limestone below the black bed in Clare County which is much thicker there than elsewhere. With the forming of a topographic basin evaporation began and dolomite and anhydrite were deposited everywhere except near the rim. There limestone continued to be deposited where inflow of fresh water prevented precipitation of calcium sulphate, (the log of the Chandler well in Presque Isle County supports this contention). Because evaporites are along the Lake Michigan shore in Mason and Manistee counties it can be assumed either that no fresh water flowed into that part of the basin or that the basin rim was farther west in Detroit River time in the area now submerged by the lake.

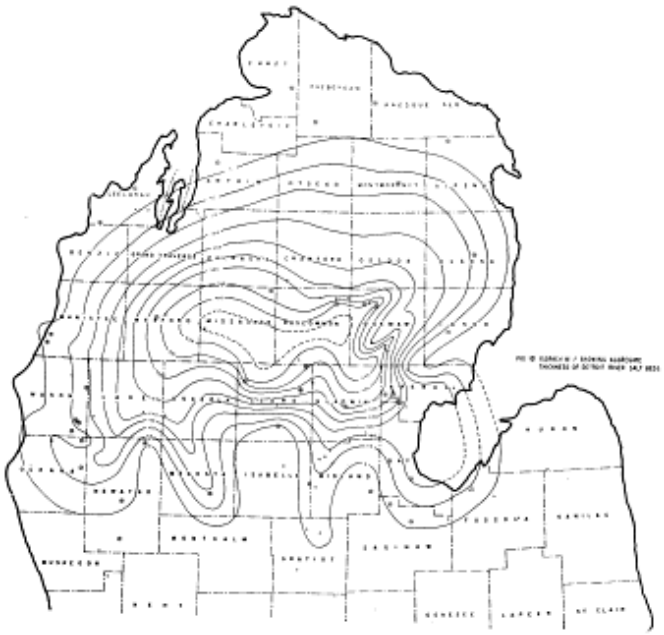

Figure 10. Isopach map showing aggregate thickness of Detroit River salt.

During the latter half of Detroit River time the sea had shrunk so that it covered only the central part of the Detroit River basin and in this smaller sea salt was precipitated, with anhydrite and dolomite. A possible source for this salt was discussed in the section on the Mackinac breccia.

SUMMARY. Comparison of the subsurface Detroit River beds with beds at the surface is prevented by the almost complete absence of outcrops of this formation in the Straits of Mackinac area.

Well samples show that the basal rocks of the Detroit River formation is a limestone (or dolomite) which is difficult to distinguish from the upper Bois Blanc limestone where the Sylvania formation is absent. From 20 to 90 feet above the base of the Detroit River is a black limestone which can be used as a marker bed.

Above the basal Detroit River limestone in the Michigan Basin is an evaporite series containing dolomite, anhydrite, and salt. This series is absent on the rim of the Basin.

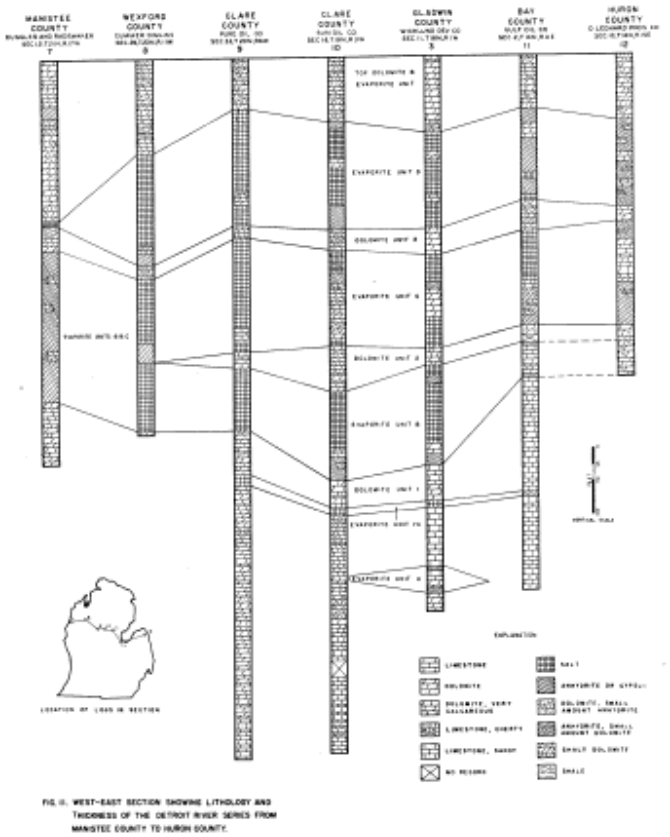

Figure 11. West-East section showing lithology end thickness of the Detroit River series from Manistee County to Huron County.

The average thickness of the lower Detroit River limestone (or dolomite) series is 130 feet. The evaporite series ranges in thickness from about 600 feet, on the flanks of the Basin, to 1,145 feet near the center of the Basin.

Between the outcrop area south of Mackinaw City and Clare County, the base of the Detroit River drops over 5,000 feet in elevation.

The lower Detroit River carbonate rocks are believed to have been deposited on the floor of a marine embayment, whereas the evaporite series was deposited in an enclosed and shrinking continental sea.

## REGIONAL STRUCTURE

The Mackinac Straits area is on the north flank of the Michigan Basin. Therefore, the regional strike is approximately east-west, and the direction of dip is south. The degree of dip increases with stratigraphic depth, as shown by the following table:

Average dip per mile between outcrop and the Bateson Well (Bay County)

| | |
|---|---|
| Upper Surface, Detroit River group | 22 |
| Upper Surface, Bois Blanc formation | 30 |
| Upper Surface, Bass Island group | 30 |
| Upper Surface, Salina group | 34 |
| Upper Surface, Niagaran series | 48 |

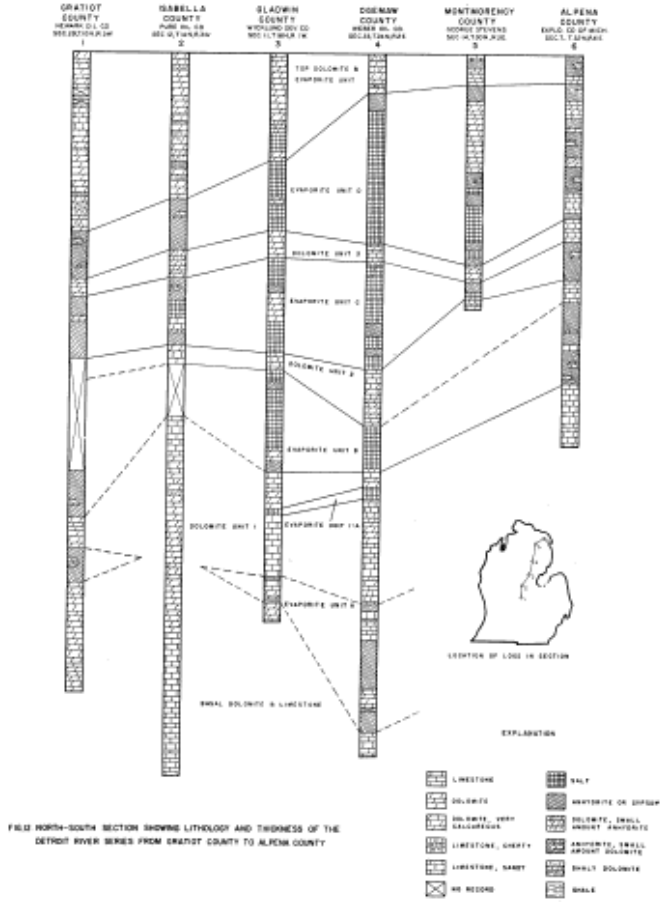


Figure 12. North-South section showing lithology and thickness of the Detroit River series from Gratiot County to Alpena County.

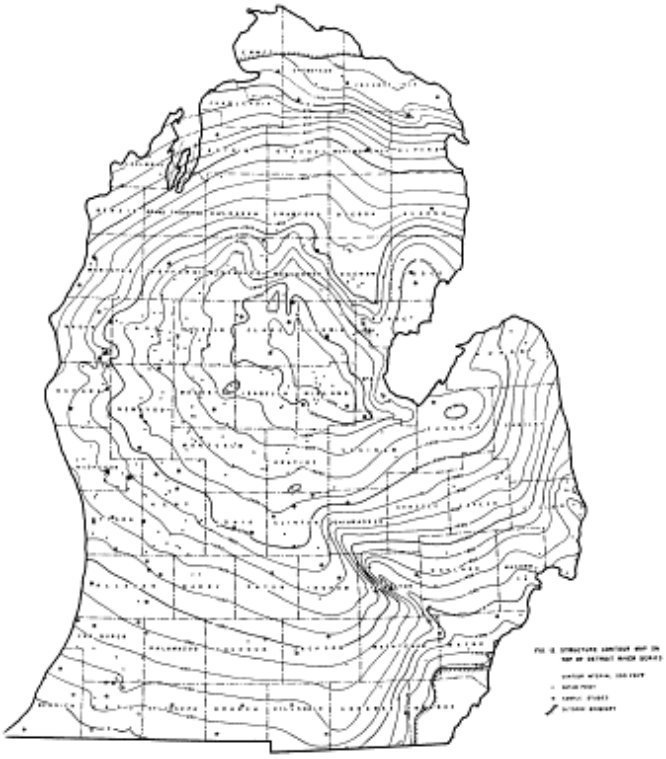

Figure 13. Structure contour map on top of the Detroit River series.

The increase in dip with stratigraphic depth is most marked within the Detroit River group (8 feet per mile difference) and the Salina group where the difference between top and bottom dips is 14 feet per mile. The reason for this increase in dip is that sinking took place in the Michigan Basin while the Detroit River and Salina sediments were being deposited. Consequently these formations thicken basinward, and the dips on the upper surfaces (which initially were flat or nearly so) are appreciably less than the dips on the lower contacts. Moderate sinking of the Michigan Basin also took place in Bass Island time. These conclusions, based on regional dip figures, are verified by the type of sediment deposited in the Basins. During the period of greatest sagging, the Salina, thick beds of salt with some anhydrite were deposited. Thinner beds of salt and considerable anhydrite were precipitated during Detroit River time. Anhydrite only, and in relatively minor amounts, was deposited during Bass Island time.

