be raised again to formational rank and used to designate the sequence of sandstones immediately overlying the Bayport Formation.

Quartz sand, commonly in the form of free grains, is the dominant lithology found in drill cuttings from the Parma. The sands range from well sorted to moderately well sorted, fine to coarse grained, and rounded to angular. The grains may be frosted and lightly iron stained, and vary from transparent to opaque. Cement, if present, is calcareous. Cemented fragments are white to yellowish gray, extremely poorly cemented, and silty. Trace amounts of metallic sulfides are found in some cuttings, but there is no well-defined horizon of metallic sulfide occurrence. Accessory minerals include zircon and tourmaline, but accessory minerals are not a large fraction of the Parma sands. No fossils are known from the Parma.

In some wells the sandstone is replaced by a siltstone or shaly siltstone. In other wells, the Parma Formation consists of sandstones interbedded with siltstones. These lithologies are inferred from geophysical logs; no examples of the finer-grained lithologies were noted in the drill cuttings, although some driller's logs refer to gray shale in the Parma. The finer-grained rocks are most commonly seen in wells located along or near the eastern edge of a thickening trend defined by the 75-foot isopach line. The finer-grained lithologies appear to interfinger laterally with clean sandstones more typical of the Parma.

The isopach map of the Parma (Figure 9) bears broad similarity to the isopach map of the Bayport and shows several interesting features . A central thickened trend runs northeast to southwest approximately through the center of the study area. The eastern edge of the trend approximately parallels the eastern edge of the thickening trend in the Bayport, but the trend of the Parma is wider and is better defined. Within the thickened trend in the Parma are several areas with a thickness of more than 100 feet. These areas are scattered more or less at random but all appear to be oriented northeast to southwest. To the east and west of the thickened trend the Parma ranges from 30 to 50 feet in thickness, and only isolated areas have more than 50 feet of Parma sediments.

Like the Bayport, the Parma also shows an area of thinning in the western portion

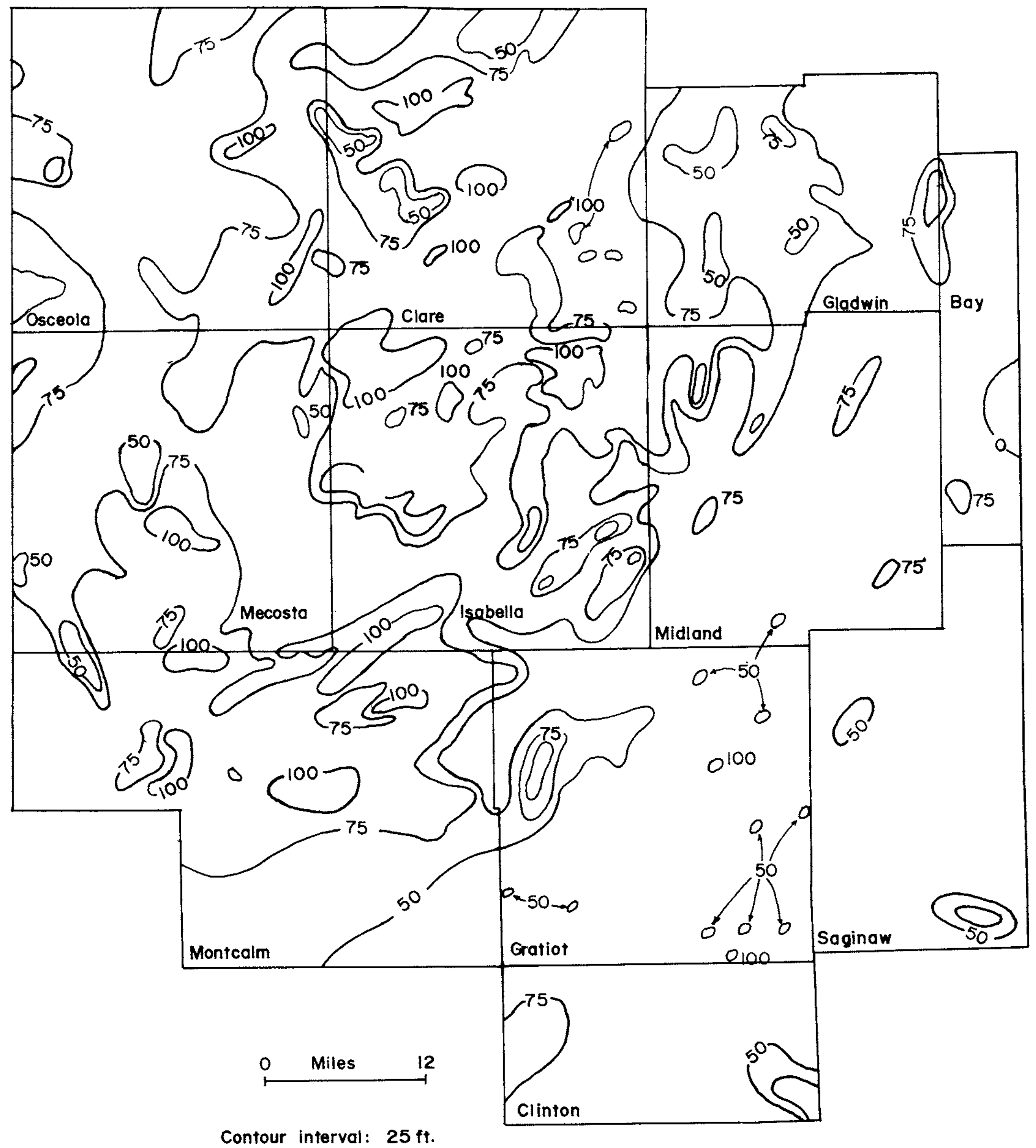


Figure 9 Isopach map of the Parma Formation

of the study area. There is only a single thinning trend which trends eastward through the southwestern part of Isabella County before expanding to cover much of eastern Isabella County and merging with the broad area of thinner Parma sediments to the east. Within the thinned zone, Parma sediments are 50 to 75 feet in thickness. In the southeastern portion of Isabella County three localized areas have more than 100 feet of Parma sediments.

At the beginning of Parma depositional time the uplift discussed above combined with the basin infilling which occurred during Bayport deposition had resulted in the formation of three structurally low areas which were considerably shallower and of a somewhat smaller total area than the low areas which had been in existence at the close of Michigan depositional time. The overall architecture of the study area had not been greatly changed by the deposition of the Bayport Formation or by the uplift discussed above (Figure 10).

Sediments of the Parma were deposited in high-energy environments from which the clay-sized and finer silt-sized material was removed. Fossils were not preserved in this environment. The Parma sediments overlie either marine sediments or marginal marine tidal flat or mudflat sediments of the Bayport. A marginal marine barrier-beach environment is proposed for the Parma sediments on the basis of these

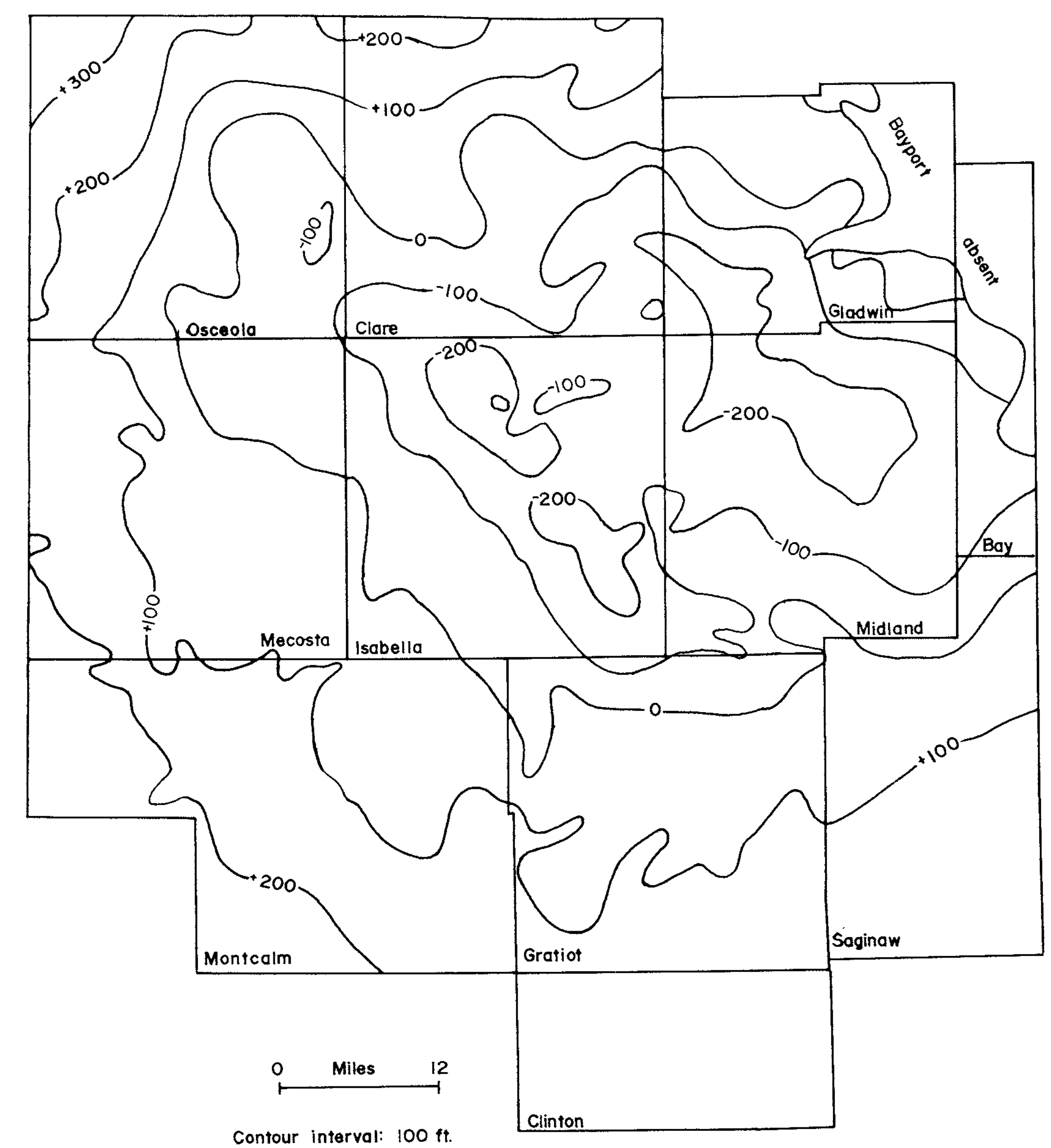


Figure 10 Structural contours on the top of the Bayport Formation

characteristics. The Parma barrier formed in the western portion of the study area and following sea level stabilization in Bayport time prograded across the marginal marine sediments of the upper part of the Bayport. The barrier sands covered the remains of those patch reefs which were still exposed above the tidal flats. The farthest eastward advance of the barrier is marked by the easternmost 75-foot contour line of the thickening trend. East of the barrier were open seas which were the sites of deposition of fine to coarse sands. It is believed that the open seas were connected to neighboring depositional basins.

