Unit 20 and some of the underlying units of the section are shown on the northern side of the Castle Rock ridge. About 200 feet west of the exposure of unit 20 a small outcrop shows three feet of gray, fine grained dolomite overlain by two feet of gray dolomite containing small grains of frosted quartz. These two beds of dolomite are stratigraphically above unit 20 and may not be separated from it by a covered interval of more than 25 feet. A poor exposure of pinkish- to reddish-gray fine grained dolomite, which occupies a position probably not more than five feet above the dolomite with frosted quartz grains, is in a lot intended for parking automobiles about 200 feet south of the small outcrop. About 150 feet southwest of the reddish-gray dolomite, a cut in the road leading to the parking lot exposes a very light buff gray to light-buff dolomite containing bands and lenses of fine and large grains of frosted quartz. This sandy dolomite, which probably is 10 to 20 feet above the reddish-gray dolomite, occupies a position near the top of the formation. A mass of breccia, of which the western limit is not visible, is on the north side of the Castle Rock ridge just west of the two dolomites having a combined thickness of five feet. A thick-bedded, buff, coarse grained dolomite six feet in thickness is near the top of the ridge about 600 feet west of the two dolomites. This dolomite is near the top of the formation and possibly occupies a position just above the very sandy dolomite of the road entering the parking lot. The succession, lithologic character, and thickness of the strata above unit 20 of the Castle Rock section are shown more clearly at other localities.

An exposure at the northwest end of a long abandoned quarry just east of the St. Ignace State Park, here designated the Hombach quarry, exhibits a section containing some of the dolomites of the Castle Rock ridge.

Section of strata exposed at the northwest end of the abandoned Hombach quarry, located about 500 feet south-southeast of the intersection of Hombach and Pero Streets, St. Ignace

	Thickness Feet	Thickness Inches
St. Ignace formation:		
2. Dolomite, light buff gray to cream-colored grading to light-buff at top, thick-bedded to massive; lowest 2 feet pinkish- to reddish-gray; upper part of unit coarser grained than lower; detached blocks possibly derived from lower half of unit, with many specimens of *Spirifer (Delthyris)* sp. aff. *S. (D.) corallinensis* (Grabau) and few samples of *"Cyathophyllum" hydraulicum* (Simpson Ms.) Grabau	16	
1. Dolomite, light-gray to cream-colored, fine-grained and thick-bedded, with scattered small frosted quartz grains in uppermost 4 to 5 feet; lowest 4 feet and 8 inches, exposed by trenching, somewhat finer grained and thinner bedded than rock above; base of unit about 2 feet above quarry floor.....	16	8
Total	32	8

The upper part of unit 1 of the quarry section and the dolomite with small grains of frosted quartz exposed about 200 feet west of the outcrop of unit 20 of the Castle Rock section with little doubt are parts of the same bed. The pinkish- to reddish-gray dolomite of the lowest two feet of unit 2 and the dolomite poorly exposed in the parking lot near the top of the Castle Rock ridge belong to the same bed. The uppermost layer of unit 2 may have a position below the very sandy dolomite of the road cut near the parking lot.

The fossils listed in unit 2 of the Hombach quarry section were found in detached blocks on the bottom of the quarry. (See pl. V, figs. 8-12 for illustrations of St. Ignace fossils.) The layer from which these blocks were derived was not found in the quarry wall. It is thought that the blocks were broken from one of the gray dolomites above the pinkish- to reddish-gray dolomite composing the lowest two feet of unit 2. However, it is possible that the fossiliferous blocks may have come from a soil-covered ledge just above the top of unit 2.

Higher strata in the formation are shown at the southeast end of the Hombach quarry which at this point is almost covered by evergreens, hardwoods, and bushes.

Section of strata exposed at the southeast end of the abandoned Hombach quarry, about 750 feet south-southeast of the intersection of Hombach and Pero Streets, St. Ignace

	Thickness Feet	Thickness Inches
St. Ignace formation:		
3. Dolomite, very light gray to cream-colored, finely crystalline and thick-bedded; weathers to light-buff and contains poorly preserved molds of a simple tetracoral, "*Cyathophyllum*" *hydraulicum* (Simpson MS.) Grabau, a fenestellid, *Camarotoechia?* sp. a spiriferid and *Whitfieldella?* sp.	2	
2. Covered	5	6
1. Dolomite, light-buff to cream-colored and thick-bedded, with spherical and ovoid grains observable on moistened surfaces; some grains apparently oolites, others possibly water-worn particles of dolomite	8±	
Total	15±	6

The upper part and possibly all of unit 1 of the section at the southeast end of the quarry occupies a position above unit 2 of the section shown at the northwest end of the quarry. It is difficult to trace particular beds of unit 1 along the old quarry wall to unit 2 of the northwest section, because the strata for most of the distance between the ends of the quarry are covered by talus, soil, and vegetation. At one place along the old quarry wall the continuity of the beds is broken by a breccia pillar 30 feet in width and the identification of a particular bed on both sides of the pillar cannot be made with certainty. The lithologic character of unit 1 and the six feet of dolomite on the Castle Rock ridge exposed 600 feet west of the gray dolomite with fine grains of frosted quartz are very similar and suggest that the rocks belong to the same bed. The fossiliferous dolomite of unit 3 and the unexposed rock of unit 2 have a position above the highest beds of unit 2 of the section at the northwest end of the quarry.

About 6 feet of light-buff to cream-colored, thick-bedded dolomite, having a position in the upper part of the St. Ignace formation and the same lithologic character as the rock of unit 1 of the section exposed in the southeast end of the Hombach quarry, is shown in an old quarry on Mackinac Island. The dolomite of this quarry, located 750 feet east of an old lime kiln on the east side of the Fort Mackinac-Sugarloaf road, doubtless was worked by the British before the United States came into possession of the island.

Strata in the upper part of the formation are exposed in a small cliff on the south side of Bois Blanc Island. Their lithologic character and thickness are noted in the following description:

Section of strata exposed in a cliff on the south shore of Bois Blanc Island in Section 14 about 500 feet south of most western point of island

	Thickness Feet	Thickness Inches
St. Ignace formation:		
3. Dolomite, light-buff to cream-colored, massive, somewhat granular on weathering	9	
2. Dolomite, light-gray, massive, finely textured, with fine grains of frosted quartz	0	8
1. Covered. Blocks of light-gray to cream-colored, finely textured dolomite are present in abundance in rock debris between the base of unit 2 and the nearby shore, and doubtless were broken from covered ledges of unit 1	8	
Total	17	8

The dolomite of unit 2 may be another exposure of the upper part of unit 1 of the section shown at the northwest end of the Hombach quarry. Unit 3 may be a weathered phase of the dolomite of unit 2 of the same quarry section.

Beds having a position in the upper part of the formation are exposed in a high cliff on the northeast side of Round Island and are described below:

Section of strata exposed in a cliff on the northeast side of Round Island, about a quarter of a mile northwest of the northeast point of the island

	Thickness Feet
St. Ignace formation:	
6. Dolomite, buff-gray to buff, thick-bedded with some small cavities filled with calcite crystals; unit contains a small coral, cf. "*Cyathophyllum*" *hydraulicum* (Simpson Ms.) Grabau, fenestrellinids, *Camarotoechia?* sp. and *Whitfieldella sp.*	4
5. Covered—possibly occupied by dolomite similar to unit 4	5
4. Dolomite, gray, finely textured, with scattered small frosted grains of quartz near middle	8
3. Covered. Base at inner margin of a terrace apparently cut by a post-Nipissing lake. Units 3 to 6 inclusive present in a cliff above the terrace	37
2. Covered. Blocks of light-gray, fine-grained, gashed dolomite present on the surface to point about 6 feet below top of unit, suggesting that unit consists of light gray dolomite characteristic of most of the St. Ignace formation	21
1. Dolomite, light-gray, thin-bedded, and laminated, exposed on shore of island and also below lake level	1
Total	76

Units 1 and 2 and possibly part of unit 3 of the section on the northeast side of Round Island are portions of the middle part of the formation. Unit 4 and possibly unit 5 seem to be another occurrence of the dolomite of unit 1 of the section shown at the

northwest end of the Hombach quarry. Unit 5, however, may contain the pinkish-to-reddish-gray dolomite at the base of unit 2 of this quarry section. Unit 6, which contains a few fossils, seems to correlate with a part of unit 2 of the quarry section.

Beds in the upper part of the formation are exposed in a continuation of the Round Island cliff at a point an eighth of a mile northwest of the place where the last section was studied. Their lithologic character is indicated in the following description:

Section of strata exposed in a cliff on the northeast side of Round Island about three eighths of a mile northwest of the northeast point of island

	Thickness Feet
St. Ignace formation:	
2. Dolomite, buff-gray to buff, thick-bedded, bedding planes unrecognizable in a moderately brecciated phase of the rock near central lower part of the cliff; cavities in brecciated part filled with crystals of calcite. A small simple coral and a *Favosites* with corallites 1 mm. in diameter present in the upper part of the unit in masses of chert; fractures in the chert lined with quartz crystals	30
1. Covered—base of unit 2 to shore of island	42
Total	72

The dolomite of unit 2 includes beds which occupy positions in the formation similar to positions of some of the strata exposed in the Hombach quarry. Further study of the beds, which are exposed in a vertical face in the cliff, probably will show the exact relationship of particular layers to strata of this quarry and the cliff exposure an eighth of a mile to the southeast. The cause of the brecciation of the dolomite of unit 2 is very interesting and is noted in another part of this report. The occurrence of a *Favosites* with small corallites in unit 2 also is of interest because this tabulate coral has not been found in any other outcrop of the formation.

Before describing the contact of the St. Ignace strata with beds of overlying formations, it is worth noting the outcrops of St. Ignace rocks on the islands of the Beaver Island group in Lake Michigan, because the locations of these outcrops aid materially in the mapping of the formational boundaries. Several pavement-like outcrops of light gray and cream-colored fine-grained dolomites and large shingle beaches of these rocks are along the shores of Squaw Island which is five miles north-northwest of Beaver Island. These dolomites, which no doubt are better exposed at lower water stages of Lake Michigan than the level of 1943, probably belong to the middle part of the formation. Light gray, finely

crystalline, thin-bedded to massive dolomites, the weathered surfaces of which are white, crop out along the south and west shores of Whiskey Island 1½ miles southwest of Squaw Island. These dolomites, also visible on the lake bottom adjacent to the south and west shores of the island, probably occupy a higher position in the formation than the beds on Squaw Island. A pavement of gray to cream-colored dolomite, which splits into large slabs, is along the shore of the northernmost point of Garden Island about three miles east of Squaw Island. This dolomite which also is visible beneath the water of the lake for a short distance offshore, most likely has a position high in the middle part of the formation. A cream-colored to light buff, thick-bedded dolomite, which is in the upper part of the formation and probably is a westward continuation of some of the strata of the Hombach quarry, appears on the bottom of the lake adjacent to the northeast shore of Garden Island about one and three quarters of a mile southeast of the northernmost point of the island.

The highest St. Ignace strata on Garden Island, though unexposed, with little doubt are overlain by arenaceous dolomite or dolomitic sandstone of the Garden Island formation, which, as far as known, is the oldest Devonian unit in the Mackinac Straits area. The rocks of the Garden Island formation contain an Oriskany fauna and are exposed on the west shore of Garden Island about two miles south of the north end of the island. Their lithologic and paleontologic character and their relationship to the St. Ignace strata are discussed in more detail in the section on the Garden Island formation.

On Mackinac Island the St. Ignace deposits are overlain by strata of the Bois Blanc formation, which contains Onondaga fossils and is younger than beds of the Garden Island formation having an Oriskany fauna. The contact between the St. Ignace and Bois Blanc rocks is sharply defined in a ravine near Fort Holmes at the top of Mackinac Island (pl. VII) and is noted in the following description of the exposure.

A

B

PLATE VII

A. Interbedded chert and dolomite of lower part of Bois Blanc formation in ravine near Ft. Holmes, Mackinac Island. View taken a short distance upstream from that in B.

B. Contact of St. Ignace and Bois Blanc formations in ravine near Ft. Holmes, Mackinac Island. Man's hand at top of St. Ignace formation. Overlying Bois Blanc strata in sides and bottom of ravine.

Section of strata exposed in a ravine just east of a reservoir located about 200 feet north of Fort Holmes, Mackinac Island

	Thickness Feet
Bois Blanc formation:	
3. Dolomite, buff-gray to gray, interbedded with gray chert; beds of chert as numerous as those of dolomite, range from one to six inches in thickness with an average thickness of four inches; fossils scarce, *Amplexus* sp. *Heterophrentis?* sp., and *Favosites* sp. found in chert. Elevation of top of unit 879 feet	40
2. Dolomite, dull gray to dull bluish gray, with thin discontinuous buff streaks and with nodules and two- to six-inch layers of chert; some beds of the dolomite very argillaceous	5
Total	45

Disconformity

	Thickness Feet
St. Ignace formation:	
1. Dolomite, oolitic, yellowish-buff, massive, having fractures and irregular cavities filled with calcite, and thin discontinuous masses of quartz sand in lower part; smooth rounded cavities in rock due to solution; much weathered surface buff to brown. Uppermost three to five inches has an earthy feel and apparently was leached prior to deposition of unit 2. The top of the dolomite has shallow solution channels and pits with little doubt made under subaerial conditions prior to the deposition of unit 2	12
Total	12

It is probable that the 12 feet of oolitic dolomite of unit 1 described above occupies a higher position in the St. Ignace formation than any strata previously noted. However, it is possible that this dolomite and the oolite-bearing dolomite of interval 1 of the section exposed at the southeast end of the Hombach quarry may be one and the same bed. Although the cherty dolomites of the Bois Blanc formation in the ravine did not yield fossils indicative of their age, there is no doubt that these rocks are of lower Onondaga age. Their lower Onondaga age is indicated by the occurrence of Onondaga species in other exposures of the same strata. It is interesting to note that the Garden Island formation is not present between the St. Ignace and Bois Blanc formations of the ravine. The rocks of this formation and older beds of Lower Devonian age, if older Lower Devonian beds were ever deposited in the Mackinac Straits area, were removed by erosion prior to the deposition of the Bois Blanc sediments.

The finely exposed strata of the ravine near Fort Holmes are in a large block within the breccia, which composes most of Mackinac Island. Extensively brecciated rock, which surrounds this block, can be seen by removing the soil on the south side of the ravine in the vicinity of the contact between the St. Ignace and Bois Blanc strata.

On Bois Blanc Island as well as on Mackinac Island the St. Ignace formation seems to be overlain by cherty dolomites of the Bois Blanc formation. The places on the island where this stratigraphic relationship is indicated are noted in the description of the Bois Blanc formation.

The St. Ignace formation seems to be overlain by cherty dolomites of the Bois Blanc formation on the St. Ignace peninsula. This stratigraphic relationship is indicated by an exposure in a hill in the eastern part of the NW¼ sec. 9, T. 40 N., R. 4 W., about one-eighth of a mile southeast of the home of Dr. Kirk Stewart and about 4 miles west of St. Ignace. About 16 feet of very light buff to cream-colored, thick-bedded dolomite with small lenses of frosted quartz grains and few poorly preserved simple corals and brachiopods are shown approximately 25 feet above the country road on the west side of the hill (see Pl. VI A). The surface of the hill above the ledge, which occupies a position near the top of the St. Ignace formation, is strewn with broken chert, pieces of dolomite and fossils of the Bois Blanc formation. Although the contact between the two formations is not visible, the absence of loose blocks of the Garden Island formation indicates that the St. Ignace strata are directly overlain by the Bois Blanc rocks.

It is of interest to note that the ledge of St. Ignace dolomite in the hill has a strike of N. 20° W. and dips 20° NE. and that the east side of the hill and a smaller hill about one-tenth of a mile to the north are composed of a massive indurated breccia.

THICKNESS: The total thickness of the St. Ignace formation is difficult to determine because no exposures of the formation are known which would make possible the measurement of considerable thicknesses of strata. The occurrence of the beds in blocks in the breccia at various elevations may not present so great a difficulty in estimating the thickness if most of the strata of the formation were not so strikingly similar in their lithologic character. The similarity in the lithology of the rocks probably would not be a hindrance if numerous beds with recognizable fossil assemblages were present to serve as guide markers in the formation.

A consideration of the probable order of super position of the strata exposed in many blocks of the breccia leads the writers to believe that the thickness of the formation in the Mackinac Straits area is not less than 250 feet and not more than 300 feet.

STRATIGRAPHIC RELATIONSHIP: At present the correlation of the St. Ignace strata with rocks outside the Mackinac Straits area must be made on relatively little stratigraphic and paleontologic evidence. The stratigraphic relationships suggested in the following paragraphs may prove to be incorrect when the present study can be extended to an examination of the Upper Silurian rocks of the entire Michigan Basin.

The St. Ignace formation is assigned by the writers to the Bass Island[19] group, the rocks of which are known from the Bass Islands in western Lake Erie, places in northern Ohio south of these islands, southeastern Michigan, and western Ontario. This assignment is made because the St. Ignace strata occupy a stratigraphic position similar to beds of this group and resemble some of the beds in lithologic character. The few St. Ignace fossils, the stratigraphic positions of which are discussed in following paragraphs, also support the placement of the formation in the Bass Island group.

The species of *Leperditia*, which is in the dolomite of the middle part of the formation along Church Street in St. Ignace and along the Lake Michigan shore northwest of Pte. la Barbe, is closely related to *Leperditia jonesi* Hall and *L. ohioensis* Bassler. *Leperditis jonesi* Hall and *L. ohioensis* Bassler are respectively characteristic of the Cobleskill limestone of New York and the Greenfield of Ohio, the oldest formation of the Bass Island group. In the recently published correlation chart of the Silurian formations of North America by C. K. Swartz, et al (1942, pp. 533-538, 1 pl.)[34] the Cobleskill limestone is correlated with the Raisin River dolomite, the youngest formation of the Bass Island group. By most workers the Greenfield dolomite is considered to be the oldest formation of the Bass Island group.

