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THE BRINE AND SALT DEPOSITS OF MICHIGAN
THEIR ORIGIN, DISTRIBUTION AND EXPLOITATION

by
CHARLES W. COOK.

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

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LETTER OF TRANSMITTAL.

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

Governor Woodbridge N. Ferris, President.
Hon. Wm. J. McKone, Vice President.
Hon. Fred L. Keeler, Secretary.

Gentlemen:—I have the honor of transmitting to you herewith manuscript of a report on the Brine and Salt Deposits of Michigan, by Dr. Charles W. Cook, with the recommendation that it be printed and bound as Publication 15, Geological Series 12. In thoroughness of treatment and excellence of presentation this monograph does full credit to the importance of the salt industry of the state. The quantity and value of the annual salt production of Michigan is greater than that of any other state and the quantity of natural brines and rock salt in the Southern Peninsula is of such enormous magnitude that it may be said, without exaggeration, that Michigan sources of available salt are inexhaustible.

The investigation and studies on which this report is based have been in progress since early in 1910. It was expected in the beginning that earlier publication would be possible but full compensation for the delay is afforded in the resulting more comprehensive study and treatment of the subject of investigation.

Very respectfully yours,
R. C. ALLEN,
Director.

Lansing, Michigan, Jan, 19, 1914.

INTRODUCTION.

For nearly half a century, Michigan has been one of the leading salt producers of the United States, and while a number of reports, both by the geological survey of the state and by private individuals, have described the industry in its various phases, they are, for the most part, antiquated and many of them are no longer available. The present report aims not only to bring together the important facts contained in the previous papers but also to make such additions as are warranted by the more recent developments and the present state of our knowledge. Furthermore, it is hoped that some light may be shed upon the possible origin of the salt brines and rock salt from which the article of commerce is obtained.

The subject matter has been treated under the following general headings: Historical Account, Origin of the Salt Deposits, Geology of the Saliferous Rocks, Methods of Manufacture, The Product, and Salt Producing Areas. An appendix giving the bibliography on the subject has also been added.

FIELD WORK.

The major portion of the field work was performed by the author during the summer of 1910, covering a period from June 27 to September 21. During this time, not only the present salt producing areas but also the districts which have been producers in the past were visited. Information was sought concerning the geological occurrence of the saliferous rocks, the composition of the brines and their products, the equipment and the methods of manufacture of the various companies, and the production and the economic conditions influencing it, together with the history of the development of the industry. An attempt was also made to locate definitely all salt wells, both the producing and non-producing. It was found, however, that in a number of instances, especially in the older districts, this was not possible. Additional visits to the producing areas were made in June 1911.

ACKNOWLEDGMENTS.

The writer wishes to take this opportunity to record the courteous treatment and generous cooperation afforded by the various companies and their officers in the preparation of this report. For the most part the information and assistance were gladly and cheerfully given. Thanks are due especially to Messrs. E. G. Filer, R. A. Nickerson, J. J. Hubbell, and Geo. Ray of Manistee; P. Hardy, J. H. Brogan, and Geo. Abair of Ludington; H. H. Dow and E. P. Rice of Midland; Temple Emery and M. L. Davies of Bay City; T. P. Whittier, W. J.

Mason, J. P. Warrick, and Geo. B. Willcox of Saginaw; Otto Huette of Port Huron, F. W. Moore of St. Clair, S. C, McLouth of Marine City, and Jos. P. Tracy of Detroit. To Dr. Wm. H. Hobbs, Professor of Geology in the University of Michigan, for many valuable suggestions and criticisms, and to Mr. R. C. Allen, State Geologist, for the facilities afforded by the Michigan Geological Survey, the author is heavily indebted.

DISTRIBUTION OF SALT DEPOSITS.

As in the case of all necessities of life, nature has provided us amply with salt. Its distribution, both areal and geological, is very widespread, so that we find it in nearly every country and in rocks of practically all ages from the earliest Paleozoic to the present time. The occurrence of salt in both the Eastern and Western Hemispheres has been so recently discussed by Harris[1] that it need not be taken up in this connection. The distribution within the United States is shown in the following table, which has been compiled from various reports, and private communications from the several state geologists.

	Brine	Rock Salt
Michigan	Carboniferous (Mississippian)	Silurian (Salina)
New York	Ordovician to Devonian.	Silurian (Salina)
Ohio	Carboniferous (Mississippian)	Silurian (Salina)
Kansas	Cretaceous	Carboniferous
Louisiana		Tertiary
California	Recent*	Tertiary (Eocene)
West Virginia	Carboniferous (Pottsville and Logan Series)	
Texas	Cretaceous Carboniferous	Carboniferous (Permian)
Utah	Recent	Recent
Virginia		Carboniferous
Pennsylvania	Carboniferous (Pocono)	(Greenbrier limestone)
Nevada		Recent
Oklahoma		Carboniferous (Permian)
New Mexico		Recent
Nebraska	Carboniferous (Dakota Shales)	

*Ocean water.

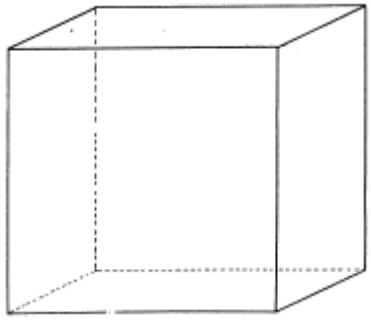


Figure 1. A cube.

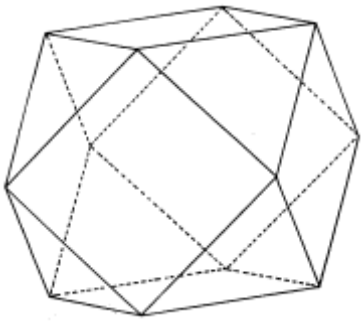


Figure 2. Combination of a cube and octahedron, the cube predominating.

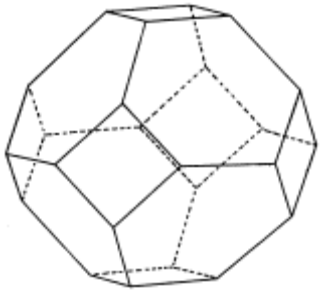


Figure 3. Combination of a cube and octahedron, the octahedron predominating.

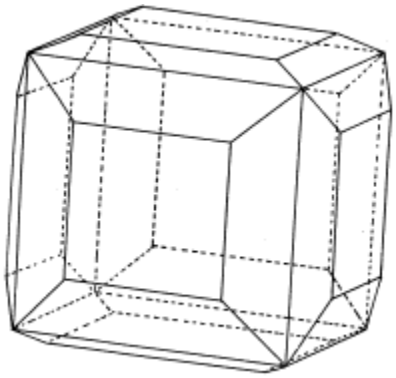


Figure 4. Combination of a cube and tetrahexahedron.

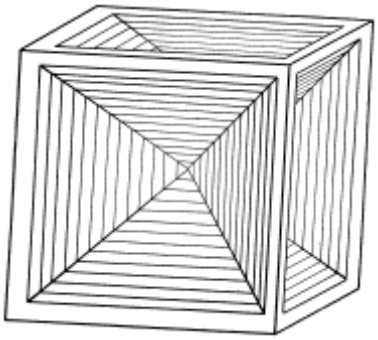


Figure 5. Showing hopper-shaped crystal of halite.

[1]Bull. No. 7, Geol. Sur. Of La., 1907.

PHYSICAL PROPERTIES OF SALT.

Common salt is composed of sodium and chlorine united in the proportions represented by the formula NaCl, or 39.59% sodium and 60.41% chlorine. It occurs in solution in sea water and in brines and in the solid state as rock salt or the mineral halite. Halite crystallizes in the cubic system, the predominating form being the cube. Among other forms which have been noted are the octahedron, rhombic dodecahedron and tetrahexahedron. Figs. 1-4 show different types of development. The crystals also often show a skeletal or hopper-shaped form as illustrated in Fig. 5. One of the most characteristic properties of halite is its perfect cubical cleavage. That is, when struck a sudden blow, it tends to break along planes parallel to the faces of a cube. It has a hardness according to Mohs scale of 2.5, and a specific gravity of 2.1-2.6[2]; pure crystals, 2.135. The color when pure is white, but it may be yellow, brown, red, purple, blue, green, or black, due to the presence of impurities. It is transparent to translucent, and is usually found interstratified with anhydrite, gypsum, shale and limestone. It may also have, as its associates, various combinations of alkali and alkaline earth chlorides and sulphates.

[2]Dana's System of Mineralogy, 6th Edition, 1904, p. 154.

PREVIOUS WORK.

As already stated in the opening paragraph, a number of reports have appeared from time to time dealing with the different aspects of the salt industry of Michigan. The important points brought out in these papers arranged in chronological order are given below:

1838. Dr. Houghton[3] reported that the brine springs of Michigan might be divided into five groups as follows: On the Grand river near Grand Rapids, on the Maple river in Gratiot county, on the Tittabawasse river in Midland county, in Macomb county and on the Saline river in Washtenaw county. No important indications of salt springs were found south of a line between Monroe and Grand Rapids. He advanced the idea that the geology of Michigan was similar to that of the Ohio Valley, but believed that the brines of Michigan occurred in a lower formation than those of Ohio.

1861. Alexander Winchell[4] outlined a correct conception of the geology of Michigan and thus furnished the first basis for the scientific search for saltbearing rocks. The following practical suggestions[5] for the successful discovery of brines were laid down by him at that time:

"1. The occurrence of a salt spring is a fact of no consequence whatever, except in connection with all the other geological facts.

2. Brine is found issuing at the outcrops of the coal measures, the Gypseous Group, the Napoleon Group, the Marshall Group and the Onondaga Salt Group. In Ohio, is also issues from the Coal Conglomerate, the Hamilton Group and the Hudson River Group.

3. Only two of these groups will be found, in our state, to produce brine of sufficient strength for manufacturing purposes; and at present only the Gypsum Group is known to do this.

4. Before deciding on the indications of a salt spring, therefore, it is necessary to know from what geological formation it issues. Here the elaborate investigation of the order of distribution of our strata, finds one of its applications.

5. Before the origin of a brine can be known, we must ascertain whether it flows out horizontally at an outcrop, or rises vertically through a fissure in the strata overlying the salt rock. A fundamental mistake, committed in the early explorations for salt, grew out of the assumption that the brine of our springs generally rises through fissures, and may be sought by boring in the vicinity of the springs.

6. Most of our springs issue at *outcrops* of saliferous strata; so that the moment we begin to bore in at such situations, we find ourselves *beneath* the source of the salt.

7. The source of the salt must be sought by traveling from the spring toward the center of the basin, when, by boring down, the brine may be expected in increasing strength and quantity.

8. Our saliferous basin extends from Grand Rapids to Sanilac County, and an unknown distance toward the north. Within the basin, the area covered by the Coal Measures may be taken as the area underlain by strata of maximum production."

Winchell further announced the occurrence of the Onondaga Salt Group (Salina) in Michigan from outcrops, especially on islands near Mackinac and in the southern part of Ida township in Monroe County, which he correlated with the Onondaga Salt Group of New York.

1862. Winchell reviewed the progress of the industry, and called attention to the fact that the erroneous views of Dr. Houghton upon the geological structure of the southern peninsula had been responsible for the early failures. He recognized three salt horizons, the Coal Measures with the Parma Sandstone below as the reservoir, the Michigan Salt Group or Gypsum Group

with the Napoleon Sandstone as a reservoir, and the Onondaga Salt Group. The latter he believed to occur 750 feet[6] below the Michigan Salt Group.

1867. Dr. H. C. Hahn, who was general manager of the salt works of the New York and Saginaw Salt Company at Zilwaukee, published a paper7 upon the manufacture of salt in the Saginaw Valley. He made a large number of analyses of the brines, bitterns and salt of the various companies, from which he worked out formulas for determining their composition under different conditions, and made suggestions as to the best methods of manufacture in order to insure the best grade salt and the greatest economies in manufacture. He, however, dealt only with the manufacture of kettle and solar salt. Hahn recognized two salt groups, the Michigan and the Onondaga. The former included both the Coal Measures and Gypsum Group of Winchell, and the latter he states to occur at Pt. Austin at a depth of 339 meters, and at Detroit below the Helderberg. His conception of the geology of the southern peninsula of Michigan was therefore somewhat different from that of the present time.

1876. Dr. C. Rominger[8] pointed out that Winchell's correlation of the beds at Ida with those of the Onondaga of New York is not justified by facts.

1876. S. S. Garrigues[9], State Salt Inspector, gave a general review of the salt industry of Michigan, including methods of manufacture, composition of the brines and inspection of the product.

1876. S. B. McCracken[10] gave a brief historical review of the industry.

1881. S. S. Garrigues[11] prepared under the direction of the legislature of the State a statistical report on the salt industry of Michigan.

1881. Dr. Hahn[12] published an article on the manufacture of solar salt.

1888. Thos. M. Chatard[13] presented a report on the chemistry of brines and discussed the methods and costs of manufacture in the Michigan, New York and Kanawaha, W. Va., districts with suggestions as to improvements in manufacturing methods.

1895. Dr. L. L. Hubbard[14] discussed the various theories for the origin of salt deposits, placing special emphasis on the theory of Ochsenius, which he appears to think directly applicable to the Michigan salt deposits, as may be seen from the following quotation:

"To account for the deposit of the salt of Michigan, in all four of the salt horizons, the assumption of an uninterrupted connection of this basin with the sea, for a long period of time, does not seem, so far as the evidence goes, to be required."

1895. Dr. A. C. Lane[15] goes a step further when he says:

"The period of the Monroe beds is that of the Salina and Lower Helderberg. At that time, Michigan was covered by an excessively salt sea which stretched from Wisconsin to New York, was bounded by a continent on the north and east, on the west by low land in Wisconsin (the edge of the Helderberg is found barely extending to just north of Milwaukee), and on the south by a great bar, or reef, or flat in Ohio, which seems to have been just awash..... If we imagine tides like those of the Bay of Fundy rushing over this flat, producing this breccia and conglomerate and bringing fresh supplies of water to the enclosed sea, and furthermore that the sea was exposed to a hot sun and received but little accession of fresh water from rivers—this latter is shown to be true by the scarcity of mud and sand—we have the conditions of the Helderberg or Monroe deposits, conditions which are evidently favorable to the formation of a sea charged with salts." Dr. Lane also[16] discussed the composition of the various mineral waters and brines.

1898. J. J. Hubbell[17] in a paper entitled "A Barrel of Salt" gave a description of a modern salt block and its operation. A more detailed reference to this article will be made in the chapter on the manufacture of salt.

1900. Dr. A. C. Lane[18] in his report on Huron County, discussed the composition of the Huron County brines and the salt industry in that district.

1900. S. S. Higgins[19] gave a brief historical review of the industry.

1901. Dr. Lane[20] compared the brine of the Berea Grit at Kilmaster, Alcona County, with the brine from the same horizon in the wells at White Rock and Pt. Austin in Huron County. The Dundee brines there are too high in sulphides and salts other than sodium chloride to be satisfactory in the manufacture of salt.

1901. The same author[21] gave a brief report on the developments in the salt industry, treating especially the wells along the Detroit and St. Clair rivers.

1906. W. F. Cooper[22] reported on the salt industry in Bay County. He discussed the various brine horizons and the composition of the brines.

1907. Eugene F. Bradt[23] described the method of overcoming the exceedingly large flow of underground water encountered in sinking the shaft of the Detroit Salt Co.

1907. Geo. B. Willcox[24] presented the results of experiments in grainer evaporation, showing the steam consumption per barrel of salt manufactured under ordinary conditions of operation.

1908. Willcox[25] gave a detailed description of a modern grainer block, showing the more recent developments in mechanical methods and appliances from the standpoint of a mechanical engineer.

1909. Dr. Lane[26] gives a general summary on the geological section of Michigan with a possible explanation[27] for the occurrence of the salt deposits of the Salina directly on top of dolomite with anhydrite above the salt. He also, apparently, would apply the Ochsenius theory to the formation of the salt deposits.

The following quotation will perhaps serve to make his position clear:

"But in some it appears as if the salt really did lie directly upon the dolomite. I have thought of this possible explanation. The thickness of salt deposited shows that the basin must have been fed from without. Suppose that it was not only fed by straits from the ocean, but partially or wholly by alkali waters draining from surrounding lands. We know pretty well that in sea water of that day, calcium chloride and magnesium chloride were present beside sodium chloride, as they are to-day, but calcium chloride was relatively much more important. Suppose to a more or less concentrated calcium chloride solution water containing sodium carbonate or sulphate like the alkali water of the western plains were added. The carbonate would throw down calcium magnesium carbonate very promptly. The sulphate might throw down calcium sulphate, in proper conditions. But calcium chloride is much more soluble than sodium chloride and the replacement of calcium by sodium in the base would tend to make the chlorides less soluble. On the other hand, calcium sulphate is much more soluble in a sodium chloride solution than in a calcium chloride one. Thus the addition of sodium carbonate would tend to retard its deposition. If then there was a good supply of sodium carbonate, the order of precipitation might be first dolomite, then salt, then anhydrite."

1910. Professors A. W. Grabau and W. H. Sherzer[28] consider that the deposition of the Salina took place under arid conditions in shallow playa lakes in basin shaped depressions. The salt they believe was derived from the Niagara and other marine limestones on the surface of which it appeared as an efflorescence. It was removed by intermittent desert streams and carried to the ephemeral lakes in which it was later deposited.

1911. Albert H. Fay[29] described the construction and equipment of the salt shaft constructed by the Detroit Salt Co., at Oakwood, Wayne County, Michigan.

In addition to the above mentioned papers, statistics have been published annually; by the State Salt Inspector since 1869, by the Commissioner of Mineral Statistics since 1878 and by the United States Geological Survey since 1880.

[3]First Annual Report of the State Geologist, Joint Doc. 1838.

[4]Geol. Sur. Mich. 1st Bien. Rpt., 1860, pp. 165-193.

[5]Ibid, pp. 165-6.

[6]"On the Saliferous Rocks and Salt Springs of Michigan." Am. Jour. Sc. Vol. 34, 2nd Ser. Pp. 307-11.

[7]Berg und Huettenmännische Zeitung, Vol. 26, 1867, pp. 97-9, 135-7, 161-3, 185-7, 209-11, 221-3, 237-9, 254-7, 283-4, 305-7, 337-339.

[8]Geol. Sur. Mich. Vol. Ill, 1876, p. 35.

[9]Ibid, Appendix B.

[10]"The State of Michigan embracing Sketches of its History, Position, Resources, and Industries." Lansing, 1876, pp. 69-72.

[11]Statistics Relating to the Salt Industry of Michigan. Lansing, 1881.

[12]Berg und Huettenmännische Zeitung, 1881, pp. 369-372, 389-391.

[13]U. S. Geol. Sur., Seventh Ann. Rpt., 1886-7, pp. 497-527.

[14]Geol. Sur. Mich., Vol. V, Part II, 1881-1893, pp. ix-xix.

[15]Geol. Sur. Mich., Vol. V, Part II, 1881-1893, p. 27.

[16]Loc. cit. pp. 32-34.

[17]Michigan Engineer's Annual, 1898, pp. 31-44.

[18]Geol. Sur. Mich. Vol. VII, Part II, 1896-1900, pp. 135-36, 224-5.

[19]"The Salt Industry in Michigan," Mich. Pol. Sc. Assoc. Vol. 4, No. 2, p. 190.

[20]Geol. Sur. Mich., Ann. Rpt. for 1901, pp. 75-6.

[21]Ibid, pp. 241-2.

[22]Geol. Sur. Mich., Ann. Rpt. for 1905, p. 389; 1906.

[23]"Crevices in a Salt Shaft," Mich. Eng., 1907, pp. 17-25.

[24]"Evaporation Tests of a Salt Grainer," Mich. Eng., 1907, pp. 164-189.

[25]"Mechanical Methods and Engineering Feature of Large Salt Plants," Trans. Am. Soc. Mech. Eng., Vol. 3, pp. 1065-1085; 1908.

[26]Geol. Sur. Mich. Ann. Rpt, for 1908, pp. 43-105; 1910.

[27]Ibid, p. 62.

[28]Mich. Geol. and Biol. Sur., Pub. 2, Geol. Ser. 1, pp. 235-237, 1910.

[29]"Shaft of the Detroit Salt Co"., Eng. and Min. Jour., Vol. 91, No. 11, pp. 565-569; 1911.

CHAPTER I. HISTORICAL ACCOUNT.

The existence of salt springs, in the southern peninsula of Michigan, was known to the Indians before the coming of the white man. It is also reported that, very soon after the arrival of the first settlers, attempts were made, on Salt River in Macomb County and also at Saline in Washtenaw County, to manufacture salt from the waters of these springs. However, the first step in the development of the industry may be said to have been taken by the convention assembled in Detroit, May 11, 1835, for the purpose of formulating a state constitution. From this point, two periods of development may be recognized. The first period, that of governmental development, was very largely one of failure; the second, or period of private initiative, has been marked by success almost from the beginning.

GOVERNMENTAL DEVELOPMENT.

The Constitutional Convention of 1835 submitted to Congress, with the proposed constitution, an ordinance, one of the articles of which reads as follows: "All salt springs within the state, and the lands reserved for the use of the same, at least one section including each spring, shall be granted to the State, to be used or disposed of as the Legislature may direct." As a result of the request, the Act of Congress admitting Michigan into the Union gave to the authorities the right to select seventy-two sections as state salt lands.

