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OF MICHIGAN

FOR THE YEAR 1904

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1904

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THE SUPERINTENDENT OF PUBLIC INSTRUCTION,

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BOARD OF GEOLOGICAL SURVEY

1905

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[1] With the permission of the Director U. S. Geological Survey.

ERRATA

Page 159, line 18 from top for westward read eastward.

Plate II was omitted as unnecessary, although it is mentioned in the table of contents on p 36.

FAILURE OF WELLS

ALONG THE LOWER HURON RIVER, MICHIGAN

IN 1904

BY

MYRON L. FULLER

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICHIGAN, Feb. 8, 1905.

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

HON. FRED M. WARNER, President.
HON. L. L. WRIGHT.
HON. PATRICK H. KELLEY, Secretary.

Gentlemen:—I herewith transmit, with the request that it be published as part of the annual report of the Board for 1904, a paper by Myron L. Fuller of the U. S. Geological Survey on "Failure of Wells Along the Lower Huron River, Michigan, in 1904." Mr. Fuller is connected with the U. S. Geologica Survey and was formerly an employe of this Survey. He is now in charge of the hydrology of the eastern United States. He kindly consented to examine this problem which has occasioned local embarrassment and newspaper comment, and the report is published with the permission of the Director of the U. S. Geological Survey. I asked the especially prompt publication of this report because it has a bearing on proposed legislation.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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FAILURE OF WELLS ALONG THE LOWER HURON RIVER, MICHIGAN, IN 1904*

BY MYRON L. FULLER.

INTRODUCTION.

General statement.—In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of the Huron river in southeastern Michigan, which up to that time had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes. Wide attention was attracted to the failure of the wells in the region because the shortage was supposed to have been brought about through under-drainage by a powerful flowing well on Grosse Isle a few miles to the east. Careful field investigations showed the improbability of such influence, the evidence indicating on the contrary the failure to be due to certain general causes of rather widespread application.

The explanation of the failure of wells in the region in question is similar to that in like districts at many points throughout the country, and it is with the object of calling attention to certain general factors, both temporary and permanent, which tend to induce a shortage of the ground water supplies over large areas that the present paper has been prepared.

Field work and acknowledgments.—The first study of the conditions of the district as made in July, 1904, by Mr. Frank Leverett, geologist, at the suggestion of the State geologist, who made a reconnaissance in the vicinity of Carleton, Flat Rock, Willow and Waltz, determining the general conditions as regards shortage. In August, the shortage still continuing, the writer visited the field and made a more detailed study of the conditions of the wells and of the cause of their failure, the results of which are presented herewith. Acknowledgments for certain geologic and well data are made to Mr. Frank Leverett, and Messrs. A. C. Lane and W. H. Sherzer of the State Geological Survey. Thanks are also due to Mr. James Swan, owner of the Grosse Isle well, and to Mr. Edward Ready and Jacob J. Lucke of Carleton for courtesies rendered.

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WATER SUPPLIES OF THE LOWER HURON RIVER REGION.

GENERAL CONDITIONS.

Location of area.—The region in which the shortage of water in 1904 was earliest felt, and in which it was severest, is a belt perhaps 10 miles wide extending in a northwest-southeast direction parallel with and including the Huron river from a point near New Boston, about 20 miles in a straight line above its mouth, to its juncture with the Detroit river, 28 miles from Detroit city. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. To the south the affected area is not only much broader, reaching a width of 7 or 8 miles, but the shortage was more pronounced, reaching a maximum along Swan Creek which parallels Huron river at a distance of from 3 to 5 miles on the south. South of Swan Creek the wells are affected only for a short distance, usually not over 2 or 3 miles.

The belt showing shortage lies in two counties, the relatively narrow strip north of the Huron river being in Wayne county and the wider one south of the river in Monroe county. The villages principally affected are Willow, Waltz, Carleton, Flat Rock and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

Character of country.—The entire region is characteristically flat, and, except in the vicinity of the streams which have cut shallow channels for themselves, almost no inequalities recognizable by the eye are to be seen over large areas. The surface materials are generally clayey, although locally the clay may be overlain by thin sheets of sand, which in places take the shape of low flat northeast-southwest ridges or terraces, representing old beach lines of the lake which formerly covered the region. Although excessively flat the country has a gentle slope southeastward towards Lake Erie, usually not exceeding 5 feet to the mile. The main streams, the Huron river and Swan Creek, flow in the direction of greatest slope to the southeast, while the smaller streams, including the tributaries of the larger streams named, flow either along similar southeast lines or converge slightly towards the main drainage lines.

The region is a populous one. Roads follow nearly every section line and houses are abundant, there being frequently from 10 to 20 to a section. The farms are correspondingly small, but are under careful cultivation and the owners appear to be prosperous. Three steam railroads and a trolley line give frequent communication with Detroit and afford abundant opportunity for the shipping of produce.

Climate.—The climate of the region is tempered to a certain extent by the proximity to Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39 degrees, the average maximum 57degrees, and the average mean 48 degrees. The rainfall, which is about 30 inches, is low as compared with certain other portions of the state where it may reach to from 35 and 40 inches. (See fig. 1.)

There are, however, considerable areas in which the precipitation does not exceed 30 inches. Normally the rainfall is lowest in January, when it is under 2 inches, and highest in May and June, when it is over 3½ inches per month. About the head of Huron river the rainfall is greater than along the lower part of its course and serves to keep the stream somewhat higher than would otherwise be the case.

GEOLOGY.—SURFACE MATERIALS.

Character.—The materials overlying the rock in the region consist largely of what is locally called clay, but which is more properly a clay with an admixture of sand and pebbles. The materials are not usually arranged in definite layers as in stratified deposits, but commonly exist rather as heterogeneous mixtures, although occasional beds of quicksand or gravel, or even scattered bowlders may occur. In consistency the material is tough and clay-like, and is of a grayish blue color when fresh, but becoming yellowish through oxydation of the iron on exposure to the weather at the surface. Some bowlders occur in the part of the area nearest the Detroit river.

Thickness.—Although the superficial materials have a flat surface, their thickness varies from place to place because of differences in elevation of the buried rock surface which reaches much nearer to the top of the ground in some places than in others. The clayey deposits are from 15 to 40 feet in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and may even have cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface as at the large quarries at Newport.

In a broad way the thickness of the clays may be said to increase as Detroit river and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 35 feet, while near Rockwood the thickness may be as high as 40 feet.

Origin.—The surficial materials are of somewhat diverse origin. The bowlders and the unstratified materials were derived from the glacial ice which once covered the region, the accumulation taking place under the ice, or very close to its margin during halts in its retreat. The waters at that time stood higher than at present, covering the entire area under discussion, reaching back as far as the base of the hills near Ypsilanti, and in them a portion of the clays and the sand locally covering the surface were deposited as the ice retreated. Ice and water deposition were simultaneous and without sharp lines of demarcation, making it difficult to differentiate one from the other. After the retreat of the ice from the region the waters finally sank, with several halts at different levels, to their present position. During these halts the deposits were subjected to more or less washing by the waves, with the result that beaches were cut in the clay or constructed of sandy materials derived from it. These are the so-called terraces, ridges or beaches extending in a northeast-southwest direction across the region northwest of the area under discussion and between it and Ypsilanti.

ROCKS.

Character of rock surface.—As was pointed out in the paragraph in which the thickness of the surface deposits was discussed, the rock surface is irregular as compared with that of the overlying clays, rising at points until it is within a few feet of the surface and again sinking 20, 30 or 40 feet below it.

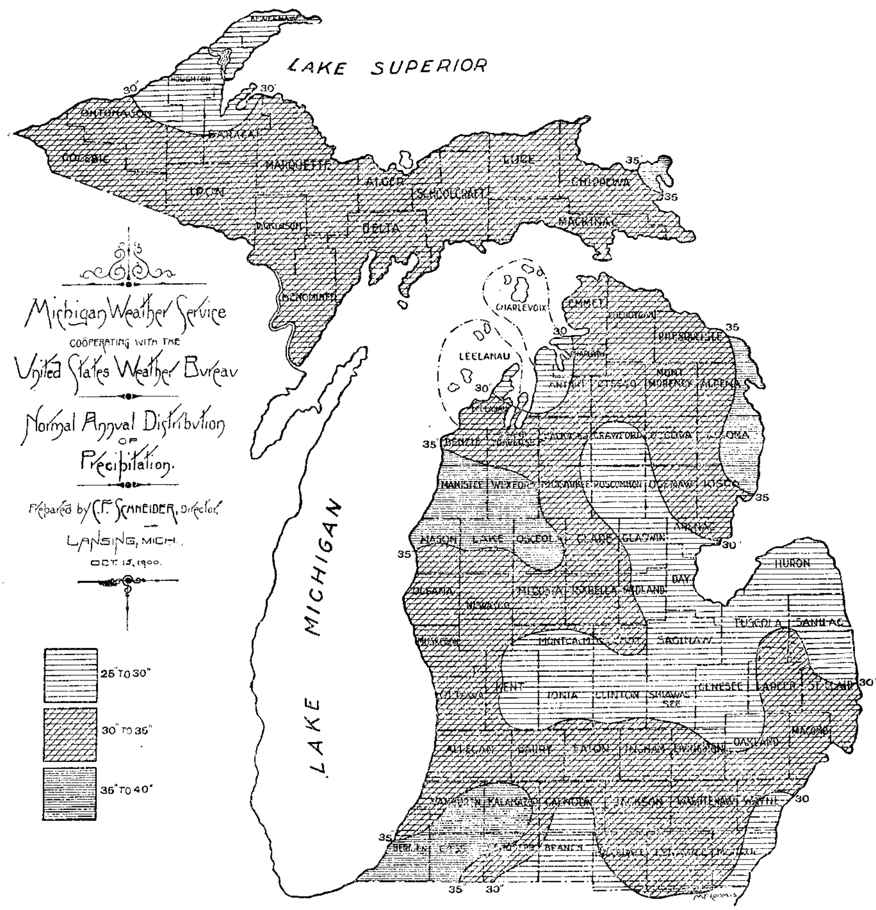

Fig. 1. Rainfall map of Michigan.

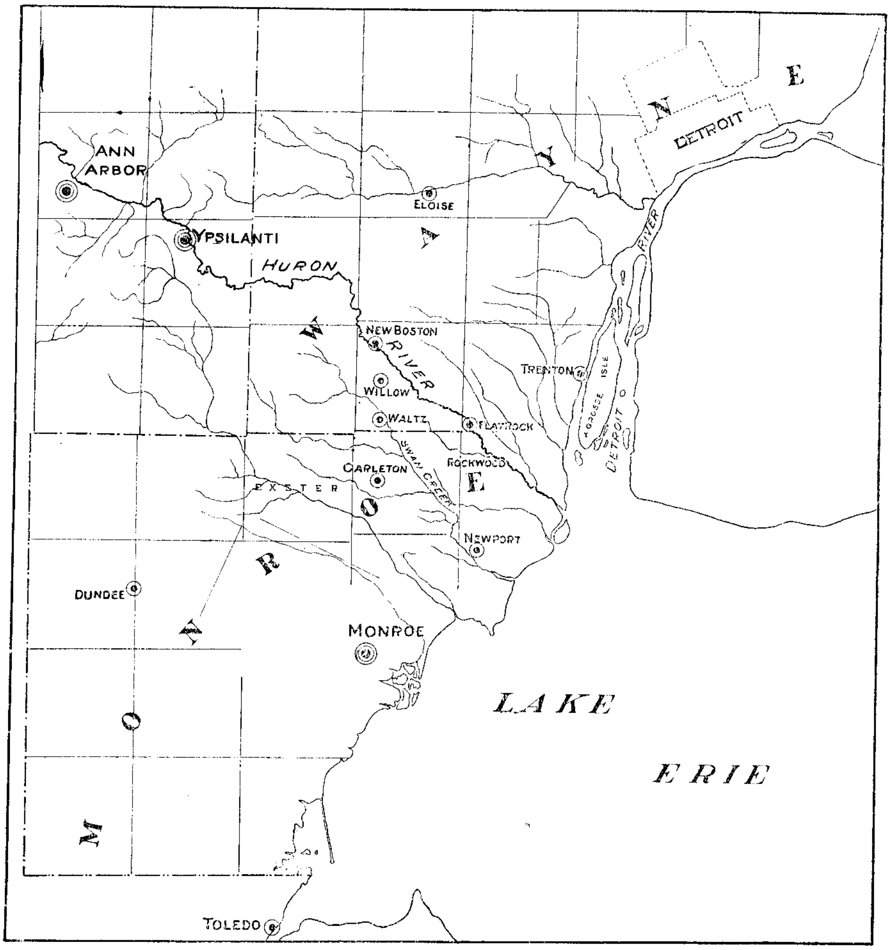

Fig. 2. Sketch map of the lower Huron region and vicinity.

There are no great inequalities, however, and even if the soil were removed the surface would still be very regular, with elevations rarely rising more than 20 feet above the surrounding level. The irregularities are entirely independent of the present streams, which in the main have been determined in location entirely by the surface deposits.

Nature of rocks.—The rocks underlying the clays in the lower Huron river region consist of limestones, sandstones, shales, etc., arranged in belts extending in a northeast-southwest direction, or at right angles to the course of the Huron river. They are reached by all but the shallow dug wells, and afford the greater part of the ground water found in the region.

Dundee limestone.—In the northwestern portion of the area, or beyond a point a couple of miles northwest of Carleton, the rock is the Dundee limestone, a fairly pure, light colored, flint bearing Devonian limestone of perhaps 100 feet in thickness and dipping northwestward at a rate of 20 to 25 feet to a mile. It is characterized by waters more or less charged with sulphur in the form of hydrogen sulphide.

Upper Monroe beds.—These are drab magnesian limestones or dolomites, sometimes carrying sand, and gypsum and other minerals. The dip is similar to that of the Dundee limestone. The waters are hard, but are not characterized by much sulphur.

Sylvania sandstone.—This is a white sandstone outcropping beneath the clay in the region at a point about a mile east of Carleton nearly to the mouth of the Huron river. The dip is somewhat flatter than either of the preceding and is more to the north than to the northwest. It yields water of a good quality.

Lower Monroe beds.—These are generally similar to the limestones and dolomites constituting the upper part of the Monroe beds already described, but are often more silicious than the latter. They outcrop parallel to the Sylvania sandstone in a narrow belt along Lake Erie and Detroit river. Their waters carry some sulphur.

WATER SUPPLIES.

The conditions as regards water supplies vary considerably throughout the region under consideration, the variations being marked by differences in composition, head, volume, and in the amount of shortage shown in the time of drought. Each of the individual areas will be separately considered.

WILLOW-EXETER REGION.

General conditions.—The term Willow-Exeter region is applied to the area, now or formerly furnishing flowing wells, which extends from the vicinity of Willow southwestward past Waltz into Exeter township, Monroe county, at its northeast corner. The area in this township is mainly included in sections 1, 11, 12, 13 and 14, with parts in sections 2, 10 and 15. The belt lies transverse to the drainage of the region and is located mainly over the outcrop of the Dundee limestone.

Character of wells and water.—There are several types of wells in the district, including dug wells obtaining a very limited supply of non-sulphur water from the clays, the drilled wells passing through the clay and penetrating the rock obtaining strong sulphur waters which will frequently flow at the surface, and a combination of the dug and drilled types uniting the characters of both of the preceding types. Such wells are usually dug about 15 feet, a small drilled hole being continued from the bottom down to the rock, which is usually penetrated for a foot or two. Such wells are particularly adapted to those cases where the water will rise nearly, but not quite, to the surface. They furnish, under such conditions, admirable opportunities for storage and will ordinarily yield much more water than the simple pipe wells, which often show a strong tendency to become clogged when water is most needed.

The depth of the wells varies from about 15 to 35 feet, of which all but a foot or two is usually through the clay. The depth is least at the eastern limits and greatest at the western border of the district. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams, or in sags of the surface, that good flows are obtained.

Condition of wells in 1904.—The portion of the district near Willow was visited on July 18, 1904, by Mr. Frank Leverett, who furnishes the data in the following paragraph:

Extending a mile or more both to the east and west of Willow is a line of flowing wells averaging 60 feet in depth and obtaining sulphur water. They all draw from the same horizon and have always interfered more or less with one another. The flowing well of Henry Ludwig, on the west side of the N. W. ¼ of section 28, which penetrated 50 feet of clay, etc., with a crust at its base before entering the rock, had a marked effect on the other wells, reducing the head or even, in cases, stopping the flow altogether. The flow of the Ludwig well was as strong as usual in July, however.