Several specimens which seem to be identical with the questionable alga *Sphaerococcites? glomeratus* Grabau were found on blocks of dolomite on the bottom of the approach to the proposed ferry terminal one mile southwest of St. Ignace (pl. V, fig. 10). With little doubt they were blasted from the 14-foot bed of dolomite of unit 3 of the section exhibited in the rock walls of the approach; this dolomite, as previously noted, is in the middle part of the St. Ignace formation and probably occupies a position above the

Leperditia-bearing dolomite exposed nearby on Church Street. The questionable alga, *Sphaerococcites? glomeratus* Grabau, is reported by Grabau (1910, p. 210)[38] as occurring in the Greenfield and Raisin River dolomites.

The dolomites of the upper part of the St. Ignace formation have more species of fossils than the rocks of the middle and lower parts of the formation, but unfortunately most of these fossils are so poorly preserved that their exact specific identity cannot be determined. A further search for fossils very likely will yield determinable species which may aid materially in the correlation of the St. Ignace strata.

The small brachiopod, found in detached blocks of dolomite from the upper part of the formation at the northwest end of the Hombach quarry and identified as *Spirifer (Delthyris)* sp. aff. *S. (D.) corallinensis* (Grabau) (see pl. V, figs. 8-9), suggests an assignment of the St. Ignace rocks to the Bass Island group. *Spirifer (Delthyris) corallinensis* (Grabau), to which the St. Ignace brachiopod is closely related, was first described from the Cobleskill limestone, which, as previously noted, has been correlated with the Raisin River dolomite of the Bass Island group. The species also has been recorded from the Decker limestone of southeastern New York, which has been correlated with the Cobleskill, and the Rondout limestone, which overlies the Cobleskill and Decker formations and hence would seem to be younger than the Raisin River dolomite. August F. Foerste[39] noted the occurrence of the species in the Kokomo limestone of Indiana. E. R. Cumings and R. R. Schrock[40] recorded the species in faunal lists of the Kenneth limestone of Indiana, which these writers (1927, pp. 76-77[41] and 1928, pp. 117-118, 121-123)[40] defined and separated from the Kokomo limestone of Foerste. In the correlation chart by C. K. Swartz and others (1942, pp. 533-538, 1 pl.)[34] the Kokomo limestone, comprising the lower part of the Kokomo limestone of Foerste, is correlated with the Greenfield dolomite. In the same chart the Kenneth limestone is shown as occupying a position between strata of the upper part of the Bass Island group and the top of the Upper Silurian of Indiana. Although the chart also states that the Kenneth limestone "may be Devonian," it seems very probable that the beds of this limestone

[38]Grabau, A. W., and Sherzer, W. H., The Monroe formation of Southern Michigan and adjoining regions: Michigan Geol. and Biol. Survey, Pub. 2, G. S. 1, pp. 26-7, 215-234, 1910.
[39]Foerste, A. F., Silurian fossils from the Kokomo West Union and Alger horizons of Indiana, Ohio, and Kentucky. Jour. Cincinnati Soc. Nat. Hist. Vol. 2, No. 1, p. 18, 1909.
[40]Cumings, E. R., and Shrock, R. R., The Geology of the Silurian rocks of northern Indiana. Indiana Dept. Cons., Div. of Geol. Pub. 75, pp. 123, 191, 1928.
[41]Cumings, E. R., and Shrock, R. R., The Silurian coral reefs of northern Indiana and their associated strata: Proc. Indiana Acad. Sci., vol. 36, 1926.

containing *Spirifer (Delthyris) corallinensis* (Grabau) are of Upper Silurian age.

At several places in the area the dolomites of the upper part of the St. Ignace formation contain a very poorly preserved coral which seems referable to *Cyathophyllum hydraulicum* (Simpson Ms.) Grabau. This species is characteristic of the Akron dolomite of western New York and part of Ontario just west of Buffalo, New York. This dolomite, as previously noted, is thought to be equivalent to the Cobleskill limestone which C. K. Swartz and others have correlated with the Raisin River dolomite of the Bass Island group.

Although the paleontologic evidence indicates that the St. Ignace formation probably occupies a position in the Bass Island group, the exact stratigraphic relationship of the formation to strata now assigned to this group is uncertain. The few poorly preserved and provisionally identified fossils possibly suggest a closer relationship of the St. Ignace strata to the Akron-Cobleskill rocks than to others. The correlation of the Akron-Cobleskill rocks with the Raisin River dolomite by C. K. Swartz, et al (1942, pp. 533-538, 1 pl.)[34] leads one to look for some fossils of this dolomite in the St. Ignace deposits. Failure to find a single diagnostic Raisin River dolomite species in the St. Ignace formation casts doubt on a correlation of this formation with the Raisin River dolomite and on the correlation of the Raisin River with the Akron-Cobleskill strata.

Several differences of opinion exist regarding the classification and correlation of some of the rocks of the Bass Island and Salina groups of the Michigan Basin. It seems unnecessary to discuss these views in this report. It is hoped that a study of these groups exposed elsewhere in the Michigan Basin may eliminate the uncertainties in the stratigraphy and provide information as to the exact correlation of the St. Ignace formation.

GARDEN ISLAND FORMATION

NOMENCLATURE: The name Garden Island is proposed for a thin Middle Devonian formation which occupies a position between the Upper Silurian St. Ignace and the Middle Devonian Bois Blanc formations. The name is taken from the type locality on Garden Island, which is north of Beaver Island, in Lake Michigan.

DISTRIBUTION: The only known outcrops of the formation are along the westernmost point of Garden Island almost directly west of the center of the island; the point is in the SW¼ sec. 3, T. 39 N., R. 10 W., Charlevoix County, and forms the north cape of

Indian Bay, the largest indentation of Lake Michigan in the western side of Garden Island.

The formation underlies a narrow belt of land having an east-northeast trend across Garden Island (see map). In the area adjacent to the Straits of Mackinac it is not exposed, but several outcrops indicate that it was eroded away prior to the deposition of the Bois Blanc formation. If not removed by erosion to the southwest of Garden Island, the formation forms the bed of Lake Michigan just south of Whiskey Island and north of Trout and Gull Islands (see map in pocket).

LITHOLOGIC AND PALEONTOLOGIC CHARACTERS: The few beds of the formation which could be examined during the summer of 1943 were covered almost entirely by the high water of Lake Michigan. They consist of light-buff, dolomitic sandstone, with frosted quartz grains, buff dolomite having few frosted quartz grains, and very hard buff gray to dark gray dolomite with few chert nodules and an apparent absence of quartz grains. The sandstone was found just awash at the extremity of the westernmost point of Garden Island and at intervals a few hundred feet to the northeast. Blocks of the sandstone and also of the buff dolomite are in the storm beaches adjacent to the shore. The buff dolomite and the hard buff gray to dark gray dolomite, which may be interbedded and which seemingly overlie the sandstone, were found at the shore line and on the lake bottom immediately south of the point. The dolomites contain *Zaphrentis?* sp. cf. *Z. cornuformis* Stewart, *Hederella?* sp. cf. *H. ramea* Clarke, *Leptostrophia magnifica* (Hall), *Costispirifer arenosus* (Conrad), *Plethorhyncha* sp. cf. *P. barrandii* (Hall), *P. oblata* (Hall), *P. pleiopleura* (Conrad), *Rensselaeria elongata* (Conrad), *Phacops* sp. cf. *P. cristata* Hall, and *Synphoria stemmatus* Clarke. The brachiopods *Rensselaeria elongata* (Conrad) and *Costispirifer arenosus* (Conrad), are the most abundant of the fossils noted (pl. VIII, IX).

THICKNESS: At the type locality probably not more than three feet of strata was seen. A greater thickness as well as a better idea of the super position of the beds may be recognized when the waters of lake Michigan are at a low level stage.

An estimate of the total thickness of the formation may be made from certain field relationships. At the northern point of Garden Island St. Ignace dolomites, which are at least 30 feet below the top of the formation, outcrop along the shore. About two miles southeast of the point numerous blocks of St. Ignace dolomite have

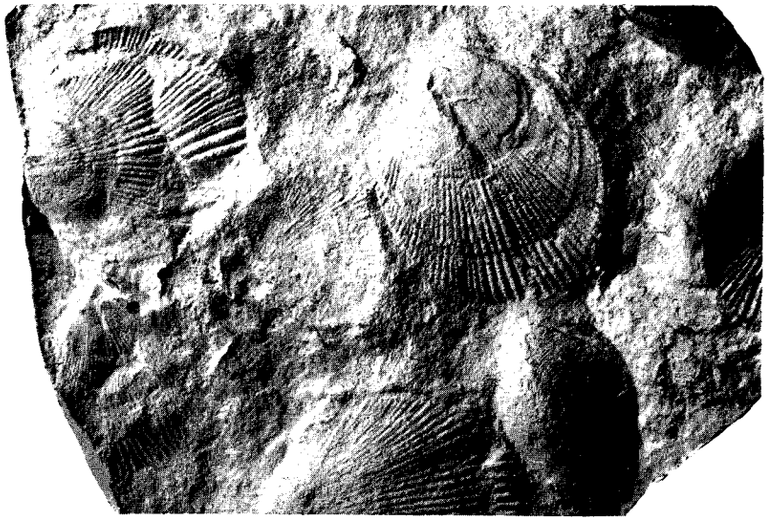
been brought to the beach by ice-push and storm waves from bedded-rock a short distance off shore. Along the shore a few hundred yards south of the type exposure of the Garden Island formation, blocks of cherty dolomite of the overlying Bois Blanc formation are fairly numerous, suggesting the presence of nearby though covered ledges of this formation. The locations of these rocks indicate that the Garden Island formation is restricted to a narrow belt of land (see map). The narrowness of this belt and the gentle dip of the strata on the island indicate that the maximum thickness of the Garden Island formation probably is not over 25 feet and that the average thickness may not be more than 15 feet.

STRATIGRAPHIC RELATIONSHIP: The Garden Island formation is a correlative of the Oriskany sandstone of southwestern Ontario and New York as shown by the common occurrence in these formations of *Costispirifer arenosus* (Conrad), *Rensselaeria elongata* (Conrad), and several other species previously noted as present in the Garden Island strata at its type locality. It also is of the same age as the Ridgely sandstone of Maryland, Pennsylvania, Virginia, and West Virginia; the Little Saline limestone of Missouri; and the Backbone limestone of Illinois. Other formations containing an Oriskany fauna and hence having a time equivalence with the Garden Island strata have been indicated by G. Arthur Cooper and others (1942, ch. 4).[35]

The presence of Oriskany species in the Garden Island formation is of great interest since it proves the northwestward extension of the typical Oriskany fauna for a distance of nearly 350 miles from its occurrence in the Oriskany deposits in the vicinity of DeCewville about 15 miles southeast of Brantford, Ontario (see Stauffer, 1915, p. 5 and map 116 A).[42] With little doubt the Oriskany fauna entered Michigan in a westward spreading of the Oriskany sea from New York through Ontario.

An unconformity, not observable, exists at the base of the Garden Island formation. In eastern New York the counterpart of the Garden Island formation, the Oriskany sandstone, was deposited on eroded Lower Devonian strata comprising the Helderberg group. In western New York and southwestern Ontario the sandstone of the westward transgressing Oriskany sea lies on Upper Silurian strata. In the Mackinac Straits region the Garden Island strata of this sea with little doubt rests on the St. Ignace formation of Upper Silurian age; any Helderberg deposits and possibly Bass

[42]Stauffer, C. R., The Devonian of Southwestern Ontario: Canada Dept. Mines, Geol. Surv. Mem. 34, pp. 5, 132-135, 1915.



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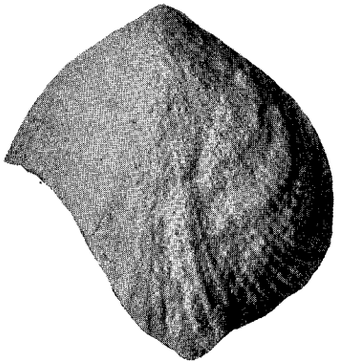

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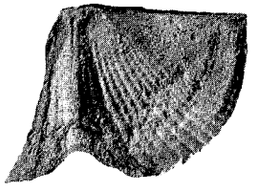

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PLATE VIII

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.

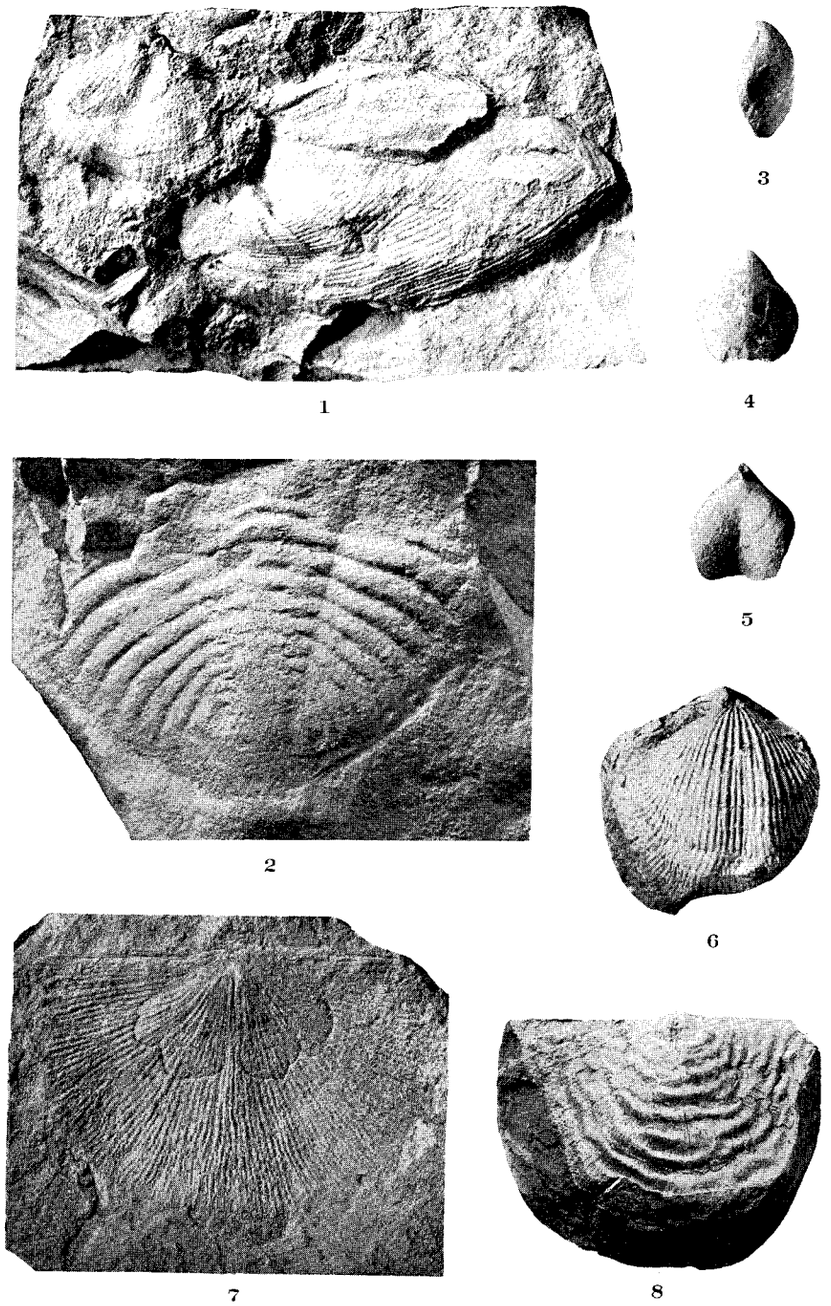

PLATE IX

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.

Island formations younger than the St. Ignace, which may have been in the Straits region, were removed by erosion in pre-Garden Island time.

Undoubtedly an uncomformity is at the top of the Garden Island formation. Evidence for its existence is presented in the description of the Bois Blanc formation.

BOIS BLANC FORMATION

NOMENCLATURE: The name Bois Blanc is proposed for a Lower or Middle Devonian formation occupying a position between the Lower Devonian Garden Island formation, or the Upper Silurian St. Ignace formation where the Garden Island is absent, and the Lower or Middle Devonian Detroit River group. The name is chosen for the reason that the rocks of the formation are well-exposed on Bois Blanc Island situated in Lake Huron slightly less than 2½ miles southeast of Mackinac Island.

DISTRIBUTION: The formation underlies the southern two-thirds of Bois Blanc Island and a narrow belt of land along the northern shore of the Southern Peninsula between a point on Lake Huron about 23 miles southeast of Mackinaw City (pl. X) and Waugoshance or Crane Island 16 west of this city (see map). Its strata constitute the surface rocks of all of Gull, High, Trout, and Hog Islands, and a few smaller islands of the Beaver Island group in Lake Michigan. The southern half of Garden Island and the northern half of Beaver Island, the two largest islands of the group, also are underlain by these rocks.

Numerous large blocks of Bois Blanc strata are in the breccia which composes most of Mackinac Island and the St. Ignace Peninsula. The boundaries of most of the blocks are so poorly exposed that the blocks had to be mapped with the Mackinac breccia (see map in pocket).