At the first meeting of the Legislature, Dr. Houghton was appointed State Geologist. He immediately began an

examination of the salt springs of the state and his first annual report was very largely devoted to the discussion of the same. His investigations showed that important saline indications were limited to five districts, namely,—on the Grand river in Kent county, on the Maple river in Gratiot and Clinton counties, on the Tittabawasse river in Midland county, in Macomb county and on the Saline river in Washtenaw county. He pointed out the importance of these springs and urged their early development by the state. Accordingly, by the Act of March 24, 1838, he was directed to commence boring for salt at one or more of the state salt springs, $3,000 being appropriated to defray the expenses. Before beginning operations, Dr. Houghton visited the salt springs of New York, Ohio and Virginia, to acquaint himself with the methods there in use. In June, a well was begun in Midland county, on the Tittabawasse river about one half mile below the mouth of Salt Creek. A month later, a second well was started on the Grand river three miles below Grand Rapids.

Although the Legislature of 1839 appropriated $15,000 to continue operations at the state salt springs, no great progress was made as experienced operators could not be obtained, because they were fearful lest the climate should be unhealthy. Therefore, in 1841, bids for the completion of the work were asked for and the contracts awarded,—the Grand river contract to the Hon. Lucius Lyon, and the Tittabawasse to Mr. Ira T. Farrand. These contracts called for a well three hundred feet deep. The Grand river contract was completed Dec. 23, 1841, a flow of one hundred and thirty gallons per minute being obtained. The strength of the brine, however, was not sufficiently great to warrant an attempt to manufacture salt. The state geologist, therefore, recommended that the well be continued to the second salt rock, which he estimated would be reached at about seven hundred feet. Upon this recommendation, the Legislature of 1842 appropriated $15,000 to continue the work and by the close of the year a depth of about eight hundred feet had been attained. The rock at that point was found to be of such a close texture that the circulation of the waters was very much impeded and the idea of production was abandoned.

In the meantime work at the Tittabawasse well had progressed very slowly. After four years of intermittent work a depth of only one hundred and thirty-nine feet had been reached, where a boulder, which the drills could not penetrate, was encountered and the work was abandoned.

Following these unsuccessful attempts to develop the state salt lands, an act was passed by the Legislature providing for the surveying and leasing of said lands. The lessee was to pay to the state four cents per bushel of fifty-six pounds of salt for the water used. The act also authorized the governor to plan for the sale of such salt lands as were not needed. In the following years, a series of laws and resolutions providing for the sale of these lands was passed and various sections were appropriated for different state institutions.

The cause of the early failures in the location of salt wells was very largely a misconception of the geology of the southern peninsula of Michigan. It was, therefore, not until the appearance of Professor Winchell's first report, in 1860, that there was any basis for a scientific search for salt brines.

PRIVATE INITIATIVE.

While the work on the state salt wells was at a standstill, the Hon. Lucius Lyon, in 1840, began a well near the Bridge Street bridge in Grand Rapids, which was completed at a depth of six hundred and sixty-one feet in July of the following year. From this well a strong flow of water, about one fifth saturated, was obtained. At this time, salt commanded a price of three dollars per barrel. He was, therefore, able to make a small quantity of salt without loss.

It was not until nearly twenty years later that any further attempts were made to manufacture salt in Michigan. In February, 1859, very largely through the exertions of Dr. Geo. A. Lathrop of East Saginaw and Mr. James Scribner of Grand Rapids, the Legislature passed "An Act to encourage the manufacture of salt in the State of Michigan." By the provisions of this act, all property employed in the manufacture of salt was exempted from taxation, and a bounty of ten cents per bushel was to be paid for all salt obtained by boring in the state. The bounty was to be paid, however, only when at least five thousand bushels should have been manufactured. Under this stimulus, the industry was revived at Grand Rapids and a well was also started at East Saginaw.

At Grand Rapids, six wells were put down and plants erected for the treatment of the brines. A small amount of salt was manufactured, but on account of the weakness of the brine, the project was finally abandoned after an expenditure of twenty-five thousand dollars.

On March 30, 1859, the subscription book of the East Saginaw Salt Manufacturing Co. was opened. The stock of the company having been disposed of, ten acres of land just at the lower part of East Saginaw was purchased from Mr. Jesse Hoyt, conditional upon the finding of brine, and the sinking of a well was begun under the directions of Dr. Lathrop. The striking of the first brine was reported on Feb. 7, 1860. A plant for the treatment of the brine was immediately erected and the boiling of salt was begun in the latter part of June.

Almost immediately, other companies began to sink wells and so rapid was the progress of the industry, that by July 1862 twenty-three companies were in operation or in the process of construction in the Saginaw Valley.

The encouragement of the industry by the state as provided in the Act of Feb. 15, 1859 was to be short lived. In March 1861 the former bounty law was amended so that it was to apply only to companies actually engaged in the manufacture of salt previous to Aug. 1, 1861. Furthermore, the tax exemption was limited to five years from the date of organization, and

the bounty was reduced to ten cents per barrel with a maximum limit of $1,000 to any one company. The law was finally repealed entirely March 22, 1869.

TABLE I.

Year.	No. of companies.	No. of blocks.				No. of solar covers.	Capacity, barrels.
		Kettle.	Pan.	Steam.			
				Grainer.	Vacuum.		
1860....	1	.....	.....	.....	.....	.....	.....
1861....	7	.....	.....	.....	.....	.....	.....
1862....	23	.....	.....	.....	.....	.....	.....
1863....	57	75	6	13	.....	1540	.....
1864....	67	79	7	31	.....	4949	.....
1865....	.....	.....	.....	.....	.....	.....	.....
1866....	61	.....	.....	†113	.....	.....	.....
1867....	60	.....	.....	†111	.....	4207	.....
1868....	62	.....	.....	†111	.....	4304	.....
1869....	69	.....	.....	†116	.....	4354	1,212,500
1870....	61	72	15	28	.....	3347	1,247,000
1871....	68	74	14	32	.....	3347	1,408,000
1872....	50	50	14	34	.....	3847	1,158,000
1873....	62	38	17	36	.....	4347	1,258,000
1874....	68	41	21	41	.....	4371	1,774,000
1875....	74	33	22	49	.....	4371	1,800,000
1876....	76	30	22	52	.....	4100	2,155,000
1877....	79	20	22	71	.....	3800	2,100,000
1878....	.....	.....	.....	.....	.....	.....	.....
1879....	.....	.....	.....	.....	.....	.....	.....
1880....	97	3	31	85	.....	4500	3,150,000
1881....	105	2	29	90	.....	4500	3,400,000
1882....	111	.....	37	96	.....	4500	3,590,000
1883....	116	.....	31	100	.....	4500	3,765,000
1884....	117	.....	27	101	.....	4500	3,875,000
1885....	122	.....	27	106	.....	4500	4,445,000
1886....	136	.....	24	116	.....	4500	5,165,000
1887....	125	.....	23	118	1	4500	5,165,000
1888....	127	.....	14	113	3	4500	5,265,000
1889....	122	.....	4	99	3	4000	4,950,000
1890....	97	.....	4	99	3	4000	4,950,000
1891....	.....	.....	.....	.....	.....	.....	.....
1892....	109	.....	10	98	4	4000	5,425,000
1893....	109	.....	7	98	8	4000	5,425,000
1894....	109	.....	7	98	8	4000	5,425,000
1895....	110	.....	7	98	8	4000	5,425,000
1896....	69	.....	4	58	10	3000	6,500,000
1897....	61	.....	3	55	9	1500	7,880,000
1898....	57	.....	3	53	10	1500	7,830,000
1899....	57	.....	3	50	10	1200	7,610,000
1900....	50	.....	3	52	11	1000	7,700,000
1901....	65	.....	6	56	11	1000	9,500,000
1902....	63	.....	6	56	12	1000	9,150,000
1903....	57	.....	6	46	13	1000	10,500,000
1904....	50	.....	5	42	12	1200	10,150,000
1905....	.....	.....	.....	.....	.....	.....	.....
1906....	35	.....	5	31	10	50	9,495,000
1907....	34	.....	4	31	10	1170	9,250,000
1908....	35	.....	4	33	11	.....	9,250,000
1909....	34	.....	4	31	11	.....	9,250,000
1910....	30	.....	3	28	13	.....	9,250,000
1911....	27	.....	.....	.....	.....	.....	8,600,000
1912....	26	.....	.....	.....	.....	.....	.....
*1913...	24	.....	.....	.....	.....	.....	8,490,000

*Dec. 1, 1912, to Aug. 15th following, when law abolishing office of State Salt Inspector went into effect.
† Includes kettle and pan blocks.

However, the industry had become established on so firm a basis that it has continued to grow until in 1905 its production exceeded that of any other state in the Union, and in 1908 it assumed first place in the value of its product as well as in the quantity produced.

The general development of the industry is shown in Table I, compiled from the reports of the State Salt Inspectors, newspaper clippings and other sources, and in Figs. 6 and 7.

In Fig. 6, are shown the curves representing (a) the number of companies operating salt blocks, (b) the total number of blocks in operation, (c) the number of kettle blocks, (d) the number of open pan blocks, (e) the number of grainer blocks, and (f) the number of vacuum pan blocks. The ordinates represent the years from 1860 to 1910 and the absiccae the units. From this diagram, it will be seen that starting with one company in operation at the beginning of 1860, the increase both in operating companies and blocks in operation was very rapid for the first five years. Then for the next five years, with the exceptions of minor fluctuations, the industry remained practically at a standstill, to be followed by a decrease in the number of firms and a still larger decrease in the number of blocks. The explanation for this is to be seen in the line representing the number of kettle blocks. In 1873, however, this backward movement was arrested by the rapid increase in the number of grainer blocks as well as a slight increase in the number of pan blocks. This increase in grainer blocks continued until the maximum number of companies operating and blocks in operation was reached in 1886 and 7 respectively, although the number of pan blocks had reached a maximum in 1882 and then had begun to disappear, the last of the kettle blocks having disappeared the preceding year. During the years 1887 to 1891, a very large number of companies suspended operations owing to a decided drop in the price received for their product, and with the exception of brief revivals in 1892-1895, and in 1901, the number of plants and companies has decreased until the present status was reached in 1905. This great decrease has been due chiefly to the passing of the lumber industry in the Saginaw Valley, and the consequent abandonment of the salt blocks operated in connection with the saw-mills.

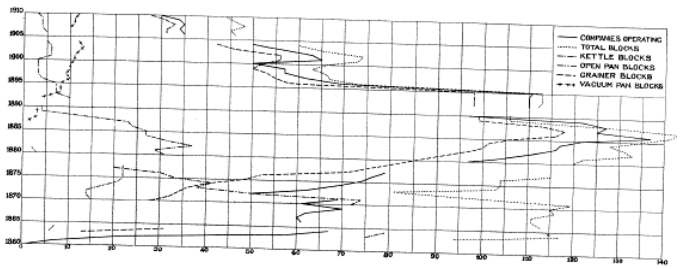


Figure 6. Showing companies in operation from 1860-1910, together with number of salt blocks and the processes employed.

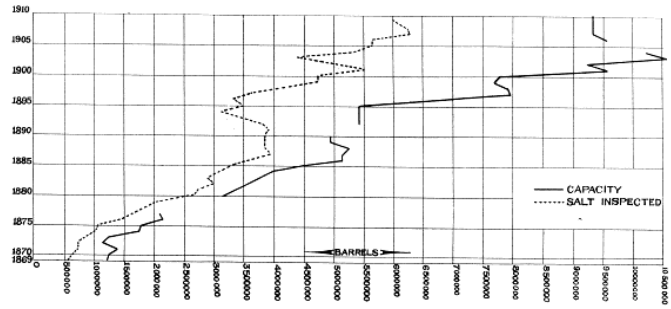


Figure 7. Showing the total amount of salt inspected annually compared with productive capacity of the plants.

With Fig. 6 in mind, it is interesting to turn now to Fig. 7 in which is represented the amount of salt inspected annually together with the estimated capacity of the blocks in the state. We see here, that in spite of the decrease in the number of companies and blocks since 1887, there has been an almost continuous increase in the capacity of the blocks. This has been due very largely to the opening of the Manistee, St. Clair, Ludington and Wayne districts, in 1881, 1883 and 1885

respectively, with their large grainer plants, and the introduction of the vacuum pan (See Fig. 6.). Fig. 7 also brings out the fact that the capacity of the various plants has always been considerably in excess of the output, in some instances the output being less than fifty per cent of the capacity.

The more local phases of the history of the industry have been reserved for later discussion, and will be treated under the several districts.

CHAPTER II. THEORIES OF THE ORIGIN OF SALT AND BRINE DEPOSITS.

SALT DEPOSITS,

The question of the origin of salt deposits has long been a subject for discussion. Different modes of formation have been assigned to different deposits at the same time and the same deposits at different times. All of the theories thus far advanced can, however, be grouped under three general classes, namely,—volcanic, evaporation and the "Dome."

Volcanic theories. Since until comparatively recent times, volcanism has been called upon to explain many different phenomena, it is not strange that the earlier theories of the origin of salt deposits should have made use of this geological process; especially is this true, since as early as 1826, Daubeny[1] announced the presence of hydrochloric acid and sodium chloride in the emanations of volcanoes. Thus Darwin[2] in discussing the deposits of salt on the island of San Lorenzo, off the coast of Peru, says, "The origin is in some way connected with volcanic heat at the bottom of the sea." Although publication was not made until 1852, Ballaert[3] conceived of the volcanic origin of salt in the Andes in 1826, and in his article on the classification and distribution of salt deposits, speaks as follows:

"In North and South America there is abundance of rock salt. In the north, among other ranges affording it, is the Wha-sacht, which is above the Great Salt Lake of Utah or of the Mormons; in South America, from the Andean region to the coast, on either side it is found, and in company with many other curious saline bodies."

"From the small percentage of saline matter in sea-water, not 4 *per cent*, we can hardly look to the ocean as the origin of *so much pure or almost pure* chloride of sodium existing in mountain regions, but rather to sources of a volcanic character at different epochs; sub-marine as well as sub-aerial volcanoes yielding it. During volcanic eruptions, with vast quantities of sulphur and other volatile bodies, the vapor of muriatic acid escapes, and salt has been found sublimed about craters as well as muriate of ammonia. Sea-water may find its way into the igneous interior of the earth; however, the formation of salt in all probability is mainly due to the direct union of chlorine and sodium; salt thus formed from its elements in the bowels of the earth, then ejected through volcanic vents, at times with steam and water as a hot saturated solution, at times with earthy matters, the salt afterwards forming masses, or in those peculiar orbicular layers, as seen in Cheshire and elsewhere, and such operations having gone on at various periods and under different circumstances and elevations, may account for rock or fossil salt being now found below the level of the sea, above it, and at great elevations on the surface of the globe."

The above named authors based their conclusions not only upon the known presence of hydrochloric acid and sodium chloride in volcanic emanations, but also upon the elevation of the deposits above sea level and their associations with igneous rocks. From certain laboratory experiments upon the action of clay and water vapor upon fusion mixtures of various salts, Gorgeu[4] found that sodium iodide and magnesium chloride disappeared very rapidly. He concluded from this that salt deposits formed from igneous eruptions should be characterized by the absence of these compounds, and on this basis would assign to the deposits at Dieuze, France, an igneous origin.

Numerous other writers have advanced different volcanic theories, all of which would fall into the following classification given by Hubbard[5]:

"1. The compounds were brought up from the interior of the earth in the form of molten masses, like ordinary extrusive rocks.

2. The compounds were formed by the action of gases, either by sublimation or by the alteration of materials in place.

3. The compounds were formed in a concentrated solution in hollows in the earth's crust and either solidified after the manner of granite or were extruded through fissures like porphyries.

4. The compounds were ejected as a slime after the manner of mud volcanoes."

However, with the possible exception of the case of deposits so small as to be of no economic importance, the various volcanic theories have been displaced by the evaporation theories and, therefore, need not claim our further attention.

Evaporation theories. It was early recognized that certain salt deposits were formed by the evaporation of saline waters. The general application of this mode of formation, however, met with two apparently great obstacles: the enormous thickness of some of the deposits in comparison with their other dimensions, and their great elevation above sea level. The latter objection was not really a serious one in the light of some of the now known great diastrophic movements, and the recent explorations in arid regions which have disclosed enormous deposits undoubtedly formed from saline waters having no connection with the ocean.

The Ochsenius theory

The first evaporation theory which, although not without objectors, explained deposits of such great thickness, is the one known as the “Bar" theory. This theory probably owes its inception to G. Bischof[6], although his conclusions were based upon erroneous data[7]. However, twelve years later, it was so forcibly readvanced, with certain modifications, by Ochsenius[8] that it is commonly known by his name.

The "Bar" theory[9] supposes a basin or arm of the sea, the entrance of which is partially closed by a bar which may have been originally present or may have been formed by the winds and currents pushing up the sand until the entrance is nearly closed. In order that the process of deposition may go on, this bar must be of such a height that the influx of water from the sea will not be greater than the loss of water due to evaporation at the surface of the bay, and also of sufficient height to prevent the action of outward sub-surface currents. It has been pointed out by Wilder[10] that the reason for the non-formation of salt deposits in the Mediterranean Sea is the fact that the bar which separates it from the Atlantic Ocean is not of sufficient height to prevent outflowing sub-surface currents, so that although evaporation is more rapid in the Mediterranean than in the Atlantic, as is shown by a specific gravity of 1.028-1.03 for the former in contrast to 1.026 for the latter, a concentration sufficient to cause deposition of the salts in solution is not reached.

On account of the shallower depth of the bay, evaporation goes on more rapidly than in the open sea, an4 furthermore, the surface is not disturbed to the same extent by winds and currents. Therefore a more concentrated layer is formed at the surface, which, on account of its higher specific gravity, sinks, producing an increase in concentration with depth until the saturation point of the solution with respect to some compound is reached and that compound is deposited.

The order of deposition and the nature of the compounds formed have long been the subject of research. In 1849, Usiglio[11] published his oft-quoted experiments upon the evaporation of sea water. Still it was not until recently, through the researches of Van't Hoff[12] and others that the exact relationship has been established.

Van’t Hoff[13] states that there are five factors which determine the order of deposition and the compounds formed. These factors are: (1) composition of the solution, (2) solubility of the substances in solution, (3) time, (4) temperature, and (5) pressure.

While it might at first be thought that the least soluble substance would be the first deposited, and that the others would follow in the order of the least solubility, yet a moment's consideration shows that the most soluble salt might be present in such large amounts and the less soluble in so much smaller amounts, with regard to their saturation points, that the most soluble salt alone would be precipitated. The law upon which the progress of crystallization is based is given by Van’t Hoff[14] as follows: "In depositing its contents, the solution gradually varies its composition away from that of a solution which is saturated with the substance being deposited at the moment and contains nothing but this substance.” The order of deposition is still further complicated by the formation of double salts, such as polyhalite ($2CaSO_4$, $MgSO_4$, K_2SO_4, $2H_2O$) and carnallite ($MgKCl_3$, $6H_2O$).

In his experiments on the evaporation of sea water, Usiglio failed to obtain certain compounds which are formed in nature. Van't Hoff[15] has shown that this is due to the neglect of the time factor. Owing to the fact that certain compounds tend to supersaturation and do not separate out as soon as their saturation point is reached, if the concentration process is carried on too rapidly these compounds may be broken up and new ones formed in their stead.

Van’t Hoff[16] has further shown that temperature also plays an important part in determining the nature of the compound formed. Thus certain minerals such as langbeinite ($K_2Mg_2(SO_4)_3$) and loewite ($Na_2Mg(SO_4)_2$) are formed only at temperatures above 37°C. for the former and 43°C. for the latter. This is especially significant in a consideration of salt deposits, since the presence or absence of certain minerals may give an indication of the temperature at which the deposits were formed.

The effect of pressure is the least important of any of the factors. Van’t Hoff finds that it tends merely to raise the temperature of formation of the salts, and since the increment per atmosphere of pressure is very small, it would be effective in very few cases in producing pronounced changes.

In the case of the Dead Sea, we have the deposition of the sodium chloride alone, since the waters have not as yet reached the saturation, point with respect to any other salt or combination of salts present. If the sea. were to be shut off from the influx of new waters, it would eventually dry up and all of the material in solution would be deposited. The order of deposition under such conditions could be foretold by the method of Van’t Hoff.

As a rule, we find the first substance which has been deposited is calcium carbonate. Usiglio[17] found by the evaporation of sea water that there are two depositions of the carbonate, one at a specific gravity 1.0506, which begins gradually and ends suddenly, and a second at 1.1304, which begins suddenly and ends gradually. This second precipitation is believed to be due to the double decomposition between calcium sulphate and sodium carbonate. Usiglio’s experiments further showed that between specific gravities 1.1304 and 1.22, 83.82 per cent of all the calcium sulphate was deposited; after this, 54.17 per cent of the sodium chloride was deposited with the balance of the calcium sulphate; and then, 8.5 per cent of the sodium chloride content without contamination. This is followed by the deposition of the

sodium chloride with the more soluble salts in various combinations.

We find calcium sulphate associated with salt deposits in two prominent forms, gypsum ($CaSO_4$, $2H_2O$) and anhydrite ($CaSO_4$). It is possible that one form has been derived from the other, either by hydration or dehydration, or that both are original and were deposited under different conditions. If secondary alteration of one to the other has taken place, this alteration should be recognized by the disturbance within the rocks caused by the great volume changes which would accompany such an alteration. Since in a great many, if not the majority of the cases, no such disturbance of the beds is apparent, it would seem that both substances are original deposits.

As to the conditions governing the form in which the calcium sulphate is deposited, there has been a considerable diversity of opinion.

Ochsenius[18] found that in the case of the great German deposits the first deposit of calcium sulphate was in the form of gypsum and that the salt deposit was capped by anhydrite. He explained the deposition of the anhydrite as being due to deposition in a concentrated solution of deliquescent salts which extracted the water of crystallization from the gypsum as it passed through the solution.

