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THE MONROE FORMATION OF SOUTHERN MICHIGAN AND ADJOINING REGIONS

BY

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LETTER OF TRANSMITTAL.

To the Honorable the Board of Geological and Biological Survey of the State of Michigan:

Gov. Fred M. Warner, President.
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Hon. L. L. Wright, Secretary.

Gentlemen—I beg to present herewith for printing as a part of the report of the Board of Geological and Biological Survey for 1909, Publication 2, Geological Series 1, being a monograph by Professors A. W. Grabau and W. H. Sherzer on the Monroe Formation of Southern Michigan and adjoining regions.

Very respectfully,

R. C. ALLEN,

Director.

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BY W. H. SHERZER.

PIONEER STUDIES UPON THE MONROE FORMATION.

The scientific study of the limestones about the western end of Lake Erie was begun almost simultaneously in 1837 by the Ohio and Michigan Geological Surveys, under the direction of Lieutenant W. W. Mather and Dr. Douglass Houghton. Previous to this time many outcrops of these beds had been located by the early settlers and shallow quarries opened from which were obtained building stone and material for lime. The outcrop of the Sylvania sand-rock, north of the Raisin river in Monroe county, Michigan, was known and samples of it had been successfully tested for a high grade glass. The presence of brine in these limestones and in the overlying drift had been discovered by the Indians and early settlers and salt was crudely manufactured at a few localities.

In his first geological report, dated January 22, 1838, Houghton describes these limestones under the heading "grey limestone," which he traced in outcrop from the rapids of the Maumee to that of the Raisin, and referred them "without doubt" to the "mountain limestone" (Carboniferous) of European geologists.[1] He did not separate the dolomitic limestones of the eastern part of this belt from the much purer and geologically younger limestones of the western part. The presence of the Sylvania sandrock was noted and its origin suggested from the adjacent silicious limestones seen along the Raisin river. More detailed study of the strata in Monroe and Wayne counties, Michigan, was assigned to the assistant geologist, Bela Hubbard, and reported upon a year later.[2] The

[1]Report of the State Geologist, 1838. Senate document No. 16; p. 7: House document No. 24, p. 281.

[2]Second Annual Report of the State Geologist, 1839. Senate document No. 12, p. 354; House document No. 23, p. 470.

outcrops and quarries were visited and briefly described. An eastern and a western belt were recognized, separated by the silicious strata and differing both lithologically and palaeontologically, but no attempt was made thus early to ascertain the approximate age of either belt by means of the fossils. The strata were found to dip towards the northwest, or northwest by north, and the dip was stated to equal about 5°. The amount of this dip was afterwards reduced to 15 feet to the mile, with a variation of 10 to 20 feet.[3] The mineral contents of the beds and their occasional oölitic and veined character were noted. Further studies by Hubbard led him to conclude that these limestones lie beneath the "black strata," now known as the Antrim, or upper division of the Devonian, and above the Cincinnati blue limestones and shales, the Cincinnatian division of the Ordovician, and that they are the geological equivalent of the so-called "Cliff limestone;" the Clinton, Niagara and Onondaga of Indiana and Ohio.[4]

A geological reconnaissance of the rock strata of northwestern Ohio had been made by Dr. J. L. Riddell, who was one of the special committee commissioned by the Ohio legislature to report upon a method of obtaining a complete geological survey of that state. His report bears date of January 12, 1837, and alludes to the calcareous sandstones and the limestones of the Maumee valley. The more detailed study of the region was assigned to assistant geologist Prof. C. Briggs, Jr., the work being done during the season of 1838 and reported upon briefly in the Second Annual Report of the Geological Survey of Ohio, 1838, p. 109. The limestones in the bed of the Maumee river, for several miles above Perrysburg, were examined, and their silicious nature and passage into a calciferous sandrock were noted. The location of a number of outcrops and quarries in Wood county is given (p. 113), based upon his own observations and those of the county surveyor. A mention is made of *marble,* this probably being the streaked and mottled dolomite known in Monroe county, Michigan, to the north. The limestones encountered in Crawford county, to the southeast, he placed higher in the geological series than those studied in Wood

[3]Fourth Annual Report of the State Geologist, 1841. Joint document No. 11, p. 571.

[4]Third Annual Report of the State Geologist, 1840. Senate document No. 7, p. 83. House document No. 7, p. 124. According to the later work of Orton this "Cliff limestone" consisted mainly of the Clinton and Niagara formations, but in Highland county, at least, included also the "Lower Helderberg." Geol. Surv. of Ohio. Report of Progress in 1870; 1871, p. 307.

county. The chief interest at this time, however, centered in the economic importance of the limestones, rather than their geological age, and the uses suggested were for buildings, chimneys, manufacture of lime, as a soil fertilizer and in road construction.

While this work was being prosecuted in Michigan and Ohio, similar reconnaissance work was being done in Indiana by Dr. D. D. Owen, his first report being published in 1838 and the second in 1839. The latter volume contains a summary of the geology of the state (p. 39) in which are given the approximate limits of the "bituminous coal formation," and the remaining rocks of the state are referred to the sub-carboniferous, which was said to correspond, in some respects to the "mountain limestones" of European geologists. The financial depression of the late 30's brought the geological work to a standstill in Michigan, Ohio and Indiana, and for the two decades there was practically no systematic work attempted in this region.

SUBSEQUENT WORK OF THE STATE SURVEYS.

Geological work was first resumed in Michigan with the organization of the Second Geological Survey in 1859, under the directorship of Prof. Alexander Winchell, but was quickly interrupted by the outbreak of the Civil War. In the meantime the New York series, with which the Monroe strata are to be correlated, was being carefully studied by W. W. Mather, Ebenezer Emmons, Lardner Vanuxem, and James Hall, and the contained fossils described and figured.[5] In a western trip, taken in 1841 for the purpose of identifying the rock strata of the middle states with those of New York, Hall referred certain limestones in the vicinity of Mackinac to the Onondaga Salt Group and Water-lime.[6] In his geological map published in 1853, Jules Marcou designated all the formations about the western end of Lake Erie as Devonian. In the light of the important work of the New York geologists, Winchell re-studied the strata of this region but without discovering their true geological equivalency with the eastern series. The dolomitic limestones, with the intercalated sandrock, were referred to the "Upper Helderberg" (Devonian), with isolated patches of the Onondaga

[5]Natural History of New York. Pt. III, Geology of the Third Geological District, 1842. Pt. IV, Geology of the Fourth Geological District, 1843. Pt. VI, Palaeontology, Vol. 3, 1859.

[6]Geology of New York. Pt. IV, 1843, p. 512. See also Geology of the Lake Superior Land District, Foster & Whitney, Pt. II, 1851, p. 162.

Salt Group at Ida, Ottawa Lake and Monroe, in Monroe county. The identification of the latter formation was based upon the occurrence of the "characteristic, acicular crystals" and a brownish, argillaceous limestone suggestive of "water-limestone." The thickness as assigned to this formation in Monroe county was 24 feet; consisting of 10 feet of chocolate colored limestone, and 14 feet of a fine, ash colored, argillaceous limestone carrying the acicular crystals (p. 140 of Biennial Rep. of Progress, 1861).

A geological map of Canada and the adjacent portion of the United States was published in 1865 by Sir William E. Logan, Director of the Geological Survey of Canada.[7] The formations in the southwestern portion of Ontario and about the western end of Lake Erie were designated as Devonian (Corniferous and Oriskany), while the broad belt of dolomitic limestone reaching from the southwestern portion of the lake, southward and southwestward across Ohio and into Indiana, forming the crest of the Cincinnati anticlinal arch, was referred to the Niagara. This was bordered on the east and west by a narrow strip of "Onondaga," but there was no recognition of the Lower Helderberg. One year before the publication of Logan's map, Prof. E. J. Chapman published a crude sketch showing the geology of the Lake Erie region.[8] A narrow strip of Hamilton borders the lake upon the south and extends southwestward across northwestern Ohio. Between this and the Corniferous limestone indicated at the extreme western end of Lake Erie and southwestern Ontario, there extend to the southwestward narrow strips of Corniferous (Onondaga), Onondaga Salt Group (Salina), Guelph, and apparently Portage formations. Just north of Long Point island, upon the Canadian side, there is indicated an undefined area of "Eurypterus formation or Lower Helderberg Group," in Bertie and Cayuga townships, Ontario. The formation here consists of thin-bedded, greyish dolomites, not exceeding 50 feet in thickness, interstratified toward the base with brownish shales and having a brecciated bed of dolomitic fragments. Concerning this formation the author remarks: "With us, in Western Canada, it might be called the 'Bertie or Cayuga dolomite,' as its only known exposures are in those townships or a still better term would be the *Eurypterus* formation, so named from

[7]Geological Survey of Canada. Report of Progress from its Commencement to 1863, Montreal, 1863.

[8]A Popular and Practical Exposition of the Minerals and Geology of Canada. Toronto, 1864, p. 202.

its principal and characteristic fossil" (p. 190). These beds rest upon 200 to 300 feet of thin-bedded dolomites, usually of a yellowish color, with greenish shale and occasional lenticular masses of gypsum (p. 188), referred to the "Onondaga or Gypsiferous Group." These observations of Chapman are of much interest and importance in the discussion of the Monroe formation, since we have here the first recognition in the Lake Erie region of one of the important members of the series. Although the author refers these dolomitic beds to the Lower Helderberg, the presence of the Eurypterus fauna shows unmistakably that they are the equivalents of the New York Waterlime.

The Ohio survey was not revived until 1869, under the directorship of Prof. J. S. Newberry, and in that year he recognized in the limestones of Put-in-Bay, North and Middle Bass islands, of Lake Erie, the characteristic Waterlime fossils: *Eurypterus remipes* (*eriensis*), *Leperditia alta, Spirifer plicatus* (*ohioensis*), and *Avicula* (*Pterinea*) *rugosa* (*lanii*).[9] In the earlier reports of the survey these beds were included in the undifferentiated "Cliff limestone." Further studies established the presence of this formation over a considerable area in the interior of the state. The presence of gypsum in the vicinity of Sandusky led to the correlation of subjacent beds with the Onondaga Salt Group (Salina). The map forming the frontispiece of the volume, bearing the date 1870, presents for the first time the formations about the western end of Lake Erie in their approximate relations and based upon correct interpretations. The Waterlime and Salina are united and form a broad belt, two to three counties wide, extending southwestward across northwestern Ohio into Indiana and sending a gradually thinning and narrowing strip southward almost to the Ohio river. The area is bordered by a narrow strip of sandrock, believed then to represent the Oriskany, but since termed the Sylvania and known to be intercalated in the dolomites referred to the Waterlime. In the Report of Progress in 1870, published in 1871, the assistant geologists, Orton and Gilbert, recorded their detailed studies upon these beds in Highland and Lucas counties. In Highland county the maximum thickness of the formation is given by Orton as 100 feet (the Greenfield dolomite of the present report), there being no recognition of the Onondaga. The rock

[9]Ohio Geological Survey for 1869; 1871, p. 16. For the synonym and correct identification of these see Chapter III.

is mainly dolomitic, drab in color and arranged in courses from 4 to 8 inches in thickness, rarely exceeding 14 inches. Concretions from one to three inches in diameter are noted, arranged in a layer, and numerous stylolites occur throughout the series. Nodules of zinc blend, shot-like grains of asphatum and fossiliferous bands of chert are common. In one 15-foot section the rock is friable and crumbly, and known locally as *marl*. An analysis of this showed 1.39% of calcium phosphate, rendering it valuable as a soil fertilizer. The dolomite is generally quite barren of fossils but occasional layers yield numerous specimens in the form of casts and molds. Similarly to that seen in the lake region the rock strata are often much disturbed and shattered, rendering them useless for flagging and building purposes. Near Rockville there were seen some 20 feet of thin but even-bedded rock, ringing under the blow of a hammer and almost destitute of fossils but showing sun-cracks and ripple-marks. Orton concluded that "it can therefore be confidently asserted that much of the Helderberg limestone grew in water so shallow that portions of its surface were from time to time left bare by the retreating tide" (p. 292, Rep. of Progress in 1870). In Lucas county, Gilbert found strata of the same geological age in the bed of the Maumee from Waterville to Maumee City and in Swan and Ten-Mile creeks. West of the village of Sylvania some 76 feet of the formation were exposed along the highway, consisting of thin-bedded, gray and drab limestones (dolomites?), massive buff limestone, partially brecciated and with chert nodules, and a gray, shaly limestone. The rock was said to show no decided dip but numerous local flexures.

The Waterlime age of the dolomites in Michigan, lying at the western end of Lake Erie, was announced in 1871 by Winchell.[10] In company with Newberry he had visited exposures upon Put-in-Bay island when the characteristic fossils were found and 60 feet of strata in Michigan were believed to be of the same geological age. It was then, and has long since remained a matter of surprise that no traces of *Eurypteri,* or related forms, were found in any of the Michigan strata. The present studies have shown that this is because they lie *above* the Eurypterus horizon and it is confidently expected that traces of these forms will be found in the lower beds of the Detroit salt shaft.[11] Winchell's notes were never published

[10]Report on the Progress of the Geological Survey of Michigan, 1871, p. 28.
[11]That this expectation was not realized, is probably due to the scattered character of the fossils, and the comparatively small size of the shaft.

by the state in the form contemplated by him and some of the material appeared in Walling's Atlas of Michigan (published by R. M. & S. T. Tackabury, Detroit, 1873), and in a small volume entitled "Michigan, its Topography, Climate and Geography, 1873." The geological map accompanying the atlas and volume shows a narrow strip of Lower Helderberg, three to four miles wide, following the shore of Lake Erie, with a broad belt of "Corniferous" (Onondaga) to the west and embracing nearly the whole of Monroe county. Small patches of Salina, with marginal strips of "Lower Helderberg" (Monroe) are shown at Ida, Ottawa Lake, Monroe and Brest. The Sylvania sandrock was given a thickness of but 4 feet and included in the Corniferous (p. 40 of atlas). The Lower Helderberg is represented also as forming the extreme tip of the Lower Peninsula of Michigan, Mackinac island, and a narrow strip of coast opposite, in the Upper Peninsula, the latter being bordered upon the west with a narrow strip of Salina. The probable thickness of the Salina, or Onondaga Salt Group, is placed at 50 to 60 feet, exclusive of the bed of rock salt penetrated at Caseville and Alpena. The Lower Helderberg as found to the north was assigned a thickness of about 50 feet and described as a series of chocolate-colored, magnesian limestones, more or less argillaceous, in regular layers 4 to 8 inches in thickness and passing by irregular gradations into an overlying brecciated mass. In the Lake Erie region the strata are characterized as evenly-bedded, rather dark ashen in color, more or less argillaceous and sometimes showing dark seams.

In Ohio detailed studies in a number of counties were made by Orton, Gilbert and N. H. Winchell and reported upon in Volume I, part 1, Ohio Geological Survey, published in 1873. The course of the Waterlime across Sandusky, Seneca, Wyandot and Marion counties was followed by Winchell, mapped and numerous sections given. In Sandusky county the important discovery was made that the so-called *Oriskany* sandstone was overlain by several feet of drab limestone having all the lithologic characters of the Waterlime, but the full significance of this was not appreciated until some years later. Upon Tymochtee creek, in Wyandot county, the beds dip toward the southwest and expose a section about 85 feet thick, which includes a series of shaly strata, making a recognizable horizon to be more fully described in the next chapter. In describing the geology of West Sister island, Lake Erie, Gilbert gives the details of a 90-foot section there exposed, showing the variable characters of the formation (p. 589). This island is located about half-way between Put-in-Bay and the Michigan shore and upon the crest of the Cincinnati anticline. In summarizing the geological structure of the state, Newberry (p. 63) assigns a thickness of 30 to 40 feet to the Salina in the neighborhood of Sandusky, from which locality the formation was believed to rapidly thin out. The term, Lower Helderberg, was contracted to Helderberg and was thought to be represented by the Waterlime with a thickness of 100 feet (p. 135). The magnesian character of the limestones he attributed to the content of magnesia in the hard parts of the organisms from which the dolomitic slime was assumed to have been derived (p. 65). The more cavernous character of the formation he ascribed to the greater solubility of the rock in atmospheric waters (p. 137).

With the resignation of Winchell, in 1871, from the Michigan Geological Survey, the work was continued by the Geological Board and the study of the palaeozoic rocks assigned to Dr. Carl Rominger. The work in the Upper Peninsula was reported upon in Geological Survey of Michigan, Volume I, part 3, 1873, and in the Lower Peninsula in Volume III, 1876. The limestones and dolomites in Monroe and Wayne counties, as well as those in the vicinity of Mackinac, are described as the Helderberg Group and mapped as a single formation. Chapter V of Volume III, is devoted to a detailed description of the strata, in which there is recognized an upper and a lower division, distinguished lithologically and palaeontologically and separated by the Sylvania sandrock, which was accepted as the probable equivalent of Oriskany (p. 29). This was given a thickness of but 8 to 10 feet, and incorrectly correlated with the oölites of Monroe county. The lower division of this Helderberg Group was regarded as the geological equivalent of the Waterlime of the New York series (p. 25), while the upper division, of purer limestone and rich in fossils, was regarded as of Corniferous (Onondaga) age, (Volume I, part 3, p. 25). No definite thickness was assigned to the Waterlime in southeastern Michigan, but it was recognized as exceeding 300 feet, while in the Upper Peninsula the formation was assigned a thickness of 150 feet, and characterized as follows:

"It is composed of a great variety of calcareous, dolomitic, cherty and calcareo-argillaceous rock fragments, mixed and thrown about through the re-cemented rock mass. A great portion of the brecciated material is distinctly recognizable as the fractured beds of the immediately underlying formation, and frequently larger rock masses, composed of a series of successive ledges, which have retained their original position to each other, are scattered through the breccia." (p. 23.) * * * * * * * "Very characteristic for this dolomitic formation, in its whole extension, are tabular leaflets of calc-spar crystals, pervading certain ledges in every direction; seen edgewise the crystals appear in acicular form. In many instances the spar-crystals subsequently have been re-dissolved, and the empty spaces present themselves as narrow slits in the rock." (p. 27).

THE MONROE FORMATION AS DEFINED AND RESTRICTED.

So tenaciously does old Mother Earth hold her secrets that 50 years of careful study, based upon the revelations of hammer and drill, were required to solve the problem of the relative position of the beds making up the Monroe formation. It was recognized by Orton, then State Geologist of Ohio, that the gypsiferous beds of Ottawa county and Put-in-Bay do not rest upon the Niagara but are underlain by several hundred feet of Waterlime, thus correcting the reference of these beds to the Salina, or Onondaga Salt Group.[12] The white sandrock, previously referred to as the Oriskany, was recognized as an intercalated member in the series of dolomites, as suggested by N. H. Winchell, and was named the Sylvania sandstone (p. 19). Between it and the base of the Onondaga there intervene some 200 feet of dolomitic limestone, indistinguishable from that which underlies the formation in northwestern Ohio. The name Lower Helderberg was now made to include all the beds from the top of the Niagara to the base of the Onondaga, was stated to attain a thickness in northern Ohio of 600 feet (p. 16), to thin to the southward and wedge out in southern Ohio and Kentucky. A large scale geological map accompanies the volume, showing the extensive distribution of the formation in northwestern and west central Ohio. Practically the same discussion again appeared in Volume VII of the Survey, 1893, pp. 13-18, with a reduced size map.

[12]Geological Survey of Ohio, Vol. VI, 1888, p. 15.

The extension of these beds into southeastern Michigan, the certainty that the Salina was heavily represented and the difficulty of separating these two formations in well records, made it desirable that a term other than Lower Helderberg be employed to cover the strata intervening between the top of the Niagara and the base of the Devonian. The term "Monroe beds" was used for this series in the early part of 1893, by Dr. A. C. Lane, then assistant geologist under Dr. M. E. Wadsworth,[13] but was not defined until 1895,[14] "as extending from the limestones of the overlying Dundee down to the lowest gypsiferous beds, and to consist mainly of buff dolomites and of calcareous and argillaceous marls, associated with anhydrite and rock salt." The thickness as judged by borings was given as more than 1,200 feet. The beds were stated by Lane to have been deposited in an excessively salt interior sea, extending from New York to eastern Wisconsin, exposed to a hot sun and receiving little accession of fresh water from rivers. Shallow water conditions prevailed in places, particularly in Ohio, where there was a great bar, reef or flat, permitting the formation of ripple-marks and mud-cracks. Over this flat great tidal waves rushed bringing in accessions of sea water to the enclosed sea and forming breccia and conglomerate. In southeastern Michigan three periods of dessication were recognized, the first and greatest of which gave rise to the heavy beds of rock salt, aggregating in thickness some 900 feet; the second preceded the formation of the Sylvania member of the series, marked by gypseous or salty dolomites and above the Sylvania, at the top of the series, a third period of dessication, during which there were deposited dolomites or gypseous marls (p. 28). Under the term "Monroe Group" the name was approved in May, 1903, by the Committee on Geological Names of the U. S. Geological Survey.

In 1898, Grabau proposed the name "Greenfield limestone," from the locality in Highland county, Ohio, for the so-called "bull head" division seen in the neighborhood of Buffalo, New York; it being supposed that the limestones at the two localities were identical.[15] The bed was more fully described two years later and correlated with the Manlius (Cobleskill) of eastern New York, having a thickness of but 7 to 8 feet,[16] and resting upon some 50 feet of

[13]Report State Board Geological Survey of Mich. for 1891 and 1892, p. 66, 1893.
[14]Geol. Surv. of Mich., Vol. V, 1895, Pt. 2, pp. 26, 27, 28.
[15]Science, Vol. VIII, New Series, 1898, p. 800.
[16]Siluro-Devonic Contact in Erie county, New York. Bull. Geol. Soc. of Am., Vol. XI, 1900, p. 350.

Waterlime (Bertie). It is now proposed to use the name "Greenfield dolomite" for the lowermost division of the Monroe, the beds being exposed at Greenfield, Highland county, and at Ballville, Sandusky county, Ohio.

Studies upon the Monroe formation in southeastern Michigan were begun in 1896 by Sherzer, and published in Geological Survey of Michigan, Volume VII, Part 1, 1900, pp. 43-100. The strata were found to have a general northwesterly dip, ranging from 26 to 56 feet to the mile and to attain a thickness of 1,300 to 1,400 feet. The Sylvania sandrock was found to occupy the position in Michigan assigned to it by Orton in Ohio, being well embedded in the series, and its course across Monroe county was mapped. Well records procured showed that the stratum thickens very considerably to the north of the Ohio-Michigan line and that it has a much heavier development than had been supposed by any of the previous surveys. In the Detroit salt shaft the thickness proved to be 117 feet, where it is overlain by 274 feet of Silurian dolomite. At Milan, Royal Oak and Ypsilanti the thickness approaches 300 feet. The most plausible explanation found at that time was that the stratum represented a littoral deposit along the margin of an encroaching, interior sea. The lithological and palaeontological characters of the Monroe beds, based upon these and subsequent observations, will be detailed in the following chapter. The union of the New York Waterlime (Rondout) with the Salina by Darton in 1892,[17] with the approval of Hall and Orton, seemed to establish the equivalency of the Monroe formation. This simple disposition of the problem of correlation was annuled by the revision of the New York series by Clarke and Schuchert and the assignment of the Rondout Waterlime to the Manlius formation.[18] The correlation of the various members of the Monroe with the New York beds is discussed by Grabau in the final chapter of this paper.

In the year 1903 Prof. C. S. Prosser, then of the Ohio Survey, proposed the name "Lucas limestone" for "all the rocks between the top of the Sylvania sandstone and the base of the Columbus limestone, or the base of the formation which Dr. Lane in Michigan has named the Dundee limestone."[19] The introduction of three new members into this series in Michigan makes it desirable

[17]Thirteenth Ann. Rep. State Geol. of N. Y., Vol. I, Geology, p. 216.
[18]American Geologist, Vol. XXXI, No. 3, 1903, p. 160.
[19]Journal of Geology, Vol. XI, No. 6, 1903, p. 540-541.

to limit the term to the dolomites in Lucas county, Ohio, which intervene between the top of the Sylvania and the base of the Columbus, or Dundee (Onondaga), while the prevailing magnesian character of the beds makes *dolomite* more appropriate than *limestone*. In the Detroit salt shaft the Lucas, as thus restricted, has a thickness of some 180 feet, and is separated from the Sylvania by the other beds mentioned, having an aggregate thickness of 85 to 100 feet. For the Monroe beds below the Sylvania Prosser suggested the provisional use of the term "Tymochtee," a name used by N. H. Winchell in 1873 for a series of thin-bedded, shaly dolomites seen along the banks of a creek of this name in Wyandot county, Ohio. Although the fauna of this series of beds is so far unknown, it is believed that it can be recognized in well records and in the salt shaft by its lithological characters alone and that it is best to employ this term in as nearly its original usage as possible for one of the subdivisions of the Lower Monroe. Our knowledge of the rock strata in Ontario, in the vicinity of the Detroit river, has been still further extended through the investigations of Rev. Thomas Nattress, of Amherstburg. This gentleman has collected an interesting suite of fossils from the dolomites blasted and dredged from the bed of the Detroit river and has carefully studied the rocks exposed in the Anderdon quarry, just east of the "Lime Kiln Crossing."[20] These collections have proven of much value in deciphering the succession of strata in the Detroit river region.

