TABLE XXVII.—Concluded.

Year.	Precipitation in inches.	Departure from normal.		Temperature, Fahrenheit.	Departure from normal.	
1902	35.53	+3.40	Accumulated excess 1.07 in.	48.8°	+0.6°	Accumulated deficiency 1.1°.
1903	35.88	+3.75		48.1	−0.1	
1904	28.32	−3.81		46.1	−2.1	
1905	32.00	−0.13		47.8	−0.4	
1906	33.67	+1.54		49.7	+1.5	
1907	30.62	−1.51		46.4	−1.8	
1908	28.59	−3.54		49.3	+1.1	
1909	40.65	+8.52		48.0	−0.2	
1910	24.98	−7.15		48.5	+0.3	

indication of a temperature cycle that can be correlated with the precipitation cycle of Brückner and this may be due to its proximity to the Great Lakes, causing it to partake to this extent of the character of his "exceptional coast stations."

Brückner in searching for an explanation of his climatic cycle considered the matter of a long period sun-spot variation, but accepting the supposed 55-year period of Wolf, he was led to reject this explanation (Klimaschwankungen, *loc. cit.*, p. 242). Admitting that the heat derived from the earth's interior is practically constant and so slight in amount as to have no appreciable effect upon our climate, we must, however, look to the sun as the chief source of energy concerned in climatic change. From *a priori* considerations, we should expect to find there only the cause of phenomena so completely involving the surface of the earth. Periodic activity in solar energy might reasonably be expected to exert some kind of periodic effect upon terrestrial climate. The times of maximum sun-spots are known to represent such stages of maximum solar activity, the spots furnishing an index, as remarked by Lockyer, but not a measure of such activity. Observations with suitably placed thermometers have shown that the earth receives at such times a great heat wave, with a period of 11 to 12 years. With this recognized solar periodicity we need not be surprised to find some corresponding terrestrial effects, as noted; shown in rainfall, temperature, atmospheric disturbance, magnetic phenomena and auroras. This, however, accounts for the minor climatic waves rather than the Brückner cycle of about 35 years. It is a very suggestive fact that this cycle is approximately three times that of the recognized sun-spot period and the remark of Hubbard (previously quoted) assumes significance. The real explanation sought may be furnished in the discovery of Lockyer (W. J. S.) that

there exists a long-period sun-spot variation of 35 years, controlling the terrestrial, climatic cycle.[27] He says, "Having found that, in addition to the well-known eleven-year period of sun-spot frequency, there is another cycle which extends over about thirty-five years, and which is indicated clearly, as has been shown, both by the changes in the time of the occurrence of the epochs of maxima and in the variations in area included in consecutive eleven-year periods of both sun-spot and magnetic curves, it is only natural to suppose that this long-period variation is the effect of a cycle of disturbances in the sun's atmosphere itself (p. 296). Such a cycle, if of sufficient intensity, should cause a variation from the normal circulation of the earth's atmosphere, and should be indicated in all meteorological and like phenomena."

As to the economic importance of a knowledge of the existence of such weather cycles, much might be written. The old adage "forewarned is forearmed" applies with great force and should lead to the conservation of food supplies in those regions in which the reduction of rainfall, or temperature, means suffering and loss of life. The planning of irrigation projects in advance of their need, methods of agriculture by which moisture is conserved and the introduction of special crops requiring a minimum of moisture may prove to be the solution of this serious problem. But even in this region where the oriental type of famine is unknown, these weather cycles mean to the farmer added labor, expense, annoyance and often complete discouragement. If we have actually entered upon the wet phase of the longer cycle, about which there may be some reasonable doubt, we may expect a succession of moderately cool summers, snowy winters, freedom from excessive drought and considerable precipitation. Land that is low-lying should be well provided with effective drains, and old drainage channels opened so as to provide the best possible flow. Wells now put in should be deep enough to allow considerable lowering of the ground water level and still supply sufficient water. If this is not done, the next dry phase may require a deepening of the well and added expense. When this phase arrives, and it is certain to do so, sooner or later, the farmer who has learned the method of "dry farming" will be well repaid. In the vicinity of Detroit River, schemes for the small scale irrigation of truck farms would be found feasible. If other factors could be eliminated, it would probably be found that the prices of farm lands fluctuate with the precipitation cycles and hence with the sun-spots. In closing his discussion of the subject Hubbard in 1886 wrote,

27. The Solar Activity, 1833-1900: Proceedings of the Royal Society of London, LXVIII, 1901, p. 285. Nature, LXIV, 1901, p. 196.

"The new century, though opening with cold and wet, gives promise, in its first cycle, of returning general prosperity, inaugurated by abundant crops, and if the nation be wise—by freer trade, restored commerce, satisfied wages, and solid wealth. Blessed be the sun-spots!"

Weather prediction. The forecasting of the weather for from one to three days ahead of its actual arrival may now be done with considerable satisfaction and many practical results. The principles employed may be readily mastered and should be taught and practiced in all our public schools, rural and urban.[28] Every rural home and school should have a weather-vane, rain gauge, simple barometer and a reliable thermometer. Where there is free rural delivery service, the daily weather map may be obtained from the Local Weather Station, at Detroit, and will be found of great service in individual forecasting. Upon these maps, the "high" and "low" areas may be noted, often several days in advance of their arrival, and their course across the country watched.

The lows, or cyclonic areas, are preceded by a drop in the barometer, indicating less atmospheric pressure, a swinging of the wind into the south, a rise in temperature, moist atmosphere, cloudy skies and generally rain or snow. With the passage of the area directly across the region occupied by the observer, the wind dies away and springs up from the north, with a cessation of precipitation, clearing skies, lower temperature, and rising barometer. Should the center of the area cross the country far enough to the southward, there appears a southeast wind, accompanying a relatively slight fall of the barometer, which wind moves around to the east and then northeast. In case the center of the area passes to the northward, there appears first a southwest wind, swinging to the west and then the northwest.

A relatively rapid drop in the barometer indicates that a storm of considerable intensity is approaching with corresponding velocity. A slow, gradual drop suggests a storm of slight intensity, moving slowly, or one of greater intensity with its center to the north or south of the observer. The key to an understanding of

28. From the U. S. Weather Bureau, Department of Agriculture, Washington, D. C., the following bulletins may be obtained gratuitously:
Bulletin No. 184, upon the use and care of instruments.
Bulletin No. 191, "Weather Forecasting."
Explanations of the Weather Map.
See also "Weather Bureau and the Public School," Weeks: Yearbook of Agriculture for 1907.
"Meteorology in School," Davis: School Review, vol. II, p. 229.
"Our Heralds of Storm and Flood," Grosvenor: National Geographic Magazine, vol. XVIII, 1907, p. 586.
Storms and Weather Forecasts, Moore: National Geographic Magazine, vol. VIII, 1897, p. 65.
About the Weather, Harrington, 1899. D. Appleton & Co.
Weather Folklore and Local Weather Signs, Garriott: U. S. Weather Bureau.
Elementary Meteorology, Waldo, 1896. American Book Co.

the behavior of the winds is furnished by the statement that there exists about such an area of low pressure a great whirl in counter-clockwise direction, the winds moving spirally in toward the center and there rising, well illustrated in miniature by the small whirls often indicated by dust, leaves, etc. In the case of these small whirl-winds, however, both the clockwise and counter-clockwise movements are represented.

In the case of the so-called high, or anti-cyclonic areas, regions of higher barometric pressure, with a descending current at the center and a clockwise, outwardly directed spiral, the above conditions are exactly reversed. Such an area very generally follows a low, being ushered in by the north wind of the latter, the two working together like great atmospheric wheels geared together. Cooler temperature, higher barometer, fair or clearing skies, dry atmosphere and absence of precipitation are accompaniments, to be followed upon the western border by the southerly wind and probable approach of the inevitable low. When the weather map is available, the procession of low and high areas across the country may be watched; their course, velocity and intensity noted and their final approach indicated by the barometer, wind-vane, thermometer and condition of the sky, along with the ordinary weather signs. Without the weather map, less satisfactory work can be done but the intelligent farmer may obtain from the meteorological reports of the daily press more or less information of what to expect, and with the help of his instruments need not often be taken by surprise. Although he can not as yet control the amount of precipitation, it is a matter of much interest and some importance to measure and record the amount of rain and snow, 10 inches of the latter being regarded as equivalent to one inch of the former. The time required for such weather observations is so small as to be neglectible, the instruments will pay for themselves many times over, there is satisfaction and profit in better shielding one's self, family, stock and crops against sudden or extreme changes and intellectual pleasure in thus pitting ones wits against the elements.

DIAGONAL SYSTEM IN WAYNE COUNTY.

Struck with the frequency with which the directions northeast, southeast, southwest and northwest entered into descriptions of the physical features of the state of Michigan, Alexander Winchell, in 1873, read a paper before the American Association for the Advancement of Science entitled "The Diagonal System of the Physical Features of Michigan.[29] This diagonal characteristic is shown

29. American Journal of Science, 3rd series, vol. VI, 1873, p. 36. Michigan (extracted from Walling's atlas), 1873, p. 32.

very strikingly in Wayne County in practically every natural feature and has left a strong impress upon those forms of construction for which man himself is responsible. Some of the original causes have no apparent connection but they have all conspired to bring about the same result. Subsequently to the formation of the great rock strata:—shale, limestone, dolomite and sandstone—that underlie the glacial deposits of southeastern Michigan, a great force disturbed their horizontality and established a slight dip to the northwest. This gave their outcropping edges a northeast-southwest trend, permitting the formation of a system of parallel troughs in the softer strata by weathering and stream erosion. The harder, projecting ridges formed northeast-southwest divides and between them lay belts of preglacial soil derived directly from each type of rock. Along these similar belts of soil the vegetation of previous geological ages must have secured its distribution, and to a greater or less extent, also the animal life directly, or indirectly dependent upon it.

The passage of the great Labradorean ice sheets across the region, from the northeast to the southwest, very nearly coincided with the *strike* of the rock strata and cleared out the troughs, deepening and broadening them to an extent. Owing to the direction of ice movement and the course of the ice margins, the morainic ridges and boulder belts were located as described in chapters II and III, with a general northeast-southwest trend, with parallel depressions between the surface slopes to the southeast or northwest. This general surface slope gave direction to the main streams and their tributaries as also described. The only ones following the chief points of the compass being the North Branch of the Rouge, deflected from its natural course by the Detroit moraine, some of the tributaries of Brownstown Creek, similarly deflected by the Grosse Isle moraine, and the lower half of Detroit River. The higher morainic features of the county gave direction to the shore lines of the series of lakes whose history was traced in Chapter II, and thus determined the direction of the belts of gravel, sand and clay. These types of soil in turn determined the direction of the belts of natural and cultivated vegetation and the distribution of animal forms. The belts of artesian water, of natural gas, underground water flow, economic materials; also of equal temperature, prevailing wind, and of rainfall have a diagonal distribution in the county. The direction of the sand and gravel ridges still further determined the course of many of the Indian trails, as it did also that of a number of the early highways, which the rectangular survey has been unable to completely efface.

In the days of early French occupancy, each claimant of government land was allowed any amount, up to 640 acres, for the surveying of which he was willing to pay. With no system of roads yet established the streams were the main highways and each farm must have its waterfront. As a result, the claims were laid out at right angles to the larger stream courses, extending back as narrow strips and thus partook of the same diagonal features as of the stream courses. This arrangement brought each claim into harmony with the natural distribution of the soil and permitted equable tillage and crop management. With the cabins facing the water and the patches of cultivated land arranged with the claims, it so happened that the various farm and household activities, as well as those of the neighborhood, were either parallel with, or at right angles to the streams. This was true also for the private lanes, the roadways between claims and those cutting across the claims, near the streams and a mile or more back. The old lake beaches often determined the location and facing of farm houses, stores, schools, churches and cemeteries. The city of Detroit is laid out on a plan fundamentally determined by the course of the river and there are but a few short unimportant streets in the northeastern and northwestern corners of the city that run with the main points of the compass. The arrangement of the streets and alleys has, of course, determined the direction of the artificial drainage (gutters and sewers); of the street railways; the facing of all buildings, with their internal arrangements and multifold activities to the most minute details. The location of the city of Detroit was determined by the moraine, upon the crest of which it stands, and to reach it there has been built an elaborate system of diagonal steam and electric railways. The steamship and ferry lines move either with, or across the strip of river opposite the city. It thus becomes apparent that practically all of the natural features of the county and many of the most important artificial constructions and lines of movement, affecting all of the people some of the time and probably 90% of the people all of the time, are traceable back to certain geological forces that operated diagonally across the county long before the advent of man. These 90% are still eating, sleeping, being educated, being transported, working, taking recreation, worshiping and will eventually be buried upon the *bias*. There is no reason to believe that it will be different with future generations. The far-reaching factors, whose influence we have thus traced, are but single links in the long chain that reaches indefinitely backward as well as forward and are now beyond human ken.

CHAPTER VI.

HARD-ROCK GEOLOGY.

MISSISSIPPIAN SYSTEM.

With the progress of geological knowledge in the United States it has been ascertained that the long recognized, but poorly named *Carboniferous* system, consists of three distinct groups of strata. These have been variously known as:

1. Subcarboniferous, Mountain limestone, Carboniferous limestone, Early or Lower Carboniferous, Mississippian.
2. Carboniferous proper, Upper Carboniferous, Coal Measures, Pennsylvanian.
3. Permian, Upper Barren Coal Measures.

The term "Subcarboniferous" was first used by David Dale Owen in 1838 for an extensive series of sandstones, shales and limestones lying below the Coal Measures, but including also Devonian and Silurian strata.[1] The term was soon restricted to include those strata only of later age than the Devonian and constituting the base of the Carboniferous series. As thus restricted, it was known to have a wide distribution in North America, attaining its maximum thickness in the Appalachians but also well developed in the Mississippi region where it consists largely of limestones. The term *Mississippian* was proposed for the formation by Williams in 1891[2] and has come into quite general use in the more recent literature. This is a slight modification in form and usage of the terms proposed by Alexander Winchell, some 12 years earlier, the "Mississippi limestone series or Mississippi group."[3] In their recent Geology (vol. II, 1906, page 508) Chamberlin and Salisbury proposed advancing the Mississippian to the rank of a distinct system, coördinate with Devonian, Silurian, etc., and thus separating it from the Coal Measures or Pennsylvanian.

Within the limits of the state of Michigan the Mississippian comprises four sets of strata, which in ascending order are,

1. Report of a Geological Reconnoissance of the State of Indiana; made in 1837; 1838, pp. 12 and 13.
2. Correlation Papers, Devonian and Carboniferous: Bulletin No. 80, U. S. Geological Survey, 1891, p. 135. To this bulletin is referred the reader who is interested especially in the nomenclature and correlation of the various formations described in this chapter.
3. The Marshall group: Proceedings of the American Philosophical Society, vol. XI, 1879, p. 79.

1. Berea sandstone.
2. Coldwater shales.
3. Marshall sandstone.
4. Grand Rapids group; dolomite, limestone, shale and gypsum.

Of these only the first two, or lowest, cross the county of Wayne and hence fall strictly within the limits of this report. They are, however, under a heavy burden of drift and are only very imperfectly known from well borings.

Coldwater shales. Where exposed in Branch and Hillsdale counties the Coldwater shales (from their good exposures along Coldwater River)[4] are seen to consist of light colored, thin-bedded, shales, with occasional bands of limestone, becoming sandy towards the top as they pass into the overlying Marshall. Occasionally there occur irregular nodules of brownish, kidney iron ore, often mistaken by drillers for limestone or sandstone.

These shales have been utilized in Branch County in the manufacture of Portland cement and numerous analyses have been made. The following table shows their range in composition in the vicinity of Coldwater.[5]

TABLE XXVIII.—ANALYSES OF COLDWATER SHALE, NEAR COLDWATER, MICHIGAN.

(Analyst H. E. Brown).

Silica, (SiO_2)	57.26 to 61.25%
Alumina, (Al_2O_3)	18.12 to 21.59%
Ferric oxide, (Fe_2O_3)	6.53 to 8.30%
Calcium oxide, (CaO)	1.25 to 1.50%
Magnesium oxide, (MgO)	1.49 to 2.31%
Sulphuric anhydride, (SO_3)	.65 to 1.34%
Carbon dioxide, (CO_2)	.95 to 1.18%
Titanium oxide, (TiO_2)	.82 to 1.12%
Alkalies, (Na_2O and K_2O)	2.25 to 3.45%
Loss on ignition (H_2O and organic matter)	6.19 to 8.32%

According to Lane, the minimum thickness in the state is 600 feet, giving a broad exposure beneath the drift from Hillsdale and Lenawee counties northeastward to Lake Huron, crossing the northwestern corner of Wayne. Upon the Lake Huron shore, good exposures of the shale occur at White Rock Point and Forestville, Sanilac and Huron counties. As in the case of all the strata to be described the *dip* of the formation is to the northwestward, giving a northeast-southwest *strike*. Were the drift completely removed from the Southern Peninsula, the outcropping edges of the strata would be seen encircling the central (Saginaw) basin, dipping towards and under it, suggestive of a nest of wooden

4. Lane, The Geological Formations of the Lower Peninsula and their Economic Products: Geological Survey of Michigan, vol. V, pt. II, 1895, p. 19. See also by same author Notes on the Geological Section of Michigan, Pt. II, From the St. Peters up: Annual Report of the State Board of Geological Survey of Michigan for the year 1908, p. 43.
5. Russell, The Portland Cement Industry in Michigan: Twenty-second Annual Report of the Director of the U. S. Geological Survey, part III, 1902, p. 666.
Ries, Clays and Shales of Michigan, their Properties and Uses: Geological Survey of Michigan, vol. VIII, pt. I, 1900, p. 42.

butter-bowls. The younger and geologically higher formations are hence found toward the northwest, the older and geologically lower toward the southeast. Originally the entire series was approximately horizontal and seems to have been deformed about the close of the Palaeozoic era by the pronounced subsidence of the Saginaw area. Within the limits of Wayne County, there are no well sections that penetrate the Coldwater series from which the thickness could be determined. In the village of Plymouth, a 280-foot well (Alfred N. Brown, driller) showed 25 feet of gray shale at a depth of 100 feet of drift. A stratum of sandrock yielded a flow of fresh water which rose to within two feet of the surface. Beneath was reported 10 feet of excessively hard "conglomerate rock" and 15 to 20 feet of sandstone, underlain by limestone. About one mile west upon the place of Dwight Berdan (NW. 1/4 SW. 1/4 sec. 27), a light flag-stone was entered six inches at a depth of 122.5 feet. The Plymouth record would indicate that we are there near the eastern margin of the series of lighter colored shales. Toward the northwest, more of them should be encountered just beneath the drift and less and less to the southeastward, until they give out completely. In the deep wells of Ypsilanti and Ann Arbor, we have more complete data relative to the geological series of the county. Four of these records are here reproduced from the Ann Arbor Folio (1908, page 3).

TABLE XXIX.—SECTION OF CORNWELL WELL, YPSILANTI.

On flood plain of Huron. Elevation of mouth about 680 feet.	Thickness in feet.	Total depth in feet.
Earth, clay, gravel, sand, etc., unconsolidated	109	109
"Slate" (probably shale)	241	350
"Flint"	5	355
Sandstone	38	393
Soft "slate" or sandstone (sandy shale)	157	550
"Bedrock" (hard limestone?)	200	750

TABLE XXX.—SECTION OF ATLANTIS WELL, YPSILANTI.

(From manuscript notes by Alexander Winchell.)

Near Normal College Campus. Surface elevation about 785 feet.	Thickness in feet.	Total depth in feet.
Sand, clay, gravel, etc., unconsolidated	185	185
Shale, soft	4	189
Sandstone, fine, slightly calcareous	10	199
Limestone, fine; all dissolves in acid	10	209
Shale, dun, dark; lower 74 feet black	84	293
Shale, sandy, dun	64	357
Sandstone, very fine, slightly calcareous; yields bromine water	4	361
Limestone, pale, cherty	10	371
Shale, sandy	5	376
Limestone, ranging from pale and cherty to dun and sparry	43	419
Shale, bluish to dun, in places gritty	22	441
Limestone, varying from siliceous to pure	24	465
Shale	21	486
Limestone, varying from pale to dun, with some shaly partings, portions magnesian, others siliceous; contains sulphurous (H_2S) water	138	624
Unrecorded	184	808

TABLE XXXI.—SECTION OF COURT HOUSE WELL, ANN ARBOR.

(Record of Dr. Carl Rominger.)

Surface elevation 835 feet.	Thickness in feet.	Total depth in feet.
Soil, gravel, clay, etc., (glacial deposits) (According to Winchell thickness of drift is 164 feet.)	155	155
Shale, blue, arenaceous, with seams of fine-grained sandstone	150	305
Shale, black, bituminous, with gas and drops of oil	28	333
Sandstone, gray, with brine	92	425
Shale, blue, with sandstone layers, and seams of pyrite	100	525
Shale, black, very bituminous, with pyrite	85	610
Shale, dark blue, arenaceous, with pyrite, traces of fossils	22	632
Shale, black, bituminous, with pyrite	68	700
Limestone, bluish, cherty	70	770

TABLE XXXII.—SECTION OF CAMPUS WELL, UNIVERSITY OF MICHIGAN, ANN ARBOR.

(Record by Dr. A. C. Lane, based upon drillings.)

Surface elevation 880 feet.	Thickness in feet.	Total depth in feet.
Quaternary:		
Coarse, cross-bedded sand and gravel	90	90
Blue, boulder clay	145	235
Coldwater shale:		
Blue shale	30	265
Pinkish shale	15	280
Fine gray, sandy shale	75	355
Fine soft, gray and black shale	20	375
Fine gray, sandy shale	10	385
Fine bluish shale	15	400
Berea sandstone:		
Fine gray sandstone	15	415
Fine sandy shale	25	440
Glossy black shale	5	445
Fine gray, sandy shale	75	520
(Salt water at 515 feet.)		
Antrim shale:		
Fine black and greenish shale	10	530
Fine gray, sandy shale	15	545
Very fine, black shale	15	560
Black, bituminous shale	15	575
Coarse, gray sandstone	5	580
Black, sandy shale	20	600
Black, bituminous shale	80	680
Traverse formation:		
Shale with pyrites	5	685
Gray, calcareous shale	60	745
Dundee limestone:		
Gray, cherty limestone	25	770
Light-gray limestone	30	800
Gray, argillaceous limestone	130	930
Monroe formation:		
Light-gray dolomite	40	970
Gray dolomite containing sand	60	1,030
Light-gray dolomite with Sylvania sand grains	205	1,235
Pure white friable sand (Sylvania)	35+	....

Well stopped at 1,326 feet in the Sylvania.

The most satisfactory record of the series is that of the University well drilled in 1899-1900, the drillings of which were examined by Lane, then state geologist, with a detailed knowledge of the various formations obtained from a study of the rocks in outcrop. This record assigns 165 feet to the Coldwater and shows that it is composed of pinkish, bluish, gray to black shale; in places somewhat sandy. The Court House well gives 178 feet of shale, above the sandrock, which appears referable to the Coldwater. In passing southeastward to the Cornwell well in Ypsilanti, some 7½ miles, the rock surface drops 74 feet, but there still remain some 241 feet which are to be considered as belonging to this same formation. In the Atlantis well and that of the Banner Oil and Gas Company, the sandstone stratum, marking the base of the Coldwater series, is not recognizable with certainty. Lithologically this formation is very similar to the Cuyahoga formation of Ohio, named by Newberry in 1870,[6] and as restricted by Orton[7] and later by Prosser[8] is very nearly its geological equivalent. The Berea shale, or Sunbury shale, however, is separated from the Cuyahoga in Ohio while it is intended to be included in the Coldwater of Michigan.[9] Lane in his latest discussion of the formation (1909) makes it the equivalent of the Sunbury, Cuyahoga, Buena Vista and Raccoon, of the Ohio series, and the lithological equivalent of the Portage and Chemung of New York.

Berea sandstone. This formation was originally defined by Lane[10] as the Richmondville sandstone and was regarded as the geological equivalent of the Berea grit of the Ohio series. Since then, however, he concluded that the "Richmondville" is not the exact equivalent of the Berea "but a stray sandstone somewhat higher up."[11] It constitutes the base of the Coldwater series although the two can not always be separated with certainty in the well records because of the frequent occurrence of sandstone strata in the Coldwater. In southeastern Michigan, the formation is a coarse, gray sandstone, 100 or more feet in thickness. Farther north in Huron County and at Tawas and Oscoda this sandrock supplies brine and in Wayne County what appears to be the course

6. Newberry, Geological Survey of Ohio, Report of Progress in 1869, pt. I, 1871, p. 22 Also Report of Progress in 1870; 1871, p. 469.
7. Orton, Geological Survey of Ohio, vol. VI, 1888, p. 37. Vol. VII, 1893, p. 31.
8. Prosser, The Nomenclature of the Ohio Geological Formations: Journal of Geology, vol. XI, 1903, p. 519. See also The American Geologist, vol. XXXIV, 1904, p. 335, and Bulletin No. 7, Fourth Series, Geological Survey of Ohio, 1905.
9. Lane, Communication of Nov. 11, 1907, to George W. Stose, Editor of Maps, U. S. Geological Survey.
10. Geological Survey of Michigan, vol. V., pt. II, 1895, p. 20.
11. Communication of Apr. 20, 1903 to Prof. Charles S. Prosser. In his latest discussion of this sandstone Lane uses the term "Berea Grit" (Michigan Geological Report for 1908, p. 74) for the sandstone, regarding it as the base of the Carboniferous and the equivalent of the Catskill of New York.

of the formation is marked by a belt of brackish to salty wells, some of them so heavily charged as to be unfit for use. The records of the character of the rock encountered by the farmers, in the comparatively few wells available, are so incomplete and often conflicting that the stratum can be traced only with difficulty. It lies in Wayne County under a cover of 50 to 100 feet of drift and is seldom penetrated or entered to any considerable depth. In the Ann Arbor Court House well, Rominger identified 92 feet of coarse, gray sandstone, charged with brine, as the correlative of the Berea and suggested that the overlying 28 feet of black, bituminous shale would correspond with the shales found in Ohio above the Berea.[12] These have been known variously as the Waverly black slate, Berea shale and Sunbury shale.[13] In the Campus well, Lane includes under "Berea sandstone" 15 feet of fine, gray sandstone and 115 feet of more or less sandy shale, above which are recognized 45 feet of dark shale with the suggestion that this may represent the Sunbury. The not infrequent references to black shale and "slate" in the townships of Canton, Nankin, Livonia and Redford suggest strongly that this stratum extends across Wayne County also, although it is difficult to distinguish between it and the Antrim shale, beneath the Berea. The record of the deep well at Pontiac, 11 miles north of the Oakland—Wayne county line, shows the rather surprising thickness of 273 feet (depth 535 to 808 feet), for the Berea sandstone,[14] above which lie 35 feet of "dark brown argillaceous shale," constituting the base of the Coldwater and the probable correlative of the Sunbury.

DEVONIAN SYSTEM.

Antrim shale. Beneath the Berea sandstone in southeastern Michigan, there lies a characteristic black shale formation, 150 to 275 feet in thickness,[15] which has been variously designated in the Michigan and Ohio Survey reports. In the Houghton survey, it was referred to as the "black strata", "black bituminous shale", "black aluminous slate". By Winchell, it constituted the main member of his "Huron Group" and was regarded as the correlative of the Genesee shale of New York. Newberry in 1871 applied the name "Huron shale" to the formation which up to that time in Ohio had been known as the "black slate," and this name is still retained in the latest Ohio bulletins. Rominger described the for-

12. Geological Survey of Michigan, vol. III, pt. I, 1876, p. 92.
13. Hicks, The Waverly Group in Central Ohio: American Journal of Science, 3rd series, vol. XVI, 1878, p. 216.
14. Geological Survey of Michigan, vol. V, pt. II, 1895, pl. XLVII.
15. In the Campus well, Ann Arbor, 160 ft. (Lane). Court House well, Ann Arbor, 275 ft. (Rominger). Pontiac deep well, 157 ft. (Wright). Adrian well, 221 ft. (Lane).

mation under the name "black shales of Ohio." Lane applied the name "St. Clair shales" in 1893[16] and, finding this name preoccupied for a Silurian limestone in Arkansas, in 1901 changed the name to "Antrim shales" from their typical exposure in that county.[17] The early names are suggestive of the black, bituminous character of the shale, so much organic matter often being present as to permit of their burning and to their being mistaken for coal.[18] An analysis of Antrim shale of Charlevoix County was made to test its possible fuel value and is given by Ries.[19] Although they do not ordinarily support combustion, beach fires on the shore of Sulphur Island, Thunder Bay, are said to have burned for many months. Upon the shores of this island these shales are black, very fissile, crisp and sharp, approaching slate when unweathered. They are finely laminated and very evenly bedded. Exposed to the weather they assume a gray, or rusty brown color, from the oxidation of the iron. Crystals of pyrite and nodules of marcasite are of common occurrence in these shales, which upon suffering decomposition stain the shales with iron oxides and sulphur and impregnate the percolating waters. Spherical to ellipsoidal calcareous concretions, varying in size from an inch to six feet in diameter, are found embedded in the shale. Toward the center of these there sometimes occur fragments of organic remains and crystals of calcite and siderite. It was from such concretions in this same formation that the remarkable fish remains of Ohio were obtained by Rev. H. Hertzer and later described by Newberry (see reference below, page 157). Concretions similar to those in Mich-

TABLE XXXIII.—ANALYSIS OF ANTRIM SHALE, CHARLEVOIX COUNTY.

(Analyst W. H. Johnson.)