The data for the other portions of the district was collected by the writer and are presented in the accompanying table.

CONDITION OF WELLS IN WILLOW-EXETER REGION IN AUGUST, 1904.

Owner	Location.				Depth.	Head		Shortage noted.	Remarks.
	T	R	S	Q		Max.	Pres.		
R. Woodward....	5	9	17	sw	16	......	—8	....	Type of well in clay. No shortage.
J J. Lucke........	5	9	18	se	45	—20	—20	....	Type of sandstone well. Good water. No shortage.
J. S. Ankerbrandt..	5	9	20	nw	21	—10	—17	June	Tiled well. Roily before storm.
Frank Woodward..	5	9	20	c	......	......	......	....	Two wells, type unknown, both dry.
George Burgess....	5	9	19	ne	18	—6	—10	not n't'd	Sandstone well. Plenty water left.
Frank Dusheck....	5	9	18	sw	33	+0	—12	....	Plenty of water by pumping.
John Wenzel......	5	8	13	se	41	—6	—6	....	No shortage. Sandstone water.
Jas. Dunn.........	5	8	13	ne	......	—1	—3	July	Plenty sulphur water. A surface well goes dry every season.
J. Crimins.........	5	8	13	sw	......	—3	—3	....	Sulphur water. Went dry in spring but water returned on cleaning well.
Henry Kingsley....	5	8	13	nw	28	+0	—2	July	Sulphur water. Another well still flows.
Edw Navarre.....	5	8	13	c	......	......	......	....	Lowered but,still plenty.
Frank Ochs.......	5	8	14	ne	28	±0	±0	1902	Plenty sulphur water but less than before 1902. No recent shortage.
John Theisen......	5	9	24	....	......	......	......	....	Good flow just struck.
D. Livernois.......	5	8	14	c	20	......	......	....	No sulphur. Plenty.
F. Maynes.........	5	8	14	c	30	+3	+½	....	Sulphur water. No recent decline.
Phillip Zink.......	5	8	14	c	30	—4	—4	....	Sulphur water. As much as usual.
F. Maynes (field)...	5	8	14	nw	33	......	+0	....	New sulphur well.
J. W. Zink........	5	8	10	se	37	—3	—8	....	Always improved by cleaning.
John Murphy......	5	8	11	sw	35	+0	—8	....	Sulphur. Failed once before but flowed again on cleaning.
C. S. Davis.......	5	8	2	sw	......	......	......	....	Fresh and sulphur wells. No unusual shortage.
A. W. Dexter......	5	8	11	nw	......	......	......	....	Fresh and sulphur wells. No unusual shortage.
A. Fay..........	5	8	2	s	......	......	......	....	Fresh and sulphur wells. No unusual shortage.
M. Vasher.........	5	8	1	se	32	+4	+3	....	Sulphur water. Weakened but supply returned on cleaning.
F. Livernors.......	5	8	1	sw	......	......	......	....	Stopped at first and permanently weakened by Vasher well. Well of Dan. Fay also weakened.
Wm. Gauss.......	5	8	12	sw	40	—9	—9	....	No change. Sulphur water.
Sam Gauss........	5	8	12	sw	44	—3	—3	....	No change. Sulphur water. Surface wells dry.
Jos. Discher.......	5	9	7	sw	......	—8	—8	....	No shortage. Surface wells full.
C. Heinzerling.....	5	9	18	nw	28	—14	—16	....	No unusual shortage. Sulphur water.
J. J. Lucke........	5	9	7	se	22	—3	—18	1903	Sulphur well improved by cleaning Surface wells all right.
J. H. Jewell.......	5	9	7	ne	......	+0	—3	spring	Flowed up to May. Sulphur water.

Summary.—An examination of the above table will show the conditions are not uniform. As to the surface wells, several are reported dry, while others report the supply to be the same as usual. No decrease is noted in the wells in the sandstone, and most of the limestone wells (yielding sulphur water) show little if any material shortage, although a few report losses which, in several instances, were returned wholly or in part after cleaning. Some interference exists.

No evidence is afforded by the wells to show that there is any shortage, except such as would always accompany an unusually dry season. The moderate decrease due to drought has not been uniform, but was felt first by the shallower wells, or by those yielding small supplies, and last by the deeper and stronger wells. The difference is naturally generally most noticeable in the flowing wells, in which a difference of a foot or two in head may determine whether it will flow or not. Shortage in previous years is reported.

The head of the water in relation to altitude declines from 622 feet above sea level in the western part of section 14, T. 5, R. 8, to 600 feet near the east line of section 19 of the next township east, or a little over 7 feet to the mile. It would indicate that the source of the supply was to the west, probably in the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of non-flowing wells, lying between the Willow-Exeter and the Swan Creek flowing well districts. The wells are commonly about 30-35 feet deep and probably enter the Sylvania sandstone for a few feet from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August although the wells were somewhat lower than usual.

SWAN CREEK REGION.

General conditions.—This is a region of flowing wells extending along the valley of Swan Creek from near the Detroit Southern railroad 1½ miles northeast of Carleton southeast to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron river and Rockwood districts of flowing wells. The area is mainly over the outcrop of the Sylvania sandstone.

Character of wells and water.—The wells are of the dug, drilled, or dug and drilled types. Except those of the first type, they all obtain their water on entering the rock after passing through the stiff impervious clays. The wells have hitherto always yielded good flows of non-sulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

Conditions of wells in 1904.—The data relating to the condition of the wells is most conveniently presented in the form of the table which is given below. Besides the wells of the district proper, or the flowing well area, a number located within a mile or so outside the limits are included.

CONDITION OF WELLS IN SWAN CREEK REGION IN AUGUST, 1904.

Owner	Location				Depth	Head.		Shortage noted	Remarks
	T	R	S	Q		Max.	Pres.		
John Cequin	5	9	17	se	33	......	......	....	No decrease. Suggests ditching as cause of shortage in other wells.
Henry Spicer	5	9	20	ne	35	......	......	....	No decrease
Albert Spicer	5	9	21	sw	30	......	......	....	No decrease in rock well, surface well failed.
Wm. Sillmore	5	9	20	se	30	......	......	June	Just to rock (surface well). Failed.
L. Graves	5	9	20	se	37	......	......	March	Low, cleaned without result.
J Lantenschlager	5	9	21	sw	32	......	......	....	18 feet, dug. Water only in pipe.
Sam McLaughlin	5	9	28	ne	......	......	......	June	To rock only Three wells went dry. Little better after cleaning.
Benj. McLaughlin	5	9	28	ne	26	±0	−0	spring	Flowed 30 years ago. Dug 8 feet. Water in pipe only
Frank Bergmoser	5	9	22	sw	22	+0	−0	May	Nearly dry. Always plenty before.
Frank Bergmoser	5	9	22	sw	28	......	......	April	Dry. Has failed before.
Frank Bergmoser	5	9	22	sw	27	......	......	May	Dug 13 feet. Water in pipe only.
Henry Hood	5	9	21	se	28	—10	—16	Aug	Deepened with success. Another lower well stopped flowing.
Mrs P. Kelly	5	9	28	se	......	......	......	....	Nearly enough.
Ed. McCormick	5	9	28	se	30	—5	—11	June	Assigns loss to frozen ground and Newport quarry. Well improved by cleaning.
B. McLaughlin	5	9	28	se	......	......	......	....	No trouble with wells.
Jos. Esper	5	9	32	ne	20	—3	—15	June	Surface well. Ascribes loss to frozen ground.
J. Funerstalk	5	9	27	s	35	—10	......	spring	Dug 12 feet. Water in boring only.
La Ranger	5	9	35	nw	......	—4	—4	....	No change. Large supply
C. Muth	5	9	33	nw	21	—6	—10	....	Low but still plenty of water.
Geo. Calkins	5	9	35	ne	21	—5	—10	....	Enters slowly but plenty of water. Ascribes shortage to frost.
Nicholas Noel	5	9	25	sw	14	—12	—13	....	Surface well. A little less than usual. Two other similar wells in vicinity get plenty of water.
E. H. Van Tassel	5	9	25	se	......	......	......	....	To rock, no decrease noted.
W. M. Swype	5	9	25	sw	20	—10	—19	July	At barn. Never dry before Drilled wells at house as much as usual.
Wm. Southworth	5	9	25	nw	33	—6	—6	....	No trouble. One well used to flow.
S. Uden	5	9	....	....	......	......	......	....	On line between secs 24 and 25 Two wells out of three failed.
Peter Bitting	5	9	26	ne	27	—8	—10	....	Plenty. Another well the same.
B. Parish	5	9	23	s	27	+4	+½	June	In field. Has been low in August of other years.
B. Parish	5	9	23	s	30	—4	—8	June	At house. Has been low in August of other years.
Ed. Parish	5	9	23	s	22	+2	—15	July	Failed suddenly. Three similar wells.
School house	5	9	23	sw	25	+0	—0	May	Run during summer of 1903.
J. McCollum	5	9	23	sw	29	—8	—13	June	Still getting some.
J. McCollum	5	9	23	sw	15	+0	+0	....	New well near creek.
G. A. Harpst	5	9	22	ne	29	—4	—14	Aug	Very low. Ascribes loss to Grosse Isle well.
Earl Baker	5	9	22	ne	28	—5	......	....	Water in pipe only
Tony Kohn	5	9	?	?	......	......	......	....	Still gets some water.
Chas. Krieger	5	9	?	?	......	......	......	....	Still gets some water.
J. Hedges	5	9	22	se	......	+0	—0	June	Still gets some water.
A. Benedict	5	9	22	se	......	+0	—0	....	Lowered pipe. Water now stands just at top.
Eli Barrow	5	9	15	e	......	+0	—0	....	Near creek. Well at house also failed
Edw. Whipple	5	9	14	w	......	+0	—18	June	Plenty by pumping Ascribes loss to Grosse Isle well.
Mark Baker	5	9	15	e	......	+0	+0	....	Slight decrease Ascribes loss to Grosse Isle well.
G. Schweitzer	5	9	15	ne	18	—0	—3	....	Near creek. Well at house also lowered but improved by going deeper.
F. Baker	5	9	14	sw	......	+0	—0	1902	Less than usual but plenty
D. Reed	5	9	23	n	......	......	......	....	Dry but got plenty by going 2 feet deeper.
H. Gretzler	5	9	23	n	32	—5	—11	July	Another well at house failed. Plenty on cleaning.
Barnard Parish	5	9	23	ne	33	—7	—12	May	Supply sufficient. Similar well across road.
C. M. Hood	5	9	13	sw	35	—6	—12	....	More water by deepening. Another well dry
F. Reinhart	5	9	13	nw	35	......	—12	....	New well. Old well failed. Ascribes loss to Grosse Isle well.
A Vizard	5	9	13	nw	35	—6	—11	....	Another similar well. Supply sufficient. A dug well also has water.
J. F. Smith	5	9	12	sw	......	......	......	....	Enough for cattle.
Henry Green	5	9	11	se	30	—4	......	June	Dug 8 feet. Water in pipe only. Very low.
Irwin Barnum	5	9	11	se	28	—5	......	May	Dug 8 feet. Water in pipe only. Very low.
W. Baker	5	9	14	ne	......	—8	......	....	Surface well. Water by go.ng 7 feet deeper.
Emily Clark	5	9	14	nw	30	—8	......	spring	Scanty supply.
Fred Renton	5	9	11	sw	37	—5	—13	June	Got more water by going 8 feet deeper.
C. Stumpmeyer	5	9	11	sw	......	—6	—13	May	Three wells 32, 33 and 35 feet deep. Nearly dry. Cleaned without success. No previous trouble.
G. W. Reeves	5	9	10	se	......	+0	—0	1902	Another well just to rock has plenty for ordinary use.
M. Reeves	5	9	10	sw	......	......	......	....	Near creek. Failed. Always plenty before.
J. E. Brown	5	9	10	sw	22	+0	—0	1902	Failed temporarily in August, 1903, and again in spring of 1904
Floyd Barnum	5	9	16	....	......	—5	—15	....	Cleaned with little effect.
Alex Todd	5	9	9	....	20	+0	—0	spring	Plenty of water by pump.

Nature of shortage.—As in the Willow-Exeter region the behavior of the wells is not uniform. In the Swan Creek region, however, nearly every well shows shortage, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very uniformly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while others, though still running, rise to only a part of their former height. In the non-flowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued in some of the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly again in the spring of 1904. Just what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Supposed causes of shortage.—Nothing could be more variable than the opinions presented as to the cause of shortage. The most general of the explanations attributed the loss of water to subterranean drainage by a deep rock well located at the southern extremity of Grosse Isle and flowing at the rate of a barrel a second. Credit was given to this supposed cause by many who would not otherwise have thought of it because of the fact that one or two of the wells near Rockwood ceased to flow temporarily in the fall of 1903, only to begin again a short time after and to continue until the spring of 1904, when they again ceased. These changes are said to have coincided respectively with the striking of the water vein, insertion of casing, and finally with the withdrawing of the pipe from the Grosse Isle well.

Others, however, see no connection with the Grosse Isle well, attributing the shortage to lack of rainfall, the frozen condition of the ground when the rains of the previous autumn fell, the extensive ditching of the land in recent years and the consequent increase of runoff as compared with absorption, and to drainage by the quarry at Newport. All are possible causes and were investigated with the view of finding the determining factor in the shortage.

Steps taken to increase supplies.—Several methods of remedying the shortage were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep-seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening of the well was resorted to. In some cases the dug part was carried a few feet deeper, and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective results were obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although of course it had to be pumped to the surface.

HURON RIVER REGION.

General conditions.—This district extends along the Huron river from a point a mile or two southeast of New Boston, down stream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The rock is largely Sylvania sandstone, except at the northern end of the district. The wells, as in the previous districts, are of the dug, drilled, or dug and drilled types, and range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water which is non-sulphur-bearing.

Condition of wells in 1904.—No special investigation was made in the New Boston part of the area this season, but the conditions are reported to be similar to those in the Willow-Exeter field, there being relatively little shortage. Some of the wells have, however, stopped flowing, but this is not characteristic of the present season alone. The well of Gus Miesner in S. W. ¼ of section 9 formerly yielded a flow from a depth of between 60 and 70 feet, but it has now ceased flowing. Near the school house, on the west side of section 15, a well, opened by Mr. Blum, flowed a 4 inch stream of sulphur water when first sunk in 1887, but now flows less than one gallon a minute. The well is 65 feet deep. South of the school house Julius Kahm sank a well in 1891 to a depth of 65 feet. This flowed at the start, but soon after ceased.[1]

In the region between the bridge, 2 miles east of Willow, and Flat Rock, most of the wells are still flowing, although some have ceased. North of the river the Horace Thompson well in the southeast part of Huron township is still flowing sulphur water after a lapse of thirty years, though at a level 1½ feet lower than usual. The depth of the well is 26 feet. In section 26 Mrs. Lawrence has a very weak flowing well of black sulphur water. In the N. W. ¼ of the same section Mr. Stoefflet sank a well in June, 1904, to a depth of 96 feet, obtaining a full 2 inch stream of water. The well drained others for a quarter of a mile west and north and had to be plugged. South of the river the conditions are very similar, some wells having ceased flowing, while others still continue, though with diminished head.[2]

Summary.—In a broad way it may be said there is a general shortage of water in the region, but not so severe as in the Swan Creek district, for along the Huron many wells still furnish good supplies or even flow, while in the latter region the failure is almost universal. The causes ascribed for the shortage are similar to those of the Swan Creek area, but with less weight given to the supposed influence of the Grosse Isle well. Cleaning, and more especially deepening the wells generally resulted in an improvement of conditions.

ROCKWOOD REGION.

General conditions.—The Rockwood area includes the region west and southwest of that town and between it and the Swan Creek area, together with the region near the town on the north side of the Huron river. It can be considered as merging into the flowing well areas of Swan Creek and Huron river on the west and with the Detroit river region on the east. The area is mainly over the outcrop of the Sylvania sandstone and yields waters generally free of sulphur. The wells are generally from 20 to 40 feet in depth and are non-flowing, except near the Huron river.

Condition of wells in 1904.—In the following table are given data relating to the condition of the wells as determined by the writer in August, 1904.

[1]Information furnished by W. M. Gregory, August 2, 1904.
[2]Information furnished by Frank Leverett, July, 1904.

CONDITION OF WELLS IN THE ROCKWOOD REGION IN AUGUST, 1904.