In a paper before the New York Academy of Sciences, presented January 6, 1908,[21] Grabau proposed a convenient subdivision of the Monroe into an upper, a middle, and a lower division, the Sylvania constituting the middle member, and proposed that the Salina beds be removed from the Monroe. The entire Siluric system was similarly divided into an upper member, this *Monroan;* a middle member the *Silinan* and a lower member, the *Niagaran.* In papers presented about the same time before the Albuquerque meeting of the Geological Society of America and the Chicago meeting of Section E, of the American Association for the Advancement of Science, by Grabau, Lane, Prosser, and Sherzer, this restriction and subdivision of the Monroe formation was recognized,[22] and the upper and lower members each divided into four subdivisions as given on page 27

[20] Report of the Bureau of Mines, Ontario, 1902, p. 123. Report for 1904, Part 2, p. 41. Ninth Annual Report Michigan Academy of Science, 1907, p. 177.
[21] Reported in Science, N. S., Vol. XXVII, p. 622.
[22] Bull. Geol. Soc. of Amer., Vol. XIX, 1907, p. 553.

of Chapter II. The Upper Monroe, or the Detroit River Series, shows a thickness in southeastern Michigan of about 100 feet at Wyandotte, to 350 feet at Windsor, including the series of dolomites and limestones between the base of the Dundee (Onondaga) and the top of the Sylvania. The Middle Monroe, or Sylvania member, consists, in the main, of a pure, incoherent sandrock, not recognizable in some well sections, but averaging in the Detroit river region about 100 feet in thickness. It is not infrequently divided by a bed of siliceous dolomite, sometimes by two such beds, for which the name Sylvania dolomite is proposed. The Lower Monroe, or Bass Islands Series, extends from the base of the Sylvania to the top of the Salina, which may be regarded in well records as the first bed of salt, or first heavy bed of gypsum. A comparison of the logs of adjacent wells, as for instance those of Wyandotte and Trenton, shows that some of the upper beds of salt are replaced to the southward by deposits of gypsum. It was hoped that in the salt shaft we would be able to determine about how much of the series, if any, above the first salt layer should be referred to the Salina. Although the beds above the salt proved unfossiliferous, still it seems probable that most of them are referable to the Monroe. When measured from the base of the Sylvania to the first salt or gypsum deposit the Lower Monroe shows a thickness of from 225 feet to 460 feet. The average thickness in the 17 wells of the Solvay Process Company, Delray, is 360 feet. As restricted, the Monroe formation in southeastern Michigan and western Ontario may be given a thickness of from 500 to 900 feet.

DISTRIBUTION OF THE MONROE FORMATION.

The beds thus far described have been confined, in the main, to the Lake Erie region and located in Michigan, Ohio, New York and Ontario. The recognition of beds of similar nature and age in other states becomes a matter of interest and importance in the present discussion for the light that is thereby shed upon the extent of the area over which Monroan conditions prevailed. Errors and uncertainties in correlating beds with the New York series and in separating them from adjacent strata make the problem difficult of solution. From Ohio all the main divisions of the Monroe may be traced into Indiana but only limited exposures of the strata occur. Upon the geological map published in 1890 by Phinney[23] the Water-

[23] Eleventh An. Rep. Dir. U. S. Geol. Sur., Pt. 1, p. 620.

lime is combined with the Lower Helderberg and together they form a rather narrow belt extending westward through Adams, Wells, Huntington, Wabash, Miami and Cass counties. Other small patches are shown in Pulaski, Tipton, Fayette and Hamilton counties, and a still larger area in the northwestern corner of the state. The Waterlime is well exposed at Kokomo, Howard county, consisting of evenly bedded strata, thinnest at the top and growing gradually thicker toward the bottom of the quarries. In general, it is of a gray or light brown color, often dark from bituminous matter, which is, at times, in thin films, giving the rock a banded appearance. Several species of *Eurypterus* demonstrate the Bertie, or the Put-in-Bay equivalency, of the Kokomo formation, which attains a thickness of about 100 feet. The strata overlying, referred to the Lower Helderberg, represent higher members of the Monroe. Their small fauna was recently described by Foerste.[24] An exposure of glass sandrock at Pendleton, Madison county, although it contains fossils of later age, is probably the representative of the Sylvania. It has here a thickness of 14 feet and immediately underlies the Corniferous (Onondaga). What is believed to be the same bed is penetrated in borings in Johnson, Hendricks, Parke, Jackson and Albion counties, the maximum thickness shown being 36 feet. Northward of the Wabash river the entire series is stated to become thicker (p. 634). In the geological map of the state compiled 1901-1903, the Waterlime and the Niagara are represented by a single color[25] and the "Kokomo limestone" is referred by Foerste to the Bertie or Lower Waterlime (p. 33).

Further westward than the State of Indiana we have no conclusive evidence of the occurrence of strata of Monroan age. In his report in 1866 Worthen referred a set of siliceous limestones, in southern Illinois, resting directly upon strata of the Cincinnati Group (Ordovician), to the Lower Helderberg and Oriskany.[26] From fossils collected he concluded that the beds ranged in age from the Niagara to the base of the Oriskany. In the map of the state, however, published by him in 1875, these beds are not recognized, and in the map of 1907 nothing is shown lying between the Niagara and the base of the Devonian. In the bulletin describing this map[27] Weller states that the deposits in Jackson, Union and

[24]Journ. Cincinnati Soc. Nat. Hist., Vol. XXI, No. 1, Sept., 1909.
[25]Dept. of Geol. and Nat. Resources of Indiana, Twenty-eighth An. Rept., 1903.
[26]Geol. Sur. of Ill., Vol. I, 1866, p. 127. See also Vol. III, Geology and Palaeontology, 1868, pp. 368-392.
[27]Bulletin No. 6, Ill. State Geol. Sur., 1907.

Alexander counties, referred to in the older reports as of Lower Helderberg age, may be so in small part, but that definite Helderbergian faunas have not been observed in the state. Such fossils, however, he recognizes in bluffs of the Mississippi river, Missouri side, opposite Grand Tower and northward in Perry county. In 1873 these beds were described as "Delthyris shale" and referred to the Lower Helderberg. They rest upon the Niagara, have an estimated thickness of 350 feet and consist of alternations of buff and bluish-gray, compact calcareo-siliceous limestone and ferruginous chert.[28] In 1900 they were described by Gallaher as the "Delthyris Shaly Limestone" and were considered as the last member of the Silurian division.[29] The fossils enumerated would not indicate equivalency with the Monroe beds.[30] Farther northward in Iowa at LeClaire, upon the Mississippi, Hall described in 1858 a series of thin-bedded, drab, argillaceous dolomites under the name "LeClaire limestone." These strata show shaly partings and are more or less laminated, and resting upon rocks of Niagara age left no doubt in Hall's mind as to their identity with the Waterlime, then considered as the upper member of the Onondaga Salt Group.[31] This disposition of the beds was not accepted by Worthen,[32] nor by White, who referred the LeClaire limestone to the Niagara upon stratigraphic and palaeontologic grounds.[33] This reference is confirmed by Calvin in his report for 1906, Vol. XVII, p. 235. In the eastern part of Wisconsin, a few miles northwest of Milwaukee, there occurs an exposure of thin-bedded, often thinly laminated, gray or ashen-colored dolomite, described by Lapham as "shaly limestone"[34] and referred by Hall to the Onondaga Salt Group.[35] In 1883 the beds were referred somewhat doubtfully by Chamberlin to Lower Helderberg.[36] They are exposed in Milwaukee and Ozaukee

[28]Reports on the Geological Survey of the State of Missouri, 1855-1871. Broadhead, Meek and Shumard, 1873, pp. 260 and 281.
[29]Preliminary Report on the Structural and Economic Geology of Missouri, 1900, p. 144. See also Geol. Surv. of Ill., Vol. III, 1868, pp. 393-406.
[30]Profs. Stewart Weller and T. E. Savage of Illinois were appealed to for information concerning the possible equivalency of any of the Helderbergian strata of the central Mississippi region with the Bertie, Cobleskill, Rondout or Manlius of the New York series. Under date of Jan. 27, 1909, Prof. Weller writes that he knows of no occurrence of these strata, either in southern Illinois or Iowa. Prof. Savage, Feb. 1, 1909, writes that there is no recognized representative of any of the strata in Illinois, Iowa, or southeastern Missouri. His recent studies upon the Helderbergian strata of southwestern Illinois gave a development of about 225 feet, all referable to the New Scotland horizon of the New York series, (Am. Jour. Science, Vol. XXV, 1908, p. 435). In Illinois no Silurian strata younger than the Niagara have been recognized.
[31]Geol. Surv. of Iowa, Vol. I, Pt. 1, 1858, p. 77.
[32]Am. Jour. of Sci., Vol. XXXIII, 1862, p. 46. Geol. Surv. of Ill., Vol. I, 1866, p. 127.
[33]Rept. of the Geol. Surv. of Iowa, Vol. I, 1870, p. 182.
[34]Report on the Geology of Lake Superior Land District, Pt. 2, 1851, p. 170.
[35]Geol. Surv. of Wisconsin, Vol. I, 1862, p. 70.
[36]Geol. Surv. of Wisconsin, Vol. I, Survey of 1873-1879, 1883, p. 197.

counties and were described as hard, brittle, light gray magnesian limestone, porous from minute angular cavities, thin-bedded and laminated. The strata rest upon Niagara and are overlain by Hamilton. *Leperditia* (referable to *alta*) is abundant and there occurs *Meristella nucleolata* and two species of *Orthis,* resembling *oblata* and *subcarinata*. This series is referable to the Monroe.

To the eastward of the Michigan and northward of the Lake Erie exposures of the Monroe already described, the formation, especially the upper series, may be recognized in heavy development. At Goodrich, Ontario, in the borings of a salt well, Hunt found beneath the Corniferous some 278 feet of chiefly dolomitic strata.[37] This series was underlain by 276 feet of a gray, non-magnesian, coralline limestone with much chert. From fragments of coral submitted to Hall he was led to believe that this limestone represented a bed of Corniferous, intercalated between the Silurian dolomites. The explanation given was that the Salina and Waterlime strata were formed in interior basins while the Corniferous conditions prevailed in the outer ocean (p. 242). A temporary influx of the sea into the region brought with it the Devonian life and conditions favorable for the formation of a limestone. This is the first recognition of the Anderdon limestone, exposed near Amherstburg and penetrated at Sibley, Detroit, and Windsor. It is of importance to note that the bed thickens thus rapidly to the northeastward as this suggests the direction of the open, interior sea of this time. In the Goodrich well the Middle Monroe, or Sylvania member, is not recognized but is represented a few miles north, at Kincardine, by a 29-foot stratum. In his summary of the palaeozoics of southern Ontario, in 1893, Brumell assigns the Lower Helderberg and Onondaga Salt Group a thickness of 300 to 1,000 feet, with an average of 650 feet.[38] In the well records of this and the following reports the strata are very generally referred to the Onondaga. A dolomitic conglomerate exposed on the Island of St. Helens, near Montreal, was referred to the Lower Helderberg by Logan. The fossils from this locality were described by Meeks in the Canadian Record of Science (Vol. IV, No. 2, 1890, pp. 104-109) and by Ami in the Annual Report of the Geological Survey of Canada (Vol. VII, New Series, 1896, p. 155 J, for 1894. A very heavy development of limestone in the Cape Gaspé region was referred by him also to the same

[37] Geol. Surv. of Canada, Rept. of Progress for 1876-7, 1878, p. 242.
[38] Geol. Surv. of Canada, New Series, Vol. V, Pt. II. 1893, p. 5Q.

geological age. This same formation extends through New Brunswick, Nova Scotia, Maine, and northern New Hampshire, but, so far as known, is to be correlated with the Helderbergian and Oriskian, rather than the Monroe.[39]

From the eastern extremity of Lake Erie there extends eastward through central New York a narrow strip of limestone, in the main magnesian, which Grabau correlates with certain members of the Monroe of the Lake Erie region. The New York series attains its greatest development in Herkimer county, east central part of the state, with a total thickness of 170 to 200 feet. The outcrop narrows eastward to the Hudson river and curves southwestward, cutting across New Jersey, entering eastern Pennsylvania and extending, with interruption, to the central part of the state. Lithologically the strata much resemble their western representatives, suggesting identity, or similarity of origin. They are, in the main, drab to gray, of bluish, argillaceous, magnesian limestone; generally thin and even-bedded, but sometimes passing into compact, massive beds. Carbonaceous, shaly seams are common, often giving the rock a finely laminated, or "ribbon structure." Some of the horizons show sun-cracks, extensive brecciation and the "gashed structure," which are common characteristics of the formation in the Lake Erie region. Both east and west the dolomite weathers to a creamy or buff, mealy product. In New Jersey, Pennsylvania, Maryland and West Virginia the Bertie cannot be separated lithologically, or palaeontologically, from the lower beds, erroneously referred to the Salina, with which it is intimately connected, the *Eurypterus* fauna being practically absent. The remainder of the Monroe; Cobleskill, Rondout and Manlius, ranges in thickness in these states, according to Schuchert, from 100 to 145 feet.[40] In Maryland the fossiliferous "Salina" probably represents Lower Monroe, while the overlying "Manlius," since described as the Corrigan formation, is Upper Monroe.

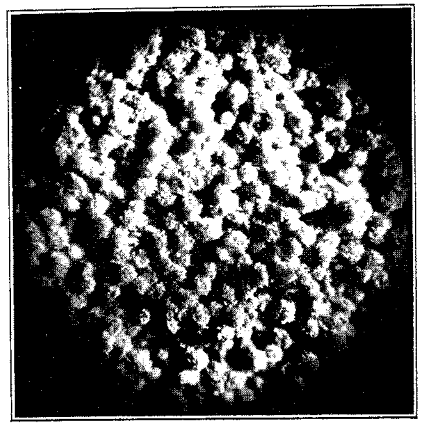
Passing southward from the Ohio localities described, there has been no recognition of the Monroe formation in Kentucky, the Onondaga limestone (Upper Helderberg) appearing to rest directly upon the Clinton. In Tennessee, however, there occurs, in the west-

[39] Geol. Surv. of Canada, Rept. of Progress to 1863; 1865, pp. 390-404. Bull. U. S. Geol. Surv., No. 165, 1900. Palaeozoic Fossils, Vol. II, Pt. I, E. Billings, 1874, pp. 1-64. Clarke, J. M., Early Devonic History of New York and Eastern North America. Mem. N. Y. State Mus. 9.
[40] Am. Geologist, Vol. XXXI, No. 3, 1903, p. 178. See also Proceedings U. S. Nat. Mus., Vol. XXVI, 1903, p. 413.

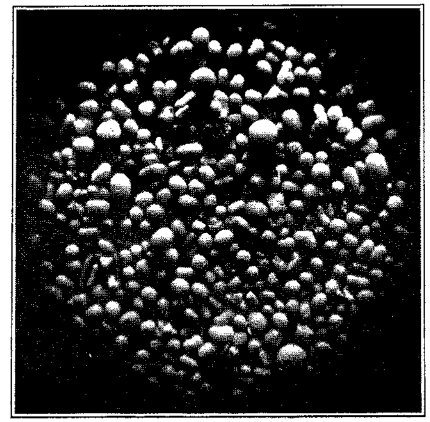
ern valley of the Tennessee river, a series of light-blue limestones, often shaly and highly fossiliferous, with frequent cherty layers, referred by Safford to the Lower Helderberg. These strata are estimated to attain a maximum thickness of 100 feet, are best seen near White Sulphur Springs, Hardin county, and disappear to the eastward. They rest upon Niagara and are overlain by a black shale, regarded as the probable representative of the Genesee shale of New York.[41]

These Lower Helderberg strata (Linden formation) correlate with the New Scotland of New York, but equivalents of the Monroe have not yet been found. From the Hudson river to the most western known exposure of the formation is about 725 miles and from St. Ignace to the Greenfield locality, in southern Ohio, is approximately 460 miles. These measurements mark the minimum limits of the interior sea in which were deposited the sediments of the Upper and Lower Monroe, covering an area of perhaps 150,000 to 200,000 square miles.

[41]Geology of Tennessee, 1869, p. 322.



(A)



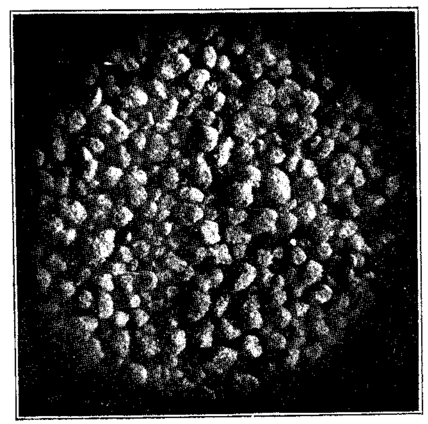
(B)

(A). DOLOMITIC OOLITE, MONROE, MICHIGAN.

The individual granules are more or less obscured by a coating of fine rhombohedrous of dolomite x6¾ times.

(B). OOLITIC SAND, GARFIELD LANDING, GREAT SALT LAKE.

Three types of granules are shown—the sub-spherical, the rod-like and sparingly the "tubercular." All are believed to have been formed through the agency of algæ. x6¾ times.

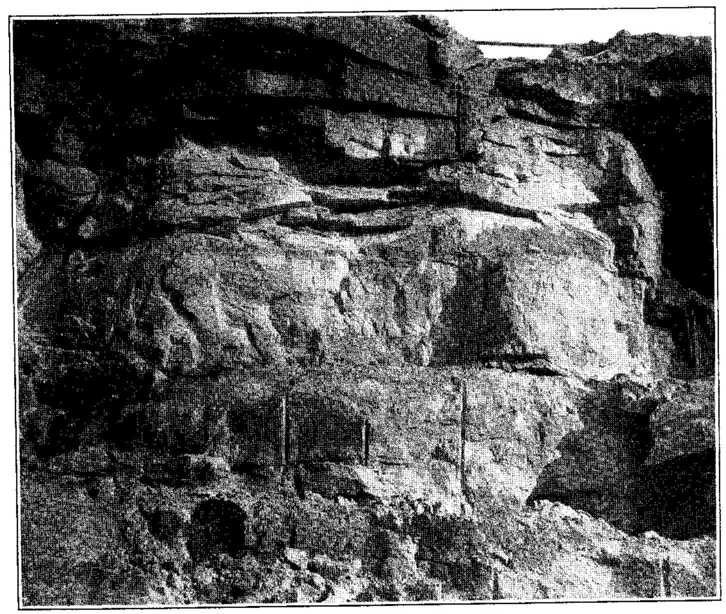


(C)

(C). OOLITE DISINTEGRATED IN THE OPERATION OF BLASTING, MONROE, MICHIGAN.

Owing to general similiarity in size, structure and types of granules this Monroe oölite is believed to have had a similar origin to that of Great Salt Lake. x6¾ times.

(A). GENERAL VIEW OF SYLVANIA QUARRY (TOLL'S PIT), MONROE COUNTY, MICHIGAN. JULY 24, 1907. NATIONAL SILICA COMPANY.



(B). STRATIFICATION OF SYLVANIA SANDSTONE. PIT OF NATIONAL SILICA COMPANY, MONROE COUNTY, MICHIGAN.

The irregular stratification indicated is believed to point to aeolian, rather than aqueous deposition.

CHAPTER II.

STRATIGRAPHY, STRUCTURE AND LOCAL DISTRIBUTION OF THE MONROE FORMATION.

BY W. H. SHERZER AND A. W. GRABAU.

The following subdivisions of the Monroe formation are now recognized:

DUNDEE FORMATION.

		disconformity	
MONROE FORMATION.	C. Upper Monroe or Detroit River Series.	Lucas dolomite	200 ft. +
		Amherstburg dolomite	20
		Anderdon limestone	35-50
		Flat Rock dolomite	40-100
		disconformity	
	B. Sylvania sandstone and dolomites		30-300
		disconformity	
	A. Lower Monroe or Bass Islands Series.	Raisin river dolomite	200
		Put-in-Bay dolomite	100
		Tymochtee shales	90
		Greenfield dolomite	100
		disconformity	

SALINA FORMATION.

The following pages are devoted to a discussion of the Monroe formation of southeastern Michigan, and hence are primarily concerned with those members of the Monroe exposed in this area. There are, however, other beds of this formation not exposed in southern Michigan, but penetrated by the deep wells and by the salt shaft. These beds are known to crop out in Ohio, and there have furnished opportunity for study. In order that our discussion of the formation—which is typically developed in Michigan—may be complete, a brief review of these lower beds is included.

A. THE LOWER MONROE OR BASS ISLANDS SERIES.

In the Detroit region well borings show 360[1] feet of dolomites below the Sylvania and overlying the salt of the Salina. Most of this is undoubtedly to be referred to the Monroe formation (using this term for the marine upper Silurics, above the Salina), though

[1]The average of the seventeen wells of the Solvay Process Co., at the mouth of the Rouge river.

some of the beds immediately above the salt may belong to the Salina series.

In the Royal Oak well No. 2, about 550 feet[2] of limestone and dolomite lie between the Sylvania and the uppermost salt bed which is nearly 100 feet thick. In one of the Wyandotte wells 440 feet of shales, dolomites and gypsum occupy the same interval. In each case a certain amount of the beds just above the salt undoubtedly belong to the Salina, but the greater part no doubt is Lower Monroe. There is no reason for believing that the first salt bed struck in these wells is other than the same bed, since it is unlikely that a bed of such thickness should be other than continuous over the area mentioned, unless, indeed, erosion occurred prior to the deposition of the Lower Monroe. If this reasoning is valid, then the difference in the thickness of the Lower Monroe in the different well sections may be attributed to unequal erosion before the deposition of the Sylvania sandstone, or it may be, that in the slow retreat of the sea which produced the dry land conditions, believed to have existed in Sylvania time, the Detroit area was uncovered before the other two areas, which therefore received higher deposits of this series than are found in the Detroit region. It is, however, most probable that in the thinner sections some of the lower beds are wanting, the higher resting by overlap on the Salina.

In the deep well at Monroe 660 feet of dolomites and shales are found overlying the "Niagara." The identification of all this as Monroe is not as yet verified,—some of it may be Salina—and some may belong even to the Upper "Niagara." Only about 200 feet of Lower Monroe are exposed in southeastern Michigan. These are shown in the quarries at Monroe, Newport, etc., and along the lower Raisin river. They constitute the Raisin river dolomite, which is the highest division of the Lower Monroe found in this region. The lower members do not crop out in southern Michigan but are seen in Ohio and in Canada. They will, however, be found in the well and shaft sections and for that reason they should be briefly described.

[2]One hundred feet of this is recorded by the driller as white sandstone and if so should be added to the base of the Sylvania, but Lane thinks it may be gypsum rather than sand. See Mich. Geol. Surv., Vol. V., well records.

1. THE GREENFIELD DOLOMITE.

The name Greenfield limestone was proposed by Grabau in 1898[3] for the deposits of late Siluric dolomites overlying the Niagaran beds in southern Ohio, from the excellent exposures found at Greenfield in Highland county, Ohio. The name Greenfield stone, used commercially, was used by Orton for this formation as a local name.[4] Since it is a pure dolomite in nearly all of its exposures the name is best changed to Greenfield dolomite. A characteristic sample from Greenfield, Ohio, gave 49.70% of $CaCO_3$ and 44.87% $MgCO_3$. Another gave 53.67% $CaCO_3$ and 42.42% $MgCO_3$[5]. It is mostly thin-bedded and drab colored on fresh exposures, but soon oxidizes to a yellowish shade. The greatest thickness in the Greenfield section is 100 feet, but higher divisions of the Monroe may be present. Some brecciated beds occur but these are chiefly of intraformational character, formed probably by the collapse of roofs of caverns or by other causes.

