SILURIAN ROCKS OF MICHIGAN AND THEIR CORRELATION

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INTRODUCTION

Silurian strata are exposed in the Northern Peninsula in a broad, arcuate, east-west belt on the northern flank of the Michigan Basin. This belt borders the northern shores of Lake Michigan, the Straits of Mackinac, and Lake Huron and extends from the Garden Peninsula and nearby islands on the east side of Big Bay de Noc (Delta and Schoolcraft Counties) to the eastern shore of Drummond Island (Chippewa County). Some strata of this belt belonging to the Lime Island dolomite and 12 feet of the overlying Byron dolomite also crop out in a small distant outlier, Limestone Mountain (Fig. 2), located about 12 miles west of Baraga, Baraga County, and about 1/2 mile northeast of Hazel, Houghton County, Michigan (Case and Robinson, 1915, p. 173; Ehlers and Kesling, 1957, p. 9).

In the Northern Peninsula, the combination of resistant Niagaran dolomites and soft underlying strata has produced, with erosion, a prominent cuesta. This conspicuous topographic feature extends through the Northern Peninsula, Cockburn and Manitoulin Islands, the Bruce Peninsula, the region of Hamilton, Ontario, and thence to Niagara Falls. Because of lateral differences in erosion of the Niagaran strata in northern Michigan, the beds forming the escarpment vary. In the Garden Peninsula, it is the rocks of the Burnt Bluff group (overlying the soft Moss Lake strata) that form the picturesque cliffs along the western edge of the peninsula. East of Trout Lake, it is the Engadine dolomite that caps the escarpment and forms the long back slope gently inclined toward the center of the Michigan Basin. In addition to these extensive natural exposures, several quarries have been excavated into the Silurian limestones and dolomites.

The only other area of exposed Silurian deposits in Michigan is in Monroe County, in the southeastern corner of the Southern Peninsula. The rocks, which are shown in a few quarries and outcrops, are of Upper Silurian age.

Silurian strata exist beneath the entire Southern Peninsula, but they are covered by younger Paleozoic deposits and Pleistocene drift. Stratigraphy and correlation of these strata must be deciphered by the study of cuttings and rock cores from deep wells.

In the following pages we briefly describe the stratigraphy and correlation of the exposed Silurian deposits. Then we attempt to utilize this information to interpret the classification of the covered Silurian strata of the Southern Peninsula and, particularly, to correlate the Silurian formations in Michigan with those in adjacent states. From our suggested paleontological correlations and from study of subsurface samples, the paleogeographic setting is postulated and the depositional provinces are discussed.

SILURIAN ROCKS OF THE NORTHERN PENINSULA

ALEXANDRIAN (OR MEDINAN) SERIES

Cataract group

MANITOULIN DOLOMITE

The Manitoulin dolomite is the oldest Silurian formation in Michigan. It consists of thin-bedded, buff-gray to gray, cherty dolomite and massive gray dolomite composing the cores of bioherms, and has the same lithology as the typical Manitoulin dolomite of Manitoulin Island. The formation has been recognized in outcrop and in deep wells southeastward from Manitoulin Island to the Hamilton, Ontario, region. In the Northern Peninsula the dolomite has been recognized in several exposures and has been traced westward along the belt of Silurian rocks from Drummond Island to the Manistique region of Michigan by means of rock cuttings from deep wells. The thickness of the Manitoulin dolomite in the Northern Peninsula ranges from 25 to 50 feet.

The Manitoulin dolomite of the Northern Peninsula contains Palaeophyllum williamsi (Chadwick) and Coelospira planoconvexa (Hall), characteristic fossils of the Manitoulin of Ontario. It also contains Atrypa latimarginata Foerste, a brachipod originally described from the Brassfield limestone, which is regarded by most paleontologists as being of the same age as the Manitoulin dolomite.

CABOT HEAD SHALE

The Cabot Head shale of the Northern Peninsula is known from two small exposures and rock cuttings from several deep wells. The outcrops consist of gray argillaceous dolomites and gypsum. The rock cuttings show that most of the lower half of the Cabot Head consists of gray argillaceous dolomite, and that the upper half is composed of interbedded green shale and thin layers of gray argillaceous dolomite, and some thin layers of red shale and gypsum. Like the underlying Manitoulin dolomite, the Cabot Head shale can be traced westward from Manitoulin and Cockburn Islands, Ontario, to the Manistique region of Michigan by means of rock cuttings from many deep wells. The thickness of the Cabot Head in the Northern Peninsula ranges from 75 to 100 feet (Ehlers and Kesling, 1957, p. 2 and fig. 1).

The few fossils found in the outcrops of the Cabot Head are too poorly preserved for specific identification. In Ontario the shales of this formation contain many fossils that can be identified specifically. The authors believe that well preserved fossils are likely to be found in larger pieces of shale or cores obtained from the further drilling operations in the Northern Peninsula.

MOSS LAKE FORMATION

The Moss Lake formation, which rests on the Cabot Head shale, is known from a few exposures and rock cuttings from deep wells (Ehlers and Kesling, 1957, pp. 5, 6, and fig. 1, p. 4). The lower part of the formation consists of gray, buff-gray and buff, cherty dolomites. The upper part is composed of thin beds of argillaceous dolomites, green shale, and gypsum; the lithology of this part is very similar to that present in the upper part of the Cabot Head. The maximum thickness of the Moss Lake formation is 150 feet in the Manistique region; examination of rock cuttings from wells shows that the formation thins when traced eastward across the belt of Silurian rocks, and is absent in eastern Chippewa County (Ehlers and Kesling, 1957, fig. 1, p. 4).

The few fossils obtained from the Moss Lake formation are very poorly preserved but seem related to species found in the Cabot Head shale.

NIAGARAN SERIES

Burnt Bluff group

LIME ISLAND DOLOMITE

The Lime Island dolomite composing the oldest stratigraphic unit of the Burnt Bluff group is exposed on the west shore of Lime Island in St. Mary's River, Chippewa County, Michigan. A second outcrop is in the Limestone Mountain outlier (Fig. 2). Although no other exposures are known, the presence of the formation in the belt of Silurian rocks is indicated by numerous erratics that were transported southward by the Pleistocene ice from outcrops now covered by glacial drift. The formation consists of thick beds of buff and buff-gray dolomites, most of which are filled with molds of the brachiopod Virgiana decussata (Whiteaves) [syn. V. mayvillensis Savage]. The thickness of the Lime Island dolomite ranges from 15 to 35 feet. The sea in which this formation was deposited was of great extent and entered the Michigan Basin from the north (Ehlers and Kesling, 1957, pp. 9, 11, 25-27).

BYRON DOLOMITE

The Byron consists in large part of light-gray, light-brown, and cream-colored, finely crystalline, evenly-bedded dolomites; some beds are light-brown dolomite. Many dolomite beds are laminated. The thickness of the Byron dolomite ranges from 80 to 150 feet.

The Byron strata of Michigan are lithologically like the Byron rocks of Wisconsin and occupy a similar stratigraphic position. The top of the Byron dolomite in the Northern Peninsula has been placed at the base of the lowest strata containing fossils that are definitely related to species existing in the fauna of the overlying Hendricks dolomite (Ehlers and Kesling, 1957, p. 11).

HENDRICKS DOLOMITE

The Hendricks consists of many beds of dolomite, few magnesian limestones, and one very pure, buff-gray limestone near the top, known as the Fiborn limestone member. The Fiborn limestone grades laterally into a light-gray to white dolomite. A short distance below the Fiborn are thick-bedded buff-gray to buff, medium to coarsely crystalline dolomites. Below these dolomites are a few thin magnesian dolomites and many thin-bedded, laminated, light-gray dolomites that strikingly resemble many dolomites in the Byron formation. The thickness of the Hendricks dolomite ranges from 60 to 120 feet and that of the Fiborn limestone member from 19 to 50 feet.

The fauna of the Hendricks is large; representatives, presently unreported, of numerous species described from the Interlake group in Manitoba and from strata in the Hudson Bay region characterize this dolomite. A few of the common diagnostic species of this fauna are Camarotoechia winiskensis Whiteaves, Plectatrypa lowi (Whiteaves), Dihogmochilina latimarginata (Jones), and Leperditia fabulina Jones. This fauna migrated southward into the Michigan Basin in a widespread sea from the Arctic region. See correlation table (Fig. 1).