Owner.	Location.				Depth.	Head.		Shortage noted.	Remarks.
	T	R	S	Q		Max.	Pres.		
D. Valrance	5	8	17	ne	28	—1	—7	May	Has been dry before. Ascribes loss to Grosse Isle well.
H. D. Valrance	5	8	17	ne	30	+3	—30	....	Pump gave relief temporarily Ascribes loss to Grosse Isle well.
V. Holmes	5	8	17	ne	......	+0	—0	May	Water in pipe only.
John Strong	5	8	17	ne	......	+0	+0	....	Diminished somewhat.
Royal French	5	8	17	nw	30	+0	—20	....	Plenty by pumping.
Geo. Case	5	8	18	ne	......	+0	—0	....	Nothing done.
Jas. Todd	5	8	7	se	36	+2	—36	....	Failed suddenly after 32 years. No water by pumping. Lays loss to Grosse Isle well. Two other wells have also ceased flowing.
John Antio	5	8	18	nw	30	—2	—8	spring	One fourth ordinary supply
S. Peters	5	8	7	sw	30	—6	—12	spring	Flowing well also stopped.
Chas. Bancroft	5	8	18	nw	31	+0	—8	1903	Two other wells also failed. Came on again during winter. One stopped temporarily during winter. Stopped again in spring of 1904.
Benj. Bancroft	5	8	18	nw	29	—5	—25	....	Two wells. Not very low in 1903.
G. Van Riper	5	8	18	sw	36	—5	—14	July	Another similar well. No previous trouble. Lays loss to salt and oil wells.
H. Chamberlin	5	9	13	se	36	—5	......	....	Water in bore only.
Philip Bally	5	8	18	sw	40	—5	—12	June	Decreased gradually.
Peter Pilkey	5	8	19	nw	40	—2	......	early	Low all winter. Water in pipe only.
Mattison	5	8	20	nw	......	—9	—18	....	Low all winter.
Mattison	5	8	20	nw	......	—5	—10	....	Low all winter
P. Donnelly	5	8	19	ne	......	—4	—17	....	Lays loss to Grosse Isle well.
Albert Root	5	8	19	se	22	—10	—14	July	Usually plenty in summer.
John Sigler	5	8	29	nw	22	—3	—12	July	Usually plenty in summer.

Nature of shortage.—The facts set forth show a marked shortage of supplies with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903 when the present shortage first began to be felt. During the winter of 1903–1904 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the individual wells stopped suddenly, the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head, hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest to the west of Rockwood, becoming less near town as the Detroit river is approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

Supposed causes of shortage.—The explanations of the shortage are the same as in the Swan Creek area, with special emphasis on the Grosse Isle well and the Newport quarry. On both of these supposed causes, however, opinions are divided, those not believing in their influence being as positive as those favoring such interference. It was noticeable, however, that the belief in both the quarry and deep well became less firm the nearer they were approached, being held rather by the owners of more distant wells than by those of the nearer ones.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and the shores of Detroit river. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, quite thickly settled and wells are abundant, but probably averaging under 20 feet in depth. In general there has been no trouble with shortage of water, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was as high or higher than is ordinarily the case, as Lake Erie, which controls the groundwater level adjacent to its shores, stood about 15 inches above the normal in the summer of 1904.

WATER SUPPLIES OF GROSSE ISLE.

General conditions.—Grosse Isle is a north-south island about 9 miles long and 2 miles wide lying on the American side of the international boundary in the Detroit river, its center being opposite the town of Trenton, 16 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being situated in the interior, notwithstanding the entire island is under cultivation. The surface is mainly clay or clayey silts, but rock is commonly found not far from river level and in one point, where it rises slightly higher is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of wind mills, no provision being made for filtering. There is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and no one had observed the slightest effect due to the big well at the southern end of the island.

The "Grosse Isle" or "James Swan well."—This well is located on the property of James Swan opposite Snake Island, about three-quarters of a mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the level of the river in 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet but at 450 feet a bigger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart a considerable amount of sulphur to the water as it issues from the pipe, which is recognizable by taste and sulphur deposit on the grass and stones about the well.[1] The water is said to have been cased off during the progress of the drilling from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable

[1] In the analysis as given all the sulphur is reckoned as SO^3. There are soluble sulphides as well as H^2S present, but so far it has proved impracticable to separate them. L.

size. (See plate I.) The flow is calculated at about 50 gallons per second and forms two sizable streams as it flows away from the well. The water was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using the water for a public supply for the island.

REPORT OF ANALYSIS

MADE AT THE CHEMICAL LABORATORY, UNIVERSITY OF MICHIGAN FOR THE STATE GEOLOGICAL SURVEY JANUARY 17, 1905.

Samples marked Grosse Isle water, James Swan's well.

Sampled and analyzed by F. K. Ovitz.

ANALYSIS

Constituents.	Grams per litre.
Silica	0.188
Calcium oxide	7.616
Strontium oxide	0.376
Magnesium oxide	1.212
Sodium oxide	0.292
Potassium oxide	0.112
Sulphuric anhydride	11.871
Chlorine	0.248
Carbon di-oxide	1.550
Iron and alumina	0.014
Loss on ignition	2.006
Total solids	23.972

DECLINE OF THE WATER SUPPLIES OF THE WELLS OF THE LOWER HURON RIVER REGION.

PRESENT CONDITIONS.

The conditions of the walls at the present time have been described in detail in the preceding pages. With the exception of the narrow belt along the shore of the Detroit river, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very slight, while along the Huron river it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large prorportion of the wells going dry and entailing much inconvenience.

BEGINNING OF THE DECLINE.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even then shrinkage of supplies had been in progress for many years. In his report on Monroe county* he states that while continued drought makes no impression on many of the wells, the flow of others is reduced, or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian waters could be secured was found to be becoming constantly more contracted. Wells in the southern part of Erie township back 3 miles from the lake, which formerly flowed, had then ceased.

The decline noted by Professor Sherzer as having already progressed for some time has continued to the present time. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the non-flowing wells is lower than formerly. In fact, the level of the groundwater in the clayey portions of southeastern Michigan is distinctly lower than it was ten years ago, and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline which has been going on for many years is probably due to a gradual and far reaching change of conditions, the nature of which will be considered on subsequent pages, but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

SUPPOSED CAUSES OF THE DECLINE.—THE GROSSE ISLE WELL.

It is this well which has most frequently been assumed as a cause of the shortage of water in the region under discussion. That it can not be the sole cause is readily shown by the fact that the decline had been going on for many years before its sinking in 1903. That it might be the cause of the special decline in that and the following year did not, however, appear unlikely at first, a special argument being afforded by the behavior of the wells of J. E. Brown of the Swan Creek and of Chas. Bancroft and others of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned coincident with the insertion of the casing, only to cease again after its withdrawal in May, 1904. There are, however, many facts which seem to show that the shortage has no connection with the Grosse Isle well.

Districts affected.—The investigation made by the writer showed, as has been described, that while wells in the Swan Creek and Rockwood districts ceased flowing or failed to yield their usual supplies, 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.

Slope of water table.—With a view of determining the source of the water of the Swan Creek-Rockwood area, the head, or height to which the water would rise, was plotted for each well in the region. It was found that this head showed an increase going west at a rate averaging about 3 feet per mile, indicating a source in the hilly region to the northwest. The increase of head to the west or decrease to the east was regular, there being no local lowering

*Geol. Surv., Mich., Vol. VII., Pt. I., pp. 194.

with a reversed slope *downward* towards the rock, such as would be present if water was being drawn down into the latter through a fissure connecting with the stratum furnishing water to the Grosse Isle well. (See Fig. 3.)

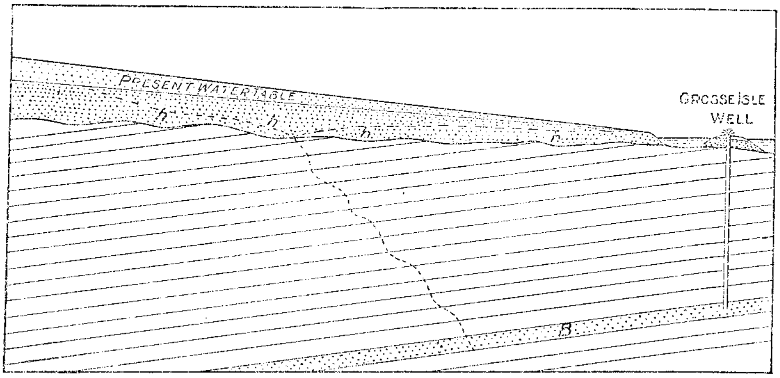

Fig. 3.—Ideal section across Grosse Isle and the mainland.

B is the previous water bearing bed from which the Grosse Isle well draws, and the line *h h h* shows the sort of form the water table should take were the surface strata connected therewith by the fisure shown by the dotted line leading down to *B*.

Geologic structure.—The precise point where the main water-bearing bed of the Grosse Isle well outcrops and where its supply of water is derived can not be stated. The rocks incline regularly to the northwest (or rise to the southeast) at a rate of perhaps 20 feet to the mile. On the basis of this dip it would seem probable that the water bed, which has a depth of 450 feet at the well, would come to the surface somewhere west of Leamington, Ontario. In the Huron river region, however, it would be even deeper than at the well, probably in the vicinity of Carleton, being nearly 800 feet below the surface. The chance of there being any fissure through all this thickness of strata, by means of which connection between the deep water beds and the surface wells might exist, is very improbable. On the other hand water can pass downward along the bedding planes with the greatest ease. Such is probably the case, the water being derived from the Ontario region rather than on the American side of the river.

Volume.—A strong impression is left on the mind of one visiting the Grosse Isle well by the immense volume of its flow, which is calculated to be between 45 and 50 gallons or over a barrel a second. When, however, it is recalled that the region in which the failure of the wells has been attributed to the Grosse Isle hole has an area of over 100 square miles, it will be seen that the amount which could be taken each second per square mile is not over half a gallon, or less than a thousandth part of a gallon per acre. The amount ordinarily taken from a square mile by the flowing wells of the Swan Creek and Rockwood districts was much more than this, in fact the taking of a thousandth part of a gallon per acre each second would probably not have a noticeable effect on the flows.

Head.—The most convincing reason why the Grosse Isle well can not have affected the Swan Creek-Rockwood wells lies in a comparison of the heads of the water in the two localities. The head of the Grosse Isle well is 25 feet above lake level, or approximately 597 feet above sea level, while that of a considerable number of the Swan Creek and Rockwood flows is less than this amount. In other words, the head of the Grosse Isle well is greater than many of the wells under discussion, and the water, if any connection existed between the two, would not be drawn from the shallow wells, but rather forced up into them.

Summary.—The evidence at hand gives no indication of any connection between the shortage of the shallow wells and the flow of the big Grosse Isle well, but affords on the other hand many indications that such is not the case. The supposed connection with the Grosse Isle well of the loss of water in the Brown and Bancroft wells in 1903 is the result of mere coincidence, the failure simply happening to take place at the height of the dry season of that year. That they should have failed in the still dryer season of 1904 was to be expected. The conditions were almost ceratinly local, as other wells in the vicinity were not similarly affected at the same time.

NEWPORT QUARRY.

The under-drainage caused by the quarry 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 investigated.

The quarry is located just east of the tracks of the Lake Shore and Michigan Southern railroad at Newport and a few feet north of Swan Creek. The quarry is 200 to 300 feet across and is excavated to a depth of 18 feet in the limestone, which is reached after 10 or 15 feet of stripping. The creek flows on top of the rock surface, 18 feet above the bottom of the quarry, and is separated from the excavation by a small dike. Water enters at various points in small amounts, but is easily removed by pumping at a rate of about one-half a gallon a second.[1] A part of the wells near at hand have been affected, but the decrease in the 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.

The small amount of water entering the quarry is in itself an indication that no extensive area is being drained, while the fact that only a part of the adjacent wells are effected while those a short distance away are unaffected, shows that even in its vicinity, the quarry may be neglected as a factor in the shortage of the water supply.

DEFORESTING THE LAND.

The existence of forests in a region, while not affecting the amount of water falling on the ground, tends to prevent its escape into the streams with the rapidity with which it runs off of non-timbered lands. By holding it back, even for a few hours, considerable greater quantities are allowed to soak into the ground than would otherwise be the case. Evaporation from the surface is also retarded, the ground remaining wet for much longer periods in wooded than in unwooded lands. The cutting of the timber must, therefore, be accepted as a factor in the general decrease of the supplies of the region, but was effective only in the earlier days. It can not be considered as one of the immediate causes of the sudden shortage of 1903–4.

[1]Four inch pipe, one-half full, but ejected with slight force.

DRAINAGE BY DITCHES.

The region under discussion is exceedingly flat, and because of its clayey soil and poorly developed stream systems was originally poorly drained, the low sags often holding water or remaining wet for long periods. All this has been gradually changed through drainage by ditches, with the result that much land has been reclaimed. The process, however, has not been without its drawbacks, for the ditches rapidly carry off much of the water which had previously soaked into the ground to become a part of the groundwater body. The result has been a gradual depletion of the groundwater especially within the past few years, so that the beginning of the present drought found an inadequate reserve supply in the ground.

DRAINAGE BY STREAMS.

The level of streams generally determines that of the groundwater 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. The 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 falls 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 FROST 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 17th, which was before the heavy autumn rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and 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 groundwater was at an unusual low stage.

DEFICIENCY OF RAINFALL IN 1904.

Because of the fact that the ground was frozen during the autumn and winter the ground was in much the same condition at the opening of the spring of 1904 as it was at the end of the preceding summer, and as month after month during the present summer went by with deficient ranifall the shortage began to be severe.

The shortage of rainfall is brought out by the following table which gives the precipitation by months for 1904. Detroit lies about 25 miles northeast of the area, Dundee about 20 miles southwest, Eloise less than 15 miles north, and Ypsilanti 20 miles northwest.

RAINFALL IN THE VICINITY OF THE LOWER HURON RIVER REGION IN 1904.

Month.	Detroit.		Eloise.		Dundee.	Ypsilanti.	
	Actual.	Normal.	Actual.	Normal	Actual.	Actual.	Normal.
	In.	In.	In.	In.	In.	In.	In.
January	3.34	1.94	3.98	1.69	5.37	4.54	1.90
February	2.55	2.33	00	2.16	4.06	2.98	2.46
March	4.09	2.29	00	3.01	5.45	4.92	2.45
April	1.65	2.24	1.01	1.32	2.36	1.66	2.24
May	2.36	3.51	1.19	3.27	3.06	2.58	4.09
June	1.08	3.69	.79	3.26	1.30	.56	4.25
July	2.94	3.36	2.52	4.16	2.84	3.03	3.33
August	3.20	2.71	3.69	1.95	4.73	3.92	2.14
September	4.23	2.47	3.83	2.61	4.20	6.21	2.86
October	.86	2.53	00	2.61	.82	1.09	2.64
November	.19	2.69	00	2.38	.05	.09	3.23
December	1.83	2.57	1.88	2.23	2.53	1.96	2.38

The low rainfall, which in the spring of 1904 varied from half to somewhat more than half of the usual amounts at the stations in the table 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, and back of that the dry season of 1903, is 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.

SHORTAGE IN OTHER REGIONS.

While the shortage was made manifest in the lower Huron region much sooner than elsewhere, later in the summer the drought became severe throughout all the states bordering the Ohio and eastward to New England, and much trouble and inconvenience were the result. In the other regions the failure was due simply to the shortage of rainfall, the complicating conditions that were present in the Huron region and served to make the scarcity of water more severe being absent.

CONCLUSIONS REGARDING SHORTAGE.

No evidence was found to show that the Grosse Isle well had affected any of the wells whatever, nor that the Newport quarry was a factor in the failure of wells other than those situated within a few hundred feet of it The deforesting of the region has been a factor in the general decrease of supplies in the past, but had no immediate connection with the present shortage. The ditching of the region was a prominent factor in the gradual depletion of the groundwater body so that when the usual fall rains were prevented by frost from being absorbed and the winter was followed by a summer of exceptional drought, the conditions were ripe for the failure of water which followed.

FUTURE PROSPECTS.

The failure of the wells being due largely to the severe drought of 1903–1904 it is probable that the return to the normal rainfall will 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 occur.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey materials 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.

REMEDIES.