This brecciation of the dolomites of the Monroe is a very general characteristic, being found in widely separated localities. Two types of brecciation must be distinguished, the general and the local. The first shows a complete shattering of the beds, a rearrangement of the blocks, so that the stratification dips in all directions, followed by a recementation. This has been interpreted by Lane as perhaps due to the inrush of great tides over shallow flats,[6] but Grabau has argued that it represents the talus breccia produced on an extensive land surface of post-Monroe time and that this talus was subsequently incorporated into the lower Onondaga on the resubmergence of this region by the sea.

The second type of brecciation is of a more local origin, and affects individual beds. This has the appearance of being due to internal movements of the rock strata (autoclastic breccias), and what is now considered to be a sufficient cause for this minor brecciation, is found in the expansion of the mineral anhydrite when it unites chemically with water and is converted into gypsum. The amount of expansion ranges, according to various authorities, from 33% to 62.3%. Many of the well records of the Lake Erie region show extensive deposits of anhydrite, less frequently of gypsum, embedded in the Monroe, and the underlying Salina, and

[3]Science, N. S., Vol. VIII, p. 800.
[4]Geol. Surv. Ohio, Report for 1870, pp. 287. et. seq.
[5]Loc. cit.
[6]Geol. Surv. of Michigan, Vol. V, 1895, Pt. II, p. 27.

it seems very probable that some of the brecciation, at least, is to be attributed to this cause. This explanation of the phenomenon in Ontario was given as early as 1864 by Chapman in his "Popular and Practical Exposition of the Minerals and Geology of Canada," p. 189. Prominent geologists, both at home and abroad, (Bischoff, Credner, Geikie, Prestwich and Dana) subsequently have called attention to the frequency with which folding, faulting and shattering of rock strata are found in formations which overlie beds of gypsum. In an interesting paper upon the formation of the small caverns seen upon Put-in-Bay island, Lake Erie, Kraus attributes the local folding of the strata to this cause and the caverns to subsequent removal by solution of the gypsum.[8] This view assumes that each particular cavern had its own lenticular mass of gypsum which was completely removed. The expansional force would be directed upwards to cause the folding and the layers involved would be subjected to a *tensional stress,* giving rise to joints and seams but not true brecciation. A simpler and possibly more plausible view, is that the folds in the strata were due to local *buckling,* under the influence of horizontal stress induced by the hydration of subjacent deposits of anhydrite. Removal of gypsum by solution may have taken place but no such action need be assumed. To induce folding in this manner the strata would need be subjected to a lateral *thrust,* giving rise to rock shattering and brecciation of a type very commonly found in the dolomites of the Lower Monroe.

Whitfield has described a number of species from the dolomite at Greenfield, Ohio, some of which have since been referred to other genera and species.[9] The following list includes all the species known from this locality, with their present generic and specific reference. The names in parentheses are those under which they were originally described:

Schuchertella hydraulica (Whitfield) Grabau.
(*Streptorhynchus hydraulicum* Whitfield).
Hindella (?) (*Greenfieldia*) *whitfieldi* Grabau.
(*Meristella bella Whitfield*).
Hindella (?) (*Greenfieldia*) *rostralis* Grabau.
Hindella (?) *rotundata* (Whitfield) Grabau.

[8]American Geologist, Vol. XXXV, 1905, p. 170.
[9]Ann. N. Y. Acad. Sci., Vol. II, 1882, p. 193 and Vol. V, p. 505, and Geol. of Ohio, Vol. VII, 1893. *Meristella laevis* Whitfield=*Whitfieldella prosseri* Grabau, described from this locality by Whitfield appears to be erroneously cited, the specimens determined by Whitfield coming most probably from the Raisin river dolomites of Lucas county, as shown more fully under the discussion of that species.

(*Nucleospira rotundata* Whitfield).
Pentamerus pes-oris Whitfield?
(Horizon doubtful).
Whitfieldella subsulcata Grabau.
Rhynchospira præformosa Grabau.
(*Retzia formosa* Whitfield.)
Camarotoechia hydraulica (Whitfield) Grabau.
(*Rhynchonella hydraulica* Whitfield.)
Leperditia altoides Grabau.
Leperditia angulifera Whitfield.
Sphærococcites glomeratus Grabau.

The Greenfield dolomite of this section rests disconformably upon the Hillsboro sandstone, the highest member of the Niagaran series[10] of southern Ohio, and in turn is disconformably overlain by the upper Devonic Ohio shale.

The Ballville Section.

Near Ballville, in central Sandusky county, a section of the lower Monroe beds is shown at Moore's mills, on the Sandusky river.[11] This comprises in descending order:

1. Thick-bedded, drab, used for building	6 ft. 6 in.	Waterline, 15 feet.
2. Thinner-bedded, drab, more sectile, weathers lighter	1 ft.	
3. Beds about 6 inches, drab, used for building	3 ft.	
4. Beds 3 to 6 inches, drab	4 ft. 6 in.	
5. Green shale, passing horizontally into an impure, bluish drab stone	1 ft.	
6. Bluish-gray Niagara; beds thick, hard and crystalline, exposed	3 ft.	

Beds 1 to 5 comprise the Greenfield, which rests disconformably upon the Niagara. The shale (5) was formerly called Salina, and appears so named on the older maps. It is, however, merely the basal portion of the Greenfield, which here rests on a former oldland surface cut on the Niagara.

The beds immediately above the shale contain an abundance of *Leperditia alta*. The rock is a light-colored, dolomitic calcilutite. The complete list of species so far found in these beds is as follows:

Schuchertella hydraulica (Whitfield).

[10]The possible Salina, or even early Monroe equivalence of the sandstone must not be overlooked. It probably represents a reworked continental deposit.
[11]Geology of Ohio, Vol. I, 1873. Geology of Sandusky county by N. H. Winchell, p. 598 and 599, and text figure.

Whitfieldella subsulcata Grabau.

Leperditia alta (Conrad).

Both lithically and faunally the beds agree with those of Greenfield, Ohio, so that the correlation of these formations at the two localities is probably correct.

2. THE TYMOCHTEE BEDS.

This name was given by N. H. Winchell in 1873[12] to the exposures on the Tymochtee creek, in Wyandotte county, Ohio. Here in sections 27 and 34 of Crawford township a total of 84 feet 10 inches of rock is shown. The section given by Winchell is as follows, in descending order:[13]

1. Thin, (1-inch) dark drab, brittle bed	1 ft.	
2. Beds 2 to 3 inches; lenticular; light drab; weathering ashen; with *Leperditia alta*	2 ft.	6 in.
3. Light drab beds; weathering ashen; 2 to 6 inches.	2 ft.	
4. Drab, slaty beds, with frequent bituminous films; deep fracture sometimes blue drab; beds half-inch thick; blue color rarely seen; the equivalent of the stone of Carey's quarry	24 ft.	
5. Beds 2 to 4 inches; drab; compact and fine-grained; showing no blue; like the stone in June's quarry, Fremont	15 ft.	
6. Beds thin (1 to 4 inches); drab; regular; fine-grained; compact; showing no blue or chocolate; on a deep fracture bluish drab or blue	12 ft.	
7. Drab, slaty beds; separated by brown bituminous films; above the beds are thicker but more lenticular	10 ft.	
8. Drab, fine-grained; slaty with bituminous films that weather blue. Some beds are 4 inches, but without long horizontal continuance	4 ft.	
9. Earthy; slaty beds, weathering blue and chocolate on the sides which are coated with bituminous films. The broken edges of the bedding dark drab, sometimes with irregular spots of light blue.	10 ft.	
10. Vesicular and carious; coarse, ungainly; of a dark drab color; with traces of fossils; mostly hid from observation, but apparently without horizontal continuance	1 ft.	6 in.
11. One bed; fine-grained; drab		4 in.
12. Beds ¼-inch; slaty; drab; with blue films	1 ft.	
13. Drab, lenticular beds of 2 inches; sometimes bulging and then harder, or in regular courses of 2 to 4 inches	1 ft.	6 in.
Total exposed	84 ft.	10 in.

[12] Geol. Ohio, Vol. I, p. 633.
[13] Loc. cit., p. 633.

Beds 7, 8, and 9, 24 feet thick, were designated by Winchell *Tymochtee slate*. They are described as homogeneous, tough and thin-bedded, sometimes having so much bituminous matter as to appear like the Ohio black slate.

From the strata of this section few fossils have apparently been obtained. Those recorded are *Leperditia alta* and a fossil which appears like a species of *Modiolopsis*.

The stratigraphic position of the Tymochtee slate must at present remain unsettled, since no data are at hand by which to determine its exact position. That it rests above the Greenfield dolomite seems certain from its geographic position, but whether it lies below or above the Put-in-Bay dolomite has not been determined. There is some reason for believing that it lies below that formation, filling the gap between the Greenfield and Put-in-Bay, since dark, shaly beds referred to the "Salina," underlie the latter formation in various places. It is, of course, not impossible that the beds of Tymochtee creek represent one or the other of the dolomites mentioned, or perhaps parts of each, constituting a somewhat more argillaceous phase. Traces of this horizon are found in Monroe and Newport wells between 400 and 500 feet below the Sylvania sandstone.

3. THE PUT-IN-BAY DOLOMITE.

This name is proposed for the next higher series of strata of the Lower Monroe which is well exposed on Put-in-Bay island in Lake Erie, and characterized by a fauna not found in the lower or upper beds. The following section was given by Newberry[14] for the southern point of this island, in descending order:

1. Gray, brecciated limestone, massive and without fossils	30 ft.
2. Cream-colored, thin-bedded limestone	3 to 7 ft.
3. Gray, brecciated limestone, similar to No. 1, containing immense numbers of *Leperditia alta*	8 ft.
4. Thin-bedded, dove-colored or gray, laminated, earthy limestone, with fossils, used for waterlime.	12 ft.
5. Blue, earthy, massive limestone, weathering chocolate, without fossils, at lake level	10 ft.
Total	63-67 ft.

Higher beds are exposed on the northern end of the island; these being similar in character to those of South Point, i. e., "massive

[14] Geol. Ohio, Vol. II, p. 202.

and brecciated layers, intersected by thin sheets of laminated limestone." At Peach Point the laminated layers have furnished large numbers of fossils, among which *Goniophora dubia* and *Spirifer (ohioensis)* predominate.

Leperditia alta is also common, and occasionally *Eurypterus eriensis* is found. *Pterinea aviculoidia* = *Pt. lanii* Grabau, described from this horizon by Whitfield, may be derived from the higher beds of Lucas county, as more fully discussed under the description of that species, though it is not impossible that it was derived from the higher beds which apparently crop out on Put-in-Bay.

These limestones are rich in celestite as well as flour spar. Large and fine specimens of the first of these have been obtained from Strontian island and other localities. In lower beds than those shown on South Point, gypsum occurs, this being often dragged up from the bottom of the channel off South Point. This gypsum is worked on the peninsula 8 miles distant. The massive beds of the series on Put-in-Bay range in carbonate of lime from 42.03% to 63.37%, the corresponding percentage of magnesium carbonate being 41.64% and 32.57%, though some of the beds range as high as 44.98% magnesium carbonate. The hydraulic layers of South Point range in carbonate of lime from 42.95% to 51.43%, a corresponding percentage of magnesium carbonate being 39.79% and 40.24%, the latter being the highest recorded. In these hydraulic beds the amount of silica may be as high as 13.3%.

Among the fossils of this division none are so abundant as *Goniophora dubia* (Hall) which sometimes covers the surface of the slabs. It appears to be nearly restricted to this horizon and may be taken as a type fossil of this palæontologic zone. *Spirifer ohioensis* Grabau, is also common in some of the beds, though not as abundant as the preceding species.

This formation is not found in contact with the underlying Greenfield, nor the Tymochtee, the waters of Lake Erie and the drift on the main land covering the line of junction. So far as definite observations go, it is not found in contact with the formation next to be described, though from the occurrence of *Whitfieldella prosseri*, and possibly *Pterinea lanii* in rocks obtained from Put-in-Bay it seems that the next higher formation is found there. This further seems probable from the course of the Sylvania

sandstone outcrop, as shown below. The same division with *Goniophora dubia* is again reported from the bed of the Scioto river at Middletown in southern Marion county, Ohio. It appears not far from the outcrop of the Dundee which seems to overlie this division disconformably, thus cutting out the higher members seen farther westward.

4. THE RAISIN RIVER DOLOMITE.

This name is applied to the dolomitic calcilutites and oölites which constitute the upper part of the Lower Monroe. It has a thickness of about 200 feet, and lies directly below the Sylvania sandstone in all its exposures in Monroe county, Michigan, and Lucas county, Ohio. The dolomites have the characteristic drab to gray color, are generally thin-bedded and more or less shattered and broken. Fossils are not abundant except at certain levels and are represented chiefly as molds. Local brecciation along joint planes and in cavities is not infrequent, while at times it is more general and involves the main body of certain beds. Thin slabs occasionally show mud cracks and ripple marks, testifying to the shallow water conditions under which their material was accumulated. Upon the floors of some of the quarries about Monroe immense hemispherical masses protrude from the lower beds, having a finely laminated, concentric structure and apparently concretionary in their nature.

The best exposures of the Raisin river series are in the quarries of the Monroe Stone Co., south of Monroe; that of the Shore Line Stone Co., just north of Monroe, and at Newport. Owing to the dip of the beds the lowest strata are seen in the quarry south of Monroe, at present writing about 60 feet below the surface, while the highest stratum exposed constitutes the top ledge at the Newport quarry, giving a range through nearly the entire series. A unique feature of the Raisin river series is the occurrence of a number of separate oölitic strata, each underlain by a peculiar bed of blotched, mottled, and streaked lutaceous dolomite; compact, unfossiliferous, brittle, and with a pronounced conchoidal fracture. The dolomite itself is light gray in color and the discoloration of a distinct bluish cast, except where exposed in outcrop when it has assumed a rusty brown, indicative of the presence of iron. Rominger compared one of these beds with *castile soap*, which it somewhat resembles. It is difficult to understand what is the connection between the oölites and this type of dolomite, but in every case they were found to be associated and the presence of the dolomite in a number of cases led to the recognition of the oölite, where the structure was obscure and might have been readily overlooked. These dolomitic beds are generally seen to consist of three separate beds, the upper 8 to 12 inches having a *gnarled* pattern, the middle 4 or 5 inches *mottled* and the lower 3 to 4 feet *streaked*. At the quarry north of Monroe in one of the lower beds there occurs a series of very perfect concentric spheres outlined by the bluish discoloration. Between these three separate beds of the dolomite there occur seams of dark clay, or shale, varying in thickness from zero to 12 inches, which in places show the same blotching as the dolomite itself. At the quarry of the Monroe Stone Co. an upper, middle and lower oölite may be recognized, having a thickness respectively of 20 inches, 34 inches and 24 to 48 inches. About 30 feet of dolomite separate the upper and middle oölites, and about 13 feet intervene between the middle and lower. At the Shore Line Stone quarry, where about 50 feet of strata are exposed, an oölite, ranging in thickness from 15 to 25 inches, is found at a depth of 20 feet, and some 7 to 8 feet lower an obscurely defined bed. At the Newport, quarry a streaked bed occurs at the crest of the wall, strongly suggesting the presence of an oölitic stratum lost by erosion. Twenty-four feet below the top of this bed an oölite occurs, with an average thickness of 12 to 13 inches, underlain by some 30 inches of streaked dolomite. Still lower, and separated by from 14 to 18 feet of dolomite, is found a third oölite with an average thickness of 32 to 33 inches and resting upon 31 inches of streaked and mottled dolomite. Judging from the dipping of the strata to the northward and westward it does not seem that these Newport oölites can be correlated with those at Monroe, and the inference is justified that the Raisin river series is made up essentially of alternating layers of drab dolomite, gray blotched dolomite and oölite, all in more or less intimate contact. The conditions necessary for the formation of each of these beds were successively repeated in the same order.

The granules of which the oölite is composed have been made the subject of microscopic study by Sherzer,[15] and found to consist of minute rhombohedrons of dolomite having a poorly defined con-

[15]Geol. Survey of Mich., Vol. VII, Pt. 1, p. 62.

centric structure, without a nucleus of other mineral, and showing about the inner portion more or less organic matter. They are roughly spherical to ellipsoidal in shape, and most of them range from .2 mm. to .6 mm. in diameter and are held more or less firmly together (see plate I, fig. A) by a dolomitic cement which in places obscures the oölitic structure. Mingled with the subspherical granules are others of the same general structure, having the diameter of the smaller granules but relatively elongated and either straight or curved. Tongue-like to frondescent masses also occur, ranging in size from a few millimeters to 7 to 10 cm. in breadth and length and with a thickness ranging from 2 to 3 cm. Their edges and corners are rounded, their surfaces somewhat undulating, frequently showing rounded tubercles and irregular ridges. Dissolved in acid they are shown to contain also considerable bituminous material. Upon comparing these three types of structures with those found in the oölitic sands of Great Salt Lake, Utah, there is little room for doubt that they have been formed under similar conditions, although the alteration from calcium carbonate to dolomite has partially disguised the similarity. (See plate I, fig. B.) According to the investigations of Dr. A. Rothpletz, of Munich, the Salt Lake oölite has resulted from the secretion of calcium carbonate by colonies of algae, known as *Glœocapsa* and *Glœotheca*, giving rise to the rounded granules, the elongated rods and the tubercular masses.[16] If the oölitic components of the Monroe rocks are identical, or very similar, to those of the Salt Lake sands it might be necessary to assume that they originated under similar conditions, in bodies of water temporarily separated from the open sea. Similar oölites are known to form, however, in partially enclosed seas, such as the Arabian Gulf, and this probably represents more nearly the conditions existing in Monroan time.

The thin-bedded, drab dolomites, lying between the upper and middle beds of oölite, at the quarry of the Monroe Stone Co., in five analyses gave:

Calcium carbonate	50.92%	to	53.50%
Magnesium carbonate	41.39%	to	44.77%
Silica, iron oxide and alumina	3.08%	to	6.08%

In the abandoned quarry to the north of Monroe, formerly oper-

[16]Botanisches Centralblatt, Nr. 35, 1892. Translation in American Geologist, Vol. X, No. 5, 1892, p. 279.

ated by the same company, the following three analyses show the nature of the rock:

	2 ft. down.	7 ft. down.	10 ft. down.
Calcium carbonate	54.54	54.47	54.94
Magnesium carbonate	42.75	43.59	42.84
Silica	2.00	.74	1.33
Iron oxide and alumina	.70	.98	.58
Difference	.01	.22	.31
	100.00	100.00	100.00

Locally the beds contain patches of iron pyrite, and in the cavities and seams deposits of well crystallized calcite and celestite occur. Less frequently small masses of strontianite occur either separately or in association with the last two minerals.

The fauna of the Raisin river beds is chiefly derived from the strata quarried at Newport and at Monroe, and less abundantly from Stony Point and outcrops on the Raisin river. In the salt-shaft section, this fauna was found well developed between 87 and 138 feet below the Sylvania standstone. The following species have so far been obtained, those starred (*) having been obtained in this fauna only in the salt shaft:

Brachiopoda.

Pholidops cf. *ovata* Hall.

**Schuchertella hydraulica* Whitfield.

**S. interstriata* (Hall).

Whitfieldella prosseri Grabau.

Camarotocchia sp.

Pelecypoda.

Pterinea lanii Grabau.

Goniophora dubia Hall.

Tellinomya sp.

Modiomorpha sp.

Gastropoda.

Solenospira minuta (Hall).

Holopea 3 species.

Loxonema sp.

Cephalopoda.

Cyrtoceras (*Cyclostomiceras*) *orodes* Billings.

Ostracoda.

Kloedenia monroense Grabau.

Plantae.

Sphaerococcites glomeratus Grabau.

Stipes of plants.

The details of the distribution of the fossils in the lower beds of the salt shaft are as follows:

At a depth of 624 to 634 feet, or from 87 to 97 feet below the Sylvania, the following species were found:

Schuchertella hydraulica with the striae approaching in character to *S. interstriata*, rare.

S. interstriata, a specimen with the characters of this species.

Whitfieldella prosseri, common.

Goniophora dubia.

Cyrtoceras orodes, rare.

At a depth of 630 to 635 feet, or from 93 to 98 feet below the Sylvania, the following species were found:

Schuchertella hydraulica, varying from the typical form, in that the difference between the striae is less marked. Between the coarse striae are one secondary and two tertiary striae, and sometimes quaternary striae. The secondary striae often become so strong, as to resemble the primary ones, when the species takes on the character of *S. interstriata*. Some specimens are more nearly like *S. interstriata* of the Akron dolomite, though there is more difference in the thickness of the striae than is the case in the western New York species. They are, however, clearly transitional forms from one to the other.

Whitfieldella prosseri, abundant.

Goniophora dubia, not uncommon.

Cyrtoceras orodes, fairly abundant.

Indeterminable bryozoan.

At 655 to 657 feet, or from 118 to 120 feet below the Sylvania, the following species have been found:

Whitfieldella prosseri, abundant.

Spirorbis laxus, abundant.

Stems or stipes of plants.

The association of these three fossils strongly suggests the horizon of the Newport quarries. There, however, *Pterinea lanii* is common, while not a trace of this species has been found in the shaft section.

At a depth of 672 feet, or 138 feet below the Sylvania sandstone, the following species have been found:

Schuchertella hydraulica, typical, common, some specimens approaching *S. interstriata* in character.

Whitfieldella prosseri, common.

Goniophora dubia, common, occurs on slab with *Whitfieldella prosseri* and *Schuchertella hydraulica*.

Impressions of bryozoans. Oölite layers occur at this horizon.

The highest exposed beds of this division, just below the Sylvania are very siliceous, being intermingled with round quartz grains which constitute a large percentage of the material of these upper layers. In these were found: *Meristina profunda* Grabau, and *S. profunda* mut. *sinosus* Grabau, both of which are of typical Siluric affinities.

B. THE SYLVANIA SANDSTONE.

This formation, varying in thickness from 30 to 300 feet in southern Michigan, everywhere separates the Lower and Upper Monroe beds. On account of its remarkable character, peculiar distribution, and palæogeographic as well as economic importance it is treated in a separate chapter.

While in most cases the contact with the overlying and underlying beds is not an abrupt one, there is nevertheless a disconformity[17] both above and below the Sylvania. So far as the records admit of interpretation it appears, that the Sylvania rests on different members of the Lower Monroe series, and is succeeded by various members of the Upper Monroe series, or by the Dundee.

Fossils have been found so far only in the intercalated dolomite in the upper part of the Sylvania, and these belong to the Upper Monroe division. Where the formation is in contact with the Dundee, as at the Toll pits, (National Silica Co., 7 miles northwest of Monroe, Michigan), internal molds apparently of Paracyclas are not uncommon.

[17]The term disconformity was proposed by Grabau for a hiatus without structural discordance of the beds involved. The term unconformity is restricted to cases where such discordance exists.

C. THE UPPER MONROE OR DETROIT RIVER SERIES.

The four recognized divisions of this series are in ascending order: Flat Rock dolomite; Anderdon limestone; Amherstburg dolomite, and Lucas dolomite. They are not always present in the various localities, one or more of the lower members being wanting through overlap of the higher ones.

1. THE FLAT ROCK DOLOMITE.

The name is given to the lowest bed in the Oakwood (Detroit) salt shaft. It is a very compact, dark gray, harsh and rather porous magnesian calcarenite (rarely a calcilutite) alternating with more uniform and softer magnesian brownish calcarenites.

Fossils are comparatively uncommon, though the porous rock contains many impressions, mainly of unrecognizable fragments. Gastropods, so characteristic of the upper dolomite (Lucas) seem to be wanting altogether, but corals are more commonly seen. The following species have been obtained from this bed in the salt shaft:

Syringopora cooperi Grabau.

Syringopora cf. *hisingeri* Billings.

Favosites maximus ? Troost.

Syringopora cooperi obtained 30 feet above the Sylvania, seems to be restricted to this bed, though a species closely related, if not identical, occurs in the brecciated magnesian calcilutite of Mackinac Island, referred to the Dundee by Hall and Rominger, but more probably referable to the horizon of the Flat Rock. *S. hisingeri* ? also occurs in the Amherstburg dolomite, where it is one of the characteristic fossils.