Manistique Group

SCHOOLCRAFT DOLOMITE

The Schoolcraft consists of different kinds of dolomite. The lowest rock, unit 1, at most places consists of a thick-bedded, grayish-buff to buff, coarsely crystalline dolomite filled with imperfect, incomplete molds of valves of Pentamerus sp. At some places this rock is a magnesian limestone with most of the valves of Pentamerus sp. replaced with greenish-gray calcite. The thickness of this lowest unit ranges from 6 to 8 feet. Overlying this bed are 12 to 22 feet of thin, even-bedded, gray to bluish-gray, finely crystalline dolomite, unit 2, containing molds of a Pentamerus that in some respects resemble

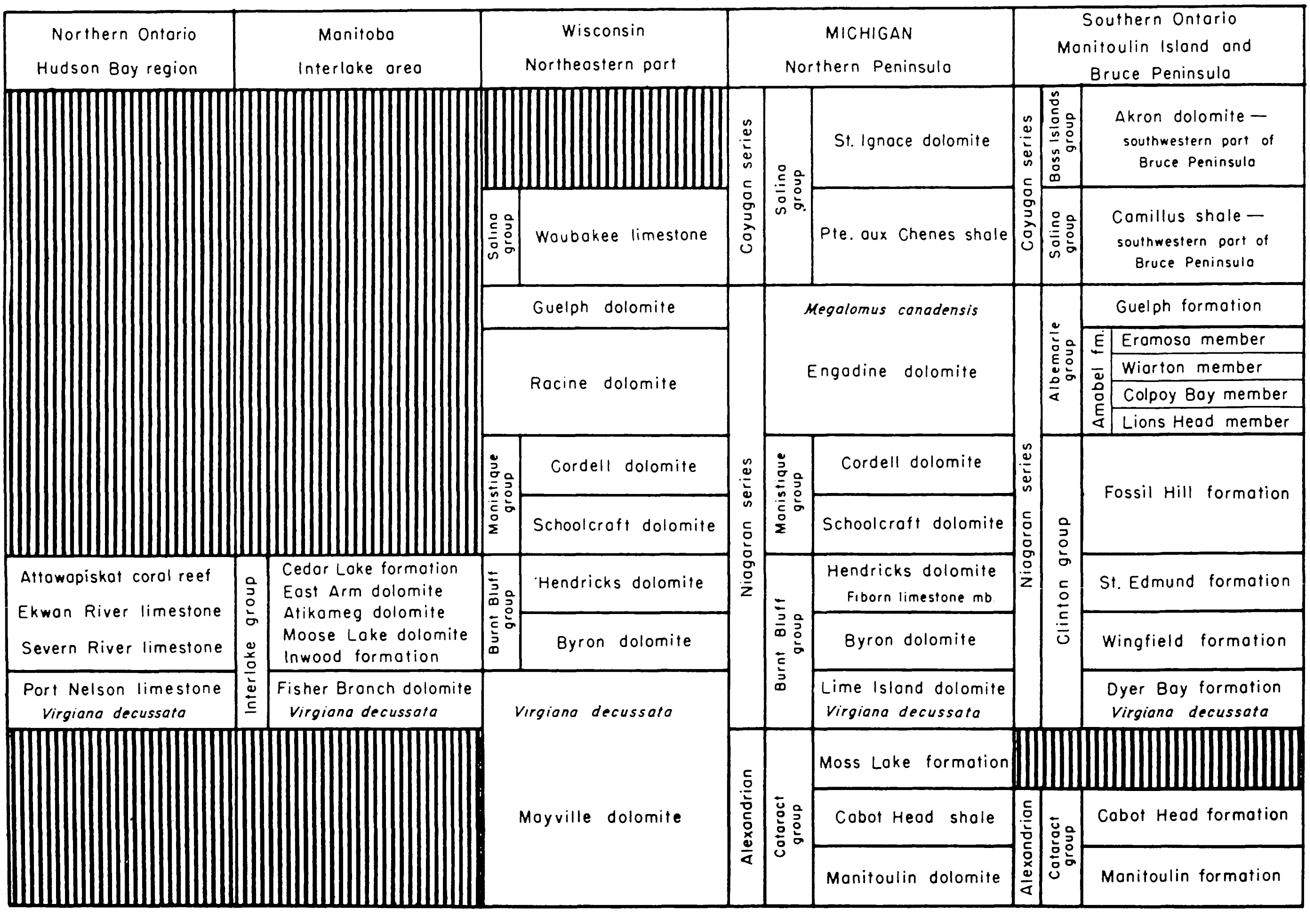


Figure 1. Chart showing correlation of strata in the Northern Peninsula of Michigan with those in areas to the north, west, and east. Megalomus canadensis occurs in the Guelph dolomite of Wisconsin, the Engadine dolomite of Michigan, and the Guelph formation of Mnitoulin Island and the Bruce Peninsula of Ontario. Modified from Ehlers and Kesling (1957, Fig. 2).

the specimens of Pentamerus "oblongus" of the Reynales limestone of western New York. Above this thin and even-bedded, gray to bluish-gray dolomite is a thick-bedded, grayish-buff to buff, coarsely crystalline, Pentamerus-bearing dolomite, unit 3, which is strikingly like the lowest rock, unit 1, although it contains more corals and stromatoporoids. It is 8 to 11 feet thick. Except for the presence of a thin-bedded, buff, cherty dolomite, all higher strata of the Schoolcraft are thin, evenly-bedded, light-gray to bluish-gray, finely crystalline dolomites. The thickness of the Schoolcraft dolomite ranges from 40 to 60 feet.

The top of the Schoolcraft dolomite contains undescribed species of Helopora and Coelospira that are related to species in the Clinton group.

The three Pentamerus-bearing dolomites, units 1-3, continue eastward from the Northern Peninsula to Cockburn and Manitoulin Islands and thence southeastward into the Bruce Peninsula, Ontario. Unit 1 or 3 is present in the Owen Sound region of Ontario, where it rests on the Cabot Head shale. One or more of these units continues into northwestern Wisconsin. Unit 1 or 3 may be present in a small outcrop a few miles from Burlington in southeastern Wisconsin.

An unconformity exists between the Schoolcraft and underlying Burnt Bluff strata. In the Inland Lime and Stone Company's quarry, located about 20 miles east and 6 miles north of the city of Manistique, several small outcrops of either units 1 or 3 were exposed in contact with the Fiborn limestone but subsequently have been removed by quarrying. At this contact at least 3 to 6 feet of Hendricks strata, known to overlie the Fiborn limestone nearby, and possibly some still higher Hendricks rocks, are missing as the result of pre-Schoolcraft erosion. Beside a dirt road about 1/10 mile south of the center of the west line of sec. 15, T42N, R14W, Schoolcraft County, approximately 9 miles east and 5 miles north of Manistique, is a thick-bedded hard, dolomite, a dolomitized equivalent of the Fiborn limestone. Examination of poorly exposed strata in and adjacent to the road south of dolomitized Fiborn indicate that the latter is overlain by unit 2 of the Schoolcraft.

CORDELL DOLOMITE

The Cordell dolomite consists of thin and a few thick layers of unevenly-bedded, buff-gray to buff, cherty dolomite. It contains many well-known species of corals belonging to Alveolites, Arachnophyllum, Asthenophyllum, Coenites, Favosites, Halysites, Heliolites, Propora, Ptychophyllum, Romingerella, Syringopora, and other genera. Several cephalopods belonging to Armenoceras, Huronia, and other genera are characteristic of the Cordell and related formations. Pentamerus and Pentameroides are present in many beds. Suggested references and illustrations of some of the species are Rominger, 1876, 161 pp., 55 pls.; Foerste, 1924, pp. 19-20, 17 pls.; and Ehlers and Kesling, 1957, pp. 19-22, pls. 8-11. The thickness of the Cordell dolomite ranges from 135 to 150 feet.

Engadine dolomite

Most of the Engadine consists of thick-bedded to massive white and bluish-gray, coarsely crystalline dolomites; many of the dolomites contain cavities, which were formed by the solution of stromatoporoids and corals. Another kind of rock is a thin-bedded, gray, finely crystalline, siliceous dolomite. A thin and unevenly-bedded buff, very cherty dolomite, about 15 feet thick, is present 120-125 feet above the base of the Engadine. Thick-bedded, white to grayish-white dolomites comprise most, possibly all, of the upper half of the Engadine. Some of these dolomites contain considerable rounded and frosted grains of quartz and almandite garnet. The thickness of the Engadine ranges from 200 to 250 feet.

Two poorly defined bioherms are present in the Engadine dolomite of Michigan. Field work indicates that the formation contains extensive biostromes, some of which are made by species of Pentamerus and others by corals and stromatoporoids.

Specimens of poorly preserved molds of Megalomus canadensis Hall occur in thick-bedded dolomite near the top of the Engadine and indicate the Guelph age of this part of the formation.

CAYUGAN SERIES

Salina group

POINTE AUX CHENES SHALE

The Engadine dolomite in the Northern Peninsula is overlain by the Pointe aux Chenes formation consisting of green and red shale, thin beds of dolomite of varied lithologic character, and small irregular masses and thin beds of gypsum (Ehlers, 1945, pp. 35-52, pls. 4, 5; Ehlers and Kesling, 1957, pp. 23-24, pl. 12, figs. 5-10). The Pointe aux Chenes shale contains a few fossils that are characteristic of the Bertie formation of New York. The thickness of the Pointe aux Chenes shale ranges from 500 to 600 feet.