Pfeiffer[19] had a somewhat different idea of the formation of the anhydrite beds. He considered that the calcium sulphate was deposited as gypsum and that the sodium chloride deposited upon it withdrew the water of crystallization and changed it to anhydrite, after which, the sodium chloride was redissolved and the process repeated until the bed had been formed.

Vater[20] has shown, however, that, at ordinary temperatures, anhydrite is not formed in saturated solutions of either sodium or magnesium chlorides, even in the presence of anhydrite.

Merrill[21] suggests that whether the deposit is to be gypsum or anhydrite "may depend upon the amount of pressure and consequently upon the depth of the enclosed basin for it is estimated that a pressure of ten atmospheres is sufficient to cause sulphate of lime to crystallize as anhydrite.'

Lane[22] also considers pressure as the possible factor in the production of anhydrite. He calculates the specific gravity of the gypsum substance to be greater in the form of anhydrite and water than in the form of gypsum and therefore more condensed. From which he draws the following conclusion: "Therefore pressure would tend to aid its (anhydrite)[23] formation or change it into the former (anhydrite) shape."

The pressure theory was first advanced by G. Bischof in the first edition[24] of his Lehrbuch der chem. u. physik. Geologie. However, he omits all mention of it in the second edition[25], thus seeming to doubt its effectiveness. Also Spezia[26], in 1886, showed experimentally that of itself a pressure of 500 atmospheres was not sufficient to cause the formation of anhydrite. Furthermore, as already pointed out, Van't Hoff[27] considers that the only effect of pressure in determining the order of deposition and compounds formed, is its effect upon the temperature at which a compound will form. The increment per atmosphere[28] is so very small (a few thousandths of a degree) that it can scarcely be considered the important factor in the formation of anhydrite.

Van't Hoff and Weigert[29] have further shown that when the water-tension of the water in the gypsum becomes greater than that of the solution in which it is contained, the calcium sulphate will be precipitated as anhydrite. The water-tension of both the solution and water of crystallization increases with temperature but at different rates, so that in sea water the water-tension of the water of crystallization becomes greater than that of the solution at 25°C. and anhydrite is deposited. In a saturated salt solution, the temperature at which anhydrite formed was found to be 30°C., and in pure water, 66°C.

The interbedded clays and shales have been explained by Ochsenius as due to influxes of fresh water from the land surface, carrying fine particles in suspension. The fact that these layers are practically always clay or very fine sediments would seem to indicate the existence of a certain type of topography. In order that the evaporation might proceed with sufficient force to produce the deposition of salt, an arid or semi-arid climate is necessary. Since rains in an arid climate are generally of the "cloud-burst" type, unless the surface of the surrounding country were rather flat with the streams entering the basin with a small gradient, much larger particles would be carried in suspension by the water.

<u>Walther's theory</u>. Johannes Walther in his Das Gesetz der Wüstungbildung[30] has taken exceptions to the "Bar" theory. From his studies of the desert and the salt deposits there found, he is led to believe that too much emphasis has been placed upon laboratory experiment without proper consideration of climatic factors. Man, being an inhabitant of the more humid regions and almost entirely ignorant of the processes of the desert, has attempted to hypothesize conditions which would produce salt deposits in a more or less humid climate. Walther gives the conditions for the formation of salt deposits as follows:

1. A solution of any source and any concentration.

2. A desert climate with greater evaporation than precipitation.

3. A desert climate with strong insolation, occasional snowfalls and periods of cold, violent storms, wandering dunes, and driving dust.

As to the sources of the solution, it may have resulted from the cutting off of an arm of the sea; it may have its origin in the weathering and solution of igneous rocks; or it may be due to the solution of sea salts contained in marine sediments of former geological periods. In arid

regions the rainwater sinks into the surface to a greater or less depth and is then returned to the surface by capillary action and is evaporated with the deposition of the salts in solution which are then subject to transportation by winds and succeeding rains.

The second factor mentioned above, i. e.; the excess of evaporation over precipitation, is considered by Walther to be the controlling factor in the formation of salt deposits. He says that it makes no difference whether the evaporation occurs 400 meters below sea-level, as in the case of the Dead Sea, or at an elevation of 1500 meters, as in the case of Great Salt Lake; whether it is sea water spread out over a flat shore or in Thibet far from the ocean; and whether a flat sand bar separates a bay from the sea, or great bodies of saline river water are evaporated in small basins far from the sea.

The characteristic phenomena included under the third heading are believed by Walther to account for certain features of salt deposits which, on the basis of laboratory experiments, are shown to require high temperatures or great pressure. In evaporating solutions in the laboratory heat is applied from below, whereas in nature the heat is applied to the evaporating surface. Also it has been found that certain compounds which in the laboratory require for their formation temperatures far higher than that of the water of any ponds, lakes or seas, are produced also under the influence of low temperatures or great changes in temperature such as would result from the melting of snow in saline solutions. The fact that deposits of sodium chloride of great thickness and purity exist may be due to the action of traveling dunes which, advancing upon the salt lake or marsh, "suck up" by capillarity the mother liquor, upon the further evaporation of which, the salts therein contained are deposited in a disseminated condition and therefore subject to the play of the wind. This may carry the dunes on until a later rain redissolves the salts from the dunes and concentrates them in depressions between dunes, giving rise to deposits of mother liquor salts free from gypsum and sodium chloride. Thus we see that in desert regions there are other means of transportation for the salts than running water.

Ochsenius[31] in 1902 discussed the work of Walther and reiterated the importance of the bar. To which Walther replied[32] that the bar, as supposed by Ochsenius, is purely hypothetical, that it does not exist, nor has it been known to exist in nature; and that, moreover, it is a superfluous condition to the formation of salt deposits, aridity being the essential factor.

Clarke[33] has also pointed out that deposits of great thickness might be formed without the existence of a bar. He supposes a large sheet of water to be cut off from the sea, forming a basin, in which there is a deep depression. By evaporation the concentrated waters would accumulate in the depression and a deposit of considerable thickness might be formed. As he says, "If the surface area of the depression were small in comparison with that of the original sheet of water, the depth of the deposit might be very great."

The Dome theory. The occurrence of salt in Louisiana, Texas, and some other localities is of such a type as to render its origin unexplainable by evaporation theories. These deposits are circular to elliptical in shape, with great thickness relative to the diameter. They are arranged along lines of jointing or faulting and apparently at the intersection of the joint or fault planes. Surrounding the salt mass are the upturned rock strata, decreasing in age from the center outward. Thus is produced a doming effect which may or may not be apparent topographically.

It was early recognized that these facts could not be explained by any surface evaporation theory, and many suggestions as to their origin were advanced. None of these, however, seemed tenable until the present theory was put forth by G. D. Harris in 1907. Harris' theory was first suggested in Bulletin No. 5 and later elaborated in Bulletin No. 7 of the Geological Survey of Louisiana. Still later it was published in a more condensed form in Economic Geology, Vol. IV, No. 1, pp. 12-35. The data here given have been taken from these papers.

The theory may be thus stated in a general way. The deposits have been formed by the crystallization of salt from waters, which have dissolved the salt out of some lower stratum, ascending along joints or fractures in the rocks. As the salt waters have ascended, a decrease in temperature has resulted in the separation of the salt crystals, and the force exerted by the growing crystals has produced the doming effect in the superimposed strata.

The nature of the process and its progress may perhaps be better understood from Fig. 8. The upper series represents conditions where the overlying strata are composed of loose and friable material, the lower, the conditions where the deposition has taken place beneath a more rigid stratum.

As to the efficiency of the pressure exerted by growing crystals to elevate several thousand feet of gravel, sand, and clay, Harris points out that, on the basis of A. L. Day's[34] experiments, which show that the linear force of growing crystals is of the same order of magnitude as the crushing strength of the crystal, the force exerted by salt crystals from this region would be sufficient to raise sand, clay, and salt layers to a thickness of 3000 to 4000 feet. Furthermore, on account of the lower specific gravity of the salt, when it had once started to form it would continue along the same vertical line, which would be the line of least resistance.

[1]Daubeny, Charles, Volcanoes, London, 1826, pp. 168-172.

[2]Darwin, Charles, Geological Observations, London, 1842, Vol. III, p. 235.

[3]Ballaert, William, Proc. Brit. Assoc. Adv. Sci., 1852, part 2, p. 100.

[4]Gorgeu, Alexander, Comp. rend. l'Acad. des Sci. 102, p. 1165.

[5]Hubbard, L. L., Geol. Sur. Mich., Vol. V, part II, p. xii.

[6]Bischof, G., Lehrbuch der Chem. u. Physik. Geologic, 1864, II, p. 48.

[7]Walther, Johannes, Centr. fur Min. Geol. u. Pal., 1903, p. 211.

[8]Ochsenius, C., Die Bildung der Steinsalzlager u. s. v., Halle, 1877: Chem. Zeit., 1887, II, pp. 848, 935. and 962: Proc. Acad. Nat. Sci., Phila., 1888, p. 181.

[9]The substance of the theory is summarized by Ochsenius (Die Bildung u. s. v., pp. 11-12.) in the following paragraph:

"Meeresbusen mit hinlänglich bedeutender Tiefe in Innern und einer annähernd horizontalen Mündungsbarre, welche nur so viel Meereswasser eintreten lässt, als die Busenoberfläche auf die Dauer zu verdunsten im Stande ist, liefert (ohne anderweitige Communication) unter vollständig oder nahezu anhydrosischen Verhältnissen ein Salzlager, dessen Mächtigkeit nur von Busentiefe und der Dauer der obwaltenden Müstande abhängt."

[10]Wilder, Frank A., Jour. Geol., Vol. II, p. 742, 1903.

[11]Ann. de Chim. et de Phys. (3) Vol. XXVII, 1849, pp. 92, 172.

[12]Sitzungsber. der Konigl. preuss. Acad. der Wissensch., von 1897 an.

[13]Physical chemistry in the Service of Science, p. 100.

[14]Ibid, p. 104.

[15]Ibid, pp. 115-118.

[16]Ibid, pp. 120-121.

[17]Loc. Cit.

[18]Loc. cit.

[19]Quoted by Ochsenius, Chem. Zeit. 1891, 15, No. 53.

[20]Vater. Heinrich, Sitzungsber. Akad., Berlin, 1900, p. 270ff.

[21]Merrill, F. J. H., Bull. N. Y. State Mus. Vol. 3, No. 11, 1893, p. 10.

[22]Lane, A. C., Geol. Sur. of Mich. Vol. IX, Part II, p. 185.

[23]The words in parentheses are the author's.

[24]1855.

[25]1864.

[26]Spezia. G., Atti della R. Academia delle Scienze di torino, 1886, 21, 20 Juni; abstract in Zeitschr. fur Kryst. u. s. v., 1888, 13, 302.

[27]Loc. cit.

[28]Van't Hoff, J. H., Physical Chemistry in the Service of Science, p. 123.

[29]Van't Hoff, J. H. and Weigert, F., Sitzungsb. d. Akad. d. Ber. 1901, 2, s. 1140-48.

[30]pp. 140-156.

[31]Ochsenius, C., Centr. fur Min. GeoL u. Pal., 1902, pp. 551, 557, and 620.

[32]Centr. fur Min. Geol. u. Pal., 1903, pp. 211-217.

[33]Clarke, F. W., U. S. Geol. Sur. Bull. No. 330, p. 176.

[34]Proc. Wash. Acad. Sci., Vol. VII, 1905, pp. 283-288.

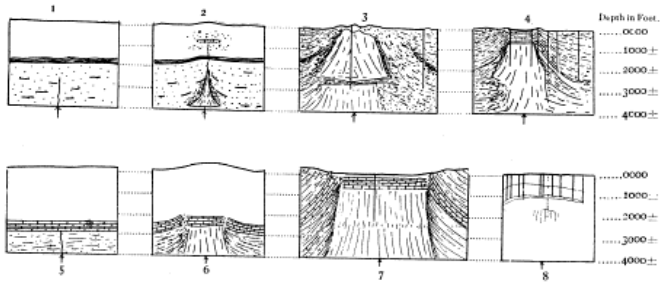


Figure 8. Figures representing the origin of dome structure by crystalline growth. (After Harris.)

BRINE DEPOSITS.

Natural brines are found in the more porous rocks, especially the sandstones. As to the origin of these brines there are two possibilities. They may be the original sea water in which the rocks containing them were laid down, or they may have been formed through the solution of salt by percolating waters.

Brines from original sea water. While it is not probable that many deposits from original sea water exist at the present time except at the surface of the lithosphere, yet it is conceivable that such deposits might be formed. A change from coarse to fine in the materials deposited in a basin cut off from the sea might imprison the sea water contained in the pore spaces of the coarser material, provided an impervious layer was also present below to prevent the circulative action of ground water. It may also be considered as a possibility that the waters of a desert sea which had an impervious substratum might be buried by wind blown material and thus preserved.

Brines from solution. In the consideration of brines formed from solution by percolating waters, a number of possible variations arise. In the first place, the salt from which the solution is produced may occur either in the form of concentrated deposits or disseminated throughout the rocks in which it is found. In the second place, the deposits may occur in the brine-bearing stratum or they may be present in some other stratum and the brine bearing layer act merely as a reservoir or conduit for the brine after it has been formed. And in the third place, the movement of the percolating waters may be downward, upward, or lateral.

The possible difficulties in the determination of the exact origin of a brine formed by solution are made manifest by the consideration of these various factors.

If the salt is in the form of a concentrated deposit or deposits, they may be of so small relative proportions that it would be extremely difficult to find them. On the other hand, the presence of disseminated material would be shown only by accurate chemical analyses. The difficulty is here increased by the second factor mentioned, that is, that the source of the material may be far removed from the brine-bearing stratum. As a rule, rock salt deposits are associated with limestones and shales. Therefore if the brine-bearing stratum be a sandstone, it is most reasonable to suppose that the deposit from which the brine has been formed is not within the brme-bearing layer. However, this is not necessarily true.

The direction of the water movement is determined by the texture and structure of the rocks and also by the nature of the forces producing the circulation.

The forces producing circulation which we shall consider are gravity and molecular attraction, or capillarity. The tendency of gravity is to cause a downward movement of water. However, the texture and structure may so act as to produce lateral and also upward movements of water.

Capillarity, on the other hand, tends to produce movements from areas of greater concentration to areas of less concentration. While both of these forces may be acting at the same time, the predominance of one or the other will depend very largely on the texture of the rocks.

The texture of the rocks determines not only the porosity or water-holding capacity of the rocks, but also the perviousness or the ability of the rock to transmit water, the latter being the more important in this connection. The perviousness of a rock depends both upon the total amount of pore space and also upon the size of the individual pores. It is therefore a relative property. The larger and more continuous the individual spaces the more readily will gravitational water be transmitted. Conversely, as they decrease in size the movement due to gravity will be slower until a diameter is reached at which it will cease and any further movement must be due to capillarity. A stratum, therefore, in which the pore spaces are all of capillary or sub-capillary size would be relatively impervious, although its porosity might be much greater than that of a more pervious stratum. We have all noticed how, after a rain, the water will form puddles in a heavy clay soil while in the case of a sandy soil it rapidly disappears. This is due to the fact that while the porosity of the clay may vary from 50 to 70% (the sand having a porosity of 30 to 40%) the Individual pore spaces are so small that it is comparatively impervious.

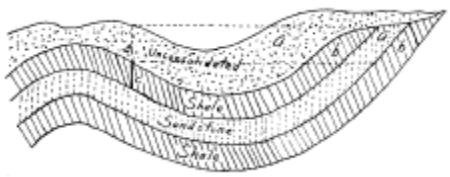


Figure 9. Showing a pervious stratum of rock between two impervious strata.

The structures which are important in the control of underground circulation are those resulting from fracturing and folding. Fracturing, which produces fissures, joints, bedding partings and the like, opens up large channels for the transfer of gravitational water. The direction of the movement will depend upon the direction of the opening and the head under which the water is flowing. Folding results in throwing the strata which were originally horizontal into a series of folds, the concave portions of which are called synclines, and the convex, anticlines. If a series of strata composed of alternating pervious and impervious layers of rock be so folded and then exposed to erosion we shall have the layers successively exposed at the surface. Rain falling on their upturned edges will pass downward in the more pervious layers due to gravity, while the less pervious layers act in determining the exact direction of the flow. If at any point having a lower elevation than the catchment area (the area from which the water is derived) an opening occurs in the impervious stratum above the pervious layer, the water will flow upward through this opening due to the head. These conditions are shown in Fig. 9, in which (a) represents the pervious strata, (b) the impervious stratum, (c) the fracture in the impervious layer, and (d) the head.

In order to determine which of the above theories are applicable to the salt and brine deposits of Michigan, it is first necessary to consider the geology and nature of the deposits, and we shall therefore turn our attention to that phase of the subject.

CHAPTER III. GEOLOGY OF THE SALT AND BRINE DEPOSITS OF MICHIGAN.

INTRODUCTION.

While solid rock outcrops in a few places, the southern peninsula of Michigan is in general covered with a mantle of drift, or material transported and deposited there by the great glaciers which formerly covered the region. These deposits are made up of till, or boulder clay, sand and gravel. They vary greatly in constitution and also in depth, a thickness of about six hundred feet being found in the region of Manistee. Our knowledge of the geology of the southern peninsula is therefore based very largely on the records of deep wells.

It has been pretty definitely established that the lower peninsula has been a more or less persistent, and in later geological times isolated, basin of deposition since at least Middle Ordovician times. Lane[1] considers this basin to have existed in the Pre-Cambrian shield which passes from Wisconsin around through Northern Michigan into Canada. That minor oscillations have occurred is shown by the disconformities[2] between the Salina and the Niagara, the Lower and Middle Monroe, and the Middle and Upper Monroe. There has also been some minor folding as Lane[3] has pointed out in the case of an anticline trending north-northwest from Saginaw, the Stronach anticline, the trend of which has not been determined, and other folds.

For our purposes, however, the different rock layers of southern Michigan may be compared to a pile of evaporating dishes cut across the top so as to present a surface of more or less concentric rings. This arrangement of the outcrops of the various strata with the superincumbent drift mantle removed may be seen at a glance from Fig. 10. A cross-sectional view of the basin is shown in Fig. 11 which represents a section on a northwest and southeast line across the center of the basin. An examination of the rocks themselves shows that they are composed of alternating beds of limestone, shale, and sandstone.

It is not the purpose of this paper to consider the complete stratigraphy of the state, inasmuch as it has recently been very ably discussed by Dr. Lane[4]. Certain formations however, on account of their being the repositories of the brines and rock salt, demand our consideration. Of these, five[5], the Parma. Marshall,

Berea. Dundee. and Monroe are brine-bearing. The Salina, is the source of the rock salt of Michigan.

[1]Lane, A. C. Notes on the Geological Section of Michigan. Geol. Sur. Mich., Ann. Report. 1908, p. 43.

[2]This term has been proposed by Grabau for unconformities showing no discordance in bedding.

[3]Lane, A. C., Geol. Sur. Mich., Vol. VIII, Part II, p. 176; Ann Rpt., 1901, p. 211; ibid, 1903, p. 291.

[4]Geol. Sur. Mich., Ann Rpt, 1908, pp. 1-91.

[5]The position of these beds is shown in Fig. 12.

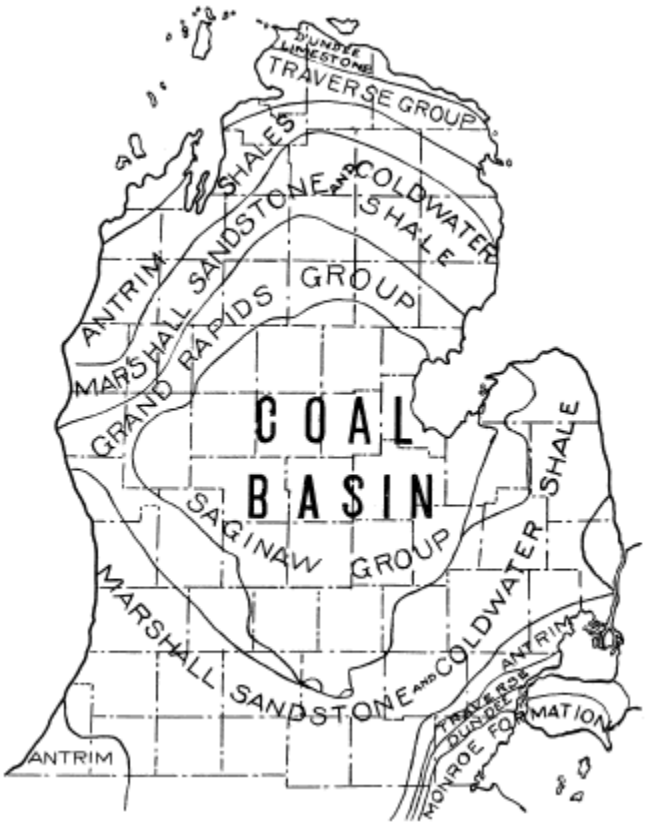


Figure 10. Outline geological map of the Southern Peninsula of Michigan.