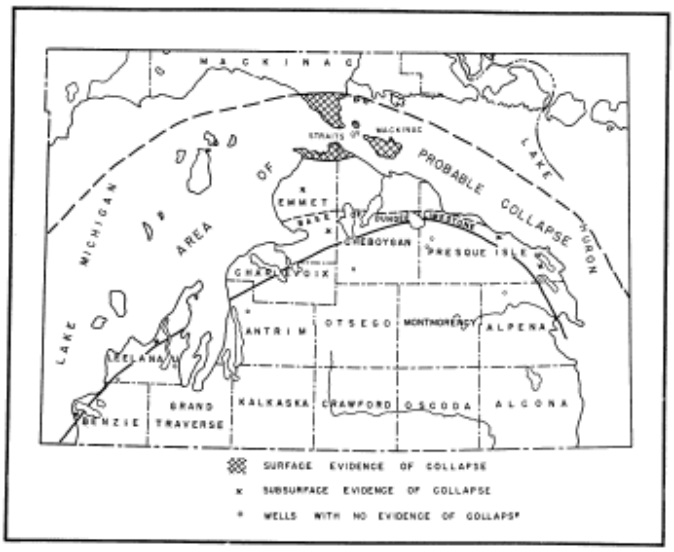


Figure 14. Map of Mackinac Straits areas showing zone of collapse and exposures of Mackinac Breccia.

The dip per mile figures given in the tabulation are relative. They are based on the log of the Bateson well which is not at the very bottom of the Basin. Therefore, the actual dips are somewhat greater. Furthermore, the figures are for the average dip between the outcrop and the Bateson well—the degree of dip decreases progressively basinward from the rim to the central part of the Basin where the dips are slight. Therefore, high on the flanks of the Basin (as in the Straits area), the dips are greater than the average. The regional dip of the rocks in the vicinity of Mackinac Straits is from 50 to 65 feet per mile.

All exposures in the Straits area are in the zone of collapse (fig. 14). Structure maps of the area can be of little value as they depict the structure of the collapsed material only and not the structure of the underlying Niagaran and older rocks. On such maps, the many faults which bound the megabreccia blocks are the most prominent features. Also because of the relatively steep dips of the mega-breccia, structure maps made on them

show local structural features of unusual magnitude. The writers do not believe it possible to find any clues as to the character of the local structure from surface observations in the zone of collapse.

In all probability, reversals of dip do occur in the rock strata of northern Michigan, and on St. Ignace peninsula. Where the collapse zone reaches the surface reversals can be determined only by structure drilling through the collapsed rock to the top of the Niagaran beds. Where Dundee and younger rocks overlie the collapsed materials it is probable that any late Paleozoic folding that took place created comparable structural features in both the older and younger rocks. In other words, an anticline in the Traverse beds would be underlain by an anticline in the Niagaran rocks, although several hundred feet of massive breccia might be between them. However, differential compaction and settling of the younger rocks overlying the breccia erosion surface may have produced folds that are entirely confined to the Dundee and higher beds.

[1]Exclusive of the Sylvania, which is classified as lower Detroit River by some writers.

[2]Prepared by Marie Tharp and submitted in partial fulfillment of the requirements for degree of Master of Science in the University of Michigan, 1944.

# Chapter V. ECONOMIC GEOLOGY

K. K. LANDES

## OIL AND GAS POSSIBILITIES

The oil and gas possibilities in the block of 15 counties lying north of T. 24 N., in the Southern Peninsula, and in Mackinac and southern Chippewa counties in the Northern Peninsula are discussed in this section. Greatest emphasis is placed on the possibilities for oil and gas in the lower Devonian and upper Silurian rocks because this part of the section was studied in the field. However, important evidence show possibilities of commercial production in younger rocks in central northern Michigan, and the older rocks throughout the area cannot be ignored as potential sources of oil and gas.

The commercial production nearest the area is in three fields which are immediately south in T. 24 N. The oldest of these fields is Richfield, in northeastern Roscommon County, T 24 N., R. 1 W. It was discovered in December, 1941, and by January 1, 1945, had 15 producing wells and a total production of 214,976 barrels. The pay zone is in, and about 1,000 feet below the top of the Detroit River group, at a depth of 4,185 feet. The pay has been named the "Richfield." Subsequent to its discovery the same zone was found to be productive in a half dozen newer fields.

The second field discovered in T. 24 N., is the East Norwich in northeastern Missaukee County, T. 24 N., R. 5 W. The discovery well was completed at a depth of 4,524 feet in the Richfield zone on July 23, 1942. The third well drilled in the East Norwich field found commercial production in the Dundee at a depth of 3,096 feet. One well in the field was producing from the Traverse in January 1945. Top of the Traverse formation is at 2,375 feet. The field produced 211,976 barrels of oil from 19 wells by January 1, 1945. In October 1942 the first successful well was drilled on the large Rose City anticline in northwestern Ogemaw County. Oil in this well is from the Richfield zone at a depth of 4,287 feet. Total production from 5 wells in the Rose City field was 31,152 barrels by the close of 1944 from one Traverse and four Detroit River wells.

One oil strike has been made, in Montmorency County, where seepages of Antrim shale gas through the glacial drift have caused sporadic interest in the area for many years. An unsuccessful Detroit River test, the Austin Rea No. 1, in sec. 24, T. 30 N., R. 3 E., was drilled in 1941 to a depth of 2,187 feet. It penetrated about 500 feet of Detroit River beds, but logged only a "smell of oil" 407 feet below the top. The second Detroit River test drilled in this county,—the Crank No. 1 well in sec. 15, T. 30 N., R. 3 E.,—struck oil 375 feet below the top of the formation, immediately beneath a salt bed. The well was drilled in the spring of 1944 to a depth of about 2,270 feet. The oil zone is between 2,180 and 2,186 feet. After drilling in, oil and water rose in the hole to the top of the casing and overflowed. Attempts to shut off the water were unsuccessful, but the well had not been abandoned by May, 1945. The possibility of producing oil in commercial quantities this far north in Michigan aroused considerable interest. Several tests have been started but no commercial wells had been drilled in by mid-1945.

More than 100 dry holes have been drilled in the 17 counties, but only 24 of these wells can be considered adequate tests. The others are either shallow wells (less than 1,000 feet deep) or were not drilled below the upper Detroit River beds. No wells have been drilled in Oscoda County for oil. Furthermore, many of these tests were drilled without benefit of geological advice, so are not necessarily tests of potential oil "traps." Obviously, the area has not been adequately explored.

### *POTENTIAL OIL AND GAS RESERVOIR ROCKS*

PRE-TRENTON ROCKS: Only two wells in the northern Southern Peninsula of Michigan have penetrated rocks below the Trenton formation,—the Nevins well in Alpena County and the Chamberlain well in Antrim County. Three wells in the area in the Northern Peninsula drilled into Cambro-Ordovician beds. Two are in western Mackinac County: the Stack Lumber Company well in sec. 26, T. 44 N., R. 12 W., and the Hiawatha Club well in sec. 17, T. 44 N., R. 9 W.; the third is the Pickford well in sec. 6, T. 43 N., R. 1 E., southern Chippewa County. Because of the scanty data, it is difficult to map the distribution of the pre-Trenton rocks in Michigan, and geologists have not yet reached an agreement on the

nomenclature that should be applied to this part of the stratigraphic section.

No oil or gas has been found in pre-Trenton rocks in Michigan, but they are very important reservoir formations in the Mid-Continent oil district, and shows of oil have been recorded from them in the Illinois Basin and along the Cincinnati Arch in Indiana and southwestern Ontario. Lithologically the pre-Trenton beds in Michigan consist of thick sandstones and siliceous dolomites, not dissimilar to the lithology of the pre-Trenton in the Mid-Continent oil fields. Also the Michigan beds are sufficiently porous and permeable to permit oil accumulation. They yield large quantities of water wherever penetrated by the drill, and the porosity is also evident in the area of outcrop. We know of no geological reason why a suitable "trap" in pre-Trenton rocks in the area should not contain oil. The depth to these formations varies from 800 feet in southern Chippewa County to between 9,000 and 10,000 feet in southern Crawford County.

TRENTON-BLACK RIVER BEDS: The Trenton group has produced a large quantity of oil in the Lima-Indiana district south of the southern border of Michigan. It is also the oil reservoir in the Deerfield pool in western Monroe County, Michigan. Oil or gas (or both) are produced from Trenton rocks in several fields in Ontario, and on Manitoulin Island a few hundred barrels of oil have been obtained from the upper 20 feet of the Trenton limestone.[1]

The Trenton-Black River beds were penetrated by five wells which were bottomed in pre-Trenton rocks. In the Hiawatha Club well in Mackinac County an oil show was recorded 150 feet below the top of the Trenton, and shows of oil are reported in the Kreetan well in sec. 17, T. 41 N., R. 7 E., Chippewa County (Drummond Island), 19 and 35 feet below the top of the Trenton. Apparently, worthwhile production in the Trenton formation is confined to areas where dolomitization of the limestone increased the porosity. The majority of the test wells reaching the Trenton formation in Michigan drilled into limestone. However, considerable dolomite is in the Trenton section in the Hiawatha Club well in Mackinac County, and some of these dolomite beds yield large quantities of water. Samples are not available from the Kreetan well on Drummond Island. The oil there may or may not be coming from a dolomitized limestone. In any event, the oil shows and evidence of porosity in the Trenton in the Northern Peninsula invite further exploration of this formation in the Straits area where it lies at estimated depths of 1,000 to 3,000 feet below sea level.[2]

NIAGARAN SERIES: Rocks of Niagaran age produce gas and oil in Ontario, but neither gas nor oil has been found in commercial amounts in these rocks in Michigan. The Kreetan well on Drummond Island reported gas 46 feet below the top of the Manistique formation. Water was found in the Niagaran rocks in the Kreetan and Hiawatha Club wells. In the Straits and Les Cheneaux Islands areas several artesian wells have been drilled into the dolomites of the Niagaran. The principal aquifer lies from 65 to 100 feet below the top of the series. Obviously, Niagaran rocks in the Straits area have both porosity and permeability. How far south this condition continues is not known. The top of the Niagaran drops from a depth of about 600 feet at St. Ignace to an estimated 3,000 feet in central Cheboygan County. The Niagaran series of rocks also merits exploration in the northern part of the Southern Peninsula.

