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AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twentieth Annual Report, for the Year 1891.

N. H. WINCHELL,
State Geologist.

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* Deceased Feb. 18, 1891.

ERRATA.

On page 10, after the footnote add *A. Irving, Metamorphism of Rocks, page 96.*
On page 16, 16th line from top, for "structure of crystallines rocks" read structures of crystalline rocks.
On page 17, under "Remarks," eighth line from the top, for "No. 1" read No. 4.
On page 68, fourth and eighth lines from the bottom, for "539" read 538.
On page 88, last line, before "T. 66-5" insert 22.
On page 138, sixth line from top, strike out "V."
On page 184, line 6 from top, after "interior" insert *of the continents.*
On page 185, line 17 from bottom, for "Ontario, Erie and Huron," read *Ontario.*
On page 188, line three from top, for "Goulai's," read *Goulais.*
On page 191, line one from top, for "labradorite" read *plagioclase.*
On page 191, line ten from top, for "altitude" read *attitude.*
On page 192, line five from top, for "oragraphic" read *orographic.*
On page 192, line nineteen from bottom. for "material" read *natural.*
On page 193, line twenty from bottom, for "canals" read *vents.*
On page 193, line seventeen from top, for "all" read *mostly.*
On page 194, line seven from top, for "this" read *the.*
On page 196, line fifteen from top, for "impossible" read *possible.*
On page 196, line nineteen from top, omit "protecting."
On page 201, line five from bottom, after "It is not" insert *infrequently.*
On page 202, line one from top, for "indentation" read *indentations.*
On page 203, line nineteen from bottom, for "embankment" read *embayment.*
On page 215, line fifteen from bottom, for "time" read *line.*
On page 216, line sixteen from top, for "Of the two" read *Of two.*
On page 217, in title of Fig. 1, for "Keewenian" read *Keweenian.*
On page 223, line 14 from bottom, for "fallen" read *full.*
On page 226, line eleven from top, for "terraces" read *terranes.*
On page 233, line thirteen from top, omit "[See Pl. X., Fig. 2]."
On page 234, line twenty-one from top, for "plane" read *plan.*
On page 236, line three from bottom, for "aerial" read *a real.*
On page 238, line twenty-two from top, for "in" read *on.*
On page 241, line six from top, for "leads" read *levels.*
On page 242, line nineteen from top, for "XXI." read *XI.*
On page 250, line two from bottom, for "339.7" read *439.7.*
On page 252, line sixteen from bottom, after "cave of the" insert *embayment.*
On page 252, line nine from bottom, for "dents" read *strands.*
On page 253, line four from top, for "thickened" read *thicker.*
On page 270, at bottom of cut, insert "Fig. 11."
On page 271, line three from top, for "build" read *built.*
On page 271, line twenty-one from bottom, for "and gravel" read *gravel.*
On page 273, line twenty from top, for "gravel" read *finest.*
On page 277, line thirteen from top, for "rigid" read *ridged.*
On page 281, line eleven from bottom, for "benches" read *beaches.*
On page 284, line fourteen from top, for "altitude" *attitude.*
On page 289, line five, from bottom, for "altitude" read *attitude.*

ADDRESS.

MINNEAPOLIS, May 1, 1892.

To the President of the University:

DEAR SIR.—Herewith is transmitted the twenthieth annual report of the Geological and Natural History Survey, of which I have charge. This marks the close of the second decade of my connection with this work, which began with the commencement of the survey in 1872. It is with some satisfaction that I can look over the work of the last twenty years, and with some regret that I can see its deficiencies. As a State enterprise, however, the Minnesota survey is unique in its plan, its supervisory auspices, its slow but uninterrupted progress, and in the duration of its personal directorship.

Ten years ago, in the submission of my tenth annual report, I ventured to congratulate the University and the State on the success which had attended the survey at that date, but the second ten years have been more prosperous than the first ten. Therefore, while renewing my congratulations, I think it is safe to bespeak for the third decade as great and, perhaps, greater advance in all the channels of scientific research ordered by the law. The University of Minnesota has a golden opportunity to place herself far in the van of progress in science among such institutions in America, and the overseers of the survey, as they are also overseers of the University, cannot fail to see the ways and means for bringing about such a result.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

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REPORT.

SUMMARY STATEMENT. The funds of the survey, derived almost wholly hitherto from sales of the Salt Spring lands, not only became exhausted, on account of increased expense of exploration in the northern part of the state, but indebted to the University fund proper for advances to the amount of about fifteen thousand dollars. The Legislature of 1887 made a cash appropriation, of ten thousand dollars for certain economic researches, and that with some aid from the Salt Spring fund kept the field work going for four years, i. e. till the report on the iron ores of the state (Bulletin No. VI.) was published. The Legislature of 1891 made another cash appropriation for the survey amounting to fifteen thousand dollars, with a view of cancelling, in part at least, the deficit in the funds and of carrying forward the field-work toward completion. In the meantime the iron ore interests have rapidly developed, and it has become incumbent on the survey to make much closer examination into the geographic distribution of the rocks carrying this ore, as well as into many questions relating to their geology. While it has been purposed to enter at once on the preparation of the final report on the geology of the northern part of the state, it is found to be judicious to prosecute further field-work there. Large public and private interests are involved in the developments taking place. It would be discreditable to stop the survey short of satisfactory completion while such important economic results are dependent on a knowledge of the rocks carrying this iron ore. The season has been spent therefore in further field examinations and especially on the Mesabi iron range. Mr. U. S. Grant was at work on the eastern end of the range, and his (accompanying) report shows some of the results of his field-work. Mr. H. V. Winchell was directed to make a general economic study of the entire range, and to carry his data and statistics to as late a date as possible. His report therefore owing to lateness of publication laps over into the year 1892. The same season

(1891) Dr. A. C. Lawson, late of the Canadian geological survey, was employed to make a survey of the elevated beaches of the north shore of lake Superior, and incidental to that to make such study of the rock formations as his opportunities afforded. His interesting report on the beaches accompanies this, and two other supplementary papers by him are to be included in a separate publication—probably Bulletin IX.

Renewed activity also has been given to paleontological work on the Trenton and Hudson River fossils. Mr. Chas. Schuchert made a collecting tour in Wisconsin and in Iowa, and in southern Minnesota, and was engaged to assist in the preparation of chapters for the Paleontology of the state, while Mr. E. O. Ulrich continued his work on the Bryozoa. In all the paleontological work the survey has been aided gratuitously by Mr. W. H. Scofield, of Cannon Falls. The printing of Vol. III, of the final report, as outlined in the "Summary statement" for the seventeenth annual report, is now going forward.

It was thought best to divide the report of Mr. Herrick on the Mammals of the state into two parts, and to issue them separately as bulletins (VII and VIII). The first part, embracing the popular and semi-technical descriptions, is now in press, and when issued will constitute an interesting publication of the survey. The other portion is in Prof. Herrick's hands, and when it has been revised by him, and changed so as to comport with the advances made since the volume was first tendered for publication, it will appear as another bulletin of the survey. The report of Dr. Hatch on the Birds of the state is intended for similar publication, but it is not at hand. Dr. Hatch left the state about a year ago and has never actually put his manuscript in the custody of the survey. His present address is unknown.

Since the last summary statement the nineteenth report has been issued and distributed. The library of the survey gradually grows. Our reports are sent in exchange to all parts of the world. The list of additions by this means shows this growth. There is also herewith presented a statement of registrations in the museum, now reaching 8,441.

I.

THE CRYSTALLINE ROCKS,

SOME PRELIMINARY CONSIDERATIONS AS TO THEIR STRUCTURES AND ORIGIN.

N. H. WINCHELL.

Sufficient field-work has now been done on the crystalline rocks of the state to enable us to enumerate the formations which they contain, and to express with some confidence the stratigraphic relations which they bear to one another. These important preliminary steps, having been taken with care and thoroughness, there remains the task to deduce from the facts ascertained some further principles of taxonomic geology and of genetic derivation for the rocks themselves.

In attempting to present these facts of the geology of the lake Superior region in such a manner as to indicate some general truths which may serve as guides for classification and nomenclature, it is the desire of the writer to acknowledge that he has been but one among several recent factors that have helped to bring some system out of confusion and chaos. After the report of Foster and Whitney in 1851, on the mineral lands of the lake Superior region, in which it was maintained that it was impossible to divide the crystalline rocks into any systematic, consistent order of succession, either stratigraphic or chronological, there have been numerous geologists who, having made examinations in one part or another of the lake Superior region, have shown that the crystalline rocks are susceptible of stratigraphic subdivision, and have attempted to express such subdivision. Generally they have shown that it is possible to separate them into two parts. This binary classification was really instituted prior to the work of Foster and Whitney by Alexander Murray and Sir William Logan of the Canadian survey. While the Canadian survey itself has tenaciously held to this simple classification, some of its individual members have, unwittingly sometimes, but intentionally at other times, put on record important facts that have called attention to inconsistencies, and to the confusion that has resulted, and some of them have in a measure abandoned the original nomenclature of Murray and Logan, and have instituted new names to express subdivisions that are needed and which were not recognized by Murray and Logan.

On the other side of lake Superior, the state surveys of Michigan and Wisconsin, while adding many and interesting facts to the general fund of knowledge of the crystalline rocks, have added but little to the advancement of their special taxonomy, or their genetic relationships. These surveys were mainly occupied with the discovery of their geographic areas, and the delineation of their local details of stratigraphy and outcrop. They adopted, in general, the stratigraphic principles and the nomenclature of the Canadian survey of 1857, but also showed that it was necessary to institute many minor distinctions in stratigraphy—without, however, attempting to establish any certain order for all the distinctions which they recorded.

It is evident that before any inquiry can be entered upon as to the more minute internal relations of these formations, it is essential that the serial order which thay sustain to each other, at least some of their grand stratigraphic taxonomy, shall be determined. To the solution of these problems very much time has been given, both by members of the United States geological survey, and by those engaged on some of the state surveys. An essential concord has been reached by the more recent investigators on some of the main questions of relationship, as well as some of the minor stratigraphic details. While the statements of this paper will be based on facts developed in Minnesota, it cannot be questioned that the principles involved, and many of the facts on which they are based will be found duplicated with equal or greater clearness, in Wisconsin and Michigan, as well as in Canada. The great synclinorium of the lake Superior valley seems to have been wrought out in a series of strata of very old date, and it manifests its concordant history in the plications and duplications of its rocky rim on all its sides alike.

The principal rock terranes, as made out in the region northwest from lake Superior are as follows :

1. A series of alternating fragmental and eruptive beds, known as Nipigon or Keewenawan, the upper portion composed almost netirely of red sandstones, placed unconformably beneath a later

series of conglomerates and sandstones in which is found the "Dieklloсephalus fauna" of the primordial.

2. Lower down are found alternating beds of "eruptive" sheets and fragmental rocks, but the fragmental are quite different from those in No. 1, being thin-bedded slates, often black siliceous and actinolitic schists, magnetitic jaspers, quartzytes and cherty quartzytes. These are interbedded with sheets of eruptive rock or rock composed of pyroclastic materials which were probably of tufaceous origin, presenting more or less evident sedimentary structures.

3. The eruptive facies is intensified at this horizon by the protrusion of immense quantities of true basic eruptive (gabbro) which is found to have embraced in itself considerable masses of the next older strata, particularly of the Pewabic quartzyte and its modifications. This gabbro is intimately associated with acid eruptive rocks of cotemporary date, constituting red felsytes, quartz porphyries and reddish granites. This gabbro is the bearer of large quantities of titanic magnetite, and very often the underlying quartzyte, involved in the gabbro, is also highly charged with magnetite, though never titaniferous.

4. The bottom of the Animikie is characterized by a great quartzyte associated with iron ores and cherts, which, however, do not always appear in their typical characters at this horizon. Associated with this quartzyte, and with some of the beds immediately overlying it, are the important iron deposits of the "Mesabi range." This quartzyte lies unconformably on all the older rocks, but principally it has been examined in its contact with the granite and greenstone of the Giant's range. Wherever its lower beds are found exposed they are apt to be conglomeritic with debris from the underlying formations. This has been styled Pewabic quartzyte. It is subject to great lithologic variations, due on the one hand to admixtures of mechanical debris from the older rocks, and on the other to chemical precipitations in the ocean in which it was gathered, and to the mingling of volcanic tuff from the eruptions that were coincident with its deposition, some of which are seen as interbedded sheets of cotemporary date. Its color is usually gray, but on the Mississippi river, at Pokegama falls, it is superficially red to the depth of two or three inches, and still further southwest, in Pipestone county, it is extensively changed to a red color. Its grains are coarse, rounded and evident, but they are joined, generally, into a compact mass by the deposition of secondary silica. In the near vicinity of the cotemporary volcanic disturbances its grain is very fine, like jaspilyte, and in some cases it has acquired a dense crystalline structure from contact with the gabbro.