LITHOLOGIC AND PALEONTOLOGIC CHARACTERS: The lower part of the Bois Blanc formation consists of interbedded chert and dolomite. The best exposed section of these strata is shown in the ravine near Fort Holmes at the top of Mackinac Island (pl. VII) and is noted in the description of the St. Ignace formation. A similar though considerably covered outcrop of the chert and dolomite is in the cliffs near the northern shore of Bois Blanc Island, the type locality for the formation. The exact location of the exposure and the lithologic character of its strata and those of the underlying St. Ignace formation are noted in the following description:

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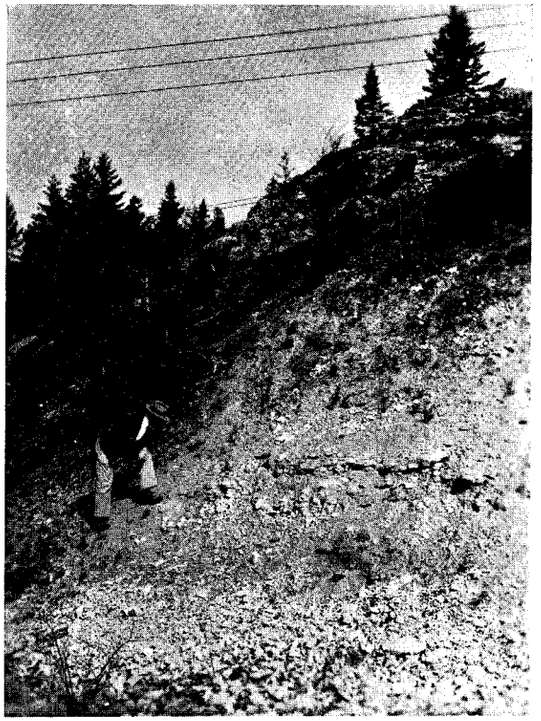

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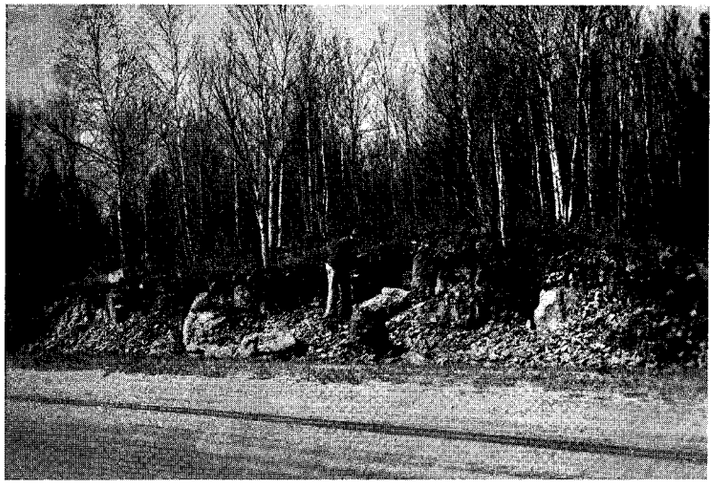


PLATE X

A. Block of very fossiliferous, cherty limestone of lower portion of middle part of Bois Blanc formation in Mackinac breccia. Slabs in talus weathered from nearly vertical beds. Cheeseman Road, 1 mile northeast of St. Ignace.

B. Small bioherm in upper part of Bois Blanc formation on U.S. Highway 31 near Mackinaw City golf course. Core rock shown to right of man and flank beds to left.

Section of strata along the shore and in cliffs in the northeastern part of sec. 9, Bois Blanc Island

	Thickness Feet
Bois Blanc formation:	
3. Dolomite, light-gray to buff-gray, interbedded with irregular layers of white to bluish-gray chert. The rock, covered in large part by soil and woods of young maple, is present in two cliffs; the upper one, about 25 feet in height, is about 600 feet south of the island shore; the lower one, 15 feet in height, is 300 feet from the shore. A prominent bench, probably cut by the waves of glacial Lake Nipissing, occurs between the two cliffs; a second bench, probably cut by a post-Nipissing lake, is present between the lower bluff and a third and lowest cliff noted in the description of unit 2. The benches decrease in width when traced westward; about a fourth of a mile to the west the cherty dolomite of unit 3 is present in a single bluff above the much narrowed lower terrace, which apparently corresponds to top of unit 2	40±
Total	40±
Disconformity—present but unexposed. The Garden Island formation, which rests on the St. Ignace formation on Garden Island, is as far as known not at the surface on Bois Blanc Island, apparently having been removed by erosion prior to the deposition of the Bois Blanc formation.	
St. Ignace formation:	
2. Dolomite, buff-gray to buff and thick-bedded, with little doubt composing most of a talus-covered cliff just south of a road adjacent to north shore of island. Dolomite in upper part of cliff is buff, has a sugary appearance, and contains very few poorly preserved remains of a small simple coral and a small *Spirifer?* sp.	32±
1. Covered—island shore to unit 2. Some, possibly all, of the covered unit is occupied by light buff gray to cream-colored, gashed, fine grained dolomite as suggested by low outcrops of this type of rock along shore about 300 feet east of this locality	5
Total	37±

Another outcrop of the beds in the lower part of the Bois Blanc formation is about two-fifths of a mile southeast of the cliff exposure. The lithologic and paleontologic character of these rocks and the lithology of the underlying St. Ignace dolomites are indicated in the following description:

Section of strata exposed between point on north shore of Bois Blanc Island near abandoned house and dock in northwest part of section 8 and point on little-used road about 600 feet inland

	Thickness Feet
Bois Blanc formation:	
6. Covered in large part along road to level of abandoned field. Unit occupied by interbedded chert and dolomite like that of unit 5; weathered-out chert abundant along road and in field just east of road. Fossils scarce, very poorly preserved, and identified as follows: *Amplexus* sp. and several other simple tetra-corals, *Favosites*—two species, *Emmonsia emmonsi* (Hall), *Dalmanella?* sp., *Rhipidomella* sp., *Pholidostrophia* sp., cf. *Amphigenia elongata* (Vanuxem), *Atrypa* sp., *Spirifer* sp., and *Cypricardinia?* sp.	15±
5. Dolomite, gray to buff-gray, interbedded with gray to bluish gray chert; beds two to six inches in thickness; unit exposed where road ascends an east-west trending cliff about a tenth of a mile southwest of outcrop of unit 2. Fossils scarce, chiefly simple tetracorals	8
4. Covered; probably occupied by rock similar to rock of unit 5	10±
Total	33
Disconformity—present but unexposed	
St. Ignace formation:	
3. Covered; with little doubt occupied by thick-bedded, light-buff dolomite; some beds of unit exposed two-fifths of a mile to the west in a cliff above the level of north shore road of island	30±
2. Dolomite, light-buff to cream-colored, thick-bedded to massive	10
1. Covered to lake level	3
Total	43±

In the description of the two sections presented above, the lower Bois Blanc strata are noted as resting disconformably on St. Ignace dolomites even though the contact between the rocks of the two formations is hidden from view by a cover of soil. The reason for believing that the Bois Blanc strata rest on St. Ignace dolomites rather than on Garden Island beds is that no detached blocks of the Garden Island formation were found at places adjacent to the covered contact. This belief is strengthened by the stratigraphic succession indicated by outcrops along the shore in the northwestern part of section 7 about three-fourths of a mile southeast of the exposure in the northwestern part of section 8. The highest St. Ignace rock at this place consists of cream-colored to very light buff dolomite with thin bands and irregular masses of medium to large grains of frosted quartz. Much of the dolomite shows coalescing rounded surfaces, which, though simulating the top of an algal layer, probably are of inorganic origin. On the shore just southeast of the easternmost outcrop of the dolomite is a small outcrop

of the cherty dolomite of the Bois Blanc formation. The nearness of the lower part of the Bois Blanc formation to the St. Ignace dolomite is shown by the abundance of chert in the bed of the little-used, north shore road which almost reaches the point on the shore where the formational contact must exist. It is doubtful whether the covered interval between the Bois Blanc and St. Ignace rocks at this point is more than two feet. If any Garden Island strata are in this interval, it seems almost certain that blocks would be broken from them by waves and lake ice and be found on the shore. The absence of such blocks at this locality and also in sections 8 and 9 shows that the Garden Island rocks, if formerly present, were removed by erosion prior to the deposition of the Bois Blanc sediments. The disconformity between the Bois Blanc and St. Ignace strata is indicated not only by the absence of the Garden Island formation but by the absence of other Lower Devonian deposits which are especially well known in New York State.

Several outcrops of the cherty Bois Blanc dolomite, which is not shown in association with St. Ignace rocks, are worth noting because their occurrence is helpful to an understanding of the stratigraphy and the areal distribution of the formation. The cherty dolomite with few poorly preserved simple corals is exposed at intervals just above lake level along the shore of LaFayette Point at the eastern extremity of Bois Blanc Island and extends offshore for a long distance beneath the very shallow water of Lake Huron. A small outcrop of the dolomite is on the southern shore of Bois Blanc Island at Zela Point about three miles northwest of the village of Point aux Pins. Another small outcrop of the dolomite, which doubtless occupies a higher stratigraphic position than that at Zela Point, is present on the shore in section 33 about 1½ miles northwest of the village. Abundant chert and dolomite in beach material at two places on Garden Island in Lake Michigan indicate that ledges of the lower part of the formation are beneath the adjacent shallow water of the lake. One of these places is only a few hundred yards south of the type exposure of the Garden Island formation on the western side of the island in the SW¼ sec. 3, T. 39 N., R. 10 W. The other is along a prominent point near the middle of the eastern side of the island in sec. 31, T. 40 N., R. 9 W. The ledges of chert and dolomite at these localities probably would be visible on the shore at low water stages of Lake Michigan. Their geographic location aids materially in mapping the boundary between the Bois Blanc and Garden Island formations and in indicating that the Garden Island formation is relatively thin.

Ledges of dolomite, which probably occupy a position at or near the top of the lower part of the Bois Blanc formation, are on Gull and Trout Islands of the Beaver Island group. They are exposed along the shore of a small point on the western side of Gull Island about a half a mile south of the north end of the island. They crop out along the southern shore of Trout Island a short distance west of the southeastern point of the island. At both places the ledges consist of fine-grained, relatively hard, gray to bluish-gray dolomite with few chert nodules; the color of the weathered rock is light buff gray to light buff. The dolomite on Gull Island contains the trilobite *Anchiopsis anchiops* (Green) and poorly preserved brachiopods and gastropods. On Trout Island the dolomite has a few simple tetracorals and stromatoporoids, a larger number of brachiopods identified as *Cymostrophia patersoni* (Hall), *Leptaena* sp., *Rhipidomella* sp. aff. *R. cleobis* (Hall), *R. livia* (Billings), *Spirifer duodenarius* (Hall), and *Stropheodonta* sp., a pelecypod *Cypricardinia?* sp., a cephalopod *Orthoceras?* sp., and the trilobites *Anchiopsis anchiops* (Green), *Phacops cristata* Hall and *Proetus* sp. The trilobite *Anchiopsis anchiops* (Green), although represented by few specimens, is the most conspicuous fossil of the dolomite on the two islands (pl. XI, figs. 8, 9). This species and the other definitely identified species are characteristic of the lower Onondaga fauna of Ontario and New York.

The middle part of the Bois Blanc formation is composed of limestones, dolomitic limestones, and few beds of dolomite. The strata range in color from light-gray to light-buff. They contain nodules and irregular masses of chert which is much more abundant in some beds than others. Minor differences in the lithology of the rocks cannot be recorded in respect to their stratigraphic positions because no outcrops exhibiting thick sections of the middle part of the formation are known. Large blocks of rock, which are in the Mackinac breccia, (pl. X A) and are derived from the middle part of the Bois Blanc formation, show that such minor differences exist and that certain strata contain distinct fossil assemblages. The middle part of the formation is very fossiliferous. The numerous specifically identified fossils, noted in the rocks described in succeeding paragraphs, are characteristic of the lower Onondaga fauna of southwestern Ontario and New York.

Light-gray to light-buff, cherty limestones of the middle part of the formation are along the south shore of Bois Blanc Island, in section 27, between Rosie and Packard Points. They contain a few simple tetracorals, the compound tetracorals *Prismatophyllum* sp.,

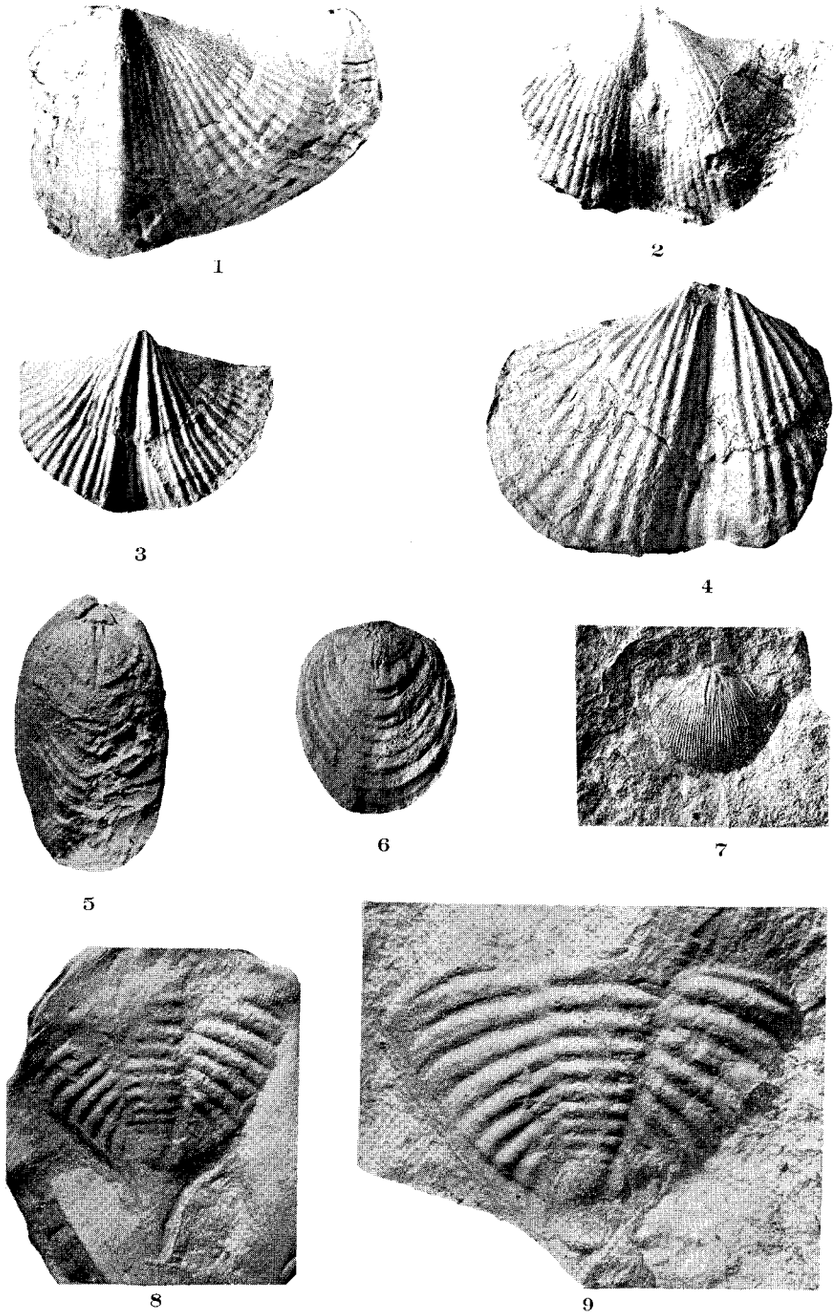


PLATE XI

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.

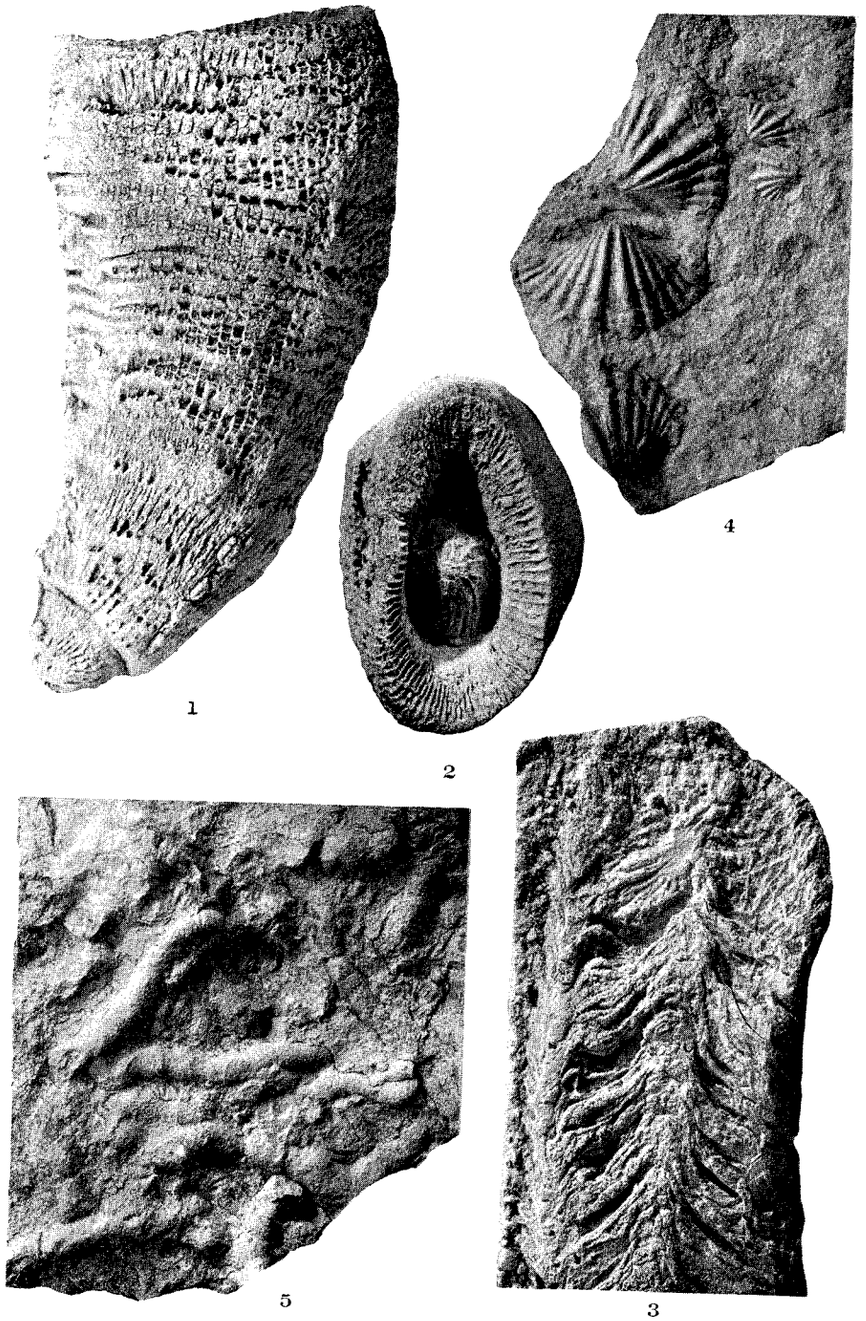


PLATE XII

EXPLANATION OF PLATE XII

Fossils of Bois Blanc formation

Acrophyllum oneidaense (Billings)