ST. IGNACE DOLOMITE

The St. Ignace dolomite overlies the Pointe aux Chenes shale and is the youngest Upper Silurian deposit in the Northern Peninsula. The formation, except for the upper part, consists of evenly-bedded, very light gray, cream-colored, and light-buff dolomites. Some of these dolomites contain slit-like gashes, probably resulting from the solution of celestite; others have spherical cavities that originally may have been occupied by halite. Many beds exhibit both gashes and spherical cavities; crystalline calcite and dolomite are present in some gashes and spherical cavities of other beds. Some of the dolomites have molds of hopper-shaped crystals of halite. A few beds of bluish to greenish-gray shale are also associated with the dolomites. The upper part of the St. Ignace consists of a few thick-bedded, buff dolomites, some of which are oolitic. Some of the buff dolomites and the light-gray dolomites of the lower part of the formation contain frosted grains of quartz. The grains are larger and more abundant in the buff dolomites near the top of the formation than those in the lower dolomites of the formation. The thickness of the St. Ignace dolomite ranges from 250 to 300 feet.

The few fossils obtained from the St. Ignace dolomite are of little value in the determination of the precise age of the formation. The St. Ignace may be represented by deposits in the upper part of the covered Salina group of the northern part of the Southern Peninsula.

SILURIAN ROCKS OF SOUTHEASTERN MICHIGAN

CAYUGAN SERIES

Bass Islands group

The Silurian rocks that are at or near the surface of southeastern Michigan occur in Monroe County and belong to the Bass Islands group of the Cayugan series.

The Bass Islands group was originally defined as a "series" by Lane, Prosser, Sherzer, and Grabau (1900, Jan. 30, pp. 554-556). The strata are designated a group because they do not compose a series, a much larger stratigraphic division. The name Bass Islands was derived from South Bass, Middle Bass, and North Bass Islands in western Lake Erie, where the two upper divisions of the group are well exposed. Many workers have erroneously used the term Bass Island, implying a single island. Incidentally, in 1945 Ehlers (footnote 19, p. 30) protested an editor's change of "Islands" to "Island" in one of his papers.

The original divisions of the Bass Islands group are, in ascending order, the Greenfield dolomite, Tymochtee beds, Put-in-Bay dolomite, and Raisin River dolomite. It is very likely that the Greenfield dolomite and Tymochtee beds should be assigned to the Salina group. The term Bass Islands will then apply to the Put-in-Bay and Raisin River dolomites.

The occurrence of the brachiopod Whitfieldella prosseri Grabau and the pelecypods Goniophora dubia Hall and Pterinea lanii Grabau (Sherzer and Grabau, 1910, pp. 34-35, 38) indicates a faunal relationship of these two formations.

Most, if not all of the outcrops of the Bass Islands strata in Monroe County consist of Raisin River dolomite. Undoubted Put-in-Bay dolomite may be near the surface but covered with glacial drift in the eastern part of the county. The combined thickness of the Put-in-Bay and Raisin River dolomites in Monroe County is probably near 200 feet. The underlying Tymochtee and Greenfield formations have not been definitely recognized as distinct formations in southeastern Michigan, where they seem to be represented by strata in the Salina group. For further information pertaining to the Bass Islands and Salina groups the reader is referred to the work of K. K. Landes (1945).

CORRELATIONS

General remarks. — For certain Silurian formations, the faunal and lithologic evidence favoring correlation is decisive. For others, it is suggestive but hardly assuring. For some, the evidence is not worth mentioning. In the following discussion, therefore, it is necessary to express the degree of our convictions.

As shown in the bibliography, many competent geologists and paleontologists have published on Silurian stratigraphy over a long period of time. Although the articles have been sporadic and many of them restricted in scope, they do represent an impressive amount of investigation.

Despite the contributions made to our knowledge of Silurian rocks, numerous uncertainties remain. For the failure to achieve stability, the blame must be shared by the stratigraphers and the litho-correlators. The literature abounds with misidentified fossils listed from misnamed strata. Many of the current maps are based on synthetic analyses of the strata in entire series.

Stratigraphers have shown a greater proficiency with the geological than with the paleontological aspects of correlation. They have amassed reasonably exact descriptions of numerous measured sections, but their work on the faunas has left much to be desired. From selected errors in previous lists, some writers have compounded fresh errors, which they cited to support their contentions. Evaluation of fossil lists is difficult, involving such diverse factors as the stratigraphic and taxonomic terminology of the time, the reliability of the data on occurrence of the fossils, and the reputation of the worker for splitting, lumping, or wishful identification. In many instances, the faunal components can only be established by new collections. Paleontology can be utilized to establish Silurian correlations only, of course, when accurately identified fossils are known from definite geographic locations and from beds precisely placed in the sequence.

Litho-correlators have also fallen short. Unable to solve (or, perhaps, to recognize) problems of correlation, they have elected to study all the strata of a series or system as a unit. All deposits are considered as products of one sedimentational episode. By mapping selected percentages or ratios of sandstones, shales, limestones, dolomites, or evaporites in the entire sequence, they interpret the history from beginning to end. Providing the uppermost Medinan and the lowermost Salina rocks have distinctive and unmistakable lithologies, for example, they will correlate the combined Niagaran rocks at one locality with the combined Niagaran rocks at another and explain the differences as facies. Now it seems to us that a dolomitic formation deposited in early Niagaran time represents a very different geological event from a similar formation deposited in late Niagaran. Hence, despite the difficulties, we believe that correlation formation-by-formation yields a more accurate account of past events than a system using averages of composition for the whole sequence.

More subsurface as well as surface information is needed. Outcrops are very limited representations of formations. Although they provide a high percentage of the fossils, outcrops cannot be used to determine details of the areal extent of rock units. Samples from wells, especially cores, supply important data for tracing the extent and lateral variation of formations. At times, key fossils have been found in cores to establish the exact zone. Many problems of Silurian correlation may ultimately be solved by the careful study of subsurface samples. Then, the complicated depositional history of reefs, restricted basins, and various sea invasions can be worked out.

Manitoulin dolomite. -- The Manitoulin dolomite of Michigan (MM) lies within the *Coelospira planoconvexa*-*Atrypa laticorrugata* zone, which also includes the Manitoulin dolomite in Ontario (MO), the Becsie formation in Anticosti Island (Bec), the lower part of the Mayville dolomite in Wisconsin (May), the lower part of the Power Glen formation of the Niagara Peninsula and western New York (PG), the Brassfield limestone of Indiana, southern Ohio, Kentucky, and states to the south (B), the Kankakee limestone in northern Illinois (K), and the Sexton Creek limestone in southern Illinois (SC). The last two formational designations, formerly used by Savage, are not now generally recognized. The fauna of the zone includes the following significant species:

Coelospira planoconvexa (Hall) - May, MM, MO, Bec.
Atrypa laticorrugata Foerste - May, MM, B.
Palaeophyllum williamsi (Chadwick) - MM, MO.
Paleofavosites asper (d'Orbigny) - MO, Bec.
Helopora fragilis Hall - PG, MO.
Platystrophia daytonensis (Foerste) - MM, MO, K, SC, B (as far south as Alabama).
Platymerella manniensis (Foerste) - K, B (as far south as Tennessee).
Hormotoma subulata (Conrad) - B, ?K, PG.

In addition, the Brassfield, Kankakee, and Sexton Creek are linked by the occurrence of two species of the trilobite *Illaenus*, *I. daytonensis* (Foerste) and *I. ambiguus* Foerste. All of the above correlations seem to us justified and substantiated.

Cabot Head shale. — Faunally, the Cabot Head shale is related to the underlying Manitoulin dolomite. Fossils, especially those well preserved, are rather scarce. *Rhinopora verrucosa* Hall occurs in the Cabot Head shale and has been reported from the Brassfield limestone in Indiana, Ohio, Tennessee, and