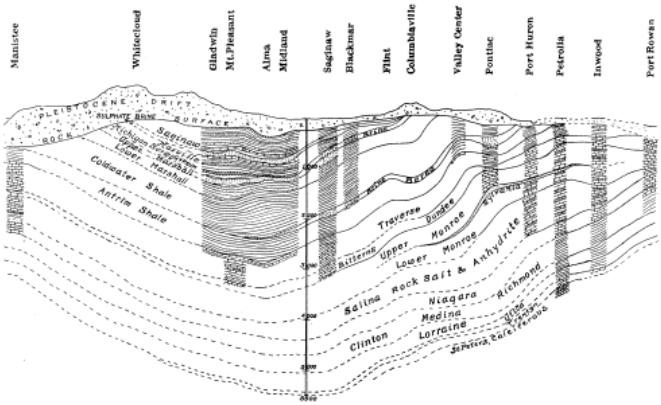
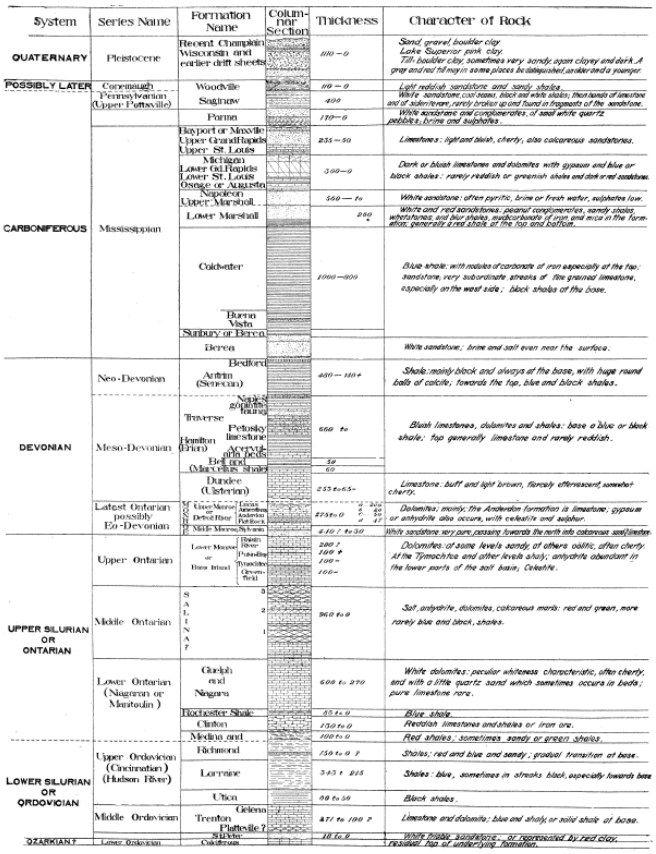


Figure 11. A section across the Michigan Basin (after R. A. Smith).



System	Series Name	Formation Name	Column-nar Section	Thickness	Character of Rock
QUATERNARY	Pleistocene	Recent Champlain Wisconsin and earlier drift sheets		110 — 0	Sand, gravel, boulder clay. Lake Superior pink clay. Till: boulder clay; sometimes very sandy, upon clayey and dark A gray and red till may in some places be distinguished, older and a younger.
POSSIBLY LATER	Carboniferous	Woodville		80 — 0	Light reddish sandstone and sandy shales.
	Pennsylvanian (Upper Pottsville)	Saginaw		400	White sandstone, coal seams, black and white shales; thin bands of limestone and of siderite rare, rarely broken up and found in fragments of the sandstone.
		Parma		170 — 0	White sandstone and conglomerates, of small white quartz pebbles; brine and sulphates.
CARBONIFEROUS	Mississippian	Bayport or Meaville		235 — 50	Limestones: light and bluish, cherty, also calcareous sandstones.
		Upper Grand Rapids			
		Upper St. Louis			
		Michigan		390 — 0	Dark or bluish limestones and dolomites with gypsum and blue or black shales: rarely reddish or greenish shales and dark red sandstones.
		Lower Gd. Rapids			
		Lower St. Louis			
		Osage or Augusta			
		Napoleon		560 — to	White sandstone: often pyritic, brine or fresh water, sulphates low.
		Upper Marshall			
		Lower Marshall		200 +	White and red sandstones: peanut conglomerates, sandy shales, siltstones, and fair shales, and carbonate of iron and mica at the formation: generally a red shale at the top and bottom.
		Coldwater		1000 — 800	Blue shale, with nodules of carbonate of iron especially at the top; sandstone, very subordinate streaks of fine grained limestone, especially on the west side; black shales of the base.
		Burnt Vista			
		Sunbury or Berea			
		Berea			White sandstone; brine and salt even near the surface.
DEVONIAN	Neo-Devonian	Bedford			
		Antrim (Senecan)		400 — 110 +	Shale: mainly black and always at the base, with huge round balls of calcite; towards the top, blue and black shales.
	Meso-Devonian	Traverse	Nawakwa Grating		
			Petoskey limestone	660 to	Bluish limestones, dolomites and shales: base a blue or black shale; top generally limestone and rarely reddish.
		Hamilton (Erian)	Alpena beds		
			Bell grit	50	
			(Alpena) shale	60	
		Dundee (Ulsterian)		255 to 65 —	Limestone: buff and light brown, fiercely effervescent, somewhat cherty.
	Latest Onterian possibly Eo-Devonian	Upper Monroe	Lucas	7 — 20	Dolomites: mainly; the Anderson formation is limestone; gypsum or anhydrite also occurs, with celestite and sulphur.
		Detroit River	Anderson	7 — 50	
			Flat Rock	0 — 47	
		Middle Monroe	Sylvania	410 ? to 30	White sandstone very pure, passing towards the north into calcareous sandy limestone.
UPPER SILURIAN OR ONTARIAN	Upper Ontarian	Lower Monroe or Bass Island	Bass River	200 ?	Dolomites: of some levels sandy, of others oolitic, often cherty. At the Tipmochitas and other levels shaly; anhydrite abundant in the lower parts of the salt basin, Celestite.
			Put-in-Bay	100 +	
			Tymochtee	100 —	
			Cayuga-field	100 —	
	Middle Ontarian	SALINA? 3		960 to 0	Salt, anhydrite, dolomites, calcareous marls: red and green, more rarely blue and black, shales.
		2			
		1			
	Lower Ontarian (Niagaran or Maritoulin)	Guelph and Niagara		600 to 270	White dolomites: peculiar whiteness characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds; pure limestone rare.
		Rochester Shale		25 to 0	Blue shale.
		Clinton		150 to 0	Reddish limestones and shales or iron ore.
		Medina and		100 to 0	Red shales, sometimes sandy or green shales.
LOWER SILURIAN OR ORDOVICIAN	Upper Ordovician (Cincinnatian) (Hudson River)	Richmond		150 to 0 ?	Shales; red and blue and sandy; gradual transition at base.
		Lorraine		345 ? 215	Shales: blue, sometimes in streaks black, especially towards base.
		Utica		80 to 50	Black shales.
	Middle Ordovician	Trenton	Glenna		
			Platteville ?	471 to 100 ?	Limestone and dolomite; blue and shaly, or solid shale at base.
		Stitzlin		18 to 0	White friable sandstone, or represented by red clay, residual top of underlying formation.
OZARKIAN ?	Lower Ordovician	Calciferous			

Figure 12. Geological column of Michigan from Trenton to Pleistocene (after Lane).

THE PARMA.

Areal distribution. The Parma sandstone lies at the base of the Coal Measures and its areal distribution may be considered roughly as that given for the Coal Basin (Fig. 10). Lane[6] estimates the area of the Coal Basin including the Parma to be eleven thousand two hundred and thirty-four square miles. That this entire area is underlain by the Parma is doubtful. It seems to be absent in certain wells, as for example at Kawkawlin, where Rominger[7] reports limestone and gypseous shales at the depth at which the sandstone should be expected.

Structure. In general this formation dips toward the center of the basin and, therefore, is found at an increasing depth, as is shown in Table II, which gives the depths of the Parma at various points, together with its thickness. The large and rapid variations in thickness are probably due to the presence of erosional unconformities, both above and below the formation. The unconformity above the Parma is indicated by the absence of the Parma at certain points where it should be expected; while at other places, the Grand Rapids group below seems to be very thin, or even absent, so that the Parma rests upon the Marshall sandstone and is indistinguishable from it, as at Corunna[8]. This may indicate an erosional unconformity or it may be due to an overlapping of the upper beds.

Figure 13. Showing the location of wells which enter the Parma sandstone.

1. Alma.
2. Bay City.
3. Carrollton.
4. Corunna.
5. Eaton Rapids.
6. Garfield.
7. Ionia.
8. Ithaca.
9. Jackson.
10. Midland
11. Owosso.
12. Saginaw.
13. Sebewaing.
14. South Bay City.
15. St. Johns.

TABLE II.[a]

Wells in the Parma sandstone.

Locality.	Approx. alt. of top of well.	Total depth of well.	Depth to Parma.	Thickness of Parma.	Approx. alt. of top of Parma.	Remarks.
Alma, Mich.	755	2861	710	80	+45	
Bay City, Mich.	592	2865	585	50	+7	
Carrollton, Mich.	590	750	375	55	+215	Bliss well.
Corunna, Mich.	776	907	231?		+545	Parma and Marshall indistinguishable.
Eaton Rapids, Mich.			116			
Garfield, Mich.			400±	50±		
Ionia, Mich.		343	246	86		Ionia Twp. Sec. 26.
Ithaca, Mich.		613	525	86		
Jackson, Mich.	928	2455	88	292	+830	
Midland, Mich.	608	1305	810	110		Dow well.
Owosso, Mich.	745	1000	250	223	+495	
Saginaw, Mich.	590	715	340	153	+250	Salina well, near P. M. bridge.
Saginaw, Mich.	600	900	474	59	+126	Saginaw Plate Glass Co.
Sebewaing, Mich.	593	303	87	13	+506	Liken well, N. E. ¼ Sec. 18.
South Bay City, Mich.	585	3508	490	50	+95	North American Chemical Co.
St. Johns, Mich.		608	468	72		Water works.

[a]For the location of the wells see Fig. 13.

Superjacent and subjacent strata. As is shown in Fig. 12, the Parma is directly overlain by the Saginaw formation, which is the coal bearing horizon of Michigan. Lithologically this formation is made up of a series of shales of various colors, sandstones, coal seams and occasional thin bands of siderite. Siderite is also present at times in the form of nodules together with pyrite and sphalerite. The record of the No. 4 well of the Saginaw Plate Glass Co.[10] shows gypsum just above the Parma. This, however, is the only record of gypsum above the Parma which has come to my notice.

Below the Parma we find in general the Bayport, or Maxville, limestone. This formation which consists for the most part of limestone strata, often containing cherty nodules, with occasional beds of shale and sandstone, is generally less than 100 feet thick. In the area south of Corunna, including Durand and Howell, the correlation is not certain, but the Parma, if present, seems to be underlain by the Lower Grand Rapids or Marshall formations.

Lithological character. The Parma in Jackson County is described by Winchell[11] as "a white, or slightly yellowish, quartzose, glistening sandstone." He also states that it is firmly cemented. In well samples, it appears as a very white sandstone, in some instances tending to be conglomeratic. The pebbles, when present, are rather small and composed of milky quartz. That the cementation process has been carried on to an advanced degree is shown by the way in which the drill breaks the rock, the rupture in some instances taking place through the pebbles while the cement remains intact. As we pass toward the center of the basin the conglomeratic phase seems to disappear and Lane[12] believes that at the center of the basin the sandstone is probably replaced by shale. However, at Mt. Pleasant, which is the point nearest the center of the basin from which information is obtainable, the Parma is represented by 124 feet of pure gray sandstone.

The Parma brines. In as much as the brines from this horizon are no longer used in the manufacture of salt, our knowledge of their composition is of necessity based upon old analyses. Although the following analyses have been published before, they are thought to be of sufficient importance to warrant repetition at this time.

TABLE III.

	1.	2.	3.
Sodium chloride	152.674	125.315	196.92
Sodium sulphate	--	--	1.16
Calcium chloride	5.302	3.472	7.42
Calcium sulphate	3.961	4.884	1.45
Magnesium chloride	4.115	4.333	4.32
Magnesium bromide	--	--	0.13
Total saline matter	166.052	138.004	211.70

1. Gilmore well, Bay City, Mich. Depth of well, 505 feet. Analysis by Dr. C. A. Goessman, October, 1862. Brine 65 degrees by salinometer. Geol. Sur. Mich., Vol. III, p. 181. Ibid, Ann. Rpt., 1905, p. 389.

2. Portsmouth, Bay Co., Mich. Depth of well, 664 feet. Brine 54 degrees by the salinometer. Analysis by Dr. C. A. Goessmann, October, 1862. Geol. Sur. Mich., Vol. III, p. 182.

3. Bay City, Michigan. Well, unknown. Specific gravity, 1.163. Analysis by Jas. R. Clinton and Co., A. Winchell, Am. Jour. Sci.; Vol. 34, p. 311, 1862.

It is to be regretted that our analyses of this brine are limited to such a small area, as they give no clue to possible variations in its composition. I think we are safe in assuming, however, that, as we pass toward the center of the basin, the earthy bases will increase relatively to the alkalis. The above analyses show that, although the Parma brines are weaker than those of the Marshall and Berea formations, they are in general freer from earthy chlorides. They are also distinguished from

the Marshall and Berea brines by a relatively larger percentage of calcium sulphate (gypsum).

Origin of the Parma brines. Winchell[13] apparently considered that the brines of the Parma sandstone had their origin in the Saginaw formation, as he speaks of the first salt horizon as "the Coal Measures with the Parma sandstone as a reservoir." Hubbard[14], on the other hand, has suggested that these brines might be the original sea water in which the sandstone was laid down or that they might have originated in the underlying saline beds. The latter hypothesis has also been advanced by Grimsley[15] in discussing the origin of the gypsum deposits of Michigan. He thinks the most probable origin of the gypsum of the Grand Rapids series to be from deposition in an isolated sea. If, however, evaporation had been complete, a much larger amount of salt (sodium chloride) than of gypsum would have undoubtedly resulted. As far as our present knowledge goes, such a deposit of salt does not exist. Grimsley believes that the present absence of known salt deposits in the Grand Rapids series would not be hostile to the hypothesis, since, "the gypsum now remaining shows marked effects of solution and these effects would have been much greater in the salt. The salt laden waters would flow downward along the slope of the rock and percolating through would work up under hydrostatic pressure, as it approaches the center of the basin, into the overlying Parma sandstone which is more gypsiferous than the underlying Marshall."

As already noted, our knowledge of the Parma and its brines is very limited, so that any explanation of their origin can be but a tentative one at best. The points to be considered are as follows:

1. The presence or absence of salt beds within the Parma sandstone.

2. The composition of the brine.

3. The presence or absence of the required salts in the overlying and underlying formations.

4. The lithological character of the overlying and underlying formations.

5. The nature and distribution of the Parma sandstone.

6. Paleontological evidence.

As yet no deposits of rock salt or gypsum have been found within the Parma sandstone. It seems probable, therefore, that if the brine has been formed through the solution of such deposits, the deposits must be sought outside of the formation. A clue to the composition of these deposits is afforded by the composition of the brines. The Parma brines, as is shown by the analyses, are characterized by a high percentage of calcium sulphate relatively to the chloride. This would seem to indicate that the source of the brines must have contained a considerable amount of gypsum. Except in the one instance, already noted, gypsum has not been found above the Parma sandstone, and while this apparent absence may be due to our lack of knowledge, yet it would seem to argue against such an origin of the Parma brines as suggested by Winchell[16]. On the other hand, below the Parma, although generally separated from it by the Bayport limestone, is found the Lower Grand Rapids formation which contains large deposits of gypsum.

As to the lithological nature of the overlying and underlying formations, we have seen that the formation above the Parma (the Saginaw) is composed largely of shales, although exhibiting sandstone facies at some points. This would form an impervious stratum against the directly downward percolation of water, the movement tending rather along the bedding planes. The movement would therefore be toward the center of the basin, and the water would be under hydrostatic pressure so that it would be forced to rise whenever fractures were encountered. Conditions would be similar within the Lower Grand Rapids formation, so that the water entering at the upturned edges would tend to move toward the center of the basin, dissolving out the salts as it progressed, until fractures were found through which, on account of the hydrostatic pressure, it would be forced up into the Parma sandstone, where it would be retained by the impervious capping of the Saginaw formation above.

It has already been noted that the Parma sandstone is undoubtedly not continuous underneath the Saginaw formation. This patchy occurrence is not, however, entirely due to the deposition, as Lane[17] has pointed out that an unconformity exists not only below but also above the Parma. This type of occurrence together with an erosion surface above makes it difficult to see how the brine might be original sea water as suggested by Hubbard[18]. Also the presence, as recorded by Winchell[19], of calamites and sigillariae, plants intolerant of salt water, would seem to argue against either an original sea water origin or the presence within the Parma of rock salt in the concentrated form or in disseminated deposits.

While not conclusive, a careful weighing of the evidence therefore seems to indicate that the brines have been formed through the solution of sodium chloride and gypsum within the Lower Grand Rapids formation and that they have risen into the Parma sandstone.

[6]Lane, A. C., Geol. Sur. Mich., Vol. VIII, Part II, p. 143.

[7]Rominger, C., Geol. Sur. Mich., Vol. Ill, p. 96

[8]Lane, A. C., Geol. Sur. Mich., Vol. VIII, Part II, p. 27.

[10]Geol. Sur. Mich., Ann. Rpt., 1908, p. 103.

[11]Winchell, A., 1st Bian. Rpt. State Geologist, 1860, p. 112.

[12]Lane, A. C., Geol. Sur. Mich., Ann. Rpt., 1908, p. 87.

[13]Loc. Cit.

[14]Hubbard, L. L., Geol. Sur. Mich., Vol. V, Part II, p. 16, 1893.

[15]Grimsley, G. P., ibid, Vol. IX, Part II, p. 190, 1904.

[16]Loc. cit.

[17]Loc. cit.

[18]Loc. cit.

[19]Winchell, A., Geol. Sur. Mich., 1st Bian. Rpt., p. 114, 1860.

THE MARSHALL SANDSTONE.

The Marshall formation was early studied by Professor Winchell[20]. He first divided it into the Napoleon, which he placed at the base of the Carboniferous, and the Marshall at the top of the Devonian. Later[21] he also placed the Marshall in the Carboniferous, uniting the Napoleon sandstone with it as the Upper Marshall. Finally he concluded there were no good grounds for separating the two. This later view was probably based on the fact that, in the Saginaw well, he found but one hundred and nine feet of sandstone before passing into the red shales, which, he says[22], "must be regarded as the commencement of the argillaceous portion of the Huron group." Lane[23] has pointed out that this is probably not the case but that toward the center of the basin the sandstone of the Lower Marshall is replaced by shale which renders it indistinguishable from the next lower formation and that therefore there are good reasons for retaining the earlier subdivisions. While it is with the Napoleon, or Upper Marshall, that we have especially to deal, in considering the areal distribution, the formation will be treated as a whole.

Areal distribution. As may be seen from Fig. 10, the Marshall formation outcrops beneath the drift in a circular zone, five to forty miles in width, bordering the Grand Rapids group, except in the southeastern part of the state where it is in contact with the Saginaw formation. On the southern side of the basin, the boundary between the Marshall and the underlying Coldwater shales has been pretty well established from outcrops and well records. On the northern side however, the dividing line has not been definitely determined.

Structure. The general dip of the Marshall is toward the center of the basin, as is shown in Table IV[24]. (The depths at which the Marshall is reached would seem to indicate, however, that the deepest part of the basin is not coincident with but north of the geographical center.) However, in his Huron County Report (page 96.), Lane says in regard to the top of the Marshall in Huron county, "It is thrown into a series of gentle folds pitching toward the northwest and corresponding in a general way to that slight fold which we have spoken of near Port Austin and to the fold in the coal mine at Sebewaing." This seems to conform to the fold at Saginaw which appears to cross the river near Carrollton, since in the Bliss well at Carrollton the Marshall is reached at -60 A. T. To the north, the depth increases until at South Bay City it drops to -265 A. T. Likewise as we go south, the Marshall is reached in the Salina well, South Saginaw, at about -100 A. T., and at the Plate Glass Works at about -200 A. T.

Superjacent and subjacent strata. Above the Marshall is a series of beds of shale, sandstone, and dolomite, with layers of gypsum, known as the Lower Grand Rapids or Michigan series. This group is of considerable interest in this connection on account of the persistence in it of the gypsum beds. Grimsley[25] states that, in the center of the basin, the gypsum is replaced by anhydrite, or the anhydrous form of calcium sulphate. The general presence of gypsum or anhydrite in this formation is shown by the records of various wells,—thus at Saginaw (gypsum. 651-676; dolomite and gypsum, 735-743), Bay City (gypsum, 780-790), Midland (fairly pure anhydrite, 970-1050), Mt. Pleasant (anhydrite and dolomite, 1150-1250; anhydrite, 1250-1295), Grayling (gypsum, 408-540), and Alma (blue and white (anhydrite) gypsum, 860-895). We see, therefore, that during Lower Grand Rapids time physical and climatic conditions in the Michigan basin were such as to cause deposition of the substances in solution through evaporation. As far as our present knowledge goes, however, the process of deposition was not carried to the point at which the concentration of the solution with respect to the sodium chloride was sufficient to bring about a precipitation in large quantities.

Figure 14. Showing the location of wells which enter the Marshall sandstone.

1. Alma
2. Allegan.
3. Assyria.
4. Battle Creek.
5. Bay City.
6. Bayport.
7. Blackmore.
8. Bridgeport.
9. Carrollton.
10. Charlotte.
11. Garfield.
12. Grand Rapids.
13. Grand Haven.
14. Grayling.
15. Ionia.
16. Jackson.
17. Kawkawlin.
18. Marshall.
19. Midland.
20. Mt. Pleasant.
21. Muskegon.
22. Owosso.
23. Saginaw.
24. Sebewaing.
25. St. Charles.