There is but little, if any doubt, that the great physical break which separates the preceding from the following extends throughout the lake Superior district, and that it marks the greatest erosion-interval which has been discovered in paleozoic geology, as distinctly pointed out by Dr. A. C. Lawson.

A scant fauna has been found to characterize the terranes down to this point, and so far as the characters indicate, the fauna is primordial. This whole series, by its stratigraphic position, its fauna, lithology, and its accidental features, is bound in one grander group, and resembles that which is known as Taconic.

Nos. 3 and 4 are separable from No. 2 by divergence in dip and strike, as well as by a marked difference of lithology. Between these and No. 2 there is in Minnesota some evidence of nonconformity, and such has also been stated of them in Wisconsin.

5. Below this group is the fundamental "complex," made up of crystalline rocks and their debris. It is in this complex that are found some of the problems that have long been studied, and in which remain some of the unsettled questions. Still great advance has been made in deciphering its structure and stratigraphy. Three grand parts have been made out, in stratigraphic order, while a fourth is well established, but occurs sporadically. The first of these parts is a volcanic formation of great thickness, occupying, however a fixed position in geographic extent and in stratigraphic order. This is known as the Keewatin. Most of its rocks are volcanic tuffs presenting more or less evidence of aqueous sedimentation. There is one important part of this series, specially designated Kawishiwin, which differs from the rest. It embraces the great bulk of the "greenstones" and chloritic schists and jasperoid hematites of the formation, and it seems to be the latest known member of the Keewatin, although it still remains to be shown whether this massive greenstone phase be not of fitful distribution and liable to occur in other parts of the Keewatin. The most of the Keewatin rocks are graywackes, sericitic schists, agglomerates, conglomerates, with some exceedingly fine-grained, glossy, serpentinous schists. It also embraces modifications of these, which will be mentioned later. The conglomerates and the agglomerates appear at different horizons, the latter being especially abundant in the Kawishiwin horizon. The hematite ores which characterize the Keewatin, are found in the Kawishiwin stage. They are in lenticular lodes, and in general they stand upright, conformable with the general position of the rocks and and all the macro-structure of the country.

6. The next older rocks are conformably linked with the Keewatin rocks in stratigraphy, and they are no less intimately united with them lithologically. There is an increasing degree of fresher crystallization evident in the Keewatin toward the bottom, and when the strata become wholly crystalline they have received the name of Vermilion series. There has not yet been seen in Minnesota any unconformity between the Keewatin and the Vermilion, and indeed it appears that the crystalline characters occur sometimes out of their normal stratigraphic place, indicating that their existence is not dependent on stratigraphic order wholly—though in the main it is. The Vermilion schists, otherwise known as crystalline schists, contain magnetic iron ore, but generally they are destitute of it. They are usually plainly stratiform, in as evident a manner as the stratified rocks of the Keewatin, but they also embrace some dark, massive "greenstone" belts in which no stratification bands are visible. They consist essentially of mica schists and hornblende schists.

7. The base of the Vermilion, when not disturbed by upheaval in Archean time, has a gradual transition into conformable, stratiform gneiss, which is of like character with the transition from the Keewatin to the Vermilion. Indeed there is nothing to distinguish the Vermilion schists from the gneiss of the Laurentian, except an increase in the feldspathic and siliceous ingredients at greater depth in the series. Even after the Laurentian characters, viz., more or less massive or gneissic acid rock, have become fully established through a thickness of a hundred, or three hundred feet, there may recur, well within the gneiss, a parallel and extended belt of rock with struction and lithology like those of the Vermilion schists, or, *vice versa*, there have been seen thick beds of gray gneiss, conformable with the sedimentary stratification, well within the Vermilion schists, making an essential part of the series. Therefore it is plain that the base of the Vermilion, when not broken by upheaval and brecciation is an uncertain and vanishing plane which cannot be located exactly with any unanimity or consistency by different field geologists—nor even by the same geologist.

But this normal interstratification and gradual passage from the Vermilion to the Laurentian is not always found, nor indeed is it, perhaps, the most frequent. There is more frequently a great disturbance manifest at this horizon, resulting in brecciation and confusion. In most cases there are numerous "dikes" of the lighter-colored granitic rock cutting the schists, and there are larger areas and knobs ureless basic rock. There is every character that indicates that these were both in a fluid or plastic state, and that the only non-fluid rock was the older schist which is seen variously embraced in isolated pieces by both.

One other character pertaining to the structural relations of the parts of the Archean complex should be mentioned, viz: The eruptive characters just described, so far as they pertain to the Laurentian gneiss, do not always come into contact with the crystalline schists of the Vermilion, but sometimes small areas of Laurentian granite are directly in contact with schists that have the imperfectly crystalline condition of the Keewatin.

The Archean complex, therefore, is, normally, a unit in its grander features, and while separable into differing members, in the same manner as the overlying Taconic, and liable to disturbance and to the action of invading igneous rock, in the same manner it is plainly one in its grander history and its chief genetic characters.

With this statement, which gives a concensus* of the results reached by several geologists who have given special attention to the field evidences, we have given, perhaps, all that can be said to be settled as to the major structural relations. It is when we go further, and attempt to discover some of the minor relations subsisting between these parts, or enter upon the study of their genesis, that we find a divergence of opinion. These differences of opinion result, of course, from a study of the problems from different points of view, or along different ways of research, by reason of which different geologists have seen only portions of the evidence. It is to be presumed that when two geologists should see and comprehend all the facts there would be between them an exact agreement of opinion. The significance of a geological fact, when once pointed out, can be apprehended and applied only in one of two diverse directions, and can be used by one geologist as well as by another. This, of course, requires that the fact and its interpretation shall be embraced in a correct underlying philosophy. If a philosophical principle be assumed, at the outset, which is false, there will be danger of a vicious interpretation of all the facts that are discussed by the geologist who holds the false philosophy. He may be very expert in the discovery and the grouping of the relations of the facts which he employs, but all his reasoning is vitiated by the weakness, or worthlessness, of his initial datum. It is necessary, therefore, to examine every assumed principle on which

*The position of the principal gabbro horizon (that at Duluth and at Little Saganaga lake) may be excepted from this statement, as it is not settled so as to be admitted by all observers, that the gabbro followed immediately after the Pewabic quartzyte.

this or the other interpretation is based, and to maintain among the facts discussed a rigid and correct rule of relationship within the accepted philosophy. It is equally certain that the correctness or falsity of a philosophical principle applicable to geologic facts, when pointed out, can be apprehended, and would be, by one candid geologist as readily as by another. There is hence, on the assumption that geologists are all candidly in pursuit of the truth only, a reason to expect that not only will all the facts necessary to the solution of present problems be discovered and known finally by all geologists concerned, but that they will be subordinated to a sound philosophical discussion and settlement.

The unsettled problems pertaining to these rocks, whether in the Laurentian, the Ontarian or the Taconic, are very frequently connected with the "eruptive" members, whether truly eruptive or not, and with the genesis of some of the minor non-eruptive parts. It might be mentioned also that there is still some question as to the stratigraphic place of the gabbro of the Mesabi range of hills and as to its relation to the Animikie. There is also some uncertainty as to the manner of distribution of the eruptive rocks both of the Animikie and of the Nipigon through those formations, and the effect of such distribution on the cotemporary sedimentary beds at places remote from the points of issue of the eruptives. In short, it is not altogether certain but that the terms Nipigon and Animikie have been applied to some extent at different and distant points to different but cotemporary phases of the same formation.* The Pewabic quartzyte shares less in this uncertainty, maintaining its identity at the base of the Taconic.

USE OF TERMS.

It is one of the primary essentials to the investigation of the crystalline rocks, after the ascertainment of their physical and stratigraphic characters, that there shall be a clear understanding of the terms selected to define them, and this necessity appears greater in no case than in the use of the terms "metamorphism," and "alteration" and the terms "schistose," "laminated," "stratified," "gneissic," "bedded" and "banded." These terms have been variously employed, and great confusion has resulted.

Anyone who has given attention to the rocks as they appear in the field will have noted that there are two opposing tendencies of change which the Archean rocks have experienced. He finds a force, or several forces, which promote what might be styled a de-

* The Nipigon here is supposed to be the equivalent of the Keweenawan, to which this statement more strictly applies.

structive or degradational transition from one mineral condition to another—in other words a *weathering process.* This has resulted both in past geologic eons and in the short time that has elapsed since the glacial epoch, in converting hornblende to chlorite and to talc or serpentine, biotite to muscovite, and to the various hydrated micas, feldspar to mica or kaolin, menaccanite to leucoxene, and in short, it is that change which is preliminary to the final disintegration of the minerals concerned and their disappearance either in the superficial soils or in solution and distribution in any waters that can carry them away. The forces that promote this change are water and atmospheric air, and since these have been present since the rocks existed as rocks, and were also present and equally or more active at the date of their birth, it is plain that the effect of their influence will be likely to be found throughout the history of the Archean rocks, at all points where there can be said to be any identifiable data to mark their history. It will be noticed that all these changes of condition result from an attack, an ever energetic assault, which the atmosphere, through some of its agents, is making on the primary elementary conditions of the minerals of the earth. It is essentially a carbonizing, an oxygenizing and a hydrating process. It is ever present, and its avenues of effective attack are myriad. As a result of this warfare between the earth and the air the surface of the earth has become habitable by the various grades of organized beings, vegetable and animal. This process is one of the most important, in its progressive steps, and one of the most stupendous in its results, however slow and gentle it appears, which we can contemplate in the history of the earth. It is not designed here to dwell upon it, although it has resulted in the production of all our limestones, sandstones, shales and usual soil-producing strata, and has brought about those conditions by which water at ordinary temperatures can remain permanently on the surface of the earth.

Opposed to this destructive process, the geologist who contemplates the crystalline rocks observes another operation. This force acts to expel the carbon and the water, and as much of the oxygen as possible, which have been taken up by the operation of the destructive process. This is essentially a reconstructive operation, and its effect is to bring all the minerals subjected to its action back again to or toward the conditions which they possessed originally. The reconstructive process will be impeded, naturally, and sometimes diverted from its normal result, by accidents of environment, either physical or chemical, which have transpired since the primary crystallization, through the action of the destructive agents of the air, already mentioned. For instance, whereas a normal and natural change, through destructive agencies, would be manifested in the conversion of augite to hornblende, and of hornblende to chlorite, and also of an orthoclase feldspar to a potash mica, and thence to sericite, and to kaolin, when the reconstructive process were to take these final products in hand, it would not be able, perhaps, to restore them to their original conditions of composition and crystallization, producing augite and orthoclase feldspar, but the utmost of its results might be a form of hornblende and a black mica. Certain natural and insurmountable obstacles seem to oppose the reformation of exactly the same minerals through that method of regeneration. It cannot be questioned, however, that could the original conditions be restored, both of heat, pressure and moisture, and the same forces be brought to bear on the same elements, in the same proportions, as in the first crystallzation, the result would be the reconstruction of identically the same crystals. This recrystallizing process, compared with that of disintegration, is much less observable, and in the later geological ages it is less common than in the earlier. This apparent diminution, however, may be only apparent, and due to the fact that its later effects are likely to be buried at great depths below the clastic strata of the supercrust, and hence invisible to the geologist. It is only where and when some of the causes that promote it break through the supercrust and become apparent at the surface of the earth, as in the cases of volcanic forces, that the student of these rocks can observe the method of this reconstruction in the production of its characteristic minerals. The causes that produce these retro-changes are, hence, only exceptional and local, and do not disturb in the grand aggregate, the onward course of the unequal warfare between the air and the earth, which inevitably is tending to the subjugation of the latter by the former. The reaction of the crystalline forces against disintegration was most powerful and effective in Archean time, when the earth was heated nearer the surface. The voluminous sedimentation that resulted from the first attacks of the atmospheric agents on the heated earth's surface, has been the most exposed to this re-construction. At that early date in the formation and dissemination of fragmental materials by the air or the ocean, the nature of the sediments themselves had not so far become differentiated from their parent sources, as are the sediments of the present ocean, and in the event of re-construction could more easily and more abundantly re-produce the minerals of the parent rock. The forces which are concerned in the reconstruction of the primary minerals in the Archean rocks, are seated below the crust of the earth, and their power seems to increase at greater depths. Whenever they manifest themselves in concrete form at or near the surface they are combined, in some occult relations with pressure and moisture. Primarily we may, perhaps as correctly as any way, express these forces in a single term, by the words *dry heat*, either as the result or as the cause of gravitation, but as dry heat was associated with varying degrees of pressure and perhaps of moisture, in the first crystallizations, so it appears to be, even more closely, associated with the same agents in the production of the restored re-crystallizations. Hence it would be equally correct, for our present purpose, to ascribe all the reconstructions of which we are speaking, to the three well known agents of metamorphism, viz., *heat, pressure* and *moisture.* When these combine in their action on any of the early sediments, such as may have been long subjected to levigation and hence may have been greatly changed from their parent condition by the ocean, the concentrated effect is to cause the greatest degree of re-crystallization, and restoration of primary characters.