SALINA GROUP: The Salina shales, dolomites, and evaporites are at, or close to, the surface in the Straits region, but lie at depths below 5,000 feet near the center of the basin. Most of the rock layers have insufficient porosity for the storage of commercial quantities of oil or gas. However, some of the dolomites, especially in the lower part of the section, are porous. Gas and natural gasoline have been obtained from the Salina from wells drilled in Livingston and Washtenaw counties, and gas only from a St. Clair County well. Only one Salina test in central or northern Michigan had important shows of oil or gas, the Gulf Refining Company Bateson No. 1 in sec. 2, T. 14 N., R. 4 E., Bay County, which struck a strong flow of gas in a dolomite at a depth of 7,760 feet. This dolomite is immediately below a thick salt bed (the second salt bed above the base of the Salina) and is 2,280 feet below the top of the Salina. A second test well, drilled about a mile to the northwest, was unsuccessful. The lower Salina section on the north flank of the Michigan Basin contains dolomite beds, but no data are available concerning their porosity.

BASS ISLAND GROUP: The St. Ignace formation of the Bass Island group is exposed in the Straits area. It consists of dense massive dolomites, and shaly dolomites. The porosity is insufficient for the storage of fluids. This condition appears to continue down the flanks of the Basin, for the logs of wells in northern Michigan penetrating the Bass Island rocks not only report no oil or gas shows, but also report no water in these beds.

GARDEN ISLAND FORMATION: The basal Devonian Garden Island formation, the age equivalent to the Oriskany sandstone, consists at the outcrop of hard, dense dolomite and sandy dolomite rather than sandstone. That it has sufficient porosity for oil accumulation is questionable. Furthermore, the Garden Island formation is in northern Michigan only in scattered remnants on a pre-Bois Blanc erosion surface. Three wells have penetrated rocks that may prove to be the Garden Island formation. Two, in Presque Isle County, are discussed in the chapter on Subsurface Stratigraphy. The third, for which samples are not available, is the Lenoran Petroleum Company Commeau No. 1 well in sec. 23, T. 35 N., R. 1 E. The log of this well records 13 feet of "water sand" at a depth of 1,122 feet. The depth to the top of the Garden Island (?) formation in western Presque Isle County is about 1,250 feet. Possibility of finding oil and gas in the Garden Island formation is much lessened by the probable unequal, spotty porosity,

erratic distribution, and the relatively shallow depth of the formation where it is present.

BOIS BLANC FORMATION: In the 17-county area, 18 wells have penetrated the Bois Blanc formation. Logs of these report no oil or gas shows, but strong flows of water were logged in the lower cherty part of the section, in several wells. For example, in two wells in Leelanau County, the Wilce Farm and Orchard well in sec. 34, T. 28 N., R. 14 W., and the Heimforth well in sec. 6, T. 28 N., R. 11 W., water was found in cherty dolomite at from 205 to 235 feet below the top of the Bois Blanc. In the Nevins well in Alpena County, and the Chandler (Onaway) well in Presque Isle County, water was found in the Bois Blanc chert.

The top of the Bois Blanc chert section drops from an elevation above lake level on Mackinac Island to depths of 1,600 feet in southern Cheboygan County and below 4,000 feet in southern Ogemaw County. Sheet porosity is more likely to be found in the Bois Blanc formation, with its water-bearing chert section, than in the other beds above the pre-Trenton rocks in the area. It should be tested in all future wells exploring structural "traps" in northern Michigan.

SYLVANIA FORMATION: The Sylvania sandstone and dolomite formation does not outcrop in northern Michigan. In fact it is not beneath most of the area under discussion. The northern boundary of the formation crosses Crawford, Kalkaska, northern Grand Traverse, and southern Leelanau counties. Only one well north of T. 24 N. penetrated the Sylvania formation,—the Wilce Farm and Orchard well in Leelanau County, which penetrated 18 feet of water-bearing sand at a depth of 2,124 feet. To date tests of the Sylvania formation in Michigan have been disappointing. The Bateson well in Bay County found five feet of oil-saturated sand between 3,960 and 3,965 feet (15 feet below the top of the formation) and it is possible that a Sylvania oil pool of small size lies beneath the surface in the vicinity. The Sylvania sandstones apparently are large lenses, not sheets of sands. But these sandstone bodies are high in porosity and permeability, and many no doubt are of sufficient size to store a large volume of oil. A likely area for further prospecting is in the southwest part of the 17-county area, where the Sylvania formation wedges out to the north on the northwest flank of the Michigan Basin. Its depth in this region ranges from 2,100 feet in southwestern Leelanau County to an estimated 4,300 feet in southeastern Crawford County.

DETROIT RIVER GROUP: The most poorly exposed rocks in the Straits area, the Detroit River group, must be considered at this time to afford the best prospects for oil production in northern Michigan, because the three pools in T. 24 N., nearest to the area, produce from Detroit River rocks, and 13 of the 24 wells over 1,000 feet deep in northern Michigan that reached the top of the Detroit River logged "shows" in these beds. A tabulation of wells in northern Michigan reporting "shows" in the Detroit River group follows.

| County | Farm | Well No. | Sec. | T. | R. | DEPTHS Below Surface | DEPTHS Below Top D.R. | DEPTHS T.D. of Well | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Alcona | Kohlman | 2 | 10 | 26N | 7E | 2644 | 431 | 3015 | Oil below lowest salt |
| | Campbell | 1 | 22 | 27N | 9E | 1710 | 115 | 1710 | Oil after shot |
| | Kohlman | 1 | 10 | 26N | 7E | 2970 | 770 | 2988 | Oil |
| Antrim | White | 1 | 31 | 31N | 5W | 1733 | 19 | 1770 | Oil and gas |
| | Chamberlain | 1 | 14 | 31N | 8W | 1861 | 616 | 6150 | Oil |
| Cheboygan | Brown | 1 | 12 | 33N | 3W | 1165 | 120 | 1694 | Oil |
| | Campbell | 1 | 7 | 34N | 1W | 600 | 0 | 650 | Gas |
| | Cimmar | 1 | 23 | 35N | 1E | 502, 591 | 67, 156 | 1178 | Oil "smell" |
| Crawford | Corning | 1 | 22 | 25N | 4W | 4120 | 1005 | 4650 | Oil |
| Kalkaska | Lawrence | 1 | 12 | 28N | 8W | 2177 | 36 | 2215 | Oil |
| Leelanau | Heimforth | 1 | 6 | 28N | 11W | 1915, 1990 | 483, 558 | 2475 | Oil |
| Montmorency | Rea | 1 | 24 | 30N | 3E | 2094 | 407 | 2187 | Oil |
| | Crank | 1 | 15 | 30N | 3E | 2182 | 365 | 2270 | Oil |

Also, many wells logged flows of water at varying levels in the Detroit River rocks. Obviously, this group contains a number of permeable beds, particularly within the evaporite succession which overlies the basal limestones.

Rocks of Detroit River age either immediately underlie the drift, or are at shallow depths, at the northern end of the Southern Peninsula and adjacent to the northwest and northeast coasts of northern Michigan. The elevation of the base of the group drops from 600 feet above sea level in the Straits area to 4,600 feet or more below sea level in the center of the Basin.

The Richfield "pay" zone in the Richfield pool is an 8-foot brown "lime" (probably dolomite) which is 1,026 feet below the top of the Detroit River group. It is apparently at the base of the evaporite succession, for 21 feet of limestone has been drilled below the oil-producing zone. In the East Norwich pool the Richfield zone is a brown dolomite 1,066 feet below the top of the Detroit River group. This is near, but not at, the base of the evaporites, for a little anhydrite has been found in samples from underlying rock. About 80 feet of dolomite and limestone containing scattered sand grains was drilled into below the Richfield zone in the east Norwich pool. These rocks probably lie close to the bottom of the Detroit River group.

The porosity of the Richfield zone is due either to original porosity in a dolomite bed or to dolomitization of an original limestone bed. The zone is in the lowest part of the evaporite succession above the basal limestone beds. In the Crank well in Montmorency County the oil is in a brown dolomite 372 feet below the top of the Detroit River group. This dolomite underlies a bed of salt. Reliable data are not available regarding the rocks beneath the oil-yielding zone, so the position of the zone in the evaporite succession cannot be definitely determined. However, the Nevins well to the northeast in Alpena County is higher on the flank of the Michigan Basin and it penetrated 610 feet of evaporites and 60 to 80 feet of basal Detroit River limestone beneath. Therefore it is reasonable to assume that the oil zone in the Crank well is near the middle of the evaporite succession. Only a well drilled through the Detroit River evaporites on the Montmorency anticline can be considered an adequate test of the Richfield zone.

In conclusion, at least two zones in the Detroit River evaporite succession offer possibilities for oil production in northern Michigan. The lower zone, lying near the bottom of the evaporite beds, has already proved productive in a half dozen fields in central Michigan. Toward the rim of the Michigan Basin the evaporite succession thins and eventually disappears, so that only the basal limestones remain in the Detroit River section. In the same area the porous zones in the evaporite succession wedge out on the flank of the Basin. The average dip of these beds pinching out up-dip is over 50 feet per mile, which is more than sufficient for oil migration. If the porosity of the dolomites in the Detroit River evaporites is at all consistent laterally, the flanks of the Basin in northern Michigan may contain oil fields of the "stratigraphic trap" type. In addition to stratigraphic traps, anticlines doubtless are in northern Michigan which offer distinctly favorable chances for oil accumulation in porous zones of the Detroit River group. Probably very few of the 15 wells (over 1,000 feet deep) in this region that reached the lower Detroit River strata were drilled near the top of the anticlines.

MACKINAC BRECCIA: The most porous rocks in the succession cropping out in the Mackinac Straits area is the Mackinac breccia. Springs are abundant around the borders of the breccia masses on St. Ignace peninsula and Mackinac Island. The indurated breccias are as porous and permeable as a conglomerate, and the non-indurated breccias are as porous as loose sand. Even the megabreccia blocks, because of their extensive fracturing, are more permeable than the undisturbed rocks. The St. Ignace No. 2 and the Cheboygan wells logged water in the breccia section, and the Frankfort (Benzie County) well reported a flow of 8,000 barrels of water a day.

The possibilities of oil storage in the Mackinac breccia are decidedly limited. Over a considerable area (fig. 14) the breccia masses extend to the bedrock surface, so lack an impervious cap. Farther south, however, the Dundee overlies the breccia and the rocks near the base of this formation are sufficiently impervious to serve as a cap rock. Everywhere the top of the breccia is at a relatively shallow depth. The maximum known depth of the Dundee-breccia contact is in the Overby well in Leelanau County, where the top of the breccia is about 1,400 feet below the surface.