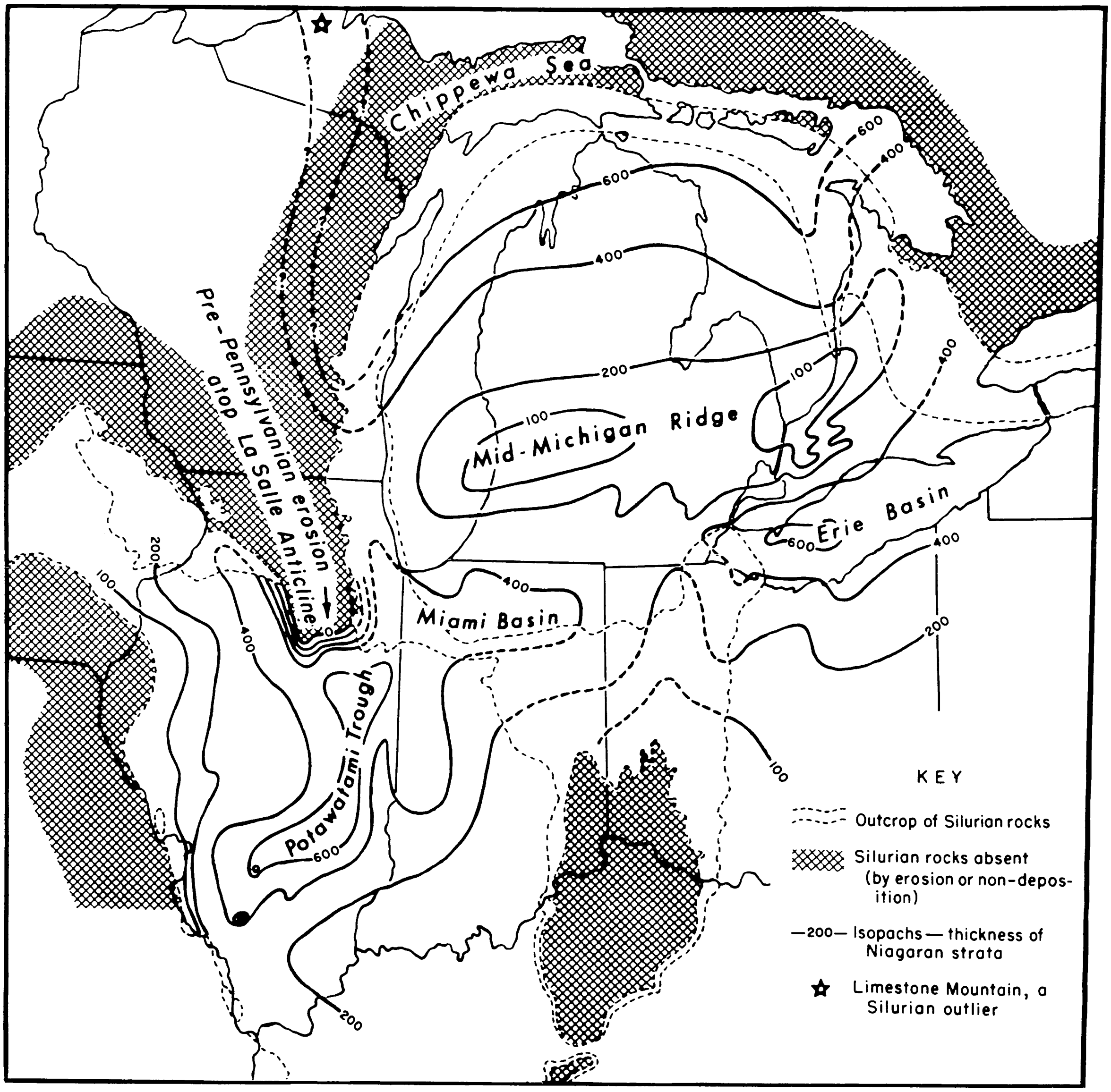


Figure 2. Map showing paleogeographic setting of the lower Niagaran time. The separation of Silurian outcrops in northern Illinois is due to Mississippian-Pennsylvanian erosion, which removed all Silurian strata in north-central Illinois, so that Ordovician rocks are in contact with Pennsylvanian. The areas of Niagaran deposition are given names of the Indian tribes which inhabited them in historic times. The name Chippewa for the sea extending from northern Michigan into Canada was suggested to us by Mr. Gilbert O. Raasch several years ago. Isopachs indicate total thickness of Niagaran rocks, based on information from Cohee (1948), Lowenstam (1949), and Roliff (1949), and on our own field observations.

Alabama, and questionably in the Sexton Creek limestone of southern Illinois. Helopora fragilis Hall is most abundant in the Cabot Head shale of Ontario and occurs in the underlying Manitoulin and in the Power Glen of the Niagara Peninsula, although the species extended into the Dyer Bay dolomite in Ontario and the Clinton formations in New York. On the basis of its distinctive layers, the Cabot Head can be traced in surface exposures and subsurface samples.

By its stratigraphic position, we suppose (as did Bolton, 1957) that the upper part of the Power Glen formation is equivalent to the Cabot Head. Whether the Grimsby formation in the Niagara Peninsula is regarded as having its lower part the same age as the entire Cabot Head (as by Fisher, 1954), or restricted to represent only the beds above the Power Glen or Cabot Head (as by Bolton, 1957), the formation has lithologic affinities with the Cataract group to the north in Ontario by its red shales.

Moss Lake formation. — Insofar as known, this formation does not extend beyond the Northern Peninsula of Michigan. It may have been deposited simultaneously with the late Medinan sands and shales of the Niagara Peninsula, but Moss Lake strata cannot be traced into Ontario and presumably were laid down in an isolated basin. Faunally, the Moss Lake contains a few poorly preserved specimens that appear to represent species known elsewhere in the Cataract group.

Lime Island dolomite. — The *Virgiana decussata* zone (Fig. 1) includes the Fisher Branch dolomite in Manitoba (FB), Port Nelson limestone in the Hudson Bay region (PN), the upper part of the Mayville dolomite in northeastern Wisconsin (May), the Lime Island dolomite in northern Michigan (LI), the Dyer Bay formation (DB) and the lower beds of the Wingfield formation (W) in Manitoulin Island and Bruce Peninsula, and the Gun River (GR) and Jupiter River (JR) formations in Anticosti Island. The fauna includes the significant species:

Virgiana decussata (Whiteaves) [= *V. mayvillensis* Savage] — FB, PN, May, LI, DB. (Foerste and Savage suggest that a brachiopod collected by A. P. Low in 1906 from Southhampton Island appears to be an immature form of *V. decussata*. This would be the northernmost occurrence of the species.)
Chilobolbina billingsi (Jones) - GR, JR, DB.
C. punctata Ulrich & Bassler - DB, GR, JR, W.
Zygobolba williamsi Ulrich & Bassler - DB, W.

Because varieties of the two species of the ostracod *Chilobolbina* occur in the *Mastigobolbina lata* zone in Maryland, Ulrich and Bassler (1923, pp. 335-36) stated that the Dyer Bay dolomite "corresponds to the latter part of the Lower Clinton or the early part of the Middle Clinton, with the former interpretation the more likely of the two."

A few isolated slabs of limestone collected on Blanch River north of Cobalt, Ontario, contain *Chilobolbina punctata* and *Zygobolba williamsi*. Their occurrence led Ulrich and Bassler (1923, p. 336) to postulate that this area may have been along the route of invasion of the Clinton sea into the Great Lakes region. At any rate, this would constitute the northernmost record of Dyer Bay strata.

We know of no deposits to the south of northeastern Wisconsin, the Northern Peninsula of Michigan, Manitoulin Island, and the Bruce Peninsula which contain this fauna, nor of any beds that can be proved to occupy this position in the sequence. Possibly the sandstones and shales of the Thorold formation of the Niagara Peninsula are the strand and near-strand facies of this zone.

Byron dolomite. — This sequence of dolomites is also present in northeastern Wisconsin, where it is recognized under the same name. The Byron probably is equivalent to all of the Wingfield formation of Manitoulin and the Bruce Peninsula except for the ostracod-bearing strata near the base (referred to above). The fossils in the Byron are related to those in the overlying Hendricks dolomite.

Hendricks dolomite. — The *Camarotoechia winiskensis-Dihogmochilina latimarginata* zone is found to include the Inwood formation (I), Moose Lake dolomite (ML), Atikameg dolomite (A), East Arm dolomite (EA), and Cedar Lake formation (CL) of the upper part of the Interlake group in Manitoba, the Severn River limestone (SR), Ekwan River limestone (ER), and Attawapiskat formation (Aw) in the Hudson Bay region, the Hendricks dolomite in Wisconsin (HW) and Michigan (HM), the Wabi formation of Lake Timiskaming (W), the St. Edmund formation in Manitoulin Island and the northern end of the Bruce Peninsula (StE), and Silurian beds in Southhampton Island in the Canadian Arctic and Offley Island, North Greenland (SO). The important species are:

Camarotoechia winiskensis Whiteaves - EA, CL, ER, HM, W, StE, SR.
Dihogmochilina latimarginata (Jones) - EA, CL, HM, SO, ER, SR.
Plectatrypa lowi (Whiteaves) - A, ER, SR, W, StE, HM.
Leperditia fabulina Jones - I, ML, A, W, HM, SR.
Multisolenia tortuosa Fritz - EA, CL, HM.
Trimerella ekwanensis Whiteaves - SR, ER, Aw.
Scutellum magnificum Teichert - SO, HM.

The distribution of the fauna — from North Greenland through central Canada and into northern Michigan and nearby areas of Wisconsin and Ontario — strongly suggests its northern origin. This was implied or stated previously by Savage (1918, p. 336), Savage and Van Tuyl (1919, p. 370), Foerste and Savage (1927, pp. 20-21), and others.

Manistique group. — For purposes of correlation, there seems no need to discuss the Schoolcraft and Cordell dolomites separately. Both formations are present and identified in eastern Wisconsin (Shrock, 1939, pp. 533-34, 549-53, pl. 1; 1940, pp. 207-08, pl. 1). In Ontario, the corresponding strata are combined in the Fossil Hill formation.