These two opposing processes produce characteristic mineral species, and in their multiform physical reactions upon each other, under constantly varying physical relations, and varying chemical surroundings, they give rise to a large number of intermediate and unstable mineral species, which are characteristic of neither one nor the other. Such are the zeolites, the sulphides, some carbonates, etc. But the principal characteristic minerals which each process gives rise to, are too familiar to need enumeration here.*

Now, as both these processes result in a change of mineral condition in the rocks, the resultant rocks may be said to be metamorphosed. Indeed, the term "metamorphic" has been applied to each. Those who are predisposed to consider all rocks sedimentary until they can be proven to be of eruptive origin, have been prone to apply the term "metamorphic" to not only those banded schists (the mica schists) which preserve a plain sedimentary structure, but also to those greenstone schists which do not preserve evident sedimentary banding, but whose minerals are fragmentary and plainly in a state of transition from a once more perfectly crystalline condition to a state of greater disintegration.

*The chemical potentialities of silicon being called out mainly at high temperatures, and those of carbon at more moderate temperatures, they seem to stand, as it were, at the two opposite poles of matter, dividing the empire between them into what we commonly call the Organic and the Inorganic, but with very undefined boundaries along which dwell a series of restless and turbulent tribes, the individuals of which own no permanent allegiance to either, passing from the domain of each into the other in the most facile manner.

On the other hand, those who have been prone to claim every crystalline rock as eruptive until it can be proven to be of sedimentary origin, have been equally liable to ignore the necessary great divergence between these two operations, and to set down as eruptive not only those massive crystallines which are plainly eruptive, but also those imperfectly crystalline masses, whose grains are in a transitional state, like the schistose greenstones, attributing their semi-disintegration to a force or a process known as "dynamic metamorphism."

For the present purpose we shall apply the term *metamorphism* only to the reconstructed rocks whose minerals have been forced to take on a condition of more thorough crystallization by the application of the forces of heat and pressure in the presence of moisture. The micaceous and hornblendic schists, the Vermilion series, as above described, illustrate this metamorphism. The gneisses into which the Vermillion schists pass conformably, downward, also illustrate it perfectly. All other rocks whose minerals are changed by weathering, from the crystalline condition in which they were when the rocks were formed, may be styled *altered rocks.* Here, however, there is danger of assuming a condition to have prevailed in a large class of rocks that have been much studied, which the facts will not prove to have been their condition. I refer to the greenstones and the green schists, as a group, although there are plainly unimportant portions of these green rocks which should be excepted.

Again, there is a tendency among those who have been familiar with the structures of sedimentary rocks, on the one hand, to carry their ideas of sedimentary structure too far, and to make all the "parallel structures" which they see pervading the crystalline rocks, so many modified forms of sedimentary structure; and on the other hand a class of geologists who have become familiar specially with the structures that crystalline rocks may be made to assume under pressure and partial fracture causing the schistose arrangement of the entire mass, have been inclined to subordinate to mechanical causes acting subsequent to solidification, all those "parallel structures" which they may discover in a crystalline rock, however plainly they may have originated from sedimentation. To one class of observers, however many mistakes they may fall into in interpreting all these structures as due to sedimentation, the terms banding, lamination, schistose, gneissic, sedimentary structure, cleavage, &c., all mean fundamentally the same thing, and with great confidence sometimes they make out a "synclinal" structure for a great area, and have no more basis for it than a superficial synclinal arrangement of the slaty cleavage. To the other class of observers, however great the apparent absurdities into which they may fall, these structures signify equally but one thing. They extend an observed result, viz., schistose or slaty cleavage, a product of pressure and shearing in a rock mass, not only so as to destroy its true, normal significance, but also so as to include structures that are known to be produced only by sedimentary forces—they attribute to pressure and dynamic metamorphism all the banding and stratification which some crystalline rocks so plainly manifest. These terms, therefore, about the significance and applicability of which so much has been written, have come to be the weapons which either party may use with perfect success, so long as they have no definite meaning. It is plain that, in order that either one or the other party shall finally prevail the distinctions which should mark these terms when correctly applied, must be ignored, and as far as possible broken down. The plutonist is inclined to ignore all the evidences of sedimentary structure in these questionable rocks, knowing that he has a firm starting point in his argument, and he ruthlessly drives the extreme of his argument into conflict with a set of important facts and structures coming from another direction. The neptunist, starting from an equally firm datum, with his eye only on one result, following his bent with equal rashness, finds himself soon beset with such problems and snares that he wantonly assails or denies evidence which is as valid as that which formed his point of departure. There must be certainly some middle ground. There must be some significance for these terms which, when carefully adhered to, will prevent one truth from apparently clashing against another. To adjust these differences by a consistent use of these terms, seems to be the most reasonable first step. It cannot be denied that there is such a thing as sedimentary bedding and banding, but this should be followed only so far as it can be distinguished as such, leaving all beyond to some other possible explanation. There is also with equal certainty, such a thing as a "diabasic structure," *i. e.* a structure resulting from crystallization from a molten magma, and so far as it can be followed, without essential modification, it ought to be allowed its full force. When its typical characters fade out, and the rock may possibly be ascribed to a different cause, it is unfair forcing of the evidence to insist that the "diabasic structure," feebly discernible, shall interpret the whole rock mass if the mass exhibits any other adverse structures.

In the field it is very easy to distinguish a true sedimentary banding(1)* from all those other structures into which it has been supposed to graduate, and with which it has been confounded. On the weathered surface it is indicated by varying shades in the color-bands that cross the surface, and on close examination it will be found to exhibit, in the different bands, or beds, which may be of any thickness from a sixteenth of an inch to several inches or several feet, not only a difference in the sizes of the constituent grains, but generally a difference in the relative abundance of the same. Usually free quartz grains will be found more common in some of the bands than in others, giving rise to lighter colored and harder layers. It so happens that very frequently the upheaving forces which have caused the strata to exhibit their truncated edges, have at the same time subjected them to such pressure, in a parallel direction, that the same rocks exhibit a finer slaty cleavage parallel with this sedimentary structure, and as the process of weathering brings out the slaty cleavage conspicuously, while the original bedding may become obscure, in case the cleavage direction gradually becomes discordant with the bedding the observer is liable to follow the cleavage in his measurements of dip and strike, under the impression that the two structures are essentially concordant. This structure which is due to sedimentation has another characteristic, viz: The coarseness observable in any chosen layer of the rockmass will be found to change gradually to one of considerable fineness, (and *vice versa*) in crossing the structure perpendicularly. There may be abrupt transitions from coarse to fine, or from light to dark, but these are not so sure evidences of sedimentary action as those gentler transitions which sedimentary materials take on under the gently changing force of currents. These color-bands will be found to maintain their courses independent of all other structures, and when they are not parallel with the schistose structure or with the slaty cleavage, the schistic structure and the cleavage will be seen to take on varying characters from layer to layer, as they cross the sedimentary beds. In general, the slaty cleavage (as well as the schistose structure) ceases, or becomes less and less evident, on entering the coarser beds. Indeed it appears to be a general principle that slaty cleavage only occurs in clastic beds of very fine grain. Clastic beds that have great uniformity, through great thicknesses, both in composition and in fineness of grain, when subjected to great pressure in two or more directions, and especially if a shearing movement be produced in the mass, take on a schistose struc-

*No. 1, of the figure on page 16.

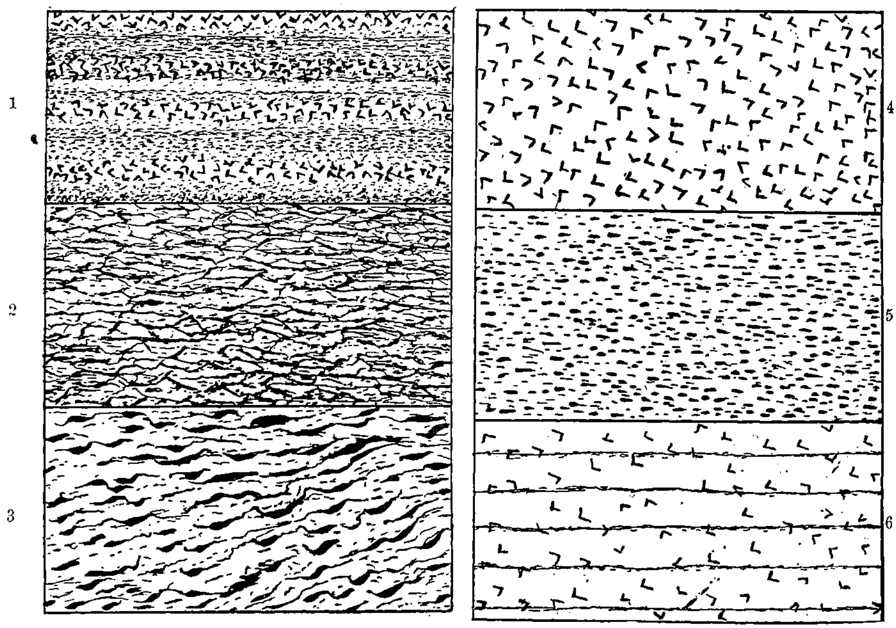
ture (2). This consists in an initial production of slaty cleavage in two or more directions, cutting the rock into rhomboidal masses of greater or less fineness. These rhombs may then be more and more elongated in a uniform direction, all the constituent grains suffering a slight disturbance and sometimes fracturing *in situ*, some of the finer grains or fragments streaming out into tails in the lea of the coarser grains. When the stretching is extreme there is apparent a pseudo-streamed structure, and even a close pseudo-basaltic jointage, which gives the apparently once plastic mass a great resemblance to true irruptive (plutonic) rock. This dynamic action results at first, of course, only in a partial destruction of the integrity of the rock, and of its embraced mineral grains, and so far as it ceases before sufficient heat is produced or concentrated to reconstruct the minerals, it is entirely a degradational process, and fits the rocks so affected, better for the destructive action of the elements. A very great difference is observable in those cases in which the shearing movements were sufficiently intense to cause fusion, or to cause a reconstruction in part or in whole, of the minerals of the rock. (3) This, however, is a phase of the subject which will have to be considered separately. I desire here only to call attention to one important fact, which distinguishes the schistose structure, and slaty cleavage, wherever produced in massive rocks, from the sedimentary structure already described, viz: There is no transference of the constituent grains *across the structure,* and no selection of the coarser or of the more siliceous portions and the arrangement of them in separate and continuous bands or sheets that show any parallelism like that of sedimentation. Indeed when the two structures are seen to cross each other, they are always very different, and they are invariably contrasted in this particular. As these three structures—or more correctly these two, since schistosity is an extreme and confused development of cleavage—have so widely different origins, and can be distinguished by so obvious a character, no competent observer ought to confound them, and in the choice of terms he ought always to restrict each to its proper object.