Below the Marshall we find a series of blue and black shales known as the Coldwater formation. The gradation between the Marshall and Coldwater is such that the determination of the boundaries between them is extremely difficult. For our purposes however, the lower limit of the sandstone member of the Upper

Marshall, or Napoleon, is a matter of more importance and is more easily determined, especially in the case of that portion of it which is brine bearing. Thus at both Saginaw and Bay City we find beneath the sandstone a red clay or shale. That the same is also true at Midland is shown by the record of the last well put down by the Dow Chemical Co. (See Fig. 40.) It is perhaps well to point out that the first appearance of this shale does not always indicate the base of the sandstone, as in some of the wells of the Saginaw Plate Glass Co. we find that the sandstone is split by 3-5 inches of red "marl." No samples of this "marl" were obtainable, but I take it to be red clay or shale.

TABLE IV.

Wells in the Marshall (Napoleon).

Locality.	Approx. alt.	Total depth of well.	Depth to Marshall.	Thickness of Marshall (Napoleon).	Approx. alt. of top of Marshall.	Remarks.
Alma, Mich.	755	2861	1015	85	−260	
Allegan, Mich.	708	1400	255	76	+453	
Assyria, Mich.	917		240	80	+677	
Bay City, Mich.	592	2865	830	90	−238	
Bay City, Mich.	585	3508	850	120	−265	North American Chemical Co.
Bay Port, Mich.	590	2000	270	135	+320	
Carrollton, Mich.	590	750	650	100	−60	Bliss well.
Charlotte, Mich.	906	2209	570	110	+536	
Corunna, Mich.	776	907	800?			G. S. M. Vol. V, Plate XII.
Garfield, Mich.			800	60		
Grand Rapids, Mich.	605	2220	128	131	+477	Ibid, Plate XX.
Midland, Mich.	608	1305	1205		−597	Dow Chemical Co.
Mt. Pleasant, Mich.	770	1550 +	1405	145 +	−635	
Owosso, Mich.	745	1000	556	45	+189	G. S. M. Vol. V, Plate XLV.
Saginaw, Mich.	590	715	690		−100	Salina well.
Saginaw, Mich.	620	900	820	78	−200	Saginaw Plate Glass Co.
Sebewaing, Mich.	593	303	248	55	+345	Liken well. Still in Marshall.

Lithological character. The Napoleon sandstone is usually a whitish sandstone, at times possessing a greenish or bluish tinge. It is generally finer grained than the Parma, not so clean looking, and less well cemented. It is at times micaceous and often pyritiferous. In well samples grains of quartz are often found to be coated with limonite, probably formed from the decomposition of pyrite. I judge this to be the case because the limonite has not imparted a general coloration to the quartz as might be expected if it were originally present.

Marshall (Napoleon) brines. At the margin of the basin near the outcrops, the Napoleon is the source of fresh water in many wells. However, as we pass toward the center of the basin, the water becomes mineralized to such an extent that it has been, and still is, the principal source of the salt of the Saginaw valley.

A large number of analyses of the brines from the vicinity of Saginaw have been published. An especially interesting series was prepared by Dr. Hahn.[26] These analyses were published originally in Germany and it is thought well to present a number of them in this connection.

TABLE IV.

	4.	5.	6.	7.	8.
([27])					
(Na, K) Cl	16.871	16.316	19.304	19.860	19.671
MgCl	1.774	1.156	1.343	1.261	1.381
CaCl	3.287	2.068	2.623	2.961	2.916
$CaSO_4$	0.098	0.173	0.080	0.072	0.082
MgO, $2CO_2$	--	--	--	--	0.0015
CaO, $2CO_2$	0.050	--	trace	--	0.0010
FeO, $2CO_2$	0.0116	--	0.0054	--	9.0123
FeCl & Fe_2Cl_3	--	--	0.0032	--	0
Na (?) Br	0.0401	--	--	--	--
Free CO_2	--	--	trace	--	trace
SiO_2 & Al_2O_3	0.0245	--	--	--	--
SH	--	--	0	--	0
HO	76.844	79.847	76.269	75.846	75.715
Total	100.000	99.560	99.628	100.000	99.758

[27] The chemical symbols are taken directly from the original. Figures represent parts per hundred.

4. East Saginaw Co., No. 1 well. Depth of well, 730 feet. Specific gravity, 1.177. Analysis by Dr. Chilton.

5. New York and Saginaw Co., No. 3 well. Depth of well, 813 feet. Specific gravity, 1.1548. Dr. H. C. Hahn, analyst.

6. Oneida Co., Zilwaukee. Specific gravity, 1.1864. Dr. H. C. Hahn, analyst.

7. Bangor Co., Bangor. Depth of well, 844 feet. Specific gravity, 1.194. C. Goessmann, analyst.

8. Michigan Co., No. 1 well, Zilwaukee. Depth of well, 928 feet. Specific gravity, 1.1909. Dr. H. C. Hahn, analyst.

TABLE VI.

	9.	10.	11.	12.	13.
([27])					
(Na, K) Cl	19.671	17.510	17.586	19.499	13.832
MgCl	1.335	1.069	1.210	2.033	0.945
CaCl	2.987	2.643	3.212	4.564	2.469
$CaSO_4$	0.079	0.098	0.065	0.048	0.070
MgO, $2CO_2$	0.0016	--	--	0.003	--
CaO, $2CO_2$	0.0009	--	--	0.0023	--
FeO, $2CO_2$	0.0116	--	--	0.0213	--
FeCl & Fe_2Cl_3	0	--	--	--	--
Free CO_2	0.0056	--	--	--	--
HO	75.477	78.680	77.927	74.401	82.684
Total	99.570	100.000	100.000	100.572	100.000

[27] The chemical symbols are taken directly from the original. Figures represent parts per hundred.

9. New York and Saginaw Co., No. 1 well. Depth of well, 959 feet. Specific gravity, 1.1739. Dr. H. C. Hahn, analyst.

10. Forest Valley Co., Saginaw City. Depth of well, 905 feet. Specific gravity, 1.173. C. Goessmann, analyst.

11. Chicago Co., Florence. Depth of well, 1,069 feet. Specific gravity, 1.165. C. Goessmann, analyst.

12. Wayne County Co., Tittabawasse. Depth of well, 1,142.5 feet. Specific gravity, 1.2045. Dr. H. C. Hahn, analyst.

13. D. H. Fitzhugh, Salsburg. Depth of well, 1,123.5 feet. Specific gravity, 1.133. C. Goessmann, analyst.

Other analyses from this area, but of more recent date, are given in Tables VII and VIII.

TABLE VII.

	14.	15.	16.	17.
Specific gravity	1.170	1.183	1.182	--
Sodium chloride	179.12	222.46	167.30	228.00
Calcium chloride	21.42	48.10	41.10	45.00
$+2H_2O$	--	14.68	--	--
Magnesium chloride	15.22	9.62	17.60	17.00
Calcium sulphate	1.16	0.884	--	0.80
$+2H_2O$	--	0.232	--	--
Potassium chloride	2.20	--	--	--
Magnesium bromide	--	0.200	0.712	0.3 to 0.1
Ferrous carbonate	1.05	--	--	0.15
Ferrous oxide	--	0.259	--	--
Ferric oxide	--	0.196	--	--
Ferrous chloride	--	--	0.05	--
Ammonium chloride	--	--	--	0.05
Silica	--	--	--	0.02
Alumina	--	--	--	0.02
Total solids	220.19	296.631	206.762	291.34

14. East Saginaw Salt Manufacturing Co., East Saginaw, Mich. Depth of well, 742 feet. Analysis by Professor Douglas, University of Michigan, April 16, 1860. (Geol. Sur. Mich., 1st Bian. Rpt., 1860, p. 171.) This was the first successful salt well in Michigan.

15. St. Charles, Mich. Depth of well, 810 feet, (Geol. Sur. Mich., Ann. Rpt., 1903, p. 107.)

16. Saginaw Salt Co., St. Charles, Mich. Analysis by J. C. Graves, Analysis furnished by the company.

17. Saginaw Valley brines. (U. S. G. S. Min. Res. 1908, Part II, p. 650.)

This is apparently a composite analysis.

TABLE VIII.

	18.*	19.*	20.†	21.†
Sodium chloride	234.05	141.00	13665.60	13270.88
Calcium chloride	32.90	83.00	2624.92	2629.69
Magnesium chloride	21.20	31.00	1004.85	1034.67
Calcium sulphate	0.80	--	--	50.06
Magnesium bromide	--	--	20.38	56.72
Magnesium sulphate	--	--	44.86	--
Ferrous carbonate	--	--	8.96	--
Ferric oxide	--	trace	--	--
Alumina	0.05	trace	--	--
Bromine	--	1. +	--	--
Water of Combination	--	--	2174.80	--
Total	289.00	256.00	19544.37	17042.02

*Grams per kilogram.
†Grains per gallon.

18. North American Chemical Co., Bay City, Mich. Depth of well, about 970 feet. Analysis by A. Llewellyn Allen. Furnished by M. L. Davies, general manager of the company.

19. Dow Chemical Co., Midland, Mich. Depth of wells, about 1,300 feet. Analysis furnished by Mr. Dow.

20. Saginaw Plate Glass Co., Saginaw, Mich. Well No. 1. Depth of well, 906 feet. Analysis by Professor F. S. Kedzie, Mich. Agr. Coll., August 8, 1905.

21. Same. Analysis by Professor E. D. Campbell, Univ. of Mich.

The following more recent analyses of Napoleon brines appeared in an article entitled, "Composition of the Salines of the United States" by J. W. Turrentine.[28]

22. Bliss VanAuken Co., Saginaw, Mich. Composite brine from three wells, 80° by salinometer. 1911. R. F. Gardner, analyst.

23. Edward Germain, Saginaw, Mich. Brine from well No. 1, 750 feet deep, 1910. R. F. Gardner, analyst.

24. Mershon, Eddy, Parker and Co., Saginaw, Mich. Composite brines from two wells. R. F. Gardner, analyst.

25. S. L. Eastman Flooring Co., Saginaw, Mich. Composite brines from two wells. 1911. R. F. Gardner, analyst.

26. Saginaw Plate Glass Co., Saginaw, Mich. Composite brine from ten wells. 1911. R. F. Gardner, analyst.

27. Dow Chemical Co., Midland, Mich. Composite brine from ten wells. 1911. R. F. Gardner, analyst.

28. Dow Chemical Co., Mt. Pleasant, Mich. Composite brine from five wells. R. F. Gardner, analyst.

29. Saginaw Salt Co., St. Charles, Mich. Brine from one well. 1911. R. F. Gardner, analyst.

30. Saginaw Salt Co., St. Charles, Midi. Plant No. 2. Composite brine from two wells. R. F. Gardner, analyst.

TABLE IX.

	22.	23.	24.	25.	26.	27.	28.	29.	30.
Potassium	trace	0.4	1.4	0.8	1.0	trace	1.2	trace	trace
Sodium	77.8	100.0	129.7	78.2	86.6	69.3	82.5	55.5	111.5
Calcium	10.8	7.6	12.8	10.8	16.0	36.6	50.2	15.8	4.2
Magnesium	3.8	1.0	3.6	3.2	4.4	8.6	11.6	4.0	13.2
Chlorine	145.4	155.1	155.4	145.0	172.0	196.4	205.4	163.0	205.4
Sulphuric anhydride	4.2	2.4	26.0	2.2	1.2	1.2	0.6	0.6	1.8
Bromine	0.4	1.7	2.0	0.5	0.4	2.2	trace	2.0	2.8

Conventional combinations.

	22.	23.	24.	25.	26.	27.	28.	29.	30.
Potassium chloride	trace	0.8	2.7	1.6	1.9	trace	2.3	trace	trace
Sodium chloride	197.3	239.6	242.8	198.4	219.7	173.8	133.3	217.0	283.2
Calcium chloride	24.9	18.3	35.4	27.4	42.9	99.8	183.0	42.9	9.4
Magnesium chloride	13.3	3.9	6.3	9.8	15.3	32.5	45.5	5.5	37.2
Sodium sulphate	.....	.....	39.7	.....	.....	.....	.....	.....	.....
Calcium sulphate	6.0	3.4	trace	3.1	1.7	1.7	0.9	0.9	2.6
Magnesium bromide	0.8	.....	4.0	1.2	0.9	2.7	7.8	4.6	6.5
Sodium bromide	.....	2.2	.....	.....	.....	.....	.....	.....	.....
Ferrous chloride	.....	.....	.....	.....	.....	2.3	.....	.....	.....

From the preceding analyses it may be seen that there is a decided increase in the percentage of earthy chlorides relatively to the sodium chloride as we go toward the center of the basin. This is shown especially well by comparing the analyses from Bay City, Saginaw, Midland, and Mt. Pleasant. In general there seems to be also an increase in the bromine content in the same direction. However, some of the analyses seem to contradict this view.

A comparison of Napoleon and Parma brines brings out a number of points of difference. The high percentage of bromine is especially characteristic of the Napoleon brines. As compared with the Parma brines those of the Napoleon are very low in gypsum, or calcium sulphate. On the other hand, they are relatively higher in the earthy chlorides. As these compounds, together with the magnesium bromide, are more soluble than the sodium chloride, they are concentrated in the mother liquor, or bittern, in the manufacture of salt.

In the early days of the salt industry, the bittern was thrown away. Later, attempts were made at some of the plants to utilize it in the manufacture of bromine. The decrease in the price of this article has, however, caused the abandonment of all of the by-product plants except those of the Saginaw Salt Co., so that at present it is manufactured only at St. Charles, Mt. Pleasant, and Midland.

Another product which is now being manufactured from the mother liquors is calcium chloride, which is present in quite large amounts, as will be seen from the following analyses, of bitterns resulting from the evaporation of Saginaw valley brines, as extracted from the scrapbook of Dr. S. S. Garrigues.

TABLE X.

	30.	32.	33.	34.	35.
Specific gravity	1.2271	1.2340	1.2432	1.2488	1.3061
Sodium chloride	142.03	122.28	106.85	89.89	28.06
Magnesium chloride	38.56	47.41	53.60	61.74	93.68
Calcium chloride	83.81	105.06	118.15	135.08	211.92
Calcium sulphate	0.23	0.23	0.34	0.21	0.07
Water	755.28	755.02	721.06	711.06	666.27
Total	1019.91	1020.00	1000.00	997.98	1000.00

A more recent set of analyses of bitterns from the Napoleon brines is given by J. W. Turrentine.[29]

TABLE XI.

	36.	37.	38.	39.	40.	41.	42.
Potassium	1.3	1.6	4.2	2.6	10.2	1.2	trace
Sodium	66.1	83.3	72.2	76.1	42.1	52.5	60.9
Calcium	40.6	32.4	36.4	32.8	192.6	50.2	0.6
Magnesium	11.5	9.6	11.0	9.6	35.2	11.6	0.4
Chlorine	207.7	198.4	202.2	195.8	427.7	205.4	91.5
Sulphuric anhydride	0.4	trace	0.8	1.4	none	0.6	3.6
Bromine	.....	4.4	3.3	2.2	trace	trace	4.3

Conventional combinations.

	36.	37.	38.	39.	40.	41.	42.
Potassium chloride	2.5	3.1	8.0	5.0	19.5	2.3	trace
Sodium chloride	167.5	211.6	198.4	193.0	106.9	133.3	147.2
Calcium chloride	111.8	89.6	99.8	89.1	532.6	138.0	1.7
Magnesium chloride	45.1	15.3	19.3	26.3	18.4	45.5	1.6
Sodium sulphate	.....	.....	.....	.....	.....	.....	5.3
Calcium sulphate	0.6	trace	1.1	2.0	none	0.9	trace
Ferric chloride	.....	.....	.....	.....	.....	2.3	.....
Magnesium bromide	.....	10.1	9.5	5.1	trace	trace	.....
Sodium bromide	.....	.....	.....	.....	.....	.....	5.5

36. Hine and Co., Bay City, Mich. Bittern from grainer, 5 day's evaporation. 1911. A. R. Merz, analyst.

37. Bliss VanAuken Co., Saginaw, Mich. Bittern from grainer, 5 day's evaporation. 1911. R. F. Gardner, analyst.

38. Edward Germain, Saginaw, Mich. Bittern from grainer, 14 day's evaporation. 1911. R. F. Gardner, analyst.

39. Mershon, Eddy, Parker Co., Saginaw, Mich. Bittern from grainer, 4 day's evaporation. 1911. R. F. Gardner, analyst.

40. Saginaw Chemical Works (Saginaw Plate Glass Co.), Saginaw, Mich. Bittern which has been evaporated to 8.5% of the volumn of the original brine, before the final evaporation for the preparation of calcium chloride. Samples taken while hot. On cooling a crystalline solid separated which contained 1.1% potassium, or 2.3% potassium chloride. 1911. R. F. Gardner, analyst.

41. Dow Chemical Co., Mt. Pleasant, Mich. Bittern after the removal of bromine. Contaminated with iron compounds. 1911. R. F. Gardner, analyst.

42. Saginaw Salt Co., St. Charles, Mich. Bittern, 4 day's evaporation. 1911. R. F. Gardner, analyst.

Origin of the Napoleon brines. According to Winchell,[30] the brines of the Napoleon sandstone were formed through solution within the "Michigan Salt Group" or Lower Grand Rapids formation and the Napoleon sandstone served merely as a reservoir for the brines. That this hypothesis is scarcely tenable is shown by a consideration of the composition of the brines themselves. From an examination of the analyses given above, it will be seen that these brines are characterized especially by their low gypsum content. As already pointed out the Lower Grand Rapids formation contains massive deposits of gypsum, whereas, so far as is known, no deposits of rock salt exist within the formation. If the Napoleon brines had been formed within the lower Grand Rapids formation through the solution of disseminated salt, it is scarcely conceivable that the gypsum which is present in vastly greater amounts should have been so slightly attacked.

The possibility of the source of the Napoleon brines being within the Lower Marshall or subjacent formations also seems remote inasmuch as the presence of large numbers of fossils, not tolerant of highly saline solutions, within the former would argue against the occurrence of either rock salt or disseminated deposits, while the brines of the latter as a rule show a much higher gypsum content than do those of the Napoleon.

It would seem, therefore, that the source of the brines must be sought within the Upper Marshall. The writer is of the opinion that the Napoleon brines are formed by the solution of disseminated salt within the red shale underlying the sandstone member. Whether this shale represents the upper portion of the Lower Marshall or is the seaward phase of the lower portion of the Upper Marshall (Napoleon) may be a debatable question but he favors the latter view, since we find that at Bay City the characteristic sandstone member has decreased to

about one half the thickness which it exhibits in Huron county. Here it is succeeded by one hundred feet of red sandstone, instead of shale, which Cooper[31] is inclined to include with the Upper Marshall.

The possibility of such an origin as mentioned above is demonstrated by the red shale sample from the No. 13 well of the Dow Chemical Co., Midland. This sample represents the formation at a depth of 1,390 feet. It is a very red, argillaceous shale and contains disseminated salt crystals which are visible to the naked eye. In order to prove that these crystals were not due to crystallization from the brine contained within the pore spaces of the shale, the following simple experiment was performed.

A 5 gram sample of the shale was treated with about 100 c.c. of distilled water, boiled about three minutes and filtered. The residue was then treated again in the same way with 50 c c. of distilled water, the filtrate added to the first filtrate, and the residue washed with distilled water until the volume of the solution amounted to about 200 c.c. The solution was then placed on a water bath and evaporated to 30 c.c., when, on being cooled to room temperature, a very pronounced deposition took place, indicating supersaturation. Inasmuch as the volume of water contained in the pore spaces of the clay could not exceed 12.5 c.c. if the pore space equalled 100 per cent, (taking the specific gravity at 2.5), it will be apparent that a portion of the salt must have been present as a disseminated deposit within the shale. While the absolute presence of disseminated salt in this one instance may not be sufficient to prove conclusively the origin of the Napoleon brines, yet when considered in connection with the improbability of their source lying either in the overlying or underlying formations, together with the lateral continuity of the Napoleon sandstone and the fact that the sample was obtained from the deeper part of the basin, it would seem to make such an origin extremely probable.

The facts of which account must be taken in considering this portion of Michigan's geological history are as follows: The general absence of fossils in the Upper Marshall, their abundance in the Lower Marshall, the fact that the fossils of the latter do not as far as known show any changes in form which might be expected with a relatively slow increase in salinity, the presence of disseminated salt beneath the Napoleon sandstone, the great variations in thickness of Napoleon sandstone within relatively short distances, and the presence of cross-bedding.[32]

These conditions, it seems, may be best explained by supposing that the Michigan sea of Lower Marshall time, in which there was an abundance of life, was connected with the main sea by a narrow strait[33] across which was a submerged bar; and that at the beginning of Upper Marshall time this outlet was closed either by a diastrophic movement or by increasing conditions of aridity, bringing the bar above the surface of the water. The southern peninsula of Michigan would then represent an isolated basin in which evaporation would proceed rapidly, especially if the separation had been produced through an increasing aridity. The streams flowing into the basin would be of the torrential type characteristic of arid regions, and enormous delta deposits (encroaching upon the saline sink with increasing aridity) would produce cross-bedded deposits of sand of considerable thickness. If the rains were sufficiently frequent to prevent too rapid concentration of the waters of the saline lake, the clays which would be washed into the lake would be deposited with the salts which were being thrown down through the evaporation of the saline waters.

It is possible that in the closing stages of the Napoleon, drifting sands may have played an important part, advancing upon the waters and entrapping them, thus preventing the formation of concentrated salt deposits and making it possible that a portion of the Napoleon brine is the original sea water within which the deposition of the sandstone occurred.

[20]Winchell, A., 1st Bian. Rpt., 1860.

[21]Winchell, A., Am. Jour. Sci., Vol. 33, pp. 352-356.

[22]Report, 1860, p. 90.

[23]Lane, A. C., Geol. Sur. Mich., Vol. VII, Part II, p. 92.

[24]For location of the wells see Fig. 14.

[25]Grimsley, G. P., Geol. Sur. Mich., Vol. IX, Part II, p. 97.