HIGHER FORMATIONS: In the southern and central parts of the area the Dundee and higher formations are at sufficient depth to permit commercial accumulation of oil and gas. The Dundee, up to 1945 the number one oil-producing formation in Michigan, is at a depth of 2,695 feet in southeastern Crawford County. Shows of oil and gas have been found in this formation in northern Michigan. The Traverse group, which immediately overlies the Dundee, ranks second in oil production in the State. Above the Traverse is the Antrim shale. Seepage of gas from the Antrim shale into the overlying glacial drift in Montmorency County has been known for many years. The logs of two wells in Alpena and Alcona counties record gas shows in the Antrim. Higher in the column is the Berea sandstone[3] which produces both gas and oil in central Michigan. A well at Harrisville, Alcona County, reported a gas show in the Berea. The stratigraphically highest gas show noted was in the Coldwater shale in a well drilled near Roscommon, but in Crawford County (sec. 31, T. 25 N., R. 2 W.).

## *OIL AND GAS POSSIBILITIES BY AREAS*

The area of probable post-Niagaran, pre-Dundee collapse is shown in figure 14. The northern boundary of the collapse zone as shown is fairly accurate. The line showing the southern boundary, however, was drawn by interpolating between widely scattered central points, and should be considered only as an approximation. The line showing the base of the Dundee formation was drawn largely from well records, as exposures are scanty in this region. Between the base of the Dundee and the northern border of the collapse zone the breccia is at the surface, or immediately beneath the superficial deposits, but to the southern boundary of the collapse zone the breccia is unconformably overlain by Dundee and younger rocks.

Because of differences in the problems involved, the region is subdivided into four areas: 1. The area north of the collapse zone; 2. the area in which the collapse materials are at and below the bed rock surface; 3. the area in which the collapsed materials are covered by younger rocks; and 4. the area south of the collapse zone.

AREA NORTH OF THE COLLAPSE ZONE: Oil production from Trenton and Cambro-Ordovician rocks at shallow depth is a possibility in Mackinac and southern Chippewa counties. The principal advantage for exploration in this area is that the surface rocks are undisturbed. Furthermore, the upper Niagaran rocks, especially of the Engadine formation, are well exposed along the east-west trending Niagaran escarpment. With detailed study of the section it is possible to recognize certain beds which can be used in structure mapping. Anticlines have been mapped on the Niagaran formation and others may be found by surface mapping.

The top of the Trenton is about 800 feet below the surface along the Niagaran escarpment, and the pre-Trenton beds are at a depth of about 1,100 feet.

THE COLLAPSE ZONE AT SURFACE: This, area includes most of the St. Ignace peninsula, northern Emmet and Cheboygan counties, and northwestern Presque Isle County. Because the breccia forms the bed rock surface it cannot be considered to have oil or gas possibilities. The breccia also completely hides the structural conditions; therefore exploration in this belt should be preceded by drilling to the Niagaran for structural information, or core drilling to a depth of approximately 600 feet in the southern part of St. Ignace peninsula, and to below 2,000 feet depth in north-central Cheboygan county. The Trenton strata, which are at an approximate depth of 2,000 feet, are the most promising

formations for oil production on St. Ignace peninsula. Both Trenton and Niagaran rocks merit testing in Emmet, Cheboygan, and Presque Isle counties north of the Dundee boundary. In these counties structure drilling is expensive, owing to the fact that here the Niagaran is 2,000 feet or more beneath the surface, but the chances of finding oil are greater. The top of the Trenton in this belt is at a depth of about 3,400 feet and the pre-Trenton rocks are about 3,700 feet below the surface.

COLLAPSE ZONE BENEATH DUNDEE AND YOUNGER ROCKS: Both of the boundaries of this belt (fig. 14) are approximations drawn from widely scattered well data. The north boundary, the lower Dundee contact, is covered with glacial drift from the Lake Michigan shore to near Rogers City on the Huron shore. In this belt the breccia lies between the undisturbed pre-Salina and post-Detroit River rocks. Presumably any folding that occurred after the younger rocks were deposited (the time of major folding in the Michigan Basin) produced anticlines in both pre-breccia and post-breccia rocks. But anticlines in the Dundee and younger rocks might also be reflections of the topography of the breccia surface. Due to difference in hardness between the non-indurated and the indurated breccias, and between the "let-down" megabreccia rocks and the surrounding rock, the modern topography of the breccia surface on St. Ignace peninsula is decidedly rugged. If the pre-Dundee erosion surface was at all uneven, initial dips or differential compaction and settling would produce structures in the younger rocks which would not continue downward into the pre-breccia formations. The many fracture planes and the erratic dips in the Dundee limestone in the Calcite quarry lend support to the "settling" hypothesis. Therefore, anticlines in the Dundee and younger rocks in the area of overlapped breccia should not be considered as anticlines in the pre-breccia rocks until proved so by drilling or by seismograph surveys.

The chances of oil discovery in this belt in the post-breccia rocks are slight because of their relatively shallow depth. The maximum depth to the upper part of the Dundee formation is about 1,300 feet, but commercial production is not impossible at that depth. Another possible oil reservoir rock in this belt is the porous and permeable breccia itself. Where the overlying rocks are arched into a dome, accumulation of oil may have taken place in the breccia. The most favorable prospects for commercial production, however, are below the collapse zone in the Niagaran and older rocks, which lie within drilling depths (4,095 feet to the top of the Niagaran in the Overby well in Leelanau County) and are not too far from points where it is known that the rocks are porous.

SOUTH OF THE COLLAPSED AREA: The greater part of the area north of T. 24 N. is south of the belt of collapsed rocks. In this region the Salina salt has not been leached, no breccia is in the section, and the anticlines at the surface are probably over anticlines in the older rocks. In the south central part of the area nearest to the center of the Michigan basin, the top of the Dundee formation is at a depth of about 3,000 feet; the Richfield zone of the Detroit River group at about 4,000 feet; and the Niagaran and older rocks are much deeper.

Information available in 1944 and drilling results in the nearby East Norwich, Richfield, and Rose City fields, and in Montmorency County, lead to the belief that the most favorable prospects for production in the area north of T. 24 N. is in the Detroit River dolomites. In the central part of the area accumulation in anticlines (as in the fields to the south) is probable. Farther out, toward the rim of the Basin, "wedge-outs" of the porous zones are possible. Also, in this outer zone, the older rocks lie within reasonable drilling depths.

The Sylvania formation although not elsewhere in the area may be found beneath the surface in the southwestern part, and is another potential oil reservoir rock. Accumulation of oil in the Sylvania sandstone could take place either in anticlines or where the sand lenses pinch out to the north and northwest.[4] The Sylvania is 2,100 feet below the surface in southwestern Leelanau County.

Alpena County is in the area south of the collapsed rocks. In Alpena County the glacial drift is thin and almost continuous exposures of bed rock make it possible to determine structure by planetable mapping, on the various units in the Traverse group. If an anticline of reasonable size were found in Alpena County it would be well worth prospecting. The Nevins well in northwestern Alpena County struck the top of the Dundee at 458 feet depth, the Detroit River at 605 feet, the Bois Blanc at approximately 1,290 feet, the Bass Island at 1,700 feet, the Salina at 2,035 feet, the Niagaran at 4,115 feet, the Trenton at 5,145 feet, and the Cambro-Ordovician at 5,650 feet.

## *CONCLUSIONS*

Because the Dundee, which is the leading oil-producing formation of Michigan, rises to the surface in northern Michigan, this part of the State has been almost ignored as possible oil-bearing territory. As a matter of fact, exploration in Michigan has suffered from the twin dogmas—"no good fields are to be found outside of the central part of the Basin," and "there is no oil in any quantity below the Dundee." History has shown analogous statements made elsewhere to be untrue. Experience in other basins and monoclinal areas has shown that oil is no respecter of formation names, or even of geologic age. As oil-bearing formations rise toward the surface, the oil reservoirs in many places drop stratigraphically, so that flank production is obtained from formations older than those exploited at the center of the basin.

The older formations on the northern Michigan "rim" and the younger rocks north of T. 24 N. have not (up to 1945) been adequately tested. By scientific prospecting

with core drill and seismograph throughout northern Michigan more oil pools might be discovered.

## LIMESTONE

Limestones are absent in the Pointe aux Chenes and St. Ignace formations so the outcrop areas of these rocks have no possibilities for limestone production. The uppermost part of the Bois Blanc formation is limestone which as shown by well records exceeds 150 feet in thickness. It is much thinner at the outcrop, but a close estimate of its thickness there could not be obtained. Many years ago a relatively small amount of Bois Blanc limestone was quarried from near the mouth of Mill Creek in the center of the north ½ of Private Claim No. 344, Cheboygan County. On the upland nearby, deep in second growth timber, in the center of the E½ sec. 29, T. 39 N., R. 3 W., a shallow trench was dug for 500 feet across the outcrop of Bois Blanc limestone very near the top of the formation by parties interested in possible commercial development.[5] However, the entire area of Bois Blanc outcrop is in the zone of collapse and for that reason quarrying would be expensive. The dip of the strata in the Mill Creek quarry is 9°. Furthermore, the Bois Blanc below this uppermost zone is extremely cherty.

Limestone is in the lower part of the Detroit River formation in the northern part of the Southern Peninsula as shown by well records and by outcrops in the NE¼ NW¼, sec. 2, T. 38 N., R. 4 W., Emmet County, where the rock is probably at or very close to the base of the Detroit River formation. With this possible exception, the Detroit River rocks do not crop out, and we know from well records that a deep valley was cut into the Detroit River outcrop in pre-glacial times across the northern end of the Southern Peninsula. This valley is now filled with about 400 feet of glacial drift. Therefore, Detroit River limestones are, in the main, inaccessible. Furthermore, this formation also collapsed like the underlying Bois Blanc.

The formation which has been proved a source of limestone is the Dundee. The Dundee, with the overlying Rogers City limestone, is quarried in the largest limestone quarry in the world, at Calcite near Rogers City in Presque Isle County. The Dundee formation (see geological map, in pocket) is immediately beneath the glacial drift in a gently curving outcrop band extending westward from just north of Presque Isle on Lake Huron to the north side of Little Traverse Bay on Lake Michigan. The covering mantle of glacial drift is thick over the western half of the outcrop but between Black Lake and Rogers City the overburden is much thinner, and it is quite possible that commercial stone is at quarryable depths at places in this area. In fact, good stone prospects may be within a reasonable distance of Grace Harbor, one-time important lumber shipping port. Between Rogers City and false Presque Isle the Dundee is at or very close to the surface.