Along the high-energy eastern edge of the Parma barrier were localized areas that were protected from the winnowing action of the open seas. These may have been small lagoons or areas to the landward of spits or offshore bars which were sheltered from wave action. It was in these areas that the siltstones and shaly sandstones discussed above accumulated. The scarcity of the finer-grained sediments indicates either that submerged bars were not common or that the coastline lacked sheltered bays where lower-energy environments might occur.

The thinning trend discussed above was caused by the same fluvial system that became active during Bayport depositional time. Southeastern Isabella County remained the site of the inlet of this system to the open seas to the east and southeast. The localized areas of increased Parma thickness in southeastern Isabella County mark the sites of tidal deltas.

HEMLOCK LAKE FORMATION (new name)

Hemlock Lake is the name here proposed for a sequence of sandstones, siltstones, shales, and carbonate rocks which immediately overlies the Parma Formation in the study area. The name is taken from a small lake near the well from which the type section was selected. This well is the Michigan Consolidated Gas Company No. L-125, located in the CN NW1/4 NW1/4, S. 29, T.18N., R.5W., Lincoln Township, Clare County (Figure 11).

Drill cuttings and geophysical logs suggest that the Hemlock Lake Formation can be divided into an upper part and a lower part. The lower part is a sequence of thinly-bedded sandstones, siltstones, and shales, with minor amounts of carbonate rocks. The sandstones are yellowish gray to

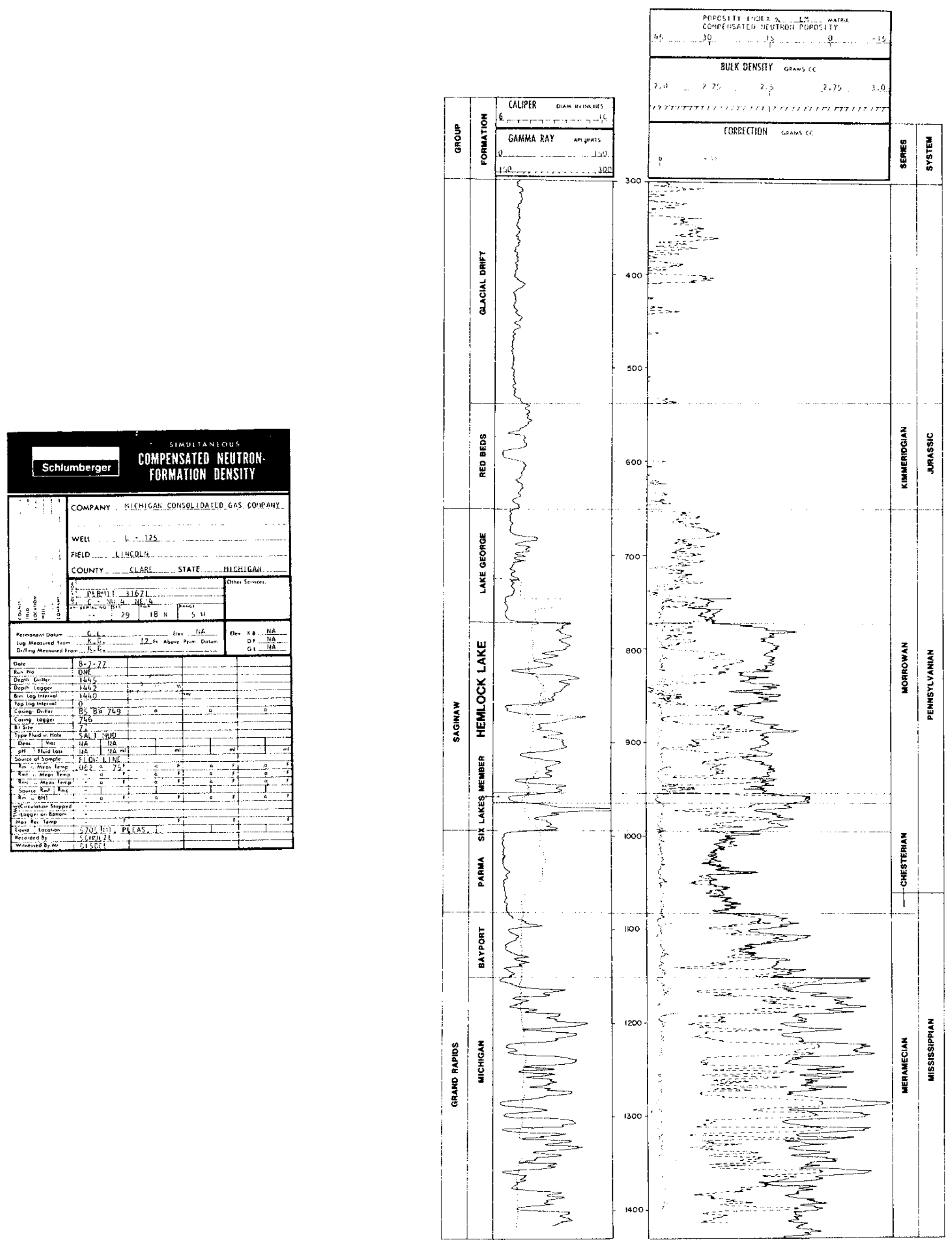


Figure 11 Geophysical logs from the well from which the type section of the Hemlock Lake Formation is taken

light gray, fine grained to medium grained, moderately well sorted to well sorted, and well-cemented with noncalcareous cement. Quartz is the dominant lithology and the grains range from angular to rounded. Grain frosting is common.

Siltstones of the lower part of the Hemlock Lake Formation are varying shades of dull reds and lighter grays. The gray and red siltstones are probably interbedded. Carbonized plant fossils are found in the red shales in some cuttings. The siltstones are dolomitic. During reaction with hydrochloric acid, the red color gradually changes to a gray or brownish gray color. In some cuttings metallic sulfides are found in the siltstones, occurring as minute euhedral crystals. Metallic sulfides are found in abundance in some sets of cuttings and may constitute as much as 40 percent of the cuttings.

The shales of the lower part of the Hemlock Lake Formation range in color from medium dark gray to medium light gray. They are highly fossiliferous to nonfossiliferous; the fossils are exclusively carbonized plant fragments. The shales commonly drill up as needle-shaped fragments. Shales are most commonly encountered near the base of the Hemlock Lake Formation, between the underlying Parma and the Six Lakes Limestone Member.

A thin discontinuous coal is present at the very base of the Hemlock Lake Formation in a few wells. No samples of this coal were observed in the drill cuttings; its existence is inferred from geophysical logs such as that shown in Figure 12, which shows responses typical of a coal bed at 835 feet.

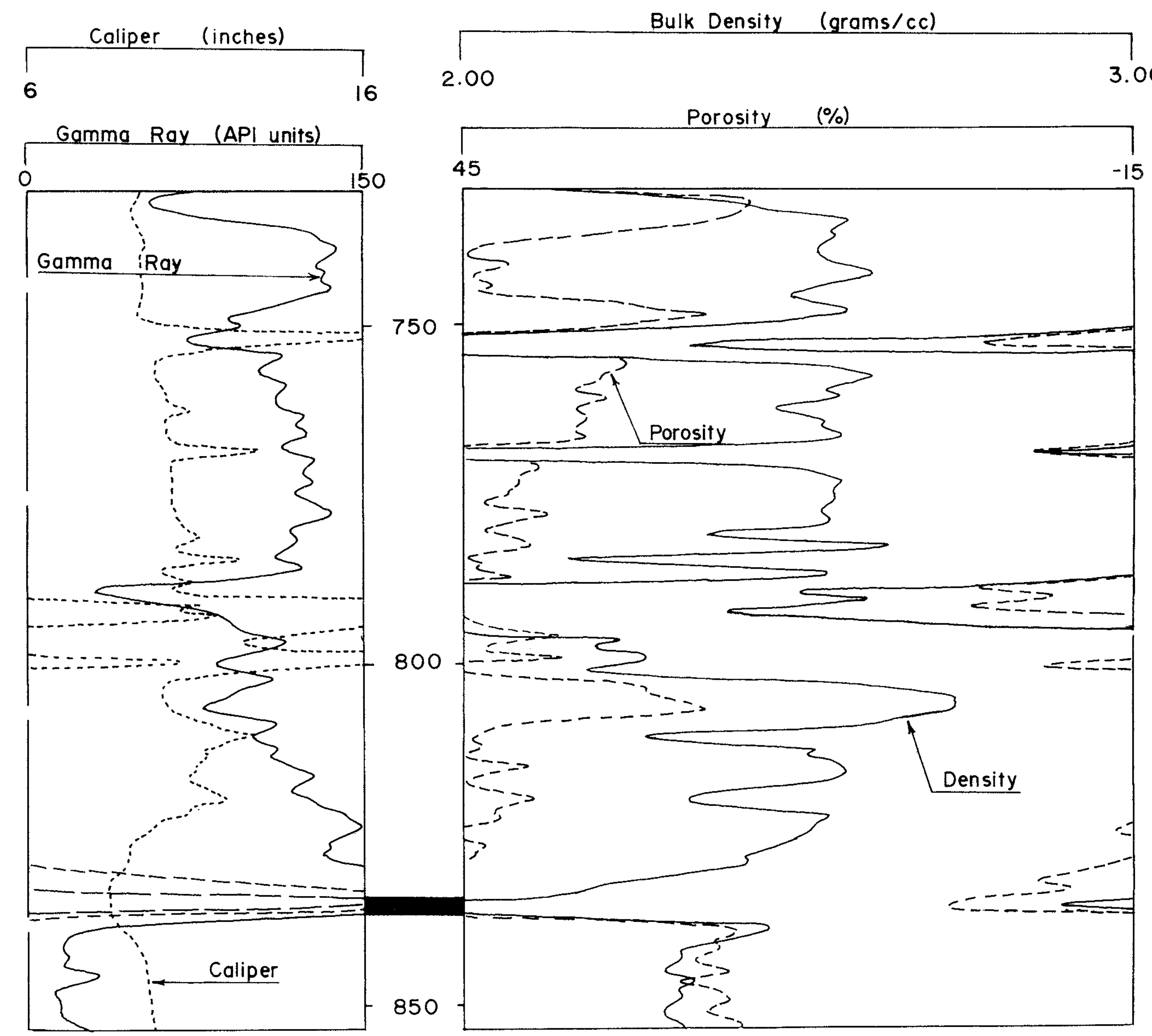


Figure 12 Geophysical logs showing a thin coal at the base of the Hemlock Lake Formation

Geophysical logs show that contacts between individual beds in the lower part of the Hemlock Lake Formation are sharp. Both the logs and the drill cuttings indicate that individual beds are less than 10 feet thick. With the exception of the Six Lakes Limestone Member none of the individual beds can be traced across the study area.

Six Lakes Limestone Member (new name)

In his unpublished master's thesis dealing with the stratigraphy of the Carboniferous rocks in the Six Lakes gas storage field, located in Montcalm County, Michigan, Tyler (1980) described an interval of limestone associated with minor shales, dolomites, and evaporites, found near the base of the Pennsylvanian. He termed this unit the cream limestone, borrowing the informal terminology of the operating company in the storage field. In this study the cream limestone of Tyler is given member status and renamed the Six Lakes Limestone.

The well from which the type section is taken is the Michigan Consolidated Gas Company No. SL-425, located in the NW1/4 NW1/4 SE1/4, S.13, T.12N., R.7W., Belvidere Township, Montcalm County (Figure 13).