The wells in the lower Huron river region obtain their supplies 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 or less jointed and open portion of the rock because there is less resistance to its flow through such crevices and openings in the rock itself than through the compact clayey deposits which generally overlie the rocks of the region. In its passage the water takes up sulphur and other mineral matter contained in the rock, its quality thus being changed from its relatively pure condition when it left the drift.

It has been shown in the discussion of the wells of the region that deepening has almost invariably met with at least partial success, especially where the wells have been sunk deeper into the rock. Throughout the entire region, however, the wells are unusually shallow, even for the surface type, a depth of 50 feet being exceptional. In many other regions in Michigan nothing is thought of going 50 to 100, or 150 feet in search of water. It is almost certain that wells of such a depth would in the lower Huron river region yield permanent supplies. Until such wells, or at least wells entering some distance into the rock, are sunk a supply adequate to the demands in times of drought cannot be expected.

DESIRABILITY OF LAWS REGULATING DEEP OR ARTESIAN WELLS.

GENERAL STATEMENT.

The desirability of regulating the use of a commodity belonging in a sense to the public at large is very generally recognized. This has been especially true of petroleum and gas, many states having stringent laws against their waste. Regulations governing the casing of wells in use, the plugging of wells about to be abandoned, and forbidding the free flow of gas, are to be found among the enactments in most states in which such commodities are found and have been of much assistance in securing a more intelligent management of wells and the husbanding of their products.

Water, even to a greater extent than oil and gas, can be regarded as a public commodity, and although its value is less than either of the former, it is nevertheless an important factor in many businesses. Because of the excessive cost of the deep water wells, which is as great as those sunk for oil and gas, the obtaining of large amounts is, however, even more essential. The great importance of obtaining cheap supplies will be appreciated when it is recalled that among the competitors of almost every manufacturing establishment there will always be some who will be able to obtain abundant supplies of the best quality at almost no cost above that of pumping.

Moreover, the occurrence of groundwater can no longer as formerly be regarded even at law as anything mysterious, there being at the present time many geologists and engineers familiar with its occurrence and the character of its movements. For this reason it should be entirely possible to make intelligent regulations by legislative enactment for controlling its use and preventing its waste.

LIMITATIONS TO AMOUNT OF GROUND WATER.

Percentage of absorption.—The rainfall throughout the United States is said to average about 30 inches per annum, that of Michigan being from 30 to 35 inches. Of this, however, not all is absorbed by the ground, large portions being carried off by the streams, or removed by evaporation. The actual amount absorbed by the ground is probably but a very few inches.

Availability of groundwater.—Groundwater occurs under a great variety of conditions which have an intimate relation to its availability. It may occur in the pores of open sands or sandstones, in cavities in limestones, along bedding planes of slates, and in fissures in any of the consolidated rocks. In sands, or in sandstones and other similar rocks, the body of the material is saturated as a sponge, and a well penetrating it at almost any point will obtain a supply. In the case of cavities, bedding planes, or fissures, the water is likewise given up with ease when encountered, but, because of the fact that it occurs only in a limited number of openings, the position of which can not be predicted, failures frequently result, and the supplies when found are generally of less volume and permanency than in the sandy beds. Notwithstanding the density of clay much water is contained in it. This, however, because of the fine grain of the containing material, is held firmly instead of being given up readily to the wells as in the case of other materials. In fact a well may penetrate a clay containing a high percentage of water and yet be able to obtain hardly a drop. The same is true of certain of the finer quicksands, but for another reason, in the latter cases the material being so fine that it unites to form a mixture with the water which soon clogs the wells, and from which the water can not be separated. Much of the water which penetrates the rocks is carried to too great a depth to be reached by ordinary wells.

From the above it will be seen that even the small quantity absorbed by the soil or rocks is still further reduced by the amounts held in clay and similar material, by the amounts entering the deep lying rocks, and by the frequently localized nature of the occurrence of the water, as a result of which wells can be obtained only at certain favored spots.

Supply not inexhaustible.—When a single well penetrates a thick, porous water-bearing bed the supply may be equal to the maximum capacity of the well, but as other wells are sunk the demand rapidly increases and soon becomes greater than the supply, the wells showing the effect of shortage by a decrease in this volume or by a lowering of their head. This is well illustrated by the wells of the Chicago area. When the first wells were put down to the Potsdam sandstone the flows were large, the water rose as high as 80 feet above the surface, and the supplies appeared inexhaustible. As the wells multiplied, however, the amount obtainable by each became much less and the heads were so reduced that the wells rarely flowed. The same has been true of many other artesian districts; in fact, it may be laid down as a general law that no pool is inexhaustible. On the contrary each pool has a definite volume from which every well takes just so much, thereby diminishing the total available supply.

Replenishment of supplies.—The groundwater supplies are replenished from rainfall. When the wells drawing upon the underground supplies are few in number the water may be replenished as fast as it is removed by the wells, but when the number of wells is large the replenishment does not keep pace with the withdrawal. The replenishment is not altogether a question of rainfall, many other factors entering into the question, among which the conditions at the outcrop and the rate of water movement are the most important. The last is of great importance for if the rock be sufficiently fine-grained the water will enter and move but slowly, even though the outcrop be constantly covered by water.

Danger from the free flow of wells.—The water in the rock represents the accumulation of years, and a well may draw off in a few hours water which it took months to get together. It is like pulling the plug out of the bottom of a barrel into which a stream of water is running, to allow a well to flow freely. Of course the only value of water lies in its availability for the use of man, and its employment for all legitimate purposes should be encouraged. It is only the useless waste of supplies that may soon become of great value that should be forbidden. Artesian water should no more be allowed to run to waste than should a young growth of timber be allowed to be burned simply because it does not at the present moment happen to be marketable.

Danger from improper casing.—In the same way that waste may take place from the free flow of a well at the surface, water from an underlying stratum may if the well is uncased rise and pass off laterally into an overlying non-saturated layer. In the same way the water from an upper stratum may pass downward and be absorbed by a lower stratum. In either case the loss is a real one, as real as if it had taken place at the surface, for the result is that the confined water, which from the very fact of its confinement furnishes the most ideal conditions of supply, becomes dissipated through a large amount of material, in no part of which is it probable will it be present in economic amounts.

SUMMARY.

Groundwater 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.

RECOMMENDATIONS.

(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 is flowing, a penalty to be attached for 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 the proper officials.

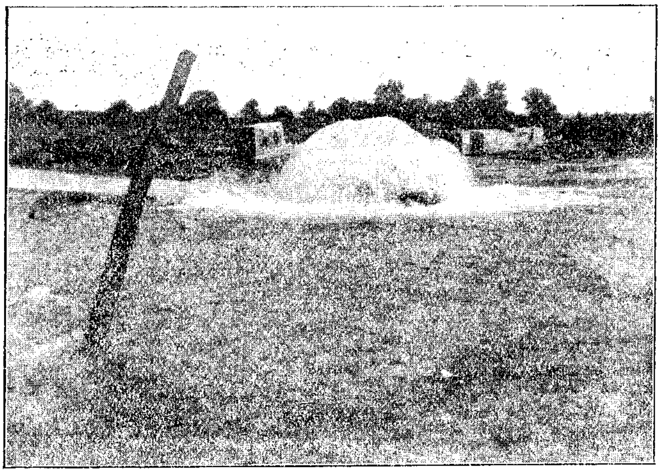

PLATE I.—VIEWS OF THE FLOWING WELL AT GROSSE ISLE.

A GEOLOGICAL RECONNAISSANCE

ALONG THE NORTH SHORE OF LAKES HURON AND MICHIGAN

BY ISRAEL C. RUSSELL

OFFICE OF THE STATE GEOLOGICAL SURVEY,
Lansing, Michigan, Feb. 7, 1905.

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

Gentlemen: I transmit herewith for publication in the annual report of the Board for 1904 the report of Prof. I. C. Russell of Ann Arbor on his field work last summer with accompanying map. It gives not only an account of some interesting features, eskers and drumlins, which have hardly been noticed in that region before, but also notes on the soils and agricultural possibilities of the region. It is worth noting that according to Mr. Russell the drift coating over the bed rock surface is rarely thick, so that even in the sandy areas it is not probable that the ground water level is very far down. The unmitigatedly sandy areas he does not find to be very large, though all the till is sandy owing to the prevalence of sandstone to the north.

The presence of interglacial lake clays is both scientifically and practically interesting.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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INTRODUCTION.

The region discussed in this report includes a strip of country varying from about six to thirty miles in width, bordering lakes Huron and Michigan on the north, and extending from Drummond Island westward to the Michigan-Wisconsin line at the mouth of Menominee river. Its northern limit is an east and west line situated six miles north of the 46th parallel of latitude. The area thus defined is indicated on the index map forming Plate I.

The immediate occasion for a re-examination of the geology of the region designated above, was the preparation of a map of the surface geology of Michigan to be published by the Geological Survey of Michigan, on a scale of six miles to an inch, to be printed on nine sheets. Six of the sheets include the Southern Peninsula of Michigan, but overlap onto the Northern Peninsula in such a manner as to embrace the row of townships next north of the 46th parallel of latitude. In order to facilitate the publication of the sheets including Southern Michigan it became desirable to map the surface geology of the strip of country mentioned above. This task was assigned to me by A. C. Lane, State Geologist of Michigan, and occupied my time from July 4th to September 10th, 1904. The region traversed is indicated on the map forming Plate XVI which obviates the necessity of describing it in detail. Owing to the area of the country to be examined, approximately 2,400 square miles, and the comparatively brief time available for the work, nothing more than a reconnaissance could be undertaken. In judging of the value of the results obtained, the rader is asked to bear in mind not only the area of the region examined and the time devoted to the task, but also the fact that by far the greater part of the country traversed is still clothed in forest and much of it occupied by almost impenetrable swamps.

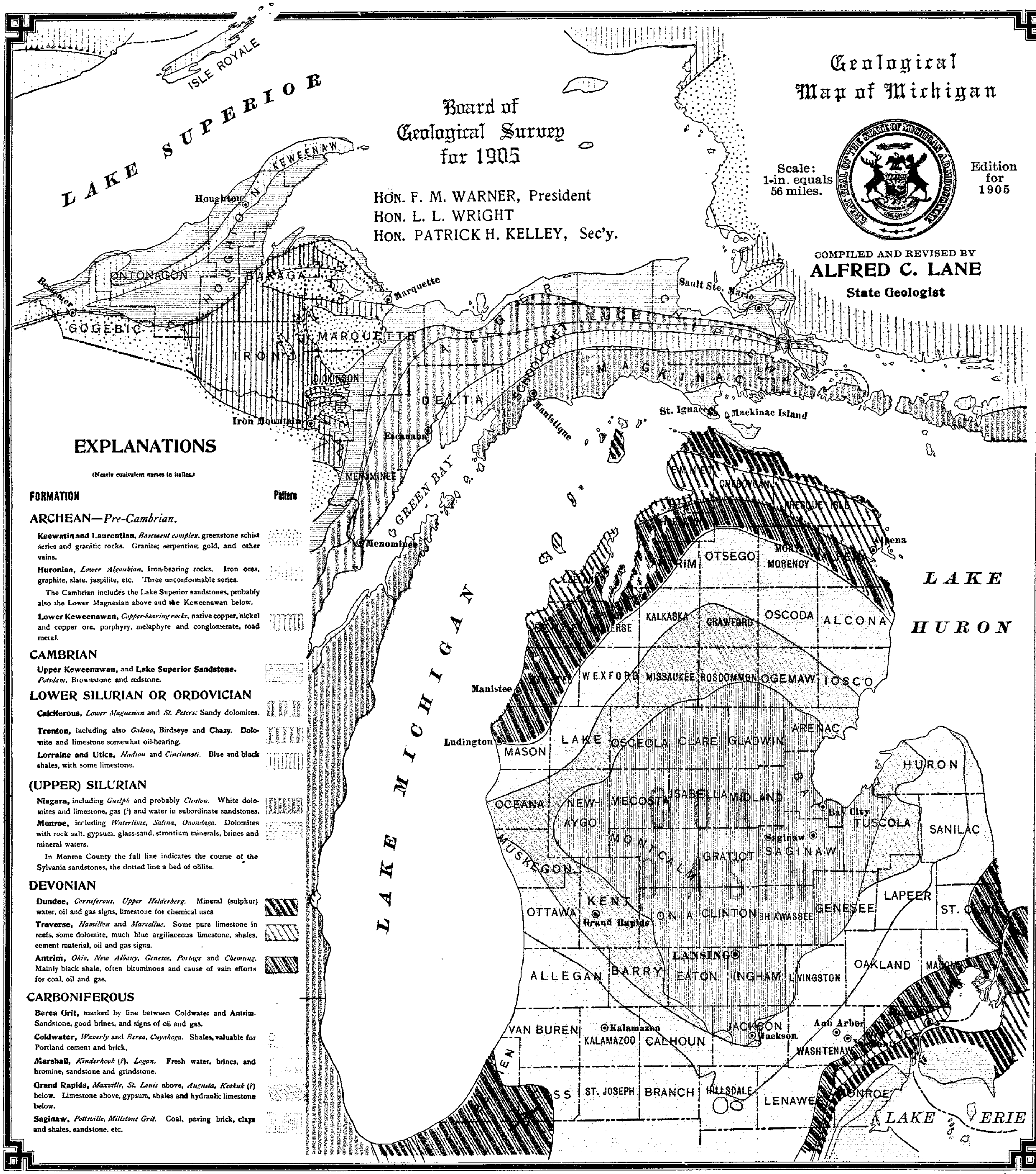
Favorable to geological exploration, on the other hand, is the fact that the portion of the Northern Peninsula under consideration, is crossed by several railroads; containg several cities, as Detour, Mackinac, St. Ignace, Manistique, Gladstone, Escanaba and Menominee, besides several villages, lumber camps, etc.; and at many localities on the shores of lakes Huron and Michigan is visited by steamboats. St. Ignace, Mackinac Island, Les Cheneaux Islands, Detour, etc., are frequented each summer by hundreds of people in search of rest and recreation, and contain a large number of summer hotels. These evidences of civilization, however, are not as great an aid to exploration as they probably seem to one who has not attempted to traverse the region indicated. The leading industry to the east of Gladstone and Escanaba is lumbering, inclusive of the cutting of pulpwood and railroad ties. As is well known, the practice in this connection even at the present day, is to fell such trees as are wanted and leave on the ground the branches and other portions not of immediate commerical value. Fires usually follow the lumbermen, and a dense growth of trees and shrubs springs up in the course of a few years on the fire-swept districts, which obscures the land and renders traveling even on foot exceedingly difficult.

The westward end of the portion of Michigan included on the above map is more favorable for agriculture than the part of the State bordering lakes Huron and Michigan on the north, and large areas particularly on Garden Peninsula, (situated between Lake Michigan and Big Bay de Noc) and in Delta and Menominee counties, lying principally to the west of Green Bay, have been cleared of their formerly dense forests, and are under cultivation. In this section wagon roads are quite numerous, comfortable farm houses abundant and the people, as is the case throughout the entire region traversed by me, most hospitable and obliging. Several railroads radiate from Escanaba and Gladstone, which faciliate geological work not only by furnishing means of transportation, but on account of the numerous excavations made during their construction. Geological work can, therefore, be carried on to the west of Green Bay more satisfactorily than in much of the eastward portion of Northern Michigan.

While the present report is based principally on personal observations, the writings of previous students of the geology of the same region have been freely used. A brief account of these writings will I think be interesting to the reader.

PREVIOUS PUBLICATIONS.