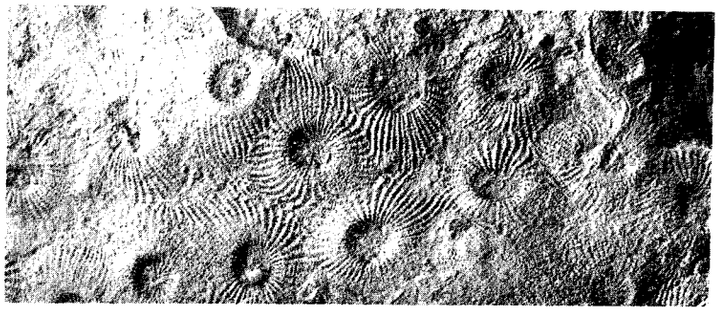
1. Side view of corallum, showing prominent wrinkles of epitheca and edges of septa and dissepiments where epitheca is worn away. Figured specimen (No. 23598, X 1). Block from middle part of Bois Blanc formation in Mackinac breccia, Mackinac Island. Collected by Dr. Carl Rominger.
2. Calyx of corallum,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



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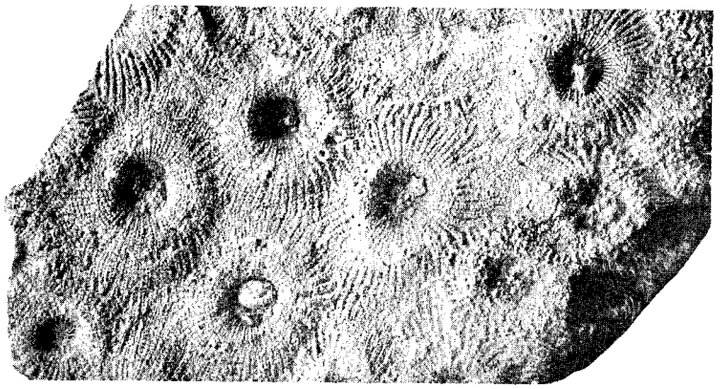

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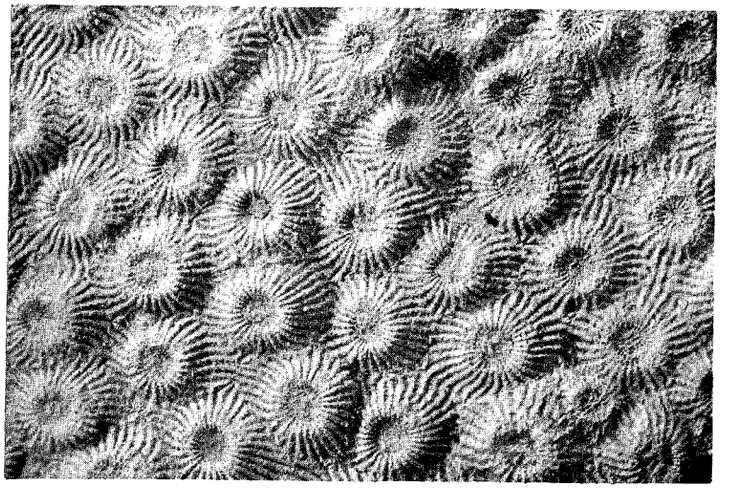

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PLATE XIII

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.

and *Billingsastraea* n. sp., the tabulate corals *Alveolites squamosus* Billings, *Cladopora labiosa* (Billings), *Emmonsia emmonsia* (Hall), *E.* sp., *Favosites* sp. and *Syringopora hisingeri* Billings, the brachiopods *Amphigenia elongata* (Vanuxem), *Atrypa* sp. aff. *A. impressa* (Hall), *Chonetes hemisphericus* (Hall), *Costispirifer unicus* (Hall), *Fimbrispirifer divaricatus* (Hall), *Leptaena* sp., cf., *Pentamerella arata* (Conrad), and *Spirifer duodenarius* (Hall), the pelecypod *Conocardium* sp., and the trilobite *Anchiopsis anchiops* (Green) (pls. X, XI, XIV). A much larger number of lower Onondaga species will be recognized when more material is obtained from the very fossiliferous limestones at this locality.

Strata of the middle part of the formation are exposed along the shore of Lake Michigan at and on both sides of McGulpin Point located about 2-1/3 miles west and three-fourths of a mile north of the business district of Mackinaw City. They appear in small disconnected outcrops at lake level between places one-third of a mile southeast of the point, in sec. 11, T. 39 N., R. 4 W., and 1-1/8 miles southwest of the point, in the NW¼ NW¼ sec. 15, T. 39 N., R. 4 W. Most of the beds are very light buff, fine grained, cherty, dolomitic limestones, with a considerable amount of comminuted remains of fossils; the others are similar in lithologic character though light gray. The limestones contain the tetracoral *Billingsastraea verneuili* (Edwards and Haime), the tabulate corals *Emmonsia emmonsia* (Hall) and *Syringopora hisingeri* Billings, the brachiopods *Amphigenia elongata* (Vanuxem), *Centronella glansfagea* (Hall), *Camarotoechia tethys* (Billings), *Chonetes hemisphericus* Hall, *Costispirifer unicus* (Hall), *Spirifer duodenarius* (Hall), and *Strophonella ampla* (Hall), and the trilobites *Anchiopsis anchiops* (Green), *Calymene platys* Green, and *Phacops cristata* Hall (pls. X-XIV). Further collecting undoubtedly will add numerous other lower Onondaga species.

A large number of tetracorals and tabulate corals are in the limestone rubble of a storm beach on the lake shore near the center of the NW¼ sec. 15, T. 39 N., R. 4 W., about 1¼ miles southwest of McGulpin Point. The identified specimens include the tetracorals *Acrophyllum oneidaense* (Billings), *Billingsastraea verneuli* (Edwards and Haime), and *B.* n. sp. and the tabulate corals *Alveolites squamosus* Billings, *Ceratopora* sp., *Cladopora labiosa* (Billings), *Emmonsia emmonsia* (Hall), *E.* sp. Nos. 1, 2, and 3 *Favosites canadensis* (Billings), *F. winchelli* Rominger, *F.* sp.-1, 2, and 3, and *Syringopora hisingeri* Billings. Associated with the corals are the brachiopods *Frimbrispirifer divaricatus* (Hall) and *Spirifer duodenarius* (Hall) and the trilobite *Anchiopsis anchiops* (Green) (pls. X-XIV). The limestone, from which the corals and other invertebrates were derived, must compose the adjacent lake bottom and occupy a higher stratigraphic position than the strata exposed at intervals along the shore between this place and McGulpin Point.

Light-gray and light-buff limestones compose most of the rubble of storm beaches of a low headland in sec. 31, T. 39 N., R. 5 W., about 7½ miles west and 1½ miles south of the business district of Mackinaw City. The ledges, from which the limestone rubble was derived, probably are on the lake bottom adjacent to the headland.

During low stages of Lake Michigan beds of light buff limestone of the middle part of the formation are exposed along the shore of Big Stone Bay in sec. 21, T. 39 N., R. 5 W., between points an eighth and a half mile northwest of Mr. Frank Laway's pier. Many simple and compound tetracorals and a smaller number of other invertebrates, nearly all of which belong to lower Onondaga species, are present in the beach rubble broken from the limestone beds and cast on the shore by storm waves. The coral-bearing limestone may be the same as the limestone near the shore about 1¼ miles southwest of McGulpin Point.

A small outcrop of light-buff limestone with few fossils is at lake level about five-eighths of a mile northwest of Frank Laway's pier. About a fourth of a mile farther northwest the beach is covered with a very cherty limestone rubble derived from ledges on the lake bottom. The rocks at both places occupy positions below the coral bed and apparently are westward continuations of some of the strata exposed along the shore near McGulpin Point.

Small exposures of light-buff dolomites interbedded with light-buff to grayish-buff limestones are at lake level along the south shore of Waugoshance (or Crane) Island, about 17 miles west of Mackinaw City. Both types of rock contain a little chert. Fossils, which are representative of species found in the middle part of the Bois Blanc formation, seem to be more abundant in the beds of limestone than in the dolomite. They occur as external and internal molds in the dolomite and as calcified or silicified remains in the limestone. A large number of lower Onondaga fossils are in the rock of the shingle beaches at this locality; possibly many of these rocks were broken from ledges on the lake bottom and cast on shore by storm waves.

Light buff gray, very cherty, dolomitic limestone is in the rubble of storm beaches between the northernmost point of Hog Island,

located about 15 miles west of Waugoshance Island, and a point on the shore about three-quarters of a mile to the southwest. The ledges from which the rubble was derived are beneath the beaches and on the adjacent bottom of the lake. The tabulate corals *Emmonsia emmonsia* (Hall), *E.* sp., and *Favosites* Sp., the brachiopods *Amphigenia elongata* (Vanuxem), *Atrypa* sp., *Centronella glansfagea* Hall, *Chonetes hemisphericus* Hall, *Cymostrophia patersoni* (Hall), *Leptaena* sp., *Protoleptostrophia perplana* (Conrad), *Rhipidomella* sp., *Spirifer macrus* Hall and *Strophonella ampla* Hall, and the trilobite *Proetus crassimarginatus* Hall, were obtained from the limestone of the storm beaches.

Light gray, cherty, dolomitic limestones are at lake level along the eastern shore of Garden Island in sec. 7, T. 39 N., R. 9 W., about a third of a mile northwest of the southeastern point of this island. They contain a few simple tetracorals, a tabulate coral *Emmonsia* sp., the brachiopods *Amphigenia elongata* (Vanuxem), *Atrypa* sp. aff. *A. impressa* Hall, *Chonetes hemisphericus* (Hall), *Costispirifer unicus* (Hall), *Elytha* sp., *Fimbrispirifer divaricatus* (Hall), *Leptaena* sp., *Rhipidomella,* sp., *Schuchertella* sp., *Spirifer duodenarius* (Hall), *Spirifer varicosus* Hall, and *Stropheodonta* sp., the pelecypods *Cypricardinia?* sp., and *Limoptera* sp., a gastropod *Platyceras* sp., and the trilobite *Proetus crassimarginatus* Hall (pls. XI-XIV).

Similar beds of limestone are exposed just above lake level and are shown on the lake bottom at a point on Garden Island in the NW¼ sec. 13, and the NE¼ sec. 14, T. 39 N., R. 10 W. They probably occupy nearly the same stratigraphic position in the middle part of the formation as the beds noted in the preceding paragraph and contain a few simple tetracorals, the compound tetracorals *Billingsastraea verneuili* (Edwards and Haime), the tabulate corals *Emmonsia emmonsi* (Hall), *E.* sp. and *Favosites* sp., the brachiopods *Amphigenia elongata* (Vanuxem), *Atrypa* sp. aff. *A. impressa* Hall, *Chonetes hemisphericus* Hall, *Leptaena* sp., cf. *Pentamerella arata* (Conrad), *Schuchertella* sp., *Spirifer* sp., cf. *S. marcus* Hall and *S.* sp. aff. *S. varicosus* Hall.

Light-gray, cherty, dolomitic limestones similar to the limestones of the two Garden Island localities, and some beds of darker gray dolomite outcrop just above lake level on the shore of Beaver Island east of the center of sec. 23, T. 39 N., R. 10 W., about two-thirds of a mile northeast of the Beaver Island Coast Guard Station, which is located about three-quarters of a mile east of the business district of St. James. They contain a few simple tetracorals, the compound tetracorals *Billingsastraea verneuili* (Edwards and Haime), and *B.* n. sp., the tabulate corals *Emmonsia emmonsia* (Hall) and *Syringopora hisingeri* Billings, a bryozoan *Fenestrellina* sp., the brachiopods *Amphigenia elongata* (Vanuxem), Atrypa sp. aff. *A. impressa* Hall, *Centronella* sp., *Chonetes hemispherica* Hall, *Costispirifer unicus* (Hall), *Cymostrophia patersoni* (Hall), *Leptaena* sp., *Merisitella?* sp., *Pentamerella* sp. aff. *P. arata* (Conrad), *Pholidops* sp., *Protoleptostrophia perplana* (Conrad), *Strophonella ampla* (Hall), *Spirifer duodenarius* (Hall), *S.* sp. cf., *S. macrus* Hall and *S. varicosus* Hall, the pelecypods *Conocardium* sp. and *Limoptera* sp., and the trilobites *Phacops* sp. and *Proetus* sp. (pls. IX, XI, XII).

The strata exposed two-thirds of a mile northeast of the Beaver Island Coast Guard Station, in the southern parts of Garden and Waugoshance Islands, in the vicinity of McGulpin Point, and on the south shore of Bois Blanc Island between Packard and Rosie Points are in the lower portion of the middle part of the Bois Blanc formation. They are thin- and uneven-bedded light-gray to light-buff limestones, dolomitic limestones, and dolomites which are characterized by much chert and many brachiopods. The most conspicuous brachiopods are *Amphigenia elongata* (Vanuxem), *Costispirifer unicus* (Hall), *Fimbrispirifer divaricatus* (Hall), and *Spirifer duodenarius* (Hall).

Rocks of the upper portion of the middle part of the Bois Blanc formation are in an upland that has a northeastward-facing slope and extends southeastward from the vicinity of McGulpin Point to the neighborhood of Mill Creek about four miles southeast of Mackinaw City. Although nearly at the surface of the upland, the strata are visible only in a few outcrops which exhibit thin sections. However, an idea of the lithology and paleontologic character of some of the rocks is indicated by the descriptions of the outcrops noted in the following paragraphs:

About three feet of dolomitic limestone is shown in a highway cut in the slope of the upland about 1¾ miles west of the business district of Mackinaw City. The limestone, exposed on the south side of the SW¼ SE¼ sec. 11, T. 39 N., R. 4 W., just north of the house on the Pierce and Son dairy farm, is buff-gray when not weathered and brown when weathered. It contains a few small cavities lined with crystals of calcite, and a small number of very poorly preserved simple tetracorals, brachiopods, and trilobites.

The base of this limestone is 46 feet above the level of Lake Michigan, which, during the summer of 1943, was approximately 581 feet above sea level. If the strata in the vicinity of the road

cut have a southward dip of about 60 feet per mile, as seems likely, possibly 75 feet of rock is between the limestone of the cut and the lowest strata exposed along the nearby shore of McGulpin Point.

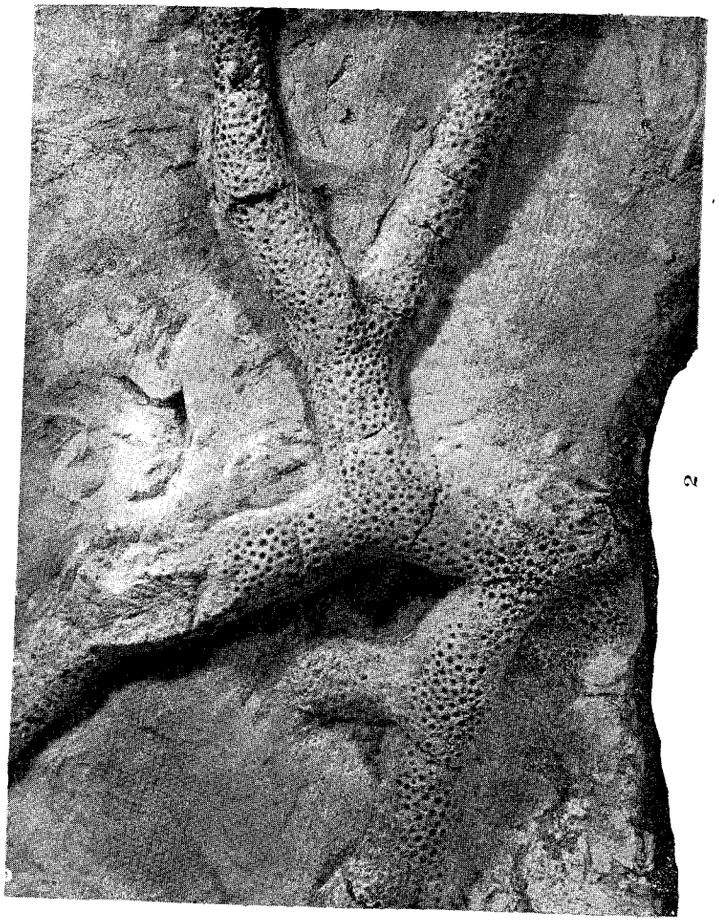
The dolomitic limestone of the road cut is overlain by light-gray to light buff gray cherty limestones, which, under a thin cover of soil, cap parts of the upland immediately northwest, west, and southwest of the highway cut. The presence of the cherty limestones is indicated by an accumulation of such material deposited as a shingle beach on the dolomitic limestone by Lake Nipissing or a post-Nipissing lake. Their existence is clearly shown by an abundance of pieces of the limestone in the soil of the cultivated fields on the upland just northwest and southwest of the road cut. Numerous slabs of the limestone, broken from ledges by plowing, have been piled along a fence on the north side of the field in the SE¼ SW¼ sec. 11, T. 39 N., R. 4 W., about an eighth of a mile northwest of the highway cut and the Pierce and Son farm house. A greater quantity of the rock has been plowed up in the field southwest of the house and placed along the fence on the south side of the NW¼ NW¼ sec. 14, T. 39 N., R. 4 W. An exceedingly large number of simple and compound tetracorals and tabulate corals are in the slabs of limestone and as weathered out specimens along this fence. It is very probable that most of the species of corals which are reported from the lower Onondaga fauna of southwestern Ontario, will be recognized in the material collected along the fence when all the specimens can be prepared for study. The lower Onondaga tetracorals *Acrophyllum oneidaense* (Billings), *Billingsastraea verneuili* (Edwards and Haime), *Chonophyllum magnificum* Billings, *Synaptophyllum arundinaceum* (Billings), and *S. simcoense* (Billings), and the tabulate corals *Alveolites aquamosus* Billings, *Ceratopora nobilis* (Billings), *Emmonsia emmonsia* (Hall), *Favosites canadensis* (Billings), *F. winchelli* (Rominger), *Thamnopora limitaris* (Rominger), *Pleurodictyum convexum* (d'Orbigny), and *P. cylindricum* (Michelin), which have been identified (pls. XII-XIV), probably represent not more than a fourth of the total number of species of the coral-bearing limestones beneath the thin soil at this locality. In addition to the corals, the limestone contains a species of *Astraeospongia*, a considerable number of stromatoporoids and massive types of bryozoa, and a few brachiopods and trilobites.