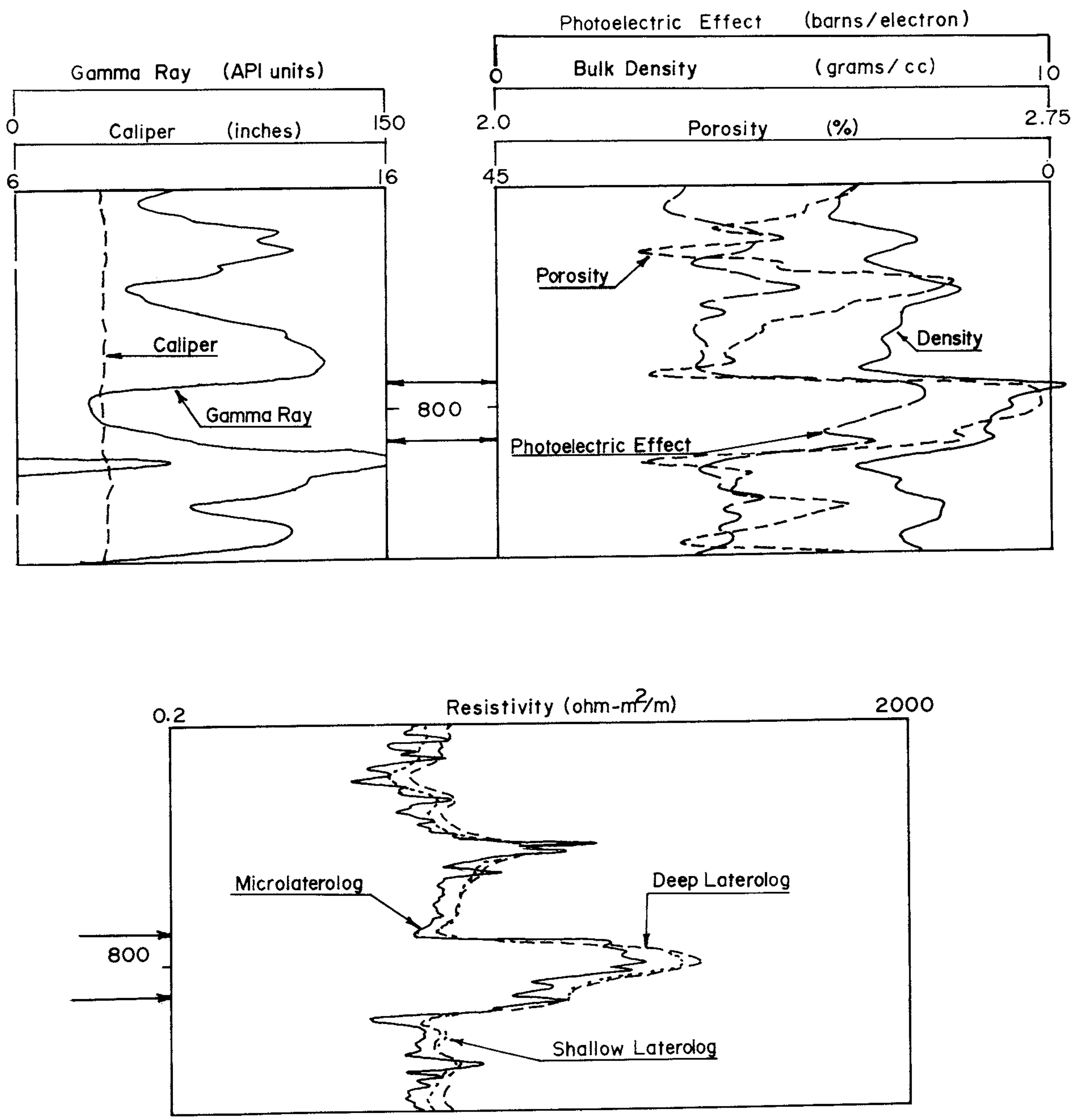


Figure 13 Geophysical logs from the well from which the type section of the Six Lakes Limestone Member is taken

The Six Lakes Limestone is a white to yellowish gray to light brown, micritic limestone. It is rarely olive gray and dolomitic. Fine, euhedral crystals of metallic sulfides are commonly found in the limestone. In some wells the Six Lakes Limestone is silty. Tyler (1980) described a blue-gray massive anhydrite and white snowy masses of gypsum present within the limestone in at least one of the wells in the gas storage field. This author did not find evaporites exclusively associated with the limestone in either the drill cuttings or on geophysical logs.

The Six Lakes Limestone Member is widespread in the western two-thirds of the study area and virtually absent from the eastern one third (Figure 14). The thickness ranges from zero to about 30 feet.

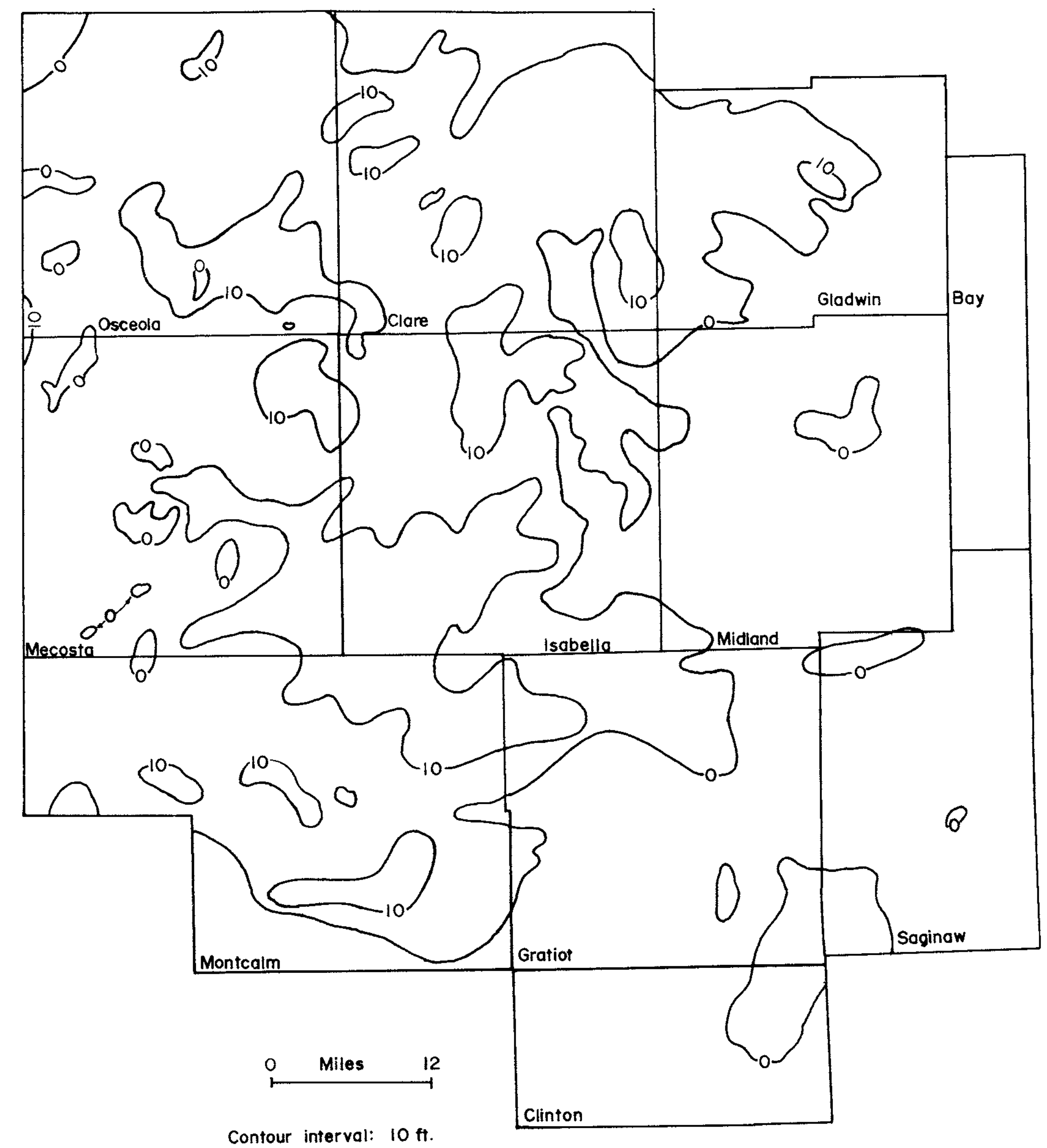


Figure 14 Isopach map of the Six Lakes Limestone Member

The upper part of the Hemlock Lake Formation is composed primarily of shale with minor amounts of siltstones, sandstones, carbonate rocks, and coal. The shale is dark gray to olive gray, clayey, micaceous, and commonly fossiliferous. Carbonized plant remains are the only fossils seen in the cuttings. Geophysical logs indicate that coal occurs in such shales in the upper part of the Hemlock Lake.

The siltstones vary in color from medium gray to light gray and commonly are thinly laminated. They have abundant carbonaceous specks and patches but identifiable fossils are rare. In a few wells, reddish siltstones similar to those found in the lower part of the formation are found.

The sandstones of the upper part of the Hemlock Lake are very similar lithologically to the sandstones in the lower part of the formation.

Carbonate rocks are uncommon in the upper part of the Hemlock Lake. The carbonates are all very clean limestones, very finely crystalline, and ranging in color from dark yellowish brown to pale yellowish brown to olive gray. Minute euhedral pyrite crystals and isolated rounded sand grains were observed in the limestones in some of the cuttings. The limestones are thin, discontinuous and restricted aerially. Individual beds can be traced from well to well only if a high density of wells is available.