So far, this formation is definitely known only from the salt shaft, at Oakwood, where it is 47 feet thick, and from Flat Rock, Wayne county, where it forms the surface rock. Southward from Oakwood it appears to thin away, until at the Wayne-Monroe county boundary line it is absent, having been overlapped against the Sylvania as a basal bed, by higher members of the series. There seems to be an exception to the general and progressive thinning away southward as shown by a recent well drilled at Wyandotte, Monroe county, Michigan, and studied by Lane and Sherzer. Here about 130 feet of brown dolomite, apparently the Flat Rock, overlies the Sylvania sandstone without any trace of the higher beds.

The Dundee, too, seems to be absent. In an earlier well section at Wyandotte, given by Lane in Volume V, of the Michigan Survey reports, the record to the Sylvania is as follows:

1.	Clay and gravel	75 ft.
2.	Dark limestone	15 ft.
3.	Light brown limestone	10 ft.
4.	Gray limestone	25 ft.
5.	Brown sand with slate	30 ft.
6.	Brown sand and lime	5 ft.
7.	Brown and white limestone	70 ft.
8.	Freestone (Sylvania)	60 ft.

Total beds 2 to 7 inclusive, 155 feet. Though in the driller's record these beds are called limestone they are undoubtedly for the most part brown dolomites. Beds 2 to 4 were correlated by Lane with the Dundee. If this correlation is correct the sandy beds 5 and 6 may represent the Oriskany horizon, and the Upper Monroe is represented by 70 feet of brown dolomites, which must be referred to the Flat Rock. It is more probable, however, that the entire series of beds overlying the Sylvania is referable to the Flat Rock horizon.

This formation is typically developed on the Huron river in the vicinity of Flat Rock, Wayne county, Michigan. Here a brown dolomite forms the banks and bed of the creek for a short distance, and has been quarried in the meadows. It is thin-bedded, hard and practically barren of organic remains, except that at rare intervals *Syringopora* cf. *hisingeri* occurs, which is also characteristic of the lower dolomites of the salt shaft.

2. THE ANDERDON FORMATION.

This is named from the Anderdon quarry about a mile northeast of Amherstburg, Ontario, where the formation is typically exposed. The section shown in the quarry is as follows, in descending order:

C. *Soil and drift.*

B. *Dundee limestone* (Devonic).

B. 4. Compact dolomitic calcilutite, weathering light brown, and resembling strikingly some layers of the Monroe formation. No fossils except the spine of a fish have been found in this bed. Thickness exposed 1-4 feet.

B. 3. Calcarenites, highly crystalline in the upper portion, with crinoidal disks and of a light gray or purplish color. Some layers are covered with specimens of *Rhypidomella livia* (Billings). Other layers of this rock are full of a small variety of *Atrypa reticularis*, together with various Stropheodontas, and other characteristic Dundee fossils. Analysis shows this bed to average 81.24% $CaCO_3$ and 16.75% $MgCO_3$. Total thickness of B. 3, 15 feet.

B. 2. Fine and uniformly grained calcarenite,—approaching closely to a calcilutite, in beds from a fraction of a foot to one foot or more in thickness, and practically barren of fossils but with numerous vertical, curved, or horizontal tubes which are formed by the decomposition of pyritous stems, and visible on the surface of the slabs as rounded pits. The rock does not show stratification well. It is bluish when fresh, but readily weathers to a buff. When unweathered it has more nearly the appearance of a calcilutite. Analysis shows a composition of 62.02% $CaCO_3$ and 34.08% $MgCO_3$ together with 2% of insoluble residue. Thickness to upper floor of quarry, 6 feet.

B. 1. Brown, compact and fine-grained dolomite, apparently unfossiliferous. Thickness to second floor of quarry about 6 feet.

Great disconformity, representing the entire Lower Devonic and a part of the uppermost Siluric.

2a. ANDERDON LIMESTONE.

A. *Siluric.* This is shown in the deepest eastern part of the quarry. In the extreme eastern part it is represented by a Stromatopora reef from 6 to 8 feet thick and composed almost entirely of large heads of *Stromatopora galtense* and *S.* (*Clathrodictyon*) *ostiolatum*, together with an abundance of the small branching Stromatoporoids, *Idiostroma nattressi.* Favosites and other corals are also abundant, but molluscs and brachiopods are rare. (See list of species.) Downward and laterally this reef passes into finely and evenly bedded calcilutites with characteristic conchoidal fracture. The lowest beds exposed are mottled, but the others are laminated. Intercalated in the calcilutites are some thin beds of calcarenites, one of which, about 4 feet above the base of the quarry, appears oölitic, and shows an occasional crinoid disk. Otherwise the rock is wholly barren of fossils except at the reef portion.

The fossils obtained from the reef are:

Stromatoporoidea.	
Clathrodictyon ostiolatum Nicholson	cc*
C. variolare V. Rosen	c
Cocnostroma pustulosum Grabau	rc
Stromatopora galtense (Dawson)	c
Stylodictyon sherzeri Grabau	rc
Idiostroma nattressi Grabau	cc
Anthozoa.	
Helenterophyllum caliculoides Grabau	rc
Cyathophyllum thoroldene Lambe	rr
Diplophyllum integumentum Barrett	rc
Cystiphyllum americanum mut. *anderdonense* Grabau	c
Ceratopora tenella (Rominger)	c
Cladopora bifurcata Grabau	
Favosites basaltica mut. *nana* Grabau	rc
F. concava Grabau	c
F. rectangulus Grabau	c
Brachiopoda.	
Spirifer (Prosserella) lucasi Grabau	rr
Gastropoda.	
Pleurotomaria cf. *velaris* Whiteaves	rr

Analysis shows this rock to be nearly pure lime, the percentage of $CaCO_3$ being as high as 99+%.

Exposed to the lowest floor of the quarry, 24 feet.

The surface of the Anderdon bed forms the middle quarry floor, and was originally overlain throughout most of its extent by the lowest brown dolomite of the Dundee (B. 1), much of this has since been removed by quarrying operations. The surface of the Anderdon bed thus uncovered shows evidence of extensive erosion before the brown dolomite of the Dundee was deposited upon it. Shallow channels of a foot or more in width traverse the calcilutite in all directions and are commonly filled by the material of the overlying bed. The channels are very similar to those worn along joints of the surface rock of certain parts of the Sahara desert, by the drifting sands,[18] and suggest eolian erosion during early Devonic time, when this surface was exposed to the atmosphere. Sections of a large species of gastropod, probably *Trochonema ovoides* Grabau, characterize the surface in many places. These large shells rested on the mud on their flat under surface and thus were sectioned parallel to the base during the erosion of the limestone surface. Along the contact with the overlying brown dolomite a quartz sandstone, or calcareous silicarenite with rounded quartz grains embedded in a more or less calcareous matrix, was found by the Rev. Thomas Nattress. This rock corresponds to a similar layer in the drill cores of the Sibley quarries as described beyond, and represents the Oriskany.

*c=common, cc=very common, r=rare, rr=very rare, rc=moderately abundant.

[18]For an illustration of these see Martonne, Ed. de, Traité de Géographic Physique, 1909, plate XXXIII, B.

A comparison of the fauna of the reef shows a very close correspondence with that of the reef of the salt shaft. Much of the material is better preserved and a few new forms are added to the salt shaft list, while several of that list are unrepresented at the Anderdon quarry. Nevertheless there can be no doubt as to the identity of the two beds. The total absence of the Lucas beds in this section shows the extent of erosion here prior to the deposition of the Dundee. There can be no question that the whole of the Lucas beds, some 180 feet thick at Detroit, and originally probably thicker, was also present at one time in the Anderdon region, and that it was wholly worn away in lower Devonic time, so that with the advent of the mid-Devonic sea, the new deposits here were laid down upon the erosion surface of the Anderdon bed.

2b. THE ANDERDON LIMESTONE OR CORAL BED OF THE SALT SHAFT.

This is a light-brown, fine-grained, calcarenite of a somewhat crumbly character. It is 37 feet thick. Fossils are abundant, consisting mainly of corals and Stromatoporoids. So far as can be ascertained the material here, as at the Anderdon quarry, represents a reef *in situ*, the contemporaneous erosion of which has supplied the lime-sand for the calcarenite of the bed.

The fauna is entirely distinct from that of the overlying Lucas dolomite and is essentially a coral fauna in which Devonic elements abound. The fossils obtained from it are:

Stromatoporoidea.	
Clathrodictyon ostiolatum Nicholson	cc
Stromatopora galtense (Dawson)	c
Stylodictyon sherzeri Grabau	rc
Idiostroma nattressi Grabau	c
Anthozoa.	
Cyathophyllum cf. *thoroldense* Lambe	r
Synaptophyllum multicaule (Hall)	rc
Diplophyllum integumentum (Barrett)	c
Favosites basaltica var *nana* Grabau	c
Cladopora dichotoma Grabau	c
Syringopora retiformis Billings	rc

Brachiopoda.	
Spirifer (Prosserella) modestoides Grabau	rc
Pelecypoda.	
Conocardium monroicum Grabau	rc
Gastropoda.	
Eotomaria galtensis (Billings)	r

The fossils are mostly calcareous but a few of the Stromatoporoids are silicified. This formation is apparently a direct succession of the Flat Rock dolomite, the one grading into the other. The formation likewise appears to grade upward into the overlying division (Lucas), though the Amherstburg dolomite has not been differentiated in the material from the shaft.

2c. THE ANDERDON OF THE SIBLEY WELLS.

The Anderdon bed is again observed in the cores of the test holes drilled in the Sibley quarry near Trenton. The section here comprises 76 feet of pure crystalline Dundee limestone, below which occur from 14 to 19 feet of a high grade limestone with the typical Anderdon species of corals. This grades downward into unfossiliferous brownish dolomites, probably representing the Flat Rock horizon. At the point of contact between the Dundee and Anderdon the cores show several inches to a foot of quartz sand, sometimes pure, but generally intimately mixed with the limestone. The grains are all perfectly rounded, small and of uniform size indicating wind transported material, or reworked Sylvania. From its position between Monroe (upper) and Dundee, the sand corresponds in a general way to the Oriskany of New York. It probably accumulated during the period of dry land and erosion, which in this region characterized the Lower Devonic, the material being derived most probably from the near at hand Sylvania.

The details of the well sections in the Sibley quarry, as determined from the cores, are as follows:

Core No. 1. Mouth about 20 feet above river, or some 594 ft. A. T. Depth 67 feet.

Dundee limestone	32 ft.
Disconformity	
Anderdon limestone with reef fossils	14 ft.
Dolomitic limestones, probably Flat Rock, to bottom of hole.	21 ft.
At 46 feet the $MgCO_3$ is	16.80%
" 50 " " " "	37.04%
" 55 " " " "	33.18%
" 60 " " " "	43.26%
" 62 " " " "	43.26%
" 67 " " " "	36.96%

Core No. 2. Mouth above river level about 9 feet or about 583 A. T. Beginning on Bed I of the Dundee:

DUNDEE:	
1. Dundee above mouth of well	35 ft.
2. Dundee in well	41 ft.
Total Dundee	76 ft.
MONROE:	
3. Calcarenite with numerous rounded grains of pure quartz	1
4. Calcilutites	2
5. Calcarenites with some Anderdon fossils	2.5
6. Typical Anderdon reef rock	4.5
7. Calcarenite with occasional reef fossils	6
8. Calcilutite	3
9. Calcilutite with 32 to 43% $MgCO_3$	14
10. Fine grained calcarenite with alternating streaks of calcilutite	8
Total Monroe	41

Of this 41 feet of Monroe the upper 19 feet (beds 3-8) are typical Anderdon, while beds 9 and 10 probably represent the Flat Rock, which is a pure dolomite. If this correlation is correct, then only the lower portion of the Anderdon (19 ft.) is present in the core sections. None of the wells were put down to the Sylvania, so we do not know the thickness of the Flat Rock in this section.

2d. THE TOLL PIT BEDS.

At the Toll pit quarry, near Scofield, the upper part of the Sylvania is interstratified with some dolomitic layers carrying an Anderdon fauna. From this *Favosites basaltica* var. *nana* and *Cladopora dichotoma* have been identified. The mixture of limestone and rounded quartz grains is intimate, the latter prevailing. This indicates that the Anderdon was the first bed to be deposited in this section, on the invasion of the Sylvania sand-area by the sea, the upper beds of the sand being incorporated in the basal deposit. That only a part of the Anderdon was deposited here, is shown by the relationship existing at the Woolmith quarry further west, where the Amherstburg fauna occurs 20 to 30 feet above the sandstone. At the Toll pits, the pre-Dundee erosion has carried away all the Monroe beds except this thin layer of Anderdon in the upper Sylvania. On top of this eroded surface the Dundee was subsequently deposited and of this traces still remain.

3. THE AMHERSTBURG OR TRANSITION BED.

This has not been recognized in the salt shaft, nor has it been preserved in the Anderdon quarries where pre-Onondaga erosion has removed it together with the overlying Lucas beds and perhaps a part of the Anderdon, as has been the case at the Sibley locality. It, however, forms the bed of the Detroit river opposite Amherstburg, where dredging in the Canadian channel of the river has brought the rock to the surface. A good exposure of the strata has also been obtained in the dry excavation of Livingston channel, along side Stony island. It consists of a brown dolomite, very porous and highly fossiliferous, containing a remarkable assemblage of species, many of them of types heretofore only known from the middle-Devonic in this country. The following list comprises the species obtained by the Rev. Thomas Nattress, of Amherstburg, from the dredgings of this channel. As will be seen by comparison with the species of the Anderdon bed, many species are found in common between these two formations, though a number of species not yet recorded from the Anderdon bed are found here. Several of the most characteristic species pass upwards into the overlying Lucas dolomite.

Species of the Amherstburg bed (dolomite) of the Detroit river:

Stromatoporoidea.	
Clathrodictyon ostiolatum Nicholson	rc
Idiostroma nattressi Grabau	rc
Anthozoa.	
Heliophrentis alternatum Grabau	c
mut compressum Grabau	r
mut *magnum* Grabau	r
Heliophrentis carinatum Grabau	c
Cystiphyllum americanum var *anderdonense* Grabau	r
Acervularia sp.	r
Synaptophyllum multicaule (Hall)	c
Diplophyllum integumentum (Barrett)	rc
Romingeria umbellifera (Billings)	c
Ceratopora regularis Grabau	rc
Favosites tuberoides Grabau	c
Cladopora dichotoma Grabau	c
Cladopora dichotoma Grabau	c
Syringopora hisingeri Billings	c
Bryozoa.	
Fenestella sp.	c
Brachiopoda.	
Schuchertella interstriata (Hall)	rc
Schuchertella amherstburgense Grabau	rc
Stropheodonta vasculosa Grabau	rc

Stropheodonta præplicata	rc
Stropheodonta sp.	rc
Spirifer sulcata mut *submersa* Grabau	rc
Spirifer (Prosserella) modestoides Grabau	rc
mut depressus Grabau	c
Whitfieldella sp.	rc
Meristina cf. *profunda* Grabau	?
Atrypa reticularis	rr
Cyrtina sp.	rr
Pelecypoda.	
Panenka canadensis Whiteaves	rc
Cypricardinia canadensis Grabau	rc
Conocardium monroicum Grabau	c
Gastropoda.	
Hormotoma subcarinata	c
Holopea antiqua pervetusta (Conrad)	rc
Acanthonema holopiformis Grabau	c
Strophostylus cyclostomus Hall	rc
Eotomaria areyi Clarke and Ruedemann	rc
Eotomaria sp.	rc
Lophospira bispiralis (Hall)	rc
Trochonema ovoides Grabau	mr
Cephalopoda.	
Dawsonoceras annulatum americanum Foord	rc
Cyrtoceras orodes Billings	rc
Poterioceras cf. *sauvidens* Clarke and Ruedemann	r
Tachoceras anderdonensis Grabau	r
Trilobitæ.	
Proetus crassimarginatus	rc
Annelida.	
Cornulites armatus Conrad	rr

The bed is again found in the lower part of the Gibraltar quarry in Brownstown township, Wayne county, 18 miles south of Detroit. Only about 5 feet of the rock are exposed, passing upward into the true Lucas dolomite. The dolomite is brown and porous and indistinguishable in lithic character and organic contents from the rock dredged in the Detroit river. There is a bed rich in Stromatoporoids exposed in the base of the quarry, but for the most part the fossils found in the lower beds are scattered. They comprise the following species:

Hydrocorallines.	
Stromatopora ostiolatum Nicholson	c
Anthozoa.	
Heliophrentis carinatum Grabau	rc
Cladopora bifurcata Grabau	c
Pelecypods.	
Conocardium monroicum Grabau	rc

The depth at which the Sylvania lies in this section is not ascertained, though the fact that across the river, at the Anderdon quarry, the Anderdon bed is shown, suggests that this bed lies below the floor of the Gibraltar quarry. The upper beds of the Gibraltar quarry are the typical gastropod bearing Lucas dolomites.

The Amherstburg bed is probably found in the lower part of, or just below, the Patrick quarry on Grosse Isle, but since this quarry is now filled with water the evidence for, or against this supposition is inaccessible. From the fossils formerly collected here, this seems to be the case. The bed in question seems to appear again in the lower part of the Woolmith quarry near the town of Scofield, Exeter township, Monroe county. Here a dolomite—bed F of Sherzer's report on this quarry—[19] lying a little below the middle of the quarry, carries a meager fauna, which though poorly preserved, clearly represents the Amherstburg horizon, though it may be a recurrent fauna at a somewhat higher level than the top of the Amherstburg.

The following species have been obtained:

Anthozoa.	
Heliophrentis carinatum Grabau	rc
Diplophyllum integumentum Barrett	rc
Cladopora bifurcata Grabau	r
Cladopora cf. *cervicornis* Hall	rc
Bryozoa.	
Fenestella sp.	r
Brachiopoda.	
Meristospira michiganensis Grabau	cc
Pelecypoda.	
Conocardium monroicum Grabau	cc
Panenka canadensis Whiteaves	r

The higher beds carry a true Lucas fauna, while below this bed are about 35 feet of siliceous dolomites resting on the Sylvania, and themselves containing streaks and grains of pure quartz. These lower dolomites clearly represent transitional phases from the Sylvania which recurs periodically in the form of these streaks or scattered grains (Sherzer). These lower beds may be exposed in some of the quarries southwestward from this point to the state line, but they have not been definitely recognized, since where they rest on the Sylvania they are not always fossiliferous.

[19]Geol. report of Monroe county, by W. H. Sherzer. Geol. Surv. Mich., Vol. VII, Pt. 1, p. 81.

In Lucas county, Ohio, the Lucas dolomite rests on the Sylvania in all the quarries, thus showing that the lower beds, including the Anderdon and Amherstburg, have been cut out by overlap of the dolomite on the Sylvania, which here has been converted into the basal bed of a transgressive, marine series.

The thickness of the Amherstburg bed is probably not over 20 feet, and very likely it is much thinner. Five feet of it are shown in the Gibraltar quarry, and below this is a Stromatoporoid bed which may represent the top of the Anderdon. From 10 to 20 feet are probably a fair estimate of this bed, which so far has not been found exposed completely in any section.

4. THE LUCAS DOLOMITE.

This is the highest Monroe bed of the salt shaft where 189 feet exist between the Anderdon and the Dundee, the basal portion probably including the Amherstburg dolomite. Southwestward from this point, at the Sibley quarries, the drill cores show that this bed is wholly wanting, the Dundee resting on the Anderdon with a bed of quartz grains marking the contact. Southeast of the Sibley quarries, at Anderdon and in the Canadian channel of the Detroit river, this bed is also wanting, the Dundee in the former resting directly upon the Anderdon, while in the Detroit river only the Amherstburg bed has thus far been found. A little to the south of this, however, and between the Anderdon and Sibley quarries, some 20 feet of the Lucas beds are exposed in the Patrick quarry on Grosse Isle, while at Gibraltar about 3½ miles further west, from 20 to 30 feet of the lower Lucas are shown resting upon the Amherstburg. The following species have been obtained from the beds of the Patrick quarry, on Grosse Isle. Those starred probably belong to the Amherstburg bed on the floor of the quarry:

Anthozoa.	
Cylindrohelium profundum Grabau	rc
**Romingeria umbellifera* (Billings)	rc
**Cladopora bifurcata* Grabau	rc
Brachiopods.	
**Prosserella modestoides* Grabau	rc
Prosserella lucasi Grabau	rc
Prosserella subtransversa Grabau	rc
Prosserella unilamellosa Grabau	rc
Meristospira michiganense Grabau	r
Cyrtina sp.	

Pelecypoda.	
Conocardium monroicum Grabau	c
Gastropoda.	
Acanthonema holopiformis Grabau	c
A. holopiformis var *obsoleta* Grabau	rc
A. laxa Grabau	rc
A. newberryi (Meek)	rc
Cephalopoda.	
Orthoceras cf. *trusitum* Clarke and Rued.	r

In the Gibraltar quarry about 20 feet belong to the Lucas dolomite, and these with the 5 foot of Amherstburg in the floor of the quarry, make up the exposed rock mass. The following species have been obtained from this horizon:

Anthozoa.	
Cylindrohelium profundum Grabau	c
Brachiopoda.	
Prosserella subtransversa Grabau	rc
Pelecypoda.	
Panenka canadensis Whiteaves	r
Conocardium monroicum Grabau	rc
Modiella ? sp.	r
Gastropoda.	
Hormotoma subcarinata Grabau	c
Hormotoma tricarinata Grabau	r
Acanthonema holopiformis Grabau	c
A. holopiformis var *obsoleta* Grabau	rc
A. laxa Grabau	rc
Eotomaria areyi Clarke and Rued.	rc
Eotomaria galtense (Billings)	rc

In the Woolmith quarry a total of 75 feet of the strata are exposed, of which the upper 40 to 50 feet are referable to the Lucas. The following species have been obtained here:

Anthozoa.	
Cylindrohelium profundum Grabau	c
Brachiopoda.	
Spirifer (*Prosserella*) *lucasi* Grabau	r
Gastropoda.	
Hormotoma subcarinata Grabau	rc

The following analyses show the variable character of these strata:

	4 ft. down.	18 ft. down.	24 ft. down.
Silica	6.19	3.05	97.76
Iron oxide and alumina	.45	.31	.55
Calcium carbonate	50.12	52.72	1.14
Magnesium carbonate	43.53	44.59	1.43
Difference	—.29	—.67	—.88
	100.00	100.00	100.00

The last of the three samples represents a recurrent streak of Sylvania.

About 4 miles southeast of the Woolmith quarries, at the Toll pits in the Sylvania sand, these beds are wholly cut out by the pre-Dundee erosion, the lower Dundee with characteristic fossils resting directly upon the Sylvania sandstone, as noted by Rominger in 1876,[20] and grading down into the Sylvania. The upper Sylvania carries an abundance of molds of *Paracyclas*, showing that during the advent of the Dundee waters the upper beds of the sand were reworked and the Dundee fossils embedded in it. In some of the beds, as already noted, Anderdon species are enclosed, showing that the Anderdon and higher beds were present originally, but were eroded before the deposition of the Dundee.

In northern Ohio the lower Lucas beds are shown in the Webster and Silica quarries west of Sylvania, Ohio. In the former the upper beds have furnished:

Cylindrohelium profundum Grabau	r
Cladopora bifurcata Grabau	c
Schuchertella interstriata (Hall)	rc
Prosserella lucasi Grabau	cc
Atrypa reticularis Linne	?
Acanthonema holopiformis Grabau	r
While the higher beds of the Silica quarry carry—	
Heliophrentis carinata Grabau	r
Cylindrohelium profundum Grabau	c
Prosserella lucasi Grabau	r
Prosserella subtransversa Grabau	rr

A quarter of a mile east of the sand pits at Silica, the lower Dundee crops out at the roadside. It carries the usual Dundee species of this region, with *Hexacrinus* stem-joints in abundance. The estimated dip of the strata would make the interval between this outcrop and the top of the Sylvania about 200 feet, but this is perhaps too great. In the S. K. Cooper quarry, 2 miles west of Sylvania and ½ mile south of the Webster quarry, Lower Dundee with *Hexacrinus* sp. nov. is again found resting directly upon the Lucas beds, similar to those of the Webster quarry. A well across the road from this quarry, however, passed, according to report, through 75 feet of dolomite without reaching the Sylvania. It is not impossible that a local fold has brought the Sylvania above the erosion plane, the well beginning below it, or that a synclinal

[20] Geol. Surv. Mich. Vol. III, Pt. I, p. 27.

fold has carried the Sylvania to a considerable depth. The beds of the Webster quarry are, however, close to the Sylvania, since the sandrock is found outcropping near by.