These two structures are both found in nearly all the crystalline terranes, the only exceptions being those rocks which are plainly the result of cooling from fusion (4), which constitute only a subordinate part. The schistose structure, in some form, pervades all the Archean complex, including also the irruptive rocks, although it is plain that its origin in the irruptive rocks which have invaded the fragmental, is of later date and its development necessarily less perfect, than in the fragmentals themselves. It here takes on the form,sometimes,which is more frequently denominated gneissic, as it is found in some of the crystalline massives. Reference is not made here to a true intersheeted,sedimentary structure(1), such as characterizes the mica hornblendic schists and the gneisses into which they gradually pass—sedimentary rocks re-crystallized *in situ*—but to a homogeneous, or nearly homogeneous, acid rock, evidently the result of crystallization from a molten or plastic condition, classed as granite or syenite ordinarily, or as simply gneiss, in which there is a roughly parallel structure in the mass, caused by the elongation of the mineral crystals all in the same direction(5). This is a very feeble "schistose" structure, and ought to be separated from the term entirely, as it is due apparently to another cause, viz.: a slight fluxion in the mass while the crystals were forming. Again, the granites carry this "gneissic" structure to a still greater development, and it is apparently some form of the same which is seen in a kind of foliation (6) by which they are separable into irregular layers or sheets from an inch to three or four inches thick. This foliation differs from the gneissic structure already described, in having a bedded rifting, which becomes conspicuous on weathering and which embraces large areas in a common strike and dip—while at the same time the layering is not attributable to sedimentation, of which it does not show the characteristic color-bands, and the peculiar intergradations of coarseness and fineness. This higher development of the gneissic structure may be attributed at present to successive applications of heat at different temperatures or to fluidal flowage while the mass was molten or plastic, although it has been taken very largely to be the remains of an original sedimentary structure. Its cause is still problematic.

In respect to the diabasic or ophitic structure in basic eruptive rocks, when it is well exhibited there are perfectly formed, lath-shaped plagioclase crystals disseminated among the imperfectly formed other crystals of the ground mass. This structure rarely appears in the granitoid acid rocks. When it does, porphyritic crystals of orthoclase with idiomorphic outlines, are surrounded either by a micro-pegmatite of quartz and feldspar or by a finer crystallization of all the regular minerals that constitute the rock. In either class of rocks this structure is considered one of the surest evidences of the igneous origin of the rock. The amygdaloidal structure, which is produced by superficial cooling, is also one of the original characters of igneous rocks, although there is produced in sedimentary strata* sometimes, when intensely affected by heat and pressure, but not reaching fusion, a spottedness, and even a partial vesicularization in which certain minerals are segregated, which strongly resembles the true amydaloidal structure of igneous rocks.

If the foregoing principles be applied to the various forms of structure, and the terms as defined above be employed to express them, there might be constructed a tabulated embodiment of this terminology which would take the form seen on p. 17. In this table the usual characters due to weathering and final disintegration, and to kaolinization, are not included. The table is designed only to express those structures, both original and secondary, which the Archean sedimentary and igneous rocks are found to assume in the field, and to ascribe to each structure its cause, and some of its relations to other structures.

FIG. 1. STRUCTURE OF CRYSTALLINES ROCKS.



*Parker Cleaveland stated in 1822 that the amygdaloidal structure is sometimes seen in bedded and clayey rocks, or "indurated ferruginous clay." "An elementary treatise on mineralogy and geology."—Vol. ii, p. 753.

TABLE OF ORIGINAL AND ACQUIRED ROCK STRUCTURES.

		CAUSES.	REMARKS.
SEDIMENTARY ROCKS. Original.	*Stratification.* (1) Color-banding and graduations in kind and size of grain across the bands.	Sedimentation.	When the grains are not of quartz they are blurred by decay. Crystal outlines not perfect.
Acquired.	(2) *Slaty-cleavage:* The grains flattened in the same direction.	Pressure in one direction.	This is usually simple compression.
	(3) *Schistosity.* The grains elongated in the same direction.	Pressure in two or more directions.	May be accompanied by shearing. No. 2, of fig. 1.
	(4) *Bedded Gneiss.* Reconstructed crystalization, *in situ.*	Deep-seated hydrothermal agents.	When fused this rock becomes igneous (acid) No. 1, of fig. 1.
	(5) *Fusion* and displacement; crystallization. *Augen-gneiss.*	Heat and shearing pressure.	This is strictly then an igneous rock. No. 3, of fig. 1.
IGNEOUS ROCKS. Original.	(6) *Granitic.* Homogeneously massive.	Normal and uniform cooling.	Applicable to both basic and acid rocks. No. 4, of fig. 1.
	(7) *Porphyritic.* (Acid and basic rocks)	Two consolidations.	Earlier crystals idiomorphic. In acid rocks, quartz and orthoclase.
	(8) *Ophitic.* (Basic rocks.)	Two consolidations.	Plagioclase crystals idiomorphic.
	(9) *Amygdaloidal.*	Rapid cooling; generally at the surface.	Later formation of zeolites, calcite, etc.
	(10) *Gneissic.* Uniform elongation of the mineral grains.	Fluxion at time of consolidation.	The rock remains massive—*i. e.* not foliated. Massive gneiss. No. 5, of fig. 1.
Acquired.	(11) *Schistosity.*	Shearing pressure.	Perhaps caused also by multiple cleavage. No. 2, of fig. 1.
	(12) *Foliation.* Regular parting-planes in massive rocks; slight formation of mica along the partings.	Cause uncertain.	Perhaps alterations of heat at different degrees. Foliated gneiss. Jointage is not here included. No. 6, of fig. 1.
	(13) *Foliation and Augen-gneiss.*	Shearing after consolidation.	Sedimentary "foliation" is not here included. Foliated gneiss. No. 3, of fig. 1.
METAMORPHIC ROCKS. Acquired Characters.	Reconstructed crystallization *in situ*; may show any of the acquired characters of sedimentary and some of those of igneous rocks.		

In what follows we shall employ these terms as here defined. We must insist on the actuality and the validity of both of these characteristic structures as they appear in their original rocks, *i. e.* on a sedimentary structure and on an igneous structure, because it is impossible to deny the existence of either, and wherever these contradictory structures appear to exist cotemporaneously in the same rock-mass, we shall try to find some means of reconciling the contradiction, or to show that the supposed existence of both is due to either an incorrect initial underlying philosophy, or to mistaken observation.

COMPARATIVE VALUE OF MICROSCOPIC AND FIELD EVIDENCE.

There is an essential difference between the evidence derivable from the microscope and that which comes from the study of the rocks in the field. At first glance it would seem that there could be no misunderstanding of the nature and relations of this different evidence, but here is where one of the fundamental errors has been committed. It is in the nature of the problem involved in the study of the complicated structures and relations of some of the Archean rocks, that the difference between the microscopic evidence and that derived from their macro-structure shall gradually fade out, and that one or the other shall usurp the whole field. This has already been alluded to. It is plain, therefore, that the two investigators, one following microscopic and the other field evidence, on a certain line of observation, would certainly reach a point, where, in respect to a certain structure, or a certain rock-mass, they would be at point-blank disagreement. That is, to the question: *Is this a sedimentary rock?* One would answer *yes*, and the other would answer *no*. It is in such a case as this that there is need of examining into the underlying principles through which these different results may have been reached.

It should be observed, at the outset, that the microscope takes cognizance of the intimate structure of the rock. Of itself it cannot observe the macro-structure, nor know anything about it. It cannot of itself take note of stratification nor of schistosity nor foliation. These are objects for the student of field relations, *i. e.*, as to their existence or non-existence. On the other hand, the field observer, of equal capacity and veracity, takes no notice of the intimate structure—or only so far as the unaided eye can detect it—and derives his conclusions from characters which are obvious. In each line of observation, the experienced observer, or the specialist in the microscopic phenomena studied, should be allowed to have his own way. His determination of the questions arising within the normal sphere of his observation should be allowed to stand. It is only when one or the other transgresses the limits of his specialty that his conclusions may be questioned in case of conflict. If the field-observer extends his theories of sedimentary structures, either original or modified, beyond the limits of actual observation, in contravention of the conclusions of the microscopist, his theories must give way to those of the microscopist. If the microscopist extend his theories beyond the limits of his domain, and attempts to draw conclusions as to megascopic characters, or physical structure, in contravention of the determinations of the field-geologist, he is equally outside of his legitimate sphere, and his results cannot stand against those of the field-observer. This is not intended to shut out any individual geologist from exercising the right to employ any and all lines of research for the solution of all the problems that he has to solve. It is only intended to call attention to the different spheres and qualities of the different kinds of evidence, whether these kinds and spheres be in the hands of different geologists, or both in the hands of the same geologist. Indeed it is the individual geologist, generally, who handles both these sorts of evidence, who is driven to weigh them carefully and to separate between them when they collide. It is for the satisfaction of the individual geologist that this contradictory testimony must be examined into, and each given its legitimate weight.

Now the existence of a sedimentary structure in a rock is one of those outward, megascopic characters which the field-geologist only can be allowed to pronounce upon with authority. The structure itself in any normal case is so evident that none will doubt its existence—the doubt that arises in any special case is that of its genesis, and hence whether the case in hand be a true sedimentary structure. The field-geologist can perchance trace the structure back by degrees to rocks that show it in unquestionable perfection. He cannot deny the testimony of his senses. The microscopist, on the other hand, may have followed his minute characters with equal assurance till they have been traced into this banded rock and he now affirms that this is not a true sedimentary structure, but is one produced on originally irruptive rock by secondary causes, such as pressure, shearing or brecciation in parallel lines, followed by substitution of greater amounts of quartz along the planes of brecciation. That there are cases of such contrariety of opinion there is no question among the geologists who have worked among the crystalline rocks. We presume here a case in which the observers are both competent and reliable, and whose veracity and judgment no one would willingly call in question. It is evident, however, that one or the other is wrong. It is the desideratum here to determine which is correct. It would seem to be a fair adjustment, other things being equal, to allow each observer in his own special field to have his own way. It is pertinent then to inquire whether the field-geologist or the microscopist is here trespassing beyond the limits of his legitimate field, and usurping functions that do not belong to him. The grand structures of a rock-mass are observable and comprehensible by all observers, and they cannot be misnamed, nor can their significance be reversed by anyone. They cover and precede all minuter inspection by the microscope. They cannot be denied by the microscope. If the microscopist by a laborious course of observation and speculation reaches a conclusion that contravenes the conclusions correctly based upon the grand rock structures, the microscopic conclusions must give way or must be amended so as to agree with the truth, which is evident to everyone or which is the result of study of patent facts correctly interpreted. In the same manner sometimes the paleontologist exalts his results above those of the student of physical structure and denies some of the most obvious truths of geological succession. He forgets that paleontology is nothing unless it be preceded by stratigraphy, and that unless there be a predetermined order of succession in rock masses, his paleontological results could not be arranged as historical data. In the same manner that stratigraphy involves and governs paleontological reasoning, so does the macro-physical structure of crystalline rocks govern and involve the study of their micro-structure.

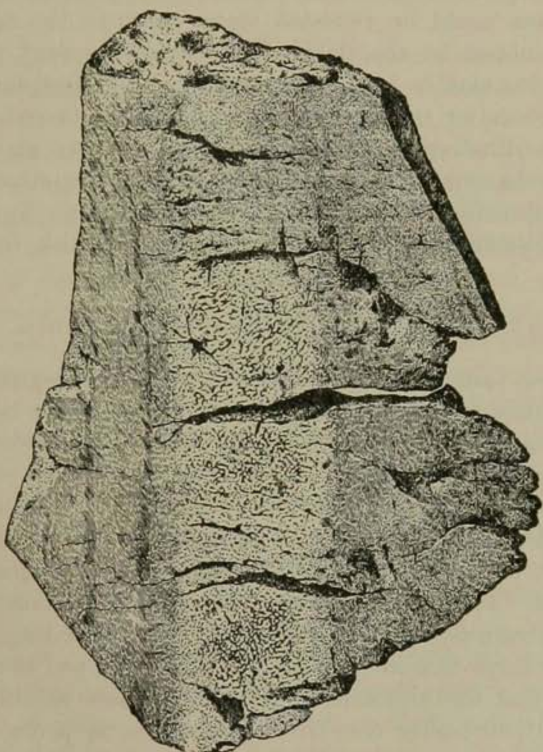
Now let us take a concrete case. Unfortunately the differences which formerly separated the plutonist from the neptunist have not been reduced materially by concession and by demonstration of error, on one side or the other, to any limited group of rocks. Therefore we may take our concrete example from the so-called greenstones, which is a class which exists in nearly all parts of the world where the Archean rocks prevail. We will choose a rock which manifests one of the structures whose origin is in dispute between the microscopist and the physicist, viz:

1. ACCORDING TO THE MICROSCOPIST.

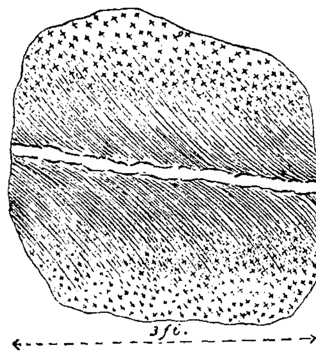
A rock alternately schistose and massive; the schistose sheets being much more broken and decayed, in their granular structure, than the massive sheets, and having a distinct parallelism in the direction of the constituent grains, with the ophitic structure completely lost; the massive sheets being of more perfect and evident crystalline integrity, and having the schistose arrangement seen in the granular condition of the schistose sheets only faintly observable, while there is preserved, with more or less distinctness, an occasional trace of the ophitic structure. These features, as they alternate, produce on the surface of the rock a parallel banding resembling stratification bands.