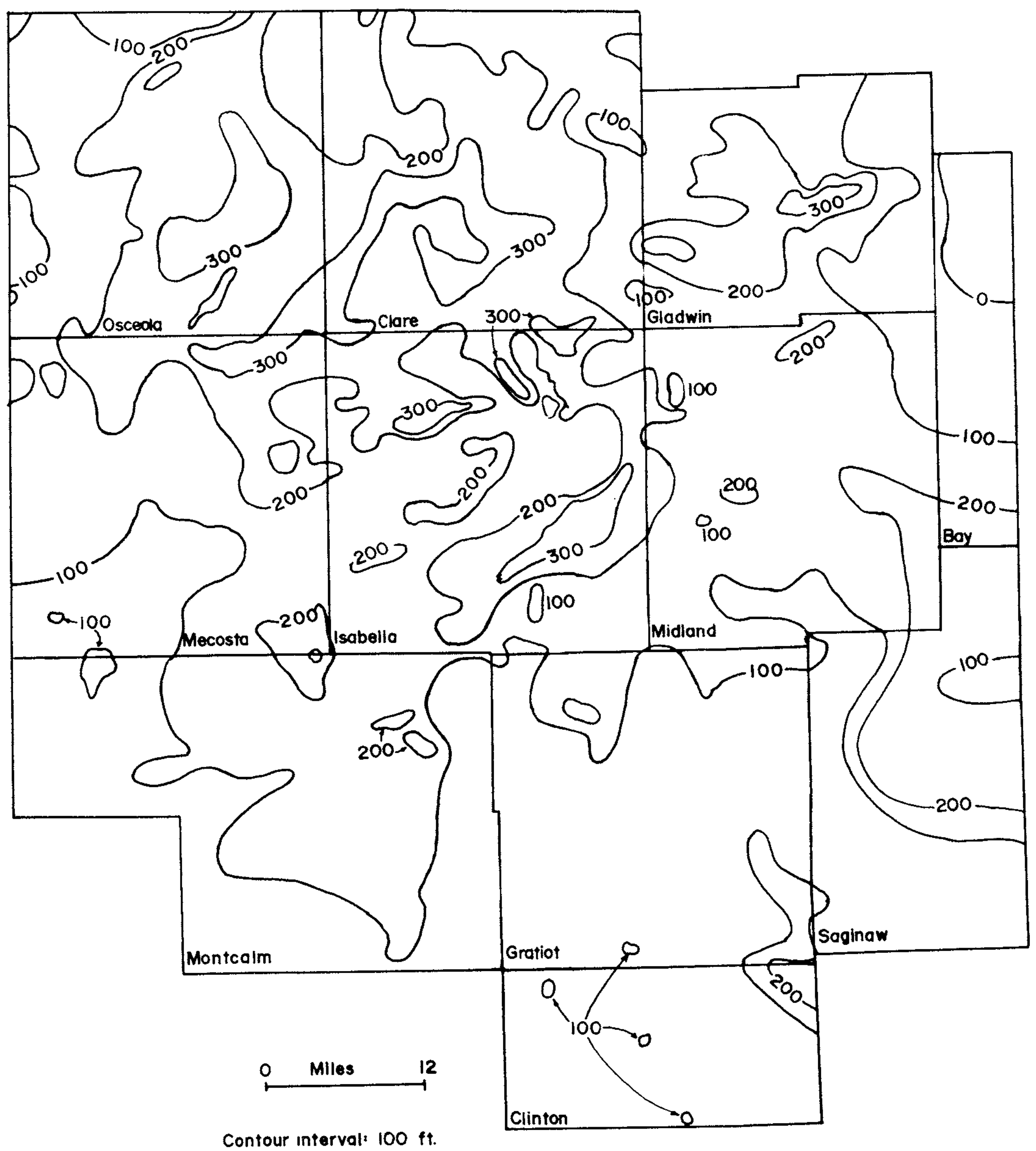


Figure 15 Isopach map of the Hemlock Lake Formation

Over most of the study area the Hemlock Lake is more than 100 feet in thickness (Figure 15). Thicknesses in excess of 200 feet are common only in the northwestern and north-central portions of the study area. In these regions the interbedded sandstone and siltstone facies of the lower part of the Hemlock Lake is most extensively and completely developed. In the southern and southeastern portions of the study area the lower part of the Hemlock Lake Formation is composed of a dark shale, and the twofold division of the formation mentioned earlier is no longer possible. The 200-foot isopach line marks the effective southern limit of the extensive sandstone and siltstone facies of the lower part of the Hemlock Lake.

Following deposition of the Parma sediments the study area had the configuration shown in Figure 16. Continued more or less undisturbed sediment deposition had only slightly decreased the areas of two of the three main depositional centers, while rendering them considerably shallower. The more southern of the two western depocenters had been almost completely filled.

The upper contact of the Hemlock Lake Formation is placed at the base of the massive sandstones of the overlying Lake George Formation (new name) where the latter unit is present. The contact is normally quite sharp and distinctive on geophysical logs. Only rarely do the logs suggest interbedding of the two formations. Where the Lake George is absent the upper contact of the Hemlock Lake Formation may be difficult to determine from samples or on geophysical logs. This is due to the similarity of the upper part of the Hemlock Lake to the shales and sandstones of the Winn Formation (new name) which overlies the Lake George.

The preservation of the barrier sands of the Parma in the face of rising sea levels suggests that the rise in sea level must have been gradual. The dark-colored clayey shales and interbedded sandstones lying between the Parma and the Six Lakes Member in many wells represent swamp and lagoon deposits. The thin sandstones in this interval are either washover fans composed of material from the Parma barrier or fan deltas composed of material transported into the lagoons and swamps by streams. Further support for the interpretation of a lagoon environment comes from the thin coals found at the very base of the Hemlock Lake Formation. These coals originated in back-barrier swamps, formed as the seas gradually inundated the Parma barrier.

Eventually marine water covered the study area and the deposition of the Six Lakes Member began. The marine setting is implied by the occurrence of the endothyroids and fusulinid found by Shideler (1963) in a thin limestone member near the base of the Saginaw Formation. The thin limestone of Shideler is probably the Six Lakes Limestone of this study. The occurrence of pyrite in the limestone also implies a marine influence. The climate was arid enough to allow local deposition of evaporites in small pools of hypersaline brine. Clastic influx into the western portion of the study area was almost nonexistent, also implying arid conditions under which many of the streams which fed the lagoons dried up. In the eastern portion of the study area fine clastic material was being deposited, preventing deposition of lime muds.

Following deposition of the Six Lakes Member, clastic influx began again, implying a change to a wetter climate. In the northern and north-central portions of the study area the lower part of the Hemlock Lake displays characteristics which indicate deposition in an alluvial environment. These include interbedded sandstones, siltstones, and shales, with little lateral continuity between the sandstones; reddish coloration of the finer-grained beds; granule-sized sediments sometimes seen in the cuttings which are interpreted as lag deposits; sharp, probably erosional contacts between the sandstones and the underlying siltstones and shales; fining upward sequences indicated by geophysical log responses; and the interbedding of the gray and red shales and siltstones. The fragmentary nature and scarcity of the fossil remains suggests transportation prior to burial, which would be expected in an alluvial environment.

The thin sandstones of the lower part of the Hemlock Lake formation were deposited in streams that meandered across a low-lying floodplain. The floodplain began to form in the northern portion of the study area following stabilization of sea levels and the climactic change at the end of Six Lakes depositional time. The floodplain then prograded to the east. south, and southeast. Red and gray siltstones were deposited in the interchannel areas which were alternately inundated and subaerially exposed. Mottling of the gray siltstones by the red siltstones suggests bioturbation by an active burrowing fauna.

As the floodplain continued to prograde, the alluvial environment was succeeded by an environment in which dark-colored fine-grained clastics were deposited almost to the exclusion of other lithologies, particularly in the southwestern portion of the study area. The dark colors, occurrence of coal, fine grain size and presence of pyrite all suggest deposition in low-energy, reducing, wet environments, typical of poorly drained swamps. Rainfall was sufficient to maintain the swamps. Finely crystalline carbonate sediments were deposited in small lakes similar to those existing in present-day northern Michigan and discussed by Murphy and Wilkinson (1980).

While the environmental changes discussed above were occurring in the western two-thirds of the study area, deposition of fine-grained dark sediments was proceeding in the eastern third. The accumulation of the dark shales and siltstones continued unbroken into late Hemlock lake depositional time, probably under marine conditions.

LAKE GEORGE FORMATION (new name)

The name Lake George is here proposed for the thick massive sandstones and minor shales and siltstones which immediately overlie the Hemlock Lake Formation in much of the study area. The name is taken from the village of Lake George in Clare County, near the well from which the type section comes. This well is the Michigan Consolidated Gas Company No. L-124, located in the NW1/4 NW 1/4 NW1/4, S. 21, T.18N., R.5W., Lincoln Township, Clare County. The Lake George Formation occurs in the interval from 764 feet to 885 feet (Figure 17). No cuttings were collected between the surface