At and near the base of the Manistique group is the *Pentamerus* zone, containing three distinct units. These units have been recognized in the Manistique group of Wisconsin and Michigan and in the Fossil Hill formation of Manitoulin Island and the Bruce Peninsula. Possibly, this zone extends also to the south of the Wisconsin outcrops as far as the vicinity of Joliet, Illinois, where Savage (1926) found *Pentamerus* which he listed as *P. oblongus* in the lower strata of the Joliet limestone. The *Pentamerus* species in the Michigan rocks may also be the same as the *Pentamerus* listed from the Lockport formation of Lake Timiskaming. The species of *Pentamerus* in unit 2 is probably different from the species in units 1 and 3. We do not believe that the species in Michigan are *Pentamerus oblongus* (Sowerby). Nor do we think they are the same as those in the Reynales limestone in New York, although they may have been contemporaneous. We wish to emphasize that the "*Pentamerus oblongus*" reported from various Clinton, Lockport, and Guelph formations is really several species, each of which has considerable variation. Even though the brachiopod is in serious need of specific discrimination, the *Pentamerus* zone is useful in the Wisconsin-Michigan-Ontario region, where beds in many exposures are densely packed with *Pentamerus* sp. The zone is an excellent marker for the base of the Schoolcraft dolomite and the Fossil Hill formation.

The *Favosites favosus* zone marks the Cordell dolomite in Michigan (MM) and Wisconsin (MW), the Hopkinton dolomite in Iowa (Hop), the Fossil Hill formation in Manitoulin Island and the Bruce Peninsula (FH), and the Lockport formation at Lake Timiskaming (LT) (called the Thornloe limestone by Flower, 1946, p. 519). The widespread coral beds in this area carry the following typical fauna:

Favosites favosus (Goldfuss) - Hop, MW, MM, FH, LT.
Arachnophyllum pentagonum (Goldfuss) - Hop, MW, MM, FH, LT.
A. striatum (d'Orbigny) - Hop, MM, FH.
Romingerella major (Rominger) [= Thecia major] - MM, FH.
Coenites crassus (Rominger) - MM, FH, LT.
Halysites labyrinthicus (Goldfuss) - MW, MM, LT.
Ptychophyllum stokesi Edwards & Haime - MM, FH.
Stokesoceras romingeri Foerste - MM, LT.
Huronia vertebralis Stokes - Hop, MM, FH.

Other corals could be added to the list which occur in more than one formation of this age. The faunas of the above formations are so much alike that one is forced to admit that they lived in the same sea. Somewhere across southern Wisconsin and possibly part of Illinois, there must have been a marine connection between the Northern Peninsula and Iowa. Ehlers and Kesling (1957, pp. 28, 29) suggested that the Manistique sea reached the Northern Peninsula via a seaway from the Middle Silurian Atlantic Ocean and that this seaway was separated from the Clinton Sea of western New York and Niagara Peninsula by a barrier. The occurrence of the Cordell fauna in the Lockport or Thornloe limestone of the Lake Timiskaming region indicates the possible existence of a seaway situated north of that in which the Clinton group of New York was deposited.

Corals which appear to be identical with *Arachnophyllum pentagonum* and *A. striatum* occur in the Louisville limestone of Kentucky and southern Indiana. One specimen of *Romingerella major* was reported 25 feet below the top of the Louisville. No specimen of the large, distinctive cephalopod siphuncle, *Huronia vertebralis*, nor other elements of the *Huronia*-*Stokesoceras*-*Armenoceras* cephalopod association which characterizes the Cordell and its equivalents, however, are known from the Louisville limestone. This poses a serious problem in interpretation. Because the cephalopods seem to have been widely distributed from Iowa to Lake Timiskaming, but apparently were barred from the area in which the Louisville was laid down, we have tentatively decided that no permanent connection between the sea in Iowa and that in Kentucky existed through Cordell time. It is possible that such a connection existed for a brief interval, long enough for the corals to become established in the Louisville sea. We do not know.

The Chicotte formation in Anticosti Island, on the other hand, contains *Huronia vertebralis* but lacks the distinctive coral fauna. We assume, tentatively again, that it correlates with the Cordell.

Other problems of finding Manistique equivalents to the south will be discussed later.

Engadine dolomite. — This formation (Fig. 1) includes strata of both Racine and Guelph age. Because exposures of the Engadine comprise only small and discontinuous segments of the rock sequence, the Engadine has been retained as a formation. When additional beds are available for study, it will perhaps rank as a group with several formations.

The *Scutellum laphami* zone is found in the lower parts of the Engadine dolomite in the Northern Peninsula of Michigan and the Racine dolomite of northeastern Wisconsin. In Michigan, *Scutellum (Scutellum) laphami* (Whitfield) has been found within 25 feet of the base of the Engadine. In Wisconsin, this fan-tailed trilobite comes from the Kewaunee beds in Kewaunee and Door Counties. Walter (1925) recorded *Scutellum laphami* from beds in Iowa which he called "Niagaran" and "Hopkinton." As shown by his figures, however, Walter's trilobites were tuberculate. They do not match *Scutellum* (*S.*) *laphami* examples from Wisconsin (at the type locality) or Michigan. They are ornamented like a very small pygidium of *Scutellum* (*S.*) sp. found in the Schoolcraft dolomite in Michigan. The species is probably unnamed.

To date, the divisions of the Amabel formation (Fig. 1) in Manitoulin Island and the Bruce Peninsula have not been traced into Michigan as distinct lithologic entities. If quarrying should expose bioherms in the Engadine, undoubtedly the fauna would be discovered to contain the same species as those in bioherms within the Amabel formation to the east and the several units of the Racine dolomite to the southwest. The *Bumastus ioxus* fauna, which occurs in both the type Racine in Wisconsin and the Eramosa member in Ontario, probably extends through the middle of the Engadine dolomite in northern Michigan.

The *Megalomus canadensis* zone extends over a large area. It is known in the upper part of the Engadine in Michigan (Eu), the Guelph dolomite in Wisconsin (GW), the Port Byron limestone in Illinois (PB), the Guelph dolomite in southern Ontario and western New York (GON) and in northern Ohio (GOh), and the Peebles dolomite in southern Ohio (P). Well samples show that the Engadine dolomite in Michigan continued in the subsurface from the Northern Peninsula into the southern part of the state, whereas older Niagaran formations did not (Figs. 3-4). In central Michigan, the Engadine thins to less than 100 feet. At this place, most, if not all, of the formation consists of Guelph age dolomites. The important species of this zone and their distribution are:

Megalomus canadensis Hall - PB, GW, Eu, GON GOh, P.
Monomorella prisca Billings - PB, ?GW, GON, GOh.
Trimerella grandis Billings - GW, Eu, GON, GOh.
T. ohioensis Meek - PB, GON, GOh, P.
Phragmoceras "*parvum*" - GW, GON.
Pycnostylus elegans Whiteaves - PB, GON.
P. guelphensis Whiteaves - PB, GON.

Phragmoceras parvum Hall & Whitfield was originally described from the Cedarville dolomite. The type (as illustrated by Foerste, 1929, pl. 25, fig. 2) and other specimens from the Cedarville dolomite (shown by Foerste in his pl. 50, figs. 5A and B) differ from such Guelph forms as those in New York identified as *P. parvum* by Clarke and Ruedemann (1903, pl. 21, figs. 1-8). These New York cephalopods have living chambers that are longer, less expanded at the aperture, and more convex ventrally than the Cedarville specimens. These differences suggest that many paleontologists have not discriminated closely enough in identifying fossils. At least some of the entrenched reports of *P. parvum* refer to *P. ontarioense* Foerste, described from Guelph cephalopods at Hespeler, Ontario.

Another difficulty in using Guelph fossil lists for correlation is the marked differences between reef and inter-reef assemblages. Certain exposures offer the opportunity to collect and study the two kinds of assemblages in strata that were contemporaneous. Most outcrops do not.

Pointe aux Chenes shale and St. Ignace dolomite. — By their strong similarities in lithology and stratigraphic position, the Pointe aux Chenes shale and the overlying St. Ignace dolomite in the Northern Peninsula can be correlated with the Camillus shale and overlying Akron dolomite in the southwestern part of the Bruce Peninsula.