Volatile matter	17.96
Fixed carbon	6.49
Ash	75.55
Total	100.00

Analysis of ash.

Silica, (SiO_2)	70.54
Alumina, (Al_2O_3)	15.33
Ferric oxide, (Fe_2O_3)	5.31
Calcium oxide, (CaO)	2.38
Magnesium oxide, (MgO)	.78
Alkalies, etc., by difference	5.66
Total	100.00

16. Michigan Geological Survey, Report for 1891 and 1892; 1893, p. 66. See also vol. V' pt. II, 1895, p. 21.
17. Michigan Miner, Sept. 1, 1901. Also Report of the State Board of Geological Survey for the year 1901; 1902, p. 209.
18. Lane, Deep Wells and Prospects for Oil and Gas: Report of the State Board of Geological Survey for the year 1901; 1902, p. 212.
19. Ries, Clays and Shales of Michigan: Geological Survey of Michigan, vol. VIII, pt. I, 1900, p. 47.

igan have been described by Daly from Kettle Point, Ontario, where the same formation is exposed by the waves. This author calls attention to the deformation of the shale on all sides of each concretion and concludes that they were formed *in situ,* that they antedate the period of joint development and final consolidation of the shale and that the deformation resulted from the change in volume when the original calcium bicarbonate was converted into the monocarbonate.[20]

Not infrequently these shales appear to be impregnated with oil, have a strong bituminous odor and have given off considerable quantities of "natural gas." When allowed to accumulate under a suitable cover of clay, "pockets" of such gas, under very great pressure, have occasionally been struck in well boring. It is likely that by entering the bed sufficiently more or less gas could always be procured which could be utilized in the homes situated over the formation, but the expectation can not be realized that any considerable flow can be long maintained. New wells could be drilled, or the former ones deepened when the supply ceased. The bituminous constituent in the shale is due very largely to the presence of enormous numbers of minute disc-like bodies, with relatively thick carbonaceous walls. These were discovered by Dawson in the shales of Kettle Point, Lake Huron, and described by him in 1871, under the name *Sporangites Huronensis.*[21] Remains of *Calamites* and *Lepidodendron* were found in association by Dawson and he regarded them as spore cases belonging to the latter type of tree. From material derived from Brazil two additional species of *Sporangites* were described in 1883 (*S. Braziliensis* and *S. bilobatus*) and the similarity noted to the macrospores of the floating fern of European rivers, *Salvinia natans.*[22] The generic name *Protosalvinia* was suggested to cover the former *Sporangites* which he then regarded as macrospores with their envelopes lost. Clarke found them abundant also in the Marcellus shale of Ontario County, New York,[23] associated with immense numbers of still smaller sub-spherical bodies which he regarded as the *microspores.* Newberry, as early as 1873, had called attention to the difficulty of conceiving of such widespread shallow water conditions, capable of furnishing the necessary shore vegetation, but with

20. Daly, The Calcareous Concretions of Kettle Point, Lambton County, Ontario: Journal of Geology, vol. VIII, No. 2, p. 135. See also Newberry, Geological Survey of Ohio, vol. I, pt. I, 1873, p. 155.
21. American Journal of Science, 3rd series, vol. I, 1871, p. 256. See also Orton, A Source of the Bituminous Matter in the Devonian and Sub-Carboniferous Black Shales of Ohio: same journal, 3rd series, vol. XXIV, 1882, p. 171.
22. Dawson, On Rhizocarps in the Palaeozoic Period: Proceedings of the American Association for the Advancement of Science, 1883, p. 260.
23. Clarke, On Devonian Spores: American Journal of Science, 3rd series, vol. XXIX, 1885, p. 284.

the evidence of the proximity of the shore so completely wanting.[24] He concluded his discussion as follows: "Waiting the demonstrative solution of the problem, which patient and exhaustive study will doubtless sometime furnish, I offer, as a possible explanation of the peculiar features of the Huron shale, the suggestion that its carbon was derived from vegetation which lined the shores and covered the surface of a quiet and almost land-surrounded sea."

Aside from the fossils above referred to, which are not serviceable for correlating these shales with the New York series, there is little help that palaeontology can render. They rest upon undoubted Hamilton and are lithologically identical with the Genesee shales of central New York. They have been so referred by Winchell, Rominger, Newberry, Whiteaves and Orton. Lane made the Antrim the equivalent of both the Bedford and Ohio shales in Ohio and these he correlated with the Tully, Genesee and Portage of New York. In the report of 1908, Lane places the shales "somewhat later" than the Genesee, based upon the evidence of a Naples fauna at the base, bringing them into the Portage of the New York scale.

Although known that the general dip of the stratum is toward the northwest, sufficient data are not available for the determination of the amount of such dip. Since these shales so nearly conform with those underlying, it may be assumed that the dip is practically the same as that of the Dundee and Upper Monroe and amounts to about 25 feet to the mile. Comparing the Ann Arbor Campus well with that at Pontiac, it is noted that the base of the Antrim at the latter place is 231 feet lower than at Ann Arbor giving an average drop in the 34 miles of about 7 feet to the mile, towards the northeast. In almost the opposite direction and in approximately the same distance, Ann Arbor to Adrian, the drop is 195 feet, or about 5¾ feet to the mile. Measured upon the top of the Antrim, or what is the same thing, the base of the Berea, at Ann Arbor, the formation is 134 feet higher than at Adrian and 234 feet higher than at Pontiac. This indicates the existence of a great arch in these strata, what is known in geology as an anticlinal fold, which might have been reasonably expected to have yielded gas or oil. The sandstone could have served as a suitable reservoir, the gas or oil under pressure displacing the brines and the overlying impervious shale acting as an ideal cover to prevent the escape to the surface. In explanation of why no considerable quantities of these desired commodities were struck

24. Geological Survey of Ohio, vol. I, pt. 1, 1873, p. 156.

in either the Ann Arbor, or Ypsilanti wells, attention may be drawn to the fact that the longitudinal crest of this broad fold is tilted downward toward the northwest and this may have allowed the gas and oil that were slowly distilled from the Antrim shales to work their way upward and southeastward until a means of escape to the surface was found. In attempting to locate these shales upon the geological map, help is furnished by the records of gas in the wells and by the amount of drift cover. The greatest de-depressions in the rock surface seem to correspond with the belt of Antrim shales, as though it had suffered greater glacial, or preglacial erosion, than the limestones beneath or the sandstones immediately above.

Traverse group. The next member of the Devonian system, as we descend in the geological scale, is the *Traverse*, originally described by Winchell as the "Hamilton group" in his First Biennial Report (1861, page 69), and subsequently as the "Little Traverse." This latter name was shortened to *Traverse* in 1895 by Lane[25] by which it is still known in the state reports. The formation was quite fully described by Rominger[26] under the name "Hamilton group" and its fossil contents carefully studied. With no outcrops in the southeastern part of the state he did not recognize its presence in the well records and denied its existence. In northern Ohio, Newberry identified some 15 to 20 feet of highly fossiliferous blue shale with the Hamilton, which formation is now regarded as the "Olentangy shale" of N. H. Winchell. In western Ontario, the same formation is readily recognized in outcrop and well sections, showing a thickness of 225 to 350 feet, and, as in Michigan, consisting of alternating layers of limestone and shale. During the last decade a very complete study of the Traverse has been made by Grabau, his paper upon the "Stratigraphy of the Traverse Group of Michigan" appearing in 1902.[27] These and subsequent studies were made upon the numerous exposures in the eastern part of the peninsula, in the Alpena region and upon those on the opposite side of the state in the Traverse Bay region.

Lithologically considered the Traverse Group of Michigan and western Ontario is transitional between the underlying Dundee limestone formation and the overlying Antrim shale, in that it consists of alternating layers of limestone and bluish, calcareous shale, often referred to in the well records as "soapstone." In the Alpena and Traverse regions, the thickness is believed to be about

25. Geological Survey of Michigan, vol. V, pt. II, 1895, p. 24.
26. Geological Survey of Michigan, vol. III, pt. I, 1876, pp. 38 to 63.
27. Report of the State Board of Geological Survey of Michigan, for the year 1901, pp. 163 to 210.

600 feet, diminishing to near 300 feet in the St. Clair River region and to less than 200 feet in the southeastern corner of the state. In the Campus well at Ann Arbor, Lane refers 65 feet of "gray, calcareous shale" to this formation and it seems probable that the last 70 feet of "bluish, cherty limestone" in the Court House well may also be so referred. The deep well at Pontiac gives the following series of Traverse strata:

TABLE XXXIV.—TRAVERSE STRATA, PONTIAC WELL.

Dark drab, coarse-grained, argillaceous limestone	25 feet.
Light drab, fine-grained limestone; 2% insoluble residue	10 feet.
Light drab, greyish white limestone; 8% insoluble residue	7 feet.
Light grey limestone; 20% insoluble residue	8 feet.
Sandy limestone, dark drab; 20% insoluble residue	35 feet.
Argillaceous limestone; 10% insoluble residue	15 feet.
Light blue, calcareous clay; 90% insoluble residue	50 feet.
	150 feet.

In this section there occur 100 feet of rather impure limestone and 50 feet of calcareous clay, which throw light upon the Wayne County records and show what may be expected in the case of new wells penetrating the formation. In the case of the Milan deep well (14 miles south-southeast from Ann Arbor) the Traverse series is as follows:

TABLE XXXV.—TRAVERSE STRATA, MILAN WELL.

Cherty limestone	30 feet.
Blue shale	45 feet.
Blue, shaly limestone	65 feet.
Limestone	28 feet.
	168 feet.

Although some of the limestone strata pass into dolomite, with the introduction of magnesium, others are of high grade, as indicated by the following table of analyses from the Alpena region.[28]

TABLE XXXVI.—ANALYSES OF TRAVERSE LIMESTONE, ALPENA PORTLAND CEMENT COMPANY.

Calcium carbonate ($CaCO_3$)	89.10% to 98.37%
Magnesium carbonate ($MgCO_3$)	.92% to 8.67%
Silica (SiO_2)	.33% to 1.77%
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	.13% to 1.21%

The clays and shales of the same formation in the Alpena region show the following composition:

28. For fuller data see Grabau's paper, Report of the State Board of Geological Survey of Michigan for the year 1901; 1902, p. 181.

TABLE XXXVII.—ANALYSES OF TRAVERSE SHALES AND CLAYS, NEAR ALPENA.

	(1)	(2)	(3)
Silica (SiO_2)	55.80	54.46	55.68
Alumina (Al_2O_3)	20.93	17.26	20.68
Ferric oxide (Fe_2O_3)	5.11	4.66	
Calcium oxide (CaO)	1.98	6.60	9.69
Magnesium oxide (MgO)	1.23	2.82	2.35
Alkalies (K_2O, Na_2O)	5.55	14.20	3 60
Loss by ignition	7.78		.....
	98.38	100.00	92.00

(1) Dock street clay; 5 feet below surface.
(2) Warner brick yard, blue shale.
(3) Fletcher dam, Thunder Bay River, blue shale.

From the same locality, Ries (*loc. cit.,* foot note 19) gives an analysis of a shale outcropping to the north of Alpena, belonging to the Alpena Portland Cement Company.

TABLE XXXVIII.—ANALYSIS OF TRAVERSE SHALE NORTH OF ALPENA.

Silica (SiO_2)	61.09%
Alumina (Al_2O_3)	19.19
Ferric oxide (Fe_2O_3)	6.78
Calcium oxide (CaO)	2.51
Magnesium oxide (MgO)	.65
Potassium oxide (K_2O)	1.80
Sodium oxide (Na_2O)	1.36
Sulphuric anhydride (SO_3)	1.42
Water (H_2O) and carbon dioxide (CO_2)	5.13
	99.93

As used by Lane, the Traverse Group of Michigan includes both the Hamilton and lower lying Marcellus of the New York series, and hence is the western equivalent of the Erian of Clarke and Schuchert. It carries an abundance of fossils which are often in splendid state of preservation and easily separated from the shales. In southeastern Michigan, these fossils are often found in the glacial gravels and fragments may be obtained in well drilling.[29] The formation forms a belt from two to five miles broad, extending northeast to southwest across the county of Wayne. It is covered by some 50 to 150 feet of drift and has approximately the same northwesterly dip as the overlying Antrim shale. The main body of Traverse shale is separated from the Antrim by the layers of limestone and is readily distinguished from it by its bluish color and soapy character when wet. The conditions favorable for the remarkable growth of marine vegetation that characterized the Antrim had not yet been established in the west during Traverse time. Highly mineralized water is sometimes met with from this formation but too impure to be utilized as a brine, in this respect differing from that of the Berea sandstone. The relatively small amount of organic matter preserved in the strata has given rise to very little or no gas and oil.

29. For descriptions and figures of Traverse fossils see vol. III, Geological Survey of Michigan, 1876, pt. II, Fossil Corals by Rominger.

Dundee limestone. Under a heavy burden of drift, the preceding geological formations are but imperfectly known in Wayne County. We come now to a series of strata which have been carefully studied in outcrop, were penetrated in the Oakwood salt shaft and of which we have numerous well records, based upon actual samples of the drillings. The first of these is the Dundee limestone, one of the first to be recognized in the state and utilized for building purposes and in the manufacture of lime. In every direction from southeastern Michigan, it extends persistently for great distances and underlies hundreds of thousands of square miles of the lake region, the Ohio and Mississippi basins. It represents the upper member of a group of strata found well exposed in the Helderberg Mountains of eastern New York, to which group the name "Helderberg" was given by Conrad, the early palæontologist of the New York Survey. Under the names "Helderberg series," or "Helderberg division," these strata were described in the Final Reports of the various districts prepared by Mather, Emmons, Vanuxem and Hall (1842-3). It was soon found that this and the other geographic names there used were entirely arbitrary and ill suited for group divisions until they had been subdivided upon the basis of their carefully studied fossil contents. In his review of these New York reports, Owen suggested a regrouping of the minor divisions and a renaming of the main divisions. Attracted by this work in the United States, the able French palæontologist M. Ed. de Verneuil made a season's study of the formations with a view to correlating them with those of Europe and suggested the grouping together of the lower strata of the Helderberg series, found to be of Silurian age, under the name "Lower Helderberg." This placed the upper members in the Devonian and suggested the use of the term "Upper Helderberg." In his translation and review of the paper of de Verneuil, Hall refers to the "upper limestone series of the Helderberg"[30] and in 1851 uses the term "Upper Helderberg series" to include the Corniferous limestone, Onondaga limestone, Schoharie grit and Caudagalli grit.[31] De Verneuil expressed the opinion that the Oriskany sandstone should also be included in the series as marking the base of the Devonian and, in this view, Hall promptly concurred (page 302). The French scientist also proposed to unite the Caudagalli and Schoharie grits and the Onondaga and Corniferous limestones. The Corniferous had been originally named by Eaton, "the Cor-

30. The American Journal of Science and Arts, second series, vol. VII, 1849, p. 230.
31. Report on the Geology of the Lake Superior Land District; Foster and Whitney, part II, 1851, p. 288.

niferous limestone," in allusion to its content of *hornstone*, or chert, and made to include both the Upper and Lower Helderberg formations.[32] The propriety of uniting the Corniferous and Onondaga limestones of the Upper Helderberg series, was early admitted because of their lithologic similarity, their content of hornstone and the close similarity in fossils. As early as 1841 Hall had traced the main limestones of the Upper and Lower Helderberg groups into the middle west and had observed the disappearance to the westward of many of the intermediate formations.[33] But C. C. Douglass, assistant upon the early Michigan survey, had already recognized the Corniferous equivalency of the limestone of Monguagon township and subdivided them as follows:[34]

Limerocks of Lake Erie.
- a. Corniferous (Dundee).
- b. Silicious limestones, passing into sand (Sylvania).
- c. Compact gray or blue limestone (Monroe).

The term Corniferous for this limestone formation was very generally used in the earlier reports of the Ontario, Michigan, Ohio and Indiana surveys; "Upper Helderberg" being sometimes substituted. In 1894, Hall proposed to revive the term *"Onondaga"* for this formation[35] and this term has come into general use in the recent geological literature. In Ohio, Prosser recognizes a double division—the Delaware and Columbus limestones.[36] Owing to the difficulty of establishing exact correlations across distant areas, especially where gaps occur in the series, Lane defined the *Dundee* in 1895, as "extending down from the bluish beds of the Hamilton (Traverse) so long as the formation continues to be limestone, stopping with the appearance of dolomite or of gypsiferous shales."[37] Although much better exposed near Trenton than at Dundee and on the Macon, this name had long been preoccupied, and the village of Sibley had not then come into existence. The base of the Dundee (Devonian) was thus intended to be placed at the top of the Monroe formation (Silurian), the uppermost strata of which are so generally dolomite. The discovery of the

32. Geological Nomenclature Exhibited in a Synopsis of North American Rocks and Detritus: The American Journal of Science and Arts, vol. XIII, 1828, p. 385.
33. Hall, Notes upon the Geology of the Western States: The American Journal of Science, vol. XLII, 1842, p. 51. See also Report on the Geology of the Lake Superior Land District, Foster and Whitney, pt. II, 1851, p. 307.
34. Fourth Annual Report of the State Geologist (Michigan), 1841, p. 109.
35. Thirteenth Annual Report of the State Geologist (New York) for the year 1893, vol. I, 1894, p. 207.
36. Revised Nomenclature of the Ohio Geological Formations: Geological Survey of Ohio, fourth series, Bulletin No. 7, 1905, p. 4.
37. Geological Survey of Michigan, vol. V, pt. II, 1895, p. 25. See also Annual Report for 1908, p. 70, in which the occurrence of magnesian beds is noted near Mackinaw City, near the base of the Dundee.

Anderdon limestone, of high grade and carrying *Devonian* fossils, embedded in the Upper Monroe[38] and that the superposed dolomite strata may be absent enables the Dundee to rest directly upon this Anderdon, or to be separated from it by a very thin stratum of sand. Such is the case at the Sibley quarry near Trenton and at the Anderdon quarry near Amherstburg, Essex County, Ontario, where the original definition of the base of the Dundee becomes inapplicable and the separation between it and the Anderdon can be made only upon a paleontological basis. As thus defined by Lane it was intended to cover the entire time of the Upper Helderberg; Oriskany to Corniferous, inclusive.[39].

As seen in southeastern Michigan and western Ontario, the Dundee is essentially a pure limestone formation with occasional nodules, seams and thin strata of chert, an impure variety of quartz. The limestone varies in color from light gray to drab, buff to yellow, in some cases merging into blue. The purer varieties show numerous cleavage faces of calcite, or crystallized lime carbonate, and are heavily charged with fossil fragments. The argillaceous ingredient, abundant in the Traverse limestones, is usually small in amount, generally less than one per cent but may run up to 6 or 7% in certain beds. The iron content is also small but the silica and magnesium carbonate are subject to considerable variation. With dilute hydrochloric acid, the Dundee always gives vigorous effervescence by which it may be distinguished from the underlying Monroe dolomites. The beds not infrequently give a strong odor of oil and show drops of thick, black, bituminous matter in the small cavities. In Ontario and near Port Huron, the formation yields oil and gas where the structural conditions have been favorable.[40] It is also the source of a highly mineralized water, too impure for salt manufacture but valuable for medicinal and chemical uses. The composition of such a "mother liquor" from a deep well[41] at Port Huron is shown in the following analysis. The well is 750 feet deep and enters the Dundee 100 feet.

38. Grabau and Sherzer, The Monroe Formation of Southern Michigan and Adjoining Regions: Michigan Geological and Biological Survey, Geological Series 1, 1910, p. 42.
39. Geological Survey of Michigan, vol. VII, pt. I, 1900, foot note, p. 37.
40. Gordon, The Port Huron Oil Field: Geological Survey of Michigan, Report for the year 1901; 1902, p. 269.
41. Annual Report for the year 1903; 1905, p. 109.

TABLE XXXIX.—ANALYSIS OF DUNDEE MINERAL WATER. "DEEP SPRINGS MINERAL WATER," PORT HURON, MICHIGAN.

(Analysts Dr. E. Ristenpart and Prof. R. C. Kedzie.)

	Parts per 1000.
Sodium chloride ($NaCl$)	66.6832
Potassium chloride (KCl)	2.8181
Ammonium chloride (NH_4Cl)	0.1431
Calcium chloride ($CaCl_2$)	5.2492
Magnesium chloride ($MgCl_2$)	6.7846
Magnesium bromide ($MgBr_2$)	0.0488
Magnesium iodide (MgI_2)	0.0003
Calcium bicarbonate $Ca(HCO_3)_2$	1.7600
Iron bicarbonate $Fe(HCO_3)_2$	0.0140
Calcium sulphate ($CaSO_4$)	3.7721
Sodium hyposulphite ($Na_2S_2O_4$)	0.0177
Sodium hydrosulphate (Na_2SO_4)	0.0136
Sodium carbonate (Na_2CO_3)	......
Lithium chloride ($LiCl$)	......
Alumina (Al_2O_3)	0.0033
Silica (SiO_2)	0.0085
Sulphuretted hydrogen gas (H_2S)	0.3146
Carbonic acid gas (CO_2)	0.7147

Studies upon the various layers of the Dundee as exposed in the Sibley quarry, near Trenton, were begun by the writer 15 years ago (June 1896), when there were recognized for commercial purposes the following series of strata; which for convenience of reference were assigned letters.

TABLE XL.—STRATA OF THE SIBLEY QUARRY, NEAR TRENTON.

A. "6 foot top." Yellow, brown to gray; thin-bedded; very fossiliferous.
B. "7 foot limestone." Thin-bedded, gray to bluish.
C. "2 foot limestone." Compact, gray, rich in fossils.
D. "5 foot limestone." Compact, crystalline, bluish where unweathered.
E. "6 foot limestone." Compact, gray to blue, fossil fragments abundant.
F. "14 inch flint." Brittle, bluish gray chert, some fossils.
G. "6 foot limestone." Gray to bluish, more heavily bedded.
H. "2 foot flint." Very brittle impure chert, some fossils.
I. "9 foot limestone." Compact, heavily bedded, blue to gray.
J. "6 foot magnesian." Similar to I but oily and fewer fossils.
K. "8 foot limestone." Gray, thin-bedded, fossiliferous.
L. "12 foot lower magnesian." Light to dark gray, fossiliferous.
M. "7 foot silicious." Thin-bedded, firm, poor in fossils.

Aside from the splendid exposure of the Dundee strata now seen at the Sibley quarry, the only other known locality in southeastern Michigan lies some 27-28 miles to the southwest at Dundee and the mouth of the Macon.[42] Four separate beds may be recognized at the Christiancy quarry, the second and third of which are separated by a thin stratum of chert, which from its fossil contents agrees with that designated "Bed F" in the Sibley quarry. If this correlation is correct, and there is much opportunity for uncertainty, the "2 foot flint" has disappeared and the four Macon beds exposed represents beds D, E, G and I of the Sibley quarry. Lithologically the beds seem to correspond, their combined thickness is 21 to 22 feet on the Macon and 26 feet at the Sibley quarry, and they seem to lie at about the same horizon, measured from the top of the dolomite (Flat Rock?). The base of "Bed I" at the

42. See author's Geological Report on Monroe County: Geological Survey of Michigan, vol. VII, pt. I, 1900, p. 75.

Sibley quarry is some 48 feet (including the Anderdon) above the dolomite while in the Christiancy quarry, the Nogard well record indicates that the base of the lowest stratum there is about 38 feet above the corresponding horizon. These variations in the thickness of the strata at these two localities harmonize with the apparent increase in the thickness of the entire formation to the northward. In actual elevation, the Sibley bed is about 18 feet lower, this representing the drop in the direction of the strike. The following analyses will be of interest for comparison with those of the Sibley and Anderdon limestones.

TABLE XLI.—ANALYSES OF DUNDEE LIMESTONE, CHRISTIANCY QUARRY.

(Analyst G. A. Kirchmeier.)

	Upper.	Second.	Third.	Lowest.
Calcium carbonate ($CaCO_3$)	90.80%	86.80%	77.60%	95.00%
Magnesium carbonate ($MgCO^8$)	6.87	11.60	17.41	3.86
Silica (SiO_2)	0.48	1.10	2.78	0.81
Iron (Fe_2O_3?)	0.16	0.12	0.56	0.41
Organic matter	1.69	......	1.63	......
Difference	0.00	0.38	0.02	—0.08
	100.00	100.00	100.00	100.00

In a brief report upon the limestone of the Anderdon quarry,[43] Rev. Nattress gives the following average composition of certain of the richer beds, the analyses having been made by the Solvay Process Company of Detroit. It seems very probable that the samples covered both the Dundee and Anderdon formations, the

TABLE XLII.—AVERAGE COMPOSITION OF DUNDEE BEDS, ANDERDON QUARRY.

(Laboratory Solvay Process Co.)

Calcium carbonate ($CaCO_3$)	97.50%
Magnesium carbonate ($MgCO_3$)	1.50
Calcium sulphate ($CaSO_4$)	0.03
Silica (SiO_2)	0.80
Ferric oxide (Fe_2O_3) and Alumina (Al_2O_3)	0.09

latter of which had not yet been recognized and separated from the former. In the case of the former, recent determinations of the lime carbonate ingredient alone shows quite a wide range in amount, depending upon the presence mainly of magnesium carbonate and silica. The 76 analyses supplied by Rev. Nattress give an average of 62.49% and an extreme range of 40.34% to 95.26%. The samples were taken from drill cores through the beds believed to represent the basal layers of the Dundee, just above the Anderdon, which is still richer in lime carbonate (see Pl. XXIII for these beds now exposed in the quarry).

43. The Limestones of Ontario: Report of the Bureau of Mines, 1904, pt. II, p. 41.

In the summer of 1905 two drill cores were removed from the eastern and western sides of the Sibley quarry for the purpose of discovering the nature and thickness of the underlying beds. "No. 2," farthest west, started upon "Bed I," elevation about 583 feet above sea level, and extended to a depth of 83 feet. Through the kindness of Mr. Sundstrom, the writer was permitted to study these cores and was given the following set of analyses, which, taken in connection with the series of strata in the quarry, bring out admirably the essential nature of this economically important formation.

TABLE XLIII.—ANALYSES OF DRILL CORES, PROSPECT HOLE NO. 2, SIBLEY QUARRY.

(Laboratory Church and Co.)

Sample.	Depth.	Elevation.	$CaCO_3$	$MgCO_3$	SiO_2	Difference.	Remarks.
1........	5	578	87.63	8.72	1.98	1.67	Bed I.
2........	10	573	87.26	9.02	1.90	1.82	Bed J.
3........	16	567	83.99	11.56	2.78	1.67	Bed K?
4........	20	563	81.08	14.63	2.39	1.89	Bed K.
5........	25	558	93.26	4.82	0.73	1.19	Fossils.
6........	27	556	81.81	14.02	2.21	1.96	
7........	33	550	75.99	15.13	8.16	0.72	
8........	35	548	82.72	9.06	7.24	0.99	
9........	40	543	92.54	4.17	2.63	0.66	Base of Dundee.
10........	42	541	87.79	2.49	9.50	0.22	Anderdon.
11........	45	538	79.99	15.55	2.89	1.57	"
12........	48	535	87.08	7.91	4.95	0.06	"
13........	53	530	68.36	23.64	1.50	6.50	"
14........	55	528	70.54	23.49	0.96	5.01	"
15........	58	525	59.99	35.70	0.54	3.76	Flat Rock?
16........	62	521	64.72	32.57	0.49	2.21	" "
17........	65	518	62.36	33.34	0.29	4.01	" "
18........	70	513	59.45	37.00	0.68	2.87	" "
19........	78	505	54.27	43.04	0.22	2.54	" "
20........	80	503	59.15	37.88	1.05	1.92	" "
21........	83	500	58.09	40.04	0.31	0.56	" "

The "differences" consisted mainly of alumina, iron oxide, and organic matter and were not determined.

In August, 1907, Prof. A. W. Grabau examined these cores with the writer and was able to recognize the Anderdon character of the fossils seen in the cores from depth (Hole No. 2) 46.5 feet to about 51 feet. From a depth of 41 to 42 feet, there occurs a light brown limerock in which are thickly embedded quantities of fine, rounded, pure white, quartz granules, not to be distinguished from those derived from the Sylvania. At what appears to be the same horizon in the Anderdon quarry, upon the opposite side of Detroit River, Rev. Thomas Nattress, found a few inches of sand, or an incoherent sandstone. This occurrence is of interest since it marks the horizon of the Oriskany sandstone of the New York series and the base of the Dundee. It probably resulted from transportation of Sylvania sand by the wind during a land interval between the Silurian and Devonian. In the table of analyses above given, the 15 to 16 feet (elevation 541 to 525) of limestone lying just beneath the sandy stratum are to be referred to the Anderdon. Beneath this lies some 25 feet of rock approaching normal dolomite in its composition and presumably representing the Flat Rock formation yet to be described. The strata of the Anderdon quarry have been made the subject of study for a number of years by Rev. Nattress and reported upon from time to time.[44] During the past summer and fall (1911), he has conducted a series of investigations for the Solvay Process Company in the district immediately to the west of the Sibley quarry.