The thickness of the limestones between the thin soil-covered, coral-bearing bed at the fence and the top of the three feet of dolomitic limestone in the road-cut just north of the Pierce and Son

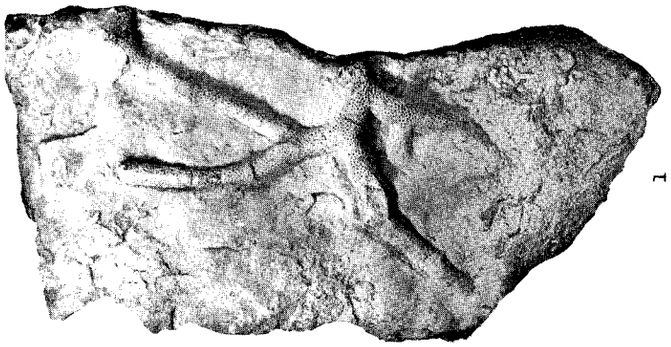
farm house is about 26 to 27 feet, as indicated by the difference in elevation of the outcrops and the southward dip of the strata of approximately 60 feet per mile. The ground elevation of the fence near the southwest corner of the NW¼ NW¼ sec. 14, T. 39 N., R. 9 W., is 651 feet. The surface of the coral-bearing bed at this place is not covered by more than two feet of soil; its elevation therefore is about 649 feet. The elevation of the top of the dolomitic limestone in the roadcut is 630 feet. The difference of 19 feet in elevation between the stratigraphic surfaces also represents closely the minimum thickness of the intervening rock. Since seven to eight feet of strata must be added to the 19 feet of rock as required by a dip of 60 feet per mile, the total thickness of the limestone between the beds of the road-cut and the field at the fenceline is 26 to 27 feet.

The relationship of the coral-bearing limestone of the Pierce and Son farm to the coral bed on the lake bottom near the center of the NW¼ sec. 15, T. 39 N., R. 4 W., about 1¼ miles southwest of McGulpin Point is not definitely known. The possibility that the limestones at the two places, which are about three-quarters of a mile apart, may be one and the same bed is suggested by the occurrence in the strata of numerous corals and of many corals of the same species. This possibility also is suggested by the locations of the limestones at places which are on the general east-west strike of the rocks of the region. The fact that the limestone on the Pierce and Son farm is about 68 feet higher than the limestone along the shore southwest of McGulpin Point is strong evidence for believing that the two limestones are distinct and occupy different stratigraphic positions. Obviously this evidence could be eliminated by local folding or by the faulting which has occurred throughout the Mackinac Straits area. Until further field studies can demonstrate the existence of a fold or a fault, the writers believe that the two coral-bearing limestones are distinct, and that the limestone on the Pierce and Son farm occupies a higher position in the formation than the limestone along the shore.

Strata having a higher position in the upper portion of the middle part of the Bois Blanc formation than the coral-bearing limestone of the Pierce and Son farm are exposed near the SW corner sec. 14, T. 39 N., R. 4 W., about three-quarters of a mile south of this farm. The lowest bed outcrops close to the southwest corner of section 14 at the side of a road leading southward to French Lake. It is a light-buff limestone having a thickness of 18 inches and containing a few simple tetracorals, *Alveolites* sp.



2



1

PLATE XIV

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 1/3). 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.

aff. *A. squamosus* Billings, and a medium-sized *Atrypa,* which has closely spaced, relatively fine plications. The elevation of this limestone is 616 feet and its position above the coral bed of the Pierce and Son farm probably is 10 to 15 feet. Eight feet of buff gray to buff, thin- and uneven-bedded limestone is shown in a cut in the road on the south side of section 14 about 200 feet east of the outcrop of the 18-inch limestone. It is separated from the top of the 18-inch limestone by a covered interval of 13 feet and has a few poorly preserved fossils which are more numerous in the upper three feet than the lower five feet of the rock. It contains a few stromatoporoids and simple tetracorals, a new species of the compound tetracoral *Billingsastraea,* the tabulate coral *Favosites,* the brachiopods *Atrypa* sp., *Meristella* sp., and *Rhipidomella* sp., the pelecypods *Conocardium* sp., and *Paracyclas?* sp., the cephalopod *Sphyradoceras* sp. cf., *S. clio* (Hall), and the trilobites *Anchiopsis* sp. aff. *A. anchiops* (Green), *Phacops* sp. aff. *P. cristata* Hall and *Proetus* sp.

Limestones, which probably occupy the same stratigraphic position as those shown in the vicinity of the SW corner sec. 14, T. 39 N., R. 4 W., and higher beds, which belong to the upper part of the Bois Blanc formation, are exposed along Mill Creek about four miles southeast of Mackinaw City. The lithologic character and fossil content of the rocks along Mill Creek are noted in the following description:

Section of strata exposed in Mill Creek between mouth of creek and top of abandoned quarry about a tenth of a mile upstream

Bois Blanc formation:	Thickness Feet	Thickness Inches
22. Limestone, gray to buff-gray, becoming light-gray toward top; upper six inches laminated; stromatoporoids present, more abundant in lower three feet	5	
21. Limestone, shaly, gray to light buff gray, with very numerous specimens of *Idiostroma* sp., a small number of massive and nodular types of stromatoporoids, a few small simple tetracorals and brachiopods, two species of *Cladopora,* and a thick-stemmed species of *Alveolites*	2	8
20. Limestone, shaly, gray, similar to unit 18 in having an abundance of thin stromatoporoids and *Idiostroma*		7
19. Limestone, light buff gray, and granular, with nodular types of stromatoporoids and few *Idiostroma;* grades into rocks of units 15 and 17 and may be a lens		9
18. Limestone, very shaly, gray, with thin stromatoporoids piled on top of one another to form a biostrome; fenestillids present in small number...		10

17. Covered; red, residual clay and light gray band in hillside suggest that unit consists of leached limestone	4	
16. Limestone, light buff gray with few specimens of *Idiostroma* and other stromatoporoids	1	3
15. Limestone, light buff gray with numerous thin stromatoporoids composing a biostrome	1	3
14. Limestone, light buff gray, fine- to medium-grained and hard, weathering to light yellowish gray and containing thin stromatoporoids, a quarter to a half inch in thickness, a few simple tetracorals, a small-tubed *Cladopora, Emmonsia* sp., *Favosites* sp. aff. *F. canadensis* (Billings), crinoid columnals, the brachiopods *Athryris?* sp., *Atrypa* sp.,—with medium-sized plications, *Atrypa* sp.—with coarse plications, *Rhipidomella* sp. and *Spirifer* sp. cf. *S. varicosus* Hall, and the trilobite *Phacops* sp. aff. *P. cristata* Hall	2	6
13. Limestone, light-buff, thin-bedded, with thin stromatoporoids; earthy appearance in weathered condition	1	5
12. Limestone, light-buff and granular. This limestone is the lowest bed of an abandoned quarry in the hillside on the north side of Mill Creek and a few hundred feet northwest of the top of unit 10		10
11. Covered	25±	
10. Limestone, light buff gray, with *Idiostroma;* lowest 7 inches filled with *Idiostroma,* constituting a biostrome. Units 7 to 4 inclusive shown in vertical rock face on south side of creek beneath old broken highway bridge	1	7
9. Limestone, light buff, with many thin and few massive stromatoporoids and *Emmonsia* sp. aff. *E. emmonsi* (Hall)	2	
8. Limestone, light-buff, with an abundance of thin stromatoporoids an eighth to three-quarters of an inch in thickness composing a biostrome	9	
7. Limestone, light buff-gray, with few thin stromatoporoids, a small-tubed, branching *Cladopora, Emmonsia* sp. aff. *E. emmonsi* (Hall), and *Spirifer* sp. aff. *S. varicosus* Hall	3	
6. Dolomite, buff, granular, and partly crystalline, uneven-bedded	16	
5. Limestone, similar to unit 3	1	
4. Covered—beneath culvert under Michigan Central Railroad	10±	
3. Limestone, light-buff and granular, with small, irregular dark buff gray, crystalline areas, thin- and uneven-bedded, weathering to a brown. Rock contains a few thin stromatoporoids and simple tetracorals, a *Stropheodonta* with thin fine plications, poorly preserved pelecypods, *Sphyradoceras* sp. cf. *S. clio* (Hall), and *Anchiopsis* sp. aff. *A. anchiops* (Green), and out-crops between culverts of U.S. Highway No. 23 and Michigan Central Railroad	7	
2. Dolomite, buff, granular, thicker- and more even-bedded than unit 1, weathering to brown; most of unit present beneath culvert of U.S. Highway No. 23	8±	

1. Limestone, light buff gray to buff, with small irregular, dark buff gray, crystalline areas, thin- and uneven-bedded, weathering to brown. Rock contains stromatoporoids, which are more abundant in lower two feet, a small tubed *Cladopora*, *Favosites* sp., a poorly preserved gastropod and *Sphyradoceras?* sp. It outcrops between the mouth of the creek and the culvert of U.S. Highway No. 23. Dip near culvert nine degrees, S. 10 degrees W....	5	
Total	108±	8

The rocks of units 1 to 6 of the section described above are considered as belonging to the upper portion of the middle part of the Bois Blanc formation. The strata of units 1, 2, and 3 are lithologically like and have several species of fossils in common with the eight feet of limestone exposed in the road cut about 200 feet east of the southwest corner of section 14, T. 39 N., R. 4 W. The lithologic and faunal similarities are so evident that they suggest a continuity of the limestones of the road cut with some of the strata of units 1, 2, and 3. The rocks of units 7 to 22 inclusive belong to the upper part of the Bois Blanc formation and are characterized by the presence of *Idiostroma* and thin, explanate types of stromatoporoids, which have built up biostromes in some of the units (pl. XV).

Several exposures of beds of the upper part of the formation are shown in the ditches and cuts of U. S. Highway 31 in the vicinity of the Mackinaw City golf course, which is located about three-quarters of a mile south of the southern boundary of Mackinaw City. The most northern exposure is in the ditch on the west side of the highway in the NE¼ SE¼ sec. 24, T. 39 N., R. 4 W. The rock at this place consists of 11 feet of thin-bedded limestone, which grades from light buff gray at the base to light-buff at the top. It contains many thin stromatoporoids, a few small simple tetracorals, the tabulate corals *Alveolites* sp., *Ceratopora* sp. cf. *C. nobilis* (Billings), *Cladopora* sp. 1 and *C.* sp. 2, numerous crinoid columnals, a few poorly preserved bryozoa, the brachiopods *Atrypa* sp. 1—with relatively fine plications, *Atrypa* sp. 2—with coarse plications, *Pentamerella?* sp., *Rhipidomella* sp. and *Spirifer* sp., the pelecypod *Paracyclas* sp. cf. *P. ellipita* Hall, a low-spired gastropod and the trilobite *Proetus* sp. The lowest bed of the limestone has an elevation of 661 feet, which is about 80 feet above the level of Lake Michigan. A covered interval of four to five feet is between the highest bed of the limestone and the lowest observable core rock of a bioherm exposed in the highway cut about 150 feet south of the uppermost limestone stratum. The

A

B

PLATE XV

A. Strata of upper part of Bois Blanc formation in abandoned Mill Creek quarry. Figure of man shown at outcrop of units 19 to 22 of Mill Creek section.

B. A close view of Idiostroma—bearing, shaley limestone of unit 21 in abandoned Mill Creek quarry.

core rock of the bioherm, which has a northeast-southwest trend, is best shown on the west side of the highway (see pl. XB). It consists of a massive, buff-gray limestone with numerous cavities in many of which are small scalenohedrons of calcite. Rounded and frosted grains of quartz are scattered throughout the rock and are so abundant in one band that they form a calcareous sandstone. An enormous number of entire and broken stromatoporoids and a smaller number of several branching species of *Cladopora* and *Favosites* are conspicuous in the core rock, the matrix of which must have been derived in large part from the comminution of the skeletons of these organisms. In addition to these fossils, the rock contains *Idiostroma* sp., the simple tetracorals *Amplexus* sp. and *Cystiphyllum* sp., the tabulate corals *Alveolites* sp., *Ceratopora* sp. cf. *C. nobilis* (Billings) and *Favosites* sp. cf. *F. canadensis* (Billings), numerous crinoid columnals, very poorly preserved bryozoa and brachiopods, the pelecypods *Conocardium* sp. and *Panenka* n. sp.—related to *P. canadensis Whiteaves*, several species of gastropods and the cephalopods *Acleistoceras* sp., *Brevicoceras?* sp. and *Nephriticeras?* sp. The thickness of the core rock including the calcareous sandstone in the road cut is about eight feet. An additional five feet of the rock is in the higher ground immediately west of the exposure on the west side of the highway. The flank-beds, where best shown on the west side of the road, consist of buff-gray to light-buff limestones which dip southward to southeastward from the core rock and have a thickness of five to six feet. Their texture becomes finer when traced from the core rock; some beds at a distance of only 75 feet from the core are very fine grained. Another exposure of beds in the upper part of the Bois Blanc formation is shown in a cut on the west side of the highway about one-tenth of a mile south of the bioherm. The lower five feet of this exposure consists of thin- and uneven-bedded, very light buff, granular limestone with *Idiostroma* and other stromatoporoids. The upper nine feet consists of thicker bedded, light buff gray to very light buff, granular limestone. In this limestone are two bands five inches in thickness which are filled with the remains of *Idiostroma* and thin explanate stromatoporoids; the bands occupy positions two and five feet above the base of the limestone. The fact that the limestones at this place resemble in lithology the flank beds of the bioherm a tenth of a mile to the north and are arched upward suggests very strongly that the limestones are part of a bioherm, the core rock of which is beneath the lowest bed of the exposure. In addition to *Idiostroma* and thin explanate

stromatoporoids, the strata contain *Chonophyllum?* sp., *Heliophyllum* sp. and a few other simple tetracorals, the tabulate corals *Ceratopora* sp. cf. *C. nobilis* (Billings), *Cladopora* sp. and *Thamnopora* sp. cf. *T. limitaris* (Rominger), crinoid columnals and the pelecypod *Conocardium* sp. About six feet of nearly massive, light-buff to light buff gray, porous limestone is shown in a cut on the east side of the highway about two-tenths of a mile farther south. It contains stromatoporoids and branching species of *Cladopora* and *Favosites* like the core rock of the bioherm exposed in the road cut three-tenths of a mile to the north and doubtless composes the central part of another bioherm. The two bioherms probably occupy the same stratigraphic position although the bioherm to the north may be lower in the section.

Another exposure of strata in the upper part of the Bois Blanc formation is shown in a shallow trench on the upland about two miles southeast of Mackinaw City. The lithologic character, thickness, and fossils of the rock are noted in the following description:

Section of strata in shallow trench excavated for testing limestone in woods of young maple and birch in the center of the E½, Sec. 29, T. 39 N., R. 3 W., about two miles southeast of Mackinaw City

	Thickness Feet
Bois Blanc formation:	
4. Limestone, light yellowish gray, very fine grained, laminated, with spherical and irregularly shaped solution cavities and some gashes filled with transparent crystals of unknown mineral; some parts of rock considerably fractured	2–3
3. Covered	3±
2. Limestone, buff-gray, medium to very finely crystalline with few small disseminated crystals of calcite	3–4
1. Limestone, buff-gray to light-buff, weathering to buff or brown and splitting into thin, uneven layers; lower part with many vugs coated with limonitic material. The rock is characterized by abundant specimens of *Idiostroma* and thin explanate stromatoporoids and less numerous examples of dumose stromatoporoids and a ramose species of *Cladopora*. It also contains *Romingeria* sp. cf. *R. cornuta* (Billings), crinoid columnals, a small multicostate and a small costellate species of *Atrypa*, *Proetus* sp. and *Phacobs* sp. cf. *P. cristata* var. *pipa* Hall and Clarke. Elevation of base of unit 698 feet	7–8
Total	15–18

The large number of *Idiostroma* and thin, explanate types of stromatoporoids in the limestone of unit 1 indicate that the strata of the trench belong to the upper part of the Bois Blanc formation.

Although the rocks of the trench, in the cuts along U. S. Highway 31 in the vicinity of the Mackinaw City golf course and in units 7 to 22 of the Mill Creek section have the same fauna, the positions

of strata of one of these exposures with respect to those of the other two are not definite. The lowest rock of the trench has an elevation of 698 feet and is 8 to 10 feet higher in elevation than the top of the core rock of the bioherm on Highway 31 nearest to Mackinaw City. The differences in elevation suggest that the beds of the trench are above the bioherm and its apparently equivalent biohermal strata exposed a short distance farther south along the highway. The base of the lowest beds along U. S. Highway 31, exposed in the ditch on the west side of the highway, has an elevation of 661 feet. Since the top of the highest bed of unit 22 of the Mill Creek section has an elevation of 635 feet, all of the Bois Blanc rocks along Mill Creek seem to occupy a position beneath the lowest bed on Highway 31. The lower elevation of the Mill Creek strata may be owing to the fact that they are farther down the dip than the beds of the highway. The lower elevation may be explained also by a greater downward movement of the rocks in the Mill Creek area than in the vicinity of the highway during the regional collapse of the strata. The relatively high dips of the rocks along Mill Creek and a breccia of post-Bois Blanc limestone in the creek a short distance upstream from the abandoned quarry indicate that a settling of the beds has occurred. The relative positions of the strata of the highway, trench, and Mill Creek as suggested by elevations may be incorrect. The rocks at the three places may be continuous and the strata along the highway and possibly in the trench may be a biohermal facies of some or all of the sediments of the upper part of the Bois Blanc formation of Mill Creek.