## DOLOMITE

The oldest formation in the area of this report, the Pointe aux Chenes, contains dolomite beds, at the top and near the base. The top dolomite beds are exposed at various places on the southern part of St. Ignace peninsula (see sections in chapter on Stratigraphy of Surface Rocks). The dolomite beds are not thick, and are inter-bedded with green and red shales. Furthermore, they are all in the megabreccia so do not have lateral continuity. For these reasons the Upper Salina dolomites are not considered to have commercial possibilities. The dolomites in the lower Pointe aux Chenes have one advantageous factor—they lie below the salt zone and therefore are not brecciated. However, these dolomites are relatively thin and are interbedded with shales. Chert was found in the dolomite at one locality, in the south center of sec. 12, T. 42 N., R. 4 W., where pinkish dolomite and cherty dolomite crop out in the bed and cause the rapids of Carp River. Another lower Pointe aux Chenes dolomite locality is on the right bank of Carp River near its mouth in the NW¼ NE¼ sec. 20, T. 42 N., R. 3 W. This outcrop consists of greenish gray, mottled pink dense dolomite and indurated shale.

The St. Ignace dolomite series is the only one thick enough to be quarried. Many years ago the uppermost dolomite beds in this formation were quarried in two places, near St. Ignace and on Mackinac Island. The St. Ignace quarry is about 500 feet south-southeast of the corner of Pero and Hombach streets, St. Ignace. The dolomite which is at least 32 feet in thickness, was quarried from the side of a bluff. The area is now grown over with trees and undergrowth. The disposition of the small amount of stone removed is not known.

The dolomite from Mackinac Island quarry was burned in a near-by lime kiln and used in the construction of the fort. The old quarry is about 750 feet east of the lime kiln, on the opposite side of the Fort Mackinac-Sugar Loaf carriage road. About 6 feet of dolomite is exposed in the quarry face. The bed was worked for many feet along the outcrop. Other exposures of dolomite can be found in this vicinity, especially along Limekiln Trail and northeast of the kiln.

At St. Ignace and on Mackinac Island the dolomite is in blocks in the megabreccia. Therefore, it is unlikely that the dolomite has much lateral continuity. Trans-formational breccia is abundant in the vicinity of both quarries.

The only dolomite deposits which the writers believe have any commercial possibilities are the St. Ignace beds on Round and western Bois Blanc islands, although the amount of stone available above lake level is limited. One of the rock strata contains a few sand grains, which gives that layer a relatively high silica percentage, but the silica content for the entire dolomite section is low. The magnesia content, however, is high. Although these rocks also are in the megabreccia, the dips are moderate, and no transformational breccia was found on either island.

On the east side of Round Island near its highest point is a steep cliff, the top of which is 76 feet above lake level. On the face of the cliff a thick section of St. Ignace dolomite is exposed—the sandy zone is 11 feet below the top. Between the cliff and the lake shore is a lower bench consisting of "gashed" dolomite, which is characteristic of the lower St. Ignace section. Apparently the higher part of Round Island is underlain by a thick block of dolomite. The total tonnage of stone available is considerable, but by no means unlimited. The entire island is owned by the U.S. government. A lighthouse is built at the end of the point at the northwest extremity of the island.

Dolomite outcrops were found on Bois Blanc Island at various places on the western and northern shores. On the northwest shore 500 feet south of the westernmost point in sec. 14, 18 feet of St. Ignace dolomite is above lake level—the upper 10 feet is exposed on the face of a low shore cliff. This rock apparently extends under the low western end of the island and has very little overburden. Along the north shore of the island, in the N½ NE¼ sec. 9, a thirty-foot cliff of dolomite, beginning 5 feet above lake level, is exposed. This section includes the brown somewhat "punky" dolomite of the upper St. Ignace and the gashed cream-colored dolomite of the lower part of the formation. Possibilities of a profitable quarry development are lessened by the fact that 300 feet inland, lower Bois Blanc chert is exposed in a 15-foot cliff. Thus, a dolomite quarry could extend but 300 feet from the shore. The higher cherty rocks swing westerly across the island. Therefore, only the low lying northwestern end of the island is a possible site for a dolomite quarry. A considerable tonnage of stone may be present, but it would be necessary to quarry over a wide area, thus development of a profitable quarry in this locality is probably not feasible.

Further southeast along the shore of Bois Blanc Island, in the northern part of the NW¼ sec. 8, more dolomite is exposed, but the overlying chert is nearer lake level than in section 9 and drops down to beach level about one-half mile farther to the southeast.

The dolomite in the Bois Blanc formation is invariably cherty. The only exposures of the Detroit River formation found in northern Michigan are limestone. High-grade dolomite beds must be somewhere within this formation, since dolomite is in the breccia at Calcite. According to well records, these dolomites are in the upper Detroit River (of northern Michigan), and their natural outcrops are buried beneath thick deposits of glacial drift.

## SALT

Many wells in Michigan have drilled into salt in the Salina (Pointe aux Chenes) formation. The map (fig. 3) shows the aggregate thickness of salt in the northern half of the Southern Peninsula. Only a few widely separated wells have penetrated the entire salt series in this area, therefore, factual information is meagre and much interpolation was necessary in constructing the map. The thickest salt so far discovered in Michigan is in the Gulf Oil Company's Bateson No. 1 well in sec. 2, T. 14 N., R. 4 E., Bay County, where several salt beds between depths of 5,480 and 8,260 feet have a total thickness of approximately 1,600 feet. The nearest record to the north is from the C. W. Teater Nevins No. 1 well in sec. 18, T. 32 N., R. 6 E., Alpena County, where the aggregate thickness of salt is 1,200 feet. About 14 miles northeast of the Nevins well, sec. 8, T. 33 N., R. 8 E., Presque Isle County, the Alpena Land Company well penetrated 290 feet of salt and stopped in the Salina formation. On the western side of Presque Isle County, the Chandler well, drilled by the Presque Isle Development Company in sec. 5, T. 34 N., R. 2 E., drilled through a total of 835 feet of salt. The McArthur Brothers well in Cheboygan City, which was drilled in 1901, allegedly found some salt, but none is in the samples from this well. Because of this reported occurrence the zero isopach has been drawn through Cheboygan.

Apparently the Salina salt is thinner on the Lake Michigan side of the Southern Peninsula. The log of a well drilled in sec. 14, T. 31 N., R. 7 W., Antrim County, records 380 feet of beds of salt and shale, and two beds of salt 50 and 160 feet thick. According to its log, a well drilled in sec. 5, T. 29 N., R. 12 W., Leelanau County, penetrated 176 feet of beds of salt and shale and four beds of salt that total 97 feet in thickness. Farther to the south, at Manistee, 524 feet of Salina salt is indicated from well samples.

The isopach map suggests rather strongly that the deepest part of the Salina salt basin may be north of the Bateson well and that in the deepest part the aggregate salt thickness is even greater than 1,600 feet. This deepest part of the basin may contain potash salts, which are of considerably greater value than common salt. It is improbable that the potash-bearing mother liquor of the evaporating Salina sea had an opportunity to escape from the basin after the sodium chloride had precipitated. But it is probable that potash and other highly soluble salts were deposited in the lowest part of the basin—an area which has not yet been explored by the drill.

Salt is also in the Detroit River formation, but the beds are thinner and the aggregate thickness and areal extent are less than in the Salina. The most northerly discovery of Detroit River salt is in the Crank well in sec. 15, T. 30 N., R. 3 E. The thickness of the salt in this well is 140 feet. Earlier in this report it was pointed out that the Detroit River salt may be reworked Salina salt from near the rim of the Salina basin. If that is true, potash would not be in the Detroit River formation.

In conclusion, the northern half of the Southern Peninsula, excepting the tip and the northwestern edge, contains abundant salt, much of it at moderate depths. Salt is such an abundant commodity in the rocks of the earth's crust that it has no value in the ground. The price paid by the consumer is largely the sum of

extracting, processing, packaging, marketing, and transportation costs.

## GYPSUM

No gypsum within reasonable quarrying depth is available in the far northern part of the Southern Peninsula. North of the Straits, however, gypsum beds in the Pointe aux Chenes formation are close to the surface. The commercial possibilities of these beds were surveyed by Grimsley[6] in 1904.

Gypsum has been quarried at only one locality in the Straits area. According to Grimsley:

> "In the 50's there was a gypsum quarry opened on the west side of the peninsula, seven miles west of St. Ignace near Point Aux Chenes, and a dock was built for loading the gypsum on boats carrying the rock to Chicago, where it was calcined. A scourge of smallpox caused a temporary abandonment of the work, and water in the quarry was a continual source of trouble. It was worked in an interrupted way for a number of years, until an ice gorge carried away the dock and the quarry was abandoned. The property is now owned by Chicago parties, but no work has been done for many years.
>
> "About 1894 the Keystone Plaster Co. of Chester, Penn., drilled some test holes about two miles west of the old quarry. The records of this work seem to have been lost, but it is stated by some of the men engaged on that work that 60 feet in all of gypsum were found in these wells, and the first ledge of a few feet in thickness was struck under a light cover. No development has followed this drilling."[6]

The writers were guided to the scene of these operations of 90 years ago by Mr. Robert D. Beveridge of St. Ignace. The so-called "plaster beds" pits are a short distance west of the head of Poupard Bay between highway U.S. 2 and the beach in the W½ SE¼ sec. 31, T. 41 N., R. 4 W. No gypsum is visible in the old pits, but some was found in an old dump which is crossed by a faintly marked road that runs from the highway to the beach.