The total thickness of the Dundee formation at the Sibley quarry appears to be about 90 to 100 feet where it has been pushed up to form a knoll, across which the earliest ice sheet moved with considerable vigor. How much was removed by glacial, or other agencies we may only surmise by ascertaining the total thickness at neighboring localities. At the Oakwood salt shaft the Dundee was found to have a thickness of 63 feet, but here again we have but a partial record, since it lies next to the drift cover of 83 feet. In Ohio, the maximum thickness of the formation is given as 100 feet, which thickness it retains for a few miles into Michigan. In the Adrian well record the separation of the Dundee and Monroe was not made but at Britton, Lenawee County, there were 100 feet of "white or brownish crinoidal limestone with water and traces of oil and gas," which are referred by Lane to the Dundee. At Milan, Monroe County, there occur 97 feet of the same formation. In the next dozen miles to the northward a rapid thickening seems to take place as indicated by the Ann Arbor and Ypsilanti records, the Campus well giving 185 feet and the Cornwell well at least 200 feet referable to this formation. The Pontiac and Royal Oak records, unfortunately, are not complete enough to be of service in this connection. At Petrolea, Ontario, the thickness is about 200 feet, according to the Canadian records. Judging from these records in the surrounding districts, the Dundee in Wayne County would have to be assigned an original thickness of about 100 feet, in the southwestern corner, to about 200 feet along

44. The Corniferous Exposure in Anderdon: Eleventh Report of the Bureau of Mines (Ontario), 1902, p. 123.

The Limestones of Ontario: Report of the Bureau of Mines, 1904, pt. II, p. 41. See also papers in the annual reports of the Michigan Academy of Science:

The Contour of the Sylvania Sandrock and related strata in the Detroit River Area: 12th Report, 1910, p. 47.

The Extent of the Anderdon Beds of Essex County, Ontario, and their place in the Geologic Column: 13th Report, 1911, p. 87.

the northern border. In the numerous wells along Detroit River, the records are either incomplete, or penetrate only a portion of the formation. The Stroh Brewery well, on Gratiot Avenue, Detroit, shows 400 feet of "limestone," from the base of the Traverse to the top of the Sylvania, two very well defined horizons. This includes the Dundee and Upper Monroe, the latter of which in the Oakwood salt shaft has a thickness of 274 feet, leaving some 126 feet for the Dundee.

Between the outcrop at the mouth of the Macon, in Monroe County, and that at Sibley, the drift cover is relatively light, but still amounting to 30 to 80 feet, hopelessly covering a rock for which there is now great demand. Towards the north, this burden of drift increases until it exceeds 100 feet. The breadth of the outcrop, *beneath this cover*, ranges from four to twelve miles (see Pl. XXV) and the strike of the formation is toward northeast as it enters the county, curving around to the eastward and apparently shifting the direction of dip from northwest around towards the north. At the Sibley quarry, the rock strata have been disturbed and both the strike, amount and direction of dip are abnormal. At the time of their study by the writer in 1896 the dip as carefully determined by transit was found to be 5° south of west and equal to 4.4 feet per hundred, measured along the top of "Bed J." The surface of "Bed I" showed a drop per hundred feet of 3.9 feet. In the old Christiancy quarry upon the Macon, the former foreman, Mr. T. J. Brandt estimated the direction of dip as W. NW. and the amount as about .45 feet to the 100 feet. In the Dundee quarry it was found to be approximately 2.25 feet to the hundred. The average dip of the strata for the county can be determined only by an examination of the well records for which we have reliable data, the base of the Dundee in the salt shaft being known to have been reached at a depth of 146 feet (elevation of mouth 575.2 feet above sea level) or at an elevation of 429 feet. In the Campus well at Ann Arbor the base of the Dundee is 50 feet *below* sea level, giving a drop in the 32.5 miles from Detroit to Ann Arbor of 479 feet, or an average of 14.74 feet to the mile. This is in a direction, however, almost due west and hence does not indicate the real dip of the beds. From Detroit towards Royal Oak, or Pontiac, would more nearly furnish the desired data but, unfortunately, the separation of the Dundee from the Monroe can not be made in the well records at these two places. Dropping to the level of the top of the Sylvania, the dip from Detroit to Ann Arbor is found to be 15.7 feet to the mile. In the Pontiac well, N. NW. from Detroit, there occurs an arenaceous limestone which probably marks the horizon of the Sylvania. If we make this assumption, the dip in this direction is about 21.2 feet to the mile. The top of the Sylvania is much better defined in the Royal Oak deep well (SW. ¼ sec. 19), at a depth of 836 feet, but unfortunately the elevation of the mouth of the well is not given with the record. If we take this from the topographic map as about 678 feet above sea level, then we have an average dip indicated in almost due north direction of about 22 feet to the mile. Until more reliable data are at hand we may assume that the average dip is not far from 25 feet to the mile and in a direction north-northwest.

In connection with the Antrim shales, attention was called to an anticlinal fold with its crest near Ann Arbor and the economic importance of such structural features was there pointed out. When the Dundee is similarly examined it is found that the base of this formation at Ann Arbor (—50 feet) is *lower* than at Milan (+290 feet), or at Royal Oak (about sea level), indicating the presence of a synclinal trough in the surface of the Upper Monroe. In private conversation Prof. I. C. Russell called attention to the fact that the production of the great basin-like depression over central Michigan must have produced a series of such wrinkles in the strata radiating from the center. The suggestion has value in the search for oil and gas in that if a series of test wells is being put down their direction should be *tangential* to the basin; i.e., northeast to southwest in southeastern Michigan. If a successful well is once reached a *radial* position for new ones is to be recommended with reference to the central basin; i.e., so placed that the line will point toward the center of the basin.

A full suite of fossils was collected from the Sibley strata and these have been made the subject of study by Prof A. W. Grabau, whose preliminary report upon the same is found in Chapter X. Dr. Carl Rominger had also collected extensively from the same beds and his lists are given in Vol. III, issued in 1876, with photographic views of the corals. Most of the strata are surprisingly rich in fossil forms, often proving to be a solid, coquina-like mass of shells, corals and crinoid joints. Even when the limestone appears quite compact, the weathered portions reveal more or less of this structure. The discussion of the conditions under which this material accumulated and resulted in the formation of limestone and chert will be found in the writer's report upon Monroe County.[45] It may be stated here simply that warm, open,

45. Geological Survey of Michigan, vol. VII, 1900, pt. I, p. 40.

shallow sea conditions prevailed, far enough removed from land to escape deposits of mud and sand. Floating vegetation, so abundant later, had not yet invaded the sea and the oil and gas were probably very largely of animal origin. The Michigan basin as far north as James Bay was covered by this epicontinental sea which communicated eastward with the Atlantic and southward with the Gulf of Mexico from which came a rich fauna of corals and brachiopods which gave rise to extensive reefs.

SILURIAN SYSTEM.

The establishment of this world-wide system dates back to 1839 and was made by Murchison as the result of his extended studies upon the formations of the region of Great Britain, formerly occupied by the ancient tribe of *Silures*.[46] Two main divisions were recognized, an Upper and a Lower Silurian (p. 265). Almost immediately, the system received recognition in this country by Conrad who endeavored to correlate the New York strata with their English equivalents upon the basis of fossil similarity.[47] Owing to the pronounced break between the upper and lower divisions, it was proposed in 1879 by Lapworth to recognize each division as a *system*, retaining *Silurian* for the upper and using *Ordovician* for the lower, the name derived as the other had been from an ancient tribe of Wales, the *Ordovices*.[48] This suggestion has been largely adopted in the recent English and American texts on geology and has much to commend it. In Wayne County, the Silurian System only has been completely penetrated by the wells and only the uppermost formations are to be seen in outcrop. The Ordovician is reached in the deeper wells in Wayne and Monroe counties and is seen in outcrop towards Ohio River.

Monroe formation. The formation to which this term is now applied has been known in the state reports under a variety of names, as an effort has been made to correlate its strata with those of the standard New York series. It has recently been made the subject of joint study by Prof. A. W. Grabau and the writer and described in a special report[49] to which those especially interested may be referred. Three main divisions are readily recognized; an upper and a lower set of dolomitic limestones, separated by a

46. The Silurian System, founded on Geological Researches in the Counties of Salop, Hereford, Radnor, etc., with descriptions of the Coal fields and overlying formations. R. J. Murchison, London, 1839.
47. On the Silurian System, with a Table of Strata and Characteristic Fossils: American Journal of Science, vol. 38, 1840, p. 86.
48. Lapworth, On the Tripartite Classification of the Lower Palaeozoic Rocks: The Geological Magazine, New Series, vol. VI, 1879, p. 13.
49. Grabau and Sherzer, The Monroe Formation of Southern Michigan and Adjoining Regions: Michigan Geological and Biological Survey, Publication 2, Geological Series 1, 1910.

stratum of incoherent sandrock known as the Sylvania. Only the upper member of the entire series is believed to extend into New York, where it makes up the lower portion of the original Helderberg division and constitutes a portion of that which was set off by De Verneuil as the "Lower Helderberg." In his western trip, taken in 1841, for the purpose of correlating the strata of the middle states with those of New York, Hall referred certain limestones in the vicinity of Mackinac to the Onondaga Salt Group and the Waterlime.[50] The first recognition of Lower Helderberg strata in the Lake Erie region was made by Chapman in 1864, who suggested for it the name "Bertie dolomite."[51] The Waterlime equivalency of the Lake Erie dolomites was announced by Newberry and Winchell in 1871 and recognized, more or less generally, in the Ohio, Michigan and Ontario survey reports. In Ohio, the term "Lower Helderberg" was contracted to *Helderberg,* which was believed to be represented by the Waterlime alone with a thickness of 100 feet. Rominger in Michigan used the name "Helderberg Group" and extended its meaning to more nearly that of the early New York reports, making it include both the Dundee and Monroe and not endeavoring to separate them upon his geological map. The sandrock stratum (Sylvania) was supposed to separate the two members and had been regarded generally as the correlative of the Oriskany. In 1873 it was noted by N. H. Winchell that this formation is *embedded* in the dolomites, instead of being at the top of the series, which observation was later confirmed by Orton in Ohio and the writer in Michigan.[52] Because of its exposure and utilization near the village of Sylvania, Ohio, Orton suggested this name for the formation (*loc. cit.*, p. 18). It must be regarded, of course, as of the same geological age as that of the dolomites themselves.

Owing to the difficulty of separating this entire series, upon which rests the Dundee, from the underlying Salina formation, it was proposed in 1893 by Lane to use the name "Monroe beds" for the series intervening between the base of the Dundee and the top of the Niagara.[53] The formation was not defined until 1895, "as extending from the limestones of the overlying Dundee down to the lowest gypsiferous beds, and to consist mainly of buff dolomites

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50. Geology of New York, pt. IV, 1843, p. 512. Also Report on the Geology of the Lake Superior Land District, Foster and Whitney, pt. II, 1851, pp. 162-3.

51. A Popular and Practical Exposition of the Minerals and Geology of Canada, E. J. Chapman, 1864, p. 190.

52. Winchell, Geological Survey of Ohio, vol. I, 1873, p. 603.
Orton, Geological Survey of Ohio, vol. VI, 1888, p. 18. Also vol. VII, 1893, p. 17.
Sherzer, Geological Survey of Michigan, vol. VII, pt. I, 1900, p. 60.

53. Report of the State Board of the Geological Survey of Michigan for 1891 and 1892; 1893, p. 66. This name was selected because of the excellent exposures of the strata in Monroe County.

and of calcareous and argillaceous marls, associated with anhydrite and rock salt."[54] Based upon the evidence of the well records the thickness was placed at 1200 feet and the beds were believed to have been deposited in an excessively salt interior sea, extending from New York to eastern Wisconsin, exposed to a hot sun and receiving little accession of fresh water from rivers. Shallow water conditions prevailed in places, particularly in Ohio, where there was a great bar, reef or flat, permitting the formation of ripple-marks and mud-cracks. In southeastern Michigan, three periods of dessication were recognized, the first and greatest of which gave rise to the heavy beds of rock salt, aggregating in thickness some 600 feet; the second preceded the formation of the Sylvania (Middle Monroe) and resulted in the formation of gypsums, or salty dolomites, and occasional beds of oölite. The third period of dessication occurred during the deposition of the Upper Monroe series. The name "Monroe Group" for this series was approved in May, 1903, by the Committee on Geological Names of the United States Geological Survey.

In 1908 Grabau proposed to subdivide the Monroe into an upper, middle and lower division and to remove from it the Salina formation,[55] which in the New York series had been known as the Onondaga Salt Group. In a joint paper by Grabau, Lane, Prosser and Sherzer, presented at the same time before the Albuquerque meeting of the Geological Society of America and the Chicago meeting of the American Association for the Advancement of Science, this subdivision and restriction of the Monroe was recognized.[56] The upper and lower divisions were further subdivided as shown in the accompanying table, with the approximate thickness of each member.

TABLE XLIV.—THE MONROE FORMATION OF MICHIGAN.

Dundee Formation.

	———— disconformity.		
MONROE FORMATION.	C. Upper Monroe or Detroit River Series.	Lucas dolomite	200 ft. +
		Amherstburg dolomite	20–50
		Anderdon limestone	35–60
		Flat Rock dolomite	40–100
	———— disconformity.		
	B. Sylvania sandstone and dolomites		30–300
	———— disconformity.		
	A. Lower Monroe or Bass Islands Series.	Raisin River dolomite	200
		Put-in-Bay dolomite	100
		Tymochtee shales	90
		Greenfield dolomite	100
	———— disconformity.		

Salina Formation.

54. Geological Survey of Michigan, vol. V, 1895, pt. II, p. 27.
55. Science, new series, vol. XXVII, 1908, p. 622.
56. Nomenclature and Subdivision of the Upper Siluric Strata of Michigan, Ohio, and Western New York: Bulletin of the Geological Society of America, vol. XIX, 1909, p. 556.

In the typical locality, the Upper Monroe, or Detroit River Series, shows a thickness of about 100 feet at Wyandotte, to 350 feet at Windsor, Ontario, including the series of dolomites and limestone that intervene between the base of the Dundee and the top of the Sylvania sandstone. Extensive erosion of these beds seems to have taken place in the present vicinity of the lower Detroit River region previous to the deposition of the Dundee. The Middle Monroe, or Sylvania member, consists, in the main, of a pure, incoherent sandrock, not infrequently divided by a bed of silicious dolomite, sometimes, by two such beds. In the upper Detroit River region, the average thickness of this member is about 100 feet, but is found to be variable and to entirely disappear in some well sections. The thickness grows less to the southward and greater toward the northwest. The Lower Monroe, or Bass Islands Series (from the islands in the western end of Lake Erie), extends from the base of the Sylvania to the top of the Salina, which may be regarded in well records as the first bed of salt, or first heavy bed of gypsum. A comparison of the logs of adjacent wells, as for instance those of Wyandotte and Trenton, shows that some of the upper rock salt strata are replaced to the southward by deposits of gypsum. Without doubt, some of the strata lying above these salt and gypsum deposits are referable to the Salina and it was hoped that the record of the salt shaft at Oakwood would enable us to ascertain the thickness of these strata for that region. Unfortunately for this purpose, these beds proved unfossiliferous and with no structural break that could be observed it seems necessary to place the base of the Monroe at, or near the heavy salt or gypsum deposits. Thus limited, the Lower Monroe in the 17 wells of the Solvay Process Company, Delray, gives an average thickness of 360 feet and the entire Monroe formation of southeastern Michigan and western Ontario has a development ranging variously from 500 to 900 feet.

The best exposures, both natural and artificial, are to be found in Monroe County of each of the three main divisions of the formation. The Upper Monroe strata in Wayne County have been best seen in the quarry west of Gibraltar, now abandoned, and were formerly exposed in the shallow quarries on Stony Island and Grosse Isle. The Middle Monroe, or Sylvania member, may be seen in the pit of the American Silica Company, just east of Rockwood, where it was covered by some 15 to 20 feet of glacial clay. The Lower Monroe is not exposed in the county but a very good section and suites of specimens were obtained at the Oakwood salt shaft.

Rev. Thomas Nattress has recently endeavored to show[57] that the dolomites which constitute the bed of Detroit River in the vicinity of Stony Island are of Lower Monroe age and that the Sylvania sandstone, or Middle Monroe, swings in a sharp, horse-shoe shaped curve from the vicinity of Gibraltar, northward about the head of Grosse Isle and back to Bois Blanc Island, opposite Amherstburg; the respective exposures being upon "opposite sides of the *Cincinnati anticline*," and with a possible distance across of but about three miles at the broadest place. The conception was that the Sylvania represents a shore deposit about this very narrow peninsula of early Monroe dolomite and the argument was based upon theoretic considerations of dip and strike and the supposed absence of the Sylvania in the lower Trenton channel of Detroit River. Against this view many objections may be urged; first of which is that the crest of the Cincinnati anticline lies some 25 to 30 miles to the eastward; that it is not a narrow ridge, having "little or nothing of the character of an anticlinal or arch, * * * * no roof-shaped arrangement of the strata whatever, * * * * but a nearly level tract," (Orton) that could not be set down in Detroit River and still leave room for the thick Sylvania deposit upon either side. Furthermore, the "Cincinnati anticline" was formed before any of these Detroit River strata came into existence and not between Lower and Middle Monroe time, as would have had to be the case if the above arrangement held. But, if not the "Cincinnati anticline," could there have been a similar, but younger wrinkle in these strata that would satisfactorily account for all the phenomena? The Sylvania formation at Rockwood is 75 feet thick, 90 and 180 feet thick at Trenton, 60 and 100 feet at Wyandotte; and, although growing thinner to the eastward, unless we assume that it possesses a very much greater dip than it, or any contiguous strata are known to have, there would not be room in the area assigned to have the formation describe such a curve about a ridge of dolomite (see Pl. XXV). Outcropping (beneath the drift) at the mouth of the Huron with a breadth of two to three miles, by the time the Sylvania reaches Trenton it has dropped to a depth of 285 feet, while at Wyandotte its average depth is 213 feet, at both of which places we should expect to find the formation at, or very near the base of the drift. Furthermore, we should expect to find some trace of the formation in the channel bed passing either side of Grosse Isle, but nothing of the kind has ever been noted. Near the southern end of Bois Blanc Island a

57. The Contour of the Sylvania Sandrock and Related Strata in the Detroit River Area: Twelfth Report of the Michigan Academy of Science, 1910, p. 47.

well belonging to Capt. Walter Campbell was abandoned because of the great quantity of this sand pumped from it. At Elliott's Point, upon the Canadian mainland, there are reported 44 feet of glacial clay, 25 feet of dolomite and then the Sylvania sandstone entered to a depth of 14 feet. At the adjoining farm to the north the depth to rock was 41 feet, with but a foot of "shale" overlying the Sylvania, which was reported as but 20 feet thick. Many reasons have been given for thinking that the Sylvania is not a shore deposit at all but a wind blown and wind deposited mass of sand, in which case it would sustain no such relation to the peninsular fold assumed by Nattress to have been dry land at the time of its formation. Its supposed absence from the bed of the river, where it has been assumed to cross to the southward of Celeron Island, where not still covered by till, may be readily accounted for by the action of the present, or early Detroit River, at one stage of which it flowed to a considerably lower level (560 feet above sea level). Furthermore, if the Sylvania is an aeolian deposit there is no reason to expect that it must be continuous from one point to another.

As to the Lower Monroe age of the dolomites of the Detroit River bed and adjacent islands, structural and stratigraphic relations can furnish only a very uncertain guide. If fossils were absent, we should be compelled to rely upon lithological characters and these all point to the Upper Monroe age of the strata exposed in the Livingstone Channel (Pl. XXIV). But, unlimited quantities of excellently preserved fossils, corals being especially abundant, are available and will continue to be until the tremendous pile of dump is removed from the river. A large box of such material was submitted to Prof. A. W. Grabau, during the summer of 1911, and he unhesitatingly pronounces the strata of Upper Monroe age (Lucas and Amherstburg), which means that the Sylvania underlies Grosse Isle. It should be noted that corals are entirely absent from the Lower Monroe of southeastern Michigan, but are so abundant in the Livingstone Channel region as to almost constitute a reef. In the case of the Swan well, at the southwestern corner of this island, the owner Judge Swan feels confident that the Sylvania was penetrated early in the drilling, the drill requiring very frequent sharpening. While the drilling was in progress by the West Virginia Drilling Company (St. Marys, West Virginia) the well was visited by Forest B. H. Brown for the State Survey. A depth of 785 feet had been reached (July, 1903) which gave 14 feet of clay, 300 feet of "limestone" and 70 + feet of sand. These figures would give an elevation here of the surface of the Sylvania of 266 feet above sea level as compared with 290 and 300 feet at Trenton (Church and Co).

The fossils collected from the exposure at the southeastern corner of Celeron Island prove to be of *Lucas* age. Being so near the outcrop of the Sylvania, we should expect these beds to represent the Flat Rock division of the Upper Monroe, which was next in age to the Sylvania. This indicates that the Amherstburg, Anderdon and Flat Rock are either absent, or greatly attenuated at the mouth of Detroit River. Instead, then, of a dolomitic *ridge* of Lower Monroe age, as made out by Rev. Nattress, the evidence indicates that there existed a sandstone *basin* of Upper Monroe age in which the Detroit River beds were deposited.

In conformity with the overlying strata already described, the Monroe strata have a general northwesterly dip, swinging towards the north in the northern part of Wayne County, amounting probably to about 25 feet to the mile. In the lower Detroit River region, local disturbances have rendered the strike and dip irregular. At the Patrick quarry, south end of Grosse Isle, the strata were observed to dip S. 30° W. and to range in amount from 1½ to 2°. In the bed of Detroit River, opposite Stony Island, while the excavation for the Livingstone Channel was in progress, the average dip of the strata (seven determinations) was found to be S. 50° W. and to be equal to 1° 58′, or about 3.438 feet to the hundred. In the northern part of the area exposed, the strata showed a pronounced anticlinal fold, extending in an east-west direction across the river bed. The strata dip rather rapidly upon the southern slope of the fold, having been eroded along the plane of the river bed and indicate that the fold is one of considerable magnitude. Upon the eastern face of the channel wall, Rev. Nattress and the writer counted 32 strata which had an average thickness of 38.3 inches and a total maximum thickness of 102 feet. Bench marks in use in the construction of the channel and located upon the surface ledges have elevations of 566.16, 568.61 and 568.69 feet, above sea level, respectively. In the Anderdon quarry, upon the Canadian side to the eastward, the foreman, Patrick Hancock, in 1907, reported the dip of the beds as 6 feet to the hundred and about S. 23° W. in direction.

Recurring to the geological equivalency of the Monroe formation, it is believed by Grabau that only the three younger members of the Upper Monroe are represented in eastern New York by the Manlius, Rondout, Cobleskill and Rosendale formations. In western New York, the representation is still more meager, only the Amherstburg and Anderdon being correlated with the Akron and Bertie dolomites. A rather full discussion of these correlations and description of the fossils of the Monroe will be found in the bulletin cited in foot note 49. To this same report also may be referred the reader interested in the lithological and structural details of the various divisions of the Monroe. In the 1908 report previously cited (foot note 37), Lane refers to the Upper Monroe, or Detroit River series, as "Eo-Devonian" implying a very close relationship with the Devonian as indicated by the remarkable fauna of the Anderdon and Amherstburg strata. To account for these forms it is necessary to assume that a Devonian fauna had already developed, probably to the northward, and migrated into southeastern Michigan before Silurian conditions had been entirely effaced, an arm from the Cordilleran sea giving temporary communication with the interior basin. These forms began to arrive in the Flat Rock, reached their culmination in the Anderdon during the existence of normal marine conditions and some of them continued to exist side by side in the Lucas with typical Siluric forms from the North Atlantic.

Salina formation. Originally known in the New York series as the "Onondaga Salt Group," this formation is now very generally referred to as the *Salina*, on account of its large content of salt, either in the form of rock salt, or in solution as brine. In southeastern Michigan, it consists of alternating layers of compact, brown to drab dolomite; anhydrite, more or less converted into gypsum and pure to impure strata of rock salt. In the deep well at Royal Oak (Oakland County), there is indicated the surprising development of 932 feet of this formation, of which 609 feet are reported as salt. Along Detroit River, the thickness is considerable, although less and diminishes gradually to the southward. With the disappearance of the beds of rock salt in the Church and Company wells, just north of Trenton, there is no means of distinguishing the Salina dolomites from those of the overlying Monroe in the well records to the south. In the Ohio scale, the formation is not now recognized as was originally done by Newberry.[58]

The wells of the Solvay Process Company, near Detroit, furnish a thickness of 709 to 748 feet, and an average of 732 feet, but with no certain knowledge that the entire series was penetrated.

58. Newberry, Report of the Geological Survey of Ohio, vol. I, 1873, p. 132.
Orton, Report of the Geological Survey of Ohio, vol. VI, 1888, p. 15.
Prosser, Geological Survey of Ohio, Bulletin No. 7, 1905, p. 3.

Similarly at the Oakwood salt shaft, the preliminary test well showed 792 feet that should be referred to the Salina. The shaft itself has thus far penetrated but 150 feet of the series and with the drill cores of the preliminary test well, gives us the first definite information relative to the stratigraphy of this portion of the formation. The revelations of this difficult and expensive piece of engineering are of such geological interest and of such economic importance that a description and complete log of the shaft will be given upon a subsequent page of this report. Reference to this log shows a succession of dolomites, salt and a mixture of these two materials, in some instances the dolomitic slime simply clouding the salt, in other cases with only a few disconnected crystals of salt embedded in the dolomitic matrix. Exposed to the weather upon the dump, the salt is soon dissolved and a honey-combed mass of brown or drab dolomite remains. Thin seams of greenish shale occur at certain horizons, becoming black and carbonaceous at times. Whereas the Monroe beds are characterized by heavy flows of water highly charged with hydrogen sulphide, the Salina is absolutely free from such flows and the tunnels radiating from the shaft are almost dusty. What are believed to be marketable strata of salt give a total of 454 feet, the heaviest bed having the enormous thickness of 369 feet. When entered, it will probably be found that this bed is really divided into two, or more, by thin layers of dolomite, as seen in a number of the Solvay wells. Careful search of the rock fragments brought up from the shaft failed to reveal any trace of fossils, plant or animal.

Passing southward from the Detroit region the deep well of the River Rouge Improvement Company, shows, at least, 723 feet of Salina, of which 378 feet are rock salt. At the bottom of the series, two beds, 120 feet and 78 feet in thickness respectively, are separated by 15 feet of a salty shale. Just above lie 125 feet of what is described by the driller also as "salt shale." The well record of the Eureka Iron Company at Wyandotte is interpreted by Lane as showing some 770 feet of Salina, but with the salt strata aggregating only 160 feet. The lowest bed of the series has a thickness of 110 feet and is the correlative, presumably, of the very heavy bed to the north. Here it is underlain by 310 feet of strata also referred to the same formation before the Niagara is reached. If this reference is correct, the heavy salt bed lies near the middle of the series and the wells in the vicinity of Detroit give only partial sections of the Salina formation, although there is, as yet, no means of knowing how rapidly these lower beds may vary in thickness to the northward. The series of six wells of the Church and Company, just north of Trenton, enable us apparently to mark the southern limit of the rock salt in southeastern Michigan. The four wells numbered 1, 3, 4 and 6 lie in an east-west line and show but a single salt stratum 26 feet, 25 feet, 30 feet and 33 feet, respectively, in thickness. Well No. 2 lies 300 feet due south of No. 1 and gives but two feet of salt, while No. 5 lying 1350 feet to the southwest of No. 1 gave no rock salt whatever. Well No. 4 gives 650 feet for the entire Salina; gypsum (probably anhydrite) very largely replacing the salt.

The frequent association of calcium and magnesium carbonate, calcium sulphate and the strong bitter brines with rock salt, as in the region just described, gave rise more than a century ago to the theory that they must all have originated from the evaporation, under arid conditions, of detached arms of the sea. To account, however, for such extensive beds of salt, gypsum and dolomite demanded depths for these inland seas which overtaxed ones belief. Furthermore, the deposits alternated in succession and were often interstratified with shale and sandstone, so that the simple evaporation of such a sea could furnish no adequate explanation. Laboratory experiments have shown that, when sea water is evaporated, there are first thrown down the calcium carbonate ($CaCO_3$) and hydrous oxide of iron (2 $Fe_2O_3+3\ H_2O$; next about 84% of the calcium sulphate ($CaSO_4$) in solution. There is next precipitated upon further concentration about 54% of the salt (NaCl) along with the balance of the calcium sulphate, followed by 8.5% of salt free from this sulphate. The remaining salt with the more soluble compounds of magnesium, potassium, bromine and iodine, finally crystallized in various combinations, or constituted the *bittern* in case evaporation was not complete. As pointed out by Hubbard (foot note 60), when such simple concentration of an inland sea takes place, the bottom and sides would be coated with calcium carbonate, more or less stained with iron, upon which would be deposited a layer of gypsum or anhydrite. The concentrated brine would shrink to the deeper portions of the basin and there be precipitated along with more gypsum, the final salt layers being practically pure. If the evaporation were not completed the bittern, or "mother liquor," would remain as a concentrated mineral water, to be incorporated into subsequent deposits. To account for a succession of the above series, for irregularities and for shale and sandstone, it has been supposed that influxes of the sea took place, as during storm, or exceptionally high tides, bringing in fresh supplies of sea water and incidentally mud and sand.[59] The enormous thickness of any single deposit, however can not be so explained.