THICKNESS: The lack of exposures from which measurements of the thickness of the complete succession of the rocks of the Bois Blanc formation can be obtained make it necessary to estimate the thickness of this stratigraphic unit. The thickness of the cherty dolomites composing the lower part of the formation is estimated to be about 75 feet. The thickness of the lower portion of the middle part of the formation containing *Amphigenia elongata* (Vanuxem), *Costispirifer* unica (Hall), *Fimbrispirifer divaricatus* (Hall), and *Spirifer duodenarius* (Hall) probably is between 100 and 150 feet; the upper portion is between 75 and 100 feet thick. The thickness of the upper part of the formation probably is about 75 feet. The total thickness of the formation probably is not less than 325 feet nor more than 400 feet.

STRATIGRAPHIC RELATIONSHIP: The fossils of the Bois Blanc formation indicate that the formation is closely related to the

Onondaga limestone of southwestern Ontario and western New York.

G. Arthur Cooper and others (1942, p. 1774)[35] have noted that the Onondaga limestone of western New York contains two faunas. According to these workers the lower fauna

> "having many Schoharie and Camden elements and characterized by *Amphigenia* and many corals is best developed west of New York on the southern peninsula of Ontario. The Schoharie elements include *Centronella, Strophonella ampla, Cyrtinaella biplicata, Calymene platys,* and *Terataspis.* Camden elements are *Eodevonaria* and *Anoplia.* Overlying the *Amphigenia* fauna is one characterized by *Paraspirifer acuminatus* occurring at the top of the Onondaga in New York. It also characterizes the top of the Columbus and Jeffersonville limestones to the southwest but has not yet been found in the Ontario peninsula. So far as known its northern-most range is Pelee Island in Lake Erie and Wayne County, Michigan."

The lower part of the Bois Blanc formation contains the brachiopods *Amphigenia, Cymostrophia patersoni* (Hall), and *Spirifer duodenarius* (Hall), and the trilobites *Anchiopsis anchiops* (Green) and *Phacops cristata* Hall, all of which have been recognized in the Schoharie faunal element of the Onondaga limestone.

The lower portion of the middle part of the Bois Blanc contains the brachiopods *Amphigenia elongata* (Vanuxem), *Centronella glansfagea* (Hall), *Chonetes hemisphericus* Hall, *Costispirifer unica* (Hall), *Cymostrophia patersoni* (Hall), *Fimbrispirifer divaricatus* (Hall), *Pentamerella arata* (Conrad), *Strophonella ampla* (Hall), *Spirifer duodenarius* (Hall), *S. macrus* Hall, and *S. varicosus* Hall, and the trilobites *Anchiopsis anchiops* (Green), *Calymene platys* Green, *Phacops cristata* Hall, and *Proetus crassimarginatus* Hall, all of which have been identified as the Schoharie faunal component of the Onondaga limestone.

The coral-bearing limestone on the Pierce and Son dairy farm about two miles west of the business section of Mackinaw City has many of the species of corals that are in the underlying strata of the Bois Blanc formation. When the corals of this limestone and of all the strata of the middle and lower parts of the Bois Blanc formation are prepared for study, most of the species will be recognized as being identical with species of corals characteristic of the Onondaga limestone of southwestern Ontario and western New York.

When reporting the discovery of the Schoharie fauna in Michigan, A. W. Grabau (1906, p. 467, 1907, pp. 718-719; and 1908, p. 267)[27] noted that fossils of this fauna were obtained from limestones of Mill Creek, four miles southeast of Mackinaw City, and stated (1907, p. 718) "the outcrops containing the Schoharie fauna are all near the Michigan Central railroad crossing" of the

creek. Many of the specimens of the species listed by Grabau (1907, pp. 718-719) are in the Museum of Paleontology of the University of Michigan. The lithologic character of the rock containing the specimens is identical with the character of the limestone of unit 3 of the Mill Creek section. The agreement in lithology and the location of the outcrop of unit 3 close to the crossing of the Michigan Central Railroad indicate that the fossils collected by Grabau almost certainly came from the limestones of unit 3. Although many of Grabau's fossils and fossils obtained by the writers are poorly preserved and possibly should be provisionally identified as to species, some of the species are identical with or closely related to species found in the Schoharie element of the Onondaga limestone.

Grabau (1907, p. 719)[27] was in error in believing that the limestones of Mill Creek with Schoharie species underlie beds on Mackinac Island with an Onondaga fauna. Grabau's error was due in part to his belief that the Schoharie grit underlies the Onondaga limestone. The Schoharie grit as noted by Winifred Goldring (1931, p. 384)[36] is a sandy facies of the Onondaga limestone. The fossils from Grabau's Onondaga limestone of Mackinac Island most likely were collected by him from blocks of the very fossiliferous lower portion of the middle part of the Bois Blanc formation. Such blocks are far more common in the breccia of Mackinac Island than rock masses containing the strata of the Mill Creek section. The strata of these blocks, which Grabau considered to have an Onondaga fauna, definitely occupy a position below instead of above the limestones exposed in Mill Creek.

Grabau also erred in correlating the strata in the breccia of Mackinac Island with the rocks of a breccia exposed in Mill Creek a short distance upstream from the abandoned quarry exhibiting the Idiostroma-bearing beds of the Bois Blanc formation. He stated (1907, p. 718) that "since beds of the Mackinac Island contain an Onondaga fauna, it is evident that they cannot be lower than those of Mill Creek, but the equivalent of the higher (brecciated) beds of that locality." The "higher (brecciated) beds" of Mill Creek compose a breccia of unfossiliferous limestone, which is stratigraphically above the highest rocks of the Bois Blanc formation and is assigned to the Detroit River group.

The strata of the upper part of the Bois Blanc formation are characterized by an abundance of *Idiostroma* and thin, explanate stromatoporoids, which, with a smaller number of tabulate corals, have built up bioherms and biostromes. A few tabulate corals,

brachipods, and trilobites from these beds seem to be related to species found in the Onondaga limestone and suggest that the beds should be included in the Bois Blanc formation. The strata may be younger than the highest rocks of the Onondaga limestone of southwestern Ontario; further paleontological study may show that they are faunally distinct from the limestone which contains the Schoharie faunal element.

DETROIT RIVER GROUP

NOMENCLATURE: The rocks of the Detroit River group are typically exposed along the Detroit River in southeastern Michigan. Before describing the occurrences of these strata in the Mackinac Straits area, it is necessary to note the various changes in the classification of the group.

The term "Monroe Beds" was used in a description of the geologic column of Michigan by A. C. Lane in a report by M. E. Wadsworth (1893, p. 66)[13] in 1893. In this column the "Monroe Beds" are shown as being overlain by the Devonian Dundee limestone. The downward extent of the beds is not clearly indicated by Lane; he apparently thought they were underlain by dolomite, salt, and anhydrite, which subsequently were placed in the Upper Silurian Salina group.

In 1895 A. C. Lane (1895, pp. 26-28)[14] defined the Monroe beds, noting that they extended "from the limestones of the overlying Dundee down to the lowest gypsiferous beds." As thus defined, the Monroe beds included all the strata between the base of the Dundee limestone and the top of the Niagaran series.

In two papers Lane (1899 a, p. 88 and 1899 b, pl. 2)[15 16] recognized the occurrence of the Sylvania sandstone in Michigan. This sandstone was named by Edward Orton (1888, pp. 4, 18-20)[43] from typical exposures near Sylvania, Lucas County, Ohio. Orton (1888, p. 19)[43] also stated that probably "the sand deposits of Monroe County, Michigan, belong to the same horizon." In one of his papers Lane (1899, b, pl. 2),[16] presented a geologic map of the Southern Peninsula on which was given the legend "Monroe below Sylvania sandstone" and "Monroe above Sylvania sandstone." He not only noted the presence of the Sylvania sandstone in Michigan but recognized that this sandstone was included in his Monroe beds.

In 1909, A. C. Lane, C. R. Prosser, W. H. Sherzer, and A. W. Grabau (1909, pp. 553-556)[18] presented a detailed classification

[43]Orton, Edward, The geology of Ohio considered in its relation to petroleum and natural gas: Ohio Geol. Surv., Vol. 6, ch. 1, 1888.

of the Monroe strata. In this classification the strata were divided into the "Lower Monroe or Bass Islands Series" including in ascending order the Greenfield dolomite, Tymochtee shales and limestones, Put-in-Bay dolomite, and Raisin River dolomite, the "Middle Monroe," consisting of the Sylvania sandstone, and the "Upper Monroe or Detroit River Series," containing in ascending order the Flat Rock dolomite, the Anderdon limestone, the Amherstburg dolomite, and the Lucas dolomite. The authorship of the various stratigraphic divisions are indicated by Lane, Prosser, Sherzer, and Grabau (1909, p. 556).

The rocks of the lower, middle, and upper Monroe were assigned by Lane, Prosser, Sherzer, and Grabau (1909, pp. 553-556)[20] to the Upper Silurian. This assignment was based in large part on the opinion of Sherzer and Grabau (1909, pp. 540-553)[44] that the faunas of these strata indicate that the rocks are of Upper Silurian age. In the most comprehensive work on the Monroe rocks, Grabau and Sherzer (1910, pp. 27-60 and 215-234)[38] used the classification of Lane, Prosser, Sherzer, and Grabau, and again assigned these rocks to the Upper Silurian.

C. R. Stauffer, (1916, pp. 72-77)[20] and M. Y. Williams (1919, pp. 18-22)[21] in their studies of the Devonian and Silurian rocks of Ontario reached the conclusion that the Sylvania sandstone and Detroit River series are of Devonian rather than of Upper Silurian age. In making this change in classification, Williams (1919, p. 22) pointed out that "the terms upper Monroe and lower Monroe are obviously no longer appropriate, since the so-called Monroe is now seen to belong to different geological systems, Grabau's alternate names "Detroit River" and "Bass Island" will hence be used."

In a paper on the "Monroe division" of rocks in Ohio, J. E. Carman (1929, pp. 481-506)[45] concluded that the Sylvania sandstone and the overlying Detroit River strata are of Devonian age, the Silurian-Devonian contact in Ohio being at the base of the Sylvania sandstone. In a later paper Carman (1936, pp. 253-266)[46] described in detail the Sylvania sandstone of Ohio, noting the unconformity at its base and the gradation of the water-laid phase of the Sylvania into the overlying Detroit River dolomite.

In this paper the Detroit River strata are regarded as a group. In southeastern Michigan, southwestern Ohio, and northwestern Ohio the Detroit River dolomites and Sylvania sandstone are underlain by dolomites of the Upper Silurian Bass Island group and overlain by the Middle Devonian Dundee limestone. The Dundee limestone in northwestern Ohio is erroneously designated the Columbus limestone. The Columbus limestone contains an upper Onondaga fauna and is older than the Dundee limestone. The Dundee limestone of the so-called Anderdon quarry near Amherstburg, Ontario, owned by the Bruner Mond Canada Limited, is incorrectly called the Onondaga limestone. An examination of several reports on the Devonian of southwestern Ontario leads to the belief that the Dundee limestone underlies large areas of southwestern Ontario where it is incorrectly designated the Onondaga limestone. In the Mackinac Straits area the Detroit River group is underlain by the Bois Blanc formation, most if not all of which is a correlative of the typical Onondaga limestone of southwestern Ontario. In the Rogers City area and apparently elsewhere in the northern part of the Southern Peninsula, the group is overlain by the Dundee limestone.

[44]Sherzer, W. H., and Grabau, A. W., New Upper Siluric Fauna from Southern Michigan: Bul. Geol. Soc. Amer., vol. 19, 1909.
[45]Carman, J. E., The Monroe Division of Rocks in Ohio: Jour. Geol., vol. 35, No. 6, 1929.
[46]_____, Sylvania Sandstone of Northwestern Ohio: Bull. Geol. Soc. Amer., vol. 47, 1 pl., 5 figs., 1936.

DISTRIBUTION: The Detroit River group underlies a wide belt of land in the northern part of the Southern Peninsula between the areas occupied by Bois Blanc and Dundee strata (see map in pocket). It also underlies the southern half of Beaver Island and probably all of North and South Fox Islands in Lake Michigan.

Unfortunately most of the rocks of the group in the northern part of the Southern Peninsula are covered with Pleistocene glacial deposits several hundreds of feet in thickness. The few outcrops herein described give little information regarding the lithology, super-position, and thicknesses of the rocks composing the group. Such information has been obtained from a study of the drillings of deep wells and is discussed in the chapter on subsurface stratigraphy.

LITHOLOGIC CHARACTER: A limestone, which is believed to be near the base of the Detroit River group of the Mackinac Straits area, is exposed in the ditch on the west side of the road on the east line of section 30, T. 39 N., R. 3 W., about 1½ miles southeast of the southern boundary of Mackinaw City. The rock, which is shown in a very small outcrop about a quarter of a mile south of the northeast corner of section 30, is very light gray to white and very fine grained, and contains thin, tabular crystals of a mineral believed to be celestite.

Another limestone is shown in numerous low ridges and mounds in the NE¼ NE¼ sec 30, T. 39 N., R. 3 W., a very short distance northwest of the roadside outcrop. This limestone is dark gray,

very fine grained and massive, and probably has a high percentage of calcium carbonate. Much of it is brecciated, the angular fragments being conspicuous on the weathered surfaces. Very small quantities of apparently wind-blown, frosted grains of quartz sand are in a buff-gray, brecciated phase of the limestone in a low mound of the rock on the northern edge of the outcrop about a quarter of a mile west of the road on the east line of section 30.

A limestone breccia, which has the same lithologic character as the breccia of the NE¼ NE¼ sec 30, T. 39 N., R. 3 W., is exposed in a test-pit at the top of the upland near the center of the E½ sec. 29, T. 39 N., R. 3 W., about an eighth of a mile southeast of the trench in which 15 to 18 feet of high Bois Blanc strata are exhibited. The pit is near the end of an abandoned logging road and about 630 feet west of the juncture of this road with another old logging road leading to the trench exposure. Several small outcrops of the breccia also are at the top of the hardwood-covered upland adjacent to the test pit.

A limestone breccia similar to rock of the test pit is in the bed of the old logging road about 200 feet west of the point where the trench with Bois Blanc strata reaches this road.

A limestone breccia is exposed on the north side of Mill creek. This exposure is a short distance upstream from the abandoned quarry containing the high Bois Blanc strata with *Idiostroma,* and thin, explanate stromatoporoids. The breccia is similar to those described above except that much of its matrix is lighter in color and more crystalline.

The breccia on Mill creek and with little doubt the breccias of the other localities were formed by collapse. The bed of limestone, which was the source of the material of the breccias, is thought to have a position in the lower part of the Detroit River group.

Rocks of the Detroit River group are poorly exposed on an abandoned farm in the NE¼ NW¼ sec. 2, T. 38 N., R. 4 W., about three miles south of the southern boundary of Mackinaw City and 1¾ miles north of Carp Lake. They are in small low mounds and a few test pits about an eighth of a mile south of a dirt road on the north line of section 2, and about the same distance east of an abandoned farmhouse. The lowest rock is a yellowish to buff gray, fine grained limestone, which shows a few laminae on its weathered surfaces and has a thickness of about one foot. This limestone is overlain by a very light gray to light buff gray, very fine grained and laminated dolomite which has an earthy feel. Some of the laminae of the rock are dark gray; groups of laminae are folded

and broken as the result of submarine gliding. The dolomite, which is about two feet in thickness, is overlain by a similar dolomite, which is very light gray to cream-colored, has an earthy feel, and shows laminae on weathered surfaces. Some layers of this higher dolomite contain slit-like cavities an eighth to a quarter of an inch in length, which probably were once filled with celestite or tabular crystals of another mineral. The dolomite has a thickness of three feet and is best shown in a test pit which has an elevation of 675 feet. About four feet of buff-gray, finely crystalline, massive limestone overlies the dolomite. Some parts of the limestone contain slit-like cavities one-half inch in length. The surfaces of the rock are much rounded by solution. A brecciated limestone, which is similar to the limestones of the upland southeast of Mackinaw City and like those probably was produced by the collapse of a bed of limestone, is shown in several exposures located east of the outcrops of the bedded limestones and dolomites. The exposures of the breccia have an alignment suggesting a north-south surface distribution of the rock at right angles to the strike of the limestones and dolomites.

Detroit River strata underlie Ile aux Galets, a very small island in Lake Michigan about 6¾ miles northwest of Cross Village, on the shore of Lake Michigan 18 miles southwest of Mackinaw City. Ledges of cream-colored, very finely crystalline dolomite with few small cavities are visible on the bottom of the lake along the north side of the island. Blocks of the dolomite compose a storm beach along the north shore west of the Ile aux Galets lighthouse. Numerous small blocks of breccia are at the surface just south of the lighthouse. Most of the angular pieces of the breccia consist of dark buff gray, very finely crystalline limestone. Some blocks are finely crystalline limestone with light and dark buff gray bands; a few pieces consist of very dark buff gray limestone having numerous small coalescing cavities. The matrix of the breccia is composed of a light buff gray and finely crystalline limestone with angular cavities formed by the solution of small pieces of the darker limestone. The breccia resembles very much the limestone breccias of the upland southeast of Mackinaw City. The limestone, from which the angular pieces of the breccia were derived, probably occupies a stratigraphic position above the cream-colored dolomite.