The portion of Michigan adjacent to lakes Huron and Michigan on the north, is by no means a new field to the geologist. It was first systematically explored in reference to its geology in 1850, while yet a portion of the Lake Superior Land District of the United States, by Messrs J. W. Foster and J. D. Whitney. Associated with this survey, were Messrs E. Desor, James Hall and Charles Whittlesey, each of whom made important contributions to previous knowledge concerning the geology of Northern Michigan. Desor in particular devoted his attention to the sands and clays which form the principal part of the soils and sub-soils, and began the study of the old beaches which record former and great changes of level of the water in the Great Lakes basin. For this task he was well prepared by previous work in Europe, having been associated with Agassiz in the study of the existing glaciers of Switzerland, and taken part in the interpretation of the records of ancient glaciers in Germany and adjacent regions. It was about this time that the importance of glaciers as agents in modifying the earth's surface began to claim the attention of Agassiz, Charpentier, Forbes, Guyot, De Saussure and others in Europe, and the foundation was laid for a systematic study of the records left by ancient glaciers in various parts of the world. Desor fresh from the land where these matters first claimed serious consideration, came to America as did Agassiz, and Guyot, and with them assisted in stimulating an interest in glacial geology in this country which has continuously increased to the present day, and is one of the chief divisions of the earth's history now receiving attention from the geologists of both Canada and the United States. On arriving in America Desor became connected with the U. S. Coast Survey, and was thus enabled to continue the study of lake shore topography, etc., previously begun in Europe, which gave him valuable training and enabled him to recognize the significance of the several abandoned beaches which form such a conspicuous feature of the slopes bordering the Great Lakes. Desor was associated wtih Forbes and Whitney during 1849 and 1850, and was enabled to examine in



Geological Map of Michigan
Board of Geological Survey for 1905
HON. F. M. WARNER, President
HON. L. L. WRIGHT
HON. PATRICK H. KELLEY, Sec'y.
Scale: 1-in. equals 56 miles.
Edition for 1905
COMPILED AND REVISED BY
ALFRED C. LANE
State Geologist
EXPLANATIONS
(Nearly equivalent names in italics.)
FORMATION
Pattern
ARCHEAN—*Pre-Cambrian.*
Keewatin and Laurentian, *Basement complex*, greenstone schist series and granitic rocks. Granite; serpentine; gold, and other veins.
Huronian, *Lower Algonkian*, Iron-bearing rocks. Iron ores, graphite, slate, jaspilite, etc. Three unconformable series.
The Cambrian includes the Lake Superior sandstones, probably also the Lower Magnesian above and the Keweenawan below.
Lower Keweenawan, *Copper-bearing rocks*, native copper, nickel and copper ore, porphyry, melaphyre and conglomerate, road metal.
CAMBRIAN
Upper Keweenawan, and **Lake Superior Sandstone.** *Potsdam*, Brownstone and redstone.
LOWER SILURIAN OR ORDOVICIAN
Calciferous, *Lower Magnesian* and *St. Peters:* Sandy dolomites.
Trenton, including also *Galena*, Birdseye and Chazy. Dolomite and limestone somewhat oil-bearing.
Lorraine and Utica, *Hudson* and *Cincinnati*. Blue and black shales, with some limestone.
(UPPER) SILURIAN
Niagara, including *Guelph* and probably *Clinton*. White dolomites and limestone, gas (?) and water in subordinate sandstones.
Monroe, including *Waterline*, *Salina*, *Onondaga*. Dolomites with rock salt, gypsum, glass-sand, strontium minerals, brines and mineral waters.
In Monroe County the full line indicates the course of the Sylvania sandstones, the dotted line a bed of oölite.
DEVONIAN
Dundee, *Corniferous*, *Upper Helderberg*. Mineral (sulphur) water, oil and gas signs, limestone for chemical uses
Traverse, *Hamilton* and *Marcellus*. Some pure limestone in reefs, some dolomite, much blue argillaceous limestone, shales, cement material, oil and gas signs.
Antrim, *Ohio*, *New Albany*, *Genesee*, *Portage* and *Chemung*. Mainly black shale, often bituminous and cause of vain efforts for coal, oil and gas.
CARBONIFEROUS
Berea Grit, marked by line between Coldwater and Antrim. Sandstone, good brines, and signs of oil and gas.
Coldwater, *Waverly* and *Berea*, *Cuyahoga*. Shales, valuable for Portland cement and brick.
Marshall, *Kinderhook* (?), *Logan*. Fresh water, brines, and bromine, sandstone and grindstone.
Grand Rapids, *Maxville*, *St. Louis* above, *Augusta*, *Keokuk* (?) below. Limestone above, gypsum, shales and hydraulic limestone below.
Saginaw, *Pottsville*, *Millstone Grit*. Coal, paving brick, clays and shales, sandstone, etc.
LAKE SUPERIOR
ISLE ROYALE
KEWEENAW
Houghton
ONTONAGON
HOUGHTON
BARAGA
Marquette
Bessemer
GOGEBIC
IRON
MARQUETTE
DICKINSON
Iron Mountain
DELTA
Escanaba
MENOMINEE
Menominee
GREEN BAY
SCHOOLCRAFT
Manistique
LUCE
CHIPPEWA
Sault Ste. Marie
MACKINAC
St. Ignace
Mackinac Island
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
EMMET
CHEBOYGAN
PRESQUE ISLE
Alpena
OTSEGO
MONTMORENCY
KALKASKA
CRAWFORD
OSCODA
ALCONA
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
Manistee
Ludington
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
BAY
Bay City
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
Saginaw
LAPEER
ST. CLAIR
OTTAWA
KENT
Grand Rapids
IONIA
CLINTON
SHIAWASSEE
GENESEE
LANSING
OAKLAND
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
VAN BUREN
Kalamazoo
KALAMAZOO
CALHOUN
JACKSON
Jackson
Ann Arbor
WASHTENAW
ST. JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

a general way nearly all of the Northern Peninsula of Michigan, which was thus made classic ground to glacial geologists. Besides several papers dealing with the surface geology of Northern Michigan, published in the scientific journals of Europe and America, he furnished two reports on his observations, which were embodied in the reports made by Foster and Whitney to the Commissioner of the General Land Office.[1] Much use has been made of Desor's observations while writing the present report.

In the second report by Foster and Whitney there is an article on the ancient and present beaches of Lake Michigan, and a chapter on the observed fluctuations in elevation of the surfaces of the Great Lakes by Charles Whittlesey, which contains many data of value not only in reference to the shoaling or deepening of harbors, but of use in demonstrating that a secular change in elevation, or a tilting, of the rocks of the region where the Great Lakes are situated, is in progress. The modern changes about the shores of the Great Lakes and the light thus furnished in reference to the history of the abandoned beaches now high above the surfaces of the lakes, were discussed by Whittlesey in "Contributions to Knowledge," published by the Smithsonian Institution and elsewhere.[2]

The geology of the stratified rocks, principally dolomite and limestone, beneath the surface covering of unconsolidated debris in the part of Michigan under consideration, was studied by James Hall during the Foster and Whitney survey, and later by Carl Rominger, State Geologist of Michigan. In the reports of Hall and Rominger, the positions which the rocks now occupy, the tract of county each formation immediately underlies, and the abundant records of the life of the time during which the several formations were deposited, received special attention. The writings of Hall and Rominger in reference to the older chapters in the geological history of Michigan are fully as interesting and instructive as the story of the much more recent changes described and discussed by Desor and Whittlesey, and are important contributions to knowledge. The report by Rominger, in particular, dealing with fossil corals, and contained in volume III of the reports of the Michigan Geological Survey, should be of great educational value to the inhabitants of the Northern Peninsula, since it contains descriptions of the marine life which flourished in that region when it was covered by tropical seas. Fossil corals occur in abundance especially in the Garden Peninsula, where they not infrequently form a large part of the stone walls built about the fields of the farmers. These beautiful objects awaken interest even in the minds of the unlearned on account of their peculiarities of shape and structure, and attract the attention of children. With the aid of Rominger's report they can easily be made stepping stones to a knowledge of nature, as well as walls about meadows and pastures.

Since Desor and Whittlesey directed attention to the glacial deposits and old lake beaches of Michigan, much interest has been taken in the later chapters of the earth's history preserved in this and adjacent regions, by the people of Canada and the United States, and a large body of literature bearing on the subject has been published. While the results of nearly all of these studies have a direct bearing on the later geological history of the

[1]Foster, J. W. and J. D. Whitney "Report on the geology and topography of a portion of the Lak e Superior Land District, in the State of Michigan. Part I. Copper lands." Executive Document No. 69, House of Representatives, 31st Congress, 1st session. Washington, 1850, pp. 186-218.
"Report on the geology of the Lake Superior Land District. Part II. The iron region together with the general geology." Executive [Document] No. 4, Senate, Special Session, March, 1851, Washington, 1851, pp. 232-270.

[2]Reference to the publications of Whittlesey and Desor, may be found in, N. H. Darton's Catalogue and index of contributions to North American geology, 1732-1891, Bulletin No. 127, U. S. Geological Survey, Washington, 1896.

region described in this report, those most intimately connected with it are the writings of F. B. Taylor, of Fort Wayne, Indiana, who has devoted much time to the study of the abandoned shore lines of the Great Lakes and especially of the region about Mackinac Island and the northern border of Lake Michigan. The numerous papers by Taylor are for the most part listed in bibliographies of North American geology[1] and will be referred to many times in the following pages.

Of the many papers relating to the Great Lakes in general, and to their geological history, which refer to the changes recorded by former water-bodies about the northern shores of lakes Huron and Michigan, perhaps the most suggestive is one by G. K. Gilbert[2] dealing with the movements in the earth's crust which has recently affected the entire Great Lakes region, and are still in progress. A knowledge of the movement or tilting of the land now in progress in the region of the Great Lakes is important not only to the engineer who has charge of harbor improvement, but of great assistance to the geologist who endeavors to account for the many changes in water-levels that have taken place and are recorded by abandoned beaches which are no longer horizontal.

The several reports and papers mentioned above, and still others, referred to later, have been of great assistance while writing the present report. In this connection mention should also be made of the splendid charts of the Great Lakes published by the U. S. War Department.

OUTLINE OF GEOLOGICAL HISTORY.

The portion of the earth's history recorded in the rocks and in the topography of the part of Michigan adjacent to lakes Huron and Michigan on the north, has two distinct divisions; one dealing with the solid rocks of ancient date, the other with the superficial layer of clays, sand, soils, etc., of comparatively recent origin which rest on the surfaces of the hard rocks.

In the older chapter the records pertain to a time when the site of Michigan was covered by the waters of ancient seas, over the bottoms of which deposits of sand and mud were spread out in horizontal layers. These beds have since been hardened into sandstone, limestone, dolomite (magnesian limestone) etc., but still retain fossil shells, corals, crustaceans, etc., which reveal the nature of the life inhabiting the ocean during the Paleozoic or ancient division of geological time. The younger chapter of the geological history deals principally with the great ice invasion, termed the Glacial Epoch, during which the site of Michigan, together with a vast region about it, was buried beneath glaciers in much the same manner that Greenland is sheltered with ice at the present day. Intimately connected with this ice invasion were lakes, at times of wider extent than the present Great Lakes, which occupied the same basins and left conspicuous beach lines about their border. Each of these two divisions of the geological history of Michigan, although conspicuously different in nearly exery detail, is full of interest even to the general reader, and in each case, also, has a direct and important bearing on human affairs.

It is instructive to tabulate the chief divisions of the two great chapters

[1]Weeks, F. B. Bibliography of North American geology, paleontology, petrology and mineralogy for the years 1892–1900, inclusive. U. S. Geological Survey, Bulletin No. 188, Washington, 1902.

[2]Recent earth movements in the Great Lakes region, U. S. Geological Survey 18th Annual Report, pt. II, pp. 595–647; republished in part in National Geographic Magazine, Vol. VIII, pp. 233–247; and also in Annual Report of the Board of Regents of the Smithsonian Institution for 1898, Washington, 1899, pp. 349–361.

of geological history just referred to, and to indicate the nature of the records on which their interpretation depends. Such a summary reads as follows:

OUTLINE CHART OF GEOLOGICAL RECORDS.

Geological Time.	*Nature of the Records.*
PRESENT EPOCH.....	Lake beaches still being formed; river silts and sands, peat, marl, etc., now being deposited or still growing; river valleys still being deepened; lake beaches formed since the Glacial Epoch and now abandoned; deposits now being made in lakes, etc.
GLACIAL EPOCH......	Abandoned beaches of ice-dammed lakes. Glacial striæ and other markings on rock surfaces. Glacial deposits, as till or boulder clay, occurring as a surface blanket over the hard rocks, and in places forming lenticular hills or drumlins. Gravel and sand deposited by glacial streams, such as irregular ridges or eskers and sand plains.

A long time-interval during which Michigan was a land area and subject to erosion.

PALEOZOIC ERA....	Monroe Period...... Niagara Period..... Lorraine and Utica Period........... Trenton Period..... Calciferous Period...	Mostly marine limestone, usually magnesian, in nearly horizontal beds, and containing fossil shells, corals, crustaceans, etc.

As this schedule suggests, a convenient plan for presenting a popular account of the geological history of the portion of Michigan under consideration, is to give: First, a brief summary of what is known concerning the older or Paleozoic formations, and a free interpretation of their history, or the hard-rock geology as it may be termed. Second, a discussion of the nature, mode of origin, etc., of the superficial blanket of rock-waste which rests on the hard rocks, or the surface geology. Of these two divisions, chief attention is here invited to the surface blanket of rock-waste inclusive of soils and sub-soils, for the reason that it is everywhere in sight, and in the region examined is of greater economic importance to man than the hard rocks beneath, as it furnishes the basis for agriculture, and forms the surface in which forests are rooted.

THE HARD-ROCK GEOLOGY.

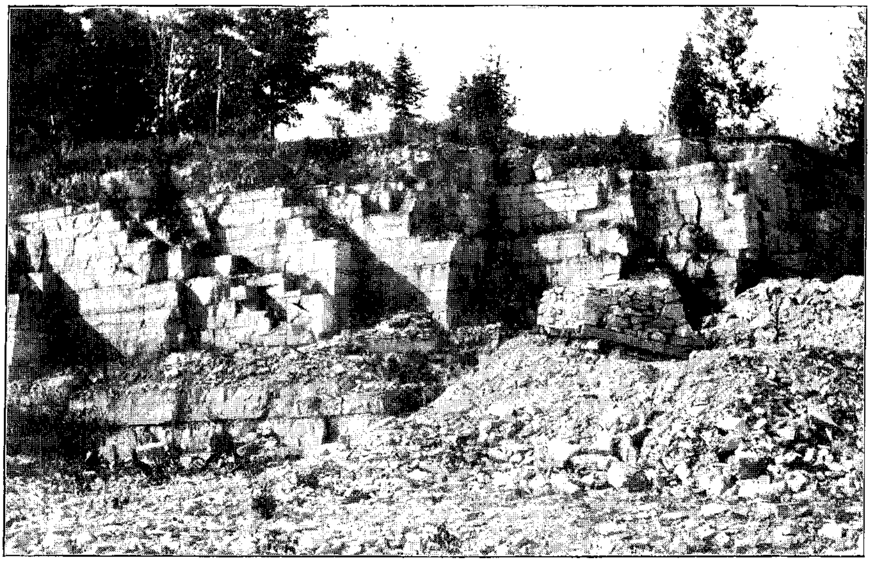
The rock formations beneath the unconsolidated surface covering of glacial deposits, lake clays, etc., of Michigan—with the exception chiefly of the igneous rocks, granite, schists, etc., of the iron and copper regions of the Northern Peninsula—are marine deposits and all belong to the Paleozoic, or most ancient of the formations at present known which contain records of life.

Within the area represented by shading on the map forming Plate I, the formations of older date than the Glacial Epoch all belong to the Silurian (or Ordovician and Silurian of some schemes of classification) and include the following sub-divisions as recognized by the Geological Survey of Michigan, namely, in descending order, the Monroe, Niagara, Lorraine and Utica, and Trenton, formations. These names have been applied to sheets of rock, mostly limestone and dolomite (magnesian limestone) which in the region bordering lakes Huron and Michigan on the north, have an aggregate thickness of about 1,800 feet from the top of the Monroe to the base of the Trenton and are inclined downward or dip southward at low angles. The dip at most localities is so gentle that the beds of rock appear to be horizontal. Owing to the dip of the formations and the manner in which they have been eroded, they come to the surface in a series of concentric belts, concave to the south, as indicated on the geological map of Michigan forming Plate III.

The Monroe Formation: The rocks thus designated are about the equivalent in age of the Manlius and Salina[1] (and Lower Helderberg of some authors) formations of New York, which include the salt and gypsum deposits near Syracuse. Similar rocks occur in Northern Ohio and southeastern Michigan where they also contain beds of salt and gypsum. In Northern Michigan this formation occurs at the surface on the St. Ignace Peninsula, Mackinac Island, Bois Blanc and other neighboring islands, as was made known by James Hall in 1850,[1] and much information concerning it is recorded in his contribution to Foster and Whitney's report already referred to. The light colored limestone forming the upper portion of the conspicuous precipices about the border of Mackinac Island and appearing in the St. Ignace Peninsula and on Bois Blanc, were identified by Hall as about the equivalent of the Helderberg formation of New York. Beneath this somewhat massive limestone and exposed at the water's edge about Mackinac Island, and in a similar position on the margin of the St. Ignace Peninsula, are gypsum bearing beds having the stratigraphic position of the Salina formation of New York. These gypsum bearing beds form the surface on the northern portion of Mackinac Island and outcrop throughout a considerable area a few miles north of St. Ignace. When at or near the surface their presence is indicated by a multiform topography characterized by a succession of irregular hills with equally irregular hollows between, and as a rule the absence of surface streams. These peculiar surface features are due to the removal of the more soluble portions of the deposit and especially the gypsum (hydrous calcium sulphate) which they contain. This mineral occurs in irregular beds, and mingled with it is a similar mineral known as anhydrite or the anhydrous calcium sulphate. Possibly beds of salt like those present in rocks of the same age near Detroit, have also been dissolved away, but borings seem to indicate that they do not extend so far north. The peculiar roughness of surface referred to, is confined to the localities where the Salina formation is present and is not found elsewhere in the portion of Northern Michigan under consideration.