In 1877 Ochsenius proposed a modification of this theory by assuming a basin of sufficient depth which continuously maintained its connection with the adjacent ocean, the water of the basin evaporating and allowing a constant inflow of sea water. The concentrated surface layers will sink, encountering layers differently charged and giving rise to the deposition of various compounds, chiefly salt and gypsum. Given sufficient time, a basin of sufficient original depth or in process of slow subsidence, the continuance of uniform conditions and an extensive bed of any of the above substances might take place. This is the theory accepted by Hubbard as explaining most satisfactorily the Salina series of Michigan.[60] Grabau has recently pointed out that according to this theory there should be found abundant remains of marine organisms in the strata enclosing the salt, and it would seem, even in the salt itself. The constant influx of sea water would sweep in countless forms whose remains would settle to the bottom, whether or not they had been able to maintain themselves alive for any considerable time in the water undergoing concentration. It has already been pointed out that the Salina strata are practically barren of fossils. Grabau further calls attention to the absence of marine strata, outside of the Salina area of Michigan, Ontario and New York, which might be regarded as contemporary with the salt and gypsum strata.[61] The complete absence of such strata, this author convincingly argues, indicates a land-locked basin, or series of such in which the Salina beds are to be laid down. Widespread desert conditions with intermittent streams; long continued erosion of pre-Salina strata containing imprisoned sea-salts; the solution, transportation and final concentration of these salts in the various basins, he believes most satisfactorily explains all the phenomena of the Salina. From computations, this author concludes that the erosion of 400 feet of Niagara limestone from Minnesota, Wisconsin, the upper Great Lake region and western Ontario would be sufficient to yield 100 feet of pure rock salt distributed over an area of 25,000 square miles.

The very general absence of fossils makes it rather difficult to account for the dolomitic strata which make up the bulk of this series and the Lower Monroe as well. Some of this may have

59. See Winchell, Geological Studies, 1886, p. 186.
60. Hubbard, Geological Survey of Michigan, vol. V, part II, 1895, p. IX.
61. Grabau, Physical and Faunal Evolution of North America during Ordovicic, Siluric and Early Devonic Time: Journal of Geology, vol. XVII, 1909, p. 245. See also The Monroe Formation: Michigan Geological and Biological Survey, 1910, p. 226.

been originally deposited as dolomitic slime resulting from the destruction of earlier dolomitic strata, but the fact that the oölitic particles and brachiopods were certainly transformed from calcium carbonate into the calcium-magnesium carbonate, known as dolomite, makes it appear that the alteration was possible in the sea itself or subsequently. In the process of dolomitization, there is a theoretical shrinkage of 13.3 per cent. but most of the Monroe and Salina dolomites of this region are exceedingly compact, indicating that the conversion took place either just before or at the time of deposition of the slime. The theory which best explains the various facts observed in this locality is that much of the dolomite resulted from the alteration of chemically precipitated calcium carbonate, this change occurring at the time of deposition. The unusual conditions which permitted this change were attained in the land-locked basins of Monroe and Salina time. During Anderdon time (Upper Monroe), normal marine conditions seem to have prevailed and the organisms furnished the great bulk of the calcium carbonate that was then deposited over the sea bottom. There occurs one very compact stratum, however, in the Sibley and Anderdon quarries, in which fossils are absent, the rock delicately laminated and which furnished an analysis of 100 per cent calcium carbonate. It seems quite probable that this stratum was chemically precipitated from the sea water directly from the breaking down of the very unstable calcium bicarbonate ($CaH_2C_2O_6$), a change now known to be taking place at the present time in connection with some of the Florida keys.

Niagara formation. This formation, named and well known because of the role which it plays in the production of the celebrated cataract, is penetrated in the deeper wells of southeastern Michigan. The log of the deep Wyandotte well shows some 360 feet of "limestone," underlain by 10 feet of "slate," which are referred by Lane to the Niagara. The so-called limestone is in reality a dolomite; compact, fine grained, light colored and hard. In color, it is thus in contrast with the drab colored dolomites of the Salina series and is not interrupted with seams of shale, salt or gypsum. There is but little content of argillaceous matter, suggesting the absence of ordinary sediment while it was forming and permitting the inference of Lane that the arid conditions of Salina time had already made their appearance.[62] This inference relative to the climate receives confirmation from the very low percentage of iron present in the rock, the occasional presence of apparently wind-

62. Annual Report for 1908, p. 57. Also vol. V, pt. II, p. 29.

blown sand grains and the fact that the strata are overlain by the salt and gypsum deposits of the Lower Monroe.

In Ohio the Niagara formation is known in outcrop, giving an opportunity for the study of its characteristic fossils and its subdivision.[63] Four groups of strata are there recognized; a sandstone, two series of dolomites and a basal shale layer. The sandstone (Hillsboro) has no representative in Michigan but the Guelph—from the typical locality in Ontario—maintains a development of some 200 feet across Ohio to the northward. Beneath the Guelph, lies the so-called "Niagara limestone," or Lockport, an even-bedded, blue to drab dolomite which is best developed in southern Ohio and thins out and is unrecognizable toward the north, even in its outcrop. For this reason, as well as from its color, it seems probable that the Michigan representative is the Guelph. The lowest member of the series is the Niagara shale, a mass of light-colored clays with numerous calcareous bands, showing a thickness of 100 feet in southern Ohio, but thinning towards the north to but a few feet, or being entirely absent. In the Wyandotte well, this division of the Niagara is represented by 10 feet of "slate." There is reason for believing that the dolomitic member, or members, of the Niagara underlie the entire Lower Peninsula and that it will be reached in all wells that penetrate its horizon. Its outcrop in Michigan is seen only along the northern border of lakes Michigan and Huron, in the southern margin of the Upper Peninsula, where at a few localities it is utilized in the manufacture of lime. Unusually fine exposures occur upon Drummonds Island, affording a choice series of fossils, especially corals. Rominger made the fullest study of the group in this northern locality and recognized three divisions, all dolomitic except a few thin layers, or irregular patches of limestone.[64] The uppermost division consists of a series of thin, uneven layers, carrying seams and nodules of chert, and containing the greatest abundance of fossils. The middle division consists of massive, highly crystalline ledges with casts or poorly preserved fossils. The lowest division shows fossils but rarely, is very regular and even-bedded, but composed of thin layers of fine, crystalline grains. This author expresses no opinion as to the approximate total thickness of the group. The logs of two deep wells at St. Ignace are now available giving two complete sections of the formation.[65] In the older of the two, there is shown 300 feet of Niagara (depth 504 to 804 feet) and in the second, which lies about two miles north, a thickness of 510 feet (depth 510 to 1020 feet). Rominger published the analyses of 10 specimens of the Niagara dolomite, showing a range of 52 to 62% of calcium carbonate, 32 to 43% of magnesium carbonate, 1 to 3% of alumina and iron and 1 to 9% of insoluble residue (*loc. cit.*, p. 48). In the limestone layers, the calcium carbonate ran as high as 95%, indicating a true limestone.

63. Orton, Geological Survey of Ohio, vol. VI, 1888, p. 13.
64. Rominger, Geological Survey of Michigan, vol. I, pt. III, 1873, p. 37.
65. See vol. V, Geological Survey of Michigan, 1895, pl. LXIII. Annual Report for 1901 p. 228.

DEEPER BEDS REACHED BY BORINGS.

Beneath the Niagara formation and between it and the much sought for Trenton limestone, there intervene approximately 600 feet of sedimentary strata, mostly shale, with some sand. These layers are believed to represent in part the Clinton and Medina formations, often highly stained with iron and belonging to the Silurian System. In the Wyandotte well, which alone furnishes a section of these strata in Wayne County, it is difficult to draw any line of division between them. Beneath these lie the Hudson River and Utica shales, grayish to bluish, more or less dolomitic, or calcareous, and passing below into black. These two, with the underlying Trenton, represent the Ordovician System in Michigan. Along with the Clinton and Medina they are only imperfectly known in outcrop in the Upper Peninsula, skirting on the northward the belt of Niagara. Over the Lower Peninsula they are deeply buried and reached only in the deeper wells along the northern and southern portions, outcropping again in southern Ohio. Southward the carbonates become more prominent than in Michigan, indicating their formation under off-shore conditions. The entire series indicates a shallowing of the Palaeozoic sea in this region, and an increase in the erosion of neighboring land areas and consequent sedimentation, an intermediate stage between the open sea conditions of Trenton and Niagara time. For a fuller discussion of these strata in Michigan, the reader is referred to recent papers in the Report of the State Board of Geological Survey of Michigan for the year 1908, pp. 23 to 105.

Notes on the Geological Section of Michigan for geologists, teachers and drillers.

Part I. The Preordovician, by A. C. Lane and A. E. Seaman, p. 23.

Part II. From the St. Peters up, by A. C. Lane, p. 43.

CHAPTER VII.

WATER RESOURCES.

Rapid increase in the density of population of any section makes the problem of a wholesome and sufficient water supply more and more difficult of solution. This difficulty arises not only from the relatively greater consumption but from complicated factors connected with its distribution, disposal of sewage, protection from fire, etc. To supply with water the army of people making up the population of Wayne County, nearly one-fifth of that of the entire state, there are four chief sources available:

1. Surface waters: streams, lakes, ponds, reservoirs and cisterns.
2. Waters from former lake and river deposits.
3. Waters from deposits of the ancient ice sheets.
4. Waters from the bedrock.

As generally understood, the source of all these waters is the atmosphere, from which the moisture is condensed and precipitated as rain, snow, hail, etc. However, when subjected to various conditions after precipitation, the waters become essentially different and typical samples from each source may generally be readily distinguished.

SURFACE WATERS.

Reservoirs and cisterns. From data obtained from Prof. M. E. Cooley, of the University of Michigan, Lane calculated that 38% of the total precipitation of a region may be collected from roofs and secured in cisterns and that with a rainfall of 32 inches, practically the same as that of Detroit, every 100 square feet of horizontal surface may yield 100 cubic feet of water annually, or about 25 barrels.[1] This is but a little over one-third of what actually falls upon the area, the remainder being lost in wetting the roof, evaporation, overflow during heavy rains, blowing or sliding of snow, etc. Where limited quantities of practically pure water are desired, simple precautions would enable one to secure a greater

1. Water-Supply and Irrigation Paper No. 30, 1899, p. 45.

yield. In addition to the dust, coal dirt and organic matter derived from the collecting surface and also from the atmosphere as well, this water contains appreciable quantities of ammonia, nitric and nitrous acid, sulphuric and sulphurous acid, nitrites, nitrates and sulphates, along with carbon dioxide and other gases of the atmosphere. For the laundry, and in some cases for full domestic use, this type of water is collected in cisterns or tanks and utilized. Where wells are especially difficult to obtain, these artificial reservoirs are connected with the barn and used in watering stock. Excavations in the old lake clays for the manufacture of brick serve as collecting basins for surface water and supply the necessary water for the softening of the stiff clays. These and other excavations made directly for the purpose often serve as ponds for ducks and geese.

Ponds and lakes. In striking contrast with Oakland to the north and Washtenaw to the west, the county of Wayne is surprisingly deficient in ponds and lakes. Aside from the small bayous found upon the river flats, the only natural lakelet in the county lies one mile east of Northville (Sec. 2, Northville township) and is known locally as Yerkes Lake (Pl. XXVI). It has a maximum diameter of about 1100 feet and is drained at higher stages than at present by a small stream into the Middle Rouge. Occupying a depression between the morainic knolls of the region, it receives considerable surface drainage and is said also to be fed with springs and to be well stocked with fish. Owing to its slight elevation (below 800 feet), it had to be rejected as the source of supply for the village of Northville.

A small artificial lakelet for ornamental purposes is maintained at Eloise, an excavation having been made into the glacial clay and supplied with water which is piped from the Rouge flats to the north. Although so poorly supplied with inland lakes, Wayne County reaches Lake St. Clair upon the north and extends to Lake Erie upon the south. The water of Lake St. Clair is utilized to a greater or less extent by the residents of Grosse Point township. Many of those who adjoin the lake, pump the water direct by means of windmills and distribute it over their grounds from elevated storage tanks. Drinking water is ordinarily derived from wells into the drift, or exceptionally from the bedrock. The village of Grosse Point Farms is supplied with water from the lake drawn at a point about 1¾ miles from the shore, this distance being necessitated by the shallow condition of the lake. The water flows by gravity into a settling basin from which it is pumped direct.[2]

Surface streams. Aside from Detroit River, the surface streams of the county are utilized to but a slight extent as a source of water, except for the watering of stock and sprinkling of small truck farms. The very irregular flow of the Rouge and its usual turbid condition have prevented its utilization as a water resource. At Dearborn, the Arno Mills use the water of the Lower Branch in their dyeing business and the main branch for a time furnished water for the boilers in the power plant of the Detroit, Ypsilanti, Ann Arbor and Jackson Railway. At Eloise, the Rouge water is used for the boilers of the Wayne County House, for sprinkling, in flushing the sewers, etc. It was originally pumped direct from the Lower Rouge but is now obtained from the flats of the Middle Rouge near Perrinsville, 3¾ miles distant. A well 35 feet in diameter and 18 feet deep has been constructed (1902), which receives the flow from the river along with surface drainage and the latter necessitates a filtering plant at Eloise. The composition of the water of the Middle Rouge is shown in the following table, the analysis having been made by L. M. Gelston, then Assistant Director of the University of Michigan Laboratory of Hygiene, Ann Arbor.

TABLE XLV. ANALYSIS OF WATER FROM MIDDLE RIVER ROUGE.

(Parts per million).

Inorganic matter	732	Free ammonia	0.133
Organic matter	96	Albuminoid ammonia	.124
Chlorine	37	Total residue by evaporation	828.
Potassium	1.5		

Reaction neutral. Algae, protozoa, and bacteria present.

In a suit brought against the infirmary in 1898 for the pollution of the Lower Rouge, the following analyses were made by Prof. J. E. Clark, M. D., of the Detroit College of Medicine. It was then legally decided that the Rouge was being seriously contaminated, and the institution was required to put in settling basins for its sewage. A series of such basins is now in use, the sewage being treated with alum and lime and then filtered through gravel.

2. Statistics relative to the various village and city water supplies of Wayne County, as well as the water powers, were collected by the writer and published in Water-Supply and Irrigation Paper No. 182, 1906, which the reader may obtain by application to the United States Geological Survey, Washington, D. C.

TABLE XLVI. ANALYSES OF WATER FROM LOWER BRANCH RIVER ROUGE SHOWING CONTAMINATION.

(Parts per million).

	Above sewer.	From sewer.	250 to 300 ft. below sewer.
Inorganic	280	740	720
Organic matter	150	380	370
Chlorine	5	105	95
Free ammonia	.302	48.8	1.512
Albuminoid ammonia..	.366	32.58	1.44
Total solids	430	1,120	1,090
Bacteria	10,900	325,000	12,500

The table is of especial interest, since it shows the normal condition of the stream water as well as those substances indicating serious sewage contamination. The amount of chlorine, combined to form common salt, has been increased 19 fold, while the ammonia has not risen in proportion to the amount actually present in the sewage itself. A complete analysis of the water would have shown that much of this had been oxidized into nitrites and nitrates, which, along with the chlorine, furnish an index to the probable amount of sewage contamination. A comparison of the amount of inorganic matter in the waters of the Middle and Lower branches shows that the former is considerably harder, due undoubtedly to the fact that it is more abundantly fed by springs along its course.

Aside from the incidental use by the farmers along its course, the water of the Huron is utilized only at one place—French Landing, for the disposition of the garbage collected from the city of Detroit. Before entering the county, it has already received the sewage from Ann Arbor and Ypsilanti, with a combined population of 21,047. Owing to the rapid and tortuous course of the river, it is likely that this contamination is rendered harmless before entering the county, although none of the villages have thus far cared to utilize this supply. The following analysis of the Huron water has been very kindly supplied by Mr. Roy W. Pryer, of the Hygienic Laboratory of the University of Michigan.

TABLE XLVII. ANALYSIS OF HURON RIVER WATER.

Sample taken at Ann Arbor, Mich., June 22, 1911.

Analyst Roy W. Pryer, Ann Arbor, July, 1911.

(*Parts per million*).

Color	slight yellow.
Odor	fishy.
Reaction	alkaline.
Hardness	162.8
Total solids	390
Loss on Ignition	192
Inorganic residue	198
Of this	
Sodium chloride (NaCl)	15
Calcium sulphate ($CaSO_4$)	72.3
Calcium carbonate ($CaCO_3$)	41.3
Magnesium carbonate ($MgCO_3$)	69.4
Parts potassium permanganate reduced by organic matter	16.95
Free ammonia (as NH_3)	.25
Albuminoid ammonia (as NH_3)	.38
Nitrates as N_2O_5	.2
Nitrites as N_2O_3	.01

Water powers have been developed for grinding purposes at certain favorable points along the Middle and North branches of the Rouge and along the Huron. Owing to the irregular flow and great reduction during the summer months, the water power must be supplemented with steam, or the turbines operated but a portion of the time. The heavy floods in the spring, often with the help of the ice, occasionally lead to the destruction of the dams. Both of these difficulties will be obviated by establishing great storage reservoirs by which the surplus water may be held back and dealt out as needed.

At the Yerkes Flouring Mill, upon the Middle Rouge, at Northville, there is a head of 16 feet and an available horse power of 40. The Argo Mills at the same place have 12 feet head and 20 horse power available. Upon the same stream at Plymouth, there are also two mills in operation, the Phoenix and Plymouth mills, each with a head of about 16 feet and developing 80 and 45 horse power respectively. Between Northville and Plymouth, at Waterford, there is an abandoned mill and power. At Pikes Peak, the Nan-

kin Mills have secured a fall of 14 feet and have developed 53 horse power, available the year around except during very dry, or very cold periods. Upon the North Branch of the Rouge, two powers have been developed—the Du Bois Mills, near Redford, with an 8-foot head and 42 horse power and the Dearborn Mills, north of the village, having 9 feet of head and 44 horse power available. Under favoring conditions, there is thus being utilized some 324 horse power in connection with these two branches of the Rouge. Higher and stronger dams, and more of them would pond the water more effectually, increase the head, regulate the flow and greatly increase the available power. The system of storage reservoirs, planned for the Huron can not be so successfully applied to the Rouge because of the absence of the natural basins.

From Rawsonville to Lake Erie the fall in the Huron is about 71 feet, or measured along the valley, at the average rate of about 2.9 feet to the mile. With high banks favorable for ponding and with an average mean flow of 670 cubic feet per second, this means that much energy is going to waste within the limits of the county. If converted into electrical energy it could readily be delivered and utilized in the city of Detroit. At four places only have powers been developed for milling purposes—Flat Rock, New Boston, Belleville and Rawsonville. The last of these had a head of 7 feet and furnished a horse power varying from 150 to 175, but the dam was destroyed in 1899, has not been restored and the mill is abandoned. The dam at Belleville was built in 1836 and held for nearly 60 years, but finally gave way. The new dam gives an 8-foot head, creates a reservoir of 25 acres and yields 400 horse power. One-half mile up from New Boston is located the New Boston Flouring Mills, with 6-foot head and 125 horse power available. At Flat Rock the head is 8 feet and the power about 100, at ordinary stages of the water. Of the 71 feet of fall theoretically present, there is thus utilized but 22 feet and only a small percentage of the actual horse power.

Over nine-tenths of the entire population of Wayne County derive their entire water supply from Detroit River, naturally one of the most magnificent streams of potable water in the world, when volume, purity, temperature and constancy of flow are considered. Opposite the city of Detroit, the breadth is 2200 feet, the average depth 37 to 38 feet and there is maintained a rather constant velocity of two miles per hour. With the level of Lake Erie at its normal, it is calculated by the U. S. Engineers that there flow by Ft. Wayne, in the western part of the city, 209,900 cubic feet each second. In the American channel, opposite Belle Isle, the maximum velocity is 2½ miles an hour, and the average somewhat less than 2 miles. During July and August, 1897, detailed measurements of the flow were made by Clarence W. Hubbell, engineer of the Detroit waterworks. Float methods gave an average flow of 65,000 cubic feet a second and current meters one of 53,000 cubic feet for this channel. When the channel is covered with ice and the Canadian channel is open, the flow is reduced to 36,000 cubic feet a second. The temperature of the water ranges from 32° to 70° F., and the greatest vertical range between the top and bottom has never been observed to exceed one-half degree. Between shore and midstream, the temperature of the water may vary as much as 8° or 9°, and this fact may be used to detect possible contamination from tributary streams. Lake St. Clair, which extends practically to the city, has served for many centuries as a great settling basin, as is evidenced by its shallow condition and the delta at its head. The turbidity of the water is low, except immediately following storms, when the bottom of Lake St. Clair becomes more or less disturbed and the tributaries bring in sediment. The following analyses, made some eight years apart, are of interest in showing the nature and amount of mineral matter contained in this water. The total solids is thus seen to be small, well adapting the water to use in various manufacturing plants, a matter of great importance to such a rapidily growing city.

TABLE XLVIII. MINERAL ANALYSES OF DETROIT RIVER WATER.

(Parts per million).

Calcium (Ca)	[3]24.610	[4]23.800
Magnesium (Mg)	7.440	5.400
Aluminum (Al)	1.800	.....
Iron (Fe)	Trace	.....
Alumina (Al_2O_3) and Ferric oxide (Fe_2O_3)		11.100
Sodium (Na)	2.760	2.910
Potassium (K)	Trace	0.0576
Chlorine (Cl)	2.990	4.550
Silica (SiO_2)	1.590	7.500
Carbonate radical (CO_3)	50.850	CO_2 30.120
Sulphate radical (SO_4)	7.620	8.630
Organic and volatile matter	36.390	38.540
Total mineral matter	101.240	Total solids....109.640

3. Twenty-first Annual Report of the Michigan Board of Health, 1902, p. 63. (Recomputed to ionic form by the United States Geological Survey.)
4. Twenty-eighth Annual Report of the Board of Health of the City of Detroit, 1909, p. 97. For other analyses see Lane, Lower Michigan Mineral Waters: Water-Supply and Irrigation Paper No. 31, 1899, pp. 18 and 19.

The city of Detroit, with its population of 465,766 souls (1910) and area of approximately 42 square miles, is supplied with this water from a single pumping station, believed to be the largest in the world. This station is located in the extreme eastern part of the city, opposite Belle Isle, and the water is taken from the head of the island through a tunnel of recent construction.[5] In addition to the city itself, this station also supplies water to the suburban villages of Hamtramck (population 3,559), Highland Park (4,120), River Rouge (4,163) and Oakwood (781); with a combined population of 12,623. This water is all metered and double the city rates are charged. With the system of direct pressure, it has been found impracticable to force the water to all parts of the city, portions of which are 60 to 70 feet above the river, and to the upper floors of the taller buildings. Accordingly, in 1898, a double system was installed each with its own set of pumps and mains, one operated under low and the other under high pressure. However, buildings over five stories high are provided with their own private pumps.

Although naturally of most excellent quality, this abundant water supply is subject to more or less contamination from surface drainage. Not far from 400,000 people reside in the St. Clair drainage basin between Detroit and Port Huron. There are many truck farms, rich in compost, the drainage from which in the early spring and after heavy rains is a menace to the city's health. Prof. Gardner S. Williams, lately of the University of Michigan, has demonstrated that the dredging of the delta of Black River, Port Huron, by the United States Government in 1892 was responsible for the outbreak of typhoid in Detroit during June of that year.[6] Compared with many other cities, the city of Detroit has a very low death rate from this disease, averaging during the past five years 87 deaths or from 4 to 5 deaths for each thousand inhabitants. In view of this low rate, there is little reason to suspect that the germs are ordinarily derived from the river, although there is the possibility that they may be at any time. A number of local outbreaks during the past two years have been traced to the milk supply, the contamination occurring in the dairies and, undoubtedly, numerous cases each summer are contracted outside,

5. Detailed data relative to the Detroit Water Works will be found in the annual reports of the Detroit Water Board. An interesting article appeared in the Engineering Record, vol. 47, No. 25, 1903, p. 650, by Clarence W. Hubbell. See also Water-Supply and Irrigation Paper, No. 182, 1906, p. 53.
6. Williams, Typhoid Fever and the Water Supply of Detroit: Proceedings of the Sanitary Convention, Detroit, 1897, p. 90.

TABLE XLIX.—SANITARY ANALYSES OF DETROIT RIVER WATER.

(Parts per million.)

	July, 1901.	August, 1901.	Sept., 1901.	Oct., 1901.	Nov., 1901.	Dec., 1901.	Jan., 1902.	Feb., 1902.	March, 1902.	April, 1902.	May, 1902.	June, 1902.
Appearance	C.	C.	C.	C.	C.	C.	C.	N. C.	N. C.	S. T.	S. T.	N. C.
Total Solids	108.4	104.2	103.0	111.0	104.0	111.0	106.2	115.0	116.4	116.0	118.2	112.0
Volatile matter	41.4	36.4	44.4	41.8	34.8	41.6	39.6	39.0	36.8	39.0	40.0	40.0
Non-volatile matter	67.0	67.8	58.6	69.2	69.2	69.4	66.6	76.0	79.6	77.0	78.2	72.0
Free ammonia	.008	.006	.020	.016	.024	.012	.026	.028	.024	.016	.022	.020
Albuminoid ammonia	.074	.080	.126	.116	.092	.102	.082	.086	.092	.086	.082	.118
Nitrogen as nitrates	.115	.082	.164	.210	.099	.198	.230	.148	.115	.164	.198	.165
Nitrogen as nitrites	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Chlorine	2.80	2.90	2.60	2.80	2.70	3.15	2.70	3.15	2.50	2.75	3.10	2.70
Oxygen absorbed in 15 minutes	.40	.32	.44	.48	.44	.48	.40	.36	.44	.40	.32	.28
Oxygen absorbed in 4 hours	.76	.72	.88	.96	.84	.72	.76	.84	.88	.80	.84	.88
Bacteria per cubic centimeter	98	106	37	37	103	104	87	124	170	105	31	398
Bacteria per cubic centimeter	43	84	98	104	170	199	132	353	105	190	48	34
Bacteria per cubic centimeter	116	192	160	82	89	265	26	197	266	235	66	140
Bacteria per cubic centimeter	62	47	52	206	204	99	204	402	333	302	115	69
Growth in .2 per ct. carbolic-acid gelatin	None.	None.	None.	None.	None.	None.	None.	None.	None.	None.	None.	None.

C.—Clear. N. C.—Nearly Clear. S. T.—Slightly Turbid.

and imported into the city. The officials of the city Board of Health are fully awake to the danger and are doing all in their power to guard the public health, making frequent sanitary analyses of the river water and each year recommending strongly the establishment of a municipal filtering plant. The preceding analyses, taken from their Twenty-first Annual Report, 1902, are of interest as showing the monthly variations in the character of the water.

Below Detroit, the city of Wyandotte and the villages of Ford and Trenton also draw their water supply from the river by separate pumping plants. Upon Grosse Isle, this water is also pumped by means of wind mills into storage tanks, from which it is distributed by gravity. Since practically all the water pumped by the Detroit plant finds its way sooner or later into the river again as sewage, or surface drainage, this means that some 85,000,000 gallons of polluted water are returned daily. If we assume that 50% of the rainfall, after collecting the filth from the roofs, streets, walks and gutters, also reaches the river, we have some 22,000,000 of gallons as a daily average from this source. The Canadian towns opposite Detroit—Walkerville, Windsor and Sandwich, with a combined population of some 20,000, contribute to the river some 6,000,000 additional gallons of sewage. The grand total of this unsavory beverage gives about 17.5 cubic feet a second, or about one gallon for every 12,000, on the supposition that it is evenly distributed. However, the Detroit drainage hugs the western bank from the mouth of the sewers to the intake pipes and in five to six hours the contents of Detroit sewers may be delivered to unsuspecting victims farther down the river. This gives insufficient time for the process of oxidation to complete its work of purification of organic refuse and bring about the death of the disease germs. Then, too, it must be remembered that it is not a matter of the *quantity* of contaminating material, but rather of its *quality* and that Detroit has upon an average some 1000 to 1500 cases of typhoid annually. Below Wyandotte the conditions are still more serious as further pollution has occurred from its sewers and the water is confined in the relatively narrow western channel. One resident of the region informed the writer that he was cured of wanting to drink this water by observing the nature of the spray tossed upon the deck of a motor boat in which he was riding. Another had noted the appearance of the water when seen through thin, clear ice in the winter.

The question of water supply for the lower Detroit River section is one for the trained engineers to settle. To the geologist, several solutions are in sight—a municipal filtering plant for each, or a single one for all; the extension of the Detroit mains to Trenton; the use of deep wells such as that upon Grosse Isle for household use, the river water still being used for manufacturing, laundry, fire and lawn purposes. In the Free Press of June 11, 1911, the suggestion of Richard P. Joy is worth consideration by those interested. This involves the construction of a canal, or aqueduct, from Port Huron to Lake Erie which would furnish the entire series of cities and villages with a wholesome and adequate water supply, well adapted to the various uses. Until some feasible plan can be devised, it is the height of wisdom for all people using the river water to either boil, or thoroughly filter, all water used for drinking, or that in any way comes in contact with food or utensils used in its preparation or serving.

That the people of this region are being aroused to the seriousness of the matter is indicated by the demand for bottled spring waters, two varieties of which are now available. One is shipped in from Rochester, Michigan, and is delivered for 10 cents a gallon; the other is known as "Maple Spring Water," from a bored well upon the place of J. H. Vreeland, NW. 1/4 NE. 1/4, sec. 12, Monguagon township. The well is 65 feet deep, entering rock some 5 feet, and flowed up to about one year ago; ceasing, the owner thinks, owing to the great amount of drainage at the Livingstone cut or Sibley quarry. The water contains some gas when first pumped, either carbon or sulphur dioxide, which is allowed to escape when it is bottled and delivered to customers for 5 cents a gallon.

WATERS FROM LACUSTRINE AND RIVER DEPOSITS.