Blocks of dolomite are abundant along the eastern shore of North Fox Island near the north end of the island, which is located in Lake Michigan about 9¾ miles southwest of Beaver Island. Some of the dolomite is light buff gray with irregular masses of chert

distributed parallel to the bedding. The few fossils in the rock are closely related to or identical with species found in the Bois Blanc formation. Some of the dolomite is buff and porous resembling some beds of dolomite in the Detroit River group of southeastern Michigan. A brownish-black dolomite is very common in the rubble along the shore. These dolomites probably were derived from ledges of the Detroit River group. All of the dolomites were carried to the shore by the Pleistocene glacier or by the waves and ice of Lake Michigan from ledges beneath the surface of this lake. All of North Fox Island probably is underlain by Detroit River strata. Beds of the Bois Blanc formation doubtless floor the bottom of the lake immediately west of the island.

Rocks of the Detroit River group are shown in the large quarry of the Michigan Limestone and Chemical Company at Rogers City, located on the shore of Lake Huron about 52 miles southeast of Mackinaw City. The lithologic character of the rocks and their relationship to the overlying Dundee limestone and higher Devonian formations are noted in the following description of the stratigraphic section exposed in the quarry.

Section of strata exposed in quarry of Michigan Limestone and Chemical Company at Rogers City, Michigan

	Thickness Feet	Thickness Inches
Traverse group (Bell shale):		
13. Shale, calcareous, bluish-gray and fossiliferous except at a few places	1–10	
Total	1–10	
Disconformity		
Rogers City limestone:		
12. Limestone, buff-gray to buff, medium grained, fairly thick-bedded and porous, containing *Hexagonaria sp.*, *Favosites sp.*, a costellate *Atrypa*, *Buchelia tyrelli*, (Whiteaves), *Omphalocirrus manitobensis* Whiteaves, and other gastropods	49	
11. Limestone, gray, finely crystalline, dense and thick-bedded, containing numerous specimens of a costellate *Atrypa*, and *Omphalocirrus manitobensis* Whiteaves	4–6	
10. Limestone. Lower 2 to 3 feet mottled buff and gray, magnesian and thin-bedded; upper 6 feet less mottled, less magnesian and thicker-bedded than underlying beds. Limestone contains numerous shells of a costellate *Atrypa*, a few specimens of *Gypidula sp.*, and *Omphalocirrus manitobensis* Whiteaves	8	6
9. Limestone, magnesian, with discontinuous, alternating buff and buff-gray bands, fine grained and thin-bedded, with molds of *Productella sp.*, *Atrypa sp.*, and other brachiopods, pelecypods, *Tentaculites sp.*, and *Proetus sp.* A grayish-black clay with small pebbles of limestone is present at the base of the limestone; it has a thickness of ¼ to 1 inch and apparently is a residium	8–9	
Total	69–6–72–6	
Disconformity		
Dundee limestone:		
8. Limestone, gray, weathering to a buff-gray, composed of numerous shells of brachipods and a smaller number of other invertebrates. Characteristic fossils are *Hexagonaria sp.*, *Atrypa costata* Bassett, *A. ehlersi* Bassett, *Brevispirifer lucasensis* (Stauffer), *Etheridgina? spinosa* Bassett, *Productella spinulocosta* Hall, and a species of *Athyris* identical with a species found in the Dundee limestone of southeastern Michigan	6	5
7. Limestone, gray, weathering buff-gray, with few chert nodules and remains of *Hexagonaria sp. Atrypa costata* Bassett, *A. ehlersi* Bassett, and other fossils	4–3	
6. Limestone, buff-gray to buff, weathering to brown, and thick-bedded, with *"Diphyphyllum" rectiseptatum* Rominger, *Hexagonaria* sp. with corallites averaging 8 mm. in diameter, *Hexagonaria sp.* with corallites 4 to 5 mm. in diameter, *Atrypa costata* Bassett, and *A. ehlersi* Bassett	59	
5. Limestone, buff-gray to gray, mottled, dense and somewhat magnesian in lower part, containing *Synaptophyllum?* sp., *Atrypa elegans* Grabau, *A. costata* Bassett, *Pentamerella sp.* cf. *P. parva* Bassett, and numerous specimens of *Paracyclas sp.*	72	
4. Limestone, slightly magnesian, dark buff gray to chocolate-colored, thin- and even-bedded with carbonaceous material on bedding planes, very finely crystalline; weathers into layers ¼ to ½ inch in thickness	2	9
3. Dolomite, buff, with some carbonaceous laminae except in upper 2 inches		10
2. Shale, buff-gray, mottled with brown. Shale is thickest in the lowest part of a small shallow pre-Dundee limestone erosion channel carved in the underlying breccia, unit 1. When traced upward along sides of channel, the stratum becomes thinner and then is overlapped by dolomite of unit 3		8
Total	142′ 8″–143′ 8″	
Disconformity		
Detroit River Group:		
1. Breccia, composed of small and large angular blocks of buff dolomite and thin-bedded to laminated dark bluish gray limestone in a matrix of dark bluish gray shale and comminuted limestone; small light-purple crystals of fluorite present in few blocks of buff dolomite. Formerly about 24 feet of this breccia was exposed in a large test pit a short distance southeast of the crusher receiving the limestone from the quarry trains. Most of the rock is now covered by water; only 2 feet of the breccia is visible above the water where units 2, 3, and 4 were observed and studied	24	
Total	24	

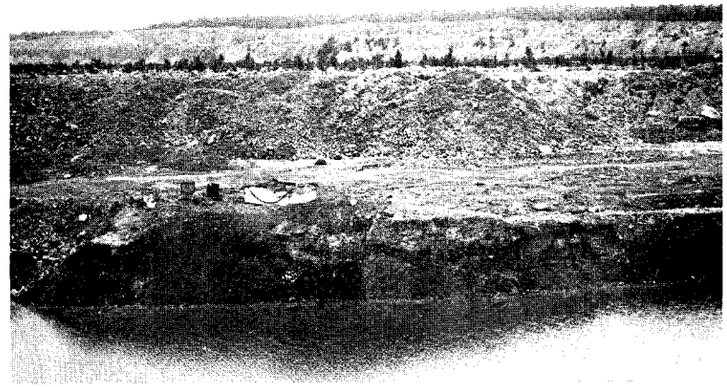
This description, which in large part is similar to the description published by Ehlers and Radabaugh (1938, pp. 442-443)[33] notes the occurrence of 24 feet of Detroit River rock in a large test pit of the quarry. This rock, unit 1 of the section, is a breccia composed of blocks of buff dolomite and dark gray limestone in a matrix of shale and comminuted limestone. The blocks of buff dolomite, a few of which contain nodules of banded chert, are similar in lithology to dolomites in the Detroit River group of the Detroit River region of southeastern Michigan. The disconformity at the top of the breccia is most interesting in showing that the brecciation of the Detroit River rocks took place prior to the deposition of the Dundee limestone (pl. XVI, A, B).

The breccia forms the bed of Lake Huron adjacent to the quarry. Numerous blocks of buff dolomite, similar to the dolomite of the test pit, are dredged from the bottom of the small harbor used for anchorage of the company's stone-carrying freighters. A large block of buff, massive dolomite, six to seven feet in diameter, is on top of the breakwater built for the protection of the harbor. The lithology of this block, taken from the breccia of the lake bottom, is the same as the lithology of some beds of the Lucas and Amherstburg dolomites of the Detroit River group of southeastern Michigan.

THICKNESS: The thickness of the Detroit River group in the northern part of the Southern Peninsula cannot be determined by measurement of outcrops. The exposures in the area near the Straits of Mackinac are few in number and exhibit small sections of strata, which presumably occupy a position in the lower part of the group. Most of the rocks of the group, although underlying a wide belt of land in the northern part of the Southern Peninsula, cannot be observed and measured because they are covered by a thick deposit of drift.

The records of deep wells indicate that the thickness of the group in the northern part of the Southern Peninsula is about 700 feet. Detailed information in regard to the thickness and also the lithology of the rocks of the group is given in the chapter on Subsurface Stratigraphy, the part of this report dealing with the study of samples of these rocks obtained by drilling deep wells.

STRATIGRAPHIC RELATIONSHIPS: It is impossible at this time to correlate the few exposed beds of the Detroit River group in the Straits area with particular formations of the group of southeastern Michigan. The lowest beds of the Straits area are limestones and dolomites. They are distinctly different in lithologic



A

B

PLATE XVI

A. Contact between Dundee limestone and brecciated Detroit River rocks at base of dark band in wall of water-filled test-pit of Rogers City quarry. Lower beds of Rogers City limestone and upper Dundee strata present in distant quarry wall.

B. A close view of part of contact shown in wall of test-pit. Line indicates approximate position of disconformity and represents part of one side of pre-Dundee erosion channel.

character from the Sylvania sandstone, which on further study may prove to be the lowest formation of the Detroit River group in southeastern Michigan. They may represent a calcareous facies of this sandstone or may be equivalent to Detroit River strata occupying a position above the Sylvania sandstone. The lithologic character of many of the blocks of dolomite in the breccia beneath the Dundee limestone of the Rogers City region is strikingly similar to the lithology of the Amherstburg and Lucas dolomites of the Detroit River region. A correlation based on similarity in lithology should be considered as tentative. The occurrence of the various formations of the group in the northern part of the Southern Peninsula ultimately may be demonstrated by the finding and identification of fossils in cores and drill cuttings from deep wells.

The occurrence of the Detroit River group between the Bois Blanc formation having a typical lower Onondaga fauna and the Dundee limestone having Middle Devonian fossils is of considerable stratigraphic interest. Most of the geologists who have studied the Devonian rocks of Michigan, Ohio, and southwestern Ontario have stated that the "Upper Monroe" or Detroit River strata underlie the Onondaga limestone, or formations thought to be equivalent to this limestone. The position of the Detroit River rocks indicated by these workers is based on erroneous correlations of certain formations with the typical Onondaga limestone. The Dundee limestone of Michigan is one of the formations which, until recent years, has been correlated with the Onondaga limestone. It contains the brachiopods *Atrypa costata* Bassett and *Brevispirifer lucasensis* (Stauffer) and other fossils which indicate a fauna distinct from the fauna of the Onondaga strata. As noted by C. F. Bassett (1935, pp. 437-444)[47] the above mentioned brachiopods are in the "Upper Columbus" limestone of the Silica and Whitehouse quarries of northwestern Ohio and the "Onondaga" limestone of the Bruner Mond Canada Limited quarry one mile north of Amherstburg, Ontario. The Dundee limestone of southeastern Michigan, the "Upper Columbus" limestone, and also the "Lower Columbus" limestone (see Bassett, 1935, pp. 438-439, 442)[47] of northwestern Ohio, and the "Onondaga" limestone of the Amherstburg quarry contain the same fauna and belong to a single stratigraphic unit, which should be designated the Dundee limestone. In northwestern Ohio the Dundee limestone rests disconformably on the Lucas dolomite of the Detroit River group; in southeastern Michigan and at Amherstburg, Ontario, it overlies unconformably the Anderdon limestone, which

[47]Bassett, C. F., Stratigraphy and Paleontology of the Dundee limestone of Southeastern Michigan. Bull. Geol. Soc. Amer., vol. 46, 1935.

is the highest formation of the Detroit River group at these places. In the Michigan Limestone and Chemical Company quarry at Rogers City the Dundee limestone with *Atrypa costata* Bassett, *Brevispirifer lucasensis* (Stauffer) and other fossils, characteristic of this limestone in southeastern Michigan, northwestern Ohio, and the Amherstburg, Ontario region, rests disconformably on the brecciated dolomites of the Detroit River group. North of Rogers City at many localities close to the Straits of Mackinac are exposures of the Bois Blanc formation with the typical lower Onondaga fauna of Ontario and western New York. Since the Bois Blanc strata underlie the Detroit River rocks in the Straits region, the Detroit River group in the northern part of the Southern Peninsula clearly occupies a position between the Bois Blanc and Dundee formations.

The stratigraphic position of the Detroit River group in the northern part of the Southern Peninsula seems to be duplicated in Ontario. According to C. R. Stauffer (1915, pp. 132-133)[42] the Detroit River strata in the vicinity of Goderich on the eastern shore of Lake Huron in Huron County, Ontario, are overlain by the "Onondaga" limestone, on which rests the Delaware limestone. In a list of fossils from the rocks at this locality, Stauffer (1915, pp. 134-135)[42] notes the occurrence of *Atrypa spinosa* Hall and *Spirifer lucasensis* Stauffer in the Delaware limestone. One of these brachiopods, *Spirifer lucasensis* Stauffer *Brevispirifer lucasensis* (Stauffer), is a diagnostic fossil of the Dundee limestone. The other brachiopod listed as *Atrypa spinosa* Hall, may be identical with the very closely related and characteristic Dundee species *Atrypa costata* Bassett. The absence of diagnostic lower Onondaga species in Stauffer's list and the inclusion of several other fossils which are represented in the Dundee fauna leads one to believe that strata above the Detroit River rocks at Goderich belong to the Dundee limestone and not to the Onondaga and Delaware formations. According to T. Sterry Hunt (1878, pp. 224-226)[48] a test well was drilled by Mr. Attrill close to the Lake Huron shore near Goderich in the early days of the Goderich salt industry. In a report on this experiment T. Sterry Hunt (1878, p. 242) states:

> "We now come to the consideration of an unexpected result of the examination of the cores from the Goderich boring; namely, the occurrence beneath 278 feet of beds, chiefly dolomite, which, according to the Geological Survey, underlie the Corniferous limestone of the region, of not less than 276 feet, chiefly of grey, non-magnesian, coralline limestone, abounding in chert, and seeming like a repetition of the Corniferous. Beneath this lower fossiliferous limestone, it will be noted, are dolomites

[48]Hunt, T. S., The Goderich Salt Region. Geol. Surv. of Canada, Rept. of Prog. for 1876-1877, 1878.

with gypsum, succeeded by variegated marls, with an aggregate thickness of not less than 364 feet before reaching the saliferous strata, which latter have been penetrated 520 feet without reaching the underlying Guelph formation. Professor James Hall, who has kindly examined such specimens of corals as I have obtained from this limestone (Division III of the section) recognizes in them two species of *Favosites*, *F. Winchelli* and *F. Emmonsi*, together with a section of *Acervularia* or *Diphyphyllum*."

The "278 feet of beds, chiefly dolomite," which T. Sterry Hunt noted as underlying the "Corniferous limestone," with little doubt belong to the Detroit River group. The "Corniferous limestone" exposed on the Maitland River near Goderich is the Dundee limestone, designated the Onondaga limestone by Stauffer. The "not less than 276 feet, chiefly of grey, non-magnesian, coralline limestone, abounding in chert, and seeming like a repetition of the Corniferous" with little doubt is the "Corniferous" or Onondaga limestone and not a part of the Detroit River group as suggested by Stauffer (1916, pp. 74-75).[20] The sequence of strata from the Onondaga to the Dundee limestone in the Goderich region is therefore like the sequence of northern Michigan. When the Dundee limestone of other places in Ontario is distinguished by its fauna from the typical Onondaga limestone, the position of the Detroit River group between these two limestones will become more evident and aid materially in the mapping of the Devonian rocks of this region.

The Bois Blanc formation or its correlative, the Onondaga limestone, does not underlie the Detroit River group in the region adjacent to the western part of Lake Erie. It fails to reach this area either because it was overlapped by the Detroit River strata or was removed by erosion prior to the deposition of Detroit River sediments. The Detroit River rock rests unconformably on Upper Silurian dolomites of the Bass Island group.

MACKINAC BRECCIA

The Mackinac breccia is composed of masses of rock from many of the described formations. It is not a stratigraphic unit representing a distinct episode of deposition, but is a record of events that involved the fracture and displacement of sedimentary rocks. The geologic processes which compose this record and a detailed description of the breccia are given in Chapter III.

THE MACKINAC BRECCIA
SUB-SURFACE STRATIGRAPHY
ECONOMIC GEOLOGY

by

K. K. LANDES

CHAPTER III

Mackinac Breccia

Douglass Houghton, first State Geologist of Michigan, named the rocks of Mackinac Island and Straits the "Mackinac Limestone." In his handwritten journal[1] Houghton states: "For a distance of about half a mile west from Goose Island the bottom of the lake was seen to be composed of water-worn masses of white (Mackinac) Limestone."[2] A few pages farther, referring to the shore line a short distance west of St. Ignace: "A naked point of Mackinaw limestone was noticed which attained an estimated altitude of about 180 feet."[3] The opposite page (179) contains a map of the "North Side of Lake Michigan" on which "Mackinaw L. Rock" is written across the St. Ignace Peninsula.

Apparently the first published reference to the Mackinac formation is in the Fourth Annual Report of the State Geologist published in 1841.[4] Here, in tabular form, is a "Section illustrative of the order of super-position of the Rocks of the Upper Peninsula." Below No. 9 "Tertiary clays and sands," and above No. 7 "Lower Limerock and shales," is group No. 8: "Upper Limerock Group (embracing as members, the Drummond Island and Mackinaw limestones)." A brief description of the Mackinac Limestone is given on page 548 of the same report in the section by C. C. Douglass, Assistant Geologist. It is interesting to note that Houghton in his first use of the word in his journal spelled it "Mackinac," but elsewhere in the journal, and in his annual report, the spelling "Mackinaw" is used. Douglass, on the other hand, consistently wrote "Mackinac," the accepted spelling today.

Since the time of Houghton the calcareous rocks of the Straits region have been referred to as either the "Monroe" or the "Mackinac" formation. The present study has shown that this "formation" includes not only breccia but also sedimentary beds which range in age from Silurian to Mid-Devonian; and that plug-like extensions of the breccias penetrate rocks of varying ages. New formation names have been given to the sedimentary units. It is

[1]Houghton, Douglass, Manuscript, Rare Book Room, Univ. of Mich. Library.
[2]————————, p. 167, Aug. 1, 1839.
[3]————————, p. 178, Aug. 14, 1839.
[4]Houghton, Douglass, Michigan Senate Documents, 1841, Vol. I, p. 486.

desirable to retain the term "Mackinac" (one of the oldest and best known Michigan rock names) but the writers suggest that it be redefined to apply exclusively to the breccias of the Straits region.