Half a mile further south, or a mile south of the Webster quarry, the Lower Dundee beds were quarried extensively. Here *Hexacrinus* sp. is not uncommon, besides the brachiopods and other fossils of this horizon.

The Monroe-Dundee Disconformity.

It is evident from the foregoing that a pronounced stratigraphic break exists between the Monroe and the Dundee, and that the former was subjected to considerable erosion before the deposition of the latter upon it. This is shown by the fact that the Dundee rests on various members of the Upper Monroe (Detroit River Series). Thus, in the Detroit region it rests on some 180 feet of Lucas dolomite, while at Sibley and Anderdon it rests on the Anderdon limestone. At the S. K. Cooper quarries it rests on the Lucas dolomite, of which at least 75 feet are present, if the reported well record is reliable. At the Toll pit quarry south of Scofield, Michigan (7 miles northwest of Monroe), it rests directly on the Sylvania, with which it is even to some extent interbedded.

Since the Monroe and Dundee strata are so nearly horizontal that the difference in the dip between the two series is not ascertainable, the stratigraphic break is not easily recognized, and has in fact been commonly overlooked. When it is seen, however, that the Dundee in different localities in Michigan and northern Ohio rests on different members of the Monroe, even down to the Sylvania, while in central Ohio it rests on Lower Monroe, it is apparent that a break does exist and that marked erosion has occurred with only sight previous folding of the strata and sometimes with none at all. This erosion is further shown by the worn shells and the solution, or erosion grooves of the Anderdon bed at the contact with the Dundee at the Anderdon quarries as described above. The stratigraphic break described falls under the term disconformity, proposed by Grabau for such breaks, which are readily distinguished from unconformities, where folding and erosion of the lower series has preceded the deposition of the upper series. The stratigraphic interval, or hiatus, thus left unrepresented, constitutes elsewhere the Lower Devonic.

STRUCTURAL RELATIONSHIPS OF THE BEDS.

A critical consideration of the relationship of the Lower Monroe beds to underlying formations brings out the fact that they represent a marine invasion of what was formerly, to a large degree at least, dry land. Thus, the lowest bed shown at Greenfield, in southern Ohio, and Ballville, in northern Ohio, the Greenfield dolomite, rests disconformably upon the Niagara, or perhaps Salina beds, (Hillsboro sandstone). It is succeeded by Devonic black shale, the Sylvania sandstone and higher members being wholly cut out. In Monroe county, Michigan, (Monroe wells), the Lower Monroe is reported over 600 feet thick, and rests on Niagara, without intervention of Salina, while a short distance north of Detroit (Royal Oak well), a thousand feet of Salina underlie nearly 500 feet of Lower Monroe. It is, of course, impossible at present to determine whether or not a disconformity exists between the Salina and the Monroe in the region around Detroit. If the Salina is interpreted as a continental (i. e. desert) deposit such a disconformity undoubtedly exists. If, on the other hand, the Salina is regarded as a border-sea deposit a disconformity need not necessarily be implied. Whatever the relationship (which will be more fully discussed in a later section), it is clear that the Salina deposit was more limited in area than the Monroe, which overlapped it southward and westward (and probably in other directions as well) and came to rest upon the eroded surfaces of earlier Siluric formations. In general it may be said that south of a line drawn so as to leave Muskegon and Wyandotte on its northeast, and Monroe and Kalamazoo on the southwest (Lane) the Monroe overlaps the Salina and rests disconformably on pre-Salina formations. The apparent absence of the Lower Monroe beds in the salt shaft section also suggests irregularity of the old Salina surface across which the sea transgressed in Lower Monroe time, and this irregularity may in part account for the varying thickness of the Lower Monroe in the different wells.

The Mid-Monroe Disconformity.

As will be more fully shown in the descriptions of the Sylvania, a disconformity of some extent probably exists at the base of that formation, thus accounting in part for the unequal thickness of the Lower Monroe in different well sections. No direct proof of this has yet been obtained, though in some Indiana wells sandstone, identified as Sylvania, rests upon Niagara, and is succeeded by Dundee (Onondaga). The disconformity at the top of the Sylvania is well established, as shown by the progressive overlap of the successive members of the Upper Monroe on the Slyvania. The more important sections showing the relationship of the higher beds with the Sylvania are the following: In the Detroit well 47 feet of dolomite (Flat Rock) lie between the Anderdon and the Sylvania. South of Detroit, at Wyandotte, 130 feet of this lower formation overlie the Sylvania. At the Windsor well, 5.6 miles east northeast from the Detroit well, about 60 feet of the lower beds overlie the Sylvania. This indicates an unequal advance of the sea over the Sylvania surface so that the Wyandotte region was submerged first, later the Windsor region, and still later the Detroit region.

No outcrops, or well sections, are known to show the relationship of the Sylvania to the overlying formations along the Detroit river. That the greater part of the Flat Rock is overlapped by the higher beds seems certain, but whether this overlap is completed or not is not definitely settled. The outcrops of brown dolomite on Celeron island are most certainly of the Flat Rock, but whether that outcrop continues eastward between the Anderdon and the Sylvania is not known, the country being low, swampy, and more or less drift covered.

The Flat Rock dolomite is most certainly overlapped by the Anderdon near Scofield. At the Sylvania sand pits (Toll pits) the upper beds of the Sylvania contain the Anderdon fauna in siliceous limestones, as already noted. Subsequent erosion has removed all these beds down to the Sylvania, and a part of the sand was incorporated in the Dundee, most of which has since been worn away. In northwestern Ohio (Webster, Cooper, Silica quarries) the Lucas has overlapped the Anderdon, resting directly upon the Sylvania.

Lower Devonic Deformation.

During Lower Devonic (post-Monroe) time, this region suffered slight deformation, the extent however, being insufficient to affect the apparent relationship of the strata so far as conformability is concerned. Thus, in all the outcrops, where the later formations

rest upon the earlier ones, which were truncated after deformation, the difference in dip between the two formations is so slight as to be unrecognizable. As a result it is extremely difficult to locate the disconformity which exists, and a hiatus covering several hundred feet of strata is recognizable only by palæontologic means. The local deformation which this region suffered in Lower Devonic (pre-Dundee) time comprises, at least, one anticline with two synclines. The general trend of the axis of these gentle folds is in a direction about north 60° east. The axis of the anticline passes through Wyandotte, and about 5 miles north of the Woolmith quarry. The axis of another, but incomplete anticline, passes south of the Anderdon quarry and through, or to the south of the Sylvania sand pits near Scofield. The axis of one of the synclines passes through Grosse Isle and the Gibraltar and Woolmith quarries, and the second through Windsor and the salt shaft. In the center of the more southern syncline, the top of the Sylvania is 280 feet below the mouth of the Church & Company's well, which begins 6 feet above the level of the Detroit river (580 A. T.), and there is probably not over 30 feet of dolomite between the Sylvania and the Anderdon. In the Wyandotte well at least 135 feet of these lower dolomites overlie the Sylvania, the surface of which was thus originally approximately 100 feet lower at Wyandotte than at the Church & Company well. Correcting for this, and assuming that, before erosion in this region, the Dundee rested directly upon this 135 feet of dolomites at Wyandotte, and likewise upon the 280 feet of dolomites and limestones of the Church & Company well, we get a measure of the amount of deformation between the anticline and syncline by noting what would be the depth of the surface of the Sylvania, assumed to be level before deformation, and the base of the Dundee as deposited on the eroded surface. This difference in the section under discussion is about 250 feet, the distance between the two points being about 5 miles, making the rate of deformation 50 feet to the mile. In the same way the deformation between the Wyandotte and salt shaft regions is about 360 feet with a distance between points of about 6 miles, or a rate of deformation of 60 feet to the mile.

The Dundee invasion, following upon prolonged erosion of this slightly deformed region resulted in the deposition of the Dundee upon various Siluric beds. Thus in the salt shaft region about

275 feet of the upper Monroe remained. In the Wyandotte region only 135 feet. In the Sibley region the Dundee came to rest on the lower 19 feet of the Anderdon,—a similar relationship existing near Amherstburg (Anderdon quarry), while between these points various thicknesses of Lucas rested beneath the Dundee. At the Toll pits the Dundee came to rest directly on the Sylvania, while southeastward in Ohio and Canada the Dundee came to rest on various members of the Lower Monroe.

The Post-Devonic Deformation.

A second deformation of this region occurred in post-Devonic time, affecting the higher as well as the lower strata. The directions of the axes of the new set of low folds was in part parallel and in part nearly at right angles to those of the earlier folds. One of these later folds apparently underlies the Detroit river with a northeastward trend, as shown by the fact that the Dundee has been removed over this region while a fragment of the Sibley outlier remains in the Sibley region. This fold also caused the southward dip of the Dundee at the Anderdon quarry[21] and also that now shown in the operations in the bed of the Detroit river, at Stony island. Another broader fold underlies the Huron river and Swan creek, and this has resulted in separating the originally continuous anticlines into two sets pitching in opposite directions. The first of these deformations, that of Lower Devonic time, was incidental to the larger deformation which produced the Michigan basin and the Cincinnati anticline. The second one, of post-Devonic origin, was probably contemporaneous with the Appalachian deformation, and was closely connected with a second basining of the Michigan and doming of the Cincinnati regions.

THE WESTERN NEW YORK SECTION.

In western New York the highest Siluric formation is a magnesian calcilutite of marine origin. It is locally known as the "Bull Head limestone" and is best exposed in the cement quarries in North Buffalo, at Williamsville, and at Akron, in Erie county. From the latter exposure it has recently been named by Grabau the Akron dolomite. In the first of these localities it is 7 feet thick, in the others its thickness is 8 feet. In all its exposures it is intimately associated with the Bertie waterlime which immediately underlies it and with which it forms a continuous depositional series. The rock is for the most part thin-bedded, and is often mottled with purplish blotches. It resembles very closely the rock from Greenfield, Ohio. Analysis shows 47.23% of $CaCO_3$ and 9.25% $MgCO_3$, the percentage of $CaCO_3$ being some 12% higher than that of the underlying Bertie waterlime.

[21]Nattress, T., Mich. Acad. Sci., 9th Ann. Report, p. 177.

The fauna of the Akron dolomite is comparatively meager. It was described by Grabau in 1900,[22] 12 species being recognized. One, a species of *Favosites*, has since been added. The species described are:

Plantae.
Nematophyton crassum Penhallow.
Anthozoa.
**Cyathophyllum hydraulicum* Simpson, abundant.
Favosites sp.
Brachiopoda.
***Orthothetes hydraulica* (non Whitefield) = *Schuchertella interstriata* (Hall) c
***Spirifer eriensis* Grabau
**Whitfieldella sulcata* (Vanuxem).
Whitfieldella (?) cf. *rotundata* (Whitfield) r
W. cf. *laevis* (Whitfield) = *Whitfieldella subsulcata* Grabau.
Rhynchonella ? sp. r
Gastropoda.
Loxonema ? sp. r
Pleurotomaria ? sp. r
Cephalopoda.
***Trochoceras gebhardi* Hall r
Crustacea.
***Leperditia scalaris* Jones c

A few of these species, such as *Leperditia scalaris* and some undescribed *Lingula* and other fossils occur in the upper beds of the Bertie waterlime, showing the oncoming of the marine fauna at the close of the Bertie time, shortly after the disappearance of the Eurypterids.

As pointed out by Grabau in 1900, this fauna is, in its leading species, that of the Coralline, or Cobleskill limestone, of eastern New York. The species in common between the Cobleskill of eastern New York and the Akron are marked with a double star (**), while those in common between the Akron and the Cobleskill of central New York are marked by a single star (*). It is thus seen that all the fully identified species are found elsewhere in the Cobles-

[22]Bull. Geol. Soc. of Am., Vol. II, pp. 347-376, Pls. 21-22.

kill, and this would seem to be a reliable indication of their equivalency. This equivalency, assumed by Schuchert and Hartnagel, has been generally accepted. If this correlation is correct it will serve as a means of further correlation between the eastern and western upper Siluric formation. (See further chapter.)

CHAPTER III.

THE SYLVANIA SANDSTONE; ITS DISTRIBUTION, NATURE AND ORIGIN.

BY W. H. SHERZER AND A. W. GRABAU.[1]

The occurrence in southeastern Michigan of a remarkably pure sandrock has been generally known since the publication of the early work of the Michigan Geological Survey, soon after the organization of the state. The silicious nature of the dolomite that one encounters as he ascends the River Raisin, in Monroe county, was noted in 1837 by Douglass Houghton, Michigan's first State Geologist, and attention called to the associated bed of pure quartz sand,[2] which occurs in outcrops some 7 miles northwest of the city of Monroe. The detailed study of this region was assigned by Houghton to his assistant Bela Hubbard and during the working season of 1838 data were secured for a brief report upon Monroe county and the adjoining county of Wayne.

The location of the sandrock in the bed of the Raisin was recognized, where it was stated to form a ledge a foot in thickness,[3] and its chief lithological characters noted. The sand was then being used locally for scouring purposes, and a sample had already been tested for glass manufacture for Thomas Colwell, upon whose farm was located the main outcrop. The silicious nature of the dolomites, occurring at the same geological horizon in northwestern Ohio, had been recognized at a slightly earlier date by John L. Riddell, M. D., who was one of a special committee commissioned by the Ohio legislature to report upon a method of obtaining a com-

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[1]The writers desire to acknowledge their indebtedness and to express their most appreciative thanks to the following persons for samples of sand: Libian desert, Mrs. Julia Sherman, Dr. Jane Sherzer and Dr. Johannes Walther, samples from the latter being obtained through the courtesy of Mr. Frank Leverett and Dr. Karl Kielhack; Prof. B. O. D'Ooge for samples of western Sahara and other sands; to Dr. Alfred C. Lane for samples from the neighborhood of Albuquerque, New Mexico; to Prof. Mark Jefferson for various samples of beach and dune sands; to Chief Milton Whitney, of the Department of Agriculture, for beach and dune sands; to Supt. O. H. Tittman, of the Coast and Geodetic Survey, for sea bottom sands off the Atlantic coast, and to Prof. Chas. P. Berkey and Geologist Samuel Weidman, for samples of the St. Peter sandstone.

[2]First Annual Report of the State Geologist, 1838. House document No. 24, p. 306.

[3]Second Annual Report of the State Geologist, 1839. Senate document No. 12, p. 377. House document No. 23, p. 493.

plete geological survey of the state. This report bears the date of January 12, 1837, and alludes to the calcareous sandstone then being procured for building purposes from the bed of the Maumee, thirteen miles above Perrysburg, and its occurrence as a ridge some three miles west of Miltonville, in Lucas county. The examination of this region for the Ohio Geological Survey was assigned to the assistant geologist, Prof. C. Briggs, Jr., and the work done during the season of 1838, at the same time that Hubbard was at work upon the Michigan series, just to the north. Apparently the main Sylvania bed was not seen, for the report states that some of the rock obtained from the Maumee bed is so sandy as to be mistaken by the inexperienced for sandstone.[4]

The crippling of both the Ohio and Michigan Surveys by the withdrawal of funds and their early suspension terminated all systematic geological work in these two states. With the temporary resumption of work in Michigan in 1859, under direction of Alexander Winchell, attention was again directed to this rock, but the full importance of the Sylvania as a separate stratum was not yet recognized, and it was included with the limestones then incorrectly referred to the Upper Helderberg.[5] The same disposition of the bed was made in the small volume entitled "Michigan," published by Dr. Winchell in 1873 and in Tackabury's Atlas of Michigan, 1873, p. 40. In the text and upon the geological map accompanying the Atlas, page 39, the site of the Sylvania outcrop is colored "Corniferous." In the reorganization of the Ohio Survey in 1869, G. K. Gilbert was assigned the work in the northwestern part of the state, under the directorship of J. S. Newberry, and by him the Sylvania bed received further study and was for the first time located upon a geological map.[6] In the preliminary geological map of Ohio, issued in connection with Newberry's Report of Progress for 1869, the outcrop beneath the drift is shown as narrow strips upon either side of the Cincinnati anticline and referred to the Oriskany (p. 17). The stratum was later assigned a thickness of fifteen to twenty feet and in the text of Volume I, was referred to the Corniferous (p. 582), but upon the map of Lucas county was still marked "Oriskany." What was regarded as the same bed was

[4]Second Annual Report of the Geological Survey of Ohio, 1838, p. 112.
[5]First Biennial Report of the Progress of the Geological Survey of Michigan, 1861, p. 63.
[6]Geological Survey of Ohio, Report of Progress for 1869, 1871. Geological Survey of Ohio, Volume I, 1873, p. 573.

further traced by N. H. Winchell across the counties of Sandusky, Seneca, Wyandot and Marion, ranging in thickness from two to twenty feet and becoming in places a gravelly sand. In Sandusky county, only, was the bed seen in section, and here it was overlain by some six to eight feet of dolomitic limestone, apparently of Waterlime age. By Newberry the bed was believed to mark the horizon of the Oriskany sandstone of New York (p. 141), although no fossils were found in the Ohio deposits to sustain such belief. This disposition of the bed was regarded as the most satisfactory by Rominger in his studies of the Michigan strata[7] and was the one commonly made by the Ontario geologists who were called upon to interpret the records of the wells in the western part of the province, the Oriskany having been recognized in eastern Ontario as early as 1863 by Sir William Logan.[8] In the year 1888 Edward Orton, then State Geologist of Ohio, assigned the name Sylvania to the bed, from the locality near which it is now being quarried[9] and confirmed the observation of N. H. Winchell, above referred to, that it lies well embedded in rocks referred by the Ohio Survey to the Lower Helderberg, or Waterlime. Studies in Monroe county, Michigan, by W. H. Sherzer, conducted for the State Survey, led to the mapping of the bed from Sylvania to the mouth of the Detroit river. Further conclusive evidence was obtained that it lies, in certain places, far below the base of the Corniferous[10] and embedded in the series of late Silurian strata to which the name *Monroe* has been given by former State Geologist, A. C. Lane.[11] The main body of the bed must be regarded as of Monroe age, and this view has been accepted by the Michigan and Ohio surveys.

The suitability of this sandrock for the manufacture of high grade glass, because of its purity, texture and incoherent nature, combined with the discoveries in the neighboring region of cheap fuel in the form of oil and gas, have greatly enhanced the value of this extensive deposit and given it economic importance. Owing to the certainty with which it could be distinguished from limestone and shale in well drillings, it has proven of much strati-

[7]Geological Survey of Michigan, Vol. III, 1876, p. 29.
[8]Geological Survey of Canada, Report of Progress from its commencement to 1863, p. 359.
[9]Geological Survey of Ohio, Vol. VI, 1888, p. 18. See also Vol. VII, 1893, p. 17.
[10]Geological Survey of Michigan, Vol. VII, 1900, Part 1, p. 60.
[11]Geological Survey of Michigan, Vol. V, 1895, Part 2, p. 26.

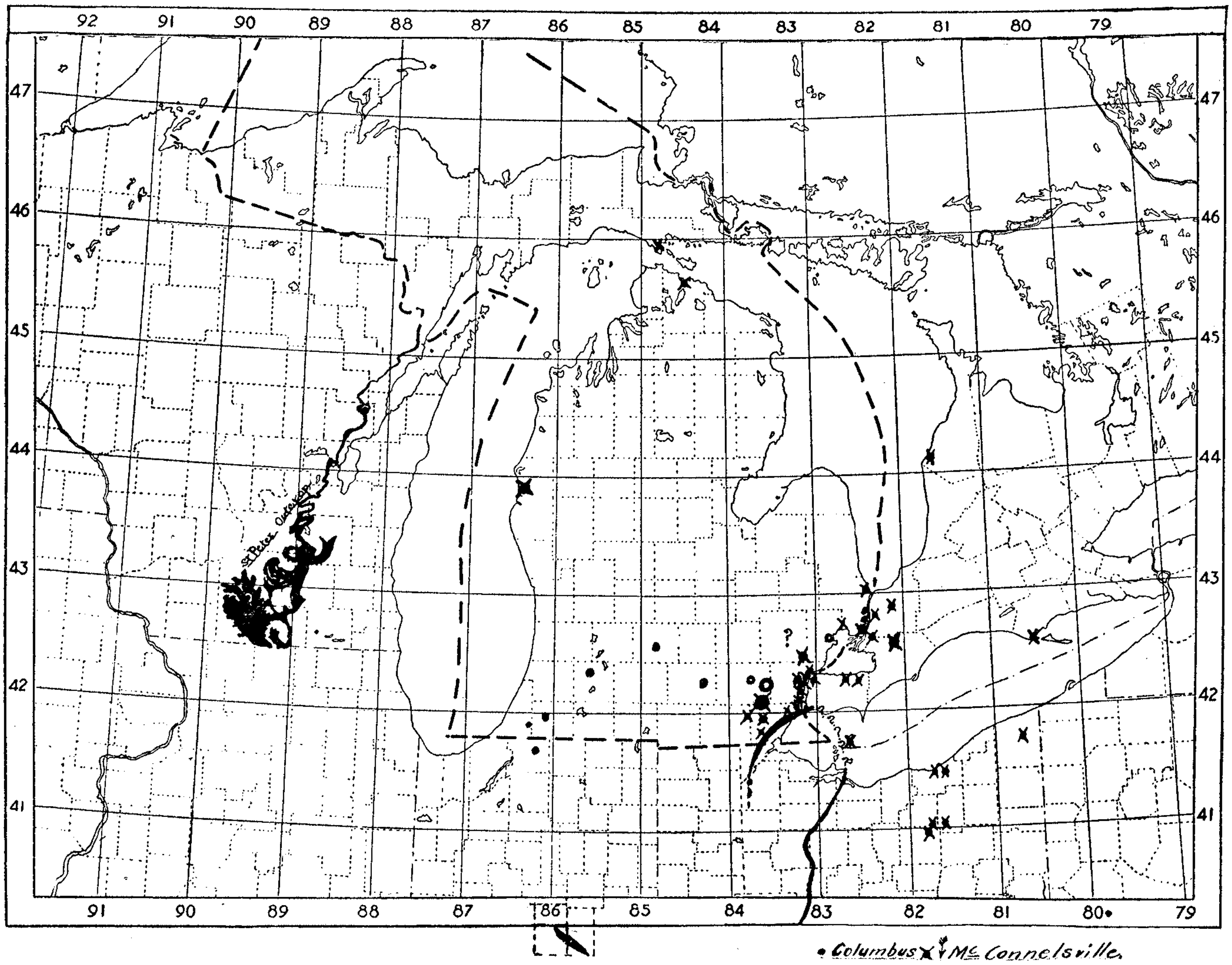


FIG. 1. MAP SHOWING DISTRIBUTION OF SYLVANIA SANDSTONE.

(Base map by permission of Prof. M. S. W. Jefferson.)