In Chapter III of this report, there has been described a series of beaches, terraces and river deltas formed during the closing stages of the Glacial Epoch as the result of wind, wave and stream action. These consist of hillocks of sand, or gravel and sand, attaining a thickness of 25 to 30 feet, resting upon the underlying clay. At times, the deposit is of the nature of a thin sheet which serves as a veneering over the glacial clay and often covering many square miles of territory. These loose, unconsolidated deposits are very porous, 30% of their volume sometimes being pore space, and readily absorb a large percentage of the rainfall unless the ground is frozen or covered with snow or ice. With a precipitation of 32 inches and a run-off of 25% there would be an average daily absorption of 132,210 cubic feet over every square mile, or nearly 1,000,000 gallons. This sinks until stopped by the

impervious clay beneath where it is either held in depressions, or slowly works its way along the slope of the clay surface.

Shallow wells. The absorption of this vast amount of water often takes place faster than it can escape and the level of the groundwater rises and often lies quite near the surface, easily reached by shallow wells, ranging from 5 or 6 feet to 20 or 25 feet, a very common depth being 10 to 15 feet. From the way in which this water is held, it is obvious that it would possess no "head." As a rule, these wells are dug, although sometimes driven, and cased with barrels, planks, brick, stone or crocks. The water is obtained usually either by suction or chain pumps, the wind mill being occasionally used. In some cases the bucket, with chain, rope or pole, is used for dipping up the water; even the old-fashioned sweep being occasionally seen. It is not ordinarily necessary to strike clay in sinking the well, unless the supply is scant, when an excavation into the clay becomes desirable. Generally the supply is reported to be sufficient for domestic purposes, and is often abundant. It, however, fluctuates with the season and after prolonged drought may entirely fail. In sinking wells it is desirable to reach the level of ground water at the time of a prolonged dry season in order to secure a permanent yield. The principle involved is shown in the accompanying figure.

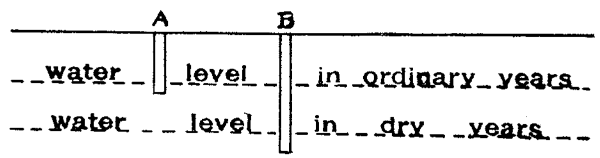


Fig. 17. Diagram showing relation between depth and permanence of wells. A. Well sunk to ordinary water level, but failing in times of drought. B. Well sunk to level of water in dry years and never failing (From U. S. Geological Survey Water-Supply Paper No. 255).

In one-third of the wells from which data were procured, the owners report the water as "soft" and suitable for laundry use, no cisterns being required. This indicates that but little calcium or magnesium carbonate has been dissolved from the sand or gravel because of the absence of these materials originally, because they have been leached out or more probably, because the water has not had time to get these substances into solution. In the remaining two-thirds of the wells, the water was pronounced "hard," particularly those which approach or reach the clay. In a few instances, the water was reported to have changed from soft to hard, or *vice versa.* Other mineral ingredients, so commonly present in other types of well water, are either absent or only very sparingly present. The temperature of the water in these wells fluctuates more than in the deeper wells, as would be expected, being affected more by the surface temperatures of the air and soil.

This type of well is obtained with the least difficulty and expense, the work being usually done by the owner himself with what little assistance he can command. Water so obtained, however, is especially liable to contamination, unless carefully guarded, since gravel and coarse sand do not make an effective filter and because of the ease with which foreign matter may enter from above. Dupuits' experiments in France have shown that the area drained by a well is in the form of an inverted cone, the radius of the base of which may range from 15 to 160 times the depth of the surface of the water in the well. This means that, if it is 10 feet from the surface of the ground to the level of the water in the well, that this well *may* receive drainage from barns and outhouses 150 to 1600 feet distant from the mouth of the well. It has also been found that a shallow well heavily pumped will drain a larger area than a deeper well subjected to moderate pumping. It thus becomes a matter of great importance to the users of the well water that it be located in the safest possible place, even if somewhat inconvenient, and it would be wise to first ascertain the probable direction of underground flow by discovering the slope of the clay surface and of the ground water. The danger of pollution is shown

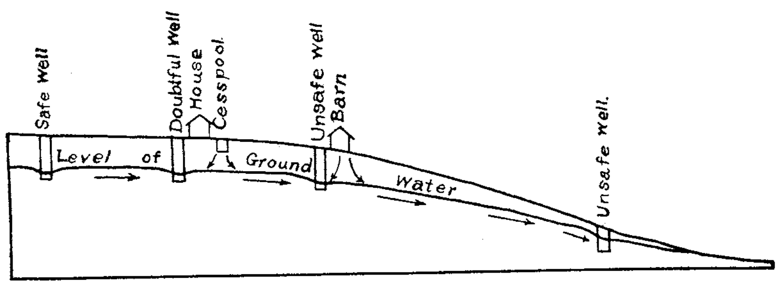


Fig. 18. Diagram showing ordinary location of farm well (From U. S. Geological Survey Water-Supply Paper No. 255).

in the accompanying diagram. It is a mistake to suppose that the surface slope of the ground controls the direction of underground drainage, the reader being able to easily construct a diagram in which the surface slopes in one direction and the surface of the impervious clay in the other. Heaping a mound of earth about the mouth of a well to keep out surface drainage from a barnyard is a very ineffective safeguard. In comparison with the dug well, the driven well is much the safer but gives a smaller

yield. The relative advantages and disadvantages of these two types of shallow wells are set forth in the following table, along with "bored" and "punched" wells. The former are made by the use of augers of various types; the latter by dropping a steel cylinder, carrying a slit upon its side for holding and lifting the material to be excavated.

TABLE L. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF WELL.[7]

Dug wells.

Advantages.	Disadvantages.
Ease of construction; can be located, sunk, and cased by owner.	Limitation to soft materials; liability to caving while being dug.
Only hand power required.	
No outfit required.	
No expensive materials required for curbing.	
Cheapness in soft material.	Costliness in hard rock.
	Wood curbing often used affords favorable conditions for the development of bacteria.
	Slight depth to which it can be sunk.
Ease of entrance of water.	Ease of entrance of polluting matter through and over top of curb.
Utilization of all water strata.	Water, not being replenished, is often stagnant.
Utilization of small seeps.	Fails frequently in time of drought.
Quick response to rainfall.	
	Must usually be at distance from house and from barns, privies, and cesspools to insure safety.
Large storage capacity.	Necessity for frequent cleaning; danger from gas while cleaning.
Accessibility for cleaning.	Short life when curbed with wood.
	Ease of entrance of animals and refuse through open top.

7. Fuller, Underground Waters for Farm Use: Water-Supply Paper No. 255, United States Geological Survey, 1910, p. 36.

Driven wells.

Advantages.	Disadvantages.
Ease of construction; often sunk in a few hours; only hand or horse power usually required.	Limitation to soft materials. Utilization of a single water stratum.
Outfit is inexpensive, can be quickly put up, and does not require skilled labor.	Usual limitation to moderate depths.
Tubing is readily obtainable and inexpensive.	Restriction to open porous water beds due to absence of storage facilities.
Cheapness.	
Safety; can be located near sources of pollution if sunk through impervious bed preventing access of contaminating matter to water bed; nothing can enter at top.	Slow response to rainfall as compared to many dug wells. Corrosion of pipes or well points. Incrustation of pipes and well points.
Permanency of supply as compared with dug wells.	Entrance of quicksand through well points. Taste of water due to solution of the iron under certain conditions.
Cleaning seldom necessary as compared to open wells.	Difficulty of cleaning in case of clogging. Short life as compared to some dug wells. Absence of information as to minor water beds or materials penetrated.

Bored wells (Arkansas type, 2 to 12 inches in diameter, tight casings).

Advantages.	Disadvantages.
Ease of construction; only hand or horse power usually required; skilled labor not essential in shallower holes.	Limitation to soft materials. Not adapted to very deep wells. Utilizes only one stratum in most places.
Cheapness for moderate depth.	Other disadvantages similar to those of drilled wells.
Deeper wells little affected by drought.	
Pollution shut out if properly cased.	
Gives good records of materials penetrated and water beds encountered.	

Punched wells.

Advantages.	Disadvantages.
When provided with pervious curbings the advantages are similar to those of open and Iowa type bored wells; when provided with tight casings, the advantages are similar to those of the Arkansas type bored wells.	Similar to those of open wells and the larger type of bored wells. Difficulty of operation; liability of crooked holes. Usual limitation to depths under 50 feet. Limitation to soft yet stiff materials, which are generally of local distribution.

In addition to safe guarding the well in every known way, great precautions should be taken in the disposition of garbage, kitchen and chamber-slops, manures, etc.; these being disposed of only at safe distances from the well that supplies the water for domestic use. The United States Department of Agriculture issues gratuitously a Farmer's Bulletin (No. 43) bearing upon the subject of Sewage Disposal on the Farm, and the Protection of Drinking Water. During outbreaks of typhoid, it is wise to apply to the Michigan State Board of Health, at Lansing, for their pamphlets dealing with the subject of the control of this expensive disease. The importance of sanitation is not generally appreciated in the rural home and should be clearly and forcibly presented in all rural schools.

Seepage springs. Around the margins of the sand dunes; wherever superficial beds of sand and gravel thin out, exposing the clay; or where these deposits are cut by surface streams to or near the clay, the water "seeps" out and gives rise to one type of springs. The flow may be slight and simply moisten the surface, or it may be concentrated into a single flow of some volume. Most of the springs of this type are seen along the banks of the Rouge and Huron rivers where they have cut into the old beaches and deltas. The conditions under which they exist are shown in the accompanying diagram.

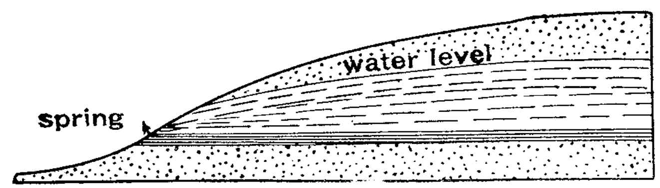


Fig. 19. Spring fed from unconfined waters in porous sands (From U. S. Geological Survey Water-Supply Paper No. 255).

In Van Buren township, some of the strongest flows are being utilized by the farmers, the water being pumped into tanks by means of hydraulic rams. These waters show only small quantities of salt, gypsum and calcium carbonate, with a little iron. The largest spring noted from this class of deposits is located upon the place G. E. Barlow, sec. 29, Livonia township. It has yielded a strong flow for many years and at the time last visited was still discharging through a 2½-inch pipe with considerable force (see Pl. XXVIII, A). Field tests showed that the water is hard, containing both calcium carbonate and sulphate but gives no reaction for salt. If this spring were fully developed, along with others upon the neighboring Rouge bank, there might be found sufficient water for such a village as Wayne, from which it is 7 miles distant. The amount of fall to this village, some 14 to 15 feet, would carry the water but could not furnish sufficient pressure. This village has been unsuccessful in securing a municipal supply from deep wells and even, at one time, seriously considered extending the Detroit mains, but the expense proved prohibitive. Recently test wells have been located to the west of the village, have been found to yield a sufficient quantity and the village was permitted to reject by ballot the question of bonding for such a water supply. At the Wayne County House, Eloise, the inmates are supplied with drinking water from a large sand dune one-half mile distant, the water being collected in small reservoirs and flowing by gravity through 3-inch tiling. The water is abundant for this purpose, pure and soft, although not making a free lather with soap.

Flowing steadily from loose deposits, spring water is more liable to be free from injurious impurities than that derived from wells. Furthermore, springs are generally more favorably situated at distances from sources of pollution than are the wells. Where buildings occupy the higher ground in their vicinity pollution may occur, however, as indicated in the accompanying diagram. If the spring water is allowed to collect in a basin this should be carefully protected from stock, surface drainage and wind blown refuse.

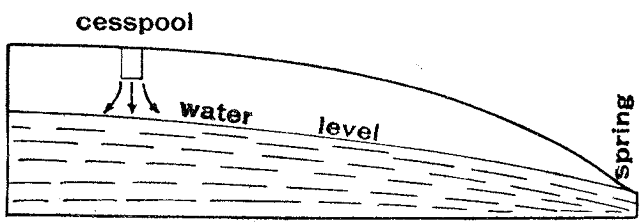


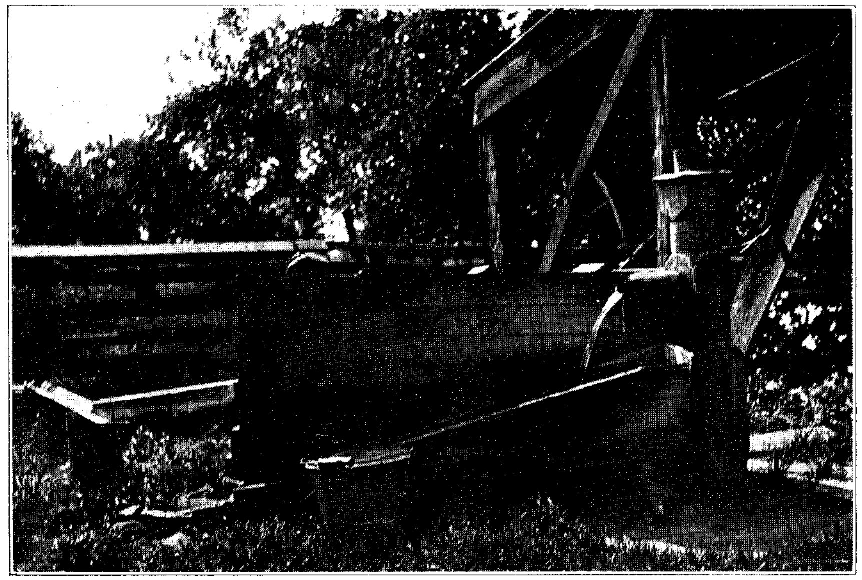
Fig. 20. Diagram showing manner in which springs may be polluted by sub-surface drainage (From U. S. Geological Survey Water-Supply Paper No. 255).

WATERS FROM GLACIAL DEPOSITS.

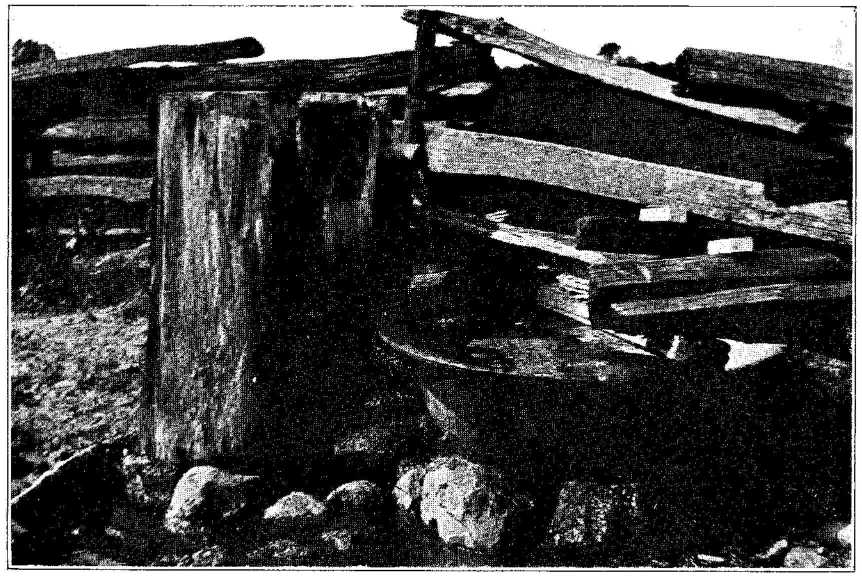
Origin of deposits. The great Canadian ice sheets made at least three advances across this section of the state, as noted in Chapter II, from northeast to southwest, reduced much hard rock to flour and spread it over the bedrock in a sheet varying in thickness from a few feet to over 200. This deposit consists of tough, unstratified clay, generally of a blue color, with sub-angular to rounded rock fragments, and is technically known as till. Stony portions of it have become much compacted and are popularly known as "hard pan," owing to the difficulty of penetrating it in sinking wells. While this great ice mill was at work reducing the rock to powder, streams of water beneath the ice, resulting from surface melting and rains, were assorting the deposits into gravel, sand and clay. The pebbles, rounded somewhat by mutual grinding, and the sand were arranged in layers in places favorable for deposition, and these were often subsequently covered by later till deposits. The finest sediment held in suspension by the glacial torrents was carried forward to the quiet bodies of water into which these streams drained forming the fringes of deltas, or being spread as a fine layer of clay over the lake bed. As has been described, beds of a similar nature resulted from the action of waves upon the till, the sand and pebbles during times of storm being tossed upon the beach, while the clay was carried lakeward into deeper and more quiet water. Although nearly the entire county was covered by these waters, the only extensive deposits of these glacial lake clays are found to the west and north of Detroit.

Water supply. Owing to the fineness of its pore space, lake clay and till usually contain much water but are so retentive that they act as impervious strata, yielding up little or none, but are still most valuable for confining the water bearing gravel and sand layers described. Owing to the distribution of these latter strata, the securing of a sufficient water supply is often difficult, uncertain and expensive, especially seen in the northeastern part of Van Buren, the northwestern part of Romulus and certain parts of Dearborn townships. The following expressions of the farmers indicate their varying success in obtaining water from these deposits; "dry as a powder-house," "regular lake," "oceans of water," etc. The rain water finds its way into these permeable beds of sand and gravel, often quite remote from the place at which they are tapped by the well and often at considerably higher levels. The result is that the water confined between two impervious beds of clay enters the well under head, which may bring the level to near the surface, or may even cause it to overflow. All such wells are now spoken of as "artesian" in which the water rises by hydraulic pressure, whether they flow or not. As the water generally comes from a greater distance and from a greater depth than that of wells previously discussed, its temperature is more uniform and the supply is more abundant and more constant. In general, also, the water is more highly mineralized, owing to its better opportunities for taking the minerals it encounters in solution. Of all those wells from which data were secured, 22 per cent were reported by the owners as soft and 78 per cent as hard. Where the water is drawn from just above the bedrock, it is sometimes highly charged with minerals, such as salt, sulphur, iron, etc., which characterize the waters from the rock itself, and the inference is that the rock water has mingled with that from the glacial deposits.

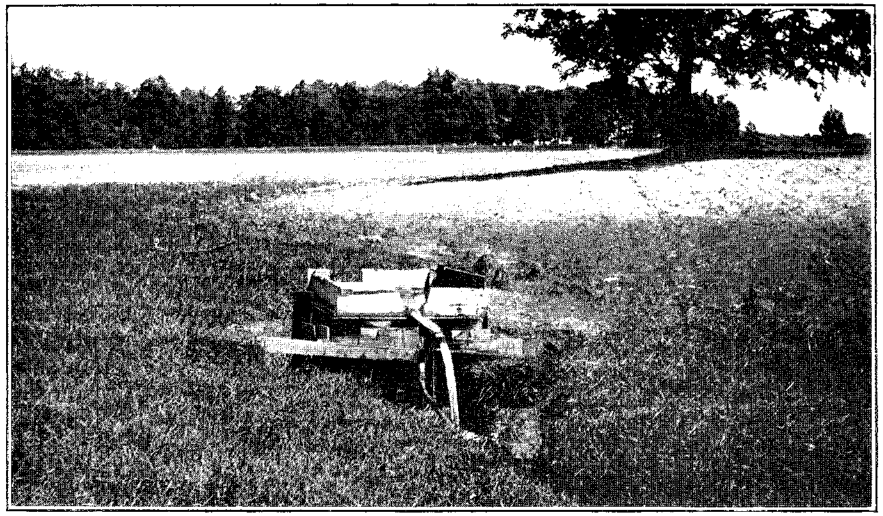
Non-flowing wells. The non-flowing wells generally vary in depth from 18 or 20 feet to 100 feet or more, 60 to 75 feet being a common depth. The shallower ones are dug and lined with stone or brick; the deeper ones are driven, bored, or drilled. In some instances no casing at all is used, the clay being firm enough to maintain the necessary opening to the water-bearing stratum. Owing to the considerable depth, heavy suction pumps are generally required and windmills are in common use. The deepest wells of this type are located in the northeastern part of Van Buren, northern Canton, northern Hamtramck, and southwestern Grosse Point townships, the maximum found having a depth of 182 feet. Owing to the nearness of bedrock to the surface in Monguagon and Brownstown townships, the wells of this class are necessarily shallow, many of them stopping just short of the rock in a bed of gravel. The height to which water will rise, with reference to the surface of the ground, depends on the head and the elevation of the ground at the mouth of the well, and each of these factors grows less toward the southeast. In the belts immediately surrounding the areas of flowing wells, to be next described, the water comes very near or quite to the surface and drops back from it as we pass to the east or the west. In the wells of this class from which data were secured, 80 per cent were reported hard and 20 per cent soft. When tightly cased to a level above ground, the wells are safe from contamination. If the casing is too short at the top, or if no casing at all is used, they may receive surface drainage and become a source of danger. The collecting areas of this water



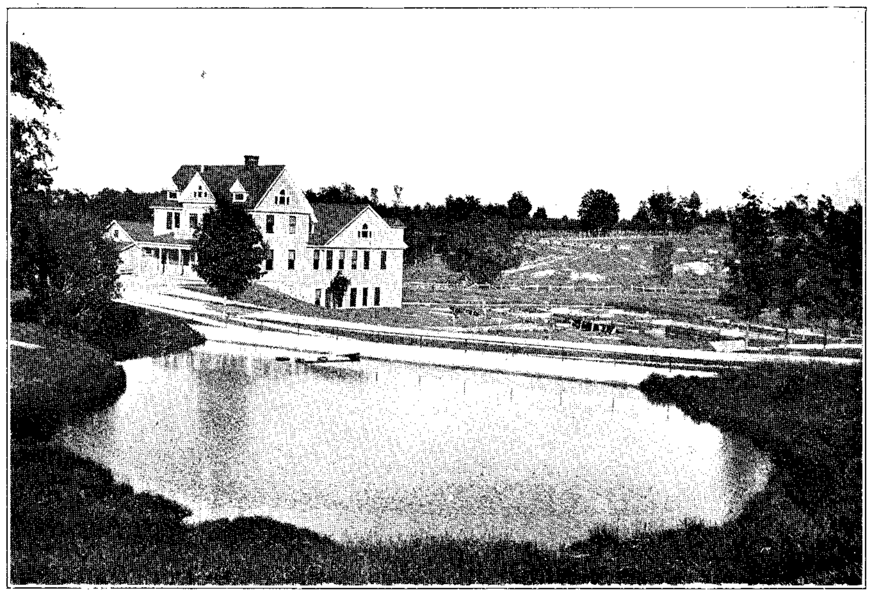
A. FLOWING WELL FROM DRIFT CLAY, CANTON TOWNSHIP.



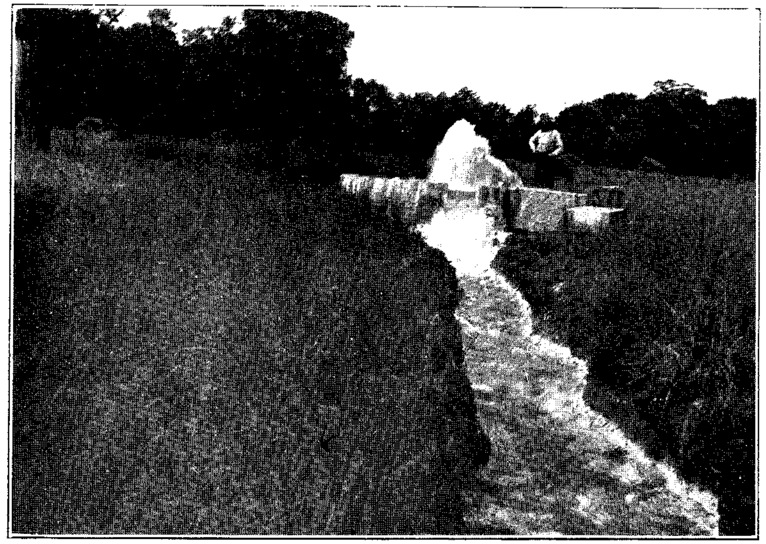
B. PRIMITIVE TYPE OF FLOWING WELL, CANTON TOWNSHIP. FLOW GREATLY REDUCED BY CLOGGING OR LEAKAGE.



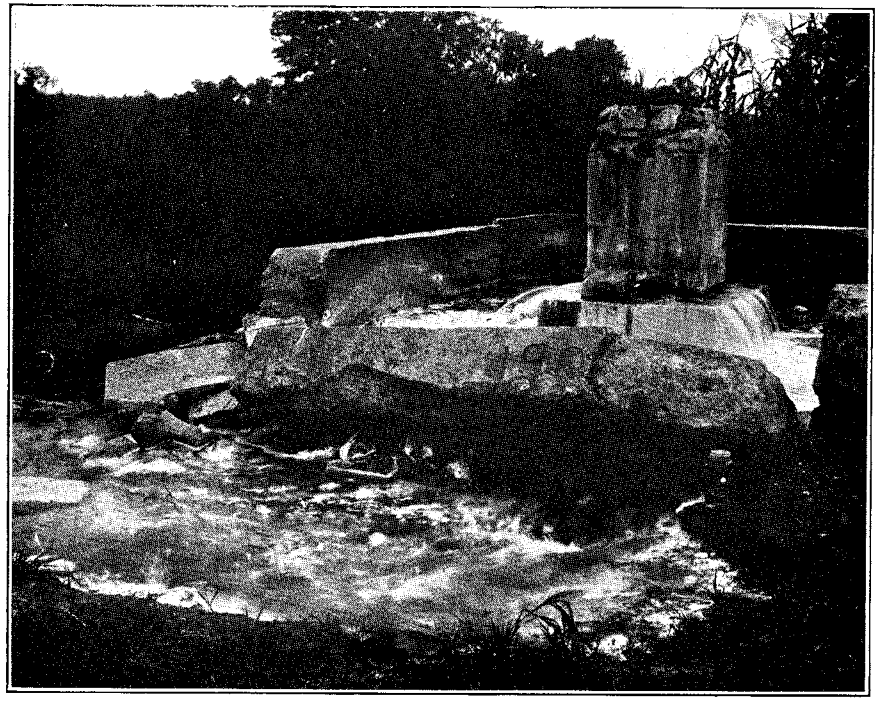
A. NATURAL SPRING FROM DELTA OF MIDDLE ROUGE.



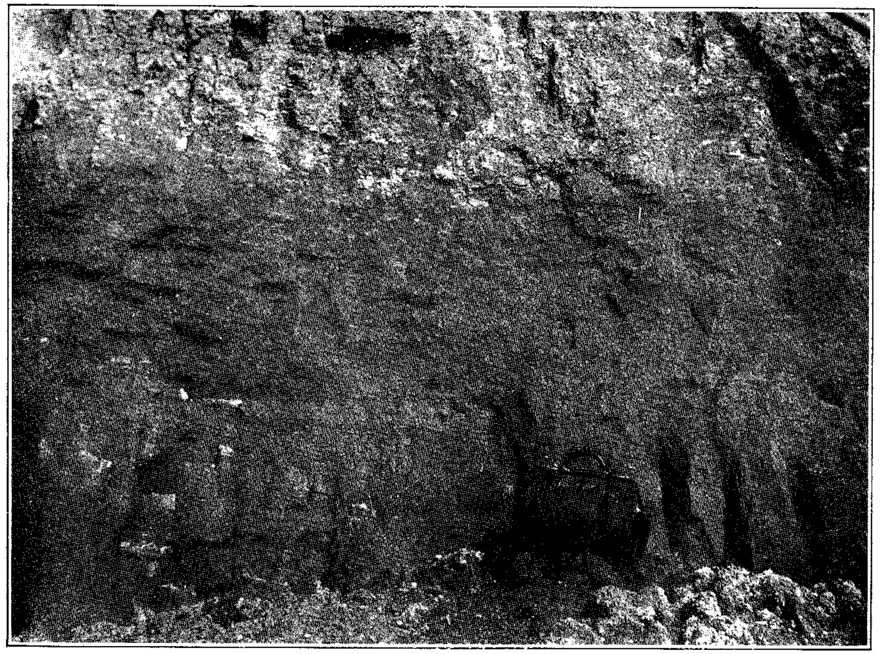
B. SPRING OF U. S. FISH HATCHERY, NORTHVILLE.



A. SWAN WELL, GROSSE ISLE, IN 1907.



B. SWAN WELL, GROSSE ISLE, AFTER SEVEN YEARS OF FLOW. CEMENT CURBING DESTROYED BY FROST.



A. STRATIFIED LAKE CLAY DEPOSIT, SPRINGWELLS TOWNSHIP.

B. PORTION OF SIBLEY QUARRY, CRUSHER AND LIME KILNS.

appear to lie in the high morainic regions to the west and north, as shown from the general diminution of head toward the south and east (see Pl. XXV). In a strip of territory extending northeastward from southern Canton and northeastern Van Buren townships, many of the deeper wells give much salt, which presumably is received from the underlying bedrock. A few data are here given concerning three of the most striking. It is likely that the Barker wells penetrated the Antrim shale without the driller knowing he had entered bedrock.

The well of C. F. Bevernitz, NW. 1/4 sec. 12, Nankin township, is 60 to 70 feet deep, the Antrim shale lying at a depth of 70 to 80 feet. The elevation of the mouth is approximately 635 feet. The supply is good, but there is too much salt in the water to permit its use; a tobacco pail full is said to have yielded, on evaporation, a pint of salt. There has been some gas in the well. The water lacks only 4 feet of reaching the surface, its actual head being about 631 feet.

Edward Barker, NE. 1/4 sec. 27, Canton township, has two wells, which were sunk to a depth of 108 feet in 1901. The Antrim shale is supposed to be from 100 to 110 feet from the surface. The approximate elevation of the mouth of the well is 657 feet and the head is —12 feet, giving the water level an elevation of 645 feet. Salt water was secured from near the bottom, 6 to 7 quarts yielding a teacup of salt. This water has been used for preserving pork and for killing thistles. The well was plugged below to shut off this supply and fresh water was used from a higher level in the well.