The Camillus shale has a fauna like that in the Bertie waterlime. The relationship between the Pointe aux Chenes in northern Michigan and the Bertie in western New York is further established by the common peculiar fauna:

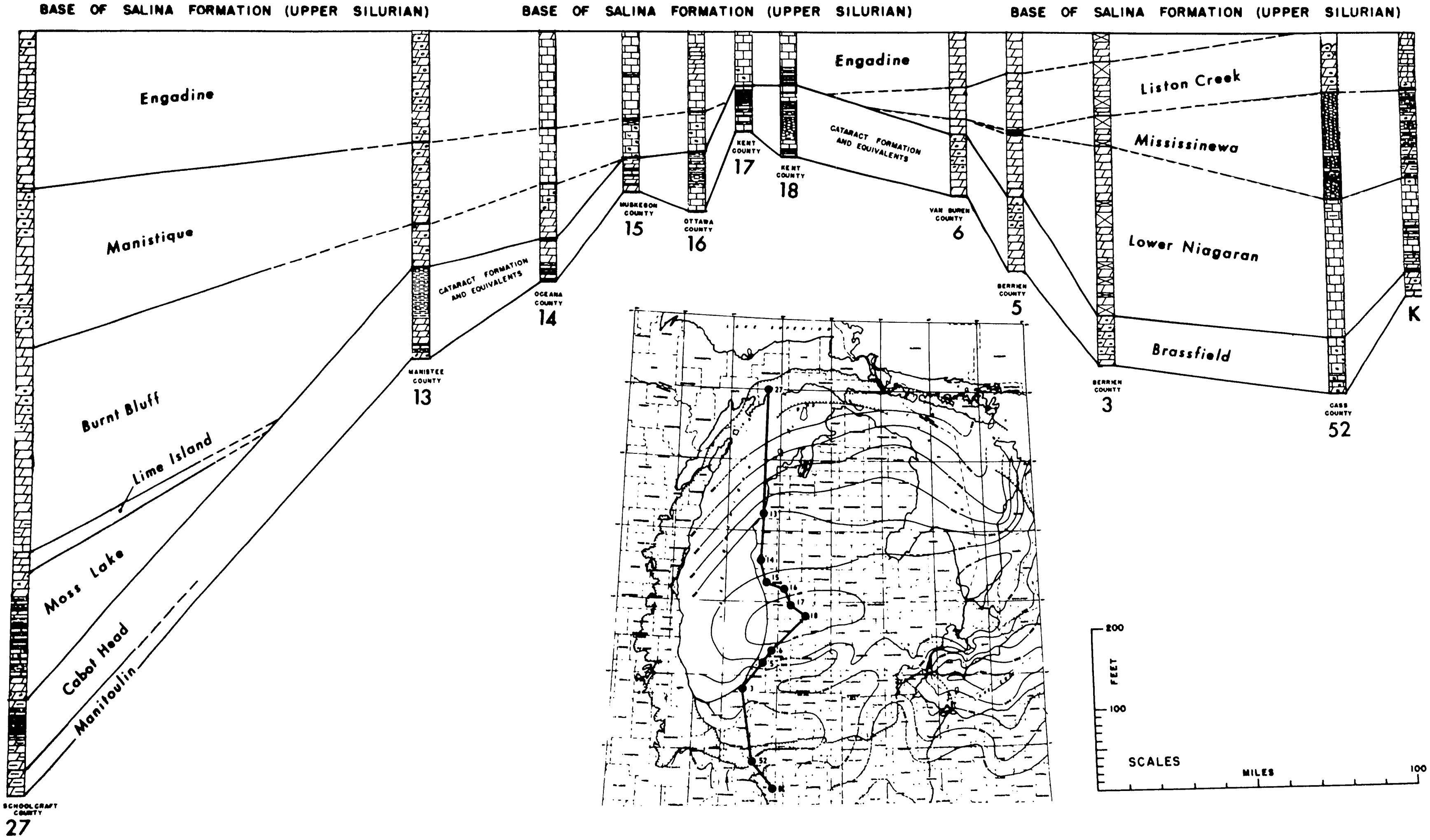
Medusaegraptus gramminiformis (Pohlman)
Orbiculoidea bertiensis Ruedemann
Leperditia scalaris (Jones)

To these, Alling and Briggs (1961, Table 2) add:

Cleidophorus salinensis (Ruedemann)
Lingula semina Ruedemann

The St. Ignace dolomite and Akron dolomite share the coral *Cyathophyllum hydraulicum* (Simpson).

From his study of samples of Salina strata from deep wells, Landes (1945) has suggested that the outcrops of Pointe aux Chenes shale represent unit G in the subsurface of the Michigan Basin, and the formation probably includes units C and E in its unexposed lower part. The St. Ignace dolomite he placed in the lower part of unit H, the uppermost Silurian unit in his terminology, which he called "Bass Island


BASE OF SALINA FORMATION (UPPER SILURIAN)
BASE OF SALINA FORMATION (UPPER SILURIAN)
BASE OF SALINA FORMATION (UPPER SILURIAN)
Engadine
Manistique
Burnt Bluff
Lime Island
Moss Lake
Cabot Head
Manitoulin
CATARACT FORMATION AND EQUIVALENTS
Engadine
CATARACT FORMATION AND EQUIVALENTS
Liston Creek
Mississinewa
Lower Niagaran
Brassfield
SCHOOLCRAFT COUNTY
27
MANISTEE COUNTY
13
OCEANA COUNTY
14
MUSKEGON COUNTY
15
OTTAWA COUNTY
16
KENT COUNTY
17
KENT COUNTY
18
VAN BUREN COUNTY
6
BERRIEN COUNTY
5
BERRIEN COUNTY
3
CASS COUNTY
52
K
27
13
14
15
16
17
18
6
5
3
52
K
200
FEET
100
SCALES
MILES
100

dolomite.'' Because exposed beds of the St. Ignace contain gashes and hopper-shaped cavities presumably recording the former presence of evaporite crystals, we infer a closer association with the Salina than with the typical Bass Islands strata.

Greenfield dolomite and Tymochtee shale. — In tracing the subsurface succession of Salina strata in the Michigan Basin, Landes (1945) stated that "the shales and dolomites of units C, E, and G may correlate with the Tymochtee beds of the surface." The remaining carbonate unit below is A, which necessarily would correlate with the Greenfield dolomite. In this interpretation, the Greenfield is older than the Pointe aux Chenes shale of Northern Michigan, and the following are equivalents: Tymochtee = Pointe aux Chenes = Camillus = Bertie.

Bass Islands group. — The Put-in-Bay and Raisin River dolomites have definitely related faunas. In both formations, *Whitfieldella prosseri* Grabau, *Goniophora dubia* Hall, and *Pterinea lanii* Grabau are well represented. The Put-in-Bay dolomite of Ohio and presumed Put-in-Bay strata of Michigan contain two subspecies of the eurypterid *Erieopterus microphthalmus microphthalmus* (Hall) of the Manlius limestone of New York, according to Stumm and Kjellesvig-Waering (1962, pp. 195-204). They (1962, p. 198) also report the occurrence of the brachiopod *Howellella vanuxemi* (Hall) in association with *Erieopterus microphthalmus turgidus* Stumm & Kjellesvig-Waering in the Put-in-Bay dolomite in Michigan. This brachiopod was originally described from the Manlius limestone, a formation that is younger than strata of the Salina group in New York.

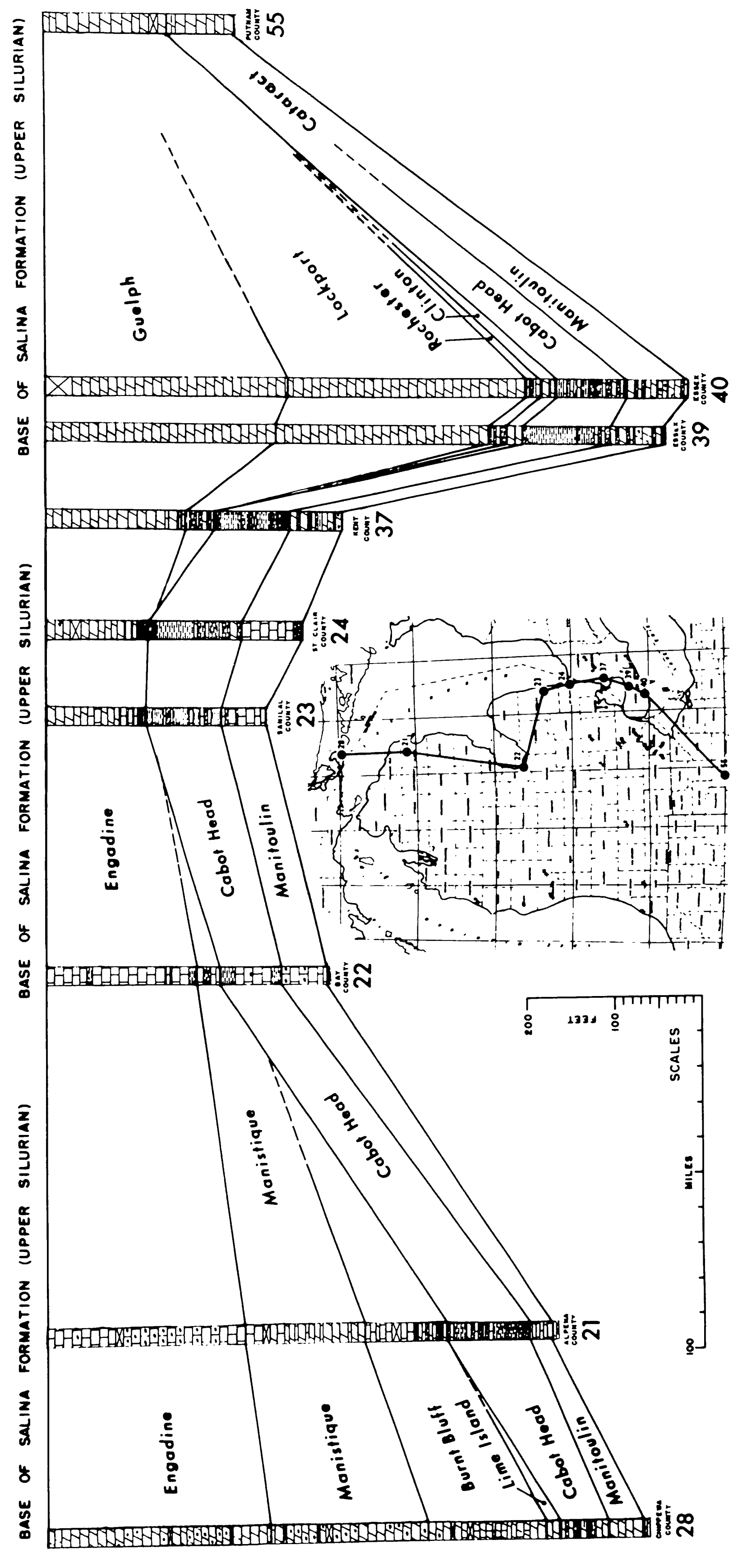
Difficulties in correlating with Niagaran strata to the south. — Stratigraphy discloses some ludicrous anomalies. As an example, we can reasonably and reliably correlate the Hendricks dolomite of Michigan with the Silurian beds of Southhampton Island, 1350 miles to the north, by the occurrence of the large and distinctive ostracod *Dihogmochilina latimarginata* and with the Offley Island formation of North Greenland, more than 2500 miles from Michigan, by the ornamented fan-tailed trilobite *Scutellum magnificum;* but we cannot venture even a logical guess as to which, if any, strata in northern Indiana are correlatives of the Hendricks.