Outcrop (beneath drift) in black streak. Well records in black dots with cross (X); relative development roughly indicated by size of dots. Dots with light centers (°), bed not fully penetrated. Black dots, silicious dolomite or shale (●).
Four wells in Kent county, Ontario, are not yet located upon map because no map is available giving data needed.
1. Ravey well, Orford township, Lot 10, Concession 11, 160 feet of Sylvania.
2. Grant well, Orford township, lot 23, Concession 14, 90‡ feet of Sylvania.
3. (a) Camden well, Camden township, Lot 3, Concession 2, 46 feet of Sylvania.
4. (b) Camden well, Camden township, Lot 2, range 5, 10 feet of Sylvania.

graphic importance in the region about the Detroit river and the western end of Lake Erie. Studies by the authors during the past year indicate that, because of its method of formation, it may possess additional scientific interest. The vigorous search for oil, gas and salt in this region, during the past two decades, has given us much information concerning the distribution, position and thickness of the Sylvania. In outcrop, beneath the drift, the bed is known to extend as a narrow belt across the western portions of Wood and Lucas counties in Ohio, northeastward across Monroe county, Michigan, curving eastward and crossing the Detroit river near its mouth, as shown upon the map. Well records in Essex and Kent counties, Ontario, show that the bed must curve around to the southeastward, apparently about the northern extremity of the Cincinnati anticlinal fold.[12] The occurrence of a white sandrock at the proper geological horizon in the well upon Pelee island, regarded by Rev. Thomas Nattress as the Sylvania, indicates that the bed crosses Lake Erie southward, and that it may be expected to appear again in Ohio some miles to the eastward of its outcrop in Wood and Lucas counties. In Newberry's Ohio report of 1873, already cited, page 141, the bed is stated as crossing the peninsula north of Sandusky bay (Ottawa county) to the west of Marblehead, indicating that its outcrop lies in the bed of Lake Erie between Pelee island and Kelleys island, upon the east and the three Bass islands (North, Middle and South) upon the west. The general southwesterly course of the bed, evidently the basal portion, was traced by Winchell, as previously noted, across the counties of Sandusky, Seneca, Wyandot and Marion. In the next county to the south, Delaware, there occurs at the base of the Columbus a calcareous conglomerate, consisting of rounded pebbles of the underlying limestone regarded by Newberry as marking the same horizon as the sandrock, but by him referred to the Oriskany. Similar pebbles were noted sparingly by Winchell in Sandusky county.[13] Beneath an outlier of the Columbus, to the west in Logan county, an exposure of Sylvania occurs at West Liberty, as noted by Newberry. The strike of the Columbus and Monroe strata in the western portion of Ohio would lead us to look for evidence of this sandrock

[12]Geological Survey of Canada, 1893, New Series, Vol. V, Part 2, Brumell's report on gas and petroleum, p. 760. Annual Report of the Michigan Academy of Science, Vol. IX. 1907, p. 177. The Geological Continuity of Essex and Kent counties, Ontario, and Monroe and Wayne counties, Michigan, Rev. Thomas Nattress.
[13]Geological Survey of Ohio, Vol. I, 1873, p. 603.

in Allen or Adams counties, Indiana, and the tiers of counties to the west. No sections, or outcrops, have, however, been here noted by the Indiana geologists, and the published well records for the localities to the north are not given in sufficient detail to enable one to recognize the presence of the sand stratum at the proper geological horizon. In his report upon the natural gas field of Indiana,[14] however, A. J. Phinney maps a narrow strip of pure bluish-white sandstone, at the base of the Corniferous, as extending across the counties of Hamilton and Madison in a northwest-southeast direction. The stratum is referred to the Schoharie, of the New York series, upon the authority of James Hall, but the correctness of this reference is questioned in the text (p. 634), and the fossils found in the bed are assigned to the Corniferous.[15] The presence of Corniferous (Dundee) fossils, especially in the upper portion of the bed, agrees with the authors' observations in Monroe county, Michigan, and may be readily reconciled with their theory of its deposition. In the counties to the west, southwest and south of the outcrop the sand stratum, presumably the same, is penetrated by the drill, giving a thickness of 5 to 36 feet. The elimination of the Upper and Lower Monroe in places allows the sand bed to rest upon the Niagara and to carry directly above it the Corniferous. It seems probable that this bed is to be correlated with the Sylvania, from a careful consideration of the available data, although it should be noted that a very thin stratum of sand, or a silicious limestone, occurs above the Sylvania at, or near the junction of the Monroe and the Dundee and near the true horizon of the Oriskany. When the calcareous cement is removed by acid the sand grains remaining cannot be distinguished from those of the Sylvania and, it is probable, were derived from the earlier bed. It seems very probable that this Indiana bed is, or at some time was, continuous with the Ohio portion described, around the northern margin of the Cincinnati anticlinal arch, (see map).

[14]Eleventh Annual Report, Director U. S. Geological Survey, 1891, Plate LXIII.
[15]*Cyathophyllum rugosum, Conocardium trigonale, C. nasutum, Tentaculites scalariformis,* with several species of favositoids.

WELL RECORDS OF SYLVANIA SANDSTONE.

Well Locality.	Total Depth.	Approximate elevation of mouth.	Distance to Sylvania.	Approx. elev. of top of Sylvania.	Separate Sand Beds.	Total thickness.	Associated Silicious Dolomite.	Depth in Monroe.	General Remarks.
Ludington, Mich	2220	590 A. T.	2100	−1510 A. T.	one	40 ft.‡	95 ft.	95 ft.	Sandstone absent in adjacent well.
Cheboygan, Mich	2750		375		two?				Record incomplete.
Ann Arbor, Mich	1326	875	1245	−370		20+	265‡	200	Record incomplete.
Ypsilanti, Mich	1210	682	885	−203	90 & 210+	300+	25+		Lower bed not fully penetrated.
Milan, Mich	1643	685	535	+150	one	288		110	Sylvania pebbly at base.
Britton, Mich	1700	705	750	−45	25 & 100	125	75	250	Sandstone is dolomitic.
Emil Twark farm, Mich	1820	633‡	385	+248	5, 87 & 45	137			Sec. 12, Romulus Twp., Wayne Co.
Royal Oak, Mich	2502	655‡	836	−181	269 & 15	284	65		Probably some dolomite in heavy bed.
Mt. Clemens, Mich	1060	617	985	−368	one	75?	95	375	Apparently stopped in Sylvania.
Port Huron, Mich	1685+	611‡	1165	−554‡	one	50	95	480	Sandstone is calcareous.
Marine City, Mich	1608	600	1095	−495	one	67	165	271	Averages of three wells.
Kincardine, Ont	1007		297		one	29			
Courtwright, Ont	1665	588	1062	−474	one	32		370	
Petrolea, Ont	1314	647‡	1076	−429	16, 26 & 47	89	28		Sylvania just above salt.
Pt. Lambton, Ont	1720	600‡	1200	−600	50 & 40	90	480	370	Wide interval between beds.
Wallaceburg, Ont	2100+		1000		one	100			
Detroit, Mich	2097	610	615	−5	one	85			Stroh's brewery, Gratiot Ave.
Detroit, Mich	1656	585	450	+135	one	175	100		Edison Power Co., Well No. 1.
Delray, Mich		575	365	+210	one	58	50+	230	Drilling samples examined.
Delray, Mich	1572	575	419	+156	one or two	93.5			Average of 17 Solvay wells.
Oakwood, Mich	1660	575	410	+165	one	117		265	Detroit Salt shaft well.
River Rouge, Mich		575	365	+210	one	127			Tecumseh Salt Co.
Windsor, Ont	1167	610‡	535	+75	one	55			Canadian Pacific, Well No. 11.
Windsor, Ont	1445	610	550	+60	one	65	15+	350	Canadian Pacific, Well.
Ecorse, Mich	1200	575	395	+180	87 & 6	93	37+		Saw mill, Brownlee & Co.
Ecorse, Mich	1096	580	438	+142	78 & 36	114‡			Well of Detroit Salt Co.
Ford City, Mich		580	235	+345	90 & 90	180			Michigan Alkali Co., No. 23.
Ford City, Mich	1603	580‡	350	+230	one	150		270+	Michigan Alkali Co.
Wyandotte, Mich	1070	574	197	+377	65 & 35	100	105‡	135+	Morton Salt Co.
Wyandotte, Mich	2500	580	230	+350	one?	60		105‡	Well Eureka Iron Works.
Trenton, Mich	1600	580	280	+300	60 & 30	90			Church & Co., Well No. 4.
Trenton, Mich	1246	580	290	+290	120 & 60	180	20‡		Church & Co., Well No. 5.
Rockwood, Mich	1040	580	15	+565	one	75			Well of Dr. Dayton Parker.
Woolmith, Mich	130+	632	79	+553	one or two	50	30‡		Test well at quarry.
Dundee, Mich	2277	680	193	+487	12, 18 & 7	37		90‡	Based only on driller's record.
Dundee, Mich	2194	675‡	235	+440	18 & 7	25		132	Well No. 2, driller's record.
Ida, Mich	1200	643	32	+611	one	45			Well of Simion VanAkin.
Cranberry Marsh, Mich	327	675	80	+595	one	45‡			Sec. 24, Summerfield twp., Monroe Co.
Sucker Creek	1144	609	410	+199	one	30		260	Anderdon twp., Essex Co., Ont.
Park's Well	1004		258		one	84			Malden twp., Essex Co., Ont.
Colwell Grove	1418		260			60			Malden twp., Essex Co., Ont.
Belle River	1465	600	275	+325	one	25			Shore of Lake St. Clair.
Pelee Island	800‡			+312‡		40			
Newberg, Ohio	3000‡	780	1660	−880	one	40			Cleveland Rolling Mill.
Pt. Rowan, Ont	1460		554			15‡		141?	Shore of Lake Erie.
Comber, Ont	1306		360		one	10			Near Comber, Essex Co., Ont.
Ravey Well	1000		555		75 & 85	160			Orford Tp., Kent Co., Ont.
Grant Well	500		410		several	90‡			Orford Tp., Kent Co., Ont.
Camden Well	500		413		one	46			Camden Tp., Kent Co., Ont.
2nd Camden Well	569		559		one?	10‡			Camden Tp., Kent Co., Ont.
Jefferson, Ohio	1992+		1992			30 to 40			Furnishes gas.
McConnelsville, O.	3186	725	3133+	−2408+					Sandstone and limestone mixed.
Barberton, Ohio	3006		2500		one	30			Columbia Chemical Co.
Jefferson, Ohio	2140		2098		13 & 13	26			Lot of J. A. Giddings.
Rittman, Ohio	2624		2303		one	30			Well No. 1., Ohio Salt Co.
Newberg, Ohio	2006		1380		33 & 16	49			Well No. 4, Union Salt Co.
Pendleton, Ind	947	841	7	+834	one	14			Well drilled for gas.
Franklin, Ind	1113	736	275	+461	one	27			Well drilled for gas.
Plainfield, Ind	1386	742*	350‡	+392	one				Gas from sandstone.
Rockville, Ind	2169		1369		one	36			Sand rock is brown.
Albion, Ind	1914	729	505	+224	one	5			Between Corniferous and Niagara.

In Table I, accompanying this paper, has been compiled the data of especial interest in connection with the distribution, position and thickness of this formation under hard rock cover, as revealed by deep borings. No one who has attempted to collect such information needs to be told that the figures given are only approximate and that the correlation of the stratum may be, at times, at fault. Those wells in which a silicious dolomite only was encountered near the middle of the Monroe series are not included in the table. Along the line of outcrop of the bed the stratum enters Michigan from Lucas county, Ohio, with a thickness of about 35 feet and attains soon its greatest elevation in the Lake Erie region of about 673 feet above sea level. Towards the south the bed thins to some 8 to 10 feet, but thickens northeastward to about 65 feet at the pits of the National Silica Co., located some 7 miles northwest of Monroe, upon the site of the outcrop, known locally as the Toll's pits, from the recent owner. Eastward along the strike the bed maintains a fairly uniform thickness to the Detroit river, the pit of the American Silica Co. having been recently opened just east of Rockwood, in Wayne county. In crossing Lake Erie and reëntering Ohio the bed is reduced in thickness to 2 to 20 feet, and seems to wedge out entirely in Delaware county. Between the northernmost portion of the outcrop and the foot of Lake Huron the bed is penetrated by practically all the wells that reach sufficient depth, but is absent at New Baltimore and replaced by a silicious limerock in the St. Clair region and at Mt. Clemens. Northward along the Detroit river the beds dip at an average rate of 27 to 32 feet to the mile, and the 17 wells of the Solvay Process Co., near Detroit, give an average thickness of 93½ feet, with a range from 70 to 165 feet. The bed dips somewhat more rapidly towards the northwest, between the outcrop and Ann Arbor, averaging 38½ feet to the mile, and, it is important to note, thickens very materially, being 288 feet at Milan, 284 feet at Royal Oak, and 300 feet+ at Ypsilanti. Upon the oppposite side of the Lower Peninsula of Michigan some 40 feet of sandrock were penetrated in one of the Ludington wells at the right geological horizon for the Sylvania and at an elevation of 1,510 feet below sea level. At Cheboygan an incomplete record shows only the presence of some sand, in one or two layers, at about the right horizon. From Detroit to the northeast, east and southeast the bed may be recognized in the deep borings, gradually dropping to lower levels and diminishing in thickness to some 15 to 30 feet. The average dip from Detroit northeastward to Port Huron, Michigan, is 12.6 feet to the mile, eastward to Port Rowan, Ont., but .7 foot, and southwestward to McConnelsville, Ohio, some 13.5 feet to the mile. How far the bed extends still farther to the southeastward can only be conjectured as the bed is dipping too rapidly to be reached in the wells of southeastern Ohio. At three localities along the St. Clair river,—St. Clair, Marysville and in one of the wells at Marine City, only a silicious dolomite is encountered at the horizon of the Sylvania. This is true also for the wells in southwestern Michigan and northwestern Indiana. In the State House well at Columbus two feet of sharp sandrock were found between the Corniferous and the Lower Helderberg, the horizon of the Oriskany, and then followed 486 feet of limestones referable to the Monroe, the upper portion of which was found to be sandy. These sand grains are believed by the writers to have been introduced into this limerock at the same time that the Sylvania sand was accumulating to the northward and hence to be of the same age. In some instances the well samples indicate that the Sylvania comes in suddenly as a pure sandrock, but not infrequently it is preceded and followed by a silicious dolomite of varying thickness. When these sand grains are separated from the limerock by the use of acid they cannot be distinguished from the Sylvania grains themselves. In many records, as shown in the table, the Sylvania sandrock is separated into two or more separate beds by one or more layers of silicious dolomite. In the Rockwood and Toll's pits this dolomite carries marine fossils sparingly, there being intercalated layers of upper Monroe dolomite. The species identified from these layers are: *Favosites basaltica* mut. *nana*, and *Cladopora bifurcata*. (See Chapter II.) In the Port Lambton, Ontario, well the Sylvania is represented by two beds of sandrock separated by some 420 feet of silicious dolomite and gypsum, suggesting that a considerable time must be allowed for the Sylvania epoch.

Typically, the sandrock is a remarkably pure, sparkling, snow-white aggregation of incoherent quartz grains. By drillers it is often compared with snow, flour, salt and granulated sugar. Lumps of it may be crumbled in the hands and when placed in water simply fall to pieces like some varieties of clay. At the Rockwood pit the rock is being disintegrated by means of a small stream of water from a hose and with the grains in suspension pumped to the washing vats of an adjacent building. The small amount of binding material present consists of a dolomitic cement, apparently introduced into the bed by percolating water, subsequent to the deposition of the sand. Immediately beneath the drift the rock is often discolored by iron oxide to a depth varying from a few inches to several feet. Before marketing the sand for glass manufacture the dolomitic cement is removed by washing, when the per cent of silica is over 99%. Grains of minerals other than quartz are relatively very infrequent. The following analysis of the sandrock, before being subjected to the washing process, is furnished by the National Silica Co., Toll's pits, Monroe county, Michigan.

Silica	96.50%
Calcium carbonate	1.50%
Magnesium carbonate	1.04%
Iron oxide	0.00%
Sulphuric acid loss and undetermined	.76%
Loss on ignition	.20%
Total	100.00%

Wherever exposed in the open pits, in both Ohio and Michigan, the sandrock shows a poorly defined and irregular stratification, the strata ranging from a few inches to several feet, within the limits of the pit, and being approximately horizontal or gently inclined. A pronounced lamination is everywhere to be seen, varying from horizontality to angles of 28° to 30°, indicated by slight differences in the color and texture of the sand. At times the lamination becomes wavy and cross-bedded as shown in text figures 2, 3, 4, 5, 6, 7 and 8, and in Plates III and IV. Oblique partings

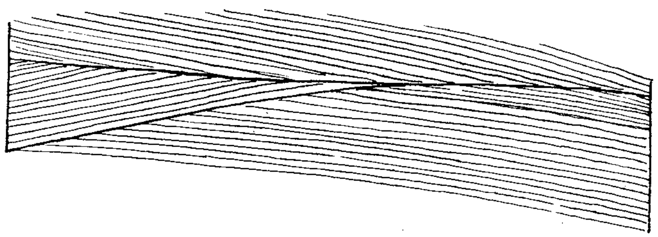
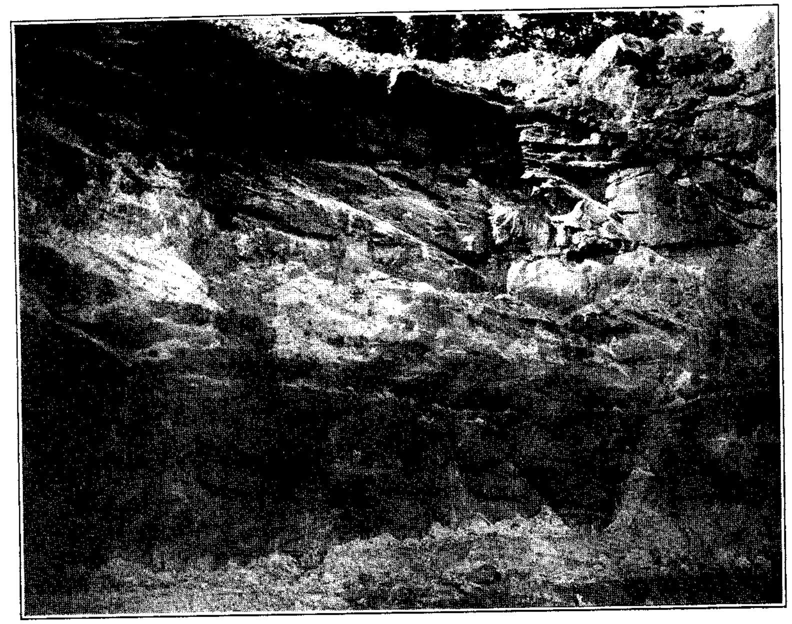
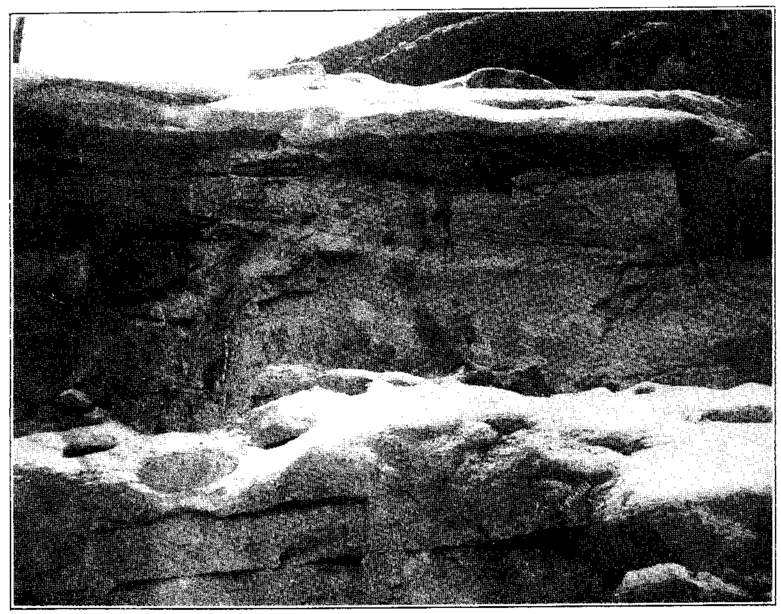


Fig. 2. Cross bedding in Sylvania sandstone. Sylvania sand pit, northwest of Monroe, Michigan. Length, 5 feet.



(A). OBLIQUE PARTINGS IN SYLVANIA SANDSTONE (UPPER HALF OF VIEW, STRATIFICATION IN LOWER HALF), NATIONAL SILICA COMPANY PITS, MONROE COUNTY, MICHIGAN.

These oblique partings, or seams, are interpreted as representing the succession of temporary dune surfaces, since they conform with neither the stratification nor the lamination.

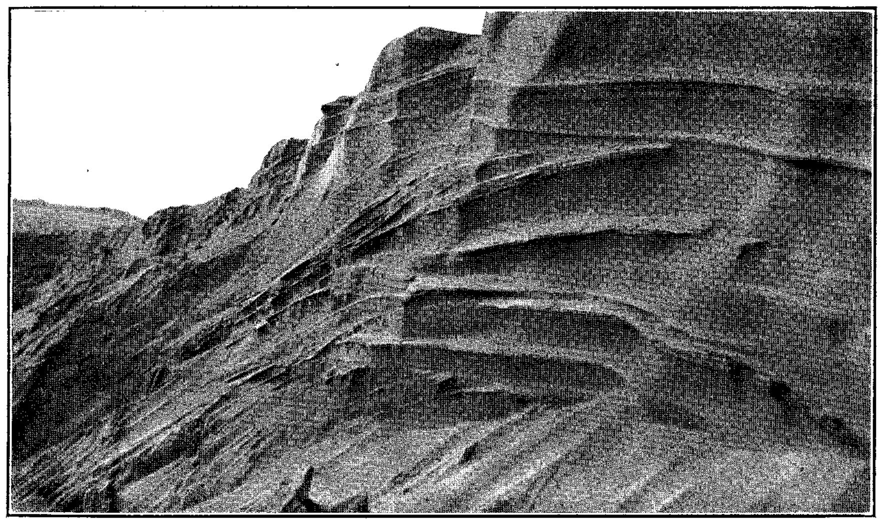


(B). SYLVANIA SANDSTONE, PIT OF NATIONAL SILICA COMPANY.

The projecting layers (snow-covered) at the top of the quarry wall are regularly stratified, rich in carbonaceous matter and contain casts of fossil brachiopods, indicated on the under side of the layers by the white specks. These layers are believed to represent the sands worked over and rearranged by the waves of the sea, encroaching upon the wind-blown land deposits.

(A). HORIZONTAL AND OBLIQUE LAMINATION, SYLVANIA SANDSTONE. PIT OF NATIONAL SILICA COMPANY, MONROE COUNTY, MICHIGAN.

This type of lamination, in which the inclined layers curve around and become tangent to the horizontal ones, is believed to be characteristic of aeolian deposits. The steeper layers shown in the cut are inclined 20° to 23° with the horizontal.



(B). STRATIFICATION AND LAMINATION, IN SAND DUNE, DUNE PARK, IND.
Photograph by E. S. Bastin, U. S. Geological Survey.

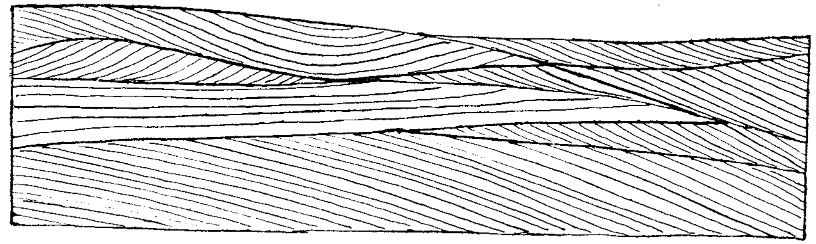


Fig. 3. Cross bedding on east wall of Toll's Pit quarry. Length, 20 feet.

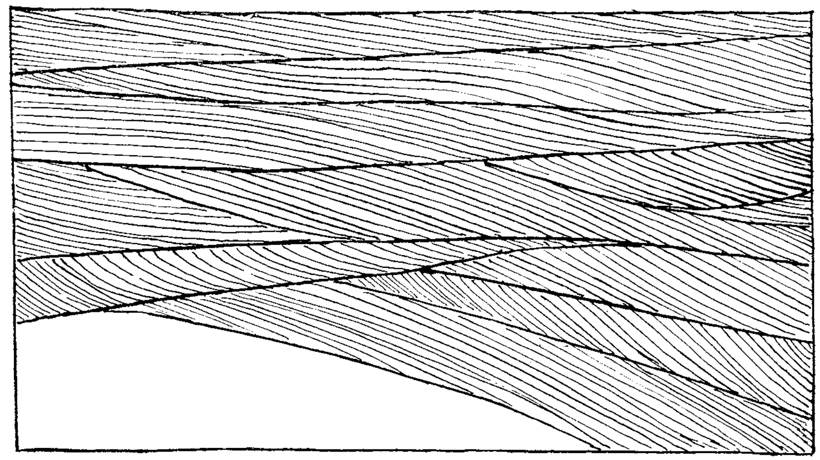


Fig. 4. Cross bedding shown on south wall of Toll's Pit quarry. Length, 15 feet; height, 10 feet. Slopes from 18° to 27.5°.

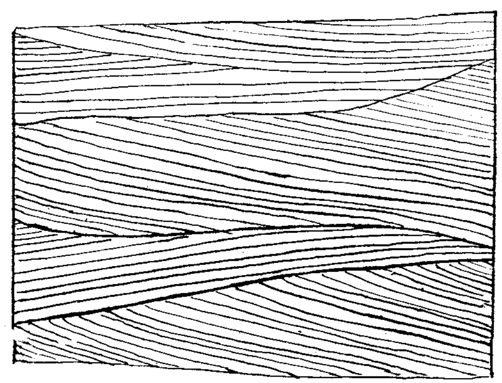


Fig. 5. Cross bedding on south wall of Toll's Pit quarry in Sylvania sandstone. Length, 5 feet.