2. ACCORDING TO THE FIELD-OBSERVER.

A stratified greenstone, alternately striped by bands of lighter and darker green. The schistose character, which sometimes is rather a slaty cleavage, is more evident in the finer beds than in the coarser ones, or wholly disappears in the latter. It does not agree in direction with the course of the stratification bands, but crosses them at an acute angle which angle vanishes as the finer beds grade into the coarser, also changing a little in direction so



as to approach nearer perpendicularity to the grand bedding—showing apparently a shearing pressure to have been its cause.



The structures here referred to are illustrated by the above figures, which are taken from bulletin No. 62, of the U. S. Geol. survey (Williams), where they are referred to dynamic metamorphism and are said to be in no way dependent on sedimentation. These figures could be repeated many times in the course of a brief examination in the field. These cases present the issues fairly. It remains to be decided whether the testimony of the student who relies on his microscope, and starts out with the idea of subordinating his facts to the answers it may give, or that of the field-observer, who only studies the grander structures and has a predisposition to explain such as the foregoing by referring them to sedimentation, shall here be received with the greater credence.

THE PHILOSOPHY OF DYNAMIC METAMORPHISM.

It has been stated already that the term metamorphism is applicable to these rocks whose constituent grains have been reconstructed by a second crystallization by the action of heat, pressure and moisture, a process the reverse of weathering, by which mineral grains undergo a degradational change. But the term "dynamic metamorphism" has been applied extensively to a set of changes that do not fall within the meaning of metamorphism as thus defined. It has been employed to explain the structures seen in the greenstones, such as schistosity, color-banding, foliation, and also all those minute imperfections in form, and the chemical transitions that the minerals of the greenstones exhibit. Hornblende wholly or partly converted to chlorite, is a degradational change. Saussuritization, a decay in a plagioclose feldspar, is a degradational change. Augite converted to hornblende is a step toward ultimate disintegration and decay; ilmenite changed to leucoxene, or to sphene, is on the road to decomposition and loss. Orthoclose kaolinized is ready to disappear on the approach of the feeblest physical disturbance. These alterations, all of which in other rock-masses are attributable without question by any one to weathering and destructive agents, are assigned, as stated by some microscopists, to "dynamic metamorphism," which therefore would be a metamorphism in the opposite direction from that which is usually understood by the term. There is no inherent valid objection to the use of the term in this sense, so long as it is clearly understood what kind of a change is meant by it. The most important point to be considered in the application of the term, is whether the assumed cause, if it should be found to have operated, could produce the effects which are seen, and whether it is the only cause which could produce those effects. The forces of dynamic metamorphism as defined and applied are wholly mechanical and then chemical. Heat and moisture are not included. Shearing pressure, direct pressure, stretching and fracture are all appealed to.

There seems, however, to be an *a priori* inconsistency in supposing that mechanical force can be applied in sufficient intensity to crush or partly crush a rock-mass and yet not to produce a perceptible degree of heat. And there is much room to doubt the possibility of such crushing in any natural rock-mass within the super crust, without the presence of moisture. While it is apparent on every hand that great deformations have taken place under the action of mechanical forces, producing upheaval, stretching, faulting, brecciation, cleavage and schistosity, it is equally apparent that where these changes have taken place in their greatest intensity the rocks have been fused and recrystallized; many examples could be given. Hence it is evident that where these forces have acted to produce less mechanical deformation, there was a smaller amount of developed heat, but not an absence of it. If mechanical force be applied therefore to a rock-mass, with shearing friction so as to disturb the grains in respect to each other or to crush some of them, the inevitable effect of the heat which is generated thereby is not a degradational one, but a reconstructive one, and, aside from the more easy weathering that might be a consequence when such rocks were exposed locally to the action of the elements, the crystal grains would be strengthened in their chemical bonds, and perhaps built out afresh in their natural contours. If a degradational change be generally observed throughout the interior of such rocks, it is unreasonable to attribute it to mechanical force *per se* operating to break the grains. It must be explained by appealing to some other cause.

Again, the philosophy of dynamic metamorphism, if not at fault fundamentally, must explain a singular anomaly. The greenstones as a body everywhere are younger than the crystalline schists as a body, but they grade into each other imperceptibly, passing through the intermediate stages of sericitic schists and graywackes. The greenstones and their appendages, the chloritic schists, must have shared in no mechanical transformations to which the underlying crystalline schists were a stranger. It would be a physical impossibility to subject the overlying schists as a body to dynamic metamorphism, (pressure, shearing and crushing) without including the lower schists, and if the forces of dynamic metamorphism be accountable for the semi-decayed condition of the "greenstones," why was not that change wrought also in the crystalline schists? On the contrary the crystalline schists, normally, are fully and perfectly crystalline still—as perfectly crystalline as any granite or gneiss, only differing from the great mass of the Archean gneiss in physical structure, or in the relative amounts of the contained minerals.

THE ANOMALOUS CHARACTERS OF THE GREENSTONES AND THE GREEN SCHISTS.

No thoughtful student of the crystalline rocks can fail to note, as long since claimed by T. Sterry Hunt, an order of succession in the relative abundance of certain minerals that constitute the Archean rock-masses. He hence also notes an order of succession of kinds of rocks. In Minnesota this order has been found to be the same as that worked out in Saxony, Italy, western France, Scandinavia and Great Britain. The same succession has been published by Lawson for the crystalline rocks of Manitoba. In each case there is a body of greenstones, associated with chloritic and sericitic schists, which forms the summit of the Archean terrances. In other words, it has been found that there is, first, a great series of acidic crystalline granites and gneisses at the bottom, these sometimes exhibiting unmistakable evidence of fusion and displacement among later bedded schists, and hence locally overlying the schists. These thoroughly crystalline rocks are followed by a series of equally crystalline schists which contain much mica and hornblende, and vary from acidic to basic. In the upper portions of these, which are here distinctively called "crystalline schists," there is an increasing amount of non-crystalline, or semi-crystalline, matters, and here the detritus has been found to consist very largely of unmistakable volcanic tuffs, intermingled minutely with chemically precipitated silica. Somewhat higher, but connected by a series of conformable gradations, both stratigraphic and petrographic, are the greenstones and chloritic schists. So far as known these constitute the highest portion of the pre-Taconic complex. As a grand division of the Archean they approach nearest of all the Archean rocks in their mineralogic characters,' as well as in their physical structures, to the well-known characters of basic eruptives. It is a remarkable fact that the first detrital depositions of the Taconic sea, which lie unconformable above these greenstones and chloritic schists, and which extend further back and also overlap in the same manner the crystalline schists and the older gneisses, are highly acidic normally, although affected locally by debris referable directly to the rock underlying or to volcanic tuffs. It appears, therefore, that the greenstones are interposed with their anomalous mineral characters, chronologically between two epochs whose rock-formations were dominated by more acidic characters. It appears also that on the lower side there is a gradual transition from the oldest acidic into this highly basic, but that on the upper side the transition is abrupt from the highly basic to the highly acidic accompanied by a widespread, pronounced unconformity of stratigraphy. It is this general semblance of the greenstones, as a body, and the identity of some portions of them actually, with well-known characters of eruptive diabases, which furnishes the most evident and powerful argument for their derivation from true irruptives through a series of long-continued so-called "dynamic" changes, and which is the chief obstacle to the neptunist in his attempt to assign them to an aqueous origin.

There is a great significance in this anomalous mineralogical character of the Kawishiwin phase of the Keewatin, and in the nature of the transitions to it from above and below. In general it points to a gradually increasing force in that agent, whatever it was, which gave origin to the "greenstone" element of the Keewatin, and to a rather sudden culmination and cessation. It further points to such a shrinkage of the bulk of the earth's land surface, compared with that of the water area, that the ocean's waters prevailed over large areas which had before been dry.

THE NATURE OF THE CAUSES WHICH GAVE ORIGIN TO THE CRYSTALLINE ROCKS.

It has been customary to speak of the crystalline rocks as a unit, and to refer their existence to the operation of a single force. In a broad sense it may be legitimate to refer them to one cause—the refrigeration of the earth—or to the action of gravitation in its specializations—but as geologists we are bound to inquire more closely. So long as we knew of no widespread, or even local, serial succession in these rocks we could but speculate on them as a whole. But since now they may be differentiated into groups having marked distinguishing characteristics, it is incumbent on us to find a cause for each group. In has been one of the striking facts in the history of geology that geologists have specialized more and more, in their observations, and have been compelled to separate their generalizations into several parts, applying only a part of their former ideas to some special phenomena, and being compelled to recognize new principles in order to explain the rest. There is, however, one great feature which binds the Archean rocks into one great group, and which indicates that they have shared in one sense in a common history. They have been upheaved and pressed together in sharp folds so that now they present everywhere in Minnesota (and the same is true of the whole Northwest and for Canada) their truncated edges vertically, or nearly vertically, to the observer. After this upheaval and truncation they were submerged beneath the Taconic ocean—at least the Taconic strata now lie, in attitude sometimes horizontal, unconformable upon them, presenting one of the most notable and widespread instances of unconformity of stratigraphy, and one of the most remarkable changes in lithological characters. In the sense then of constituting a "floor" on which the admittedly clastic strata repose, those rocks may be classed as a unit, and may be said to occupy a single period in the earth's geognosy entirely unique and separate from all the other periods. Yet when we look at the series by itself we soon see that there is no other equal amount of rock-material in the purview of the science of geology which presents so numerous and so great contrasts of composition, and yet which presents a greater persistence in the orderly succession of its main parts. We are forced therefore to note, as the *first* element in the nature of the forces that evolved the crystalline rocks, that they were not local in their extent, but were apparently world-wide, and as such succeeded each other in their operation.

Secondly. Although there is a profound stratigraphic break between the Taconic and the uppermost member of the "Archean floor," yet it is plain, by the existence within the Taconic of rocks of the same nature as those of the "greenstone" stage of the Keewatin, that the close of the Archean did not witness the suppression of the characteristic forces of the Keewatin. Those forces (plainly those which gave origin to basic eruptive materials) simply waned after the Taconic began, and finally ceased to have any marked effect on the clastic sediments.

Thirdly. As the banding and schistosity, and the elevatory movements which gave the Archean rocks their present position and trend, forming certain geographic areas, all of which took place in Archean time, have a general parallelism with the strike and the areal increments of the Taconic rocks in their present distribution at the surface, there was a continuation of the Archean genetic forces into the Taconic—*i. e.*, those forces which give rocks their elevation and strike, and a persistent order of growth to continents.

Fourth. The order of succession already mentioned from the volcanic Keewatin, giving birth to its basic debris, downward with a gradual, and not a sudden transition, to the acidic gneisses, shows a very gradual waning of the eruptive forces in descending order, and points to some other force than eruption for the origination of the basal Laurentian gneisses.