W. A. Wallace, SE. 1/4 sec. 32, Canton township, has a bored well 70 feet deep. The Antrim shale lies at 80 to 90 feet. The elevation of the well mouth is 695 feet and of the water surface 687 feet. The water is secured from just over hardpan and is hard and salty, too much so to drink, but may be used for other household purposes. Cattle will drink it and require no other salt.

Some of these mineralized waters not so highly charged with salt are being put on the market for their medicinal properties and sold in Detroit by the gallon. One of these sources of supply is on the Rouge flats at Plymouth. It is owned by Dr. M. V. B. Saunders, of Detroit, and is advertised as the "Plymouth Rock Mineral Well." The depth is 74 feet, the first 25 feet of which were dug and the remainder drilled. The elevation of the mouth of the well is about 700 feet, and, as the rock surface here is believed to be from 630 to 640 feet, it is likely that the well penetrated the Coldwater shales. The water was said to have been secured from beneath an exceedingly hard 18-inch stratum. It is reported that 3,000 gallons are sold annually, and that it has been found especially efficacious in cases of rheumatism, kidney and bladder troubles. The following analysis, taken from the advertising circular, was made by Prof. John E. Clark, M. D., of the Detroit College of Medicine:

TABLE LI. ANALYSIS OF PLYMOUTH ROCK MINERAL WATER.

(Parts per million).

Potassium (K)	11.58
Silica (SiO_2)	8.57
Iron and alumina (Fe_2O_3; Al_2O_3)	29.76
Chlorine (Cl)	149.43
Sodium (Na)	124.01
Sulphate radical (SO_4)	4.31
Carbonate radical (CO_3)	192.95
Calcium (Ca)	24.22
Magnesium (Mg)	14.36
Organic and volatile	22.25

Carbonic-acid gas and carbonate of lithium present, but not estimated. A similar well near the above is owned by H. P. Peters and has a depth of 80 feet, possibly also reaching bedrock. The water is said to have originally flowed, and has been put on the market as "Hydrocarbon Mineral Water." Bubbles of gas, apparently carbon dioxide, are continually rising to the surface.

Flowing wells. When the head or pressure with which these waters enter the wells is sufficient, the water reaches the well mouth and overflows. Three disconnected belts of such flowing wells cross Wayne County, being the continuation of similar belts in Monroe and Washtenaw counties. One of these belts begins in the northwestern part of Van Buren township (secs. 3, 4, 5 and 6), extends northward across Canton, with a breadth of 2 to 3 miles, reaches into sec. 34 of Plymouth, and continues into the western part of Livonia township. The belt is not continuous, and all of the wells that are still flowing lie to the east of the gravel ridge formed by the waters of glacial Lake Whittlesey and known as the Whittlesey beach. This is due to the fact that the water does not have sufficient pressure to reach the level of this beach, which is about 740 feet above sea level. The artesian head in Wayne County ranges from 680 feet above sea level to about 730, but farther north in Farmington township, Oakland County, rises to 760 feet. A second belt of flowing wells, artesian head 580 to 600 feet, lies in the eastern part of the county, extending from the vicinity of Flat Rock northeastward through Brownstown, Ecorse and Taylor, into Springwells, where it is interrupted by the Detroit moraine. In the northeastern part of Grosse Point township, the belt again appears and continues along the lake shore into Macomb County. It is this belt, especially that portion of it near the Huron, that has suffered great loss of head and volume. Between these two lies the third belt entering Huron township from Exeter and Ash townships of Monroe County although most of the wells have ceased to flow during the past decade. In looking northward for the continuation of this middle belt there is some doubt as to its course. Probably the area immediately to the west and north of Wayne continuing northeastward into Redford, across northwestern Dearborn, should be connected with those in the Willow-Waltz district, although the head is some 20 feet higher about Wayne and we should expect the belt to have a more northeasterly course.

The average temperature of the wells of the county as measured in May and June, is 52° F., or slightly less, but some show a rise of 1° to 3° in the fall, owing to the effect of the summer heat on pipes through which they slowly discharge. It is probable that if the bottom temperature were taken it would be found to be more constant, especially in the case of the deeper wells and wells with a weak flow. In these, the waters are either warmed or cooled as they approach the surface, except at times of year when the surface temperature corresponds closely with the temperature of the bottom of the well.

To the farmers, these wells are a great saving in time and expense of pumping (see Pl. XXVII, A and B) while the low summer temperature and constant flow are of great service in caring for milk in the dairy. The tanks do not ordinarily freeze over in winter and are thus available for the stock. The wells are about equally divided between hard and soft water, some of unusual softness occurring at Dentons, where they take the place of cistern water.

The two following partial analyses, furnished by M. O. Leighton, of the United States Geological Survey, show the relative composition of drift and rock waters at Dearborn:

TABLE LII. PARTIAL ANALYSES OF DRIFT AND ROCK WATERS AT DEARBORN.

(Parts per million).

	1.	2.
Color	32	32
Iron (Fe)	Trace	2
Chlorine (Cl)	19	15
Carbon dioxide (CO_2)	87.94	97.61
Sulphur trioxide (SO_3)	86	522

S. J. Lewis, analyst. 1. A. Wagner; depth, 28 feet. 2. A. Wagner (rock); depth, 115 feet.

These waters are said to produce only a very little scale in the tea kettle, even after several years' use. Simple tests show slight traces of salt, iron, and lime carbonate, but no lime sulphates, or but a trace. This condition of the water may be due in part to continuous leaching, the result of which would be to change flowing wells from hard to soft. The breaking in of new veins might, however, suddenly change the water from soft to hard. The water in the eastern belt is almost invariable charged with either iron or sulphur, along with the other minerals commonly present, owing to the nearness of bedrock. The pressure is generally low and sufficient only to elevate the water a few feet above ground level, but is somewhat greater in the western district. In the Penny well, sec. 3, Canton township, there is a strong flow which will rise 12 feet, thus having an elevation of about 727 feet above sea level. Most other wells in the western part of this belt indicate an artesian head of 710 to 720 feet, which, as a rule, drops to the southeast more rapidly than does the surface slope of the land, ranging from 6 to 12 feet to the mile within the belt. Most of the flowing wells in the eastern belt are from the bedrock, and thus belong to the class next to be described. The similarity in the character of the water would indicate that the western wells derive their supply and head from the same source, and hence that the eastern and western belts of flowing wells are genetically distinct, the western coming from the drift to the north and west and the eastern from bedrock. Table LIII shows the chief characteristics of this group of wells.

TABLE LIII.—FLOWING WELLS IN DRIFT, WAYNE COUNTY.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Quality.	Temperature.	Size of flow.	Head. Maximum.	Head. Present.	Elevation.	Remarks.
						Feet.		°F.	Inches.	Feet.	Feet.	Feet.	
1	8	34	NW.	Plymouth	S. Bennett	70	Soft	51	1/4	...	0.7	720	Small amount of salt.
2	8	3	NW.	Canton	O. F. Penny	86	Hard	51.5	1/2	+12	3	715	Will flow a 2-inch stream.
2	8	4	NE.	Canton	E. Everett	35	Hard	51.5	1/2	+5	2.5	708	Some salt.
2	8	8	NE.	Canton	G. S. Bonsteel	28	Soft	52	1/3	+8	3	711	Has flowed 3.5-inch stream.
2	8	8	SE.	Canton	H. O. Hanford	30-35	...	...	3/8	+2.5	...	708	Strong in iron.
2	8	9	NW.	Canton	Mrs. D. Schrader	50-60	Hard	60	1/4	+2	2	708	Waters 75 head of cattle.
2	8	9	NW.	Canton	J. Quartle	28	Soft	...	3/4	+9	3	711	Made in 1868; contains salt.
2	8	31	NW.	Canton	S. Goddell	70	Soft	50	1/2	+4	2	715	Used in dairy and laundry.
2	8	30	SE.	Canton	J. Smith Estate	50-60	Soft	...	1/4	+2	...	689	Free from iron.
2	8	32	SE.	Canton	J. F. Duntley	...	Soft	51	1/4	...	2	692	Used in dairy.
2	8	33	SE.	Canton	J. E. Betts	30	Hard	51	...	...	1	685	Not affected by drought.
2	8	33	SE.	Canton	G. Kissane	...	Hard	55	1/2	...	1.5	686	Running 15 years.
3	8	4	NW.	Van Buren	J. Couch	63	...	53	1/4	...	3	696	Used in dairy.
3	8	4	NW.	Van Buren	W. Deyo	42	...	51	1/4	...	2	693	Once flowed 49 gallons a minute.
3	8	4	NE.	Van Buren	A. Kruger	75	Soft	51.5	1/3	...	3	690	Used in laundry.
3	8	4	NE.	Van Buren	C. Nass	70	...	52	1/4	...	2	690	...
3	8	4	NE.	Van Buren	A. Gunther	72	...	50	...	+4	...	688	Running 14 years.
3	8	5	SE.	Van Buren	W. H. Burrell	70	Soft	51	1/2	...	3	698	Used in laundry.
3	8	5	SE.	Van Buren	F. Van Tassel	48	Hard	...	1/4	+12	4	696	Has flowed 1.5-inch stream.
3	8	6	NE.	Van Buren	I. Glass	76	Soft	51	1/4	+2.5	...	705	Used in laundry.
3	8	6	NE.	Van Buren	C. Shlicht	72	Soft	...	1/4	...	1	706	Denton village.
1	9	18	SE.	Livonia	W. Hake	50	Medium	51	...	...	1	690	Would flow 1-inch stream.
1	9	17	SW.	Livonia	R. L. Alexander	45	Hard	50.5	1/4	+4	2.5	693	From gravel over bedrock.
1	9	19	NE.	Livonia	O. Melow	55	Soft	...	1/4	+12	1	680	Has flowed 2.5-inch stream.
2	11	18	SE.	Springwells	Detroit Brick Co.	80	Hard	51	1 1/4	...	4	590	Flows 90 barrels a day.
2	11	20	NW.	Springwells	L. Maples	67.5	Hard	52	1/2	...	3	595	Strong in sulphur.
3	11	14	SE.	Ecorse	J. Porout	78	...	...	Trickle	+4	.5	599	Contains sulphur.
5	10	5	SE.	Ecorse	R. Smithson	28	...	51	1	+25	...	588	Iron but no sulphur.

The village of Wayne recently purchased five acres of the Kissane property, near the center of sec. 33, Canton township, and put in a test well to the depth of 120 feet, without reaching rock. A heavy vein of water was struck in a gravel stratum at a depth of 63 feet and a flowing well secured. The water is of medium hardness and shows no especial mineral substance. The pumping test conducted by Riggs and Sherman, engineers of Toledo, indicated an available daily supply from this one well of 150,000 gallons.

The following partial analysis of an unusually soft water from the parsonage well (depth 75 feet) near Denton, in the western part of the county, has been furnished by M. O. Leighton of the United States Geological Survey. The water tested is one of the softest in the state.

TABLE LIV. PARTIAL ANALYSIS OF WELL WATER AT DENTON.

	Parts per million.
Color	10
Iron (Fe)	Trace
Chlorine (Cl)	8.75
Carbon dioxide (CO_2)	97.61
Sulphur trioxide (SO_3)	.29 (?)
Hardness	56.1

The following partial analysis of the well water at the Commercial Hotel at Wayne is furnished by M. O. Leighton, of the United States Geological Survey.

TABLE LV. PARTIAL ANALYSIS OF WELL WATER AT COMMERCIAL HOTEL, WAYNE.

	Parts per million.
Color	19
Iron (Fe)	Trace
Chlorine (Cl)	15
Carbon dioxide (CO_2)	99.81
Sulphur trioxide (SO_3)	88

S. J. Lewis, analyst. Depth of well, 14 feet.

Boiling springs. The western half of Plymouth and nearly the whole of Northville townships are covered with ridges and knolls of till, interpersed with similar masses of stratified gravel and sand, giving a very rough aspect to the country. The features are those of a moraine formed at the ice margin during a temporary

halt in its general eastward retreat. The glacial lake waters subsequently covered the lower knolls lying to the east, but elsewhere the original roughness left by the ice has been very largely retained. Securing water from these clay knolls and ridges by means of wells is as difficult and uncertain as on the clay plains to the east and at times becomes impossible. The deposits of sand and gravel, however, serve as reservoirs for water, and, owing to their extent and height to the north and west, frequently yield large quantities under pressure. Along the hill slopes and in the valleys heavy natural flows occur, giving rise to what are known as "bold" or "boiling" springs. They differ from the seepage springs in that they have "head," and a generally stronger flow, are subject to less variation, show a steadier temperature, and yield a harder water. In numerous cases, the waters are piped to dwellings and barns and yield an ideal supply, as on the Starkweather place in the southwest part of Northville township, where a spring located in the NW. ¼ sec. 8, is piped to the house, having a fall of 16 feet, delivering a 1-inch stream and keeping 5 troughs supplied with most excellent water for stock. This water contains considerable calcium carbonate, a very little salt, and gives no reaction for calcium sulphate.

Two similar springs are utilized by the United States fish hatchery at Northville (Pl. XXVIII, B). After cleaning in 1896, the flow from the large spring was somewhat more than 500 gallons a minute, but has been gradually declining since. In the fall of 1904, a second cleaning failed to increase the flow much. According to the earlier reports, the temperature was 47° F., but is now 48°, with only slight variation from season to season. This is the coldest water observed in any part of the county. It is rendered hard by considerable calcium carbonate, but gives no reaction for salt or gypsum. Immediately beneath the hatchery building is a second spring which has yielded 136 gallons a minute and has a temperature of 48°. There are two flowing wells having a depth of 106 feet, which yield 1½ and 2 gallons a minute, with a temperature of 50°, but the water contains sulphur and iron and is destructive to both eggs and fish.

The villages of Northville and Plymouth are favorably situated for utilizing similar flows from springs sufficiently elevated to give the necessary pressure without pumping. The water is cold and pure; is rendered hard by calcium carbonate; gives no reaction for gypsum, and only a slight one for salt. The supply is sufficient except during times of prolonged drought. The water is not metered and no estimates are kept of the amount used. Neither of the villages is supplied with sewers, the drainage being good in both cases. The plants are owned and operated by the villages themselves. Northville, with a population of 1665 draws its supply from two springs in Oakland County, about 4 miles distant. The springs are about 1,000 feet apart and empty into a small receiving basin, from which the water flows by gravity, with slight fall, to a reservoir overlooking the village and 100 feet above it. The village of Plymouth, with a population of 1671 has a system similar to that of Northville, its springs being in the NE. ¼ sec. 8, Northville township, in the bottom of an old drainage channel from the ice sheet. The village has here purchased an acre of land on which an excavation 50 by 60 by 6 feet has been made, lined with cobble, and surrounded by a high wire fence. From this the water flows by gravity to a reservoir, which is located 2 miles from the village and 103 feet above it. Both of these villages made the mistake of first putting in vitrified crock instead of iron piping and this had to be replaced with the latter at great expense.

WATERS FROM THE BEDROCK.

Geological formations. Beneath the mantle of clay, sand, and gravel, resulting from the joint action of wind, water and ice, there lies a series of stratified rocks, consisting of sandstone, shale, limestone and dolomite (see Pl. XXV). These have been described in detail in Chapter VI of this report and only a brief summary need be given here. Formed in the sea, in approximately horizontal layers, they were early upheaved and tilted, so that their edges have a general northeast trend in Wayne County, and the beds themselves dip to the northwest at the rate of some 25 feet to the mile. They still retain some of the minerals belonging to the concentrated brines of the primitive seas, and others deposited at the time the rocks were forming, or subsequently. These beds supply a limited part of the county with a more or less highly mineralized water, much of which flows, but some of which must be pumped. The youngest and highest of this series of beds in Wayne County cuts across the northwest corner. It consists of shales, with some sandstone, and is known in the state as the Coldwater shale (Waverly and Cuyahoga). Beneath this lies the dark Antrim shale (Genesee), generally yielding gas and faint traces of oil. Next in order come the bluish beds of shale and limestone, making up the Traverse group (Hamilton), and frequently referred to as "soapstone;" beneath which lies a solid, light-gray limestone known in the state as the Dundee (Onondaga). Below this limestone is a drab dolomite, the Monroe group ("Lower Helderberg"), which drillers do not ordinarily separate from the preceding. Embedded in it and of the same geologic age is the so-called Sylvania sandstone, a pure glass sand, cutting across the extreme southeastern part of the county; this is the oldest of the formations reached directly beneath the clay in the county. Still older and lower, however, and coming near the surface in Monroe County and bordering parts of Ohio, lie, in order, the Monroe beds below the Sylvania sandstone, the Salina, Niagara, Medina, Hudson, Utica and Trenton, the last being the oldest bed reached by borings in the county.

Flowing wells. The wells of this class comprise most of those in the eastern belt described above. They are heavily mineralized, as a rule, and frequently rendered rank by sulphur and iron. The average temperature is 51.4°, as compared with 52° for the flowing drift wells, but rises slowly as the water comes from greater depth. Theoretically the temperature should be still more constant than in the drift wells, but it must be affected in the same way and to the same extent as it rises to the surface. With reference to the level of the ground the head is generally slight, ranging from a mere rise to the surface to 15 and 25 feet above in exceptional cases. At Dentons, in a well along the railroad track, the water is reported to have reached the second story of a building, indicating its rise to about 715 feet above sea level. The Swan well on Grosse Isle is the easternmost of the flowing wells in the county and has a head of 597 feet. Measured between these two extreme wells, the average reduction in head toward the southeast is 5.6 feet to the mile. Between the Flat Rock wells and those on the lake shore, the average reduction per mile is 3.5 feet. Although the rock strata are dipping to the northwest, these facts indicate that the source of supply is to the west, as pointed out by Fuller in his report on the failure of wells along lower Huron River (p. 37). In his investigation of the wells of this region, he found the average reduction in head of the wells about the Swan Creek-Rockwood district to be about 3 feet per mile to the eastward.

Table LVI gives the principal data concerning the flowing wells from bedrock. The most wonderful of the entire set is the Swan well described by Fuller (pp. 43-44), which flows 3,000 gallons a minute, or 4,320,000 gallons a day—enough to supply several times over the entire river front from Trenton to Detroit.

The following analysis shows the composition of this water.

TABLE LVI. ANALYSIS OF WATER FROM JAMES SWAN'S WELL ON GROSSE ISLE.

(Parts per million).

F. K. Ovitz, Ann Arbor, analyst, Jan., 1905.

Silica (SiO_2)	188.00
Iron and alumina (Fe_2O_3, Al_2O_3)	14.00
Calcium (Ca)	5,082.96
Strontium (Sr)	317.00
Magnesium (Mg)	730.57
Sodium (Na)	216.78
Potassium (K)	79.68
Sulphate radical (SO_4)	14,245.21
Carbonate radical (CO_3)	871.35
	21,745.55

It was the original intention of the owner to market the water under the trade name "Kathairo" but this was done for but a short time. When the water is fresh, there is a pronounced flavor of sulphur which does not appear in the above analysis. In 1905 a strong flow of sulphur water (temperature 52.3°F.) was struck at Dearborn, upon the River Rouge flats (NE. 1/4 NE. 1/4 sec. 21), at a depth of 108 feet and penetrated 182 feet, the water rising to a height of some 30 feet above the mouth of the well in the casing, and indicating a head of 635 to 640 feet above sea level. The well is capped but the casing is leaking and indicates no loss in pressure, suggesting that the flow is truly hydrostatic and not due to gas pressure as originally supposed.

TABLE LVII.—FLOWING WELLS FROM BEDROCK, WAYNE COUNTY.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Diameter of discharge pipe.	Temperature.	Depth of rock.	Remarks.
						Feet.			Feet.	Inch.	°F.	Feet.	
3	8	6	NE.	Van Buren	Bandy	125	Coldwater	Soft	705			81	Village of Denton.
2	8	28	NE.	Canton	M. Carleton	140	Antrim	Salt and iron	682	(a)		70	Gas; not usable.
2	11	18	SW.	Springwells	A. Lapham	129	Traverse	Hard	588	1/4	52	100	Recently ceased flowing.
3	10	34	SW.	Taylor	J. Shetrum	86	Corniferous (b)	Sulphury	603			83	Now rises 4 feet.
2	11	4	SW.	Springwells	J. C. McDonald	250	Corniferous	Hard	605	3/4	53	125	Rank in iron and sulphur.
3	11	30	SW.	Ecorse	Beaubien	64	Corniferous	Hard	587	1/4	51	64	Strongly mineralized.
3	10	35	NE.	Ecorse	Unger		Corniferous	Hard	598	1/4	51		Minerals abundant.
4	10	13	SE.	Monguagon	Duman	30	Corniferous	Hard	580	1/2	52	2	Strongly mineralized.
4	10	25	NW.	Monguagon	E. Lathrop	12	Corniferous	Sulphury	578	3/4		10	
4	10	3	NE.	Brownstown	Clark	68	Corniferous	Hard	597	1/8	51		Mineralized.
4	10	3	NW.	Brownstown	G. McDonald	76	Corniferous	Hard	602	1/8	52	76	
4	10	4	NE.	Brownstown	J. G. Carson	65	Corniferous	Hard	603	1/8	51		Strongly mineralized.
2	10	1	SW.	Dearborn	W. Robertson	357	Monroe	Hard	611	1/4	52	100	Rank in sulphur.
2	11			Ecorse	Detroit Salt Co.	1,096	Monroe	Sulphur	582			95	Sulphur water at 223 feet.
2	11			Ecorse	Brownlee & Co.	1,200	Monroe	Sulphur	578			82	Strong sulphur vein at 168 feet.
2	10	21	NE.	Dearborn	Dr. T. V. Law	290	Monroe	Sulphur	605	8		108	Head 635 to 640 ft.
5	10	8	NE.	Brownstown	B. Hall, Sr.		Monroe	Hard	587	1/2	51		Iron and sulphur; little salt.
5	10	9	NW.	Brownstown	E. T. Wood	22	Monroe	Hard	587	1/2	55	22	Iron and sulphur; little salt.
5	11			Grosse Isle	J. Swan	2,375	Trenton	See analysis	575	13	52	17	Flows 50 gallons a second; head 597 feet.

(a) Trickle. (b) Corniferous (Dundee.)

The deep wells about the mouth of the Rouge will flow if permitted to do so, giving a type of water strongly mineralized and rank in sulphur. Two samples of such water from the Oakwood salt shaft have been analyzed in the laboratory of the Bureau of Mines, Department of the Interior, Washington. The first is of the cold water as it comes from the rock, before it has had an opportunity to become heated by mingling with the steam. The second analysis is of the hot water as it flows from the pipe at the mouth of the shaft. The depth of the first sample is not given, probably between 480 and 533 feet, the latter depth being the greatest at which water now enters.

TABLE LVIII. ANALYSIS OF WATER FROM OAKWOOD SALT SHAFT.

Analyst A. C. Fieldner, Bureau of Mines.

(Parts per million).

	Cold.	Hot.
Total solids at 105°C.	4785	9520
Loss on ignition	389	933
Silica (SiO_2)	16	14
Alumina (Al)	5	9
Iron (Fe)	3	9
Calcium (Ca)	727	927
Magnesium (Mg)	217	310
Sodium (Na, as alkali)	502	1848
Sulphate radical (SO_4)	1990	1937
Chlorine (Cl)	1117	3880
Hydrogen sulphide (H_2S)	249	43

The head of the combined flows here was found to equal 20 feet above the surface, or about 595 feet above sea level. By the time 420 feet of depth was secured, the total flow into the shaft was estimated by the engineer, Mr. Eugene Bradt, as 2,000,000 gallons a minute, or about 1-47 of that of Detroit River. A more detailed description of the various veins encountered in this remarkable undertaking will be found in the chapter following. Compared with the water of the Swan well, the salt shaft water is seen to be less heavily mineralized. This may be due to the partial leaching of the neighboring strata in consequence of the excessive flow from them during the past five years. The first heavy flow in the Swan well was encountered at 420 feet and a still heavier one at 450, corresponding very closely to that of the salt shaft. The head of

the water in the two cases is so nearly the same (595 and 597) that a close connection between the veins may be inferred. In passing northwestward towards Dearborn, the head rises to 635 or 640 feet, a gain of 40 to 45 feet, or somewhat less than 8 feet to the mile, the water being encountered some 160 feet higher in the rock series. Whether we assume that these two flows are connected, or not, we must look to the northwestward for their source, the most probable collecting area being the high morainic strip of country passing NE.-SW. across Washtenaw and Oakland counties. The rock surface here rises from 700 to 800 feet, above sea level, and reaches 900 feet in western Washtenaw and Livingston counties.[8] The water may be assumed to find its way through the drift cover to bedrock, entering through joints and fissures, and working its way to lower levels across the strata, dissolving minerals en route, is ready to escape under great hydraulic pressure whenever an artificial opening is afforded. Not being confined to a single, pervious rock stratum, as is generally the case, makes the obtaining of such artesian flows at any given point a decidedly uncertain matter.

At the plant of the Murphy Power and Ice Co., corner Wayne and Congress streets, Detroit, four wells have recently been put in to a depth of 275 to 300 feet. Rock was struck at about 100 to 110 feet (about 490 feet above sea level), from which a flow of sulphur water was obtained. A much heavier vein was reached at a depth in the limerock (dolomite) of 170 to 200 feet, rising to within about 15 feet of the surface, where the elevation is about 595 feet above sea level, thus showing 580 feet as its head. Tests relative to the amount of flow from the wells indicated a possible 1000 to 1200 gallons per minute. The temperature of the water is 52°F., especially adapting it to use in the condensers.

Springs. In the Brownstown region of flowing wells, there are numerous natural flows charged with iron, sulphur, calcium sulphate, calcium carbonate, and sometimes considerable salt. These are most numerous along Huron River, from Flat Rock to Lake Erie and northward to Gibraltar. The water is generally too rank for use and is believed to come from bedrock, having made for itself a natural channel through the clay. Such springs are found in Brownstown as follows:

T. 4 S., R. 10 E.; NE. 1/4 sec. 28, SW. 1/4 sec. 30, SE. 1/4 sec. 31, NE. 1/4 sec. 36.

T. 5 S., R. 10 E.; SW. 1/4 sec. 5, NE. 1/4 sec. 9, SE. 1/4 sec. 13, NW. 1/4 sec. 1, eastern and southern portions of sec. 24.

8. Geological Survey of Michigan, Report for 1907, plate VI. Also Water-Supply Paper 183, plate II, U. S. Geological Survey.

An analysis of the "Wyandotte White Sulphur Springs," the location of which is unknown to the writer, is given by Peale[9] and is quoted by Lane.[10]

Non-flowing wells. The principal facts relating to the non-flowing wells from rock have been grouped together in table LIX from which the character of the water from the various geologic horizons may be seen at a glance. The water is generally hard and highly mineralized, in a few cases only being reported to be soft. Time did not permit the securing of records of the temperatures of the water of these wells, but owing to the fact that it stands more quietly in the pipes, frequently not far from the surface, it is undoubtedly more variable than in the artesian wells. The head of these rock waters also drops as we pass eastward. The following analysis of the water from an 850-foot well at the Wayne County Infirmary at Eloise shows how heavily charged with minerals these waters may become. The well was drilled for gas by C. C. Nims. The Traverse group was struck at 130 feet (the elevation of the well mouth being about 625 feet) and yielded a flow of fresh water. The well passed through this formation and the underlying Dundee (Corniferous) and entered the Monroe group, from which a strong brine was secured, with some suggestions of oil. The analysis was made by Dr. S. P. Duffield, of Detroit, April 18, 1888.

9. Peale, A. C., Lists and analyses of the mineral springs of the United States: Bull. U. S. Geol. Survey, No. 32, 1886, p. 150.
10. Lane, A. C., Lower Michigan mineral waters: Water Supply and Irrigation Paper, No. 31, U. S. Geol. Survey, 1899, p. 72.