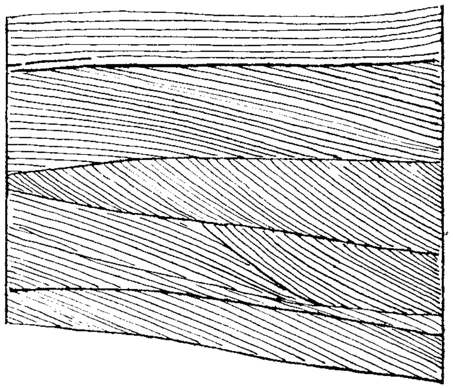


Fig. 6. Cross bedding shown in south wall of Toll's Pit quarry in Sylvania sandstone. Length, 8 feet.

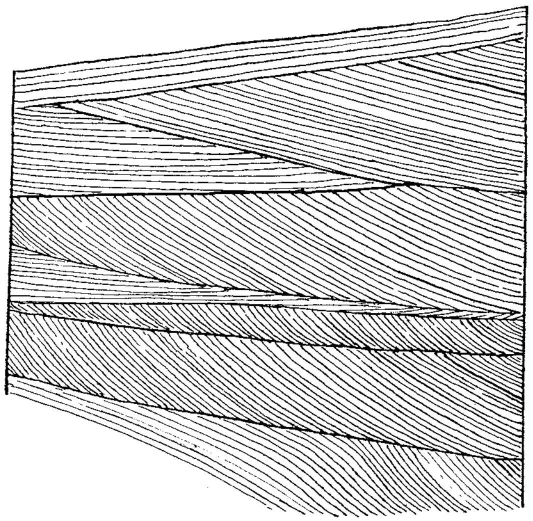


Fig. 7. Cross bedding shown in south wall of Toll's Pit quarry in Sylvania sandstone. Length and height, 8 feet.

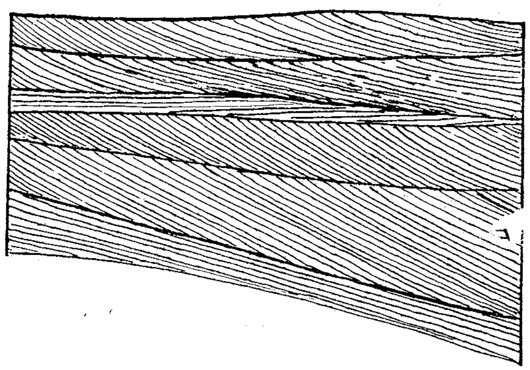


Fig. 8. Cross bedding on south wall of Toll's Pit quarry. Length, 5 feet.

are met with in the Rockwood and Toll's pits making about the same angle with the horizontal as the more steeply inclined laminae, but not observed to be conformable with them (Plate III, Fig. A).

The body of the rock itself in Michigan and Ohio has yielded no fossils, so far as known, but in the Toll pit, where the rock is succeeded by the Dundee, the less pure, upper beds one to two feet thick, contain *Paracyclas*-like casts in abundance, along with traces of plant life. These layers are horizontally bedded and contain more binding material, enabling them to overhang somewhat when the sandrock is removed from beneath. This is shown in Plate III, figure B, in which the *Paracyclas*-like casts of white sand contrast strongly with the dark under surface of the stratum. In blocks of sandrock removed from the River Raisin, near Grape, one of the authors in 1896, found a nest of fossils consisting of casts of trilobites, corals, brachiopods, pelecypods and gastropods, well preserved for the Sylvania, but still unsatisfactory for specific determination. These fossils seem to have disappeared but it is interesting to note, in the light of our present knowledge, that in looking them over at the time of the Detroit meeting of the Geological Society of America, Edward Orton commented upon the *Corniferous* (Dundee) aspect of some of the material. The carbonaceous films penetrate the rock in various directions, probably due to secondary deposition. Small pellets, two to three mm. in diameter, occur abundantly in portions of the bed, which have to be removed by screening before the sand can be marketed for glass manufacture. These consist of collections of rather coarser grains, bound together by a dolomitic, but in slight part silicious cement. They are probably of a concretionary nature.

To the eye the sand generally glistens like fine snow crystals, and it proves most destructive upon drills and the valves of pumps. At the Detroit salt shaft the jackets to the pumps, engaged in lifting the water from the bed, have had to be replaced every second day. The cause of this appearance and the marked abrasive character of the sand are understood if the grains are examined under the miscroscope. Numbers of them are thus seen to consist of doubly-terminated quartz crystals, with brilliant faces and sharp edges, as first recognized by Hubbard.[16] The original rounded grains have

[16]Second Annual Report of the State Geologist (Michigan), 1839, Senate document No. 12, p. 377.

been secondarily enlarged, as described by one of the authors in 1900,[17] the silica crystallizing about the granule so as to make the entire crystal optically homogenous throughout. In the case of the granules embedded in the associated dolomites they are sometimes seen to have enlarged against the dolomitic matrix and exhibit over their surfaces microscopic molds of the rhombohedrons. Something of this effect was described by Sorby as occurring in the New Red Sandstone of Penrith.[18] It shows conclusively that the granules of the dolomite were enlarged after the deposition of the bed, and leads to the safe inference that the granules in the underlying Sylvania beds received their secondary enlargement also subsequently to its deposition, probably from percolating water carrying silica in solution. Confirmatory evidence of this view is furnished by the entire absence of any evidence of abrasion upon the faces and edges of the enlarged crystals. Very exceptionally sufficient silica has been deposited about the grains to convert the sandstone into a quartzite. In the original rounded granules Prof. C. H. Smyth has identified fluid inclusions and crystalline inclusions of hornblende, tourmaline, apatite, rutile and zircon.

For a bed of such extent and thickness the individual grains are remarkably fine and uniform throughout their vertical and horizontal range. Some 14 samples of sand, selected from three different localities, have been analyzed by J. A. Rosen, of the Michigan Agricultural College, and only in one case did any of the grains remain upon a sieve having a mesh of .8 mm. The bulk of the grains passed a sieve of .42 mm. mesh and were caught upon sieves of .35 mm. and .18 mm. mesh respectively. Only small percentages, ranging from .10 to 4.85%, passed the finest sieve used with a mesh of .08 mm. and the bulk of this material must have consisted of the dolomitic cement secondarily introduced. Using an aspirating machine, by which the percentage of pore space was determined, the average size of the granules in these 14 samples was found to range from .18 mm. to .39½ mm. For purposes of comparison some dune and desert sands were similarly treated and the results given in the accompanying table. Aside from the uniformity and fine-

[17] W. H. Sherzer, Geol. Sur. Mich., Vol. VII, Pt. 1, p. 57.

[18] Quarterly Journal of Geol. Society of London, 1880, Vol. 36, p. 63. A fuller discussion of the secondary enlargement of quartz grains in sandstones will be found in Bulletin No. 8, of the U. S. Geol. Survey, 1884, by Irving and VanHise. See also VanHise's Treatise on Metamorphism, Monograph XLVII, U. S. Geol. Survey, 1904, pp. 75, 121, 619 and 864.

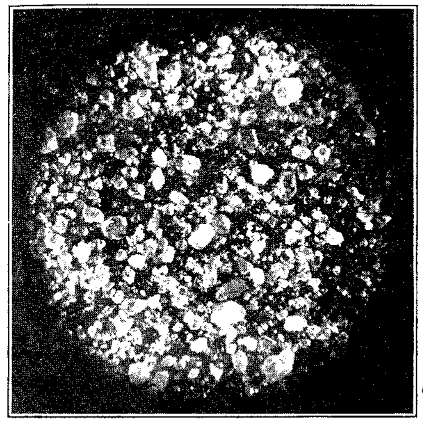
MECHANICAL ANALYSIS OF THE SANDS.

No.	Sand. No. 10 sieve= 1.80 mm. mesh.	On No. 20 .80 mm. mesh.	On No. 30 .50 mm. mesh.	On No. 40 .42 mm. mesh.	On No. 50 .35 mm. mesh.	On No. 80 .18 mm. mesh.	On No. 100 .16 mm. mesh.	On No. 200 .08 mm. mesh.	Through No. 200 .08 mm. mesh.	Average size of grain determined by the aspirator method.
	Toll's pit.	%	%	%	%	%	%	%	%	mm.
1	One ft. down....	0.05	0.40	3.50	9.05	58.78	16.52	9.80	1.90	0.2454
2	6 ft. down.......	0.00	1.55	9.42	19.98	51.70	6.25	6.25	4.85	0.2385
3	11 ft. down.......	0.00	0.55	2.10	18.18	65.72	7.05	4.65	1.75	0.2841
4	16 ft. down.......	0.00	0.00	3.40	29.03	61.52	1.95	2.10	2.00	0.2967
5	21 ft. down.......	0.00	0.00	2.85	6.31	76.83	8.36	4.20	1.45	0.2660
6	26 ft. down.......	0.00	1.80	1.95	4.05	42.46	31.92	13.37	4.45	0.1810
	Rockwood.									
7	4 ft. down........	0.00	0.40	7.65	40.50	50.60	0.50	0.25	0.10	0.3950
8	15 ft. down.......	0.00	0.60	0.60	2.35	70.45	16.60	9.10	0.30	0.2392
9	20 ft. down.......	0.00	0.35	6.65	34.10	53.70	2.30	2.25	0.65	0.3497
	Detroit salt shaft									
10	Near top.........	0.00	1.00	7.51	11.51	43.20	19.52	16.11	1.15	0.2448
11	440 ft. down......	0.00	0.10	3.00	15.35	64.93	8.35	6.85	1.40	0.2513
12	450 ft. down......	0.00	0.65	6.90	15.95	59.70	11.10	5.30	0,40	0.3071
13	460 ft. down (a)	0.00	0.85	7.55	14.45	44.90	18.70	12.20	1.35	0.2766
14	460 (b).........	0.00	0.75	7.23	16.00	47.35	16.16	11.65	0.82	0.2760
	Dune sand									
15	Mich. City, Ind....	0.15	0.15	1.95	10.40	80.90	5.35	1.05	0.05	0.2990
16	Albuquerque (a)	0.05	1.15	5.80	8.59	45.85	14.36	21.48	2.69	0.1990
17	Albuquerque (b)	0.20	1.40	17.56	24.16	41.38	7.30	5.43	0.54	0.2970
18	Albuquerque (c)	3.20	2.45	6.10	6.73	28.14	9.62	27.44	15.86	0.1340
19	Albuquerque (d)	0.00	0.13	17.90	40.14	35.56	3.33	2.50	0.39	0.2990

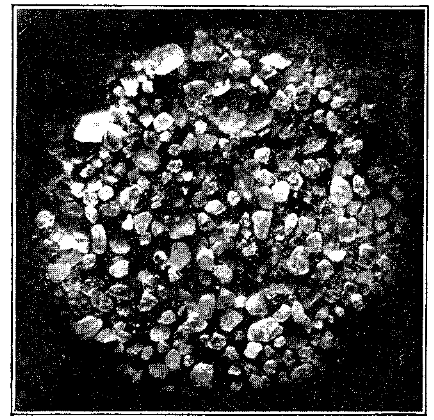
The loss in each case amounted from 0.03 to 0.05 of 1% and was distributed proportionally among the separations.

ness of the grains a noteworthy point is the practical absence of any original material of the nature of clay or dust. Another striking characteristic of the granules, important because of the light that it may shed upon the origin of the bed, is the very general rounding which the grains show when moderately magnified. Even in the case of grains secondarily enlarged the rounded character of the original nucleus is generally apparent. This rounding is seen strikingly in grains of various sizes and continues down to those but .1 mm. in diameter. (Plate VII, Figs. A-D.) It impresses one most strongly after he has been examining a series of beach, dune and even desert sands to turn to a mount of the typical Sylvania, in which not only the corners and edges are rounded but the body of the granule approaches the sphere or ellipsoid. The surfaces of the Sylvania granules, except those secondarily enlarged, do not show the vitreous luster of quartz fragments but, under the microscope, are seen to be roughened and pitted, and to present the appearance of frosted glass.

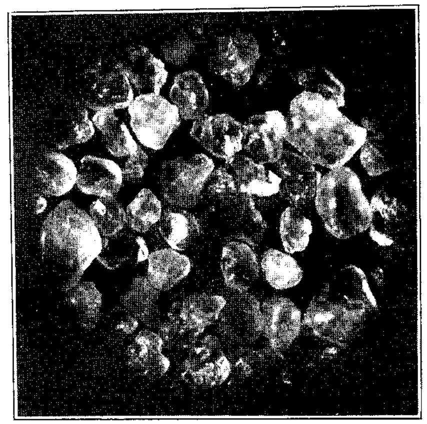
This unusual assemblage of characteristics would suggest that the Sylvania has had a history different from that of the ordinary sedimentary sandstone and but few attempts have been made thus far to give any explanation of its origin. The original suggestion of Houghton was that the bed of sand had been derived from the disintegration of the silicious dolomite, with which it is often associated. This view was concurred in by Hubbard and Winchell of the Michigan Survey and by Briggs, of the Ohio Survey, but before they had any idea of the thickness and extent of the bed. The difficulty of finding a suitable explanation is thus pushed backward but a step for there still remains the question of how sand of such character could find its way into the sedimentary slimes from which the dolomites themselves were formed, and how, after disintegration, the bed could have acquired its marked stratigraphic characters. In his Monroe county report, previously cited (p. 58), Sherzer endeavored to explain the bed as a littoral deposit made by a sea encroaching upon the land. The sand grains were supposed to have been derived from some silicious, crystalline rock, concentrated, rounded, assorted and deposited by wave action over the broad littoral belt. The destruction of the softer minerals and their reduction to clay called for a correlative bed of shale, seaward from the sand deposit, but which was not known, and the suggestion was made that the sand for the Sylvania may have been derived from some previously formed sandstone, such as the Potsdam, carrying only a small percentage of finer particles. The gradual subsidence, supposed to be in progress, would permit the accumulation of sand to a considerable thickness, but it was recognized that the granules of the layers should become successively finer, terminating in silicious shale. Much fuller knowledge concerning the distribution, thickness and structure of the bed and a better acquaintance with the component granules indicate that the theory of an encroaching sea could be applied to the upper fossiliferous layers only, and that the body of the sand was not accumulated originally under water. Opposed to any theory of water accumulation stand the irregular stratification, highly inclined



(A). MER-DE-GLACE, ALPS.

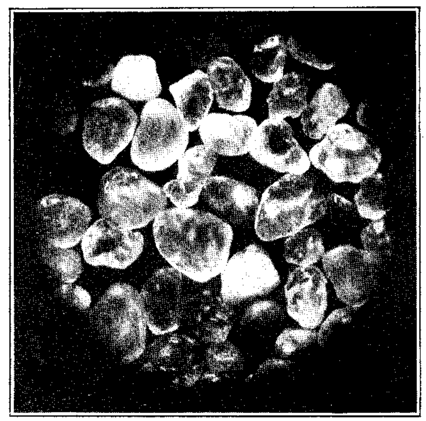


(B). WASHED FROM TILL, YPSILANTI, MICHIGAN.

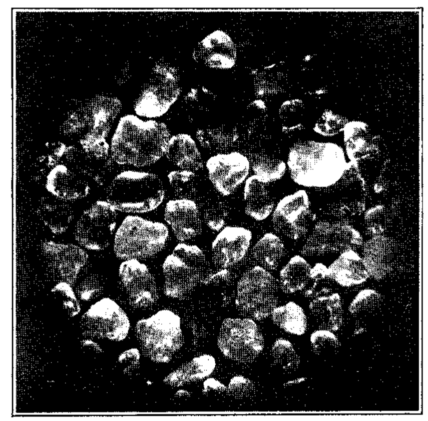


(C). BEACH, MARTHA'S VINEYARD.

(D). BEACH, GULF OF MEXICO, ESCAMBIA COUNTY, FLORIDA.



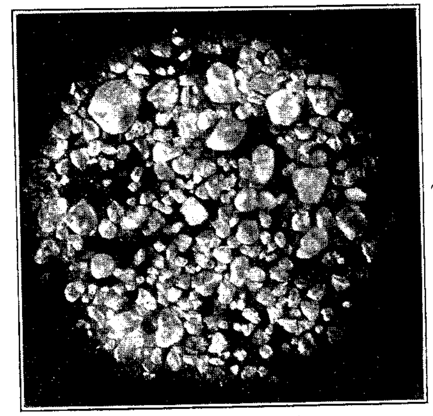
(E). BEACH, HOLLAND, LAKE MICHIGAN.



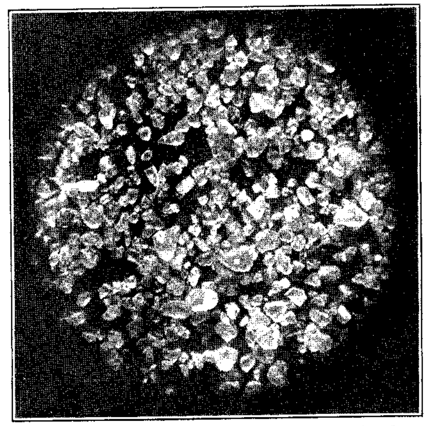
(F). DUNE SAND, HOLLAND, MICHIGAN.

Sand grains, enlarged 14½ times, showing the passage from the sharp, fresh, glacially manufactured sand to the subangular and rounded varieties resulting from water and wind action.

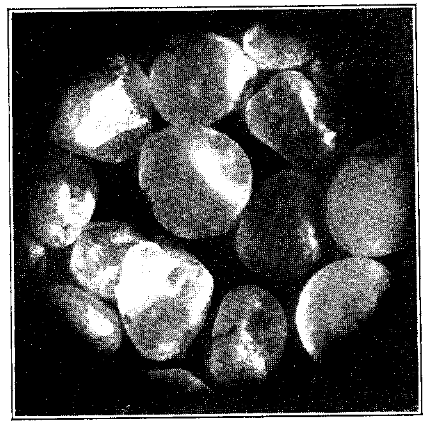
(A). LIBYAN DESERT, NEAR GHIZEH, EGYPT.



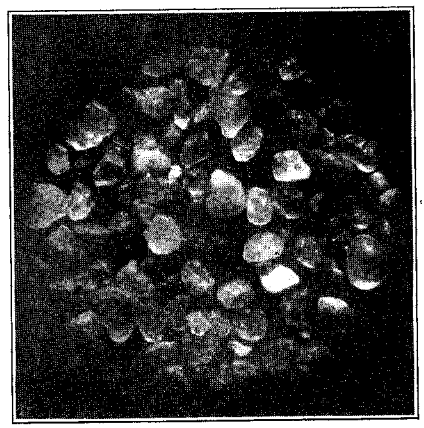
(B). LIBYAN DESERT.



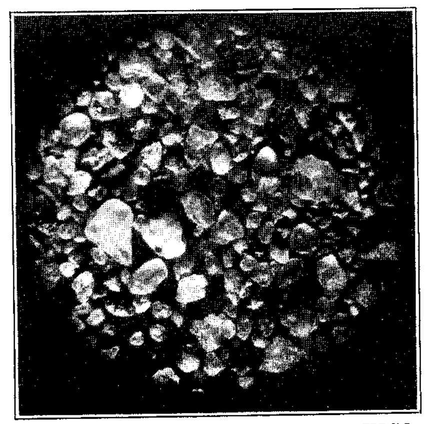
(C). LIBYAN DESERT, FINER SAND.



(D). LIBYAN DESERT, COARSER SAND.

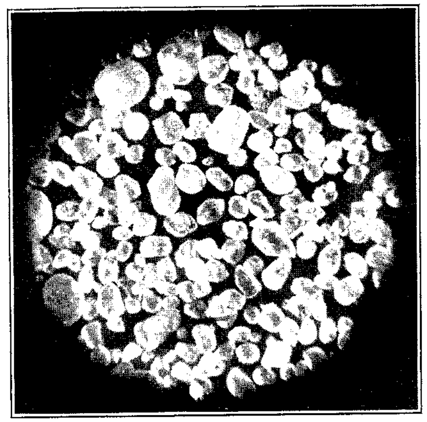


(E). ALBUQUERQUE, NEW MEXICO.

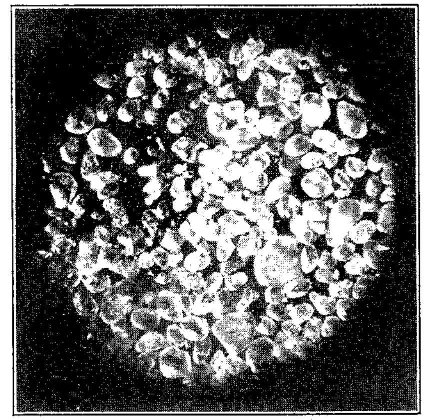


(F). ALBUQUERQUE, NEW MEXICO.

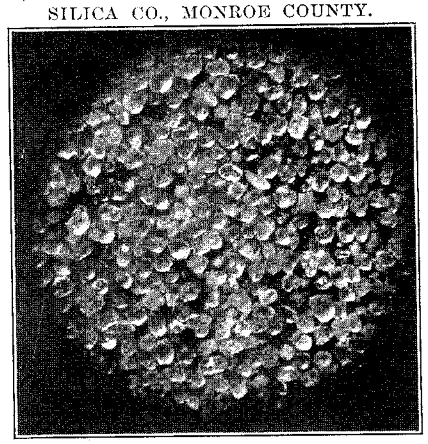
Desert sand grains, enlarged 14½ times, showing the tendency of the wind to produce a sub-spherical type of granule. The finer, angular material present in the sand of modern deserts is believed to be due to accessions of new material or the continuance of residual action and consequent incompleteness of the aeolian agency.



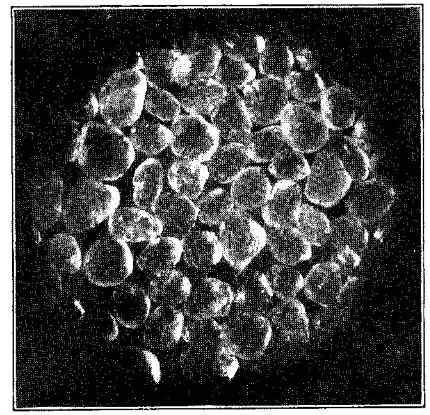
(A). FROM PELLETS, NATIONAL SILICA CO., MONROE COUNTY.



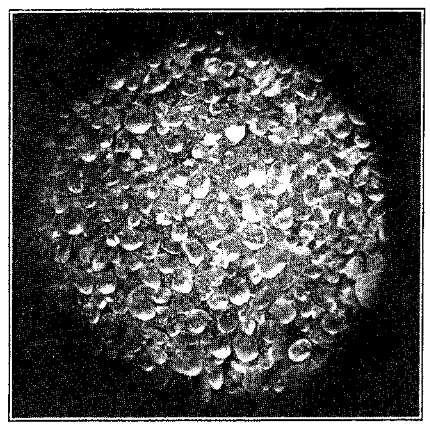
(B). DETROIT SALT SHAFT, NEAR TOP.



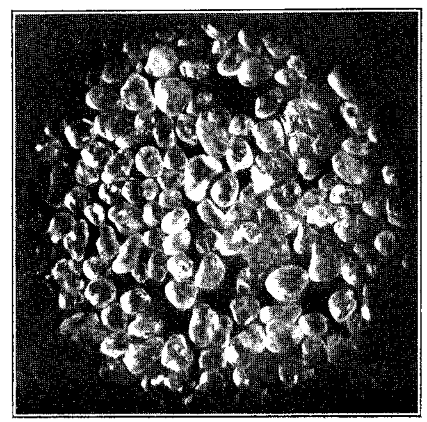
(C). NATIONAL SILICA CO., NEAR TOP.



(D). ROCKWOOD PITS, FOUR FEET DOWN. AMERICAN SILICA CO.



(E). ST. PETER SAND, MISSOURI.



(F). ST. PETER SAND, MINNEAPOLIS.