So little has been made known about the so-called Lower Niagaran rocks in northern Indiana, that their age and equivalents remain very much in doubt. These rocks do not crop out; they have been examined in well cores, where they are superjacent to the Brassfield limestone. The Indiana wells show no shaly strata which can be called Cabot Head. Typical Cabot Head lithology can be followed in outcrops from the Northern Peninsula through the Bruce Peninsula and into southern Ontario, where it grades and interfingers into the sandy Power Glen formation. Subsurface, it can be traced to the middle of the Southern Peninsula, southernmost Ontario, and northwestern Ohio (Figs. 3-4). That the Brassfield in northern Indiana wells is equivalent to all of the Cataract is just a presumption.

Figure 3. Cross section of Lower and Middle Silurian strata from Manistique, Michigan, to Kokomo, Indiana. Datum: top of Niagaran. From the Chippewa Sea at the north and from the Miami Basin at the south, lower Niagaran formations pinch out against the Mid- Michigan Ridge. Only the Engadine dolomite of upper Niagaran age crossed over the Ridge. The Mid-Michigan Ridge evidently developed after Cataract time, inasmuch as the Moss Lake is the first formation which is confined to the Chippewa Sea and does not pass across the Ridge. In Indiana, the rise of the Ridge can be dated as post-Brassfield. The wells shown in the section are:

27. Schoolcraft Developmental Syndicate No. 2, sec 31, T41N, R13W, Schoolcraft County, Michigan (Supplemented with additional information from nearby outcrops).
13. Ruggles & Rademaker No. 24, sec 12, T21N, R17W, Manistee County, Michigan.
14. Oceana Petroleum Co., Vanderwaal No. 1, sec 33, T14N, R17W, Oceana County, Michigan.
15. Muskegon Oil Corp., Heinz No. 5, sec 8, T10N, R16W, Muskegon County, Michigan.
16. Michigan Petroleum, Charles E. Moe No. 1, sec 6, T9N, R13W, Ottawa County, Michigan.
17. Producers Committee, George Riddering No. 1, sec 30, T7N, R17W, Kent County, Michigan.
18. Smith Petroleum Co., Ralph Sherk et al. No. 1, sec 21, T5N, R10W, Kent County, Michigan.
6. Michi-Cal Oil Corp., William Piper No. 1, sec 36, T1S, R16W, Van Buren County, Michigan.
5. John Warman, Fee No. 1, sec 34, T3S, R17W, Berrien County, Michigan.
3. Alfred Violette, C. K. Warren No. 1, sec 8, T8S, R20W, Berrien County, Michigan.
52. Eastman, Schaeffer No. 1, sec 11, T28N, R1W, Cass County, Indiana.
K. Indiana Geological Survey No. 72, Markland Avenue Quarry, Kokomo, sec 36, T24N, R3E, Howard County, Indiana. (Data from R. H. Shaver, 1961, p. 10).

Data from G. V. Cohee (1948), except as noted.


BASE OF SALINA FORMATION (UPPER SILURIAN)
Engadine
Manistique
Burnt Bluff
Lime Island
Cabot Head
Manitoulin
CHIPPEWA COUNTY
28
ALPENA COUNTY
21
BASE OF SALINA FORMATION (UPPER SILURIAN)
Manistique
Cabot Head
BAY COUNTY
22
Engadine
Cabot Head
Manitoulin
SANILAC COUNTY
23
ST CLAIR COUNTY
24
BASE OF SALINA FORMATION (UPPER SILURIAN)
KENT COUNTY
37
ESSEX COUNTY
39
ESSEX COUNTY
40
Guelph
Lockport
Rochester
Clinton
Cabot Head
Manitoulin
Cataract
PUTNAM COUNTY
55
28
21
22
23
24
37
39
40
55
SCALES
MILES
100
FEET
200
100

There is no evidence to counter Shaver's suggestion (1961, Fig. 1) that these strata are Clinton in age, but we can only repeat his terminology that they are (p. 15) "pre-Mississinewa-post-Brassfield rocks." Shaver (pp. 10-15) thinks that in the Kokomo core (see our Fig. 3, K) the lowermost 39-foot dolomitic unit is older than Osgood, the overlying 31-foot mottled limestone represents the Osgood formation and Laurel limestone, the next 10-foot dark shaly limestone equals the Waldron shale, and the uppermost 43-foot dense limestone unit the Louisville limestone.

We have doubts that the Waldron shale and Louisville limestone correspond to rocks this low in the northern Indiana section. Tentatively, we endorse Esarey and Bieberman's correlation (1948) of the calcareous silty Waldron "shale" in southern Indiana with the calcareous arenaceous Mississinewa "shale" in northern Indiana. Neither formation appears to have continuity with the rocks in northern Michigan (Fig. 3).

The marked associations and relationships of corals in the highly fossiliferous Louisville limestone and Liston Creek limestone impress us, as they have others. As pointed out above, the sea of Manistique deposition can be established as far south as Iowa. The absence of *Huronia*, *Stokesoceras*, and other large related cephalopods in the Louisville, however, argue against a connection (at least of any appreciable duration) between Iowa and southern Indiana. In our opinion, the Louisville has a southern fauna distinct from the northern fauna of the Manistique, although they may have been contemporaneous.

Until the rock sequence in northern Indiana and the southern margin of Michigan is better understood, we would be very reluctant to abandon the term Huntington dolomite. The absence of *Megalomus canadensis* in the Huntington leads us to postulate that the uppermost strata of the Niagaran succession in northern Indiana may be older than the upper part of the Engadine dolomite, which contains this pelecypod and extends subsurface into southern Michigan (Fig. 3). We are tempted to review some of the fossil lists to show the reports of typically Racine and Guelph species in the Huntington dolomite, but this would involve close discrimination between lists and faunas and between reports and occurrences. Paleontologically, little can be stated except that the Niagaran faunas of Indiana bear certain resemblances to the Niagaran faunas of Michigan but do not constitute their direct extensions.

PALEOGEOGRAPHY

Late Ordovician. — During this interval, the area uplifted by the Taconic orogeny provided enormous quantities of clastic debris. Gradually, this was spread out to the westward as the Queenston Delta, grading from conglomerates and breccias to sandstones to shales, and finally interfingering with marine strata in central Ontario. Despite the massive bulk of the Queenston deposits, the sea was widespread over North America during Richmond time. The orogeny was locally intense in the New England region, but did not elevate the shallow continental sea covering the Midwest. The westward migration of the shoreline seems to have been the result of filling by clastics.

Figure 4. Cross section of Lower and Middle Silurian strata from Drummond Island, Michigan, to Putnam County, Ohio, showing the deposits of the Chippewa Sea at the north and the Erie Basin at the south. Datum: top of Niagaran. From the disposition of the formations, the Mid-Michigan Ridge can be dated as post-Cataract. The inset map (modified from Cohee, 1948, Sheet 2, Fig. 9) shows 100-foot isopachs of Niagaran strata and the course of the section. The wells shown are:

28. F. D. Barton, et al., Kreetan Co., sec 17, T41N, R7E, Drummond Island, Chippewa Co., Michigan. (Supplemented with additional information from nearby outcrops).
21. C. W. Teater, Nevins No. 1, sec 18, T32N, R6E, Alpena County, Michigan.
22. Gulf Refining Co., William Bateson No. 1, sec 2, T14N, R4E, Bay County, Michigan.
23. Shell Oil Co., J. Burch No. 1, sec 15, T10N, R15 E, Sanilac County, Michigan.
24. Mueller Brass Co., William Van Antwerp No. 1, sec 9, T6N, R17E, St. Clair County, Michigan.
37. Union Gas & Imperial Oil, Chatham No. 1, Lot 1, Con. 14, Chatham Twp., Kent County, Ontario.
39. E. Coste, M. J. Keck (Rosslyn No. 1), Lot 5, Con. 10, Tilbury W. Twp., Essex County, Ontario.
40. Morley & Ferris No. 15, Lot 8, Con. 1, Gosfield South Twp., Essex County, Ontario.
55. Ohio Oil Co., Louis Barlage No. 1, sec 29, T2N, R7E, Putnam County, Ohio.