TABLE LIX.—NON-FLOWING WELLS IN BEDROCK, WAYNE COUNTY.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Head.	Depth to rock.	Remarks.
						Feet.			Feet.	Feet.	Feet.	
2	8	27	NE.	Canton	B. Barker	132	St. Clair	Very salty	677	−12	100	"Water will support an egg."
1	9	35	NW.	Livonia	C. Kinney	80	St. Clair	Fresh	636	−8	70	Considerable gas.
1	9	24	SW.	Livonia	F. Schroeder	160	St. Clair	Medium	635	−25	65	Water abundant.
2	9	15	SW.	Nankin	C. Schultz	97	St. Clair	Rather soft	652	−2	77	Some gas at first.
2	9	10	NE.	Nankin	W. Dickinson	110	St. Clair		639	−4	50	Some little gas.
1	10	22	SE.	Redford	J. F. Chavey	82	St. Clair	Hard	628	−17	73	Flowed at first; some gas.
1	10	25	NW.	Redford	A. David	116	St. Clair	Salt and sulphur	630	−10	72	Heavy gas flow at 114 feet.
1	10	23	NE.	Redford	J. F. Stahelin	93	St. Clair	Hard	633	−6	80	Still yields gas.
1	10	13	NW.	Redford	G. Miller	107	St. Clair	Medium	647	−30	80	Considerable gas.
1	11	1	SW.	Greenfield	C. and E. Roberts	127	St. Clair	Very soft	632	−14	124	Iron and gas; good supply.
1	11	11	SW.	Greenfield	Log Cabin dairy	126	St. Clair	Salt and magnesia	643	−26	90 (?)	Five wells about the same.
1	11	13	SW.	Greenfield	Stevens estate	156	St. Clair	Hard	640	−12		Heavy flow of gas at first.
1	12	8	NE.	Hamtramck	W. S. Thomas	163	St. Clair	Hard	628	−19	146 (?)	Salty; gas at 100 feet and 158 feet.
1	12	15	NE.	Hamtramck	Store	137	St. Clair		623	−20	130	Used in greenhouse; little gas.
1	12	9	SW.	Hamtramck	E. A. Norris	170	St. Clair	Salt	627	−25	160+	Some gas.
1	12	16	NW.	Hamtramck	H. Arbeter	162	St. Clair	Salty	627		140	Little gas.
1	12	12	SW.	Hamtramck	G. Brinckman	147	St. Clair	Soft	615	−8	130	"Good as cistern water."
1	12	15	SE.	Grossepoint	J. Brinckman	143	St. Clair	Sulphury	615	−12	138	Neither salt nor gas.
1	12	15	SE.	Hamtramck	Pelky	141	St. Clair	Soft	615	−8	140	"Regular river of water."
1	12	23	NW.	Grossepoint	J. S. Sullivan	260	St. Clair	No water	600		160	Some oil and gas.
1	13			Grossepoint	A. K. Kiefer	133	St. Clair	Hard	586	−7	110	On lake shore; some salt.
1	13			Grossepoint	Claire View farm	162	St. Clair	Salty	587	−12	112	Abundant; near lake shore.
3	8	11	NW.	Van Buren	Wm. Stirling	160	Traverse	Soft, milky	680	−17		Sulphur and iron; stock only.
3	8	21	SE.	Van Buren	S. Campbell	183	Traverse	Magnesia	678	−18	99	Belleville; good flow at 99 feet.
3	8	24	SW.	Van Buren	Sanitary works	250	Traverse	Salty	660		175	Well abandoned.
2	10			Dearborn	Arna Mills	140	Traverse	Sulphury	620	−30	140	Not usable in dyeing.
1	8	26	SW.	Plymouth	Plymouth well	280	Traverse	Salt	730	−2	100	One vein rose 2 feet above surface.
1	10	5	NW.	Redford	Rodgers	336	Dundee (Corniferous.)		640	−3	90	Flows at 94, 150 and 200 feet.
2	9	28	SW.	Nankin	Wayne	305	Dundee	Sulphury	638	−60	157 (?)	Water at 220 feet; some gas.
2	12			City	Detroit	268	Dundee	No water	600		127	Old test well in 1829.
2	12			City	Sanitarium	307	Dundee	Sulphury	595		120	Strong mineral water.
3	8	17	NE.	Van Buren	D. L. Quirk	383	Monroe		703		100	Water only at bottom.
2	9	26	SW.	Nankin	County House	850	Monroe	Salt	625	−9	130	Fresh water over rock.
1	12	5	NW.	Hamtramck	C. Krause	996	Monroe		635		180	Gas reached at 100 feet.
3	9	12	NW.	Romulus	E. Twark	1,820	Niagara	Salt	632	−18	95	Fresh vein at 125 feet; sulphur at 220 feet.

TABLE LX. ANALYSIS OF WATER FROM SALT WELL, WAYNE COUNTY INFIRMARY, ELOISE.[11]

	Parts per million.
Calcium (Ca)	9,714.65
Carbonate radical (CO_3)	3,970.25
Magnesium (Mg)	150.17
Sulphate radical (SO_4)	12,354.88
Chlorine (Cl)	40,214.11
Sodium (Na)	25,354.54
Total solids	91,758.60
Hydrogen sulphide	405.00

These highly charged mineral waters are used for bathing purposes at two places in Detroit—the Clark Riverside Bath House and the Detroit Mineral Bath Co. Along Detroit River from Delray to Trenton, artificial brines are made by forcing water to the salt beds of the Salina series, where they dissolve the solid rock salt and flow to the surface. The salt is then secured by evaporation or used in the manufacture of soda, soda ash, and bleaching powder. The most promising horizon for securing a supply of fresh water is the Sylvania sandstone, a porous bed of pure sandrock holding an abundance of water. Although fresh, it is liable to contain sulphur and iron, carried up from the dolomites of the underlying Monroe group. In the northern part of Monroe County and the southern part of Brownstown township, this bed lies immediately beneath the clay and furnishes an abundance of good water. In the 7 miles to Trenton it drops to 280 feet below the surface, or at the rate of about 40 feet to the mile. Toward Wyandotte the bed thickens, with practically no dip, and in the Eureka well it was reached at 230 feet, while in a well of the Michigan Rock Salt Company, at Ecorse, it was reached at 220 feet. Beyond Ecorse, it drops rather rapidly again, having an average thickness of 99 feet in ten wells of the Solvay Company at Delray.

WATER DECLINE IN LOWER HURON REGION.

Facts relative to decline. During the past twenty years, or more, a marked decline in the volume and head of the well water of the lower Huron region has been in progress, causing great annoyance and much expense to the farmers of the localities involved. This is in striking contrast with the belt of flowing wells in the western

11. Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

part of Wayne County where the only reduction observed may be reasonably ascribed to accumulation of sand and defective casing; difficulties that are rather easily remedied. In the lower Huron region, however, from the vicinity of New Boston to Lake Erie, the wells appear to have been flowing too near the level of their head and, over a strip 5 to 6 miles broad, upon either side of the river, have virtually ceased to flow. The loss of head during the past ten years averages from 5 to 10 feet and, in regions where flowing wells could be counted by hundreds, scarcely a one remains (see Pl. XXV). To the south of the Huron in Monroe County a careful survey of the flowing well districts, made during the summer of 1911, revealed the fact that not a single well now reaches the general surface and but five still remain flowing upon flats from 3 to 5 feet below the general level. North of the river, very exceptionally a genuine flowing well may still be found, but giving only a greatly reduced flow under low head. The wooden casing projecting above ground with its succession of holes tells the pathetic story. Although the decline has been continuous over a long period it does not appear to have been gradual. A very marked reduction occurred in 1904 and led to an investigation of the probable causes by Myron L. Fuller, of the U. S. States Geological Survey.[12]

Fuller's investigation. The data gathered for this report were obtained in the main from Monroe County, adjacent to the Huron, the region north of the river, between Rockwood and Detroit River, then showing comparatively little shortage. Since then, however, every well in this section upon the general level has ceased to flow, some of them as late as August, 1911. Evidently the causes are still operative and before discussing what these appear to the writer to be, it will be of interest to the reader to learn the conclusions of Fuller as presented in his report.

"The general decline which has been going on for many years is probably due to a gradual and far-reaching change of conditions, such as deforesting of the land, improvement in surface drainage, etc., but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question."

Grosse Isle well.—"That the Grosse Isle well (see Pl. XXIX, A and B) is the cause of the special decline in 1903 and 1904 may at first thought seem well sustained by the behavior of certain wells, as J. E. Brown's of the Swan Creek and Charles Bancroft's

12. See Water Supplies of the Lower Huron River Region. Flowing Wells and Municipal Water Supplies in the Southern Portion of the Southern Peninsula of Michigan, 1906, p. 33. Water-supply and Irrigation Paper No. 182, U. S. Geological Survey, Washington, D. C. Also Geological Survey of Michigan, Annual Report for 1904, p. 7.

of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned soon after the insertion of the casing, only to cease again after its withdrawal in May, 1904. This interpretation, however, seems opposed by the fact that numerous other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be very exceptional, which would leave a nearby district unharmed while seriously affecting more remote districts, and belief in them would need be supported by indisputable evidence in the altered slope of the water table. In order to obtain light on this point the height to which water will rise was platted for each well in the Swan Creek-Rockwood region. It was found that this height showed an increase westward which averaged about 3 feet to the mile, indicating a source from that direction. The increase of head to the west or decrease to the east was found to be quite regular, with no local lowering or reversed slope that could be referred to a strong intake at a particular place. It was also found that the water level of the Grosse Isle gusher is higher than that of the shallow wells around it, and even higher than that of the wells of the Rockwood and eastern portion of the Swan Creek area, being 25 feet above the lake, or 597 feet above the sea, while the normal level in many of the wells which have been thought to feed it is several feet lower, in some of them being less than 590 feet. It would appear, therefore, that if any connection exists between the Grosse Isle well and the shallow wells in the Rockwood and Swan Creek areas the water would be forced up in the shallow wells rather than drawn away from them. The failure of such wells as the Brown and the Bancroft flows in 1903 was probably a mere coincidence. The precise point where the main water-bearing bed of the Grosse Isle well outcrops and takes in its main supply can not be stated. On the basis of the dip of the rock formations from southeast to northwest, at the rate of about 20 feet a mile, it would seem probable that the bed struck at 450 feet in this well will come to the surface somewhere west of Leamington in Canada. The supply seems, therefore, more likely to come from the Canadian than the Michigan side of Detroit River.

Newport quarry.—The underdrainage caused by the quarry at Newport was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions were investigated. It was found that a few of the wells near at hand have been affected, but the decrease in water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted. From this it appears that the quarry can not be considered a factor in the shortage along Swan Creek or in the Rockwood region.

Low stage of streams.—The level of streams generally determines that of the ground water in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron River and Swan Creek were unusually low, and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. Huron River, being a longer stream, and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which is within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is most marked along its course rather than in any other part of the region.

Early winter of 1903.—This appears to have been an important factor in bringing on the present acute shortage. According to the official records, the permanent freezing of the ground took place on November 17, which was before heavy snows and heavy winter rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and early spring months. This was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the ground water was at an unusually low stage.

CONCLUSIONS.

The low rainfall, which in the spring of 1904 varied from one-eighth to somewhat more than one-half of the usual amount at the stations in the tables, was, on the whole, even less in the lower Huron River region itself. The deficiency of rainfall, following as it did an autumn and winter during which little water was absorbed owing to the frozen condition of the ground, together with the preceding dry season of 1903, seems ample to explain much if not all of the observed shortage.

Although considerable rain fell in July, and even more than the normal in August, it came largely as short heavy showers, and the water, instead of soaking into the ground, as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell. In this connection it may be remarked that, while the shortage was felt in the region under discussion sooner than elsewhere, the drought became severe enough later in the summer to be felt through all the states bordering the Ohio and eastward to New England, causing much shortage in wells.

If, as seems probable, the failure of the well is due largely to the severe drought of 1903-4, the return to the normal rainfall should result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or perhaps a succession of wet years, occurs.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey material when dried out may, to a certain extent, crumble and become more or less clogged, so that their capacity for carrying water is lessened or destroyed even when the ground again becomes soaked. The return in any case will probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

The wells in the lower Huron River region obtain their supplies largely in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more open and jointed portion of the rock, because there is less resistance to its flow through the crevices and openings in the rock than through the compact clayey deposits which so generally overlie the rock formations of the region. The rock formations appear, therefore, to take in the water from the overlying glacial deposits, and, as shown above, a deepening of the wells into the rock has generally met with at least partial success. The great majority of wells now are exceptionally shallow compared with those of large areas in Michigan, where depths of 100 to 150 feet or more are common. It seems probable that wells of such depths in the region under discussion would yield permanent and abundant supplies."

Present conditions. The exceptional climatic conditions of 1903-4 held responsible for the decline of the water in the above region have passed away but without furnishing any relief in the situation. So far as we may judge from the Detroit records, the amount

of precipitation in this section of the state has about held its own during the last decade. Deforestation, better drainage, cultivation of the soil over the collecting areas for this underground water, along with cycles of climatic change, may be expected to have operated equally upon the western belt of flowing wells and upon the northeastern extension of this same eastern belt. Not having done so, leads one to infer that some exceptional causes are operative in the lower Huron area. There is little doubt that the large number of flowing wells and springs opened in the district, with no attempt whatever to reduce their flow, would sooner or later, bring about a marked reduction in head. The effect should show itself first in the higher, western tract and gradually work its way toward the lake, near which we should expect to find some wells still flowing. That these have also ceased indicates, either that the collecting area has failed to receive the amount of water adequate to maintain the regular flow, or that the water is being drawn off at a lower level. In view of the facts stated above the former of these hypotheses may be eliminated from the discussion and we may consider any facts relative to the latter in our search for the probable cause of the water failure in this region. Our attention is thus directed to the quarries of the region, the Livingstone cut, the Grosse Isle flowing well and the Oakwood salt shaft, all of which are instrumental in abstracting the water from the deeper strata and delivering it at the surface.

Mr. Fuller has given good theoretic reasons for believing that the Grosse Isle well of James Swan could not be held responsible for the sharp decline which called forth his investigation. The farmers of the district were thoroughly convinced, however, from the behavior of their wells, that it was the immediate cause and made up a purse in 1904, which was used in bringing about a conference between Judge Swan and the supervisors of the townships interested. As a result of this conference, the farmers were asked to raise a fund of $500 for the purpose of reducing the flow of the well to a 4-inch stream, when, if it should appear that the well was really responsible for the loss of head upon the mainland, a gross sum or annuity, to be decided upon later, should be paid Mr. Swan. The proposition was not accepted by the farmers and the well is still discharging into Detroit River some 4,320,000 gallons daily, with no attempt at utilization. As to the possible connection between this well and the sudden decline in the wells at Flat Rock, Mr. Curtis L. Mettler, flour and lumber merchant, writes: "In the summer of 1903, Mr. Swan was boring a well on his farm, supposedly for oil; and at about 400 feet below the surface, struck a vein of water. So strong was the flow, that he was obliged to case it in order to proceed drilling. During the time between the striking of the vein and getting the casing in place, many of the small flowing wells stopped running. When the casing was placed in the well, it cut off the flow of water, and all, or nearly all of the wells commenced flowing again. He continued drilling until the well was about 2200 feet deep, and gave it up, (in the summer of 1904) and drew the casing out, which allowed the water to run again. The wells on all the farms again ceased flowing, and are still dry" (Dated Nov. 15, 1911). The heavy flows of water referred to were struck at depths of 420 feet and 450 feet, consisting of fresh water, the sulphur being introduced from smaller flows at a greater depth. The casing was in position from August, 1903, to May, 1904. It might be urged that the response of the wells upon the mainland was too prompt, but with subterranean passages in the dolomitic strata perhaps this can not be urged against the explanation given.

From the Livingstone cut in the strata of the Detroit River bed, opposite Stony Island (see Pls. V, A and XXIV), there has been a very heavy pumpage, estimated by Supt. G. P. Locker at 12,000,000 gallons daily. Since the first steam shovel was started Oct. 27, 1908, the flow from strata has gradually increased and although some of this comes directly from the river, the presence of much sulphur and iron indicates that the bulk of it is directly from the rock, to a depth of 24 feet below the river level, or an actual elevation of 550 feet above sea level. Mr. George H. Cohoon, a well driller of Trenton, of many years' experience, is convinced that we have here the cause of the recent failure of wells in northern Brownstown and Monguagon townships. Before this report finds its way into print, the water will have been allowed to fill this cut and former conditions to some extent restored by water pressure. Mr. Fuller considered the possibility of the quarry at Newport being responsible for the shortage in that vicinity, but finding that the drainage into this amounted to but about 43,200 gallons daily and that some wells near at hand seemed to be unaffected, decided that this might be neglected. When, however, all of the quarries of the Detroit River region and the Oakwood salt shaft are considered together there seems much more probability that we may have here one of the efficient factors. An effort was made to collect as definite data as possible from those in charge of these industries relative to the average daily pumpage. In combination with the loss of water from other sources, we have the following table which shows that the rock strata during the past three years have been losing *daily* between 17 and 18 millions of gallons, equal to the entire flow of Detroit River for *11 seconds*. Or to look at the matter differently, this quantity of water represents the probable absorption over 17 to 18 square miles of the collecting area. With these data before us there is little cause of surprise that the wells of the adjacent region should have lost a few feet of head.

TABLE LXI. ESTIMATED AVERAGE DAILY PUMPAGE.

Livingstone Channel cut	12,000,000 gallons.
Grosse Isle well	4,320,000 gallons.
Oakwood salt shaft	568,800 gallons.
Sibley quarry	350,000 gallons.
Anderdon quarry	150,000 gallons.
Gibraltar quarry (now filling)	144,000 gallons.
Rockwood sand pit (no estimate available).	
Newport quarry (now filled)	43,200 gallons.
Total	17,576,000 gallons.

Remedies. As to remedies there is something to be said although there may be little of practical value to be done. The Livingstone cut is now filled, the Patrick quarry upon Grosse Isle, the Gibraltar and Newport quarries have been abandoned and now stand full of water, the pressure of which will prevent loss from the strata. The shaft of the Oakwood salt shaft will be eventually completely jacketed with cement which will take care of the loss there. So long as there is no attempt made to utilize the flow from the Grosse Isle well, this should be securely confined. In this way, the loss will be reduced to 600,000 gallons daily, a very small percentage of what it has been during the past three years. In closing his report, as published in the Michigan Geological Report for 1904, Fuller calls attention to the desirability of legislation looking towards the control and conservation of this very important resource, the necessity for such legislation becoming more and more urgent each year (page 29).

"Ground water is properly a commodity belonging to the public at large, and is an asset of recognized value. The amount is not unlimited at any point, and any decrease in its volume means a reduction of assets and a permanent loss to the community. It is difficult to prove damages to surrounding wells caused by free flows, but when it is remembered that the underground supply is limited in amount, and that the available supply is being constantly decreased by such flow, it is readily seen that the loss is none the less real. A freely flowing well is in itself a proof of such loss, and should be forbidden, except where reasonable use is made of it.

(1) An enactment should be passed making it unlawful to permit water to escape where no use is made of it regardless of the size of pipe or volume of flow, and a penalty should be fixed for its infraction.

(2) An enactment should be passed making it obligatory in case of abandoning a well over two inches in diameter to securely plug it above and below each water horizon, or to fill the hole with cement or other impervious material, with a penalty fixed for its infraction as before.

(3) An enactment should be passed requiring that wells, when not in use, shall be closed down until not more than an inch stream[13] is flowing, a penalty to be attached for its infraction as before.

(4) Provision should be made for restraint of flows by injunction on application of parties presenting evidence of waste.

(5) The power of entering private property for the purpose of determining questions relating to waste should be given to proper officials."

13. The writer would make this a quarter-inch stream instead, or perhaps prescribe a certain measured flow per minute.

CHAPTER VIII.

ECONOMIC RESOURCES.[1]

MATERIALS USED IN CONSTRUCTION.

Clays. Although the bedrock of the county is covered with a heavy burden of glacial clay, the occurrence of pebbles more or less abundantly throughout the formation renders it unfit for the usual forms of manufacture. In certain sections, the percentage is relatively low and, by running the raw clay through a crusher, they may be reduced to powder, the rock fragments too coarse for the crusher being removed by hand. Another method for utilizing such clay is to place it in tanks where it may be disintegrated by water and the water, carrying the clay in suspension, allowed to flow into settling vats from which it may be recovered. The inconvenience and expense necessitated by either of these methods prevent their use until the purer grades of sedimentary clays have been exhausted in this region. As pointed out in Chapter III, these clays have already been subjected to this washing process in Nature's great laundry, resulting in the removal of the sand, gravel and boulders and the deposition of the clay along the river courses and over the beds of the extinct lakes. The most important of these deposits have been described in Chapter III of this report and their characteristics presented.

When subjected to the burning process, as in the manufacture of brick and tile, the clay loses its original color and assumes a pink, or pale red. The deeper red, commonly desired, is obtained in the case of the brick by dusting over them, before burning, pulverized iron oxide and in the case of the roofing tile a clay wash rich in iron. The paleness of the burned clay is not due to an insufficiency of iron in the clay itself but to its neutralization by the alkalies present, and is a positive advantage in the case of the roofing tile since this color serves as a better background for the ordinary glazes than a deep red would do. The shrinkage of the clay is ordinarily low and may be still further reduced by adding sand in small quantity, too much giving a porous product. Data

1. When the original data relative to the economic resources of Wayne County were collected in 1902-3, detailed statistics were obtained concerning the various industries. Since these are now out of date and the State Geological Survey has recently been assigned the duty of gathering such statistical data, the reader is referred to the Survey for such information.

relative to the air and fire shrinkage have been obtained by W. G. Worcester, formerly superintendent of the Detroit Roofing Tile Company, as follows:

TABLE LXII. SHRINKAGE UPON SIMPLE DRYING OF SPRINGWELLS CLAY.

Percentage of water loss.	Percentage of shrinkage.
2.0%	1.0%
4.0	4.5
12.3	5.0
17.0	5.0

This table indicates that although the loss of water beyond 12.3% continues, the shrinkage ceases at 5%. The fire shrinkage is indicated in the following table:

TABLE LXIII. SHRINKAGE UPON FIRING OF SPRINGWELLS CLAY.

Cone	.010	.08	.06	.04	.02	1	2	3	4	5
% Shrinkage ..	0	0	0	.50	.50	2.50	3.75	5.50	6.00	Melting.

These experiments were conducted in a small kiln, "under commercial conditions," and indicate a fusing point of approximately 2246° F. (1230°C.) for the clay. With long continued firing, as in the actual kiln, Mr. Worcester thinks that the clay would fuse at about cone 3, or 2174°F. (1190°C.). The following table shows the composition of ordinary brick clays, giving the range met with and the average percentage of each ingredient.

TABLE LXIV. CHEMICAL COMPOSITION OF COMMON BRICK CLAYS. (RIES.)

Constituent.	Range.	Average.
Silica (SiO_2)	34.350-90.877%	49.270%
Alumina (Al_2O_3)	22.140-44.000	22.774
Ferric oxide (Fe_2O_3)	0.126-33.120	5.311
Calcium oxide (CaO)	0.024-15.380	1.513
Magnesium oxide (MgO)	0.020- 7.290	1.052
Alkalies (K_2O, Na_2O, NH_3)	0.170-15.320	2.768
Water (H_2O) chemically combined...	0.050-13.600	5.749
Moisture mechanically combined	0.170- 9.640	2.502

These lake clays are utilized mainly in the manufacture of the common variety of building brick, some two dozen plants being so employed, one of them making also drain tile. In general, only the "soft mud" process is employed, the brick being moulded

by hand or machinery and ordinarily "burned" in the familiar type of "scove kiln." These kilns are loosely constructed each time of thoroughly dried brick to be burned, are of rough, rectangular form, crossed at the base with a series of parallel arches in which the fuel is consumed and the heat generated. The top of the mass is covered with a more tightly fitting layer of brick ("platting") while the sides and ends are daubed with mud to exclude the cold air while the burning takes place. Wood, coal and coke have been used as fuel but are now almost entirely replaced by crude oil. The burning requires from 5 to 7 days, depending upon the nature and condition of the clay and the atmospheric conditions prevailing at the time. At a few of the yards, especially where the drying is done artificially in steam-heated rooms, the burning is done in kilns more permanently constructed and provided with the "down-draft" system, thus securing a more uniform distribution of the heat. At the Clippert plant dryers are used with a capacity of 64,000 brick into which they are introduced at a temperature of 160°F. and pushed along to where the temperature is about 212°F. The air is heated by the fan system, drawn in over hot coils and about 48 hours are required for the drying. Many millions of brick have been burned here for years, the shallower deposits of clay nearer the city being gradually used up and the works shifted westward along Michigan Avenue. The markets have been mainly local, the product delivered by teams, but some have also been shipped by rail to various parts of southern Michigan and northern Ohio. Most of the yards are operated 5½ to 6 months of the year, closing down with the advent of freezing weather in the fall. Two or three of the larger plants, however, are so equipped that they can operate the year round, the clay being handled with steam shovels and small cable-drawn carts.

The manufacture of pressed brick was attempted for a short time by the Detroit Red Pressed Brick Co. but soon given up, the clay not being well adapted to this style of brick. According to the observations and experiments of Mr. W. G. Worcester, the clay has a strong tendency to laminate, thus unfitting it for pressed brick, as well as those made by stiff-mud processes. These clays were found to possess very high cross breaking strength while in dry condition, permitting their use for thin section ware. A small plant is in operation at Fifty-Ninth St., just south of Michigan Avenue, for the manufacture of flower-pots.

Drain tile are manufactured at the plant of J. C. McDonald and Son, Warren Ave. (SW. ¼ sec. 4, Springwells), in addition to the common brick. The local markets only are supplied, this being the only tile plant within the limits of the county at present. The southern part of the county, however, is supplied with drain tile from the John Strong plant at South Rockwood, just south of the Huron. The chief demand is for 3 and 4-in. sizes but 2½, 6 and a few 8-inch sizes are also manufactured. Only the circular style is made, which burn to a pale red in down-draft kilns in about 3½ to 5 days. The "stiff mud" process is employed in moulding the tile and about a week's time is required for drying. The Detroit Roofing Tile Co., one of but 13 now in this country, has been in operation since 1905, located alongside the Michigan Central Ry., halfway between West End and Woodmere. Here they have 12 feet of clay well suited to their purpose, overlain by 3 feet of sandy loam stripping. After being thoroughly worked in the pug mill, the raw clay is allowed to "age" for 3 to 4 days by which process it is considerably toughened. The soft mud process is employed and many styles and varieties of interlocking roofing tile are turned out, most of which are shipped to the Atlantic coast and south as far as New Orleans. The local demand for this product is growing and seems destined to greatly increase because of its durability and artistic qualities.

Some 40 to 50 years ago, the city of Detroit was supplied with brick mainly from the vicinity of Leesville, Gratiot Ave., where some 6 feet of a yellow clay were available. The plants were located from a half mile south to a mile north of the village and some were in operation as late as 1900. Although the clay suitable for brick was not entirely exhausted, the business has been shifted to Michigan Avenue. Brick are also manufactured at Dearborn, in the southeastern part of the village, by Anthony Wagner and shipped to neighboring cities. The clay is of a brownish yellow variety, about 7 feet deep and said to extend over about 28 acres, about one-half of which has been used. It burns to a good shade of red in about 8 days, the plant running from 6 to 7 months each year. Both brick and tile were manufactured in the SE. ¼ NE. ¼ sec. 26, Redford township, up to about 1892, supplying the local demand only. There is said to occur here some 40 acres of suitable clay, from 6 to 10 feet thick. Brick and tile have been manufactured for many years by Milton E. Carlton, SE. ¼ NE. ¼ sec. 28, Canton township, the clay being obtained from the Rouge flats, brown in color and about 4 feet thick. Below this clay is a sandy type of clay, utilizable for brick but not tile. Two down-draft kilns are used for burning the product. Brick were made some 35 to 40 years ago at the NW. ¼ NW. ¼ sec. 5, Dearborn, to

supply the demand for use in chimneys when the old fashioned stick and mud chimneys passed out of date. Some drain tile were also made here, only surface clays being available. For a time, some brick were also burned in sec. 33 of Redford (NE. ¼ NE. ¼). Farther north in sec. 10 (SW. ¼ NW. ¼), S. K. Burgess began making brick and a few tile in 1871,—at the time of visit, the plant being operated by L. J. Burns. The clay is stratified, 4 to 5 feet thick and overlain by 4 to 8 inches of surface soil, containing enough sand so that none needs to be added. Below the clay is two feet of quick sand and then blue clay ("till"). The stiff clay process was the one employed. In the village of Northville, along the Rouge (NE. ¼ NE. ¼ sec. 9), a small brick establishment was operated for a time by Walter Randall, the bricks made being perforated at either end with a ⅝-inch hole (stiff clay process). The clay deposit was 4 to 5 feet thick and contained some pebbles; burning very unsatisfactorily, to a yellow, then red and sometimes a dark purple.

That the clays of Wayne County have not been utilized in the manufacture of Portland cement is due probably to the absence of any very extensive beds of marl, or "bog lime." An entirely suitable rock can be obtained from the Sibley and Macon quarries, but is in great demand for the purification of beet sugar and the manufacture of soda-ash.

Sand, gravel and boulders. Along the broad belts described and mapped as the Wayne, Grassmere and Elkton beaches, almost unlimited quantities of a more or less pure yellow sand are available. Although heaped up by wind action, and with little sign of stratification, a small percentage of clay is generally present. Many such ridges and mounds are entirely free from pebbles. The most accessible deposits are those near Sand Hill and Romulus, but less extensive ones can be reached along any of the steam and electric roads leading out from Detroit. The Maumee, Whittlesey and Warren beaches contain poorly assorted patches of a sharper, gray sand, interstratified with gravel strata. The kame hills in the northwestern corner of the county, although largely gravel, contain also some sand which locally became separated from the pebbles. The gravel in the kames is generally pretty well assorted but differs considerably in different ones, as might be expected. The pebbles are rounded to subangular and consist of 40 to 50% of limestone and dolomite, with 12 to 20% each of chert, quartzite and igneous fragments. The sandstone and argillites were largely eliminated from the deposits, perhaps by stream action. In the case of one kame from which 200 pebbles were collected at random (NW. 1/4 SE. 1/4 sec. 11, Northville) and then classified, the limestones and dolomites numbered but 9 (4½%), with a corresponding increase in the number of the harder fragments. If the sample studied fairly represents the entire kame such gravel would have much higher value for road construction; since the limestones and dolomites are more readily ground to powder and blown away. The composition of the beach pebbles does not differ greatly from those of the kames, being slightly lower in the limestones and dolomites and somewhat higher in the quartzites and igneous varieties. The location of these beaches, especially rich in gravel, as the younger ones are in sand, is shown upon Pl. X. Nearly the entire upper two-thirds of Northville township is dotted with gravel deposits; especially sections 2 to 11, inclusive. Many of these could be made very accessible by building short spurs from the Pere Marquette Ry. and the electric lines. Much of this gravel has been already utilized in road building in Northville and Plymouth townships, but comparatively little has been shipped outside.