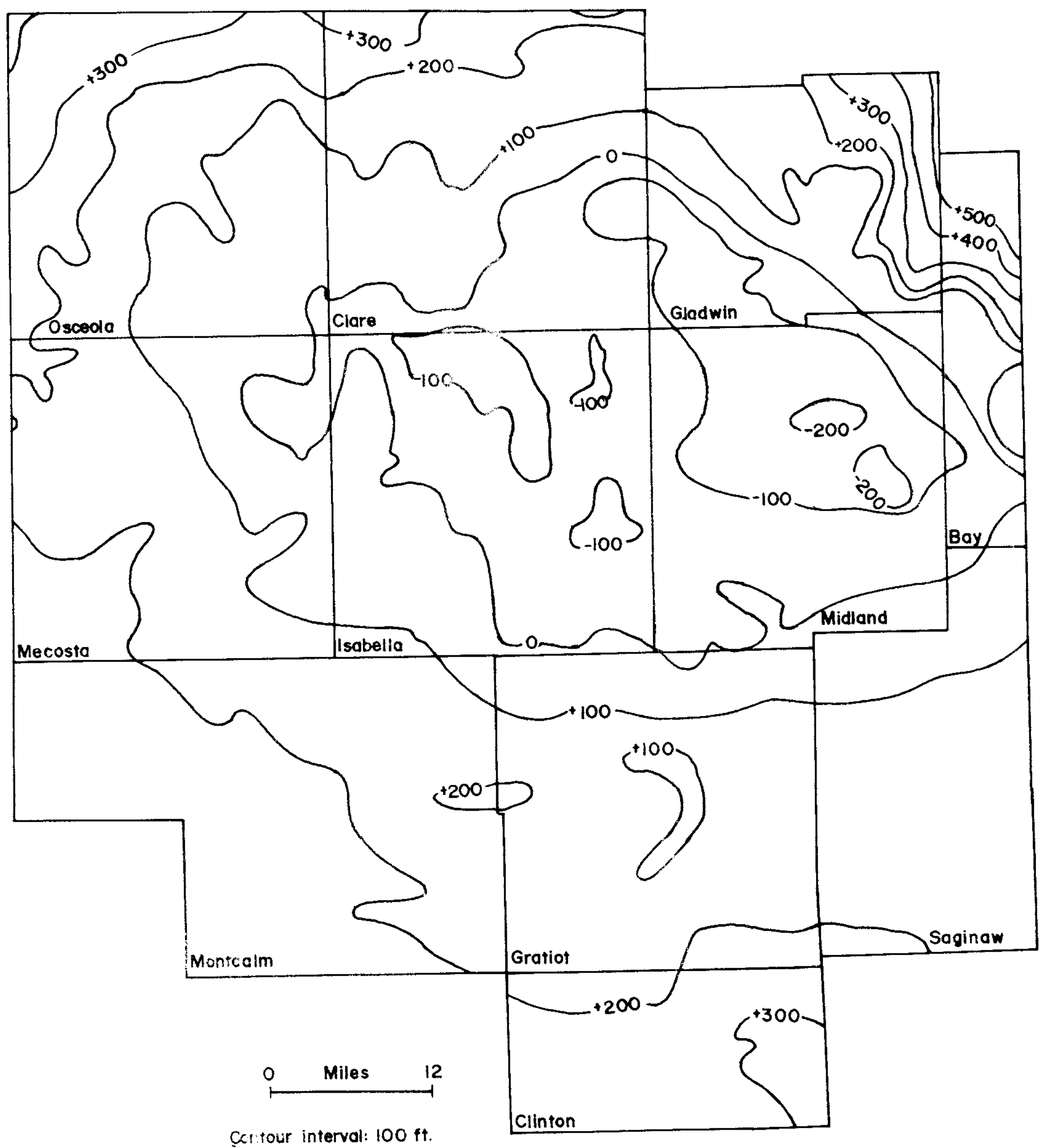


Figure 16 Structural contours on the base of the Hemlock Lake Formation

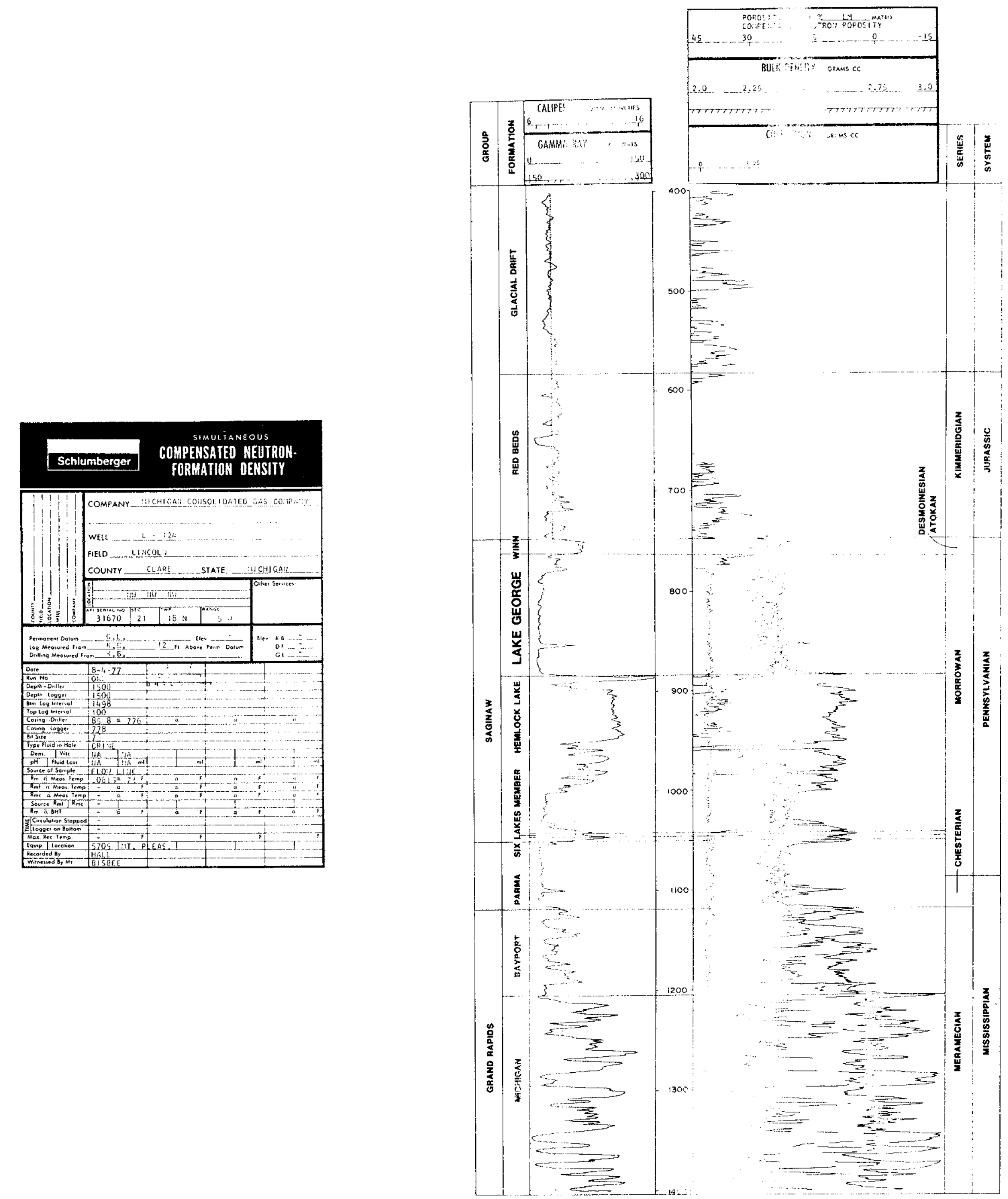


Figure 17 Geophysical logs from the well from which the type section of the Lake George Formation is taken

and a depth of 795 feet. Between 795 feet and 880 feet the cuttings were described as free sand grains: clear to slightly frosted, good medium grain size, subrounded and subangular, a white looking sand, very clean.

The Lake George Formation consists of a white or yellowish-gray to light gray to grayish-red, fine- to very coarse-grained, somewhat friable, quartz sandstone. The grains are usually well sorted. Accessory non-quartz minerals comprise a small proportion of the Lake George. The sandstones of the Lake George commonly drill up as loose grains which range from subangular to well-rounded, are iron-stained in many samples, and vary from transparent to opaque. Grain frosting is uncommon.

Portions of the Lake George Formation consist of a grayish-brown rather hard massive claystone. The claystone is slightly calcareous, rarely pyritic, and displays plumose structure on broken surfaces. This rock occurs as discontinuous lenses within the massive sandstone.

Shales and siltstones locally constitute a major proportion of the Lake George Formation. These rocks are medium dark gray to dark gray, micaceous, and commonly have carbonized plant fossil remains. The siltstones are frequently thinly laminated. Where these rocks are present, there is a gradual fining upward sequence from sandstone through siltstone to

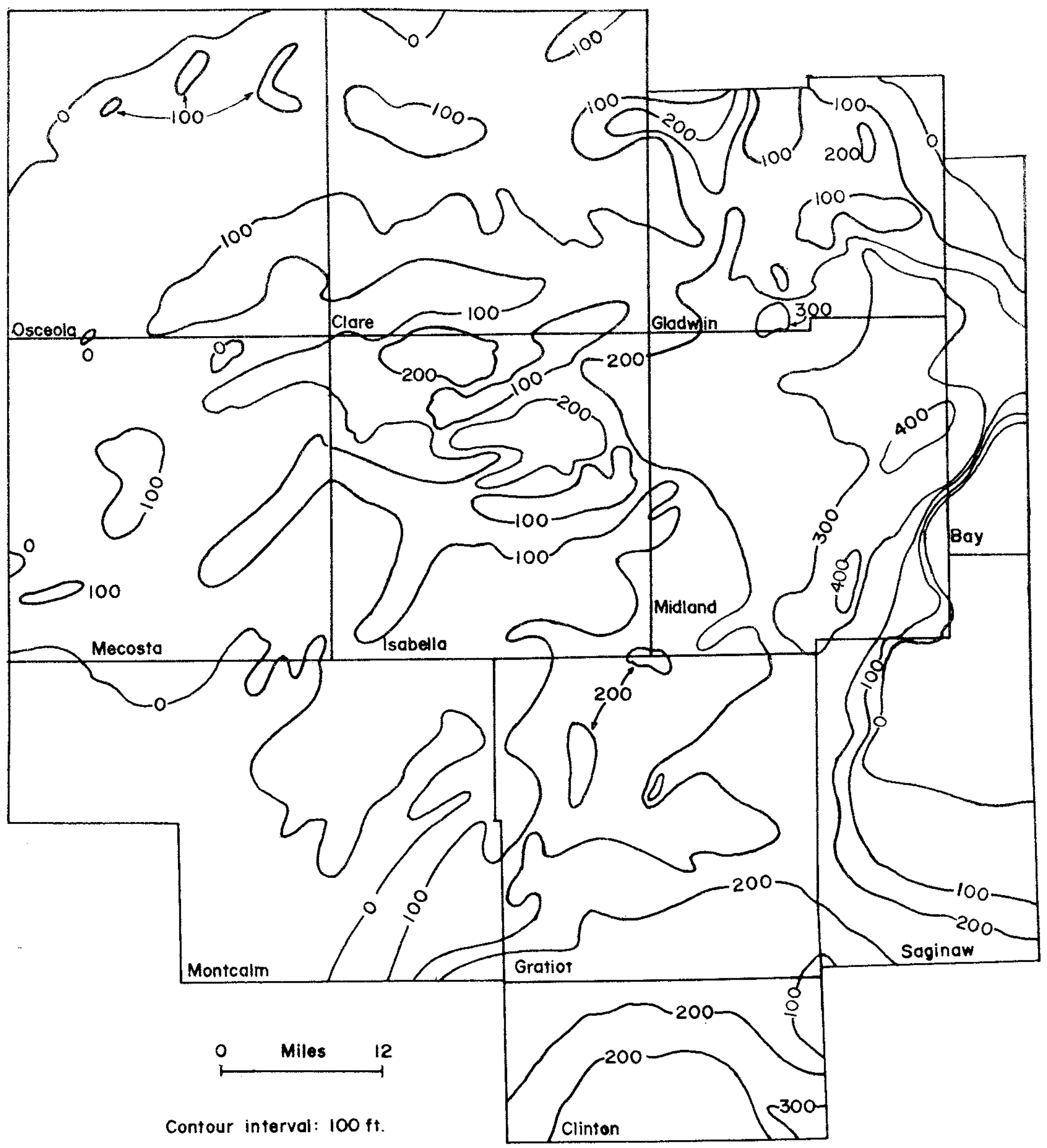


Figure 18 Isopach map of the Lake George Formation

shale.

Beds of well-rounded, granule-sized, unconsolidated sediments of varying lithologies occur in the Lake George. These sediments occupy varying stratigraphic positions and range from a few inches to several feet in thickness.

A single core of a portion of the Lake George was made available to the author by Patrick Huber of the Dart Oil and Gas Corporation. The core was cut on the No. 1-20 Hardin Coal Test, located in the SW1/4 NW1/4 SE1/4, S.20, T.9N., R.5W., Bloomer Township, Montcalm County. Core was cut between 435 feet and 456 feet and between 456 feet and 485 feet. Along with the core the geophysical logs and core descriptions were kindly given to the author.

The cores reveal a massive, well-sorted, moderately well cemented, friable, medium light gray to yellowish gray sandstone. Pebble layers less than 3 inches thick occur as do similarly thin coals. Floating pebbles of shale, quartz and possibly coal are present. The pebbles have long axes of 1mm to 4 mm length. The cement is calcareous and there is abundant interstitial clay, some of which may be drilling mud that invaded the highly permeable sandstone. The pebble layers suggest low angle bedding.

The sandstone in the upper core is in sharp upper and lower contact with siltstone. The lower siltstone is medium gray with abundant lath-shaped clasts of medium-gray, soft, waxey, clayey shale and some floating quartz pebbles. The siltstone is calcareous; bedding is at a low angle.

The upper siltstone is yellowish gray and calcareous and has rare shale clasts. Bedding in this siltstone is at an angle which may be as high as 20 degrees. The contact with the lower siltstone dips at about 15 degrees.

The lower core consists of sandstone that is similar to the sandstone of the upper core. The major difference is the occurrence of a four-inch-thick coal seam in the lower core.

Most of the eastern third of the study area has Lake George sediments that are more than 200 feet thick (Figure 18). Midland County and to a lesser extent Gratiot County and Clinton County acted as depocenters for the Lake George sediments. To the west of the area of thick sandstones are four more or less well-defined areas in which the sandstone thickness exceeds 100 feet. These areas have high length-to-width ratios and extend 30 to 40 miles to the west. Cross sections show that these ribbons of sandstone occupy variable stratigraphic positions. The elevation of the base of the Lake George Formation decreases from west to east.