Sylvania and St. Peter sand grains, enlarged 14½ times, the latter the supposed source of the former. In these sands the assorting, the concentration of quartz and the general rounding of the granules are far more pronounced than in the sand of any known modern desert. Many of the granules in cut A have been secondarily enlarged and give angular outlines, (see text).

lamination, absence of original binding material, absence of fossils, uniformity in size of grain, the rounding of the finer granules and the pitted character of their surfaces. In connection with the silicious dolomites it is somewhat difficult to understand how currents from the shore capable of carrying sand grains would fail to take into suspension the ooze of which these dolomites were evidently formed.

The writers have been led to adopt the eolian theory by which to account for the accumulation of the main body of the bed, as furnishing the most satisfactory explanation of all the stratigraphic and lithologic characters of the formation. The increase in thickness from the Detroit river region towards the northwest and the decrease in thickness in every other direction, combined with the passage into silicious dolomite, suggest strongly that the source of the material lay to the northwest. Unfortunately none of the wells in the central portion of the Lower Peninsula reach the horizon and we have no means of knowing whether or not the bed is continuous from Ann Arbor and Port Huron to Ludington and Cheboygan, as would naturally be inferred. The retreat of the sea toward the northeast and southwest at the opening of the epoch would lay bare a peninsula, or isthmus, of largely dolomitic strata of mid-Monroe to earlier age, extending in a northeast-southwest direction from Wisconsin, across Michigan and Ontario and into Ohio. The destruction of some previously formed pure sandstone, such as the St. Peter, or Potsdam, by wave action and the carriage of the granules by prevailing northwesterly winds across this area would give rise to the Sylvania. Whether the sand was moved entirely over land, or worked along shore by wave action, as suggested by Lane, there is now no means of judging, the essential thing being the rehandling of the sand by the wind. During the slow retreat of the shore line the heavier winds would carry the finer grains to sea where they mingled with the accumulating dolomitic slime, giving rise to the silicious dolomites underlying the Sylvania. One or more readvances of the sea established, in southeastern Michigan and Western Ontario, off-shore to littoral conditions, and permitted the formation of a purer dolomite carrying marine fossils. This was followed by another pronounced retreat and the deposition under atmospheric conditions of the upper Sylvania bed, or beds. Upon the final return of the sea, and the closing of the Sylvania episode, the upper layers were reworked by the waves, horizontally stratified, and some finer sediment and fossils introduced. This reworking of the sands by seas of later geological age may have happened locally and permitted the introduction of fossils of later age, as for instance those of the Dundee found in Monroe county, Michigan. Since this bed formed here an outcrop in the bed of glacial Lake Warren it is readily conceivable that it might have carried even *Pleistocene* fossils. The final stage of the transgressing Monroe sea again allowed the mingling of dolomitic slime and wind transported sand grains and the formation here and there of silicious dolomite overlying the Sylvania. Around the outskirts of the Sylvania desert, kept so by shifting sands, barren soil and probably arid climatic conditions, only silicious dolomite and shale, or sedimentary sandrock could be formed. At the base of the lowest bed we might reasonably expect coarse sand and gravel, formed as a beach deposit, and just beyond the limits of sand distribution, this type of deposit only, as in Deleware county, Ohio. With mainly the sand itself to work upon such a deposit would not be expected at the top of the series and, so far as known, does not occur. In the main body of the Sylvania no granules have thus far been found which do not come well within the limits for wind transportation.

With the geographic conditions thus presented it remains to inquire to what extent this eolian theory is more satisfactory than any sedimentary one that might be proposed. The stratification of a sand dune, such as that described by Walther in his classic work *Die Denudation in der Wuste,* 1891, and shown in Figure 92, is strikingly like that seen in the pits, irregular, more or less poorly defined in places and varying in thickness. The steepest inclination observed—28° to 30°—agrees with that found upon the lee side of modern sand dunes (29° to 32°).[19]

In the quiet conditions of the laboratory dry Sylvania sand may be made to assume an angle of rest of 33° to 34° with the horizontal plane upon which it rests, while in absolutely quiet water the slope is equally steep. Sorby[20] found from many experiments that the angle of rest assumed under water by angular sand, varying from about .03 to .07 inch and averaging about .05, was about 41° when coming to rest, but about 49° when

[19]Die Dunen, Sokolow, 1884. Translated from Russian into German by Arzruni, 1894, p. 82.
[20]Quart. Journ. Geol. Soc., Vol. 64, p. 174, 1908.

giving away after being at rest. For sizes varying from .005 to .020 inch and averaging about .010 inch, the angle when coming to rest was about 34° and after giving away 36°. For grains varying from .001 to .005 and averaging about .003 inch, the corresponding angles were 30° and 33°.

A further fact to be noted is that the cross-bedding of wind-blown deposits is not uniformly inclined in one direction, or in a uniformly varying direction, as would be the case in delta deposits, where the dip of the oblique layers is uniformly away from the direction of the source, though a certain variation is possible through lobation of the delta. In wind-blown deposits on the other hand constant variation in the direction, including repeated reversals, are characteristic. Moreover, in wind-blown deposits the successive cross-bedded strata are separated by more or less oblique erosion planes, while the lower part of the oblique layers is, as a rule, tangent to this erosion plane. In delta deposits, on the other hand, only a single set of oblique beds—the fore sets—are well developed and these are bounded above and below by horizontal top and bottom set beds. The only subaqueous deposit with a structure comparable to that of wind-blown deposits is the wave built bar. This, however, has a lineal distribution, with a narrow cross section and is continually re-eroded on the seaward side, as it is being built up on the landward side, so that its width never becomes very great. It certainly never covers the area which wind blown deposits may cover, and hence the areal extent of the cross-bedded deposit becomes an important factor in the determination of its origin. The Sylvania is distributed over too wide an area to permit of its being interpreted as of bar origin, while the type of cross-bedding does not correspond to that of subaqueous deltas, but does correspond in all its characters to that of wind blown deposits. So far as the cross-bedding is concerned, therefore, the eolian theory of origin is sustained.

Great irregularities in the thickness of the beds, as reported from the Sylvania in neighboring wells, are to be expected upon the eolian hypothesis, but are difficult to explain if we assume that the deposit took place under water. The total disappearance of the bed, as at New Baltimore, Michigan, surrounded by localities in which the bed is known to occur, is readily accounted for on the eolian theory. A certain uniformity in the size of grain throughout the entire vertical and horizontal extent is demanded by the eolian hypothesis but difficult to reconcile with any theory of water deposition, where flocculation would cause large and small particles to sink together. The absence of anything of the nature of original clay or dust, the very complete rounding of the smaller granules, and the pitted character of the surfaces of the coarser granules, when not extinguished by secondary enlargement, all point to a long continued wind action.

For purposes of comparison with the Sylvania grains a study has been made of the different types of sand and photographs taken to illustrate the characteristic differences.[21] (Plates V to VII.) At one end of the series stand the glacial sands with the granules typically sharp and angular, the quartz fragments fresh and vitreous looking, showing conchoidal fracture, with a variety of material and little evidence of assorting. The few rounded grains seen probably possessed this form in the original rock from which they were derived. Sand washed from glacial till (Plate V, Fig. B.) shows much the same appearance, but with a larger proportion of partially, or completely rounded granules. In the case of typical beach sand the grains are relatively coarse, the finer material having been removed by the continued washing process; there is more or less variety in the minerals represented; the quartz fragments are vitreous, with more or less conchoidal fracture; and the general form of the granules is angular, but with rounded corners and edges. Occasionally very perfectly rounded grains are to be seen, especially amongst the coarser fragments. Transportation for long distances along shore would be expected to emphasize this character, if there were no opportunity for a fresh supply of sand, and there would be gradually eliminated the softer minerals leading to a concentration of the quartz. A remarkably pure beach sand, from which practically all other minerals than quartz have been eliminated, is found on the coast of the Gulf of Mexico, Escambia county, Florida. A mechanical analysis of this sand by the U. S. Department of Agriculture shows that practically all the material below .1 mm. has been removed and that the granules range from 1.0 mm. to .1 mm., 56% constituting their "medium sand" with granules .5 mm. to .25 mm. An inspection of figure D, plate V, shows that the process by which the quartz was concentrated did not result in the general rounding of the grains. The surfaces are smoothed, the edges and corners ground off but the bodies of the granules still remain angular in striking contrast with the Sylvania. A very similar gray sand occurs upon the Atlantic coast at West Palm Beach, Florida, showing the same degree of purity and the same characteristics of grain. The two sands have evidently been derived from crystalline rocks to the north and have traveled along shore for a considerable distance. Evidently the purity of the sand is attained long before the complete rounding of the grains. In the case of shore dunes, for which the material is derived more or less directly from the beach, the differences in the granules are not strikingly shown. The extent and thickness of the deposits are greater, however, and the assorting of the granules rather more perfect. The dune sands show a larger percentage of rounded grains, as a rule, and there are more that appear dulled and frosted, with pitted surfaces. Owing to the opportunity for shifting their position from dune to water and water back to dune, there occurs a mixture of granules and a difficulty arises in attempting to distinguish between the two classes of deposits. It seems probable, however, that typical beach sand, not yet acted upon by the wind, can be distinguished from typical dune sand. Desert sands, so far as examined, show a higher degree of rounding, extending down to granules less than one-tenth of a mm. in diameter. As pointed out by Zittel, Walther and Sokolow, typical desert sand contains also considerable angular and subangular material, but not as much as that ordinarily found in beach and littoral deposits. The bulk of the sand consists of quartz, showing in the coarser grains especially, a characteristic pitted and frosted appearance, but fragments of other minerals are much in evidence. This variety of material and its angular character are probably due to fresh accessions from the original sources and the more or less continuous action of residual agencies. In describing sand of the Libyan desert Zittel says that it "consists of irregularly formed, rounded, perfectly pure—washed and polished quartz grains from .5 mm. to 2.0 mm. in diameter. Generally the grains of a given sample have a nearly uniform size, sand masses of fine,

[21]Since the preparation of this manuscript Sherzer has extended his studies upon sand grains and has worked out a genetic classification of the same, which will appear in a forthcoming bulletin of the Geological Society of America. (Vol. 21). Seven distinct types of granules are recognized; glacial, volcanic, residual, aqueous, eolian, concentration and organic. Numerous sub-types are described and illustrated, resulting from the secondary action of the various geological agencies upon these main types; as, for instance, water upon a sand of residual origin, or the wind acting upon an aqueous or volcanic sand.

medium and coarse grain being as a rule separated. Under the microscope the separate grains are seen to consist of clear, colorless or wine yellow quartz or again of clouded, milky or brown ferruginous quartz. * * * Clay, marl or iron impurities are not found in the desert sand, the aggregation is free from dust and of most agreeable purity."[22] Owing to the cleavable character of the common rock forming minerals except quartz, their softer character and greater tendency toward disintegration, they are in time reduced to powder, which is carried away by the winds to form deposits of clay about the margin of the desert. In speaking of this action Walther says, "It is no accident that the bed of vegetationless desert is covered with quartz sand, the bed of grass grown steppe with clay dust. It is also no accident that the North African deserts are surrounded by clay dust steppes. Desert and steppe belong together, not only from the view point of climatology, but also sedimentary formation. The steppe is often the child of the desert." (p. 152.)

In comparing the Sylvania sand with the types studied it is found to lie upon the opposite side of the desert sand from the glacial, littoral and dune sands; to actually *out-Sahara* the Sahara sand itself so far as purity, rounding and assorting are concerned. It is a more typical desert sand than is known from any modern desert and has already attained the condition which present desert sands are approaching but never reach. This perfected character of the Sylvania sand is readily understood when its probable history is made known—a lengthy and repeated buffeting with wind and wave, with no opportunity for the accession of new material. There has thus been a concentration of the resistant quartz after the manner emphasized in the recent presidential address of the late Prof. I. C. Russell.[23] In looking to the northwestward for a possible source of the material from which the deposit could have been derived there is encountered at once, upon the western side of Lake Michigan, a sandstone of early Ordovicic age—the St. Peter. This bed has a northeast-southwest strike, approximately parallel to the lake shore, extends for more than 120 miles in Wisconsin, varying in thickness from zero to 212 feet and presumably enters the northern peninsula of Michigan, although not known there in

[22]Geologie der Lybischen Wuste, etc., 1883, p. 138.
[23]Concentration as a Geological Principle. Bull. Geol. Soc. of Am., Vol. 18, 1907, p. 6.

outcrop. This formation is the counterpart, stratigraphically and lithologically of the Sylvania, having recently been made the subject of special study by Prof. C. P. Berkey and by him believed to have been deposited in part by wind and in part by water.[24] This sandstone is typically white or yellowish, consisting of uniform quartz grains which range in size from .01 to 2 mm., but the bulk of the rock consists of grains from .05 to .4 mm. in diameter. The grains are generally rounded down to a diameter of .1 mm. to .2 mm., the coarser ones being more perfectly rounded and showing pitted surfaces. In comparing samples of St. Peter granules from Missouri, Illinois, Wisconsin and Minnesota, with those of the Sylvania from southeastern Michigan, the granules are not so completely rounded nor so perfectly assorted. (Compare figures C and D with E and F on plate VII.) The original clay or dust has been removed and the percentage of silica is sometimes above 99%. The basal deposits of sandstone of the Upper Mississippi region, of late Cambrian age, are believed to have furnished the material for the St. Peter and this, in turn, was derived from the original crystallines to the north and east as the result of wave action. This repeated working of the granules by waves and currents and later by wind has eliminated the softer and decomposable minerals originally present, the finer material has been washed out and blown away, and the remaining quartz grains assorted, rounded and pitted. The absence of deposits of shale about the margin of the Sylvania desert is to be explained by the purity of the St. Peter itself and furnishes confirmatory evidence that the Sylvania must have been derived from some bed of highly silicious rock. At Niles, Michigan, some 20 feet of a silicious shale was met, at what appears to be the Sylvania horizon,[25] but this is the only record known of such a bed; the Tymochtee shale of the Monroe series being of earlier age.

If the Sylvania formation has had the history ascribed to it by the authors, the basal layers sedimentary, the body eolian, the upper eolian deposits reworked by a transgressing sea, and the materials in the main derived from the St. Peter,—it will be recognized that it will be difficult to assign the beds to any definite geological horizon. Basally it will be found to rest upon successively younger strata as we pass southeastward from the St. Peter

[24]Paleogeography of Saint Peter Time. Bull. Geol. Soc. of Am., Vol. 17, 1906, p. 229. This paper contains references to St. Peter literature. See also Grabau, A. W., Types of Sedimentary Overlap. Ibid., pp. 616-620.
[25]Geol. Surv. of Mich., Vol. V, Pl. 44.

in Wisconsin and northern Michigan and to be younger than the youngest bed upon which it rests. As the result of the work of the encroaching sea it will be successively overlapped by strata younger than itself and will be geological older than the oldest of these beds. The key to the geological age of the formation is found in the Detroit river region where the Sylvania is found to rest upon dolomites of the Lower Monroe series and to be capped by 250 to 350 feet of strata of the Upper Monroe series. The Sylvania episode is to be referred to about mid-Monroe time and probably lasted long enough for the accumulation in the littoral region of some 200 to 300 feet of dolomitic slime.

CHAPTER IV.

DESCRIPTION OF MONROE FOSSILS BY A. W. GRABAU.

STROMATOPOROIDEA.

Genus CLATHRODICTYON Nicholson and Murie.

1. CLATHRODICTYON OSTIOLATUM (Nicholson).

(Plate VIII, Fig. 6; XIII, Fig. 1; XVI, Fig. 18.)

1873. *Stromatopora ostiolata* Nicholson, Ann. and Mag. of Nat. History, 4th ser., Vol. XII, p. 90, pl. IV, figs. 1, 1a.

1874. *Stromatopora ostiolata* Nicholson, Pal. Province of Ontario, pl. I, fig. 1, 1a, p. 63. 1875.

1886. *Clathrodictyon* (*Stromatopora*) *ostiolatum* Nicholson, Mem. British Stromatoporidaea pt. 1, p. 14.

1887. *Clathrodictyon ostiolatum* Nicholson, Ann. and Mag. of Nat. History, 5th ser., Vol. 19, p. 11, pl. 3, figs. 1-3.

1895. *Clathrodictyon ostiolatum* Whiteaves, Palaeozoic fossils, Vol. 3, pt. 2, p. 52.

1903. *Clathrodictyon ostiolatum* Clarke and Ruedemann, Mem. N. Y. State Mus. No. 5, p. 37, pl. 1, figs. 10-12.

1906. *Clathrodictyon ostiolatum* Grabau and Shimer, North American Index fossils, p. 41.

Specimens showing the essential characters of the species are abundantly represented in the collection. In form they are massive, no specimen showing the under side. They frequently constitute masses a foot or more in diameter. The surface is commonly drawn out into numerous nipple-like projections which are sometimes sharp and in other cases more rounded. Rarely is there an apical depression simulating a pore. In some large fragments the projections are more botryoidal than nipple-like, while in others still they approach in regularity and form the mamelons of other genera. Generally the protuberances are coarse and conical, but in some specimens they approach a finger-like character, though, as a rule, the "fingers" are contiguous and united for most of their length.

In section the specimens show the typical structure of Clathrodictyon in its discontinuous vertical pillars. These join the two lamellæ, rarely projecting downwards in the form of spines as in *C. striatellum.* The double character of the spines of that species has not been observed in any specimens sectioned. On the average five lamellæ and four interspaces occur to the millimeter, the interlaminar space being for the most part twice the thickness of the laminæ. At irregular intervals, however, the width of the interlaminar spaces may increase to twice that amount or more, up to half (or even .6 of) a millimeter. Around the nipple-like projections the growth is concentric, but otherwise it has the form of undulating laminæ. Frequently, however, the *coenosteum* envelopes foreign bodies, such as the corals *Diplophyllum* and *Syringopora* and other tubular structures which may belong to tubiculous annelids. (Plate XVI, fig. 18.) This gives rise to the Caunopora structure, often exceedingly well developed in this species. The growth in all cases is concentric around these tubes, unless, as is sometimes the case, they lie parallel to the laminæ.

The surfaces of the laminæ in most broken specimens show an irregular series of granules, frequently anastomosing. No astrorhizae have been observed, nor do any of the surfaces show the raised "oscula" described in the original Canadian specimen. These, however, do not appear in other specimens from the same horizon in New York judging from the figures given by Clarke and Ruedemann in their Monograph of the Guelph faunas, (Plate I, Figs. 10-12). "Conic oscula" are mentioned in the description, but the authors add that "in the specimens under observation they are, however, not arranged distinctly as described by Nicholson."[1]

[1]Clarke, J. M. and Ruedemann, R. Guelph Fauna in the state of New York. Memoir N. Y. State Museum. 5 p. 38.

Tangential sections of the laminæ show a delicately reticulated net work. The original specimens from the Guelph of Guelph, Ontario, was a dolomitic specimen, and is the only one sharing the elevations described as oscula. In all other respects our specimens agree with this, and they further agree with specimens identified as this species from the Guelph of New York. According to Clarke and Ruedemann the species also occurs in the Cobleskill of the Schoharie region.

Certain portions of the specimens in the collection from the salt shaft are silicified, while intermediate layers still remain in a calcareous condition, the interspaces being mostly infiltrated with calcium carbonate. In other specimens the structure is still open, what infiltration has occurred being limited to a crystallization of calcite on the surfaces of the laminæ. When worn the surface commonly shows the concentric structure of the laminæ.

Horizon and localities.—This species is the most abundantly represented stromatoporoid in the collection from the Anderdon limestone of the salt shaft, and likewise occurs in large masses in the reef at the Anderdon quarry where it is abundant. A few silicified specimens have been obtained from the Amherstburg bed of the Detroit river. It also occurs in the Guelph and Cobleskill of New York and Canada.

2. CLATHRODICTYON VARIOLARE von Rosen.

(Plate IX, Figs. 1-2.)

1867. *Stromatopora variolaris* von Rosen, Ueber die Natur der Stromatoporen, p. 61, pl. II, figs. 2-5.
1887. *Clathrodictyon variolare* Nicholson, Ann. and Mag. of Nat. History XIX, 5th series, p. 4, pl. I, figs. 4-6.
1888. *Clathrodictyon variolare* Nicholson, Mon. British Stromatoporoids, p. 150, pl. XVIII, figs. 1-5, pl. XVII, fig. 14.

Coenosteum massive, the material obtained representing fragments of heads of considerable size. A somewhat obscure arrangement into latilaminæ is indicated on polished sections. Surface marked by mamelons which are closely crowded and obtusely rounded in one specimen, and rather distant and more sharply pointed in another. Astrorhizae rather faint, and generally coinciding with the mamelons, but not wholly confined to them. In sections the latilaminæ show a wavy character and the laminæ appear to be finely crumpled. The alternation of several rows of coarser vesicles with rows or zones of minute ones, characteristic of this species, is well shown in our specimens. A zone of five coarser vesicles has a width of 1.4 mm., while an adjoining zone, one of the same width, contains twice as many vesicles. The stratified appearance of the fossil in section is largely due to this alternation of coarser and finer vesicles.

Horizon and localities.—In the reef portion of the Anderdon limestone, Anderdon quarry near Amherstburg, Ontario. Not very common. Originally described from the Niagaran.

Genus STROMATOPORA Goldfuss.

3. STROMATOPORA GALTENSE (Dawson).

(Plate VIII, Fig. 1.)

1879. *Coenostroma galtense* Dawson, Quart. Journ. Geol. Soc., Vol. XXXV, p. 52.

1903. *Stromatopora galtense* Clarke and Ruedemann, Guelph Fauna of New York, Memoir 5, N. Y. State Museum, p. 36, pl. I, fig. 13.

Compare:

1852. *Stromatopora constelleta* Hall, Pal. N. Y., Vol. II, p. 324, pl. 72, fig. 2.

1891. *Stromatopora typica* v. Rosen, Nicholson, Mon. British Stromatoporoids, p. 169, pl. I, V, XXI, XXII.

The specimens identified with the above species are massive, or occur in the form of thin layers of a number of laminæ. Their occurrence in this manner seems to prove that the coenosteum is divided into latilaminæ along the dividing planes of which separation takes place. No epithecal surface has been observed.

The latilaminæ are undulating but no regular mamelons appear. The surfaces of the laminæ show the characteristic roughness due to the irregular granules and ridges which represent the vertical elements of the coenosteum, but no pustulose character appears. This character is similar to that illustrated for *S. typica* by Nicholson (British Stromatoporoids, pl. XXI, fig. 7). The astrorhizae are rather large and irregularly distributed, their centers slightly raised, and separated 10 to 12 mm. (sometimes more, sometimes less) from one another. In some specimens the distance varies from 8 to 19 mm. The radiating canals branch once or twice, extending from 4 to 6 or 7 millimeters from the center. Often the center appears as if formed into a tube, and "Caunopora" tubes are sometimes found.

In the massive specimens the latilaminar character, or stratification, is shown by the separation of the coenosteum into strata a few millimeters thick. The surfaces are undulating and the astrorhizae generally occur on the summits of the undulations which can scarcely be called mamelons. But the astrorhizae are variable, sometimes occurring in depressions. They are best seen on the under side of the latilaminæ. Distance between their centers varies in different specimens from 5 to 13 mm., and there is also some variation in the frequency of branching of the canals. Under certain conditions of preservation the horizontal laminæ are readily distinguished, though the vertical elements are less clearly differentiated. The laminæ are three to four times as thick as the interspaces. Transverse sections of the massive specimens show the latilaminæ, but the laminate and radial pillars are not readily distinguishable. Occasionally vertical tubules, such as described for *S. typica* are found. Tangential sections likewise show an exceedingly dense tissue.

Horizon and localities.—This species is common in the coral bed of the salt shaft, and is easily recognized by its astrorhizae and its dense tissue, as well as the absence of mamelons and pustules. It is not uncommon in the Anderdon reef of the Anderdon quarry Amherstburg, Ontario. It has also been described from the Guelph of Ontario and New York, and from the Cobleskill horizon of eastern New York.

4. STROMATOPORA (COENOSTROMA) PUSTULOSUM.

(Plate IX, Figs. 3-4.)

Coenosteum massive, generally occurring as large hemispheric heads, up to a foot or more in diameter. A latilaminate structure is more or less perfectly developed, the coenosteum readily splitting into layers sometimes less than a millimeter thick. Surface of the latilaminæ undulating, but without mamelons; minutely and strongly pustulose, the pustules .5 mm. in diameter, and separated by from .6 to .8 mm. The pustules are rounded and without apical openings, while the interpustular surface is finely granulose. Astrorhizae well developed, though generally visible only on the