As the primarily eruptive basic tuffs of the Keewatin, distributed like sediments in the Keewatin sea, assume some characteristic new mineralogic features on passing conformably into the "crystalline schists" below, there is proof (*fifth*) that the deeper-seated portions of these schists have undergone some later transformation which the upper portions did not experience, and that, therefore they have been acted upon by some reconstructing agents whose seat and source are from below. As this force had a similar effect on the acidic portions of the Keewatin, when associated with the basic, and as these acidic elements gradually become *per decensum* the acidic elements of the mica-hornblendic schists, and finally, increasing over the basic, become the characteristic element of the gneisses, we can trace the continuation of a force or forces from the Keewatin back into the Laurentian, such not only that they could give origin to the common acidic element, but could later transform it into the acidic crystalline gneisses.

It is necessary, therefore, to recognize various forces concerned in the production of the elements and the crystalline structures of the basal rocks, and it is necessary further to allow them to act in a sort of succession. As to the nature of the materials, however, they are primarily reducible to two kinds—very acidic and very basic, standing at the extremes of the stratigraphic order. Everything between consists of gradations, stratigraphically conformable, between these two. The eruptive force which was most powerful in the production of these basic rocks at the close of the Archean scarcely acted at all at the beginning, or at least it left no records, and that force which transformed the lower materials into crystalline forms was different from and acted later than those which gave them origin. It is necessary also to account for a sudden cessation, or at least a remarkable reduction in the activity of volcanic forces just before the opening of the Taconic, and for that universal crumpling and almost vertical attitude which the Archean strata exhibit.

II.

FIELD NOTES OF N. H. WINCHELL.

In 1890.

Northern Pacific Junction. Slate quarries of Dietz and Dugan; about three miles north of N. P. Junction, Oct. 16. Calcareous but soft, rusty lumps appear here in the same manner as at N. P. Junction, and at the falls of the Vermilion, northwest from Sudbury in Ontario, furnishing a strong lithological bond of idenity of age. These lumps were first noticed here by Dr. T. Sterry Hunt, on occasion of an excursion of the American Association for the Advancement of Science, from Minneapolis, in 1883. These calcareous lumps are of dark gray color within, approximating the color of the slates, but they are granular and crystalline. They decay superficially and become spongy, acquiring a darker shade. (Compare rock samples 1591, 1607 and 1616.)

The slate extends at least to Cloquet, and is all of the same formation, at least from the quarry of Dietz and Dugan. It dips in opposite directions, showing several great anticlinals, the inclination being frequently 75°-90°, and rarely less than 50°. This refers not to the cleavage, which traverses the sedimentation, but to the sedimentary bedding. The general color, when fresh, is purplish-black, but on weathering this varies from gray to greenish-gray, with fleckings of lighter, this lighter flecking appearing where the rock is of coarser grain. The calcareous lumps extend all the way to Cloquet.

N. P. Jnnction, Oct. 17. I have looked over this formation with a view of learning certainly whether it be of the Taconic or the Keewatin. I had rather expected to see some resemblance to the Keewatin, on looking it all over, but so far as the west side of the river is concerned, I do not think I can say I have seen any Keewatin. There are some portions of the Keewatin that resemble this rock, but so far as I have ever observed they are a very small and unimportant part, and are associated with lithological features on which they depend, which are wanting here. This is nearly all a true slate, with a cleavage oblique to the bedding, though in two instances I saw them coincident. The slate is not all suitable for economic purposes as roofing slate, but much of it is—i. e. so far as the quality and the grain of the rock is concerned. It is much jointed, and that fact may interfere with the practical development of slate in a profitable industry. This rock in general possesses a sameness of lithological character over large areas, and in this respect contrasts with the Keewatin which usually is much more changeable. It also possesses everywhere a distinct fresh sedimentary structure with ripple and other water marks. Another feature that allies it with the Taconic is the prevalence of those dark calcareous lumps or secretions. These are the same that Drs. Hunt and Dawson supposed to contain traces of a keratose sponge, and which Dr. Selwyn pointed out as "snow-shoe tracks" —so-called by the Indians—where their weathered contour-forms appear on the slates at the Vermilion river in the region northwest from Sudbury, Ontario. On the exposed surfaces these masses are dark brown and soft, from decay, and often present, when not subjected to friction at the same time, a suggestive resemblance to a semi-vesicular structure, the preserved mesh or net work that stands out beyond the softer parts being due to some trace of a more siliceous matrix. When these lumps are fresh they are gray, crystalline, apparently consisting essentially of lime, in which, in some parts, the small crystals of calcite are visible in compacted marmorized structure. But there is also a layered, concentric, rather coarse structure reminding one of Cryptozoon, across which perpendicularly there is a transverse jointage, or very fine "basaltic" disintegration. This perpendicular transverse disintegration is best characterized, as far as observed, in a layer that is nearest the outside, involving a thickness of about one inch. These limestone masses are in the midst of the finest-grained slate, and extend, with more or less frequency, from the N. P. Junction, where they were first seen in 1883, to Knife Falls (Cloquet), indicating that this is all of one formation, and allying it with the slate seen on the Vermilion river in Canada. They also seem to answer to some of the limestone "lentilles" which have been described by Mr. Marcou in the Taconic slates in Vermont. After considerable search, however, it has not yet been possible to say these masses are fossiliferous at this place. These limestone masses, broken and erratic as they appear, may be the remaining trace of the gray limestones of the Animikie at Thunder bay and at Gunflint lake. It may be that under other circumstances, and in other places, they would be found to increase, so as to become more continuous, and constitute limestone beds like those seen on the north side of

Gunflint lake. In every respect, so far as color, structure, composition and tendency to decomposition, as well as associated rock-strata can indicate it, these are the same as those.

As between this slate and that seen at the crossing of the Vermilion river, northwest from Sudbury, there is a perfect correspondence, and there can be no question of idenity of stratigraphy. Here the tracing to the Taconic, through the parallelization by Irving and others, of the original Huronian with the Animikie is more unbroken, though more circuitous. The above notes pertain to the rocks seen on the west side of the river at N. P. Junction.

Northern Pacific Junction, Oct. 17, 1890. After writing the foregoing a re-examination was made of the prominent ridges of slate immediately at and east of the depot, but still west of the river, north of the railroad track. Here the first thing noticed was the manner of distribution of these limestone masses. There is a plain confirmation of the idea that they are the analogue of the limestone layers of the Gunflint region. Not only are they numerous, varying in size from a peck measure to a walnut, but they run in belts coincident with the sedimentary structure, and in one instance they make a continuous layer, somewhat nodular, that extends for 33 feet at least, and maintains a thickness of about two inches, but vanishes toward the east. The layer is marked by a rusty surface coating which is nothing but the rusty oxidation seen on such rock at Gunflint lake. As limestone it is not pure, but very firm, gray and slate-colored. Except for its weathering out rapidly it could hardly be distinguished on the rock surface. It makes numerous elongated, lenticular holes over the surface, the origin and significance of which were not noted in any previous visit to this locality.

Besides the old Thompson test of the slates, the test of the St. Paul and Duluth R. R., about two miles south of Cloquet, and the recent one of Dietz and Dugan, there is now being made what will be a most thorough test by the C. E. Nelson Lumber Company, of Cloquet, at about a mile and a half south of Knife Falls. It is near the railroad, where an east and west ravine crosses it. The plan is to make at first a shaft about 75 or 100 feet in depth for the purpose of proving the character of the rock at that depth below the surface.

On the east side of the river the graphite locality, mentioned by Schoolcraft, is on n e $\frac{1}{4}$, n e $\frac{1}{4}$, sec 31, lot 1, about 4 miles north of Thomson, near the river, and near a creek, which enters the river. It is now owned by H. H. Hawkins, C. d'Autremont Jr. and D. V. Scott. The vein in which graphite is found is about 12 inches wide. It amounts to but little. Some work has been done recently on the vein, the resulting excavation being about 20 feet deep. The vein itself is one of quartz, cutting the slates, and has much associated plumbaginous matter. Recent work was of no avail to show its importance. The formation here looks like the rock westward from Pigeon point on the international boundary.

A little below (but nearly opposite) the foot of the large island which is opposite the graphite locality, is a basic dyke about 25 feet wide, coming in diagonally across the river bank. It runs north 10° east, and is coarse-grained in general, but fine-grained at the side, having basaltified and hardened the slates. This may be in extension of a great dyke noted on the west side of the river some years ago not far from the slaty Fortress island.

The river roars with rapids much of the way, and at ¼ of a mile further south there is a fall of about six feet. At about two miles north from Thomson is a massive, light-weathering but gritty, rather coarse-grained stratum in this formation; and this also contains the rusty calcareous masses noticed in the fine-grained slates. This calcareous mass could hardly be distinguished from the rock in which it is embraced except for the rusty spot which it causes on the weathered surface (1616).

Apparently the old portage trail runs along near here, near the river, from Fond du Lac to Knife Falls. I imagined I put my foot in the same niches over the rock ridges that Schoolcraft, Houghton and Boutwell stepped on, and where thousands of furriers and Indians have stepped for more than 200 years on their trips from Winnipeg to Montreal.

The first rock-cut in gabbro, east of Thomson, is a short ¼ mile east of Short Line Park station, where the "Duluth deep well" was drilled about 1700 feet in search for gas. (See Bulletin No. 5). This is the station for old Fond du Lac, and a number of Indians here leave the train, with some half breeds, for that old town. They asserted that the old trail from Fond du Lac runs about four miles further east than where the graphite locality is known near the river, crossing the railroad (short line) at about one mile west of the Short Line Park station. This gabbro is like that at Rice's point, and the spur runs southwest from the main belt. There are also several other spurs further east. From this cut rises toward the east and northeast a marked precipitous range of gabbro. The track hugs the foot of this range with occasional cuts, until it has passed the head of a deep ravine, and then swings south to pass another spur, with several gabbro cuts further east as it descends to the terrace flats of the St. Louis river.

At the station called Sargent, a short distance east of Duluth, the usual "trap" of the region underlies the surface at the depth of a few feet. The excavations for water works are principally in red clay, but frequently encounter this rock, which is there well exposed by the blasting and cutting. It is reddish-brown, and in some places amygdaloidal with calcite, and at the same time has disseminated fine red crystals of some feldspar. On some favorable fractures this feldspar has the form of twinned tablets of some plagioclase, but generally it is not evidently twinned, but so crowded and compressed that no cleavage can be characterized, though evidently a cleavable mineral. It apparently also is disseminated in finer forms throughout the mass of the trap. The rock therefore is sparingly porphyritic, and conspicuously and coarsely amygdaloidal with calcite. 1615 is the above rock.

[NOTE. Most of the field notes of 1890 were incorporated in the report on the "Iron Ores of Minnesota," Bulletin VI, 1891. See also the accompanying list of rock samples].

ADDITIONAL ROCK SAMPLES NUMBERED.

[TO ILLUSTRATE NOTES OF N. H. WINCHELL],

IN 1890.

1607. Calcareous, soft, rusty lumps. Dietz and Dugan's slate quarries, about three miles above N. P. Junction. (See also 1616.)

1608. From near the old saw mill, a short distance north of the the last. A square slate piece showing lime seams on each side—joints that cross the slates in too great frequency for the good of the economic outlook.

1609. A fragment from an almost unweathered lump of the calcareous concretions abounding in these slates, broken from the hard fresh slates at the old trial quarry of the St. Paul and Duluth R. R., about 1½ miles south of Cloquet.

1610. Sliver from the slate showing fine ripple marks. Coarser ripple marks and other water-marks are common.

1611. Chipping from one of the calcareous nodules from the slates at N. P. Junction east of the village, north of the east and west railroad. This came from about the same place as that from which Dr. Hunt obtained the specimens in which were thought to be remains of a keratose sponge.

1612. Chipping from one of the lighter-colored siliceous, thicker beds in the ridges, six inches thick, north and east from the R. R. junction.

1613. Same as 1612, from a layer 20 feet thick. When fresh this is dense.

1614. Graphite and quartzose slaty rock, from the "graphite vein," N. E. ¼, N. E. ¼, sec 31, lot 1, T 49-16.

1615. Slightly porphyritic, and amygdaloidal trap, from Sargent, east of Duluth, from the trenches dug for water-works.

1617. Samples of iron, from Camp's land, S. W. ¼, sec. 33, a mile southwest of Ely.

1618. Ore from the narrow magnetic belt on Camp's land, S. W. ¼, sec. 33, about a mile southwest of Ely. (Iron ores of Minnesota, page 202.)