[26]Hahn, Dr. H. C., Berg und Huettenmaenische Zeitung, 26, 1867, pp. 136-7.

[28]Jour. Industrial and Engineering Chem., Vol. 4, No. 12, Dec. 1912, p. 887.

[29]Loc. Cit. p. 888.

[30]Loc. cit.

[31]Cooper, W. F., Geol. Sur. Mich., Ann. Rpt., 1905, p. 154.

[32]Winchell, A., Proc. Am. Phil. Soc. Vol. II, 1871, p. 74.

[33]Schuehert, Chas., Bull. Geol. Soc. Am., Vol. 20, Plate 80.

THE BEREA GRIT.

Although the Berea brines are no longer employed as a source of salt, they are of considerable interest on account of their earlier use at plants along the shore of Lake Huron.

Areal distribution. According to Lane,[34] the Berea grit has not been observed in outcrops in Michigan, but may be traced in wells along the border of the Cincinnati anticlinal northeast from Adrian, past Ann Arbor, Birmingham, and Utica to the southeast comer of Sanilac county. From here, it is observed in the wells along the lake shore at White Rock, Harbor Beach, East Tawas, Oscoda and Harrisville, where it is found immediately underlying the drift. To the west it thins rapidly and occurs only in isolated patches.

Structure. While the Berea dips in general to the west and is therefore found at an increasing depth toward the center of the basin, as is shown in Table XII, from Fig. 16, we see that with respect to the Marshall, taken as a

datum plane the dip is to the east and the resulting westward dip would therefore be less than that of the Marshall. The figure also shows that the deposit thins rapidly to the west and more gradually to the east. From the table it is likewise apparent that there is a decided dip north and south from White Rock and Harrisville respectively. Lane[36] inclines to the idea that the Berea grit was formed in a sea whose west shore ran nearly north and south through the center of Michigan.

Figure 15. Showing the location of wells given in Table XII.

1. Adrian.
2. Ann Arbor.
3. Bay City.
4. Blackmar.
5. Birmingham.
6. Caseville.
7. Charlotte.
8. Coldwater.
9. Constantine.
10. Dowagiac.
11. East Tawas.
12. Gr'd Rapids.
13. Grindstone City.
14. Harbor Beach.
15. Harrisville.
16. Jackson.
17. Killmaster.
18. Oscoda.
19. Port Hope.
20. Port Austin.
21. Pontiac.
22. Romeo.
23. White Rock.

Figure 16. Structure section showing the Berea (after Lane).

Superjacent and subjacent strata. Above the Berea grit are a series of shales known as the Coldwater. The lowest member of the series is a black shale probably the equivalent of the Simbury or Berea black shale of Ohio. This shale is characteristically present when the Berea grit appears below and often extends beyond the limits of the Berea. The Coldwater shales contain numerous sand streaks, many of which are brine bearing. These minor brine bearing strata are generally thin and vary so in position that correlation, at present, is not possible. Neither are any analyses of these brines available.

The underlying formation, the Antrim, consists of another series of shales. These shales are black in the lower portions, generally grading upward into blue shales with red shales, sometimes sandy, at the top. Lane[37] states that where the Berea grit is well marked the red phase has never been found.

Lithological character. The Berea is a micaceous sandstone, gray in color. It varies considerably in texture, being in general finer grained in the thicker portions. At some places, as at Oscoda, it is so fine grained and well cemented that it does not readily yield up its brines.

TABLE XII.[35]

Locality.	Approx. alt.	Total depth of well.	Depth to Berea.	Thickness of Berea.	Approx. alt. of top of Berea.	Remarks.
Adrian	810	1650	554	30	256	
Ann Arbor	875	1325	400	115	475	
Bay City	592	2865	2141	165	−1549	
Bay City	585	3508	2100	170	−1515	North American Chemical Co.
Blackmar	613	1677	1653	110	−1042	
Caseville		2300	1700	100		
Charlotte	906	2209	1660	40	−754	Gritty shale.
Coldwater	983	1200	816	14	+167	Red calcareous shale.
Constantine	803	1080	286	15	+517	Red shale.
East Tawas	590	883	678	195	−88	Grant and Sons.
Grand Rapids	605	2220	1175?	30?	−570	Brine 26°. Small amount.
Grindstone City	592		1010	70	−418	
Harbor Beach	600	1920	603	61	−3	(Sand Beach).
Harrisville	640	506	230	30	+410	Beneath drift.
Jackson	928	2455	1410	55	−482	
Killmaster	670	1732	570	40	+100	
Oscoda	590	1800±	950±		−360	Pack Wood & Co.
Port Hope	600	787	716	71	−116	
Pontiac	934	1505	620	179	+314	
Port Austin	597	1225	1160	65	−563	
Romeo		1600	750±			
White Rock	590	1311	495	60	+95	

[35] For location of the wells see Fig. 15.

Berea brines. The Berea brines are very highly saturated and in general are characterized by a very low percentage of sulphates. Lane[38] states that this may possibly be due to a reduction of the sulphates by the black shales, or the oil and gas sometimes associated with them, but that more probably they were originally low in sulphates. That the resulting hydrogen sulphide is not present in the brine is explained as being due to the presence of iron which has precipitated it as pyrite. With an increase in depth, the brines are marked by a considerable percentage of bromides and the bittern was formerly used at East Tawas for the manufacture of bromine. The following analyses bring out the composition and variations in the brines.

TABLE XIII.

	43.	44.	45.	46.	47.	48.
Sodium chloride	156.141	179.3	176.161	225.673	189.134	186.19
Magnesium chloride	12.433	19.2	15.675	1.591	4.106	33.47
Calcium chloride	34.843	42.1	31.274	33.000	5.373	110.60
Calcium sulphate	0.350	trace	0.129	2.539	2.623	0.33
Ferric oxide and alumina						1.14
Total	203.767	240.7	223.239	232.803	201.236	331.73

43. Grant and Co., East Tawas, Mick Depth of well, 905 feet. Salinometer 85°. C. A. Goessmann, analyst. Geol. Sur. Mich., Vol. III, p. 184.

44. Smith Kelly and Dwight, Oscoda, Mich. Depth of well, 1070 feet. Specific gravity, 1.182. Dr. H. C. Hahn, analyst. Ibid, p. 186.

45. Ayre's well, Port Austin, Mich. Depth of well, 1,198 feet. Salinometer 88°. Ibid, p. 183.

46. Harbor Beach, Mich. Depth of well, 702 feet. Salinometer 84°. S. P. Duffield, analyst. Geol. Sur. Mich., Vol. VII, Part II, p. 135.

47. Thomson Bros., White Rock, Mich. Depth of well, 566 feet. Geol. Sur. Mich., Vol. III, p. 184.

48. North American Chemical Co., Bay City, Mich. Depth to the Berea, 2,100 feet. Geol. Sur. Mich., Ann. Rpt., 1905, p. 388.

From the above analyses it will be seen that in general, there is a decrease in calcium sulphate with an increase in the depth to the Berea. Also we note that the percentage of earthy chlorides relatively to the sodium chloride increases rapidly in the same direction. (Compare analyses 47 and 48).

Origin of the Berea brines. As far as is known definitely[39] no deposits of rock salt exist within the Berea or within the overlying or underlying Coldwater and Antrim shales. Both of these formations, however, do contain alkali salts in fairly large proportions, as may be seen from the following analyses.

Coldwater shales.[40]	
Silica	58.70
Alumina	18.31
Ferric oxide	7.19
Calcium carbonate	1.80
Magnesium (carbonate?)	.90
Alkalis	3.67
Water and organic matter	9.35
Total	100.00

Antrim Shales.[41]	
Silica	55.95
Alumina	17.43
Ferric oxide	7.67
Calcium carbonate	2.14
Magnesium carbonate	1.55
Alkalis as K2O	2.86
Water and organic matter	12.40
Total	100.00

Antrim Shale.[42]	
Volatile matter	17.96
Fixed carbon	6.49
Ash	77.55
Total	100.00

Ash.	
Silica	70.54
Alumina	15.33
Ferric oxide	5.31
Lime	2.38
Magnesia	1.78
Alkalis by difference	5.56
Total	100.00

Also both shales show a considerable amount of water soluble constituents. Thus Ries[43] reports soluble salts in the Coldwater shales at Union City, 0.4%, at Quincy, 0.2%, and at Bronson, 0.5%; and in the Antrim shales at East Jordan, 0.8%, and at Norwood, 0.6%. It should be borne in mind that these determinations were made on samples obtained from outcrops, which would have been subjected to the greatest leaching action and therefore would probably have a smaller content of soluble salts than the same shale at greater depths.

It is possible that the brines of the Berea may have been formed through solution in either or both of these shale series. As we have seen, the Berea apparently forms a wedge, or possibly a lens, between the Coldwater and Antrim shales, thinning rapidly to the west and more gradually to the east. These shale layers would form relatively impervious strata which would tend to confine the movement of underground water to a direction parallel to their bedding. Water therefore which enters at the outcrops of the shale would pass downward along the bedding planes, dissolving the soluble salts en route, and finally enter the Berea which would act as a reservoir. That the brines of the Berea are under considerable hydrostatic pressure is shown by the fact that when pierced by wells the brine rises nearly to the top of the wells.

Figure 17. Showing location of wells in the Dundee.

1. Adrian.
2. Algonac.
3. Allegan.
4. Alpena.
5. Ann Arbor.
6. Bay City.
7. Benton Harbor.
8. Bridgman.
9. Charlotte.
10. Constantine.
11. Dowagiac.
12. Grayling.
13. Harbor Beach.
14. Jackson.
15. Kalamazoo.
16. Ludington.
17. Manistee.
18. Marine City.
19. Marysville.
20. Milan.
21. Muskegon.
22. Mt. Clemens.
23. New Baltimore.
24. Pontiac.
25. Port Huron.
26. Royal Oak.
27. St. Clair.
28. Ypsilanti.
29. White Pigeon.

In discussing the Antrim shale, it was stated that they generally change from a bituminous black shale through blue to red at the top, except where overlain by the Berea. This may represent an elevation of the land, perhaps with an eastward tilt, which permitted the oxidation of the clay by the atmosphere; or it may mean increasing aridity. Lane[44] inclines to the former view. In either instance the Berea would represent a very much contracted sea in which the concentration of the saline constituents would probably be relatively high, and it is therefore conceivable that the Berea brine may be, in part at least, the original sea water in which the Berea was deposited. Lane[45] suggests that the saltiness of the Berea brines may be due in part to the erosion of the underlying salt beds of the Salina during uplift. I have been unable however to find any record of the Berea or overlying formations coming into contact with the Salina in this region, and this suggestion can therefore be considered only as a possibility, which from our present knowledge we can neither prove nor disprove.

[34]Lane, A. C., Geol. Sur. Mich., Ann. Rpt., 1908, p. 73.

[36]Loc. cit.

[37]Lane, A. C., Geol. Sur. Mich., Ann. Rpt., 1908, p. 75.

[38]Loc. cit., p. 76.

[39]Both Lane (Geol. Sur. Mich., 1908, p. 74) and Cooper (Geol. Sur. Mich., 1905, p. 158) seem to question the bed of rock salt reported as occurring in the Antrim in the Bay City well.

[40]From White Rock. Cited by H. Ries, Geol. Sur. Mich., Vol. VIII, Part I, p. 44.

[41]Ibid, p. 46. A. N. Clark, analyst.

[42]Ibid, p 47. W. H. Johnson, analyst.

[43]Ries, H., Geol. Sur. Mich., Vol. VIII, Part I, pp. 41-46.

[44]Loc. cit., p. 76

[45]Loc. cit., p. 75.

THE DUNDEE.

Areal distribution. The Dundee outcrops beneath the drift in the southeastern part of the state, in Monroe, Lenawee, and Wayne counties, along the shore of Lake Huron in southeastern Presque Isle county, and in a narrow zone running a little north of west from Cheboygan, in Cheboygan and Emmet counties, as shown in Fig. 10. From the records of wells, it is believed to extend over the entire southern peninsula of Michigan.

Structure. As indicated in Table XIV[46] the Dundee beds dip in general toward the center of the basin. There seems also to be a thickening of the beds in the same direction.

Superjacent and Subjacent strata. Above the Dundee is the Traverse group. This group consists of a series of limestones and shales, the lower member of which is the Bell shale, which is blue to black in color. The lithological change from the Bell shale to the Dundee limestone is of such a definite character that it may be quite easily recognized.

The Dundee is bounded below by a pronounced unconformity, as is shown by the fact that it rests upon the upturned and eroded edges of the Monroe series.[47] The lithological change from the Dundee to the Monroe. while generally one from limestone to dolomite, may therefore, be from limestone to sandstone, limestone to limestone, or limestone to shale. In addition to their general dolomitic character, the Monroe series is marked to a certain extent by the presence of gypsum or anhydrite.

TABLE XIV.

Wells in the Dundee.

Locality.	Approx. alt.	Total depth of well.	Depth to Dundee.	Thickness of Dundee.	Approx. alt. of top of Dundee.	Remarks.
Adrian	810	1650	900	.....	−90	Brine at 1635.
Algonac	590	1727	510	.....	+80	.....
Algonac	660	1614	549	.....	+51	Trace of mineral water.
Allegan	708	1400	1260	.....	−552	.....
Alpena	609	1025	480	120	+129	.....
Ann Arbor	875	1326	930	.....	−55	Brine containing 13% salts.
Assyria	917	2008+	1875	.....	.....	.....
Bay City	585	3508	3270	233	−2685	North American Chemical Co.
Berton Harbor	600	1205	665	140±	−65	.....
Bridgman	636	768	508	255	+128	25 ft. salt sand at 513.
Charlotte	906	2209	1985	120±	−979	Brine 97°, Sp. gr. 1.198 at 2050.
Constantine	803	1060	790?	.....	+13	Brine with H₂S at 700.
Courtwright, Ont.	630	1650	840?	.....	−210	Brine 60% salt by salinometer.
Dowagiac	740	1760	875?	125	−115	Brine 100° salinometer at 874.
Grayling	1140	2730	2625?	.....	.....	Brine Sp. gr. 1.198 at 2750.
Harbor Beach	600	1926	1725	185?	.....	Brine high in K₂O.
Jackson	928	2455	1760	240?	−832	Brine at 1765.
Kalamazoo	777	2350	1270	225±	−493	Strong brine.
Manistee	590±	2026	1645	50	.....	.....
Marine City	600	1630	625	125	−25	Brine at 750.
Marysville	600	1150	558	157	+42	.....
Milan	870	1643	298	97	+572	.....
Muskegon	594	2627	2000±	50±	−1406	Brine 100° sal.
Mt. Clemens	617	1060	400	210	+217	.....
New Baltimore	.....	1640	690	136	.....	.....
Pontiac	934	1505	1115	.....	−181	Very strong brine.
Port Lambton, Ont.	600	1720	710	120	−110	Porous limestone, salt brine.
Royal Oak	.....	2205	520	.....	.....	Salt water at 548, 583, 836.
Ypsilanti	.....	1210	520	160	.....	Mineral water at 525, 530, and 570.
White Pigeon	800	763	683	80	+117	Salt sand at 710.

Lithological character. The Dundee is generally a very pure limestone. Lane[48] states that it frequently runs over 98% calcium carbonate. It is gray, yellowish, or buff in color, and in places especially near the top of the formation, is cherty or sandy in character. This cherty phase is rather porous and acts as a repository for the brines.

Dundee brines. The Dundee is not always brine-bearing and its brines vary considerably in composition. Where present, the brine is generally very strong, but the high percentage of earthy bases renders it economically unfitted for the manufacture of salt where so many purer brines are obtainable. It is of considerable importance, however, in that it is used in the preparation of medicinal salts. Its composition may be seen from the following analyses.

TABLE XV.

	49.	50.	51.	52.	53.
Sodium chloride	66.6832	119.66	26.197644	134.684	0.409
Potassium chloride	2.8181	--	--	0.873	trace
Ammonium chloride	0.1431	--	--	3.07	--
Calcium chloride	5.2492	78.02	2.45765	--	-
Magnesium chloride	6.7846	24.67	2.19596	20.128	--
Magnesium bromide	0.0488	1.27	0.188	2.116	--
Magnesium sulphate	--	--	1.774	--	1.100
Magnesium iodide	0.0003	--	--	--	--
Magnesium carbonate	--	--	--	--	0.090
Calcium bicarbonate	1.7600	--	a0.98181	--	--
Calcium sulphate	3.7721	--	3.01121	--	1.220

Ferrous bicarbonate	0.0140	--	trace	--	c0.018
Potassium sulphate	--	--	0.6058	0.248	--
Sodium hyposulphate	0.0177	--	--	--	--
Sodium hydrosulphite	0.0136	--	--	--	--
Sodium sulphide	--	--	0.1445	--	0.580
Alumina	0.0033	--	--	--	--
Silica	0.0085	--	0.3398	--	0.017
Hydrogen sulphide	0.3146	--	b32.216	absent	b44.5
Carbonic acid gas	0.7147	--	--	--	--
Total	88.346	237.62	38.6788	233.746	3.44

a. Normal carbonate. b. In cubic inches per gallon. c. As Fe_2O_3.

49. Deep-spring Mineral Water, Port Huron, Mich. Depth of well, 750 feet. Above analysis compiled from analyses by Dr. E. Ristenpart, Patterson, N. J., and Professor F. S. Kedzie, Mich. Agr. Coll. (Mich. Geol. Sur., Ann. Rpt., 1903, p. 109.)

50. Assyria, Mich. Analysis by E. E. Ware, University of Michigan, Ann Arbor, Mich. The spectroscope revealed strontium, lithium, and perhaps barium. (Geol. Sur. Mich., Ann. Rpt., 1903, pp. 277-278).

51. Ypsilanti Mineral Bath Co., Ypsilanti, Mich., Moorman well. Water drawn September 5, 1884, at which time the well was cased to 550 feet to shut off all waters above the Dundee. Specific gravity, 1.0280. Reaction, alkaline. Jas. H. Shepard, analyst. (U. S. G. S. Water Supply Paper No. 31, pp. 73 and 76.)

52. Sailing Hanson and Co., Grayling, Mich. Depth of well, 2,750 feet. Analysis from the U. S. G. S. Mineral Resources, 1908, Part 2, p. 656. This brine may come from the lower portion of the Traverse, but is probably from the Dundee.

53. Butler's well, Frankfort, Mich. Main flow at 1,400 feet. R. C. Kedzie, analyst. (U. S. G. S. Water Supply Paper No. 317 pp. 72-3.)

The following analyses of brine from the Ryerson well, Muskegon, Michigan, are especially interesting on account of the large percentage of potassium which is shown. Depth of well, 2,050 feet.

	54.	55.
Calcium chloride	58.205	54.10
Calcium sulphate	0.548	4.22
Magnesium chloride	17.034	14.97
Magnesium bromide	2.346	2.37
Potassium chloride	--	22.16
Sodium chloride	174.933	157.17
Total	233.103	255.95
Specific gravity	1.20342	1.21

Figure 18. Showing the location of wells in the Monroe formation.

1. Ann Arbor.
2. Algonac.
3. Alpena.
4. Britton.
5. Detroit.
6. Delray.
7. Dundee
8. Ford City.
9. Milan.
10. Marine City.
11. Mt. Clemens.
12. Marysville.
13. New Baltimore.
14. Oakwood.
15. Port Huron.
16. St. Clair.
17. Sand Beach (Harbor Beach.)

54. Analysis by Professor A. B. Prescott, University of Michigan, September 8, 1883. Geol. Sur. Mich., Ann. Rpt., 1901, p. 233. Lane states that the potassium chloride is probably included in the sodium chloride.

55. Analysis by C. A. Goessman, September 25, 1883.

As will be noted from the foregoing analyses the most prominent characteristic of the Dundee brines is their high content of hydrogen sulphide. Furthermore the percentage of earthy bases is high relatively to the alkalis, as are also the chlorides relatively to the sulphates.

Origin of the Dundee brines. Inasmuch as the origin of the Dundee brines seems to be related to that of the Monroe brines, it will be discussed under the Monroe formation.

[46]For the location of the wells, see Fig. 17.

[47]Grabau, A. W. and Sherzer, W. H., The Monroe Formation, Mich. Geol. and Biol. Sur. Pub. 2, Geol. Ser. 1, p. 54.

[48]Lane, A. C., Ann. Rpt. for 1908, p. 70.

UPPER MONROE OR DETROIT RIVER SERIES.[49]

Although but one attempt, namely that at Mt. Clemens, has ever been made to manufacture salt from the brines of this series, the brines are of considerable importance

on account of their medicinal properties. The major portion of the mineral waters used at the health resorts of southeastern Michigan, especially at Mt. Clemens and along the St. Clair river, are derived from this horizon.

Areal distribution. The Upper Monroe seems to be confined areally to the eastern and southeastern part of the state, where it outcrops beneath the drift in a narrow belt extending from the southeast corner of Lena wee county northeast through Monroe county into Wayne county and across the Detroit river into Canada. It is also traceable in wells north from Detroit, appearing at Mt. Clemens, New Baltimore, Marine City, St. Clair, Port Huron, Harbor Beach, and Alpena.

Structure. According to Lane,[50] these beds seem to have been deposited in a narrow trough, the series not always being complete, on account of the lower beds having been overlapped by the upper members.[51] After the deposition of the Upper Monroe and before the deposition of the Dundee, a deformation of the Monroe beds occurred which in southeastern Michigan resulted in the production of at least one anticline with two synclines.[52] The trend of the axes of the folds is about N. 60° E. The axis of the anticline passes through Wyandotte and about five miles north of Woolmith quarry. Another incomplete anticline passes south of Anderdon quarry and near Scofield. The thickness of the formation and depths at which it is found are shown in Table XVI.[53]

TABLE XVI.