The rock, mostly impure limestone, at the top of the gypsum bearing formation and marking the passage into the overlying formation, is peculiar, inasmuch as it consists of angular fragments of limestone inclined in all directions and cemented into a compact mass by carbonate of lime which has been deposited in the cracks and crevices between them. This *breccia* is well exposed in the rocky ridges in the western portion of the town of

1 The New York correlation was made by Hall. The presence of gypsum, etc., and a very fair description of the formations associated with it, however, had already been given by Bigsby in 1822.



QUARRY IN JOINTED NIAGARA LIMESTONE, DRUMMOND.

July 24, 1904.

St. Ignace, and at the "Sugar Loaf" and other localities on Mackinac Island. An explanation of the origin of the breccia, so far as I am aware, has not been offered, although Hall directed attention to it and judging from the statements made in his report, seemed to consider it as evidence of an unconformity,[1] that is, the occurrence of an interval during which the lower formation was exposed to the air and broken and eroded before the rocks resting on it were deposited. The fragments of limestone in the breccia, however, are sharply angular and not rounded as is nearly always the case with stones that have been weathered, or removed and re-deposited by water. The nature of the breccia and its occurrence above strata containing easily soluble beds of gypsum,—and of anhydrite which in the presence of water is prone to change to a hydrous condition, accompanied by an increase in volume—suggests that the fracturing and displacement of the rocks may be due to the removal of material in solution, and to changes in volume caused by the hydration of the anhydrite. Remembering that the present surface of the St. Ignace Peninsula, etc., has been exposed owing to the removal of very considerable depths and probably many hundreds of feet of rock, it is evident that the solution of beds of gypsum or the alteration of the anhydrite, at any time subsequent to the consolidation of the formations resting on it, would lead to movements, and particularly the settling and fracturing of the rocks above the gypsum-bearing layers, which would become broken, and displaced and if re-cemented would form a breccia. The above suggestion may perhaps lead future visitors to the region about Mackinac to examine the rocks attentively with the view of discovering evidence which will sustain or disprove the hypothesis here proposed.

As has been described by Hall, the limestone of Onondaga age in the St. Ignace region, like the limestones or dolomites of similar age in New York and Southeastern Michigan, are frequently vesicular owing to the removal from them of material more soluble than the main bulk of the rock. The cavities thus produced are frequently angular or gash-like and as has recently been shown by E. H. Kraus, have resulted in many if not all instances from the solution of crystals of celestite (strontium sulphate) with which unweathered rocks in the same formation are frequently changed.

Gypsum has been found on the St. Ignace Peninsula in considerable abundance, and is exposed at certain localities on Mackinac, St. Martin, and Goose islands, but is not known to occur at these localities in sufficient quantity and of the requisite purity to be of commercial importance.[2]

While rocks of the same age as those forming at the St. Ignace Peninsula and neighboring islands, are sometimes rich in fossils, those outcropping to the north of the straits of Mackinac are mostly barren of such remains and offer but little inducement to collectors of the relics of ancient life.

The Niagara Limestone: The rocks corresponding in age with the Niagara and Clinton formation of New York and consisting almost entirely of light colored, white or bluish, magnesian limestone or dolomite, are the most widely distributed and in several ways the most important of the formations exposed in the region treated in the present report. They extend in a curving bed concave to the south, (see Plate III) and with an average width of about fifteen miles, from Drummond Island westward to the end of Garden Peninsula. The thickness of the sheet according to Hall, is about 350 feet,[3]

[1] Foster, J. D. and J. D. Whitney, Report on the geology of the Lake Superior Land District, Washington, 1851, p. 162.
[2] See, however, vol. 9 of the Reports of the Michigan Geological Survey.
[3] Probably more rather than less. See Annual Report of the Geological Survey of Michigan for 1903, pp. 114–122.

and its inclination or dip is southward at a low angle, in general amounting to a descent of about thirty-five or forty feet to a mile. In a general way the dip changes from southwest in the vicinity of Detour to southeast on the Garden Peninsula, indicating as will be discussed more fully on a subsequent page, that this immense sheet of rock, in common with other and adjacent sheets both above and below has been depressed in the region occupied by Southern Michigan so as to have a saucerlike shape.

The Niagara limestone was deposited in a shallow ocean, in which the conditions were for the most part favored the growth of corals, mollusks and other invertebrate animals which live in the open sea. The condition changed, however, from time to time, and mechanical sediment such as mud and sand were carried by currents far from shore and mingled with the organic debris of the open waters. These changes are recorded in the nature of the rocks and by the relics of life they contain. Throughout the region under consideration, the land during the Niagara period was sufficiently distant to prevent the detritus brought from it by streams from making conspicuous deposits. The material accumulated on the oceans floor was mainly supplied by the hard parts of animals and especially corals, which lived in its waters, although clayey sediments derived from the land did at times interfere with or modify the development of the living organisms. The more purely calcareous layers of rock or the ones with no appreciable admixture of argillaceous matter, abound in corals, as remarked by Hall, and appear to have been coral reefs, which even now occupy their original positions. In many instances these ancient coral-reefs were covered by deposits composed in part of finely comminuted matter, probably derived from the remains of corals and other marine animals, but containing also appreciable quantities of land-derived mud. When those impure limestones were formed no corals lived nor as a rule are other fossils to be seen in such portions of the rocks. Again the conditions varied and corals reappeared and continued to flourish for a longer or shorter period, until another change unfavorable to their growth occurred; and in this manner several alternating bands of limestone, some crowded with fossils and others barren of the records of life, came into existence.

In some instances the Niagara limestone, as in the southern portion of the Garden Peninsula, is crowded with finely preserved fossils, consisting principally of corals and representing ancient coral reefs. Beautiful specimens of these relics are there strewn over the fields and in numerous instances have been gathered together and used in making stone fences. The reason for the abundance of these fossils at the surface is that owing to changes produced by the deposition of silica, after the rocks were consolidated and before being eroded, the original lime of the corals and other organisms was removed and replaced by silica, while the inclosing rock was not thus altered. By this process of silicification the fossils were rendered much less soluble than the rock containing them, and when exposed to the air and beaten upon by rains, were left when the more calcareous material surrounding them was removed. Resulting from this combination of conditions, we find today, strewn over the fields, wonderfully perfect and frequently exceedingly delicate and faithful representations of corals which lived many millions of years ago.

At certain localities as on Drummond Island, and in exposures of limestone in the hills about seven miles north of Hessel and Cedarville, the Niagara limestone is crowded with natural casts of the interiors of large brachiopod shells of the genus *Pentamerus*. These may be readily recognized by the five divisions into which the casts are divided in the part where the two valves of the shell were hinged together. Other fossils are also abundant at many localities where the Niagara limestone is exposed, and make an attentive study of such outcrops both interesting and instructive. The fossil corals of the Niagara limestone and of other formations in Michigan, have been faithfully described and well illustrated by Carl Rominger, in Volume 3 of the reports of the Geological Survey of Michigan.

The Niagara limestone as will be more fully considered on a subsequent page, is in general and especially in its upper portion, harder and more massive than the formations with which it is immediately associated and hence has resisted erosion more efficiently than its neighboring terranes. It is also in general a magnesian limestone and in part a typical dolomite, and for this reason is less readily soluble than if composed of pure calcium carbonate; this also favors its preservation and together with its hardness, has enabled it to stand in relief while the surfaces of the less resistant adjacent formations have been lowered so as to form valleys.

A view of an artificial exposure of the lower portion of the Niagara limestone, in a quarry at Drummond, on the north shore of Drummond Island, is presented on Plate IV, which shows the nearly horizontal position occupied by the thin sheets of rock there present. A still more prominent feature, however, to be seen in the same picture, is the presence of two series of nearly vertical dividing planes or joints which cut the strata, and together with the bedding planes divide the rock into rudely rectangular blocks, thus greatly aiding the work of the quarryman. The joints so far as now exposed are narrow, nearly smooth sided fissures, such as one may suppose would be produced by sawing the rocks along two series of parallel lines at right-angles to each other; the saw being slightly inclined instead of vertical. The two series of master joints bear respectively N. 39° E. and N. 58° W.[1] or approximately at right angles; the joint planes although nearly vertical, are inclined to a horizontal plane as may be seen in the accompanying illustration.

Joints similiar to those just noted occur in many sedimentary rocks and in fact have a world wide distribution, but their mode of origin has not as yet been satisfactorily explained. As a modest contribution to the data, on which the desired explanation must be based, the following facts are here recorded: Near the Lake Survey Signal Station at Detour, nearly flat surfaces of limestone are divided by joints, and in their at present weathered condition resemble a rude pavement of flat stones; the joints having been widened to several inches owing to the solvent action of water on their walls. The major joints are here, as is usual in two series nearly at right angles to each other; the average of several measurements, shows that one series bears N. 39° E. and the other N. 53.8° W. In a neighboring exposure the respective bearings are, N. 51° E. and N. 48° W. In each case the nearly northwest joints are stronger and more prominent than the northeast series. The joint planes are nearly vertical but owing to the effects of weathering no satisfactory measurements of their inclination were obtained. In the Niagara limestone quarries near Marblehead, two systems of joints are again conspicuous, one bearing N. 66° E. and dipping southeast at an angle varying from 85 to 88°; and the other bearing N. 44° W. and dipping northeastward at an angle of about 80°. At Whitedale, two series of joints rendered con-

[1]These and other compass readings given in this report, have been corrected for secular magnetic variation, i. e. are referred to the geographic instead of the magnetic pole.

spicuous by weathering, were observed, one series bearing N. 24° E. and the other series N. 46° W.

The full significance of these and other measures of the position of joint planes is not now apparent, as they pertain to an unsolved problem, but are well worth noting. It will perhaps be found that the joints which are such a prominent feature of nearly all sedimentary rocks, have been produced by torsion generated in the earth's crust perhaps on account of variations in the rate of the earth's rotation, assisted as has been suggested, by earthquake shocks, and hence having an important bearing on profound questions concerning the relation of the earth to other planets, etc. There is yet another reason why joints should receive general recognition. They influence the manner in which rocks weather, and hence furnish a reason for many features in the shapes of cliffs and valley sides. By giving direction to streams, they also determine the major topographic features of many regions, such as hills and valleys, which have been produced by erosion.

The Lorraine and Utica Formation: The rocks to which this compound name is applied in recent publications of the Geological Survey of Michigan, are, as shown principally by their fossils, about the equivalent in age of the Hudson River shales of New York, and the Cincinnati limestone of Ohio, but in composition are intermediate between the two. They are not typical shales or representative limestones, but impure or argillaceous limestones. The significance of these differences in the rocks of the same age, deposited in the same ocean but at different localities, is that near the land in the case of the Paleozoic ocean as in the ocean at the present day, sand and mud were spread over the bottom while far from land calcareous deposits accumulated. In Northern Michigan, the rocks of the Lorraine and Utica formation were formed in a sea teeming with life, but where mud washed from land was being deposited in considerable abundance. The influence of these conditions is expressed by the organic remains still to be found in the rocks, which consist largely of brachiopod and molluscan shells and crustaceans, (trilobites) with but few and mostly small representatives of the corals. That is, the life was such as rejoiced in muddy bottoms, and did not include forms, like the corals, which thrive best in clear seas.

The rocks of the Lorraine and Utica formation occur in a belt from about two to five or six miles wide, concentric with and to the north of the similar curved belt occupied by the Niagara limestone, and extend from St. Marys River on the east to Big Bay de Noc on the west. Their distribution is shown on Plate III. The breadth of the outcrop of the formation just stated is not considered as accurate, since the region where it occurs is forested and occupied to a considerable extent by swamps, so that the nature of the underlying rocks and the precise boundaries of formations are difficult to ascertain. One of the chief features of interest concerning the Lorraine and Utica formations is its relative weakness in reference to erosion. Its softness and the thin bedding permit it to yield readily to mechanical agencies of erosion such as sand-laden streams, and glaciers in the basal portion of which stones are embedded, while at the same time the calcareous portions are subject to solution by surface or percolating waters. Mainly for these reasons the surface where these rocks are present has been eroded to a lower level as a rule, than the adjacent country where more resistant rocks occur and on account of its low relative position is now largely swampy. The Lorraine and Utica formation yields to denuding agencies more readily than the Niagara which overlies it or the Trenton which occurs beneath it, and this finds expression, as will be considered more fully later, in the relief of the hard-rock surface beneath the glacial drift, etc. and especially in the presence of Green Bay at the west and Georgian Bay at the east, where the rocks of this formation have been excavated so as to form basins.

The best exposure of the Lorraine and Utica formation in the region especially considered in this report, is in the low lake-cliff on the east side of Little Bay de Noc opposite Escanaba. At this locality the nearly horizontal bedding of the deposit, its conspicuously argillaceous character, and its richness in organic remains are well illustrated. These same cliffs also show how the waves of the lake, by cutting away soft beds which occur beneath harder and more massive layers, lead to the production of precipitous and even overhanging escarpments.

The Trenton Limestone: A series of thin, mostly bluish, impure limestone beds occurring beneath the Lorraine and Utica formation in Northern Michigan is stated by Hall to be in reality compound and to represent several formations each of which has a thickness of many score feet in New York, but is termed the Trenton limestone of which it is mainly the representative. Its thickness in Northern Michigan as computed for its dip and breadth of outcrop, as well as from the records of drilled wells, is about 200 feet. It is stratigraphically next below the Lorraine and Utica formation, and owing to the basin-like structure of the rocks beneath the greater part of Michigan, comes to the surface in a curved belt concentric with the similar belts formed by the Niagara, etc., between St. Mary River on the east and the Menominee River on the west. This outcrop is mostly to the north of the region to which attention is invited in this report, but to the west of Green Bay, underlies the surface covering of glacial drift, etc., for a distance of twelve to over twenty miles westward from the bay shore. The formation is well exposed along the lower portion of Escanaba River, where it is quarried for building stone, and also appears at the mouth of Ford River, and at a number of other neighboring localities where it has been laid bare by erosion or trenched by streams.

To the north of the Trenton limestone in Northern Michigan, other layers of rock belonging to the Ordovician or Lower Silurian, and Cambrian periods are present, including as the lower member, the Lake Superior or Potsdam sandstone, which outcrops along the southern shore of Lake Superior from near Marquette eastward to St. Mary River, but concerning this important formation little need be said at this time.[1]

Geological Structure: By this term is meant the positions or attitude occupied by the layers of rock in the earth's crust. It is a well established fact that sheets of marine sediments of the general nature of those described above, are horizontal or essentially so, unless some force has been exerted on them and cause them to become inclined or folded. In Northern Michigan as already explained, the Paleozoic formations ranging in age from the Potsdam sandstone at the bottom, to the Monroe formation at the top, are inclined southward at low angles; the dip being southwest in the eastern portion of the country beneath which they occur, and changing gradually to southeast, when traced westward to the region bordering Green Bay. The succession of the rocks together with their gentle southward inclination is indicated in the following diagram, which represents the manner in which the edges of the various formations present from Point St. Ignace northward to Lake Superior, would appear if a great railroad cut for example, should be made along such a line and extended down to sea level.

[1] See Annual Report Geological Survey of Michigan for 1903, pp. 124–142.

As an attempt has been made to show in the following section, the edges of the more resistant beds stand in relief forming hills, while the less resistant rocks underlie depressions or valleys. The entire series of beds dips southward, the inclination being in general over forty feet to a mile. Similar sections in the Georgian Bay region would show a southwest, and if made in the Green Bay region a southeast dip. Without attempting to present all the evidence in this connection, the conclusion may be stated, as the result of a long series of observations carried on by various geologists, that Southern Michigan and a large region about it including the portion of Northern Michigan to the east of the longitude of Marquette, has a basin-like structure; the rocks in the central portion occuping a horizontal position, and those about the central area, being depressed and passing under it.