1619. Loadstone ore said to have come from the same place as 1618. (Iron ores of Minnesota, page 202.)

1620. A "quicksand" which is encountered at the bottom of the pits in the Anderson location, near Ely. It is very fine-grained and clay like. Are the grains angular, and referable to disintegrated jaspilyte?

1621. In the greenstone of one of the ridges on the S. W. ¼, sec. 33, about a mile southwest from Ely, is the indefinite rock which has been described in this region—neither greenstone nor graywacke. In the midst of it is a harder and more siliceous area, which seems to be only a phase of it, represented by 1621.

1622. A boulder was taken out from one of the pits by Mr. Camp, which represents another phase of the greenstone, but this is not seen in place anywhere about here. It may have come from north of Long lake. It is one of those coarsely crystalline (fragmental) greenstones, with free quartz grains and pyrite, and seems to consist largely of plagioclase and hornblende.

1623. Globular and nodular mixture of the white kaolinic and red hematitic soft rock, the two not mingling so as to stain each other though in immediate contact. From the dump of the Chandler mine. This kaolin seems to be one of the very early constituents of the rocks of the region, and not the result of recent change.

1624. Fragment of the amygdaloidal scale that surrounds the volcanic bombs seen in the rock-cut at Ely, and some of the matrix.

1625. Some of the dark-green schistose rock that fills the interspaces between the bombs.

1626. A piece of the bomb from toward the centre, away from the amygdaloidal crust. (American Geologist, Vol. ix, p. 359.)

III.

FIELD OBSERVATIONS ON

CERTAIN GRANITIC AREAS

In Northeastern Minnesota.

BY ULYSSES SHERMAN GRANT.

CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

In the summer of 1891 the writer, accompanied by Mr. Herbert R. Wood and one Indian canoeman, spent the greater part of the months of August and September in examining certain granitic areas in Lake and Cook counties, Minnesota. The areas visited are four in number, and may be distinguished as the following: (1) the Kawishiwi river area, which extends from the division of the Kawishiwi river in T. 63–10 west and southwest for a considerable distance; (2) the Snowbank lake area, which is mostly confined to the islands and shores of Snowbank lake; (3) the Kekequabic lake area, in the immediate vicinity of the lake of this name; (4) the Saganaga lake area, in which the larger part of Saganaga lake lies. The object of the examination was more to study the age and origin of these granite masses and to ascertain their relation to the surrounding rocks than to make any minute study of the structures and variations of the granites themselves.

The present paper is simply an account of the phenomena as seen in the field, supplemented by but a small amount of laboratory study. A number of the rocks, especially the normal facies of the different types, have been examined in thin section, and considerable progress has been made towards a systematic study of one of these areas—that of Kekequabic lake. The writer hopes in the near future to be able to give a more complete account of the different rocks of this interesting area, both stratagraphically and petrographically.

On account of the incomplete character of the work and the lack of sufficient time in the preparation of this report it is thought best not to give a detailed description of each area nor to make any generalizations concerning the region studied. However, it will not be amiss to say a few words as to the results reached thus far. In the parts of the four areas studied there has been seen no evidence of a transition from the semi-crystalline and crystalline schists to granite. On the other hand there is abundant evidence to prove the true irruptive nature of these granitic rocks into the surrounding sediments, notwithstanding the fact that these granites have been described as granitoid gneisses formed from the metamorphism of certain clastics and now seen to pass imperceptively into these same clastics.* The gneissic and so-called "bedded" structure in these rocks is not nearly as common as has been supposed, in fact the usual structure is truly granitic. The Kawishiwi river "granite," where studied, is a hornblende syenite, as is also that around Snowbank lake. The Saganaga granite is a very coarse hornblende granite. The granite around Kekequabic lake is a pyroxene granite, and associated with it is a peculiar pyroxene granite porphyry.

PART I. RECORD OF FIELD OBSERVATIONS.

In giving the township and range in the following notes the township is always north, and the range is always west of the fourth principal meridian, Minnesota, unless stated otherwise. The bearings given refer to magnetic north, no correction having been made either for general or local variation. When giving the strike and dip of slates reference is always had to the lamination, unless otherwise stated. As a rule the edges of the different granite areas have been studied, as here only could the relations to the surrounding rocks be seen.

KAWISHIWI RIVER AREA.

The examination of this area was confined entirely to its eastern end, and most of the notes were taken in the southern half of T. 63–10.

Pickerel lake.

Pickerel lake† is a small body of water cut by the line between secs. 24 and 25, T. 63–11, and secs. 19 and 30, T. 63-10. The shore where visited was found to be made of a more or less massive rock, which in all the reports on this region has been called greenstone or greenstone-schist. From the little bay of the Kawishiwi river in the N. E. ¼ of S. W. ¼ sec. 25, T. 63–11, a portage leads to the southwest corner of this lake. The southern half of the portage shows angular blocks of mica-schist, probably not far removed from their original position, and the northern one-third of the

*15th (1886) Annual Report, pp. 199-204.

†The Chippewa name for this lake is Gi-nó-ses, which is the word for pickerel.

portage is over a ridge of rather massive greenstone represented by Nos. 302, 303 and 304, the latter from the lake shore. No. 303 is, however, more like an altered graywacke and is quite schistose. The greenstone extends all along the south shore of the lake. It is shown by No. 305, which is very dark-green and schistose, and occurs just east of the portage, No. 306, more compact and silicious, and No. 307, which was taken from the outlet of the lake in the N. E. ¼ of N. W. ¼ sec 30, T. 63–10. At the east end of the lake just south of the section line the rock is green, very tough and massive; it presents the appearance of a consolidated volcanic ash (No. 308). Only one spot (S. W. ¼ of S. W. ¼ sec. 19, T. 63–10) on the north shore of the lake was examined; here the rock is a fine grained massive greenstone (No. 309).

A section was made from this lake south along a trail, which is almost on the range line, to the Kawishiwi river. Several low ridges were crossed, the general trend of the ridges being east and west. Just south of the lake there are no outcrops seen, but a low ridge of fine grained compact greenstone (No. 299) is soon reached. This rock is cut in every direction by minute, branching, yellow and pink veins; it shows no structural lines, but appears perfectly massive. On going farther south the rock becomes schistose, this structure being vertical and running east and west. It is cut by a small dyke, four or five feet wide, of a quartzless porphyry (No. 300). This rock held a small piece of the greenstone, which is very schistose at the dyke walls, otherwise not being different from that farther away. The dyke runs almost east and west and was traced rather disconnectedly for fifty feet. No. 301 shows the contact of the two rocks. Farther south occur several outcrops of a finely laminated schistose rock (No. 310) which approaches a mica-schist. The lamniæ have been twisted considerably in places, but the general strike is east and west and the dip is vertical. This rock continues nearly to the quarter post, but just before reaching this a rather course grained red syenite is seen (No. 311). The hornblende is roughly arranged in elongated spots, thus giving to the rock a decidedly gneissic structure, which runs east and west and stands nearly vertical. Associated with this syenite are small areas of a fine grained granitic rock (No. 312). This gneissic syenite continues about half the distance from the quarter post to the Kawishiwi river and then assumes a darker, finer grained aspect (No. 313) with the hornblende much more abundant than in No. 311. It now contains fragments from one inch to several feet in length of a dark mica-schist (No. 314); these fragments are mostly lens-shaped and their outlines are distinct. The syenite also holds many veins, up to ten inches across, of a rather fine grained biotite granite (No. 315). At this place the gneissic structure in the syenite, the long axes of the mica-schist fragments and the general direction of the granitic veins are northwest and southeast. Mica-schist now extends to the river and also occurs on the little point in the S. W. ¼ of S. W. ¼ sec. 30, T. 63–10; here a little back from the shore is a low ridge of the schist (No. 316) which strikes 80° W. of N. and dips N. 65°. In it is an irregular vein of very fine granitic rock (No. 317).

Clearwater lake.

Clearwater* lake lies almost entirely in sec. 32, T. 63–10, with a small bay projecting into the E. ½ of N. E. ¼ sec. 31. Excepting a small area at the northwest corner of the lake near the portage north to the Kawishiwi river, the shores are composed of reddish syenite which is quite constant in character. In the S. W. ¼ of N. W. ¼ sec. 32, the syenite shows an irregular flow structure, which is more evident here than elsewhere on the lake, although seen in several other places. It twists considerably, but stands about vertical and its general trend is east and west. No. 337 shows this structure very well, although the lines are not usually as near together and as distinct as on this specimen. The syenite of this lake is well represented by Nos. 338 and 339, the former coming from the same locality as No. 337, and the latter from the extreme northern end of the little bay that extends into the S, W. ¼ of S. E. ¼ sec. 29. The rock is microscopically a rather coarse grained aggregate of hornblende and reddish feldspar in about equal amounts.

Where the line between secs. 32 and 31 cuts the north shore of the lake the syenite is seen mixed in with mica-schist. See Fig. 1. The schist is much twisted and the syenite exhibits the flowage structure as shown by No. 337. Most of the syenite here is of the usual character, but

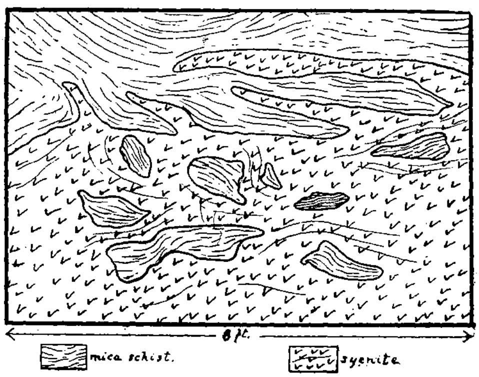


Fig. 1. Contact of syenite and mica-schist; N. E. ¼ N. E. ¼ sec. 31, T. 63–10. north shore of Clearwater lake.

*The Chippewa name is Gawaukamik.

in some areas it is of a finer grain (No. 340). Just west of this place the syenite and mica-schist are seen in contact. The schist is much disturbed and twisted and the dip and strike could not be accurately determined, but the general trend is a little south of east with a very high northerly dip. The contact is irregular, but sharp, and is shown in the specimens numbered 341. No. 342 is the syenite within a foot of the contact.

At one place on the portage, running northwest from the lake, and in several places on the shore in the E. ½ of N. E. ¼ sec. 32, there is a dark green rock (No. 343) which is a coarse grained aggregate of hornblende with a small variable quantity of feldspar. It presents a very rough, jagged, weathered surface. It is cut by vein-like stringers of reddish syenite (No. 344) similar to the ordinary syenite of the region, by a gray variety (No. 345) of the same and by a small trap dyke (No. 346). The last is but four inches wide and was traced for fifteen feet; it is probably a very fine grained diabase. A section of No. 344, at the contact with the hornblende rock, shows the former to be composed of a granular aggregate of (1) an almost opaque feldspar, which, notwithstanding its alteration, shows some traces of polysynthetic twinning, (2) a fresh feldspar with abundant twinning lamellæ and (3) a few pieces of green hornblende; the two feldspars are in about equal amounts. The small part of the hornblende rock in the section is seen to be made up almost entirely of green, highly pleochroic hornblende; a small amount of the altered feldspar is also present. The two rocks are seen to be separated quite sharply even in thin section.

Mr. Wood examined the shores of the small lake in the N. ¼ of sec. 31, T. 63–10, and found them to be composed of the same syenite as is seen on Clearwater lake. At the southwest corner of this small lake he found fragments of mica-schist embedded in the syenite.

South branch of the Kawishiwi river in T. 63–10 and T. 62–10.

Going north from the river nearly on the line between secs. 5 and 6, T. 62–10, the syenite is seen to be cut by irregular small dykes or branching veins of a hornblende rock (No. 349) similar to that mentioned above (No. 343). These veins cut the syenite in every direction and their outlines are very sharp and distinct, especially on weathered surfaces. The syenite here varies somewhat, and as a rule is darker colored than that seen elsewhere in this vicinity; it is represented by Nos. 347 and 348. The syenite on the river shore near the above mentioned section line is also somewhat finer grained and darker than is usual (Nos. 350 and 351). On the north shore of the river in the S. W. ¼ N. W. ¼ sec. 5, T. 62–10, is a rather coarse grained diorite (Nos. 352, 353 and 354); it is more than half made up of green hornblende, and the feldspar is white or grayish,—the rock thus standing in sharp contrast to the surrounding syenite. The relations of the two rocks were not seen here, but the diorite probably is the same as the hornblende vein rocks described above, although in this place the diorite may possibly represent a basic facies of the syenite.