Data from G. V. Cohee (1948), except as noted.

Early Silurian. — At the beginning of Silurian time, sand from the Queenston Delta was swept westward over the Queenston shales, in Ontario extending nearly to the base of the Bruce Peninsula. This constituted the Whirlpool sandstone, a relatively thin formation.

After this short-lived influx of sand from the east, the continental sea, still widespread, deepened slightly and extended its boundaries. In it were deposited the Manitoulin dolomite and the Cabot Head shale, formations of the Cataract group, and their equivalents, such as the Brassfield and Kankakee. The uniform depth of the continental sea produced the remarkably constant thickness of the Manitoulin dolomite over an extensive area. This formation has the same lithology in northern Michigan, Manitoulin Island, Ontario, and New York, as seen in exposures, and can be readily recognized in well cuttings and cores throughout Michigan and Ontario. To the south the dolomite grades into limestone, and becomes the Brassfield.

The next sequence represents numerous fluctuations near sea level, still over a broad area. These resulted in numerous thin bands of dolomite, shale, anhydrite, and limestone, the Cabot Head shale. The extraordinary feature of this formation is its extent, considering the repeated production of evaporites. Like the underlying Manitoulin dolomite, it can be recognized in exposures and wells throughout Michigan, Ontario, and westernmost New York, wherever Silurian rocks have not been eroded away. In Wisconsin, it may be represented by dolomite, the middle part of the Mayville.

Near the close of Early Silurian time, the westward migration of the strand line in western New York and southeastern Ontario resulted from uplift in the east. Sediments from the higher land repeated the Queenston conditions. This time, the nearshore sandy part of the delta was made up largely of the Grimsby sandstone. The alternating sands and shales which interfinger with the Cabot Head were called the "Marine Grimsby" by Fisher (1954) and the Power Glen formation by Bolton (1957). The overlying Thorold sandstone is regarded by some as Lower Silurian (Williams, 1919; Sanford, 1936), by others as Middle Silurian (Bolton, 1953; 1957), and by Fisher (1954) as both. Bolton, Liberty, et al. regard Thorold as basal Clinton.

The uppermost Alexandrian (or Medinan) in Michigan is the Moss Lake formation. It more or less repeats the Manitoulin-Cabot Head sequence, with dolomite layers more numerous in the lower part and shale and anhydrite layers more numerous in the upper part. To date, the Moss Lake formation has only been recognized in the Northern Peninsula of Michigan. It is thickest in the region of Manistique, Michigan, and thins eastward. It is absent in the sections in Chippewa County, and cannot be identified in wells drilled in the Southern Peninsula. It is the first Silurian formation in the Northern Peninsula to be restricted by an elevation to the south and east. By the beginning of Middle Silurian sedimentation, this elevation had become more pronounced. The Moss Lake formation, therefore, presages the division of Niagaran sediments into basins.

Middle Silurian. — During Niagaran time, the Michigan-Ohio-Indiana-Illinois-Wisconsin region featured a conspicuous ridge across the Southern Peninsula of Michigan, which separated deposits in the north from those in the south (Fig. 2). We name it the Mid-Michigan Ridge. At that time, northeastern Wisconsin, the Northern Peninsula of Michigan, Manitoulin Island, and the northern part of the Bruce Peninsula formed the southern part of a large sea that extended northwest to the Interlake area of Manitoba and northeast to Hudson Bay. In naming the Niagaran basins of deposition after the Indian tribes that inhabited the areas during historic times, we have elected to call this northern basin the Chippewa Sea, a name suggested to us several years ago by Mr. Gilbert O. Raasch.

To the southeast of the Mid-Michigan Ridge lay the Erie Basin, the western extension of a long trough from New York. To the south lay the Miami Basin in Indiana, and to the southwest the Potawatami Trough* in Illinois. The Miami and Erie Basins were separated, for much of Niagaran time, by a northern extension of the Cincinnati Arch. The Miami Basin and Potawatami Trough, on the other hand, appear to have been confluent, although circulation between them was probably restricted by the establishment and growth of numerous reefs.

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*According to Samuel G. Drake ("The Aborginal Races of North America," 1880, p. 637), Chief Keewagoushkum claimed, "The Chippewas of Wisconsin and northern Michigan, the Pottawattomies of Illinois, and the Ottawas of central Michigan were, originally, but one nation. We separated from each other near Michilimackinac. We were related by ties of blood, language, and interest; but in the course of a long time, these things have been forgotten..." We report this as a historical note, intending no allegory.

The nature of Niagaran paleogeography in northern Illinois and southeastern Wisconsin is particularly difficult to decipher. Between the deposition of uppermost Chester strata and that of basal Pennsylvania (Payne, 1940), the LaSalle Anticline was formed, and all of the Silurian deposits in north-central Illinois were removed by erosion (Fig. 2). Hence, the Silurian outcrops of northeastern Illinois are completely cut off from those of northwestern Illinois. In the belt of erosion, Pennsylvanian strata were laid down upon Ordovician. Undoubtedly, the very late Mississippian or very early Pennsylvanian erosion also removed some of the Silurian beds from southern Wisconsin, beveling the section. From the isopach pattern (Fig. 2) we can only speculate that the Niagaran 400-foot isopach originally extended into Wisconsin, completing the encirclement of both the Miami Basin and the deeper Potawatami Trough. From paleontologic evidence, we know that the Chippewa Sea at one time reached as far southwestward as Iowa, crossing over the southern Wisconsin area, where the Mississippian-Pennsylvanian erosion very effectively erased the rocks necessary to trace the precise channel.

The so-called positive areas were not elevated equally during Middle Silurian. The clastic nature of Silurian deposits in southern Illinois, as summarized by Lowenstam (1949), indicates that the Ozark Uplift supplied quantities of detritus. In contrast, the Canadian Shield, the Cincinnati Arch, and the Wisconsin Uplift were relatively low. The invasion of the Chippewa Sea into Manitoba and the Hudson Bay region demonstrates the low elevation of the Canadian Shield at the time. The entire Silurian sequence around the Cincinnati Arch is very thin (Fig. 2), because this area was incapable of supplying much sediment. The low-clastic ratio of beds bordering the Wisconsin Uplift testifies to the low elevation of that area also. An outlier at Limestone Mountain in the Northern Peninsula of Michigan (Fig. 2) shows that the Chippewa Sea extended westward well beyond the present outcrop. Indeed, the Niagaran seas may have covered most of Wisconsin.

Again, we wish to emphasize that the dominant physiographic feature of the region was the Mid-Michigan Ridge. It is wrong to consider (as have many writers) that Michigan was the Michigan Basin during Middle Silurian time. Only during the latter part of Guelph time, near the close of the Niagaran, did the Mid-Michigan Ridge subside to receive marine deposits (Guelph) upon its surface.

Late Silurian. — The Mid-Michigan Ridge further subsided, and lost its identity during Salina time; northern Illinois apparently rose above sea level, since no Salina strata are present; and slight rise in the other areas bordering Michigan, locally abetted by Niagaran reefs, formed a barrier around the Michigan Basin. In it were deposited hundreds of feet of salt, anhydrite, limestone, and a few red beds. In the center of the Michigan Basin 2500 feet of evaporites were laid down. As would be expected, the margins of the basin received mostly carbonates; these include the Waubakee limestone of Wisconsin and the Greenfield dolomite of northern Ohio. Near shore, clastics predominated. Temporary slight elevations extended the zone of clastics toward the center of the basin, accounting for the Pointe aux Chenes shale below the St. Ignace dolomite in northern Michigan, and the Camillus shale below the Akron dolomite in the Bruce Peninsula, southwestern Ontario, and New York.

In the Northern Peninsula of Michigan, blocks of the Pointe aux Chenes shale, the overlying St. Ignace dolomite, and Devonian strata as young as Detroit River, locally form thick masses of breccia, called the Mackinac breccia, in which blocks of dolomite and shale have been jumbled and locally cemented. St. Anthony's Rock and Castle Rock at St. Ignace are outstanding examples. At other localities, the beds of Pointe aux Chenes and St. Ignace are distorted and faulted to a lesser degree. The evidence for collapse is striking, and the logical explanation for collapse is solution of underlying salt beds. See Landes (1945).

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