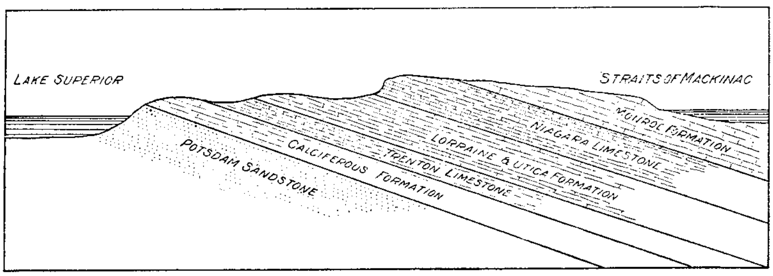


Fig. 4,—Ideal section showing succession of formations in Northern Michigan.

Owing to this basin-like structure the formations indicated in the above sketch section which in Northern Michigan have an inclination downward to the south, and disappear in succession as one crosses their edges in traveling from the north toward the south in the order of their age; reappear in part in Southern Michigan in reverse order and with a downward inclination to the north. That is, the originally horizontal beds in the Michigan region have been depressed in the central part of that area, so as to resemble a pile of shallow saucerlike dishes. The upper portion of the pile has been eroded to a generally plane surface, somewhat lower than the original surface of the central and last formed member of the pile. The concentric arrangement of the surface exposures or outcrops of the formations involved in the movements just described, is shown in part on the geological map forming Plate III.

The subsidence referred to went on during the time the various layers of sediments were being deposited, and was perhaps due in part to their weight, but was mainly produced, as is believed, by a more general cause, namely, contraction of the central mass of the earth beneath its cool and rigid crust. The downward movement while extending from the earlier portion of the Paleozoic era to the close of the Carboniferous period, was not necessarily continuous throughout this immense period of time, and there is evidence showing that upward movements occurred during certain stages, as near the middle of the Carboniferous period, when a land surface existed in the central part of the Southern Peninsula of Michigan, which was eroded and had gypsum deposited in its lake basins or lagoons, before the next succeeding sheet of marine deposits was laid down.

The deformation which produces the great structural or tectonic basin of Michigan, is one of the unique features in the geology of North America.

and one to which popular attention has seldom been directed. A proper understanding of its importance is necessary, however, in order to enable one to appreciate the significance of many facts concerning the geology of the hard rocks which have a direct bearing on matters of commercial importance, and in order also to learn the fundamental reason for the existence of some of the geographical features of the Great Lakes region. The Michigan tectonic basin is rudely circular and approximately 500 miles in diameter; its center being in the medial portion of the Southern Peninsula, near Midland. In this central region the amount to which the lowest rocks involved in the downward movement have been depressed below their original position, is as nearly as can now be judged, not less than five or six thousand feet. In many portions of the earth's crust, the rocks composing it have been upheaved into great domes from which mountains have been carved, but it is exceptional to find an extensive region where the opposite result or the production of a reversed dome of vast dimensions, has been reached with but little secondary disturbance, and not followed by an upward movement.

In the Michigan region the great subsidence mentioned went on during a large portion of, if not the entire, Paleozoic era; the oldest sediments known to have been involved being the Cambrian, and the youngest the Coal Measures. The subsidence permitted of the deposition of sheet after sheet of marine sediments, within generally narrower and narrower limits as the pile increased in thickness, until the coal-bearing rocks which occupy the center of the basin were deposited. This great subsidence occurred with but little secondary folding or crumpling. It is probable, however, that irregularities of the nature of up and down folds, radiating from the central portion of the depressed region towards its periphery are present, but are as yet undiscovered. This conclusion is suggested by the fact that a series of horizontal beds if depressed in its central part must be either stretched to admit of the change of shape, or be plicated in radial folds. Evidence of plication in beds that have been elevated into domes is well known, but a flow of the material of which rocks are composed so as to admit of an adjustment to a new position during such movements is much more difficult to detect. Probably each of these changes were brought about in the rocks of the Michigan region and evidence of radial folding should be looked for, since it is a matter of great economic importance in reference to the storage of gas and oil.[1]

The significance of the general structure of the Michigan tectonic or structural basin in reference to the geology of the part of the State under immediate consideration, is, that the hard rocks there present are included in the outer portion of the series of concentric belts formed by the coming to the surface of the deeper of the basinshaped formations which underly Southern Michigan. The rims of the lower members of the pile of geological saucers, so to speak, form segments of concentric belts, concave southward, which sweep in remarkably regular curves from St. Mary's River westward well into Wisconsin. On the west this series of curved belts meets a region of crystalline rocks exposed owing to the erosion of a region of upheavel, but on the east the influence of the Michigan tectonic basin is apparent throughout the western part of Ontario.

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1 In this connection it may be suggested that wells drilled in Southern Michigan with the hope of obtaining gas or oil, would have the best chance of success if distributed about the borders of that Peninsula where radial anticlinals pitching toward the central part of the basin, may be expected to approach the surface and to afford the requisite conditions for the storage of oil and gas. Where these localities are, if they exist, has yet to be discovered. Information in this connection, however, may be found in the reports of the Geological Survey of Michigan for 1901, and 1903.

Topography of the hard-rock surface. The attention of the reader has already been directed to the fact that the geology of the region bordering lakes Huron and Michigan on the north, has two leading and conspicuously different divisions; one relating to the stratified sheets of marine sediments, now for the most part hardened into compact rock, mostly limestone; and the other dealing with the superficial covering of loose and in large part unconsolidated debris, largely sandy and stony clay, resting on the surface of the older series of formations. In the language of geologists, the younger formation rests unconformably on the older series of formations, and between the two periods of accumulation there was a vast time interval. This interval, lost so far as the geological deposits of Michigan were concerned, extends from near the close of the Carboniferous period to the Glacial epoch. During much of this interval the region occupied by Michigan was a land area, and subjected to erosion. The records of the changes that occurred are therefore, to be looked for on the surfaces of the older rocks, and as is to be expected, must be mainly of the nature of hills and valleys produced by erosion. The shapes and other characteristics imparted to the outcrops of the older rocks thus become matters of great interest, since such features take the place of the more common class of geological evidence furnished by sedimentary and other deposits. The relief of the hard rock surface is also of interest in connection with the study of the superficial deposits resting on it, for the reason that it enables one to measure the thickness and ascertain other features of the superficial accumulations.

To ascertain the characteristics of a rock surface buried beneath subsequent deposits, is in most cases a difficult task, and one that is usually accomplished principally by obtaining the records of wells, mines, etc., which pass through the material beneath which it is concealed. In Northern Michigan, this task is less difficult than in most of the formerly glacier-covered portions of the United States, for the reason that the glacial and other deposits occupying the surface are everywhere comparatively thin, but as much of the country is forest and swamp-covered, the work of assembling the necessary data is tedious. Over large areas, wells and other excavations are wanting and natural conditions such as rock outcrops, etc., are alone available.

In spite of the meagerness of the facts in hand it is evident that in the part of Michigan under consideration, the hard rock topography does not differ materially from the relief of the surface of the superficial material resting on it. This conclusion will no doubt be a surprise to persons who have studied other portions of the formerly glaciated region of the United States, where as a rule, the superficial accumulations are deep enough to effectively conceal the relief of the surfaces of hard rock on which they repose. Throughout Northern Michigan, however, the glacial drift is so thin and forms such a uniform blanket, that it has essentially the same inequalities of surface as the floor on which it rests. It is only locally that the surface deposits have a topography peculiar to themselves which thoroughly masks the relief of the hard rock surface beneath.

The major features in the present relief of the region to the north of lakes Huron and Michigan, can be correlated with the varying degree of resistance to erosion of the Paleozoic formations there present. Here as elsewhere, the resistant rocks stand in relief, forming hills and ridges, while the less resistant rocks have been eroded so as to give origin to valleys. The basins of lakes Huron and Michigan as was first pointed out I believe, by Hall and Whittlesey, are situated where the Monroe formation (the Helderberg and

Onondaga salt group of Hall) which is less resistant both to the mechanical and to the chemical agencies of erosion than the formations above and below it, would be present, if it had not to a large extent been removed. Remembering the concentric arrangement of the belts of rocks formed by the edges of the various layers in the Michigan tectonic basin, it follows that if the basins of lakes Huron and Michigan have been excavated in the Monroe formation they should have the position which would have been occupied by that formation if it had not been excavated. By referring to a geological map of the Great Lakes region (Plate III) this will be seen to be essentially true.

As stated by James Hall, the basin of "Lake Michigan has been, to a great extent, excavated from the Onondaga salt group and the upper Helderberg series" [the Monroe and Dundee formations] "while the Niagara limestone, being harder and more indestructible, forms its western border from one extremity to the other. From the breadth of the country over which we find vestiges of the Onondaga salt group and the upper Helderberg series in the northern parts of lakes Huron and Michigan we are warranted in the conclusion that at least two-thirds of the latter lake in a direction conforming to its trend, has been excavated in these limestones." A similar conclusion was also reached by Whittlesey, in reference to Lake Huron; "The Niagara limestone there forms a barrier occasionally broken through, extending along its northern shore embracing Cabot's Head, and the Grand Manitoulin islands. It dips southerly, so as to leave the Onondaga salt group and the upper Helderberg series to the south; and the area once occupied by them is now covered by the waters of this lake."

The eastern and northern shore of Lake Huron from Goderich northward, and the entire northern and western shore of Lake Michigan, are composed of Niagara limestone which dips toward the water bodies it margins. The only exception to the continuity of the Niagara in the nearly semicircular coast line, over 600 miles long, extending from Goderich to Chicago, is where the rocks of the Monroe formation appear in the St. Ignace Peninsula. This exception is significant and a reason for it is suggested on page 57.

The fact that the sheet of Niagara limestone dips toward the lakes it margins, as just mentioned, at once suggests a reason for the general lowness of these shores, and their lack of bold or picturesque scenery. At many localities the gently-sloping surface of the limestone passes beneath the water at the lake margin without noticeable change due to abrasion by the waves. At other localities and particularly at the ends of capes, the waves and currents have cut small lake-cliffs, but those features are seldom conspicuous. Bluffs are present at certain localities, however, about the portions of lake shores just referred to, but so far as I am aware, they owe their prominence to lake-cliffs cut in glacial drift and similar material belonging to the surface blanket of rock debris, or to the presence of sand that has been drifted into dunes by the wind.

From the brief outline of the conditions about the outer shores, as they may be termed, of lakes Huron and Michigan, that is, the shores farthest removed from the center of the Michigan tectonic basin, it will be seen that not only do the basins of these lakes owe their existence and position to the structures and differences in resistance to erosion of the underlying rocks, but many of the scenic features of their present borders are controlled by these same conditions.

1. Foster, J. W. and J. D. Whitney, Report on the geology of the Lake Superior Land District, 1851, p. 176.

As the Niagara limestone dips toward the two of the Great Lakes which it borders respectively, and gives them low shores, it will be inferred no doubt, that the outer margin of the outcrop of the same bed of resistant rock should rise high in the air and form a bold ridge, or a series of prominent hills. This deduction is sustained in part by the present relief.

While the Lake Michigan shore of the Garden Peninsula is low and sandy, the opposite shore facing Big Bay de Noc, is notably bold, and presents several headlands which are prominent and mildly picturesque. The most conspicuous of these headlands known as Burnt Bluff, rises precipitously to a height of 225 feet above Big Bay de Noc, and is composed of Niagara limestone which dips gently toward the southeast. The prominence of Burnt Bluff and in general the boldness of the southeast shore of Big Bay de Noc inclusive of Middle Bluff, Garden Bluff, etc., is due directly to the structure of the rocks, and especially to the greater resistance offered to the agencies or erosion, by the Niagara limestone than by the weaker Lorraine and Utica formation on which it rests and which comes to the surface in the next concentric belt outward from the Niagara belt.

The greater prominence of the outward-facing or northern border of the Niagara limestone over its inner or southern border, is manifest also in the hills situated six to eight miles north of Manistique, and again in the hills which rise to the north of Hessel and Cederville. Whether a northward facing escarpment is present or not, between these two localities is unknown. An examination of such maps of this region as are available, fail to show that the Niagara limestone has controlled the direction of the present streams. This fact suggests that the maps are not sufficiently exact, to bring out such a relation if it exists, or that the erosion particularly by glaciers, together with the glacial deposits left on the country, have modified the topography to such an extent that the influence of the hard rocks on the direction the streams follow is no longer the controlling condition. On the northern border of Drummond Island, and generally about the southwest shore of Georgian Bay, the land is bolder and more picturesque than the neighboring shores of Lake Huron, for the same reason that the Bay de Noc border of the Garden Peninsula is higher and more precipitous than its Lake Michigan border.

The belt of rocks next to the outer margin of the curved belt underlain by the Niagara limestone, namely the Lorraine and Utica formation it will be remembered, is composed of earthy limestone in thin layers, and is much less resistant to the agencies of erosion than the formations adjacent to it. This belt of weak rocks should therefore have been eroded away more effectually than the adjacent beds, and given origin to valleys and lake basins. In fulfillment of this prediction we have Green Bay and its connecting bays, in the northwest portion of the Michigan tectonic basin, opening to Lake Michigan through narrow channels in the Niagara limestone; and Georgian Bay and North Channel in the northeast portion of the same great basin, opening to Lake Huron by means of narrow channels through the intervening land, composed of the same sheets of limestone, namely the Niagara, which shuts in Green Bay, etc. This symmetrical arrangement of Green and Georgian bays, with reference to the structure of the underlying rocks, is of the same nature as the relation of the basins of lakes Huron and Michigan to the same series of conditions, and increases one's confidence in the conclusions reached by Hall, Whittlesey and others, in reference to the basins of the Great Lakes being due largely to erosion. Now, two chief agencies of erosion, namely streams and glaciers, have been in operation in the Great Lakes region, and the question arises, which of the two is to be held chiefly responsible for the production of the basins the Great Lakes occupy. This question has been much discussed, but is still not answered to the satisfaction of all persons interested in it. It may perhaps not be digressing too far to suggest, that the intimate relation between the basins of lakes Huron and Michigan, and of Green and Georgian bays, respectively, to the weak formations on which they are located, suggests the long continued action of streams previous to the Glacial epoch, rather than the work of ice. Strengthening this view is the fact, as will be stated more fully later, that the main direction of ice movement as recorded by striæ, etc., on the Garden Peninsula, was athwart the longer axis of Big Bay de Noc and on Drummond Island was again nearly at right angles to the adjacent portion of the longer axis of Lake Huron. There were other glacial movements in each of these regions, however, and how much the flow of the ice favored the deepening of the lake or bay basins is difficult to determine. There is another series of facts of interest in this connection which needs to be discussed, that is the deposits of remarkable thickness, in places and over large areas amounting to between three and five hundred feet, which the former glaciers left in the region south of the Straits of Mackinaw and extending to central Ohio and Indiana. It thus seems probable that the glaciers did more toward the filling of the basins of lakes Huron and Michigan than they did in the way of deepening them.

Beside the basins now occupied by the waters of the Great Lakes a brief account of which has just been presented, there are other features in the hard-rock topography which have a bearing on the question as to the depth of glacial erosion. The valleys now occupied by the principal streams which enter Green Bay and the northern portion of Lake Michigan, such as the Manistee, Escanaba, Rapid and White Fish, and Manistique rivers, are older than the glacial epoch and show something of the relief of the surface before it was modified by glacial action. This conclusion is based on the size of these valleys in reference to the volume of the streams now occupying them, and the fact that above the reach of the present streams, the valley bottoms are covered with glacially deposited debris and their floor in places scored with glacial striæ. It is apparent that the valleys are not only of pre-glacial origin and were modified to only a slight degree by the glaciers which subsequently occupied them, but that the present streams have been enabled to do but little rock cutting since their present cycle of work began. The conclusion which one has forced upon him while travelling over the country drained by the river just named, and the same is true also of the region extending east from Manistique River to Drummond Island, is that the relief of the hard-rock surface beneath the superficial blanket of glacial and other debris, controls the present topography. That is, the depth of the glacial deposits, etc. is usually only locally sufficient to mask the relief of the underlying hard-rocks and give a new topography to the land. More than this, as seems to be generally true, the changes produced in the hard-rock topography by the glaciers which have passed over it, are of minor importance. The present relief, is therefore, with the exception of details, such as the long period of subaerial erosion which preceded the Glacial epoch impressed upon the surface of the land. This broad conclusion will no doubt be controverted by some students of the changes glaciers produce and is admittedly based on less evidence than I desire, but I think will sustain the test of future and more extended investigation.