Locality.	Approx. alt.	Total depth of well.	Depth to Upper Monroe.	Thickness of formation.	Approx. alt. of top of Monroe.	Remarks.
Ann Arbor	875	1326	1045	200	−170	Ann. Rpt. 1901, p. 215.
Algonac	590?	1727	700?			Albert Miller well.
Alpena	609	1025	600			Near bed of Thunder Bay river.
Britton	705	1700	500	250	+205	
Courtwright, Ont	588	1665	629	370	−104	
Detroit	610	2097	a			Stroh's well.
Delray	575		135	230	+440	
Dundee	675	2197	103	132	+572	
Ford City	580	1603	80+	270+	+500	
Milan	685	1643	425	110	+265	
Marine City	600	1641	770	290	−170	Lester & Roberts.
Marine City	600	1630	750	250	−150	National Salt Co. Brine at 750.
Marine City	600	1470	825	265	−225	Morley well, 1 mile north of city.
Mt. Clemens	617	1060	610	375	+7	Mr. Cousin, owner.
Marysville	600	1150	745	265	−145	Burch farm, strong salt water at 745. Mineral water at 845, 920, and 985. H₂S strong at 985.
New Baltimore		1640	820	b		
Oakwood	575	1660	145	265	+430	Detroit Salt Shaft well.
Port Huron	611	1685	685	480	−74	Plate LVII, G. S. M. Vol. V.
St. Clair		1850	910	270±		Diamond Crystal Salt Co.
Sand Beach (Harbor Beach)		1920	1844?			Sand Beach Mineral Bath Co.

a. Dundee limestone with sulphur water in the Monroe beds 300-615 feet. Geol. Sur. Mich., Ann. Rpt., 1901, p. 217.
b. Lower limit not determinable from the data at hand on account of the absence of the Sylvania sandstone.

Superjacent and subjacent strata. The Upper Monroe is overlain unconformably by the Dundee formation, as indicated under the discussion of the latter. Its lower limits, where determinate, are marked by the appearance of the Sylvania sandstone. This sandstone, which is believed by Grabau and Sherzer[54] to be of subaerial origin, is characterized by the whiteness of the quartz grains and the imperfection of cementation. It is generally present in the wells of sufficient depth in southeastern Michigan, but is absent[55] at New Baltimore, and replaced by siliceous dolomite at Mt. Clemens, and in the vicinity of St. Clair.'

Lithological character. The complete series of the Upper Monroe consists of four beds, three of which are dolomites and one, a limestone. The dolomites tend to be brown in color and the portion just above the Sylvania is generally very siliceous. In some instances, the various members show quite a high content of fossils.

Upper Monroe brines. The nature of the Upper Monroe brines may be seen from the analyses given in Table XVII. It is to be noted that these brines are generally relatively high in earthy bases and in their content of hydrogen sulphide. In this respect they resemble quite closely the Dundee brines. In the analyses given there appears to be a considerable variation in the brines in wells quite close together or, even in different samples from the same well. This may be due to changes in the brine but is more likely due to differences in depths to which the wells are cased. Analyses 56 and 57 are of samples from wells relatively near to one another, yet in 56 bromine and potassium chloride do not appear, whereas in 57 they are present in very considerable amounts. This might be due to different methods of analysis, but inasmuch as both were examined by the same analyst, it does not seem likely. Furthermore it is to be noted that the calcium chloride and potassium bear a sort of reciprocal relationship to each other. According to Lane,[56] this reciprocal relationship is not at all uncommon. The most likely explanation seems to be that in the Oakland well, which was cased to 1000 feet, waters which were allowed to mix with the deeper brines in the Somerville well were excluded. Analyses 58 and 59 are of samples from the same well. The first analysis probably represents the original brine before the casing was withdrawn, the second, after the waters from higher horizons had been allowed to intermingle. The variations especially in bromine and potassium chloride between 59 and 60, which is from the same locality as 59, may be due to the fact that 60 is shallower and therefore has not been contaminated with lower waters high in sodium chloride. If this be true, it would perhaps help to support Lane's hypothesis that the decrease in the bromine and potash content of the Harbor Beach well (61 and 62) as shown by later analysis, is due to the intermingling of the deeper waters with those at 1860 feet, the point at which the samples whose analyses are represented by 61 and 62 were taken.

TABLE XVII.

	56.	57.	58.	59.	60.	61.	62.
Ammonium chloride			trace				
Calcium chloride	105.46	40.654	b 172.41	d 934.5 e 13.35	42.820	56.89	62.6636
Calcium sulphate	2.06	1.254	b 35.20	d 100.335 e 1.433	11.060	0.90	0.9936
Calcium carbonate	trace		b 3.98	d 0.88 e 0.014			
Magnesium chloride	14.46	3.470	b 129.60	d 648.48 e 9.246	18.396	4.85	5.3542
Magnesium bromide		0.980		d 66.37 e 0.091		22.50	24.84
Magnesium iodide	trace		hc 0.32	d 0.07 e 0.001			
Magnesium carbonate	trace		trace	d 0.70 e 0.01			
Sodium chloride	116.00	128.342	b 8637.44	d 11900.00 e 170.00	86.080	162.64	179.2391
Sodium sulphate		0.170	b 77.25		0.028		
Potassium chloride		24.00			11.602	34.22	24.84
Alumina	12.00			d 20.47 e 0.421	0.044		
Silica	5.80	1.700	b 8.07	d 27.60 e 0.394			0.7303
Ferric oxide		0.430		d 0.560 fe 0.080	g 0.029		
Total solids	255.78	200.4400	b 9065.17	d 13654.105 e 195.062	170.259	282.00	311.60
Hydrogen sulphide	a 25.597		a 37.152	a 40.00	a 9.910	a 10.5	a 10.745
Carbon dioxide			trace	a 5.85	a 3.457		

a. Cubic inches. b. Grains per gallon. c. Iodine. d. Grains per U. S. gallon. e. Grams per kilogram. f. Ferrous carbonate. g. $FeH_2(CO_3)_2$.

56. Oakland Hotel well, St. Clair, Mich. Depth of well, 1,250 feet, cased 1,000 feet. S. P. Duffield, analyst. U. S. G. S. Water Supply Paper No. 31, pp. 79 and 84.

57. Somerville Mineral Spring, St. Clair, Mich. S. P. Duffield, analyst. U. S. G. S. Water Supply Paper No. 31, pp. 79 and 84.

58. Original well, Mt. Clemens, Mich. H. F. Meier, analyst. U. G. S. Water Supply Paper No. 31, pp. 79 and 85,

59. Same. S. P. Duffield, analyst. Reference, same.

60. Clementine well, B. B. Coursin, proprietor, Mt. Clemens, Mich. Depth of well, 1,060 feet. Theo. Tonnele, McKeesport, Pa., analyst. U. S. G. S. Water Supply Paper No. 31, pp. 79-80 and 85.

61. Mineral well, Harbor Beach (Sand Beach), Mich. Depth of well, 1,920 feet. R. C. Kedzie, analyst, August 1890. Geol. Sur. Mich.. Vol. V, Part II, p. 82. Results changed to grams per kilogram.

62. Same. S. P. Duffield, analyst. Geol. Sur. Mich.; Vol. V, Part II, p. 82.

Origin of the Dundee and Monroe brines. While it is difficult to determine the exact nature of the Dundee brines, as is also the case with those of the Monroe, owing to the fact that the wells from which they are obtained are rarely cased to a sufficient depth to limit the brines to a definite horizon, thereby making correlation possible, we note that in general the brines of these formations are characterized, in addition to the hydrogen sulphide content, by a high percentage of earthy chlorides relatively to the sodium chloride, and in some instances, by a very noticeable percentage of potash. These brines, it will be noted, resemble very closely the mother liquors, or bitterns, produced through the evaporation of the purer brines from which salt is manufactured. It would seem therefore that these brines must represent either natural mother liquors, or they have been derived from deposits which have been formed through the evaporation of mother liquors.

If they represent the natural mother liquors, it is to be expected that deposits of the less soluble salts should be found in more or less close association with them. Within the Dundee no deposits either of rock salt or gypsum have been reported; we do find, however, in the Monroe formation anhydrite and gypsum. (It may be that some of the rock salt deposits are of Monroe age, but they are, on the basis of our present lack of knowledge, arbitrarily assigned to the Salina). According to Grabau and Sherzer,[57] the Monroe formation is separated from the Dundee above and the Salina below by disconformities; the Monroe overlapping the Salina onto the Niagara, and the Dundee overlapping the various members of the Monroe formation.

There seems therefore to be two possibilities as far as the origin of the Monroe brines is concerned: (1) That the lake or lakes in which the rock salt of the Salina was deposited did not disappear entirely, and that the Monroe brines represent, in part at least, the mother liquors from the Salina, which have been retained within the interstices of the rock, or the contained salts which have been deposited around the grains of the rock; (2) that the Monroe brines were formed by the erosion of a portion of the Salina in which these salts had originally been deposited. Although difficult of proof, the latter possibility seems the more plausible. This point of view may perhaps be better understood after the discussion of the origin of the salt deposits of the Salina.

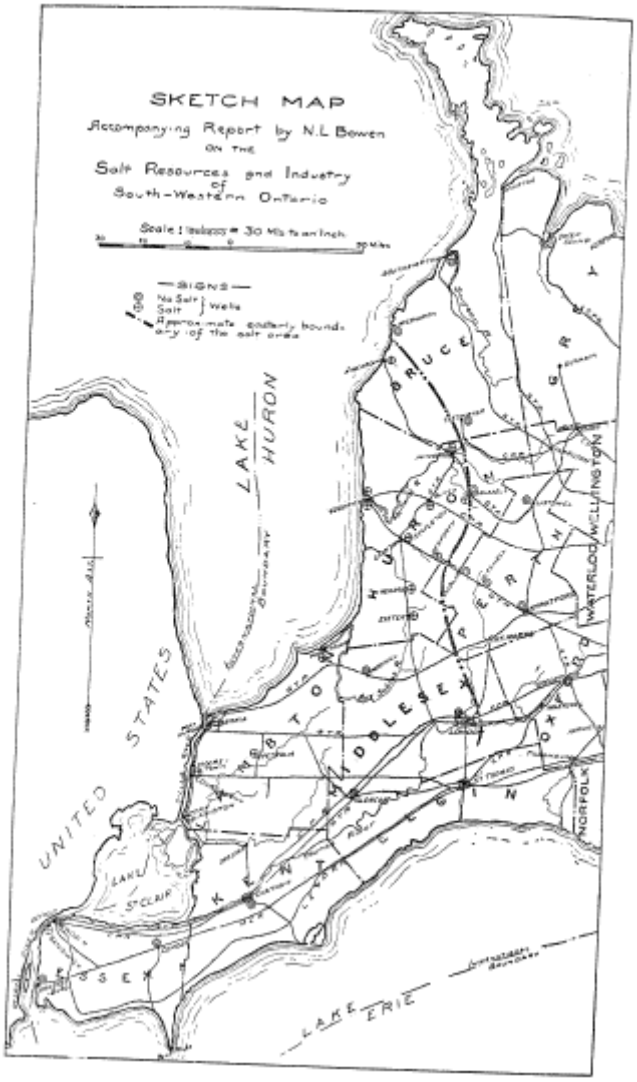


Figure 19. Map showing the eastern limits of the salt deposits in Canada (after Bowen). Canadian Bureau of Mines, 1911.

The Dundee brines may then possibly have been formed through the erosion of the Monroe formation and the solution of the soluble salts therein contained.

[49]For a more complete discussion, see Mich. Geol. and Biol. Sur., Pub. 2, Geol. Ser. 1, The Monroe Formation, Grabau and Sherzer, 1909.

[50]Lane, A. C., Geol. Sur. Mich., Ann. Rpt., 1908, p. 67.

[51]Grabau, A. W. and Sherzer, W. H., loc. cit., p. 41.

[52]Ibid, p. 57.

[53]For location of the wells, see Fig. 18.

[54]Loc. cit.

[55]Grabau and Sherzer, loc. cit., p. 70.

[56]Lane, A. C., U. S. G. S. Water Supply Paper No. 31, p. 79.

[57]Loc. cit.

THE SALINA.

The separation of the Salina from the Lower Monroe is very difficult, especially where no rock salt is present. Therefore, in the present discussion we shall limit

ourselves to those portions of the Salina in which rock salt is known to exist.

Areal distribution. In Michigan there are three districts in which rock salt has been found,—(1) along the Detroit and St. Clair rivers, (2) the Ludington-Manistee district, and (3) the Alpena district.

As far as our present knowledge goes, the district along the Detroit and St. Clair rivers is by far the largest of the three. The southern limit of the district has been pretty well established since in the six Church wells about one half mile north of Trenton salt was found in all but one. As may be seen from Tables XVIII and XIX, no salt was found at Monroe, Dundee, Britton, or Jackson, while there is but five feet at Milan. To the north Port Huron is the last point from which information is available. However, as the aggregate thickness of the salt beds at this point is about four hundred feet, it is reasonable to expect that they continue considerably farther north. Between these north and south limits, salt is found in a series of wells at Wyandotte, Ford City, Ecorse, River Rouge, Detroit, Pearl Beach, Algonac, Marine City, and St. Clair. To the west our information is again limited on account of the increased depth at which the formation occurs. At Romulus, we find beds of salt aggregating 329 feet in thickness and at Royal Oak, a total thickness of 609 feet. There is, therefore, every indication of a decided northwestward extension of the salt bearing strata. Eastward the salt extends into Canada and is found in wells at Petrolia and Goderich, but is absent at Stratford, Dublin, and Inverhuron. The eastern limits of the salt deposits as fixed by the Canadian Bureau of Mines[58] is shown in Fig. 19. If a physical connection exists between the Salina salt beds of Michigan and those of New York, it must be either as a narrow strait in the region of Amherstburg, Comber, and Chatham, where its apparent absence may be the result of an insufficient depth having been attained in the wells at those points, or, and this seems more likely, farther north across Lake Huron and Georgian Bay.

Manistee and Ludington would appear to occupy a position near the edge of the Salina, inasmuch as no salt was found at Muskegon, Milwaukee, and Frankfort in wells which should have pierced the beds had they been present. As to the eastward extension of the beds, no information is available.

The Alpena area has been explored the least of any of the three mentioned. An aggregate thickness of 31.1 feet of salt and anhydrite appears in the well of the Alpena Land Co.[59] at Grand Lake near Alpena, while more recent reports, the exact data for which are not at hand, give over 600 feet of solid rock salt. These facts would seem to indicate the existence of quite an extensive salt area.

In view of the fact that these deposits appear very closely related in age, and having regard to the general structure of the state, we are comparatively safe in assuming that these three districts are but parts of one large area and that at sufficient depth salt may reasonably be expected anywhere within lines joining them.

Structure. The variations in the thickness and number of the individual salt beds in the different areas make their correlation extremely difficult. Undoubtedly many of them are purely local, while variations in the contour of the floor upon which they were laid down, would result in such changes in thickness as to render a layer unrecognizable at certain points. Lane[60] states that there is usually quite a gap without salt above the lowest and largest bed. Owing to the fact that in the Diamond Crystal Salt Co's. No. 5 well at St. Clair no large gap appears above their largest bed, which has a thickness of over 250 feet, he believes that this is not the first salt bed, but the one above it, and may correspond to the bed found at Zug Island at 1290-1528, River Rouge Improvement Co. at 1180-1573, Solvay No. 17 at 1400-1599, Edison Fort Wayne well at 1445-1636 and possibly, Royal Oak at 2115-2475.

Figure 20. Showing the location of wells which encounter salt in the Salina.

1. Algonac.
2. Alpena.
3. Buttersville.
4. Detroit.
5. Ecorse.
6. Ford City.
7. Ludington.
8. Manistee.
9. Marine City.
10. Milan.
11. New Baltimore.
12. Port Huron.
13. River Rouge.
14. Romulus.
15. Royal Oak.
16. St. Clair.
17. St. Ignace.
18. Stronach.
19. Wyandotte.
20. Windsor, Ont.

The possibility of decided changes in short distances may be seen from a comparison of the Diamond Crystal wells Nos. 5, 6, and 7, which may be represented as occupying the apices of a triangle, whose sides are approximately 1000 feet in length. The well records from the lime layer above the uppermost salt bed are as follows:

	5.	6.	7.
Lime	1595-1630	1600-1620	--
Salt	1630-1660	1620-1625	1623-1653
Lime	1660-1748	1625-1635	1653-1743
Salt	--	1635-1655	--
Lime	--	1655-1750	--
Salt	1748-1768	1750-1770	1743-1763
Lime	1768-1773	1770-1775	1763-1768
Salt	1773-1783	1775-1785	1768-1778
Shale	1783-1859	1785-1855	1778-1854
Salt	1859-1883	1855-1885	1854-1884
Lime	1883-1893	1885-1890	1884-1892
Salt	1893-1903	1890-1905	1892-1902
Lime	1903-1913	1905-1912	1902-1912
Salt	*1913-2165	†1912-2113	1912-2020
Lime	--	--	2020-2025
Salt	--	--	2025-2130
Lime	--	--	2130-2135
Salt	--	--	2135-2165
Lime	2165-2170	--	2165-2200

*Five feet of lime between 2100 and 2165.
†Stopped in salt.

Although the correlation of the different beds in various localities may be very difficult, if at all possible, yet from an examination of Table XVIII,[61] we see that in general salt is struck at greater and greater depths away from the Cincinnati anticlinal, and also that the beds increase in thickness down the dip. How far this increase will proceed we have no means of knowing inasmuch as no records are available beyond Royal Oak. It should be borne in mind however that these remarks refer only to the region along the Detroit and St. Clair rivers. Our information from the other areas is too meager to permit of a determination of the structure, but it is probable that in both instances the beds dip toward the center of the basin.

Superjacent and subjacent strata. Above, the Salina passes imperceptibly into the Lower Monroe. The separation of the two is therefore very difficult, even if possible. Lane[64] finds that if we go 400 feet below the Sylvania sandstone, where this is present, and then take the top of the nearest salt or gypsum bed, fairly consistent results are obtained. The Lower Monroe is essentially a series of dolomites and shales containing beds of gypsum or anhydrite. The lower boundary of the Salina is somewhat better marked, since the uppermost member of the Niagara formation, the Guelph dolomite, is a characteristically hard and white dolomite.

Lithological character. The Salina in Michigan is in the main a limestone formation. The limestones, which are dolomitic, are generally gray, buff, or brown in color and at times argillaceous. In fact the appearance of shaley layers is not at all uncommon. Interbedded with the dolomitic limestones are bands of salt and anhydrite. The beds of salt vary from a fraction of a foot to several hundred feet in thickness. The anhydrite layers are relatively much thinner. Generally the salt rests upon the anhydrite, but in some instances it appears to rest directly upon the limestone or dolomite.

TABLE XVIII.[61]

Wells in the Salina showing salt.

Locality.	Approx. alt.	Total depth of well.	Approx. alt. of top of first salt.	Depth to first salt.	Number of salt beds.	Aggregate thickness of salt beds.	Remarks.
Algonac	590	1727	−916	1500	3	193	80 feet of mixed salt and shale.
Algonac	600	1614	−950	1550	1	52	Algonac Salt Co.
Alpena	600	1025	−451	1000	1	.....	Near bed of Thunder Bay river.
Alpena	.....	1712	.....	1284	5	311	Streaked with anhydrite.
Buttersville	590	2260	−1652	2242	1	.....	.....
Detroit	610	2097	−540	1150	3	329	Stroh's Brewery.
Ecorse	575	1527	−225	800	7	449	Worcester Salt Co.
Ford City	.....	1300	.....	830	5	227	Ford No. 1.
Ludington	590	2304	−1706	2296	1	8	Stearns well.
Ludington	.....	2404+	.....	2263	4	44	Anchor Salt Co., No. 4.
Manistee	.....	2012	.....	1978	2	31	Sands well.
Manistee	.....	2000	.....	1980	1	20	Peters No. 6.
Manistee	610	2015	−1375	1985	1	30	Buckley and Douglas.
Marine City	600	1641	−1004	1604	1	33	Lester and Roberts.
Marine City	600	1735	−1034	1634	1	101	Baird Bros. Still in salt.
Marine City	600	1737	−1022	1622	3	100	Toledo Salt Co.
Marine City	600	.....	−965	1565	1	250	Davidson-Wonsey Co.
Marine City	600	1630	−970	1570	2	50	Michigan Salt Co., No. 1.
Marine City	600	1731	−970	1570	3	163	Michigan Salt Co., No. 2.
Milan	870	1643	−670	1540	1	5	.....
New Baltimore	.....	1640	.....	1600	1	40	.....
Petrolia, Ont	.....	3777	.....	1210	5	595	Carmen well.
Port Huron	590	2195	−1075	1665	5	402	.....
River Rouge	.....	1603	.....	815	7	378	.....
Romulus Twp	620	1820	−305	925	10	329	S. E. ¼ N. W. ¼ Sec. 12.
Royal Oak	.....	2502	.....	1543	9	609	.....
St. Clair	590	2170	−1040	1630	7	346	Diamond Crystal, No. 5.
St. Clair	590	2113	−1030	1620	7	306	Diamond Crystal, No. 6. Stopped in salt.
St. Ignace	600	919	+200	400	1	.....	Four feet shale and salt.
Stronach	604	1972	−1326	1930	1	34	Stronach Lumber Co.
Wyandotte	580	1323	−212	792	4	281	Morton Salt Co.
Windsor, Ont	610	1167	−517	1127	1	40	C. P. R. R., No. 11.

[61]For location of wells, see Fig. 20.

TABLE XIX.[61]

Wells in the Salina horizon showing no salt.