The sandstones of the Lake George were deposited by rivers which flowed down a relatively gentle paleoslope from west to east. Erosion of the underlying Hemlock Lake sediments was significant in parts of Gratiot, Clinton, and Midland counties, where in some wells the entire Pennsylvanian section from the top of the Parma Formation consists of sandstone.

The core discussed above shows two fining-upward sequences which resemble the fining-upward cycles discussed by Allen (1970a) and referred by him to a fluvial depositional environment. They are remarkably similar to cores cut in a fluvial sequence which were illustrated by Cant (1982). The core in the Dart well was probably cut through a point-bar deposit and supports the interpretation of a fluvial origin for the Lake George sediments.

The beds of granule-sized sediments mentioned above represent lag deposits. The variable stratigraphic positions of individual lag deposits suggest meandering rivers that deposited stacked or multi-story sand bodies. From time to time, the rivers abandoned their channels by cutting off meander loops. These abandoned loops formed oxbow lakes which gradually filled with fine-grained sediments which eventually formed the sequences of dark-colored siltstones and shales observed in some wells.

WINN FORMATION (new name)

Winn Formation is the name proposed for the sequence of shales, siltstones, and sandstones lying above the Lake George Formation in much of the study area. The type section of the Winn Formation is chosen to be the interval between 573 feet and 706 feet in the McClure Oil Company No. 1-20 Paul and Karen Bigelow, located in the SE1/4 SE1/4 NW1/4, S.30, T.13N., R.4W., Lincoln Township, Isabella County (Figure 19).

The Winn Formation is composed predominantly of medium gray to dark gray, soft, clayey shale. The shale is slightly silty in some drill cuttings and commonly contains abundant plant fossils.

Some of the Winn shales are massive, dolomitic, hard and apparently structureless. These shales infrequently contain isolated quartz grains and carbonaceous inclusions and are often silty. Their color is reddish, although mottling or interbedding with gray shales occurs in some samples.

Sandstones of the Winn Formation are not as clean as the sandstones of the lower portions of the Pennsylvanian section. Shale fragments and interstitial pyrite are common constituents of the Winn sands. Grain size varies from fine to coarse although individual sand beds are composed of well sorted grains which are commonly frosted and vary from rounded to subangular. The cement is commonly highly

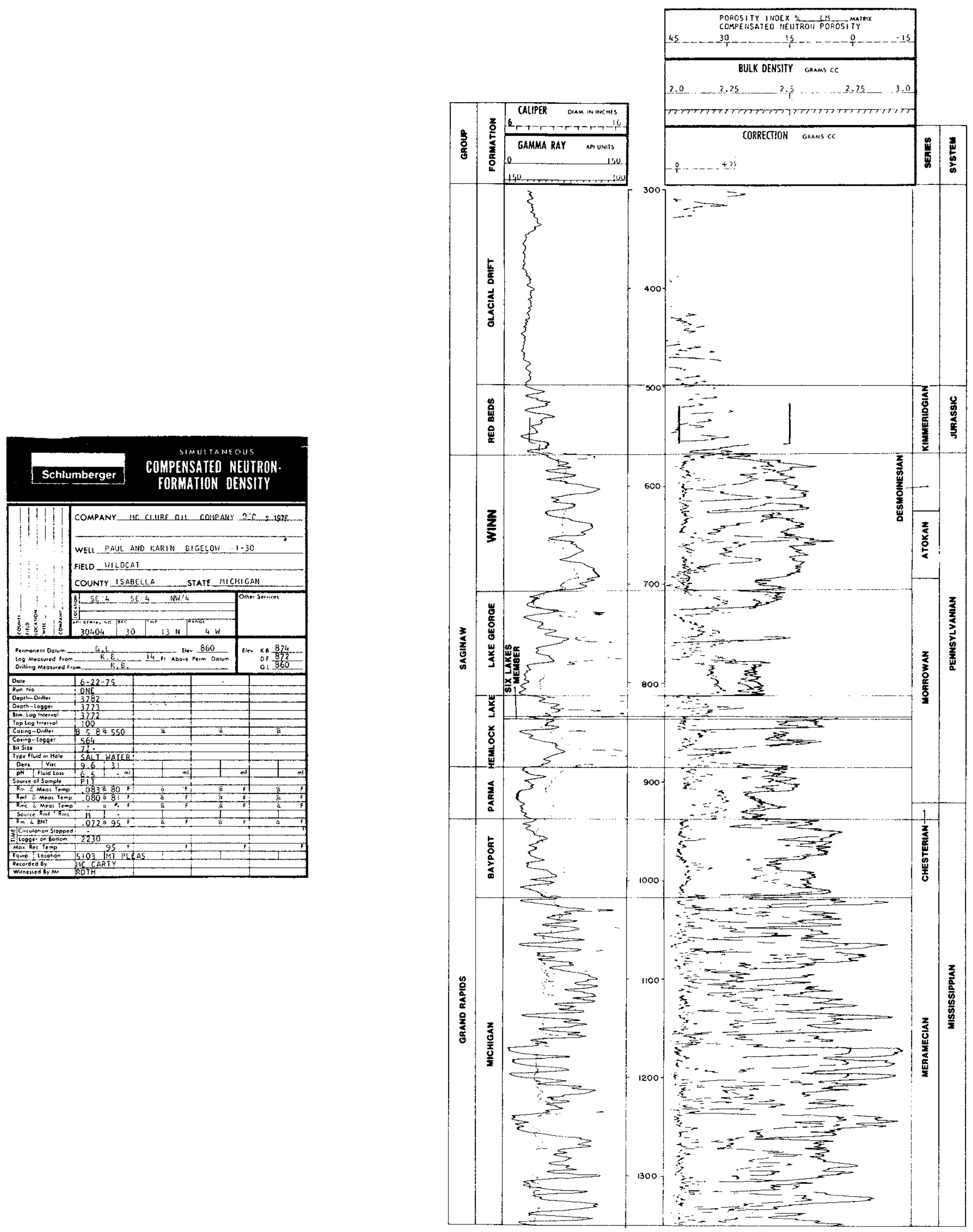


Figure 19 Geophysical logs from the well from which the type section of the Winn Formation is taken

calcareous, but sandstones with noncalcareous cement are found. These may be restricted to the upper portions of the formation. The sandstones of the Winn Formation vary in color from yellowish gray to light gray.

Light gray to medium light gray siltstones are associated with the dark shales. The siltstones vary from highly micaceous to nonmicaceous, and the few plant fossils present are poorly preserved and commonly occur as carbonized fragments. Millimeter-scale laminae of coarse-silt-sized to fine-sand-sized grains are common. The laminae are lighter colored than the main body of the rock.

Contacts between individual beds in the Winn vary from sharp to gradational. Beds near the base of the formation tend to be better defined than beds that are stratigraphically higher . Bed thickness varies considerably from well to well and without closely spaced well control correlation of individual beds is impossible.

Verne Member

A thin bed, variously described as a calcareous black shale or black argillaceous limestone, and containing a fauna dominated by brachiopods and molluscs, occurs in outcrops in Eaton County and Shiawassee County and is known from formerly active coal mines in Bay and Saginaw Counties and western Genessee County. Kelly (1936) discussed the occurrence of this bed and the similarity of its fauna at various localities and proposed reviving the name Verne, to be applied to all occurrences of similar tocks in the Pennsylvanian System in Michigan. Because of the apparent persistence of this unit, and in spite of the fact that it probably cannot be distinguished using geophysical logs, it seems appropriate to retain the name and assign it member status.

Kelly (1936) gave rather general descriptions of the Verne lithology, but he indicated a change from black argillaceous limestone in the south to a slightly calcareous shale and patches of limestone in the northeastern area of the Verne occurrence. Lithologies similar to those described by Kelly were noted by the author in only one set of drill cuttings. A black limestone associated with dark-colored shale and calcareous sandstone occurs between 580 feet and 590 feet in the Sohio Petroleum Company No. 1 Sid Struble, located in section 18 of Gilmore Township, Isabella County. No similar lithology was noted in either drill cuttings or in cuttings descriptions from wells located farther to the east or south and geophysical logs do not show a response typical of limestone in the Winn Formation.

The Verne Member is probably of limited extent. Kelly (1936) did not mention its occurrence in either Jackson or Tuscola Counties, in which are located respectively the southern and eastern boundaries of the Pennsylvanian rocks in Michigan. The Gilmore Township well is at least 50 miles from the nearest occurrences of the Verne Member in coal mines in Bay County. Correlation of the two occurrences across that distance with no intermediate occurrences is speculative. In the absence of better information nothing can be said but that if it occurs in the study area the Verne Member is limited to isolated areas and may occur in the extreme southeastern and eastern portions.

The Winn Formation has been extensively eroded since the Pennsylvanian (Figure 20). The pattern of erosion suggests that the drainage of post-Winn streams was to the southwest.

The lower contact with the Lake George Formation varies from abrupt to gradational. The base of the Winn is difficult to determine if the contact is gradational. The upper surface of the Winn Formation marks an unconformity overlain by the unnamed red beds of Jurassic age or unconsolidated post-Jurassic deposits. The upper contact is easily picked in drill cuttings by noting the first appearance of dark gray shales, gray siltstones, or light gray consolidated sandstones. The upper contact may be difficult to determine from geophysical logs, but is commonly chosen at a marked increase in gamma-ray count.

Low-energy environments with minor influx of coarse sediments were the settings in which the Winn sediments were deposited. The structural relief of the depositional area was low and the basin was practically filled by the Lake George sandstones. The abundant dark sediments indicate widespread reducing conditions although at least locally sediments must have been subaerially exposed and reddened by the formation of iron oxides. Sands and silts were deposited by sluggish streams which flowed in easterly and southeasterly directions.

The gradational lower contact which the Winn in many instances displays suggests the fining-upward sequence commonly seen in channel fill deposits of fluvial origin. The lower portion of the Winn Formation almost certainly originated as channel-fill, topping off the abandoned channels of the Lake George rivers.