Additional and conspicuously obvious facts bearing on the above mentioned conclusion, are furnished by Mackinac Island and Burnt Bluff. Mackinac Island rises 317 feet above Lake Huron, and the surrounding water is in general from 100 to 200 feet deep. Burnt Bluff has a height of 225 feet above Lake Michigan, and the adjacent water is from ten to fifty feet deep. Each of these bold eminences stood in the paths of the glaciers which successively covered the region where they are situated but were not removed. Mackinac is precipitous on its southern border and declines less abruptly but still with steep slopes toward the north, and may perhaps be claimed to exhibit in its general contour the effects of ice abrasion on its northern side, and of "ice-plucking" on its steeper southern face. In the case of Burnt Bluff, however, the topographic relations are reversed in reference to ice movement as the precipitous side of the bluff faces the northwest, which as shown by striæ on neighboring rock-surfaces, is the direction from which came the last of the former ice sheets which covered the region. Both Mackinac Island and Burnt Bluff have till on their summits, showing that they have been completely buried beneath glaciers. Burnt Bluff reveals no evidence of ice abrasion in its general shape, or in the contour of its summit. It might perhaps be surmised that its present cliffs which face the direction from which came the glaciers that passed over and around it, are due to wave action since the last ice sheet melted. This is not true however, since the shore marks of lakes Algonquin and Nipissing are present on the face of the cliff and show that but little undermining has been done by the present lake. The effect of glaciers in rounding rock escarpments against which they flow, is here as conspicuous by its absence as in other localities it is rendered evident by the topographic forms produced. Both Mackinac Island and Burnt Bluff stand as conspicuous monuments to the fact that great glaciers even when their attacks are several times repeated, are under certain but as not yet well understood conditions, unable to seriously abrade, much less remove rock bosses and prominent peaks which stand in their paths.

Mackinac Island: An exceptional feature not only in the topography of the part of Michigan especially considered in this report, but unique in comparison with the relief of the entire Great Lakes region, is furnished by Mackinac Island and to a less conspicuous degree by the hills about St. Ignace. Mackinac Island, as is well known, is situated in the extreme northwest portion of Lake Huron. It is about nine miles in circumference, contains 2,221 acres and is the highest land in that region, within a radius of probably more than a hundred miles. Considering the topography of the hard-rocks of the island beneath the surface covering of glacial drift, etc., its prominence becomes still more significant. The height of the summit of the island above the adjacent lake bottom as stated above, is not less than 500 feet. Its southern border is precipitous and in places forms cliffs a hundred feet or more high, near the bases of which the water is in places about 100 feet deep.

The precipitous southern border of the island and including also the similar cliffs on its eastern and western shores have been accounted for by Hall as resulting from the presence beneath the massive Helderberg limestone of weaker limestone and gypsum of the Onondaga salt group. No doubt this explanation is the true one so far as the precipitous nature of the cliffs in question is concerned, but a greater problem, namely how did it happen that the isolated mass of rock forming Mackinac Island came to be left in bold relief while nearly all other portions of the outcrop of the formation to which it belongs has been eroded so as to form deep depressions, namely, as already explained, the basins now occupied by lakes Huron and Michigan.

Limestone is as a rule a weak rock in reference to its ability to resist the attacks of the agents of either mechanical or chemical denudation. Very commonly also, limestone areas are depressed in reference to the region about them for the reason that in general limestone is more easily eroded than most other common rock. This is due principally to the readiness with which limestone—and dolomite also—is dissolved in percolating water, and the small per cent. of insoluble matter which it usually contains.

Mackinac Island, standing as it does in bold relief presents a conspicuous exception to the normal topography of regions underlain by rocks similar to those of which it is composed and its preservation must evidently be due to some exceptional condition which influenced erosion. The explanation which suggests itself in this connection is that the great sheet of rocks of the Monroe formation which comes to the surface in the region now occupied by lakes Huron and Michigan, was cavernous at the localitiy where Mackinac Island is situated, and that during the long period of subaerial exposure and stream erosion preceding the Glacial epoch, the drainage at that locality was subterranean and surface streams were locally absent. That is, the rain water instead of being gathered into rills and brooks at the surface and eroding, descended into the openings in the limestone, which was partially removed in solution but at a less rate than the surface was lowered when the waters formed streams in the ordinary manner. This explanation is in harmony with the fact that the rocks of Mackinac Island and of the St. Ignace Peninsula, are brecciated as already explained, and the suggestion furnished by Arch Rock, that caverns are present. Under this explanation, Mackinac Island and the less conspicuous hills about St. Ignace, are to be considered as remnants left by erosion or "monadnocks" as similar residual hills have been termed; and owe their preservation to the influence of subterranean drainage

The instances just described do not stand alone as examples of rock masses spared by erosion because of their broken and cavernous condition, but are of special interest for the reason that the influence of subterranean drainage on topography has received but little attention.[1]

SURFACE GEOLOGY.

As I have already attempted to indicate, much of the geological history of Northern Michigan is recorded in the topography of the hard-rock surface. The older portion of this record pertaining to the time previous to the Glacial epoch, is much defaced and difficult to read, and as yet has received but little attention. Inscribed on the same surface, or resting upon it, however, are much fresher records the significance of which is clear. I refer to the striæ and other markings and the deposits of debris, left by the glaciers which passed over the land in times geologically modern. As is well known, ice sheets of the type of continental glaciers, such as cover the greater part of Greenland at the present day, formerly moved southward over Michigan

[1] A brief essay in this connection may be found in Science, Vol. XXI, 1905, p. 30–32.

in common with the vast area embracing about one-half of the continent of which it forms a part, and extending as far south as the Ohio river and Kansas. As is also well known, there were several distinct advances and recessions of the ice, or glacial and inter-glacial stages. In order to indicate at least in a general way the position in this complex history, to be assigned the glacial records of Northern Michigan, the following schedule of the subdivisions of the Glacial deposits in North America, as now known, is here introduced; the deposits made during the earliest known ice-advance being at the bottom of the list.

Glacial or Pleistocene Series..	9. Wisconsin till-sheet. (earlier and later.)
	8. Interglacial deposits. (Peoria beds).
	7. Iowan till-sheet.
	6. Interglacial deposits (Sangamon beds.)
	5. Illinoian till-sheet.
	4. Interglacial deposits (Buchanan beds.)
	3. Kansan till-sheet.
	2. Interglacial deposits (Aftonian beds.)
	1. Pre-Kansan (Albertan) till-sheet.

These subdivisions of the glacial records have been made out principally for the deposits which the glaciers left in the region to the south of the portion of Michigan especially considered in this report, and we look with interest for similar evidence in more northern regions with the hope of discovering in particular, how far north the ice front retreated during the several interglacial stages. Some evidence in reference to a far northward extension of the deposits made during what seems to have been the Sangamon interglacial stage, has recently been obtained by Frank Leverett as will be stated later, but in general the glacial records in north Michigan are referred to the Wisconsin stage of ice advance.

The records pertaining to the Glacial epoch in the region under consideration, are principally striæ and other markings on the surfaces of the hard-rocks; deposits such as till or stony-clay in widely extended sheets or fashioned into smooth, oval hills termed drumlins; boulders strewn over the land; ridges of sand and gravel made by streams beneath the glaciers and known as eskers; and sand and gravel plains due to the deposition of debris swept southward from the glaciers by the streams fed by their melting.

EVIDENCES OF ICE ABRASION.

Striæ: Both existing and ancient glaciers, under certain conditions,as has been abundantly proven, in moving over their beds plane away the rocks on which they rest and frequently polish and striate them as well as bring about other changes by abrasion which may be easily recognized. These results are produced especially when the ice is lightly charged with sand and stones set in its basal portion. If the supply of debris thus held becomes sufficiently abundant the movement of the ice is checked, the clearer part above passing over the more thoroughly debris-charged portion below, and the hard-rock surface beneath a glacier is protected instead of being abraded.

Smoothed and striated rock surfaces are common in North Michigan wherever the hard-rock has recently been brought to view by the removal of a protection covering such as sand and clay. On the rock surfaces that have been exposed to the air for a considerable but indefinite time, weathering has in most instances removed all evidences of ice abrasion which may formerly have been present. The most promising localities to look for glacial striæ and associated inscriptions, are where excavations have recently been made which lay bare the surface of the hard-rock beneath the deposits of clay or other protecting material. The localities where glacial striæ has been observed in the region represented on the map forming Plate XVI, are indicated on the map by arrows. Where the dircetion in which the ice moved is definitely known the arrows are barbed; when two directions of ice movement are present the weaker and in all instances as seems evident, the older series is indicated by a broken arrow. The arrows without barbs have been drawn from observations made by E. Desor, in 1850; the remainder are based on notes made by myself.

It is apparent from an examination of the map just referred to, that the directions of ice movement there recorded, are discordant in a conspicuous manner. The only general conclusion to be derived from the striæ is that the glaciers which made them flowed from a northerly to a southerly region, but the variations embrace a range from north to south and west to east. Certain of the striæ are at right angles to the directions of neighboring striæ, and in one case, namely at the mouth of Ford River, two series of glacial grooves on the same surface are at right angles one to the other.

The chief reason for the discrepancies just indicated seems to be that the ice sheets which made the striæ did not flow uniformly in one direction but in currents which took various directions during different stages in their advance or retreat, and also that the markings even in a single locality, were not all made at one time.

As has been well determined, the ancient glaciers which covered the Michigan region advanced more in certain portions of their southern margins than in other portions, and became strongly lobate, and also that the ice in each lobe spread laterally in addition to advancing toward its end. As the ice front receded northward, the lobes about its margin also receded and therefore at any specific locality, a change in the direction of the striæ made on the rocks at different times would vary in direction. As has been shown especially by T. C. Chamberlin, the ice over the Michigan region during its last retreat formed conspicuous lobes in the basins of Green Bay, Lake Michigan, etc., but so far as is apparent, the striæ platted on the accompanying map do not have a definite relation to the glacial lobes thus far recognized.

The data in hand although confessedly meager, certainly suggest that currents with diverse directions, were present in the basal portion of the glacier which made the striæ referred to; their direction being determined by local variations in the relief of the underlying rock, or due to the greater abundance of debris in the lower part of the ice at one locality than at another—the presence of debris tending to retard the motion of the ice containing it.

Observations favoring the idea that a broad ice sheet does not flow in a single uniform direction, but in currents which have different rates of motion and different courses, have been made on the Malaspina glacier, Alaska.[1] On that glacier a conspicuous compound moraine supplied by the great tributary ice stream named the Seward glacier, crosses its surface from the north and on meeting the stagnant ice near its southern margin, divides and

[1] Russell, Israel C. "Second expedition to Mount St. Elias, in 1891," in U. S. Geological Survey, 13th Annual Report, Part II, Plate IV.

forms a series of concentric bands, several miles in diameter, on either hand. On looking down on the glacier from neighboring mountains, the medial moraine referred to is seen to divide at its distal end in much the same manner that the broken end of a celery stalk usually divides and curls upon itself. Evidently very complex currents must be present in the glacier to produce such conspicuous changes in the direction of its surface moraines, and similar currents may be expected to be characteristic of the flow of other widely extended ice sheets.

Another reason which may be appealed to in attempting to account for the observed diversity in direction of glacial striæ along the northern borders of lakes Huron and Michigan, is that such markings made during one ice advance might be covered by till or other deposits, and thus preserved during a subsequent stage of glaciation. Or, what is essentially the same in principle, a glacier may abrade the rocks over which it flows, during one portion of its existence, and deposit subglacial till upon them during another stage; and perhaps still later re-erode its own deposits and continue the work of rock abrasion in a different direction. I suspect that some such combination of conditions is mainly responsible for the conspicuous diversity in the direction of the ice movements referred to above.

It is instructive to note in the above connection that the region under consideration, is situated to the north of a deeply moraine and till covered region and south of a still greater region from which the former glaciers removed nearly all superficial material and abraded the rock surface thus exposed. In the belt of country between the region where glacial abrasion was in excess of deposition and the region where deposition was conspicuously great, alternate abrasion and deposition under the control of fluctuating conditions may well have been the rule.

Instances where two series of glacial striæ are present on the same rock surface, as at a quarry near the mouth of Ford River, and again about one mile north of Hessel (and many similar instances are known elsewhere) are difficult to explain on the supposition that the abrasive action of the ice was continuous at each locality, or, as has been assumed in reference to such instances, that each set of striæ is a record of a separate ice advance, without the intervention of a protecting layer. One suggestive fact in connection with rock surfaces which are inscribed with two sets of striæ is, that the abrasion which produced the second series of records, was not intense. The striæ in the instances referred to above, are only a fraction of an inch deep, and the older series would have been completely removed during the production of the younger series if more than an inch of the rock surface had been worn away at the time the ice last rested upon it. It is not correct to assume, however, from this fact taken singly, that glacial abrasion is but slight, since a deep protecting sheet of till might have been laid down on the inscribed rock surface after the first series of markings was made and efficiently sheltered it from abrasion during a part of a later stage in the advance of the ice. It thus appears that striæ and associated glacial markings while affording definite and important evidence of ice work and recording faithfully the direction of glacier motion for a given locality, do not furnish a sure basis for generalization in reference to different ice advances, or separate stages of the glacial epoch, unless similar evidence is recorded at a large number of localities, and the conclusion reached is sustained by other testimony.

Two sets of glacial striæ on the same rock surface have in some instances and perhaps truthfully, been assumed to furnish evidence of two stages of the Glacial epoch, separated by an interglacial stage of ice retreat. To permit of the making of such a double record it is self evident that the first series of records must have been well covered during the intervening stage of deglaciation, for if exposed to the air for even a few score years they would have been removed or seriously defaced by weathering; and also, that during the second ice advance, the period of abrasion must have been brief, or the intensity with which the sand-and-stone-charged ice scored and scratched the rock surface exceedingly slight. Otherwise the earlier record,—in many observed instances consisting of shallow grooves and striæ, none of them when first formed as may be reasonably inferred, being over an inch deep,—would have been completely removed. When two series of glacial striæ are present on the same rock surface, the inference seems warrantable that the second series were made during a brief period of time or else that the bottom of the passing glacier was nearly free of tools with which to work.

The best general principle to bear in mind, while seeking to interpret the meaning of glaciated surfaces, seems to be that glaciers are capable both of abrading and of making deposits on the surfaces over which they pass, and that these two processes may alternate, the one with the other at a given locality; and also that broad ice sheets do not flow uniformly in one direction but have at least basal currents which are more or less flexible, although for a considerable area following the same general course.

Knobs and Trains: On the surfaces of the limestones and dolomites crossed by grooves and striæ as noted above, there are several other kinds of markings which are significant and have their special stories to tell in reference to the manner in which glaciers abrade rock surfaces. The nature of the markings referred to has been critically described and their meanings discussed by T. C. Chamberlin[1] and while I have nothing new to contribute to this branch of glacial geology, certain observations are at least of local interest.

An approximately level surface composed of rock of uniform texture and hardness, when worn by the passage over it of a glacier charged with fine debris, will be worn smooth and perhaps highly polished, but on the polished surface straight parallel striæ produced by individual sand grains are usually visible. Departing from this normal result as it may be termed, modifications are produced owing (1) to variations in the relief of the rock surface, (2) variations in the texture of the rock, and especially the presence of silicified fossils, chert nodules, etc., harder than the matrix holding them, and (3) variations in the size and character of the foreign bodies embedded in the moving ice which serve as abrading tools.

The influence of inequalities of surface, need not be considered at this time, since in the region about the northern shores of lakes Huron and Michigan the rocks which have been glaciated are in general nearly flat, and no conspicuous evidence of the rounding of prominences or the broadening of depressions was observed. On the other hand, what appear to be conspicuous exceptions to the rule that glaciers tend to remove prominent elevations on the surfaces over which they pass, or to impart to such eminences rounded and flowing outlines, are furnished by the rocks forming Mackinac Island, and the hills about St. Ignace; as well as by several equally conspicuous elevations on the west shore of Garden Peninsula, the most prominent of which is Burnt Bluff. The hills referred to, as already explained, stood

[1] Rock-scorings of the great ice invasion, in U. S. Geological Survey, 7th Annual Report, Washington, 1888, pp. 147–248.