The most prominent rock in the Mackinac Straits region is the Mackinac breccia. Whereas one has to search for stratified rocks, no one can pass through the Straits region without noticing the breccia pillars or stacks.

DISTRIBUTION: The Mackinac breccia is at the surface on both sides of the Straits and on the adjacent islands (fig. 14). It is the principal rock that crops out on the St. Ignace Peninsula and on Mackinac Island. It is also found in several places in the northern part of the Southern Peninsula, on Round and Bois Blanc Islands, and in a few small areas in the Beaver Islands. Breccia occurs in Monroe County in the southeast corner of Michigan; in Lucas County, Ohio; on the islands at the western end of Lake Erie; and perhaps also in southwestern Ontario. The discussion on breccia in this report is confined to the breccia in the Mackinac Straits area.

The brecciated rocks range in age from within the Pointe aux Chenes formation through the St. Ignace, Bois Blanc, and Detroit River formations. The Niagaran and lowermost Pointe aux Chenes rocks are not brecciated, nor are the Dundee and younger formations. Evidence of brecciation is found throughout the Straits region where post-Lower Pointe aux Chenes and pre-Dundee rocks lie at or close to the surface.

CLASSIFICATION: Although several types of breccia were found in the Mackinac region during the course of this investigation, all belong to the "founder" classification in the nomenclature of breccia proposed by Norton.[5]

Three types of breccia are recognized in the Mackinac Straits area. These we term megabreccia, intra-formational breccia, and trans-formational breccia. The trans-formational breccia is divided into the indurated and non-indurated types.

MEGABRECCIA: As the name implies, megabreccia is produced by brecciation on a very large scale. Great blocks of sedimentary rock are the "fragments" in megabreccia. These blocks are invariably tilted at angles from 6° to 25°. Orientation is entirely at random. The horizontal dimensions of the blocks range from a few feet to hundreds of feet. Only in the smaller blocks

[5]Norton, W. H., A classification of breccias: Jour. Geology, vol. 25, pp. 192-3, 1917.

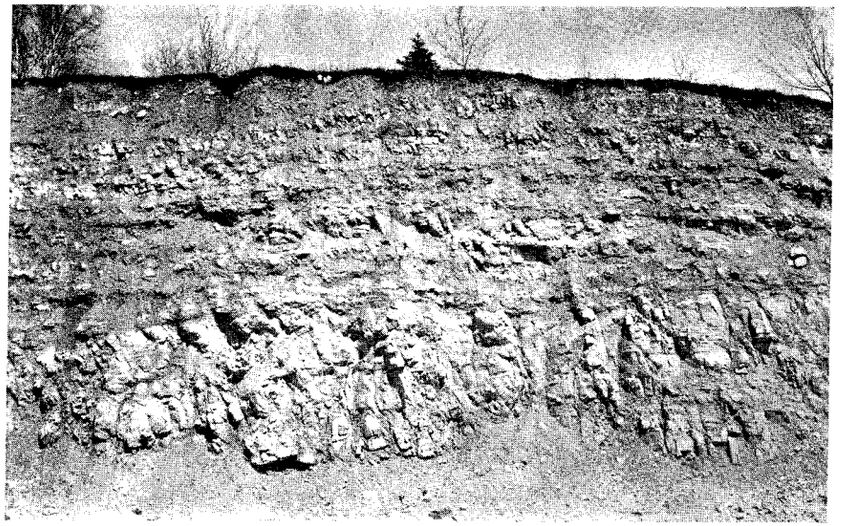
are the natural or artificial exposures sufficient to permit tracing a block from one side to the other. The top of the tilted blocks in the megabreccia is the top of the bed rock except where the uncomformably overlying Dundee is present. In no place is the base of a tilted block visible. It is thought that the base lies well within the Pointe aux Chenes formation. The lateral boundaries of the tilted blocks are marked by faults and slickensided surfaces.

Good examples of the megabreccia can be seen at a number of places. An interesting exposure can be seen in a road cut (pl. III B) on U. S. Highway 2 a few miles west of St. Ignace (in the E½ SW¼ sec. 9, T. 40 N., R. 4 W.). On the north side of the road beginning at the east end of the exposure is first a shale and dolomite section which has a 25° east dip, and is bounded on the west by a normal fault. The same sedimentary rocks are across the fault, but they have been dropped eight feet and have an east dip of much less magnitude. West of the second tilted block are successively a vertical column of non-indurated breccia, a block of red and green shale, another unindurated breccia, and, at the west end of the outcrop, a dolomite and shale block which has a west dip. In terms of the nomenclature used in this report, the U. S. Highway 2 cut shows three blocks in the megabreccia, and two columns of transformational breccia of the non-indurated type.

The best place to see the various types of breccia is a big cut excavated near the south tip of the St. Ignace Peninsula for the purpose of connecting U. S. Highway 2 with a projected ferry mole. Several different blocks with the beds tilted at various angles can be seen on the face of this cut (pl. XVII A). As in the highway cut, these blocks are separated one from another by either faults or breccia masses. All stages of brecciation occur between simple "let-down", in which the stratification is but little disturbed, and dropped blocks in which the stratification is still visible, but the beds are severely shattered and disturbed.

A block of rock which contains both the Lower Bois Blanc and the Upper St. Ignace with the contact between undisturbed, is exposed in the gulch made by overflow water from the reservoir on the east side of Mackinac Island just north of Fort Holmes. The rock has a dip of 12° to the southeast (pl. VI B). The sedimentary rocks exposed in Mill Creek near Mackinaw City beneath the railroad and highway bridges and in the nearby quarry have a dip of 9° to the south.

Many other examples of the blocks composing the megabreccia could be cited. As a matter of fact, practically all, if not all, the



A

B

PLATE XVII

A. St. Ignace Formation in Ferry Mole Cut, St. Ignace Peninsula.
B. Breccia Chimney, Ferry Mole Cut, St. Ignace Peninsula.

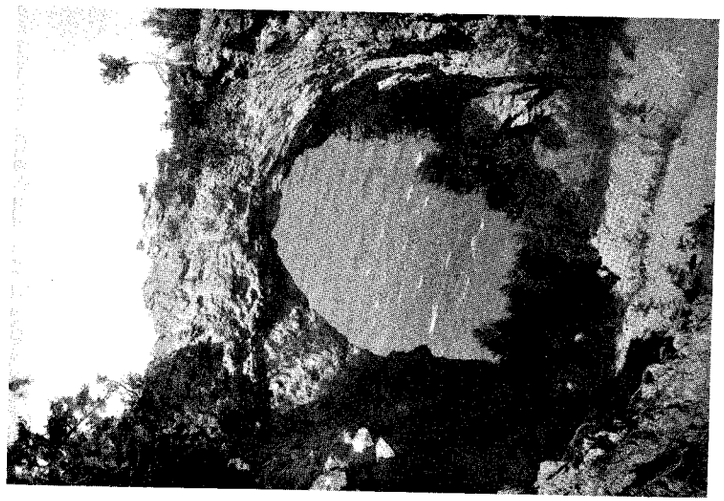
exposures from which the stratigraphic section given in the preceding discussion was obtained, are tilted blocks of this type.

Because no pillars of undisturbed rock could be recognized in the Straits area, it was not possible to determine the number of feet which these blocks dropped down from their original position. In studying the stratigraphy it became apparent that some blocks had dropped much farther than others. Furthermore, it is obvious that where such extreme dips as 25° occur one side of the block fell much farther than the other side. As a general rule, rocks of the same general age lie at approximately the same elevation along the regional strike. Therefore, it is assumed that the upper end of the tilted blocks dropped only a few feet. However, the drop of the lower ends of the larger tilted blocks may have been of the order of magnitude of tens of feet.

INTRA-FORMATIONAL BRECCIA: Intra-formational breccia is volumetrically insignificant compared with the megabreccia and the trans-formational breccia. It is found in layers overlain and underlain by non-brecciated rock. In the Mackinac Straits area it is in beds in the megabreccia. It is suggested that in the dropping of these blocks the less competent rock layers were fractured, and in extreme disturbance the fragments were jumbled. Subsequently ground waters circulating through the porous layers precipitated calcium carbonate cement as the final stage in the brecciated process. All stages were observed between rock layers in the tilted blocks which suffered extensive fissuring and rock layers which are completely brecciated. Most of the intra-formational breccia layers are only a few inches thick. Examples can be seen in several places in the ferry mole cut.

TRANS-FORMATIONAL BRECCIA: The trans-formational breccias are so named because they cut through the stratigraphic section from the Detroit River formation to the Upper Pointe aux Chenes, inclusive. They occur in vertical bodies which range from a few feet to several hundred feet in width. At no place was it possible to find the bottom of one of these breccia columns. In several places (as at the exposure south of Dwightwood Spring on the east side of Mackinac Island) the breccia was observed high on the side of a cliff with bedded rocks apparently lying beneath. However, excavation with pick and shovel proved that the breccia continues downward with near vertical walls, and the bedded rocks lower on the cliff abut against the breccia. Sedimentary rocks were not found directly overlying breccia, except in the Calcite quarry at Rogers City, where the overlying bedded rocks are of

B. Castle Rock.



A. Arch Rock.

PLATE XVIII

Dundee age, and on Round Island, an exceptional condition described on page 152.

The vertical dimensions of the breccia masses can only be estimated. The greatest vertical distances exposed are at Castle Rock on St. Ignace Peninsula, and Arch Rock on Mackinac Island (pl. XVIII). At each of those places about 133 feet of breccia is exposed. However, a short distance west of Arch Rock, at Lookout Point, the top of a breccia column is 300 feet above lake level. Presumably this breccia, like the breccia at Arch Rock, extends down to and below lake level. It is the thesis of this chapter (developed subsequently) that the breccias extend for some distance into the Pointe aux Chenes formation. Therefore, to the 300-foot vertical dimension of the breccia at Lookout Point should be added at least 400 feet at the lower end, and an unknown amount which has been eroded at the top.

The writers estimate that the top of the Pointe aux Chenes formation at Rogers City is about 1000 feet below the Dundee. Therefore, if this theory is correct, the breccia exposed in the Calcite quarry extends downward 1000 feet plus 400 or 500 feet more into the Pointe aux Chenes.

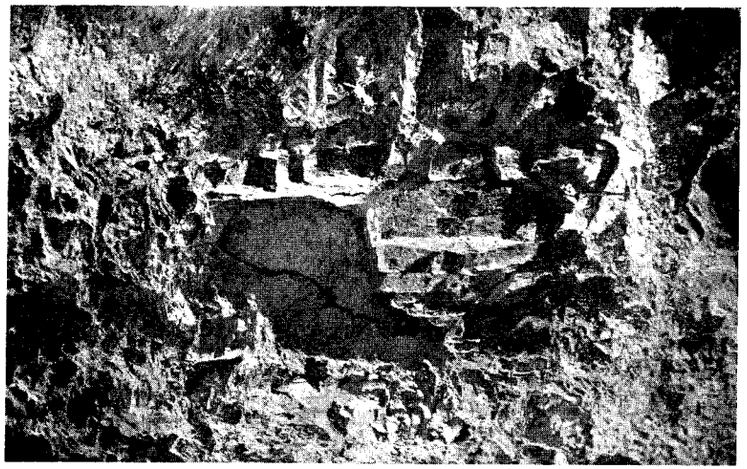
It is also possible to estimate the downward drop of individual fragments found in the breccia. In the mounds south of Allenville (northwest of St. Ignace) are Bois Blanc slabs containing the same faunas that are in the rocks on McGulpin Point south of the Straits. The country rock in which these breccia fragments occur belongs to the lower part of the middle third of the Pointe aux Chenes formation. The dip on the top of the Niagaran rocks between the Engadine escarpment, Mackinac County, and wells in Cheboygan and Alpena counties is 65 feet per mile to the south. If the McGulpin Point rocks are projected northward at this rate of dip they would lie about 750 feet above the breccia knobs at Allenville. This is probably an extreme estimate, because the formations thin to the northward. By adding a part of the Point aux Chenes, all of the St. Ignace, and part of the Bois Blanc thicknesses, as measured at the outcrop, the figure of 600 feet is obtained. It is probable that the Bois Blanc slabs at Allenville dropped somewhere between 600 and 750 feet.

If a fragment fell 600 feet plus, an open space of 600 feet or more would be necessary. The largest cavern at Carlsbad is nearly 300 feet high. "Great heaps of fallen blocks encumber the floor; some

[6]Davis, W. M., Origin of limestone caverns: Bull. Geol. Soc. America, No. 41, p. 588, 1930.

A

Dolomite fragments in breccia.



B

Limestone in Sugar Loaf Stack, Mackinac Island.

PLATE XIX

of the blocks are of enormous size; one that fell 200 feet is estimated to weigh 100,000 tons."[6] A combination of a large cavern and a break through above to the surface might produce an opening through which rock could fall a distance of 600-700 feet.

The component fragments of the trans-formational breccia range in size from powder to rock slabs measuring over 20 feet in maximum dimension. Stratification can be seen in the larger fragments. Dips of these rock fragments range from horizontal to vertical with absolutely no relationship between the orientation of adjacent fragments.

As a general rule the rock fragments are decidedly angular (pl. XIX). In freshly exposed breccia most of the slabs have sharp edges. However, fairly well rounded fragments and numerous rounded corners were observed on the fragments projecting from breccia masses which have been exposed to weathering for a considerable period. On fresh surfaces of breccia rounded fragments are decidedly exceptional. According to the theory proposed, some rounding by attrition could take place during the formation of the breccia. Initially spheroidal or sub-angular surface rock fragments could have been incorporated in these breccias.

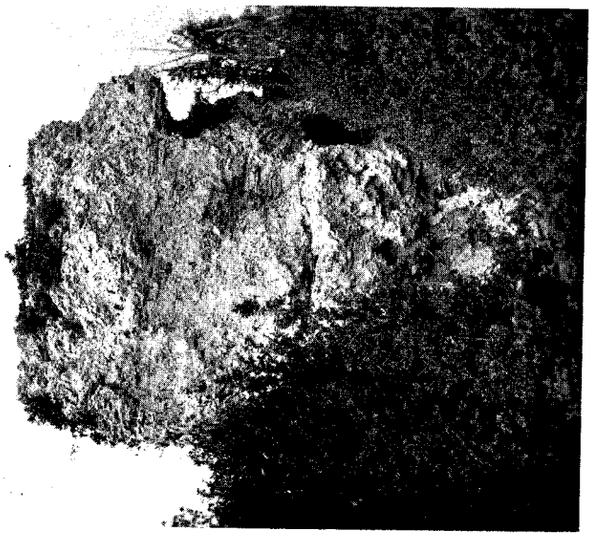
Limestone and dolomite are the main rock types found in the breccia. Chert is in many places, and in a few places shale fragments can be recognized. Because of its characteristic fossils, fragments at the Bois Blanc formation can be recognized readily. Even where fossils are absent, fragments can be assumed to be of Bois Blanc age if chert is present, as this is the only formation in the district which contains any appreciable amount of chert. It is also possible to identify St. Ignace fragments on lithologic grounds. Due to the almost complete absence of outcrops of the Detroit River formation in northern Michigan, it was not possible to identify definitely fragments from this formation. However, it was assumed that fragments which were from neither Bois Blanc nor St. Ignace probably came from the Detroit River, although in the northern part of the area investigated Pointe aux Chenes materials may also be in the breccia. The breccia beneath the Dundee in the Calcite quarry near Rogers City must be composed exclusively of Detroit River rock because it lies above the Bois Blanc and St. Ignace formations.

In a few places, notably in the E½ NE¼, sec. 30, T. 39 N., R. 3 W., in Cheboygan County, southeast of Mackinaw City, are breccias in which all the fragments, and the matrix material also, came from the same source rock. It is virtually impossible

B

Stack near Gros Cap
Indurated breccia.

Breccia near State Police Post, St. Ignace.



A

PLATE XV

to identify this rock as breccia by the examination of fresh surfaces. However, the weathered surfaces show unmistakably that the rock is a breccia, as the rock fragments stand out in relief from the matrix.

On the basis of the degree of cementation of the breccia fragments, the trans-formational breccia can be divided into two types —indurated and non-indurated. Percolating ground waters precipitated calcium carbonate in places to produce indurated breccia. The type of material in the breccia apparently bears a definite relationship to the degree of induration. Shale in the matrix tended to fill the interstices between the limestone or dolomite fragments, thereby impeded the movement of ground water and prevented induration. Most of the breccias composed dominantly of chert fragments are not indurated, probably because the circulating ground waters had less calcium carbonate in solution. For the same reason dolomite breccias are less strongly indurated than breccias which consist largely of limestone fragments.

INDURATED BRECCIA: The very scenic chimney rocks of the Straits region are made of indurated breccia. Outstanding examples are Gros Cap (pl. XX A), St. Anthony's Rock, and Castle Rock (pl. XVIII B) on the St. Ignace peninsula; Robinson's Folly, Arch Rock (pl. XVIII A), Sugar Loaf, and many others on Mackinac Island. Indurated breccia is much less common on the other islands and on the mainland south of the Straits. However, a large mass of indurated breccia is on the left bank of Mill creek above the quarry, in the center of the N½, Private Claim No. 344, Cheboygan County.

Perhaps the outstanding characteristic of the indurated breccia is its resistance to erosion. It is much harder than the rock which originally surrounded it; therefore breccia masses have become isolated by the removal of adjacent rocks, not only by the usual forces of erosion but also by wave action during the fairly recent geologic past when the higher post-glacial lakes, Lake Algonquin and Lake Nipissing, were in existence. (Chap. I).

Differential erosion not only sculptured the indurated breccia masses from the less resistant surrounding rock but also acted upon the breccia rock itself. Naturally some of the rock fragments in the breccia are less resistant than others and are more readily removed. Therefore, most of the chimney rocks or stacks have been pock-marked on a large scale by the removal of less resistant rock fragments and groups of rock fragments. At St. Anthony's Rock (Frontispiece) and Sugar Loaf, for example, small caves have