Rabbit's Back, four miles north of St. Ignace, is a mixture of transformational breccia and megabreccia. The lowland surrounding it is underlain by shale and gypsum. Grimsley stated: "The gypsum in this point outcrops near the water's edge and can be seen under the water near the shore."[6]

Farther north along the shore other exposures of gypsum are reported by Grimsley:

> "Gypsum was found at Gros Point four miles north of Rabbit's Back and its outcrop is seen near the shore from this point on to the east for several miles."[6]

Bigsby[7] and Grimsley found gypsum on St. Martin Island, but Rominger[8] and the writers did not. Bigsby and Grimsley probably explored the area when lakes Michigan and Huron were at a low level and rocks on their floors were better exposed. According to Grimsley:

> "Some gypsum exploration was carried on a few years ago on St. Martin Island to the east of Rabbit's Back, and the rock shows in the water and was found in shallow wells over a large portion of the southern part of the island. The rock by analysis shows 98 per cent of gypsum, and so contains very little impurity. The records at hand would indicate good deposits which could be worked to advantage if the water could be kept down in the mines at a reasonable cost. The rock on St. Martin Island is stated to be three feet thick in the ledge close to the surface, with other layers further down."[6]

Two wells were drilled in the vicinity of St. Ignace. In the log of the northern well, in sec. 31, T. 41 N., R. 1 E. several beds of gypsum are recorded, including a 13-foot stratum at a depth of 174 feet.[6] As the regional dip is to the south this bed must be closer to the surface farther north. Possibly the same bed was penetrated in a well drilled on the Underwood farm near Evergreen Shores north of St. Ignace where "8 or 10" feet of the gypsum was found at a depth of 80 feet.[9]

The following conclusions regarding the gypsum prospects of the St. Ignace region are drawn by Grimsley:

> "The objections to the St. Ignace gypsum deposits, that they are in thin veins and of poor quality, are apparently untrue. The evidence at hand does not accord with these rumors. The price of fuel might prevent the manufacture of plaster in this section of the State though water transportation is available, but the gypsum might be mined and shipped to other points further south. At the present time there is no development of these gypsum fields."[6]

The writers are not quite so optimistic as Grimsley. The gypsum bearing rocks are in the zone of collapse, therefore, the gypsum beds are probably tilted and faulted and not continuous. Furthermore, all of the known gypsum beds are below lake level, and to quarry gypsum from them would involve very high, perhaps prohibitive, pumping expense.

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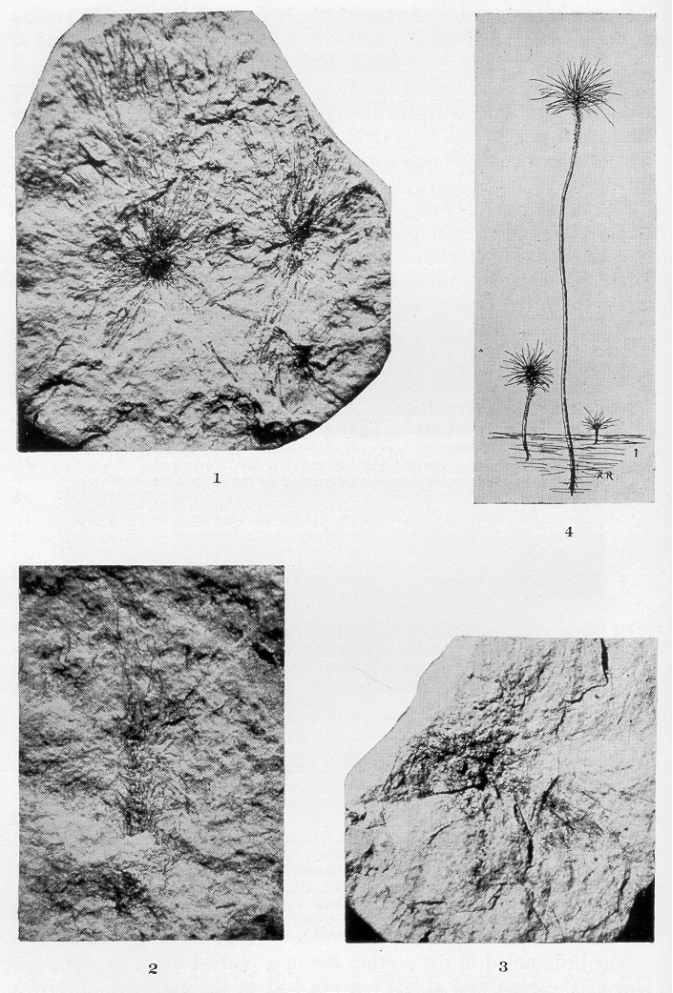
STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
P. J. Hoffmaster, Director

GEOLOGICAL SURVEY DIVISION
R. A. Smith, State Geologist

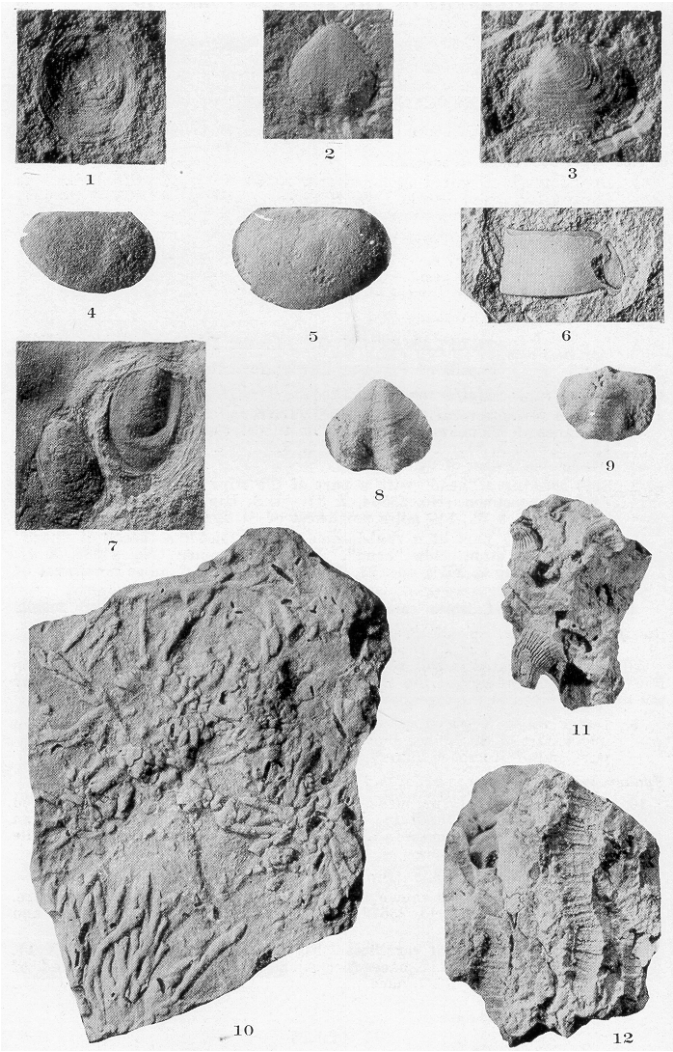



EXPLANATION OF PLATE IV
Fossils of Pte. aux Chenes formation

*Medusaegraptus graminiformis* (Pohlman)

1. Slab showing several "heads" with numerous, crowded, extremely fine, unbranched filaments, believed to be thecal tubes. Figured specimen (No. 23563, X 3). U.S. Highway 2, SE¼ sec. 23, T. 41 N., R. 5 W., 7 miles northwest of St. Ignace.
2. Slab showing a "head" with a part of the stipe just below the "head". Figured specimen (No. 23564, X 3). U.S. Highway 2, SW¼ sec. 23, T. 41 N., R. 5 W., 7½ miles northwest of St. Ignace.
3. Slab showing part of a rhabdosome with thread-like thecae of "head" and part of stipe below "head". Figured specimen (No. 23565, X 3). U.S. Highway 2, SE¼ sec. 23, T. 41 N., R. 5 W., 7 miles northwest of St. Ignace.
4. Restoration of three complete rhabdosomes. X ½. After Rudolf Ruedemann.

All fossils illustrated in this report have been placed in the collection of the Museum of Paleontology of the University of Michigan and catalogued under the numbers given in the explanations of plates.




EXPLANATION OF PLATE V
Fossils of Pte. aux Chenes and St. Ignace formations

*Orbiculoidea bertiensis* Ruedemann.

1. Dorsal valve. Figured specimen (No. 23566, X 3). Slab from Pte. aux Chenes formation beside U.S. Highway 2, SW¼ sec. 23, T. 41 N., R. 5 W., 7½ miles northwest of St. Ignace.

*Whitfieldella* sp. cf. *W. subsulcata* Grabau.

2. Mold of ventral valve. Figured specimen (No. 23567, X 2). Pte. aux Chenes formation beside U.S. Highway 2, SE¼ sec. 23, T. 41 N., R. 5 W., 7 miles northwest of St. Ignace.

*Rhytimya buffaloensis* Ruedemann.

3. Mold of left valve. Figured specimen (No. 23568, X 2). Same formation and locality as figure 2.

*Leperditia scalaris* (Jones)

4. Mold of left valve. Figured specimen (No. 23569, X 2). Pte. aux Chenes formation, unit 2 of section exposed in cut of U.S. Highway 2, SW¼ sec. 9, T. 40 N., R. 4 W., about 4 miles west of St. Ignace.

5. Mold of right valve. Figured specimen (No. 23570, X 2). Same stratum and locality as figure 4.

*Eurypterid*

6. One-half of a sternite. Figured specimen (No. 23571, X 1). Pte. aux Chenes formation, U.S. Highway 2, SW¼ sec. 23, T. 41 N., R. 5 W., 7½ miles northwest of St. Ignace.

*Lingula media* Ruedemann.

7. Two almost completely exfoliated valves. Figured specimens (No. 23572, X 2). Same bed and locality as figure 4.

*Spirifer (Delthyris)* sp. aff. *S. (D.) corallinensis* (Grabau)

8. Ventral valve. Figured specimen (No. 23573, X 3). Block from upper part of St. Ignace formation, enclosed in Mackinac breccia. About 500 feet west of Arch Rock on Arch Rock—Sugar Loaf road, Mackinac Island.

9. Dorsal valve. Figured specimen (No. 23574, X 3). Detached block from upper part of St. Ignace formation, probably unit 2 of section at northwest end of Hombach quarry, St. Ignace.