Marine conditions existed in part of the Michigan Basin during Winn depositional time, as shown by the crinoid, echinoderm, and brachiopod fauna of the Verne Member. The change in lithology of the Verne from limestone in the south to shale in the north indicates an increase in fine clastic input

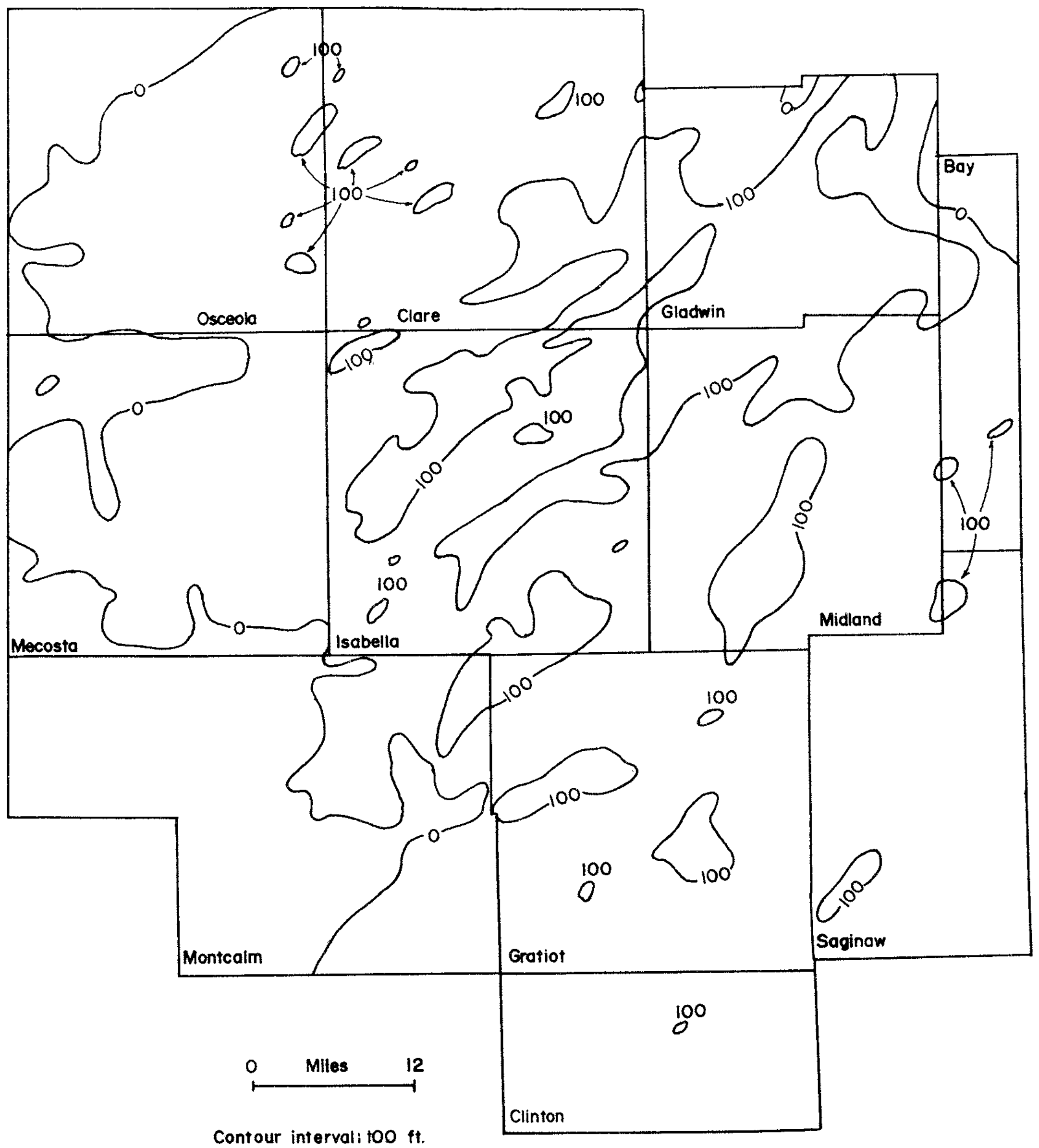


Figure 20 Isopach map of the Winn Formation

into the Verne sea in what are now Bay and Saginaw Counties. The fine sediments interfered with the feeding mechanisms of corals and echinoderms, restricting them to the cleaner waters to the south where lime mud was being deposited. The limited aerial extent and thinness of the Verne indicate that is was a short-lived tongue of the sea which this author believes existed in southeastern Michigan for much of the Pennsylvanian. The Verne Member marks the last known major incursion of marine water into the Michigan basin. That marine conditions did not persist is shown by the disappearence of the Verne fauna from the overlying beds of black shale which are characterized by the occurrence of the inarticuate brachiopod Lingula.

POST-PENNSYLVANIAN DEPOSITION

At the present time the top of the Pennsylvanian is marked by a shallow basin centered over Mecosta and Isabella Counties and portions of Clinton, Midland, and Montcalm Counties (Figure 21). The basin is coincident with much of the area in which Sander (1959) showed that the so-called red beds of Jurassic age are known to occur. The extent to which it existed at the close of Winn depositional time and whether it was ever connected with depositional basins to the south or southwest are not known. A

careful study of microfossils recovered from well cuttings might help to determine whether sediments of Permian or Triassic age were ever deposited in the Michigan Basin.

ECONOMIC POTENTIAL

Hydrocarbons

Only two commercial hydrocarbon deposits have been reported from rocks in the interval under study. The first of these was the Elba gas field, located in Elba Township, Gratiot County. This field produced approximately 250 million cubic feet of gas in the period 1928-1957 (Geological Survey Division, 1982, p. 19). The producing formation was apparently the Parma.

The second occurrence was in the Edenville Section 5 field, located in Edenville Township, Midland County. This field is reported to be a shut in gas field producing from the "Saginaw Formation" (Geological Survey Division, 1982, p. 19). Geophysical logs from wells offsetting the field indicate that the gas production is from a sandstone in the upper part of the Winn Formation. No production history is available for the Edenville field.

Although driller's logs mention oil-stained cuttings from the Bayport in one or two wells, no commercial hydrocarbons

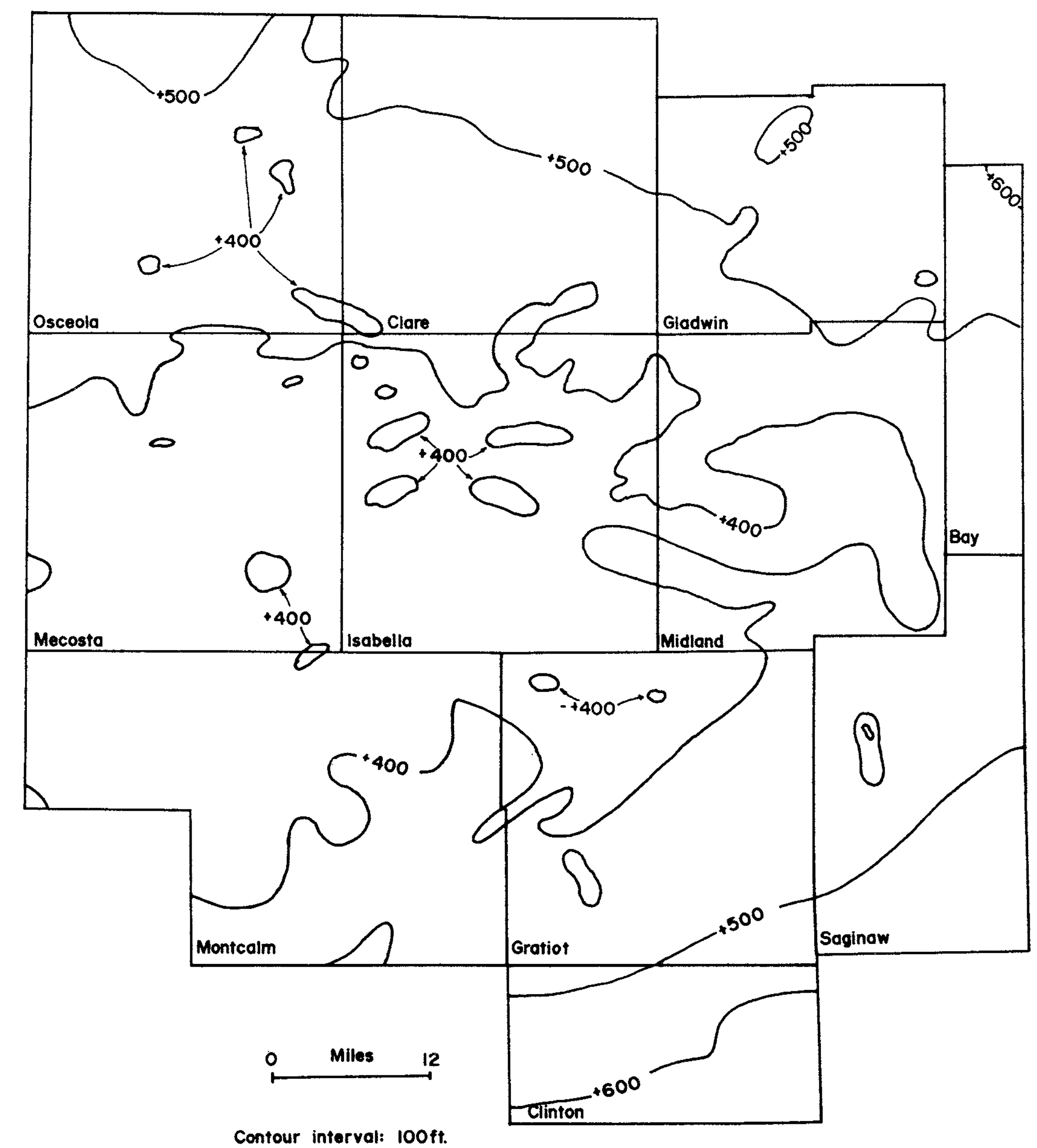


Figure 21 Structural contours on the top of the Pennsylvanian System

have ever been found in this formation.

Natural brines

Nothing is known of the composition of formation waters from strata higher than the Parma beyond what can be extracted from resistivity and spontaneous potential logs. Some analyses are available for brines produced from the Parma Formation (Cook, 1914, and Geological Survey Division files). These analyses show a very high sodium chloride content (18%) and a much lower calcium chloride content (1.2%). Magnesium chloride contents (2.3%) are in the same range as those produced from older formations. The halogen content (0.04% bromine) is low in comparison with other brines. Inasmuch as the major brine producers in Michigan manufacture halogen compounds from the brine, the low halogen content makes it unlikely that Parma brines will ever be exploited as sources for these compounds. At one time, Parma brines were used in the manufacture of salt, but this industry was already defunct in Cook's time.

No information is known concerning the composition of brine produced from the Bayport. So far as is known brines from the Bayport have never been commercially exploited.

Coal

The occurrence of coal in Pennsylvanian rocks of the eastern portion of Michigan's coal basin has been discussed in detail by Lane (1901), Cohee and others (1950) and Kalliokoski and Welch (1977) and will not be reviewed here.

Exploration for coal in Michigan will of necessity be conducted by subsurface methods, principally by interpretation of drill cuttings, cores and geophysical logs. The responses of various geophysical logs to coal are widely known and were discussed by Tixier and Alger (1967). The log responses characteristic of coal are shown in Figure 12, at a depth of about 839 feet. The interpretation of the geophysical logs is complicated by the fact that severe caving causes the same log response as does coal. Examples of caving, indicated by the caliper log, are also seen in Figure 12 at depths of 790 feet and 752 feet.

Geophysical logs from several wells indicate the presence of coal (Figure 22 and Chart 1). Most of the coal occurrences were in the upper part of the Hemlock Lake Formation and most were less than five feet thick. The occurrences in Mecosta County, with thicknesses of 7 feet, appear to be exceptional, both because of the thickness and because the two occurrences are approximately a mile apart.