The gravel for the system of concrete roads now being built has been obtained from the neighborhood of Chilson, Livingston County, where the deposit is more accessible to the railway. The firm supplying the same is known as the Michigan and Ohio Sand and Gravel Company. In geological reports, it has been customary to urge the importance of good roads, but this would be a waste of effort so far as Wayne is concerned. The people of this county are thoroughly awake as to their importance and have set a splendid example for other counties to follow, who may well send their officials here to investigate the working of the plan. With some 57 miles of good roads already constructed outside of the limits of Detroit and Wyandotte, the county voted upon Nov. 8, 1910, to bond itself for $2,000,000 by which it is proposed to build 200 additional miles of concrete road within the next five years. This splendid work has already begun with most gratifying results, the farmers estimating that fully 60% of the expense of marketing their produce is thereby saved. This saving is in horse flesh, wagon and harness repairs, and in time; besides which are to be considered the advantage of marketing produce at the convenience of the farmer, or when the market is just right, instead of when the roads happen to permit. The roads now under construction are built of concrete, 6½ to 7 inches thick and 10 feet to 18 feet in width, and will form a net work over the county.

The field stone, or "hard heads," were quarried by the old ice sheets in Canadian territory and transported for many miles to Wayne County, being dropped as the ice melted from beneath them. They mantle the moraines already described and are arranged in three rather distinct belts across the county, from north to south (see Pl. X). They have been extensively gathered and used as supports for sills, horse blocks, foundation walls for barns, houses and other buildings, for chimneys; in some cases entire buildings being constructed of them. Where especially abundant, ridges formed of these boulders and cobbles serve as fences. They are often utilized to prevent a stream from eroding its bank, or to check the velocity of a temporary torrent in a side hill gully. An examination showed that these stone consist largely of igneous rocks (62%) and quartzite (29%) rocks; the softer limestones and argillites being comparatively rare (3%). When crushed, they form a much more durable material for road macadam, than gravel, limestone or dolomite. Owing, however, to their relative scarcity, the expense of collecting them and the abundance of other road metal in the county, they are not thus utilized. Occasionally one is found capable of receiving a good polish, in which case it may be used for a monument, corner stone, key stone, etc. Within the last few years, several car loads of such cobbles have been shipped from Michigan, as far west as Iowa, to be used in the grinding of portland cement.

Limestone and dolomite. The artificial exposures of these rocks in the vicinity of the lower Detroit River region furnish three types of material that may be classified under the head of construction; viz.: building stone, macadam and lime. The various localities in which such materials are available have been described in some detail in Chapter VI of this report. Solid blocks of bluish-gray limestone, of almost any desired size, may be obtained from the lower strata of the Sibley quarry, just north of Trenton (Pl. XXX, B). The drab dolomitic strata of Monroe age are not so heavily bedded and still some massive blocks were obtained for the retaining wall at the northern end of the Livingstone cut. Buildings constructed of this dolomite in Monroe show that the rocks remain intact but in the course of 36 to 50 years a mealy coating 1-10 of an inch thick has formed over the surface. In the case of Trinity Church, built in 1868, the sandstone sills still retain some of the tool marks, but the dolomitic blocks give considerable evidence of surface decay.

The limestone appears to be more resistant to the atmospheric influences. The above church contains a water-table of Sandusky limestone, of the same general nature and geological age as that of the Sibley quarry, which shows much less evidence of decay than does the Monroe dolomite. The present popularity of cement for bridges, culverts, side-walks and curbing has greatly reduced the demand for building stone of the type here available.

When run through heavy crushers, both the limestone and dolomite are converted into road metal, for macadamizing purposes, for which there has been considerable demand. Much of this has also been used in providing a dustless and weedless ballast for the steam and electric railways. The demand for such material seems to have slackened, since the Patrick and Gibraltar quarries have been temporaily abandoned and the two great dump heaps of the Livingstone cut (Pl. V, A) are to remain unutilized. The Sibley quarry converts its rock, unsuited to other purposes, into macadam (Pl. XXXI, A).

When subjected to heat, the high grade limestone of the Sibley quarry loses its carbon dioxide gas and is converted into calcium oxide, or quick-lime ($CaCO_3—CO_2=CaO$). This has the well known property of uniting with water ("slaking"), forming calcium hydrate, with the evolution of much heat ($CaO+H_2O=Ca(OH)_2$). In this form, it is sparingly soluble in water forming "limewater," useful as a mild form of alkali in medicines and various industries. When a slush of calcium hydrate is mixed with sand, to prevent shrinkage and to render it more porous, and exposed to the air, the carbon dioxide of the atmosphere unites with the hydrate forming lime carbonate over again and water ($Ca(OH)_2+CO_2=CaCO_3+H_2O$). The excess of water originally present, as well as that newly formed, is evaporated and the mortar, or plaster, is slowly hardened, adapting it to the familiar building uses. An excellent quality of lime is made at the Sibley quarry in iron kilns of the "continuous" type, which are fed periodically with suitable stone at the top and from which there is periodically removed the fresh lime at the bottom. These are a great improvement over the side-hill stone kilns in vogue a few years past. The dolomites yield a different type of lime, which slakes more slowly, develops less heat, capable of binding less sand and requiring more time for setting. The chemical action taking place is shown by the following equation, showing that magnesium oxide ($CaO.\ MgO+H_2O=Ca(OH)_2.\ MgO$) is combined with the calcium hydrate. When once thoroughly set, however, the product is often harder than that obtained from the limestones, partaking sometimes of the character of hydraulic cement. Owing to their in-accessibility, these dolomitic strata were not much used in Wayne County in an early day, the supply of this type of lime coming from Monroe County. Some 25 years ago, small quantities of lime were burned at Flat Rock by James and William Breeland, father and son, the rock being obtained from the bed of the Huron.

The impression has been held by different individuals that the Monroe dolomites, upon being properly handled, should yield hydraulic cement which differs from ordinary plaster and mortar in that it will harden out of contact with air, as under water, thus adapting it to many new uses. The rock employed which may be either a limestone or dolomite, should contain some 15 to 35% of clay and a little potash or soda. The presence of sand in the form of grit is objectionable. The analyses of the Monroe County strata and the few experiments that have been made upon them have not held out much prospect of success along this line.[2] An artificial mixture of calcium carbonate (72 to 77%) with a silicious, but not gritty clay (23 to 28%), containing potash or soda, may be heated to a high temperature (2900°F.) and reduced to powder, forming Portland cement. During the so-called "burning" there are formed tricalcium ortho-silicate ($3CaO, SiO_2$) and tricalcium aluminate ($3CaO, Al_2O_3$),[3] which, upon becoming wet, are converted into crystalline insoluble hydrates of calcium and aluminum. Certain beds of the Sibley quarry could be selected, which with the lake clays of the West Detroit area would give the right combination for the manufacture of this much utilized product.

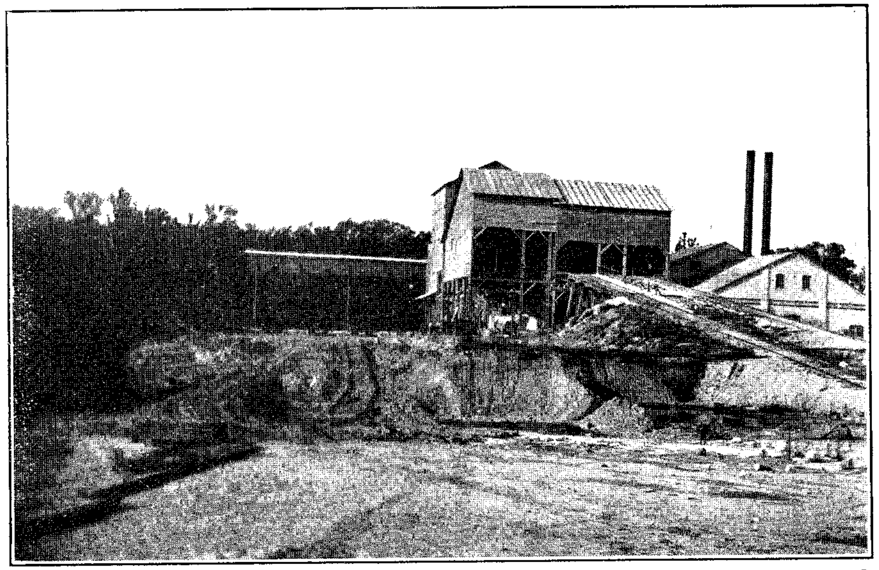
Sand-lime brick. Wayne County possesses two plants for the manufacture of this type of building material, in which Michigan leads all other states. The industry is but 12 years old in this country, having been introduced from Germany, and consists in the moulding of brick from a mixture of lime (CaO) and quartz sand (SiO_2). As carried out by the Sibley Brick Company, operating since 1904, thoroughly hydrated lime of their own manufacture is ground to powder and mixed with sand, sucked from the bed of Lake Erie, near Gibraltar. Any type of silicious sand may be used which is reasonably free from clay and not too coarse, but those sands are preferred in which there is considerable variation in the size of grain. The granules should be sharp and angular to secure the best results, so that the Sylvania with its rounded, evenly assorted granules is not ideally adapted to this use. The lime used should be as free as possible from any content of mag-

2. See Geological Report on Monroe County, 1900, p. 180. Geological Survey of Michigan, vol. VII, pt. 1.
3. Along with tricalcium aluminoferrite, $3CaO2(AlFe)_2O_3$.

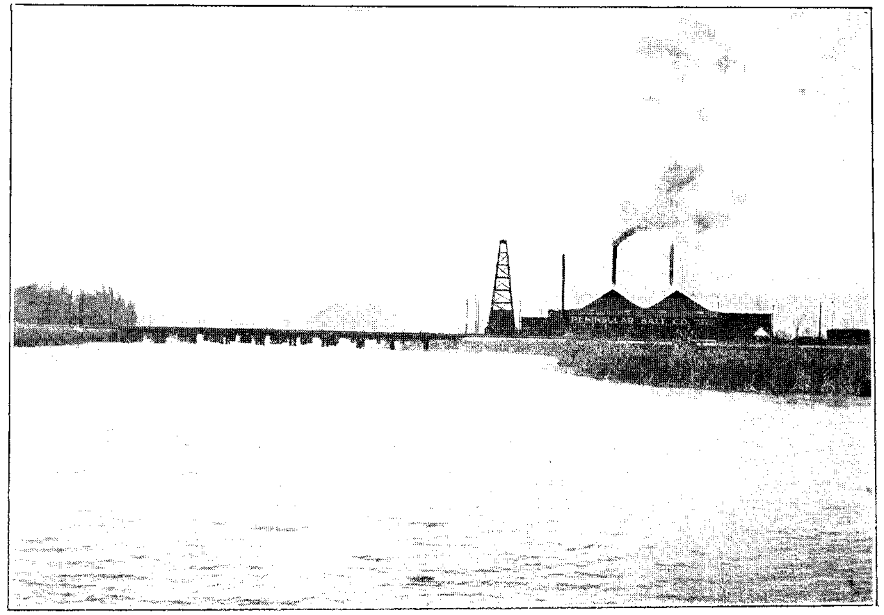
nesia. Five shovels-full of moist sand are thoroughly mixed with one of the powdered lime hydrate, producing a mixture in which about 95% is silica and 5% lime. The bricks are moulded under a pressure of 8,000 lbs. to the square inch, placed in a boiler and subjected to a steam pressure of 125 lbs. to the square inch for 10 hours, giving rise to a chemical union of the calcium and silica to form calcium silicate ($CaSiO_3$). The bricks are then allowed to stand for about three months before being placed upon the market, during which an absorption of carbon dioxide gas from the atmosphere occurs. The bricks thus produced are a very light gray, perfectly formed, with sharp edges and smooth surfaces and have undergone practically no shrinkage or warping. They may be colored to almost any desired shade. Subjected to pressure tests it has been found that they show greater regularity than common brick and a crushing strength equal to that demanded for brick of good quality. The average of 255 tests gave an average of 2190 lbs. pressure per square inch. The loss of strength through the absorption of water averaged 14%. The amount of water absorbed amounted to 14.9% weight and 26.3% volume, less than for ordinary clay brick, while the test with heat and sudden dash of water shows that they stand up as well as the clay. Mortar is found to adhere slightly better to the sand-lime brick than to those made of clay and because of their more nearly uniform size and shape they can be more rapidly laid. In localities where clay is absent or scarce and sand and lime abundant, this type of brick is bound to come into favor. In addition to the plant at Sibleys, they are also manufactured in Detroit by the Michigan Pressed Brick Co., corner of Lawton Avenue and the Michigan Central Railway, this present company having operated since 1908. The lime is obtained from the Sibley Quarry Co. and the sand from near Rochester, Michigan.

CHEMICAL MATERIALS FOR DIRECT USE OR MANUFACTURE.

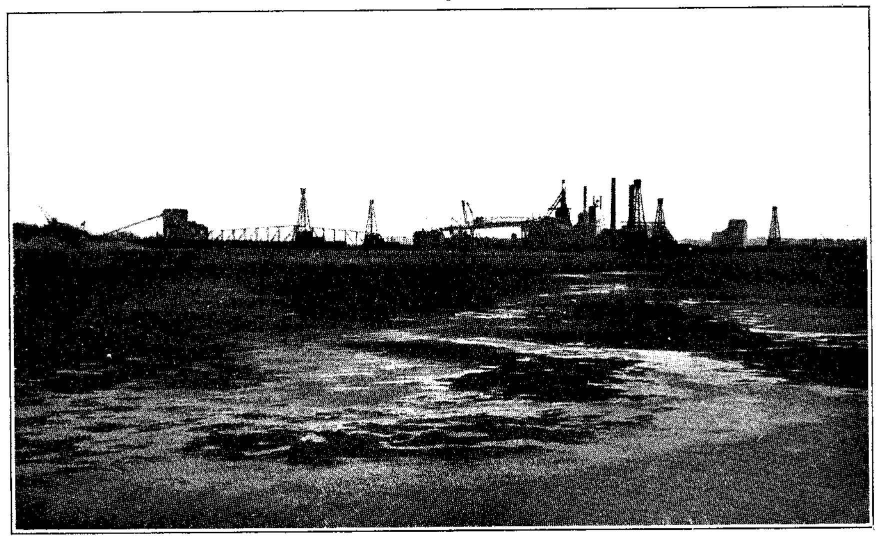
Calcium carbonate. High grade calcium carbonate with very little or no magnesia, and small percentages of silica and iron, is in great demand for the manufacture of soda-ash (Na_2CO_3) and the purification of beet sugar, in both of which industries Michigan holds a leading rank. The rock should contain from 95 to 99% of the calcium carbonate and can be obtained from the "9-foot bed" of the Sibley quarry, which averages 98% pure. The Anderdon bed has been reached in the deeper excavations of the quarry and will probably be found to carry a uniformly high percentage



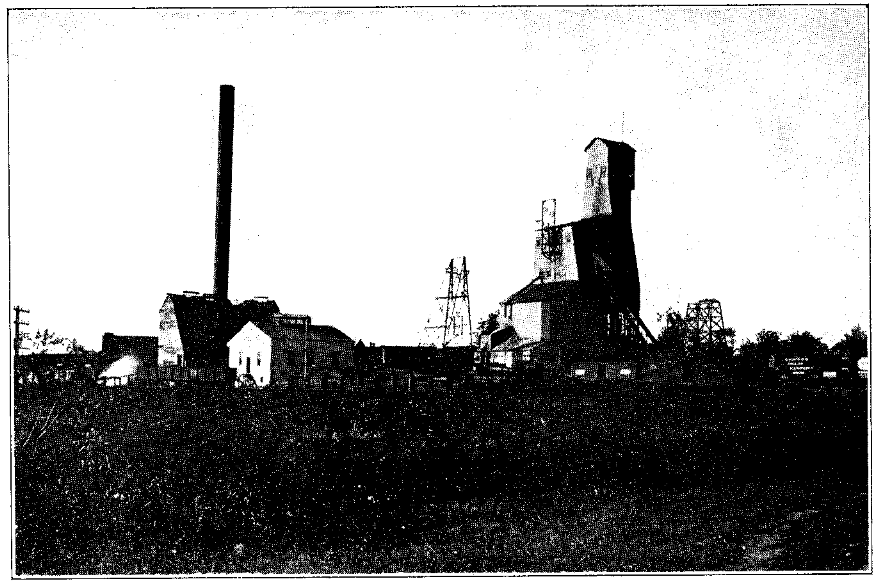
A. NEAR VIEW OF SIBLEY CRUSHING PLANT.



B. PLANT OF PENINSULA SALT COMPANY AND RIVER ROUGE.



A. PLANT OF SOLVAY PROCESS COMPANY, DELRAY, FOR THE MANUFACTURE OF SODA ASH.



B. SURFACE PLANT OF OAKWOOD SALT SHAFT, MICHIGAN'S ONLY SALT MINE.

of this carbonate, as at the Anderdon quarry upon the eastern side of Detroit River. One of the first steps in the manufacture of the so-called soda-ash is to secure a quantity of ammonium hydrogen carbonate (NH_4HCO_3) and this is done by saturating water with ammonia gas and passing through it a current of carbon dioxide gas, obtained by heating calcium carbonate as in the manufacture of quick lime previously described. The reaction that takes place is indicated by the following equation:

$$(1)\quad NH_3+H_2O+CO_2=NH_4HCO_3.$$

This product is converted into sodium carbonate, through the agency of salt in a way to be mentioned later.

In the manufacture of beet sugar, a high grade limestone is also required, a plant using 300 tons of beets daily needing from 35 to 40 tons of limerock. Both the quick lime and carbon dioxide gas obtained by heating the calcium carbonate are utilized, the two being again united. Too much silica, silicates and alumina cause trouble in the burning, while magnesia and gypsum interfere with the filtering and evaporation of the juice. The lime in the form of powder, or in solution as "milk of lime," is added to the beet juice and unites mechanically and chemically with the impurities present. The addition then of the carbon dioxide gas brings about a union between it and the calcium hydrate, according to the equation previously given:

$$Ca(OH)_2+CO_2=CaCO_3+H_2O.$$

The calcium carbonate appears as a flaky precipitate and settles to the bottom carrying its load of impurities, being then readily separated from the juice by filtering. At present this material is carted away as waste and used as a land fertilizer by the farmers. If some practical scheme for purifying it could be devised the calcium carbonate could be recovered, with some necessary waste, and utilized over and over again. The exhaustion of the supply of suitable limestone may eventually make this necessary. Lime is still further used in recovering from the "molasses" its final content of sugar, forming with it tricalcium saccharate, $C_{12}H_{19}O_{11}.(CaOH)_3$. From this saccharate, both the sugar and the calcium hydrate may be recovered. Were it not for the heavy covering of drift the section of country between Sibley and Dundee would supply a high grade carbonate for many years to come.

Deposits of marl occur only in limited amounts in the county and usually in too impure condition to be used for the production of soda-ash or beet sugar, but entirely suitable for cement manufacture, for quicklime and as a fertilizer. This form of calcium carbonate is produced in ponds and swamps through the action of plant and animal organisms in secreting from the water the calcium carbonate there held in solution. The mollusca extract this substance for use in the production of their shells and, upon their death, the animal substances decay and these shells may accumulate in quantity, before undergoing complete solution again. The amount of calcium carbonate (actually in the form of the bicarbonate $CaH_2(CO_3)_2$ held in solution is dependent upon the presence of the carbon dioxide gas in the water, and when this gas is abstracted by green plants, for their use in securing carbon, the calcium carbonate is deposited often over their stems and leaves in the form of minute crystals forming an incrustation. One very common plant of this character forms thick mats over the bottoms of our ponds and is known as *Chara*. It secretes and deposits so much of the calcium carbonate as to render its slender leaves and branches quite brittle, suggesting that this material may be deposited as the result of some physiological action on the part of the plant. Upon the decay of these and related plants quantities of the slightly soluble calcium carbonate collect upon the bottom and give rise to a chalky deposit known as marl. It is evident that shells may also be present in greater or less quantity and more or less mineral impurity in the form of sand and clay.[4] Under favorable conditions deposits many feet in thickness have been formed since the withdrawal of the ice sheet from Michigan. In Wayne County, however, owing to its long submergence by the glacial lakes and the almost complete absence of subsequent ponds and minor lakes no very extensive deposits were formed. Although favorable conditions for marl formation and deposition occur about the present margins of Lake St. Clair, Detroit River and Lake Erie, the time that these present conditions have existed seems of too short duration. In the vicinity of the swamps, those still existent and those which have been drained, often in association with peat, shallow deposits of marl are found; as in secs. 5, 8, NE. 1/4 sec. 28, of Brownstown; secs. 9, 10, 15 and 16 of Sumpter; NE. 1/4 sec. 18 of Canton. This latter deposit is estimated to cover some 10 acres, to be 2 to 3 feet thick and is overlain by 10 to 16 inches of muck. These marl beds could all be utilized as a land fertilizer and when mixed with thoroughly dried and disintegrated peat would add very greatly to the fertility of the soil.

Glass sand. The Sylvania sandrock formation, described as of probable æolian origin, has all the qualities needed for high grade glass manufacture. It is finely and uniformly grained, runs very high in silica and is so incoherent that it is readily disintegrated by water and pumped from the pit. Mixed with the fusible bases it melts readily and yields a glass free from color. This sand has been mined and marketed for a number of years in Monroe County, where there was a natural outcrop. The bed strikes northeastward, with an outcrop of two to three miles beneath the drift cover, and crosses the southern point of Brownstown township, as shown upon Pl. XXV. Just east of Rockwood, upon the land of Dr. Dayton Parker (NW. 1/4 SE. 1/4 sec. 15) a pit has been opened under 15 to 18 feet of a hard glacial till and is operated by the American Silica Co. The deposit here is said to be 75 feet thick, but all of this will probably not yield to the hydraulic treatment now employed. A sample of this washed sand was analyzed by Dr. John E. Clark, Detroit, and gave 99.70% silica (SiO_2); .08% calcium carbonate ($CaCO_3$); .22% magnesium carbonate ($Mg CO_3$). The Rockwood Silica Sand Co. acquired 82 acres of land just east of the Grand Trunk Ry. (SE.1/4 SW.1/4 sec.10), and three years ago sunk a well to the depth of 122 feet, through 15 feet of clay. An additional 15 feet of limestone (dolomite) was penetrated when the glass sand was entered to a depth of 92 feet, without reaching the base. A 6-inch casing was used to the rock and below a 4-inch, through which steam under 60 lbs. pressure is forced, bringing out water and sand. The sand is dried and screened to the amount of about a carload a day, being shipped to Ohio and Pennsylvania. The water from the well contains sulphur and when allowed to do so rises to within 3 feet of the surface. In the Oakwood salt shaft, the bed was reached at a depth of 420 feet, has a thickness of 113 feet and much of it could be removed if it was desired to do so, using the same hoisting machinery as that employed for the salt.

Mineral waters. Although all natural water may be regarded as a *mineral resource*, Chapter VII has been devoted to its discussion and there has been reserved for this section only a brief discussion of those waters which are economically valuable because of their mineral content. The waters which permeate the beds of the Dundee and Monroe formations become heavily charged with a great variety of minerals; chief of which are sulphur, salt, calcium and magnesium sulphate and carbonate. When heated and properly administered, such waters have undoubted medicinal value for certain diseases and are in demand. By penetrating the proper horizon, almost unlimited quantities may be obtained over the entire county. Two plants are in operation in Detroit,

Riverside Bath House, Clarke Ave. and Fort.

4. For a discussion of the origin of marl, its occurrence and uses see report in the Geological Survey of Michigan, vol. VIII, pt. III, 1903.

Detroit Mineral Bath Co., Cor. 21st St. and Fort.

The various industries utilizing the salt deposits along Detroit River (Pls. XXXI, B and XXXII, A) from Delray to Trenton, prepare an artificial brine by forcing the water of the river to the salt strata, where it becomes saturated and flows to the surface. The salt is then recovered by the evaporation of the water and marketed as such, or utilized in the manufacture of soda-ash and caustic soda. As explained in an earlier part of this chapter the first step in the manufacture of the former product (Na_2CO_3) is the production of ammonium hydrogen carbonate (NH_4HCO_3), by the use of ammonia and carbon dioxide. When this solution receives a strong solution of salt ($NaCl$), two new substances are formed: sodium hydrogen carbonate ($NaHCO_3$), or bicarbonate of soda, and ammonium chloride (NH_4Cl), as shown in the following equation:

$$(2)\quad NaCl+NH_4HCO_3=NaHCO_3+NH_4Cl.$$

The sodium hydrogen carbonate is but sparingly soluble and is precipitated and recovered. This is the common baking soda which is manufactured extensively at Ford City and formerly at Trenton. Upon being heated in a retort, this compound breaks up into its three components, according to the following equation:

$$(3)\quad 2NaHCO_3=Na_2CO_3+H_2O+CO_2.$$

Upon being treated with lime, the ammonium chloride of equation 2, is converted into calcium chloride ($CaCl_2$), with the liberation of ammonia and water.

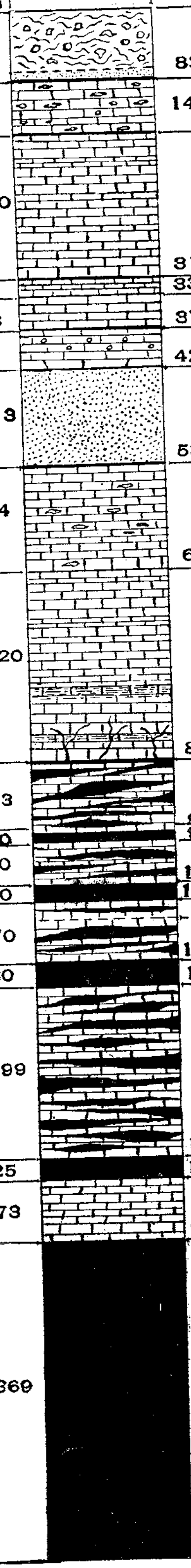
$$(4)\quad 2NH_4Cl+CaO=CaCl_2+2NH_3+H_2O.$$

It is thus seen from equations 3 and 4 that all of the ammonia and half of the carbon dioxide gas are recovered and may be used in the further production of ammonium hydrogen carbonate, according to equation 1. The calcium chloride containing the calcium of the lime and the chlorine of the salt, form the by-product, great quantities of which may be seen about the plants of the soda-ash manufacturies at Delray and Wyandotte. When heated, this becomes a valuable drying agent because of its strong attraction for water. The soda-ash sought contains the sodium of the salt and the carbonate radical (CO_3) of the limestone, which has been exchanged for the chlorine. This is known in the market as *sal soda*, is used extensively for softening water, in the manufacture of glass and numerous other chemicals. When dissolved and treated with calcium hydrate ($Ca(OH)_2$), a recombination occurs,

$$(5)\quad Na_2CO_3+Ca(OH)_2=CaCO_3+2NaOH,$$

resulting in the formation of lime carbonate and sodium hydroxide, commonly known as *caustic soda*, or "alkali." This is extensively

SECTION OF OAKWOOD SALT SHAFT.

System		Formation	Thickness	Section	Depth	Elevation	Character of Rock
Pleistocene	Wis.					575 A.T.	
Pleistocene	Wis.	Drift	83		83	492	Blue boulder clay, glacial origin. 10 foot sand deposit.
Devonian	Middle	Dundee	63		146	429	High grade limestone with some chert nodules.
Silurian	Upper Monroe	Lucas	170		316	259	Bluish to brownish-gray dolomite, much of it finely laminated, with streaks of asphaltum. Small amount of gypsum. Poor in fossils.
Silurian	Upper Monroe	Amherstburg	19		335	240	Brownish laminated dolomite.
Silurian	Upper Monroe	Anderson	38		373	202	High grade limestone, rich in fossils. Some celestite.
Silurian	Upper Monroe	Flat Rock	47		420	155	Dark drab dolomite, with few casts and moulds of fossils. Some concretions and gypsum.
Silurian	Middle Monroe	Sylvania	113		533	42	Snow white sandstone, more or less cross bedded. Generally incoherent, compacted into sandstone from about 490 to 510 feet.
Silurian	Lower Monroe	Raisin River	124		657	-82	Bluish gray or brownish laminated dolomite, occasional oolitic strata; line of seperation between it and Sylvania very distinct. Some chert nodules and pyrite. Bed of breccia encountered about 580 feet. Some fossils.
Silurian	Lower Monroe	Put in Bay Possibly including Tymochtee	220		877	-302	Bluish to brownish dolomite with seams of fossils. Thin strata of breccia and oolite. Some selenite, alabaster, anhydrite, calcite, asphaltum, and pyrite. Shaly and carbonaceous in places. Dolomite shows gashed structure at certain levels. Veins of salt encountered near bottom.
Silurian	Division of upper series*	Salina	83		960	-885	Salt and dolomite irregularly mixed. No fossils found.
Silurian	Division of upper series*	Salina	10		970	-895	Salt.
Silurian	Division of upper series*	Salina	50		1020	-445	Salt and dolomite.
Silurian	Division of upper series*	Salina	20		1040	-465	Salt slightly blotched with dol. slime.
					- - -	- -	Present bottom of shaft.
Silurian	Division of upper series*	Salina	70		1110	-535	Salt and dolomite.
Silurian	Division of upper series*	Salina	30		1140	-565	Salt.
Silurian	Division of upper series*	Salina	199		1339	-764	Salt and dolomite.
Silurian	Division of upper series*	Salina	25		1364	-789	Salt.
Silurian	Division of upper series*	Salina	73		1437	-862	Dolomite.
Silurian	Division of upper series*	Salina	369		1806	1231	Salt. When entered this will probably be found to be divided by minor strata of dolomite.