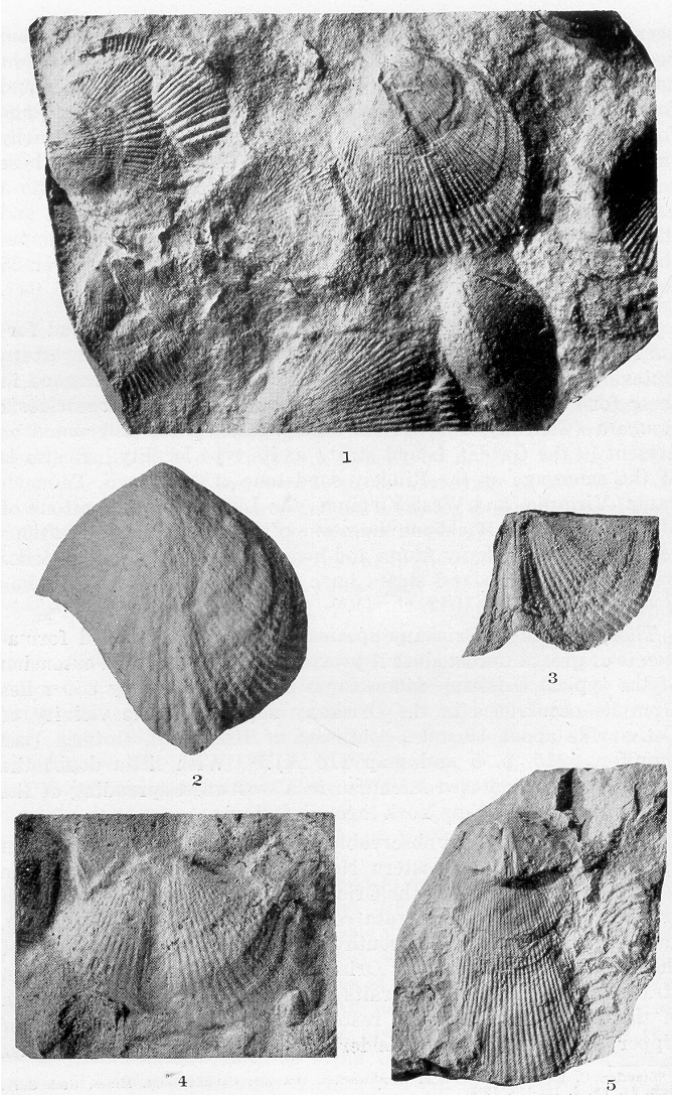
*Sphaerococcites? glomeratus* Grabau.

10. Slab with several specimens, doubtfully identified as algae. Figured specimen (No. 23575, X 1). St. Ignace formation, detached slab from unit 3 of section exposed in approach to proposed ferry terminal, 1 mile southwest of St. Ignace.

*"Cyathophyllum" hydraulicum* (Simpson Ms.) Grabau.

11. Molds of two calices shown at lower and upper left corners of figure. Figured specimen (No. 23576, X 1). Same stratigraphic position and locality as figure 8.

12. Molds of exteriors of corallites. Figured specimen (No. 23577, X 1). Highest bed of St. Ignace formation exposed at southeast end of Hombach quarry, St. Ignace.




EXPLANATION OF PLATE VIII
Fossils of Garden Island formation

*Plethorhyncha oblata* (Hall)

1. Casts of exteriors of several flattened valves. Figured specimen No. 23578, X 1). Garden Island formation. Westernmost point of Garden Island, Lake Michigan in the SW¼ sec. 3, T. 39 N., R. 10 W., Charlevoix County.

*Plethorhyncha pleiopleura* (Conrad)

2. Cast of exterior of incomplete dorsal value. Figured specimen (No. 23579, X 1). Same formation and locality as figure 1.

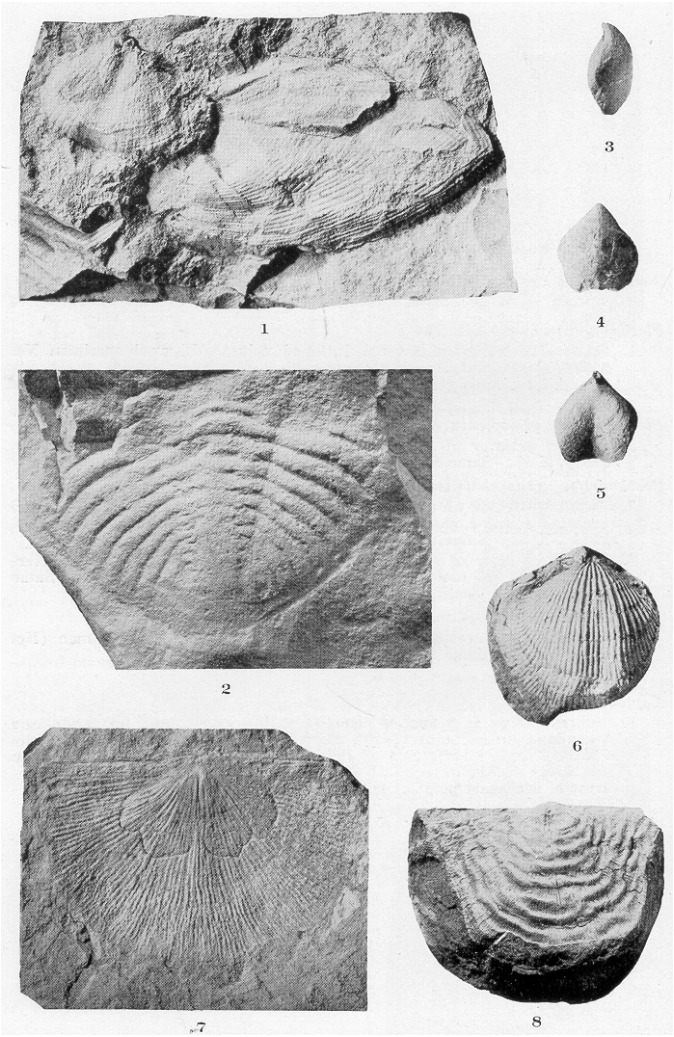
*Costispirifer arenosus* (Conrad)

3. Cast of exterior of incomplete dorsal valve showing median fold and broad, flat costae, characteristic of this species. Figured specimen (No. 23580, X 1). Same formation and locality as figure 1.

4. Cast of exterior of ventral valve showing median sinus and characteristic broad, flat costae. Figured specimen (No. 23581, X 1). Same formation and locality as figure 1.

*Rensselaeria elongata* (Conrad)

5. Dorsal valve showing fine ribs, multicostellae. Figured specimen (No. 23582, X 1). Same formation and locality as figure 1.




EXPLANATION OF PLATE IX
Fossils of Garden Island and Bois Blanc formations

*Rensselaeria elongata* (Conrad)

1. Lateral view of crushed shell, ventral valve below and dorsal valve above. Ventral valve of *Costispirifer arenosus* (Conrad) shown at upper left. Figured specimen (No. 23583, X 1). Westernmost point of Garden Island, Lake Michigan in the SW¼ sec. 3, T. 39 N., R 10 W., Charlevoix County.

*Synphoria stemmatus* Clarke

2. Water-worn pygidium. Figured specimen (No. 23584, X 1). Same formation and locality as figure 1.

*Centronella glansfagea* (Hall)

3-5. Lateral, ventral and dorsal views of one shell. Figured specimen (No. 23585, X 2). Collected by A. W. Grabau from a block of Bois Blanc strata within Mackinac breccia of Mackinac Island.

*Atrypa* sp. aff. *A. impressa* Hall

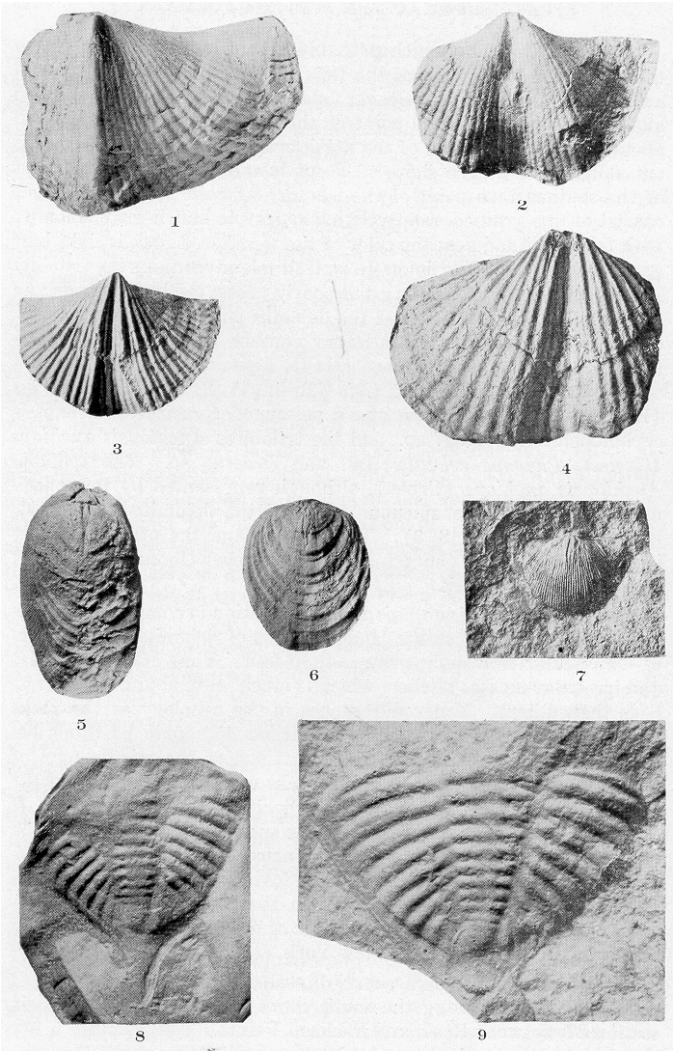
6. Dorsal view of shell showing shallow median sinus and lamellate extension of shell at left. Figured specimen (No. 23586, X 1). Middle part of Bois Blanc formation. Shore of Beaver Island, Lake Michigan, three-quarters of a mile northeast of Coast Guard Station.

*Strophonella ampla* (Hall)

7. Ventral valve through which has been impressed outline of area of muscle attachment. Figured specimen (No. 23587, X 1). Same formation and locality as figure 6.

*Leptaena* sp.

8. Ventral valve of a species common to the Bois Blanc formation and Onondaga limestone of southwestern Ontario. Figured specimen (No. 23588, X 1). Middle part of Bois Blanc formation. Shore of Garden Id., Lake Michigan, sec. 7, T 39 N., R. 9 W., one-third of a mile northwest of southeast point of island.




EXPLANATION OF PLATE XI
Fossils of Bois Blanc formation

*Costispirifer unicus* (Hall)

1. Incomplete dorsal valve, showing median fold and broad flat costae. Figured specimen (No. 23589, X 1). Lower portion of middle part of Bois Blanc formation. Shore of Beaver Island, Lake Michigan, three-quarters of a mile northeast of Coast Guard Station.

2. Incomplete ventral valve showing median sinus and broad, flat costae. Figured specimen (No. 23590, X 1). Block from middle part of Bois Blanc formation in Mackinac breccia. Cliff on north side of Cheeseman Road, 1 mile northeast of St. Ignace.