Locality.	Approx. alt	Depth of well.	Remarks.
Benton Harbor	600	1205	Salt water at 1000 feet.
Britton	705	1643	.....
Cheboygan	.....	2750	61° brine at 1360 feet.
Dowagiac	760	1760	.....
Dundee	680	2133	N. E. ¼ N. E. ¼ Sec. 25, T. 6 S., R. 6 E.
Dundee	660	2150	N. W. ¼ N. W. ¼ Sec. 8, T. 6 S., R. 7 E.
Frankfort	600	1800±	.....
Goshen, Ind	780	2054	.....
Grand Rapids	605	2220	Brine at 2200.
Jackson	928	2455	Anhydrite and salty.
Kalamazoo	777	2250	From 1490 to 1650 salty with anhydrite.
Monroe	.....	1765	.....
Muskegon	594	2627	.....
Niles	681	1140	.....
Port Rowan, Ont	.....	1460	.....
Port Lambton, Ont.[1]	.....	1720	.....
South Bend, Ind	725	1670	.....
Trenton	.....	1370	Church well.

[61]For location of wells, see Fig. 21.

1. Lane, A. C., Geol. Sur. Mich., Ann. Rpt., 1908, p. 58. According to Bowen, (20th Report. Ontario Bureau of Mines, 1911, p. 255.) however, salt occurs at Port Lambton.

Figure 21. Showing location of wells which enter the Salina horizon but show no salt.

1. Benton Harbor.
2. Britton.
3. Cheboygan.
4. Dowagiac.
5. Dundee.
6. Frankfort.
7. Grand Rapids.
8. Jackson.
9. Kalamazoo.
10. Muskegon.
11. Niles.
12. Trenton.

Salina brines. With the exception of the rock salt, which is obtained from the shaft of the Detroit Salt Co., Oakwood, the salt of the Salina formation is obtained in Michigan from wells in the form of an artificial brine. Analyses of these brines are given in Tables XX and XXI, the latter being taken from an article by J. W. Turrentine.[65]

TABLE XX.

	63.	64.	65.	66.	67.	68.	69.	70.
Specific gravity	1.188	1.153	1.170	1.1745	1.206	.....	.....	.....
Calcium sulphate	5.660	4.62	4.92	5.566	4.7368	16.74	2.3	3.121
Calcium chloride	.....	.....	.....	.....	0.4648	.....	1.0	1.732
Magnesium sulphate	.....	.....	.....	.....	2.9271	.....	.....	.....
Magnesium chloride	2.015	0.40	2.65	0.158	.....	0.17	0.7	1.944
Sodium sulphate	.....	2.43	trace	1.749	.....	1.81	.....	.....
Ferric oxide and alumina	.....	.....	.....	.....	.....	0.66	trace	0.300
Sodium chloride	247.400	266.20	256.20	221.789	260.3287	190.16	265.7	290.321
Total solids	255.075	273.65	263.77	229.262	268.4774	209.54	269.7	297.418

63–69, grams per kilogram; 70, grams per litre.

TABLE XXI.

	71.	72.	73.	74.	75.	76.	77.	78.	79.	80.	81.
Potassium	trace	trace	0.1	0.1	0.2	0.1	0.2	trace	1.4	2.4	trace
Sodium	114.5	119.2	113.7	113.4	112.3	114.4	113.4	120.6	78.2	123.3	121.3
Calcium	0.5	1.4	1.8	2.1	1.9	1.8	1.2	0.8	17.8	0.8	0.6
Magnesium	1.0	0.4	0.4	0.4	0.7	0.8	0.6	trace	12.8	trace	trace
Chlorine	175.0	185.0	176.9	176.9	175.9	178.6	178.0	183.8	182.1	189.3	185.2
Sulphuric anhydride	2.2	2.8	3.3	3.7	3.2	4.0	0.8	4.4	4.2	4.0	3.4
Bromine	trace	trace	.....	.....	.....	.....	trace	trace	1.7	0.9	none

Conventional combinations.

	71.	72.	73.	74.	75.	76.	77.	78.	79.	80.	81.
Potassium chloride	trace	trace	0.2	0.2	0.4	0.2	0.4	trace	2.7	4.6	trace
Sodium chloride	290.6	302.6	288.6	287.8	285.0	290.4	288.1	300.9	198.5	306.4	303.8
Calcium chloride	trace	0.6	1.1	1.7	1.7	0.3	2.3	2.2	40.1	2.2	1.7
Magnesium chloride	3.6	1.6	1.6	1.6	2.7	3.1	2.4	trace	45.5	trace	trace
Calcium sulphate	3.1	4.0	4.7	5.2	4.5	5.7	1.1	trace	7.5	trace	trace
Magnesium bromide	trace	trace	.....	.....	.....	.....	trace	trace	3.9	.....	none
Sodium bromide	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.6

63. Filer and Sons, Filer City, Mich. Brines from well 92° by salinometer. Analysis by W. and H. Heim, Saginaw, Mich., 1888.

64. Same. Sample taken from settler, 100° by salinometer.

65. Same. Brine from settler, saturated at 60° F. and then raised to 172° F.

66. Same. Brine from well. Analysis by Dr. F. E. Englehardt, Syracuse, N. Y., September 9, 1889.

67. Same. Settled brine.

68. Buckley and Douglas Lumber Co., Manistee, Mich. Analysis by Fred Ruschaupt and Son, Milwaukee, Wis., February 14, 1910.

69. Michigan Salt Co., Marine City, Mich. Analysis by Robt, E, Devine, 301 Park Bldg., Detroit, Mich., July 16, 1910.

70. Port Huron Salt Co., Port Huron, Mich. Analysis by Dr. Chas. D. Aaron, Detroit, Mich., March 13, 1909.

71. Delray Salt Co., Delray, Mich. Artificial brine direct from well. 1911. R. F. Gardner, analyst.

72. Michigan Alkali Co., Detroit, Mich. Artificial brine from well. 1911. R. F. Gardner, analyst.

73. Louis Sands Salt and Lumber Co., Manistee, Mich. Artificial brine from wells. A. R. Merz, analyst.

74. R. G. Peters Salt and Lumber Co., Eastlake, Mich. Composite artificial brine from six wells, contains hydrogen sulphide. 1 911. A. R. Merz, analyst.

75. Filer and Sons, Filer City, Mich. Artificial brine from wells, 1911. A. R. Merz, analyst.

76. State Lumber Co., Manistee, Mich. Composite brine from two wells. 1911. A. R. Merz and R. F. Gardner, analysts.

77. Stearns Salt and Lumber Co., Ludington, Mich. Composite artificial brine from four wells. 1911. R. F. Gardner, analyst.

78. Diamond Crystal Salt Co., St. Clair, Mich. Brine from a single well. 1911. R. F. Gardner, analyst.

79. Davidson-Wonsey Co., Marine City, Mich. Brine from two wells. 1911. R. F. Gardner, analyst.

80. Michigan Salt Works, Marine City, Mich. Brine from company's one (No. 1?) well. 1911. R. F. Gardner, analyst.

81. Worcester Salt Co., Ecorse, Mich. Composite brine from two wells. 1911. R. F. Gardner, analyst.

Table XXII, also published by Turrentine,[66] shows the composition of the mother liquors, or bitterns, resulting from the evaporation of the artificial brines in the manufacture of salt.

TABLE XXII.

	82.	83.	84.	85.	86.	87.	88.	89.	90.	91.	92.
Potassium	0.1	trace	0.4	trace	trace	2.0	2.0	0.5	0.2	0.7	trace
Sodium	121.3	121.1	115.9	117.1	121.4	104.6	89.7	115.1	119.1	111.1	121.4
Calcium	2.0	1.9	2.2	3.4	0.6	13.8	5.2	3.9	2.4	3.5	2.8
Magnesium	0.2	0.2	1.4	0.6	trace	2.7	15.4	3.0	1.6	4.6	0.3
Chlorine	186.8	187.5	184.4	188.0	185.5	194.6	191.8	191.4	189.8	189.8	190.4
Sulphuric anhydride	3.8	3.4	3.6	2.0	1.8	0.6	3.2	2.3	3.4	2.3	2.4
Bromine	.....	.....	none	0.8	2.5	.....	trace	.....	.....	.....	.....

Conventional combinations.

	82.	83.	84.	85.	86.	87.	88.	89.	90.	91.	92.
Potassium chloride	0.2	trace	0.8	trace	trace	3.8	3.8	1.0	0.4	1.3	trace
Sodium chloride	305.3	306.9	295.0	296.5	304.2	265.9	227.9	292.0	302.1	282.8	307.4
Calcium chloride	1.7	1.4	1.9	9.2	1.7	37.3	10.8	8.0	2.8	6.9	5.0
Magnesium chloride	0.8	0.8	5.5	2.4	trace	10.6	60.4	11.8	6.3	18.0	1.2
Sodium sulphate	.....	.....	.....	.....	2.7	.....	.....	.....	.....	.....	.....
Calcium sulphate	5.4	4.8	5.1	2.8	trace	0.9	4.5	3.3	4.8	3.3	3.4
Sodium bromide	.....	.....	none	1.0	3.2	.....	.....	.....	.....	.....	.....
Magnesium bromide	.....	.....	none	.....	.....	.....	trace	.....	.....	.....	.....

82. Delray Salt Co., Delray, Mich. Bittern, drippings from salt as conveyed from vacuum pans. Probably but slight concentration. 1911. A. R. Merz, analyst.

83. Delray Salt Co. Bittern from grainers, 12 days evaporation. 1911. A. R. Merz, analyst.

84. Pennsylvania Salt Co., Wyandotte, Mich. Bittern from dripping vats. 1910. R. F. Gardner, analyst.

85. Diamond Crystal Salt Co., St. Clair, Mich. Bittern from grainer, 23 days evaporation. 1911. R. F. Gardner, analyst.

86. Davidson-Wonsey Co., Marine City, Mich. Bittern, drippings from vacuum pan salt. 1911. R. F. Gardner, analyst.

87. Michigan Salt Works, Marine City, Mich. Bittern from grainer, 6 weeks evaporation. 1911. A. R. Merz, analyst.

88. Filer and Son, Filer City, Mich. Drippings from salt. 1911. R. F. Gardner, analyst.

89. R. G. Peters Salt and Lumber Co., Eastlake, Mich. Bittern from grainer, 19 days evaporation. 1911. A. R. Merz, analyst.

90. Buckley and Douglas Lumber Co., Manistee, Mich. Bittern from grainer, 4 weeks evaporation. 1911. A. R. Merz, analyst.

91. Louis Sands Salt and Lumber Co., Manistee. Mich. Bittern from grainer, 3 weeks evaporation. 1911. A. R. Merz, analyst.

92. Stearns Salt and Lumber Co., Ludington, Mich. Bittern from grainer. 1911. A. R. Merz, analyst.

The foregoing analyses show that the Salina brines possess the greatest purity with respect to the sodium chloride, as well as the highest concentration of that salt. They are therefore preferable to all the others for use in the manufacture of salt. It may be seen from the analyses in Table XXII that the potassium chloride content of the bitterns is not as large as might be expected from the composition of the brines before evaporation. Turrentine[67] believes this to be due to the physical adsorption of that salt by the sodium chloride.

Origin of the Salina deposits. There has been some diversity of opinion as to the origin of the rock salt of the Salina formation. Among the earlier writers, Hubbard[68] and Lane[69] have applied the theory of Ochsenius, Lane going into considerable detail and locating the bar, which is the essential factor in Ochsenius' theory, in Ohio. However, according to Schuchert's[70] map of the Lower Salina, the waters must have passed more largely around through New York and Canada into Michigan, while Grabau[71] believes the breccia and conglomerate, upon the presence of which Lane bases the location of the bar represent, "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."

Grabau and Sherzer,[72] would follow Walther and assign to aridity the principal role in the formation of these deposits, since they speak as follows:

"Over the Michigan-Ontario-Western New York area, which constituted one or more basin-shaped depressions, the deposition of the Salina muds began. These were derived from the erosion of the earlier marine strata, especially the Niagaran series, which according to all indications had a wide distribution in pre-Salina time. Since the Niagaran is so largely calcareous, the resultant detrital material made more or less argillaceous calcilutites or lime mud rocks. These were carried by the intermittent desert streams to the center of the Salina desert, which was in the Michigan region, and there deposited in shallow playa lakes. This accounts for the fine stratification and other depositional features of these formations. The deposits carried by rivers from the northern Appalachians, were mostly argillaceous and at first predominantly red. These are now found in the lower Salina shales of New York, etc. The salt and gypsum found in these deposits was the old sea-salt imprisoned in the Niagaran and earlier marine strata at the time of their formation under the sea. On exposure of these salt impregnated limestones (the salt in which constituted about one per cent of the mass), to the dry and hot desert climate of Salina time, the salt and gypsum formed as an effloresence upon the surface of the exposed rocks, and this in rainy periods was washed toward the center of the basin; i. e., the Michigan and New York regions. Here it was deposited on the evaporation of the shallow playa lakes, after the. manner of deposition of salt in desert basins of to-day. To produce a salt bed 100 ft. thick and covering an area of 25,000 square miles, which is probably in excess of the area covered by the thick salt beds, it would require the erosion of 100 ft. of marine limestone covering an area of 2,500,000 square miles, or 400 ft. of limestone covering an area of 625,000 square miles, and the concentration of the derived salt in the basin 25,000 square miles in area. Thus for the production of a pure mass of rock salt covering 25,000 square miles, and 100 ft. thick, the erosion of 400 ft. of limestone from Wisconsin, Minnesota, the upper Great Lake region, and the Ontario region west of Toronto would suffice. But since we know, that the thickness of the Niagaran limestone over this region was at least twice 400 ft., not to mention the thickness of the lower marine strata which have also been removed by erosion, it will be seen that the removal of the Niagaran limestones from this area would give a salt mass 200 ft. thick and covering an area of 25,000 square miles or approximately 1,000 cubic miles of rock salt. This is probably much more than the total quantity of rock salt in the Salina of Michigan, while that of Canada, with a total thickness of 126 ft. at Goderich, comprises probably not much over 100 cubic miles of salt, and that of New York perhaps less than half that amount. It is therefore probable, that the Niagara formation alone was able to furnish all the salt found in the succeeding Salina formation, of New York, Ontario, and Michigan"

Schuchert[73] also lays emphasis upon the arid climate of the Salina time when he says:

"In the United States, after the Guelph, these seas were very shallow—not normal marine waters. The sedimentary record is one either of red shales with salt and gypsum, or thin dolomites or water limestones. The seas were those of an arid climate, with salt pans and shallow stretches alternately exposed to the effects of the sun, as demonstrated by the sun-cracked 'ribbon limestones' or calcareous shales to be seen in many widely separated places. At last the greater part of these waters subsided, and the Siluric ended with an emergence that was nearly as extensive as the one at the beginning of this period."

From a consideration of the data at hand, it would appear that the latter explanation, that of a desert origin, is the more probable one, since, as pointed out by Grabau,[74] these occurrences show the characteristics which Walther[75] has found to be exhibited by desert salt

deposits, namely,—the general absence of marine fossils, the limitation of the salt beds to circumscribed basins, the red color of the associated shales, and the mud cracks. In addition to these indications of continental deposits, it seems to the writer that there are at least three other facts which have an important bearing upon the subject but which have not received proper recognition: (1) The general irregularity in the distribution of the beds, (2) the variations from the order of deposition of salts which would be expected from the evaporation of sea water, and (3) the association of the salt (sodium chloride) beds with anhydrite.

If the Salina salt deposits of Michigan had been formed in a basin shut off from the sea by a bar such as demanded by the theory of Ochsenius, a greater continuity of deposits would be expected than seems apparent from a consideration of Table XVIII, and more specifically in the case of the wells of the Diamond Crystal Salt Co. On the other hand, wandering dunes and the dry deltas of torrential streams would afford the depressions in which the more or less localized deposits could be formed.

As has been already indicated, the salt (sodium chloride) is generally underlaid by anhydrite or gypsum, in some instances however resting directly upon the dolomite. If the deposition took place from sea water according to Ochsenius' theory, how could this phenomenon be explained? It could not be argued that the sea of that time was deficient in calcium sulphate, since enormous deposits of that salt occur within the Salina. Walther[76] has shown that just such occurrences are characteristic of desert salt deposits due to the repeated working over of the deposits accompanied by the segregating action of drifting sands. This same action may possibly explain the apparent absence of the "Abraumsalze" from the Salina deposits. If such be the case, it is possible that deposits of these salts may be found by more extensive explorations, unless, as has been suggested as a possibility, they have been eroded during Monroe time and now appear in the form of the Monroe and Dundee brines.

It has been pointed out that Van't Hoff and Weigert[77] have shown that the relationship between the water tension of the water of crystallization and that of the solution determines whether calcium sulphate shall be precipitated as anhydrite or as gypsum. When the former is the greater, the product is anhydrite, and when the latter is the greater, gypsum is deposited. Since the water tension of both the water of crystallization and that of the solution increases with an increase of temperature, but at different rates; with a solution of given composition, temperature is the controlling factor. The critical temperature for sea water, as determined by Van't Hoff and Weigert, is 25° C (77° F), while that for a saturated salt solution is 30° C (86° F). Although it is impossible to determine the exact composition of the solution from which the anhydrite of the Salina was deposited, the assumption that the presence of anhydrite indicates relatively high temperature for that solution during the deposition, does not seem far fetched. The conditions which would favor such temperature would be aridity, permitting of increased insolation; and exceedingly shallow bodies of water which would permit the penetration of the sun's rays.

The factors just discussed, in connection with the work of other writers, would seem to demonstrate pretty clearly that the salt deposits of the Salina are of continental origin and were formed under arid conditions.

[58]20th Report, Ontario Bureau of Mines, 1911, p. 256.

[59]Geol. Sur. Mich., Ann. Rpt., 1908, p. 93.

[60]Lane, A. C., ibid, p. 58.

[61]For the location of the wells, see Fig. 20.

[64]Lane, A. C., Geol. Sur. Midi., Ann. Rpt., 1908, p. 58.

[65]Jour. Industrial and Engineering Chem., Vol. 4, No. 11, p. 832.

[66]Loc. cit. pp. 832-3.

[67]Loc. Cit.

[68]Hubbard, L. L., Geol. Sur. Mich., Vol. V, 1895, Part II, pp. ix-xix.

[69]Lane, A. C., ibid, p, 27.

[70]Schuchert, Charles, Paleogeography of North America, Bull. Geol. Soc. Am., Vol. 20, 1908, Pl. 69.

[71]Geol. and Biol. Sur. Mich., Pub. 2, Geol. Ser. 1, 1910, p. 29.

[72]Ibid, pp. 235-6.

[73]Loc. cit., p. 149.

[74]Grabau, A. W., Outlines of Geologic History, University Press, 1910, p. 80.

[75]Walther, Johannes, Das Gesetz der Wüstenbildung, Berlin, 1900, pp. 140-156

[76].Loc. cit., p. 153.

[77]Loc. cit.

SUMMARY.

The important points brought out by the preceding discussion are:

1. Saline waters are obtainable in Michigan from five horizons,—the Parma, Napoleon, Berea, Dundee, and Upper Monroe.

2. Rock salt occurs in but one formation,—the Salina.

3. The artificial brines of the Salina are superior to all the other brines for the manufacture of salt.

4. The natural brines which are suitable for the manufacture of salt, given in the order of suitability, are the Berea, Napoleon, and Parma.

5. The brines of the Dundee and Upper Monroe limestones have the composition of bitterns and are therefore unsuited for use in the manufacture of salt, but they are important as the mineral waters of the health resorts of Michigan, and offer some possibilities as a source of potash and bromine.

6. The Napoleon and Berea brines are the best suited for use in the manufacture of bromine and calcium chloride.

7. The Parma brines are considered to have been formed by the solution of disseminated salt within the underlying gypsiferous Lower Grand Rapids series and to have been forced up, under hydrostatic pressure, along fractures into the Parma.

8. The Napoleon brines are believed to have their origin in the solution of disseminated salt within the underlying red shale layer which is considered to represent the basal member of the Upper Marshall rather than the upper member of the Lower Marshall. They may also in part represent the original sea water in which the Napoleon was laid down.

9. The Berea brines may have been formed either through the solution of disseminated salt within the Antrim or Coldwater shales or they may in part represent original sea water.

10. The Upper Monroe brines may possibly have been formed through the erosion of that portion of the Salina which contained the mother liquor salts. The Dundee brines in turn may have been formed through the erosion of the Monroe.

11. The beds of rock salt within the Salina formation are believed to have been formed as continental deposits, an arid climate, with its attendant agents of weathering and transportation, being the essential factor in their deposition.

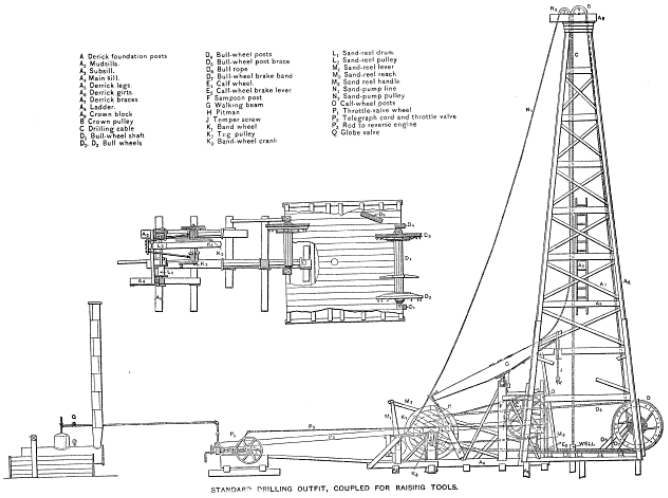


Figure 22. Plan of derrick house and equipment (after Bowman). U. S. Geological Survey Water Supply Paper No. 257.

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