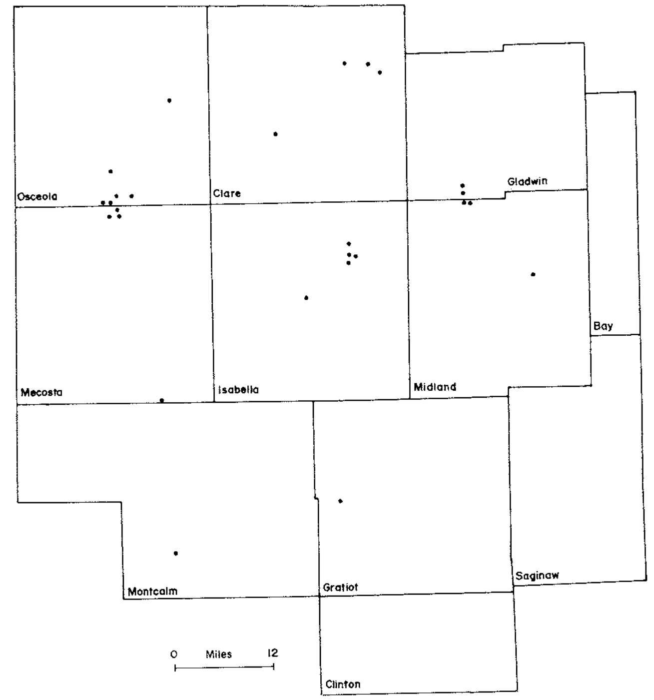


Figure 22 Location of wells in which coal is indicated by geophysical logs

Fresh water

Jones and Buford (1951) and Turcan (1962) discussed the use of spontaneous potential and conventional resistivity logs to evaluate groundwater quality in freshwater aquifers. The methods utilized by these authors relied on measured and calculated quantities to produce quantitative indications of the dissolved salts present in the groundwater. For most of the wells used in this study the information required by these methods is either difficult or impossible to obtain and no effort has been made to calculate hypothetical chemical analyses of waters present in Pennsylvanian strata. Nevertheless the conventional resistivity log can be used to indicate the presence of fresh water by noting that the absence of highly conductive sodium chloride brine results in high resistivities opposite freshwater-bearing zones. Resistivities as high as 150 ohms/meter^2/meter are given by Jones and Buford (1951). Turcan (1962) gives as a rule of thumb that a resistivity of 15 ohms/meter^2/meter or more indicates fresh water. He cautions that this rule applies only to sands of the Wilcox Group in Bossier and Caddo Parishes, Louisiana.

High resistivities have been noted on conventional resistivity logs of the Lake George Formation in wells in the study area. These suggest that the sandstones of the Lake George may be freshwater aquifers in some areas. The entire formation is not freshwater-bearing and occurrences of fresh water in the Lake George are probably rather

Permit Number	Location	Depth to coal (ft)	Thickness (ft)	Formation
		Osceola County		
35482	31 19N 7W	850	2	Hemlock Lake
36506	13 17N 9W	754	2	Hemlock Lake
36186	35 17N 9W	949	6	Hemlock Lake
36355	35 17N 9W	1029	4	Hemlock Lake
		1027	4	Hemlock Lake
36110	36 17N 9W	1021	4	Hemlock Lake
36426	28 17N 8W	922	2	Hemlock Lake
27157	30 17N 8W	1000	3	Hemlock Lake
33466	30 17N 8W	940	2	Hemlock Lake
		Clare County		
27456	11 19N 4W	734	2	Winn
27354	8 19N 3W	6882	3	Hemlock Lake
27265	16 19N 3W	755	3	Hemlock Lake
31670	21 18N 5W	955	3	Hemlock Lake
		Gladwin County		
35200	30 17N 1W	835	3	Hemlock Lake
35284	31 17N 1W	830	3	Hemlock Lake
		Mecosta County		
36283	12 16N 9W	908	2	Hemlock Lake
		920	2	Hemlock Lake
36067	6 16N 8W	936	7	Hemlock Lake
36187	7 16N 8W	950	8	Hemlock Lake
33520	36 13N 8W	760	4	Hemlock Lake
		Isabella County		
35091	26 16N 4W	762	3	Hemlock Lake
34166	36 12N 5W	720	2	Hemlock Lake
35744	2 15N 4W	745	2	Hemlock Lake
36073	12 15N 4W	729	2	Hemlock Lake
36202	14 15N 4W	759	2	Hemlock Lake
		Midland County		
34575	5 16N 1W	835	2	Hemlock Lake
35338	6 16N 1W	800	2	Hemlock Lake
36090	23 15N 1E	742	2	Hemlock Lake
		Bay County		
35096	17 14N 4E	194	2	Hemlock Lake
		280	2	Hemlock Lake
		Gratiot County		
30884	4 10N 4W	518	4	Hemlock Lake
		Montcalm County		
30117	6 9N 7W	791	3	Winn

Chart 1 Occurrences of coal in the study area indicated by geophysical logs

localized. A few logs show resistivity decreasing with depth in the Lake George, suggesting density stratification of the increasingly saline water.

No information is available regarding the deliverability of the Lake George aquifers. Driller's logs occasionally refer to a "heavy flow of water" in this portion of the stratigraphic column. Patrick Huber of Dart Oil and Gas Company advised that the sands cored in the No. 1-20 Hardin Coal Test well in Montcalm County produced large amounts of water. The water was not sampled for analysis. Locally the Lake George may be a significant source of fresh water in the center of Michigan, as it already is to the south in the Lansing area.

CHRONOSTRATIGRAPHY

Several studies have considered the chronostratigraphy of the Pennsylvanian and Bayport strata of Michigan and their relationship with units deposited in neighboring depositional basins. White (1902) examined plant fossils obtained from mines and outcrops and concluded that the Pennsylvanian strata of Michigan are equivalent to the Pottsville Group of Ohio, Pennsylvania and West Virginia.

Kelly (1936) reviewed the fauna of the Verne Member and concluded that it is Early Pennsylvanian in age.

The most comprehensive investigation of Michigan's coal flora was conducted by Arnold (1949). After a review of the species found in various mines and at outcrops located at Grand Ledge in Eaton County, Williamston in Ingham County, and near Jackson in Jackson County, he discussed the composition and characteristics of the flora and distinguished three floral zones. His "lower zone" is referred to the so-called Saginaw Coal and is known from material collected from six mines in Saginaw County. The "intermediate zone" occurs at Grand Ledge in ". . . the lower of the cyclical formations asigned by Kelly to the lower Verne . . ." (Arnold, 1949, p. 150). The "upper zone" occurs in mines in Bay County and in the stratigraphically higher parts of the Grand Ledge exposures. Each zone has a characteristic flora not found in the other zones.

Following his discussion of the Michigan flora and its comparison with fossil floras from the eastern United States, the Canadian Maritime Provinces, and Europe, Arnold drew the following conclusions:

(1) The "lower zone" is equivalent to the upper Lee of Kentucky.

(2) The "intermediate zone" is the time equivalent of the upper parts of the Tradewater and Kanawah Formations.

(3) The "upper zone" is probably not as young as the Allegheney Group of West Virginia.

McKee. Crosby and others (1976) give ages ranging from late Morrowan to latest Atokan to the rocks discussed by Arnold (1949).

Of the Verne species discussed by Kelly (1936), the brachiopod *Marginifera muricatina*, the gastropod *Meekospira peracuta*, and the pelecypod *Pseudoorthoceras knoxense* are listed as late Desmoinesian in age by Shimer and Shrock (1944). Wanless (1958) in his study of Pennsylvanian faunas of Illinois places the brachiopod *Mesolobus mesolobus cf. euampygus* in the St. David and Brereton cyclothems of the Desmoinesian age Carbondale Group and also in the Sparland cyclothem from the McLeansboro Group of Missourian age. He placed the brachiopods *Marginifera muricatina* and *Spirifer occidentalis* in cyclothems ranging in age from latest Atokan to late Desmoinesian.

The studies of Arnold (1949) and Wanless (1958) suggest that the Winn Formation ranges in age from late Morrowan to late Desmoinesian and that the bulk of the Pennsylvanian sediments in Michigan are of Morrowan age (Figure 23).

The Pennsylvanian-Mississippian boundary has been traditionally placed at the contact of the Bayport and Parma Formations. However, the age of the Parma is uncertain at best. The overlying Six Lakes Member is undoubtedly the source of the endothyroids and fusulinids discussed by Shideler (1963). These include a species of the genus *Paramillerella*, which Shideler believed to indicate a Morrowan age. However, Shideler admitted that his identification was tentative, and it was not improved upon by Shideler and Wanless (1975). In their revision of the genus *Paramillerella*, Anisgard and Campau (1963, p. 106) stated:

> The published records of the ages of the forms reclassified as *Paramillerella* indicate an age range for the genus from the Mississippian Osagean to the Pennsylvanian lower Atokan.

This statement suggests that the Six Lakes Member could be as old as the Osagean of Mississippian time. However, the Bayport Formation in the type section and in nearby Arenac County was believed by Anisgard and Campau (1963) and Ehlers and Humphrey (1944) on the basis of fossil evidence to be of Meramecian age. This assignment restricts the age of the overlying sediments to at most Meramecian, and indicates that the Pennsylvanian-Mississippian boundary should be placed above the Bayport Formation.

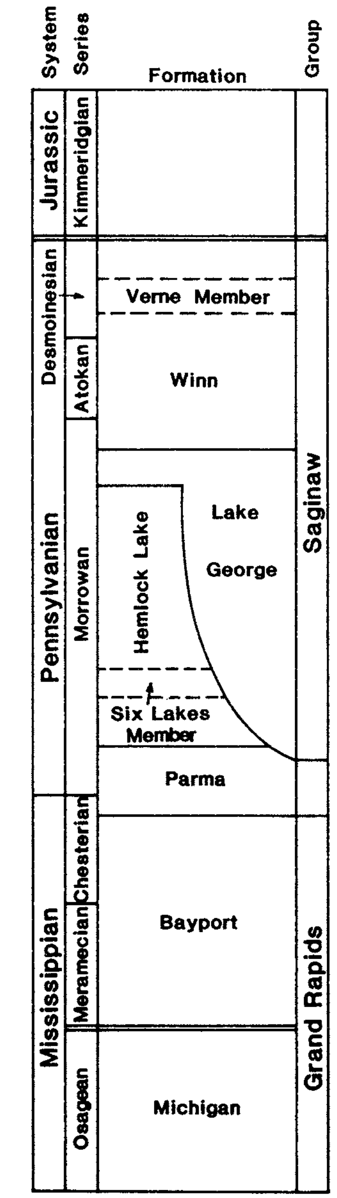


Figure 23 Generalized relationships between Carboniferous rock-stratigraphic and time-stratigraphic units in Michigan

Swann (1963, plate 1) illustrated red shales that occur sporadically throughout Chesterian sediments in Illinois. Similar red beds in an alluvial setting are known from the northern part of the Appalachian Basin (Craig and Varnes, 1979) where they were deposited as a result of uplift and the subsequent withdrawal of marine water into southern Ohio from southwestern Pennsylvania. Dewitt and McGrew (1979) indicated that during Chesterian time the Appalachian Basin was the site of increasing influx of terrigenous clastics into areas formerly dominated by marine environments. A variety of marine and nonmarine nearshore environments developed. Lithologic characteristics deemed to be indicative of Chesterian sediments in Illinois were discussed at length by Atherton and others (1960). The following criteria distinguish Chesterian sediments from the overlying Caseyville rocks of Pennsylvanian age: calcareous red or green shales, lath-shaped drill cuttings, and fewer radioactive black shales.

On the basis of their lithologies and inferred depositional histories, and in conjunction with the material discussed in the preceding paragraphs, the sediments between the middle unit of the Bayport Formation and the lower part of the Parma Formation are tentatively assigned a Chesterian age. The Parma Formation thus becomes a time-transgressive unit and the boundary between the Pennsylvanian and Mississippian is placed in the lower part of the Parma (Figure 23).

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