*Fimbrispirifer divaricatus* (Hall)

3. Ventral valve of small shell, showing median sinus and strong, bifurcating costae. Figured specimen (No. 23591, X 1). Lower portion of middle part of Bois Blanc formation. Top of small hill in eastern part of NW¼ sec. 9, T. 40 N., R. 4 W., about one-eighth mile southeast of Dr. Kirk Stewart's home and 4 miles west of St. Ignace.

4. Incomplete ventral valve of an average-sized shell, showing sinus and bifurcating septa. Figured specimen (No. 23592, X 1). Lower portion of middle part of Bois Blanc formation. Shore of Garden Id., Lake Michigan, sec. 7, T. 39 N., R. 9 W., one-third of a mile northwest of southeast point of island.

*Amphigenia elongata* (Vanuxem)

5. Dorsal view of a nearly complete elongate shell. Figured specimen (No. 23593, X 1). Lower portion of middle part of Bois Blanc formation. South shore of Bois Blanc Island between Rosie and Packard Points.

6. View of a complete dorsal valve, showing prominent growth lines common to many shells of this species. Figured specimen (No. 23594, X 1). Same strata and locality as figure 4.

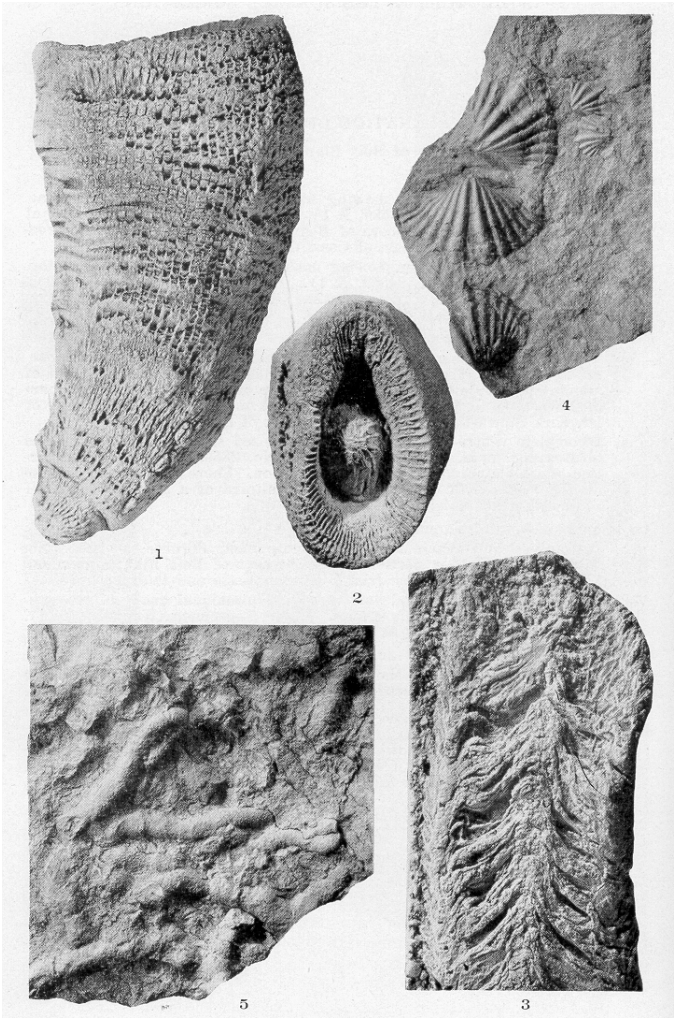
*Chonetes hemisphericus* Hall

7. View of ventral valve, showing fine ribs or costellae and auriculate hinge extremities. Figured specimen (No. 23595, X 1). Same strata and locality as figure 4.

*Anchiopsis anchiops* (Green)

8. Incomplete pygidium showing prominent, up-turned spine at posterior end. Figured specimen (No. 23596, X 1.) Near top of lower part of Bois Blanc formation. Point on west shore of Gull Id., Lake Michigan, about one-half mile south of north end of island.

9. A larger and nearly complete pygidium lacking most of posterior spine. Figured specimen (No. 23597, X 1.) Same bed and locality as figure 8.




EXPLANATION OF PLATE XII
Fossils of Bois Blanc formation

*Acrophyllum oneidaense* (Billings)

1. Side view of corallum, showing prominent wrinkles of epitheca and edges of septa and dissepiments where epitheca is worn away. Figured specimen (No. 23598, X 1). Block from middle part of Bois Blanc formation in Mackinac breccia, Mackinac Island. Collected by Dr. Carl Rominger.

2. Calyx of corallum, showing upper edges of septa and conical elevation at center. Septa twisted on surface of central elevation. Same specimen as figure 1.

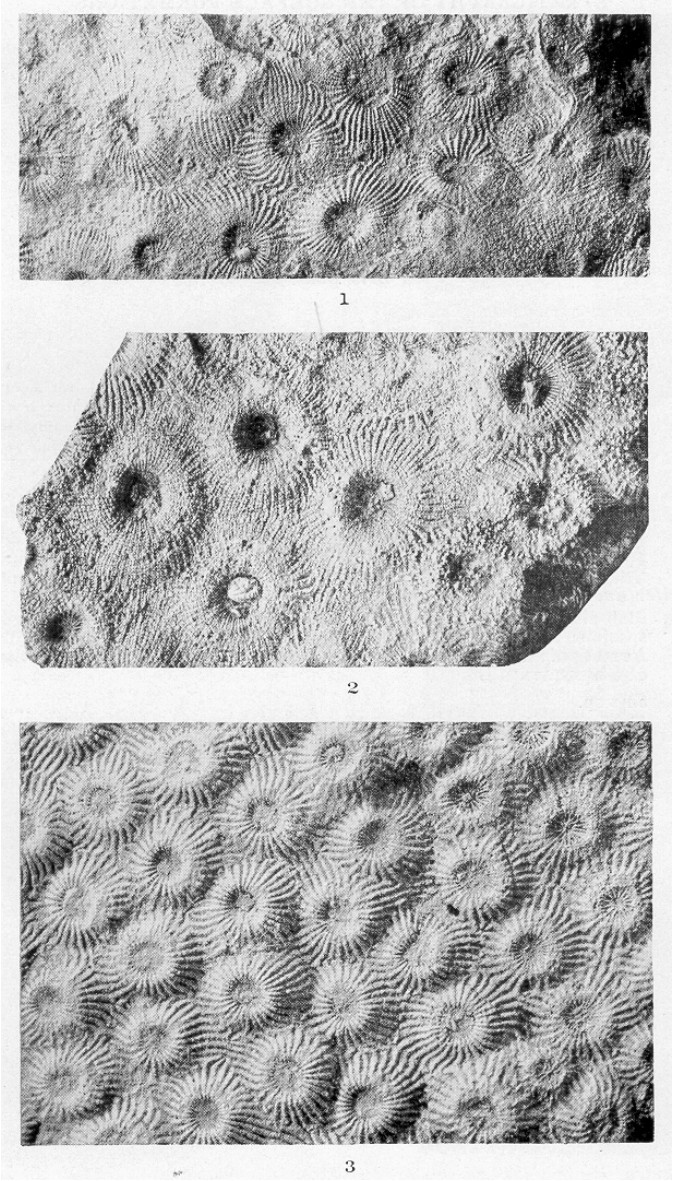
3. Part of a water-worn corallum, showing in longitudinal section tent-like tabulae which compose conical elevation of calyx. Figured specimen (No. 23599, X 1). Upper portion of middle part of Bois Blanc formation. Field of Pierce and Son Dairy Farm, NW¼ NW¼ sec. 14, T. 39 N., R. 9 W., about 2 miles west of Mackinaw City.

*Spirifer duodenarius* (Hall)

4. Slab showing several ventral valves of this common species. Figured specimen (No. 23600, X 1). Lower portion of middle part of Bois Blanc formation. Cliff on north side of Cheeseman Road, 1 mile northeast of St. Ignace.

*Idiostroma* sp.

5. Slab of shaley limestone with cylindrical branches of this supposed stromatoporoid. Figured specimen (No. 23601, X 1). Upper part of Bois Blanc formation, unit 21 of Mill Creek section. Abandoned quarry, west side of Mill Creek about 4 miles southeast of Mackinaw City.




EXPLANATION OF PLATE XIII
Fossils of Bois Blanc Formation

*Billingsastraea* sp.

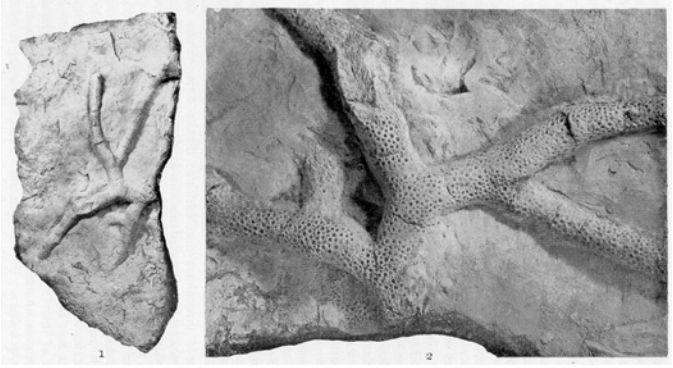
1. Part of upper surface of a corallum with corallites having an average of forty septa. Figured specimen (No. 23602, X 1). Upper portion of middle part of Bois Blanc formation. Field of Pierce and Son Dairy Farm, NW¼ NW¼ sec. 14, T. 39 N., R. 9 W., about 2 miles west of Mackinaw City. This species is fairly common in and characteristic of the entire middle part of the formation.

*Billingsastraea* sp.

2. Part of upper surface of a corallum with forty-eight to fifty septa. Figured specimen (No. 23603, X 1). Same bed and locality as figure 1. This species, like that illustrated by figure 1, seems to be present in many beds of the formation.

*Billingsastraea verneuili* (Edwards and Haime)

3. Part of upper surface of a corallum with corallites having an average of thirty septa. Figured specimen (No. 23604, X 1). Same bed and locality as figure 1. This species, which is characteristic of the lower Onondaga fauna, is much less common in the Bois Blanc formation than those illustrated by figures 1 and 2.



EXPLANATION OF PLATE XIV
Fossils of Bois Blanc formation

*Thamnopora limitaris* (Rominger)

1. Slab of limestone with a nearly complete corallum. Figured specimen (No. 23605, X ⅓). Middle part of Bois Blanc formation. Field of Pierce and Son Dairy Farm, NW¼ NW¼ sec. 14, T. 39 N., R. 9 W., about 2 miles west of Mackinaw City.

2. Lower part of same corallum. Illustrated natural size to show details of branching and circular orifices of corallites.