No. 355, from the S. E. ¼ of N. E. ¼ sec. 5, T. 62–10, well represents the syenite in this immediate vicinity; it is a rock of medium grain, reddish in color, and composed of a flesh-colored to reddish feldspar and hornblende; the latter makes up about one-third of the rock. Going south along the river in secs. 5, 4 and 9, the syenite, as a rule, becomes finer grained and in some places holds biotite instead of hornblende.

At the north end of the portage, N. W. ¼ of S. W. ¼ sec. 9, T. 62–10, just at the water's edge, is an outcrop of medium grained hornblende granite (No. 356); the quartz makes up about one-fourth of the rock. This is evidently a part of the syenite of the region, but is the first seen that contains macroscopic quartz grains in any amount. About one-third way across the portage the coarse grained grey gabbro (No. 357) common to this region is seen. This was traced west of the portage to within 200 feet of the syenite, but low ground with no exposures intervened between the two rocks. Here the syenite is fine grained and micaceous, as is shown by Nos. 358 and 359, the former being more properly a biotite granite. The syenite is cut by small dykes or veins of a fine grained red aplite (No. 360) composed almost entirely of a red feldspar and quartz. The gabbro retained its coarse grained character as near to the syenite as it was found.

The east side of the rapids, in S. W. ¼ sec. 9, T. 62–10, was carefully examined in order to study the relations of the syenite and gabbro, but nothing conclusive was seen. The syenite here is shown by Nos. 361 and 362, both rather fine grained and micaceous. Between the syenite and gabbro were found Nos. 363 and 364, the former partaking of the characters of the syenite and containing large quantities of a dark mineral, probably hornblende; the latter is finer grained and very dark in color. There were no continuous exposures connecting the syenite and gabbro. At the foot of the rapids I found several angular blocks, apparently not far removed from their original position, of a fine grained purplish rock, probably a porphyrite (No. 365). Mr. Wood examined the west side of the rapids, but could not find the gabbro and syenite near each other.

The west shore of the river in secs. 34, 35 and 26, T. 63–10, is made up of the ordinary syenite, which varies somewhat in the amount of hornblende it contains, as seen in Nos. 366 and 367. No. 366 is quite dark in color and the hornblende makes up more than one-half of the rock,—this facies, however, is exceptional. No. 367 is much lighter colored and is at least three-fourths composed of feldspar. No. 368, from the S. W. ¼ of sec. 34, fairly shows the syenite along this shore; it is composed of flesh-colored to red feldspar and black hornblende, the latter making up perhaps one-third of the rock. This rock is of a medium coarse grain. In section it is seen to be a granitic aggregate of orthoclase, hornblende and quartz. The orthoclase is gray and usually shows a cloudiness due to alteration; a few of the grains show polysynthetic twinning lamellæ. The hornblende is the ordinary green, highly pleochroic variety, and is completely allotriomorphic; it has altered in some places to chlorite, but elsewhere appears to be quite fresh. Quartz is scattered through the whole section, but is not noticeable macroscopically; it presents the characters of ordinary granitic quartz. It occurs oftentimes in polysomatic areas, and a large number of the grains show decided undulatory extinction. The quartz makes up less than ten per cent. of the whole rock. Apatite, sphene and magnetite are the accessory minerals; they all occur in only small amount. The apatite is in both short, stout and long, slender prisms. The sphene and magnetite show no characteristic crystal outlines.

Careful search was made for mica-schist along this shore, but no trace of it was found.

North branch of the Kawishiwi river in T. 63-10 and sec. 19, T. 63-9.

Mr. Wood went south from the river about on the west line of sec. 31, T. 63-10, for about half a mile. He reported mica-schist (No. 318) all the way, but in a few places, ecpecially just south of the river, a green schistose rock (No. 319), probably a condition of the greenstone, was seen. From this section line he went northeast to the bay in the S. E. ¼ of S. W. ¼ of sec. 30, but saw no rock in situ except the mica-schist.

The little promontory on the south side of the river in the N. E. ¼ of S. W. ¼ sec. 30 is made up of red syenite (No. 320). This is a rather coarse grained rock and in some places it shows a distinct gneissic arrangement of the feldspar and hornblende. It is cut by a dyke of a dark hornblendic rock (No. 321); this dyke is vertical and varies from ten inches to two feet in width; it runs a little south of east and was traced for fifty feet. The west end of the portage across this promontory is in the mica-schist, but the line between the schist and syenite soon crosses the portage and runs a little south of the bay in the S. W. ¼ of S. E. ¼ of sec. 30. The two rocks were seen in actual contact just north of the portage; there was no transition from one to the other, the line between them being quite distinct. The syenite was finer grained and grayer in color near the contact; this is shown by Nos. 322 to 325 which were taken within a distance of two feet. The last one was touching No. 326 which is unmistakably part of the mica-schist. No. 327 is the mica-schist near to the last and No. 328 represents it a few feet from the seyenite. The line of contact was vertical and rather irregular, the syenite usually followed the direction of the schistosity, but in some places broke across it for a few inches. On the portage a few loose blocks were seen which showed both rocks in sharp contact (No. 329); however, it is not certain that these blocks had not been moved some distance.

The west shore of the river in the E. ½ of sec. 30 is almost all syenite, but about the center of the shore line some mica-schist is seen mixed with the syenite. The latter extends in vein-like branches into the former and also encloses pieces of it. Mr. Wood went from this place west to the stream that enters the river in the S. E. ¼ of N. W. ¼ sec. 30 and reported syenite all the way. He also found a fine grained diorite dyke (No. 330) in the syenite; this ran north and south, was ten feet in width and was traced for sixty feet. He also reported many inclusions in the syenite, of which Nos. 331 and 332 are samples; the former is a dark, rather fine grained diorite, the latter a fine grained silicious schist.

At the rapids in the S. E. ¼ of N. E. ¼ sec. 30 the river flows over angular syenite fragments. On the east shore of the river in the same $\frac{1}{16}$ section mica-schist and syenite are seen in contact. There is not as sharp a line here between the two rocks as at the above described locality; the change from one to the other occurs within one or two inches; Nos. 333 to 336 represent this change, the first three of these were taken within a distance of three inches.

The point in the N. E. ¼ of sec. 26 is made up of the ordinary coarse red syenite of the region, but on the north side of this point, about the center of the section, is a dark, rather coarse grained diorite (No. 369). Macroscopically this is seen to consist of hornblende and a white feldspar, the former in larger amount than the latter. Under the microscope the feldspar is seen to be very highly altered and in only a few places is it fresh enough to show traces of polysynthetic twinning ; the hornblende is of the ordinary green variety and is extensively changed to chlorite and some few flakes of biotite. The relation of this diorite to the syenite of the region was not determined, but the impression is that this is a basic facies of the syenite. The diorite is cut by a fine grained trap dyke (No. 370) and also by a light reddish fine grained granite (No. 371). The last appears in quite an amount and extends along the south shore of the river as far as the west end of the island in the S. E. ¼ of N. W. ¼ sec. 26. A short distance beyond this the diorite is seen in contact with a fine grained gray granite (No. 372), which is probably a part of the same rock as No. 371. The diorite here (No. 373) has both red and white feldspar and seems to be rather intermediate between the ordinary syenite and the diorite described above (No. 369), thus indicating the probable identity of the two rocks. No. 374 shows the two rocks (Nos. 372 and 373) in contact ; the line is very sharp and distinct, but at this place nothing was seen to indicate the relative ages of the two. The diorite continues along the shore in the S. W. ¼ of sec. 26, and in some places becomes lighter colored as shown by No. 375. In a westerly facing diorite cliff (N. W. ¼ of S. W. ¼ sec. 26) are three small dykes, about a foot wide, running diagonally up the cliff towards the north. No. 376 was taken from one of these dykes ; it is a dark, rather fine grained rock, composed almost entirely of hornblende.

At the southern end of the bay in S. W. ¼ of S. W. ¼ sec. 26 the syenite again occurs. It is here represented by No. 377, which has most of its hornblende altered to chlorite. At this place a small piece of finely laminated gneiss (No. 378) was found enclosed in the syenite. The western shore in the E. ½ of sec. 27 is composed of the syenite similar to No. 377.

Just north of the river on the line between sec. 21 and 22 is a low outcrop of aphanitic greenstone (No. 379). It is much cracked and fissured and shows an indistinct, coarse schistose structure, which is vertical and runs east and west. Farther north from the lake on the same section line is an outcrop of very massive greenstone (No. 380), which is of coarser grain and grayer color than that last mentioned. This is seen in contact with a quartz porphyry (No. 381) which holds a few quartz crystals, many white feldspars and numerous small pyrite grains in a grayish groundmass. The contact line between the two rocks is sharp, stands vertical and runs north and south. Only a small area of the quartz porphyry was exposed; it probably forms a dyke in the greenstone. Continuing northward on this section line for about three-quarters of a mile from the river, several ridges of massive greenstone are crossed. No. 382 shows the most massive and coarse grained condition of this greenstone.

On the north shore of the river, just west of the line between secs. 27 and 28 are several outcrops of a fissured greenstone similar to No. 379. Farther west on the same shore and just east of the portage is a large outcrop of a finely laminated graywacke-like rock (No. 383); it is in some places much coarser grained, as shown by No. 384. The strike is N. 75° E., and the dip from 75° to 80° S. On the north side of the river and between the portage and the head of the rapids (N. E. ¼ of N. E. ¼ sec. 28) a rock similar to the last, except that it is more massive in appearance, is found. Here on some of the weathered surfaces an indistinct vertical lamination is seen; this varies somewhat in direction but the general trend appears to be about 25° E. of N. Nos. 385 and 386 represent the rock at this place. This laminated rock belongs to a fragmental series which is here in contact with syenite. This series is made up of rocks which are very often graywackes and often mica-schists, with all intermediate stages; and there are also some facies that are more like coarse grits, silicious schists and even sericitic schists. These different facies constantly intergrade. For convenience the term "graywacke-like rock" will be used for the finer grained and less crystalline rocks of this series. Mica-schist and gneiss will be used to refer to parts of the same series which are more highly altered.

A short distance from the east end of the above mentioned portage rock similar to Nos. 383 and 384 is found; here the lamination is distinct; the strike is 72° E. of N. and the dip S. 85°. A little further west the syenite (No. 387) occurs. It has a vertical gneissic structure which is very evident on weathered surfaces; this strikes on the average about 70° E. of N., but varies as much as 15° either side of this direction. This syenite occurs directly in the strike of the last mentioned outcrop of laminated graywacke-like rock.

About half way across the portage is a soft fissile greenstone or greenstone schist (No. 388). In this is a series of parallel veinings which coincide with the direction of the cleavage planes in the rock; both stand vertical and strike N. 80° E. A few feet south of this the ordinary syenite is seen. There is almost a continuous exposure between the two rocks, and samples illustrating the change from one to the other were taken. No. 389, from eight inches south of 388; 390 was eight inches further south; then within a foot came 391 and 392; two feet further was 393, and three feet from this 394, which grades into the ordinary syenite represented by No. 387. The change from the greenstone schist to the syenite is first noticed by a small amount of red feldspar in the greenstone; the feldspar gradually increases in amount and the green material decreases until the ordinary syenite is reached. The schistose structure in the greenstone and the gneissic structure in the syenite are parallel and grade into each other as the two rocks intermingle. One hundred feet north of this place is a low southerly facing bluff of greenstone, much cracked and fissured. On the weathered surfaces it shows a series of reddish, vertical veinings whose average strike is N. 70° E., and almost at right angles to this are two nearly parallel systems of joints which cut the rock into small elongated diamond-shaped areas.* Specimen No. 395 shows this jointing fairly well.

Further west on the portage trail more of the greenstone is seen. Then the syenite appears again, and beyond this, not more than 200 yards east of the west end of the portage, the graywacke-like rock again appears. It has the distinct lamination seen before and strikes N. 60° E.; the dip varies from 80° towards the north of this line to 70° on the other side. The syenite occurs on the portage directly in the strike of this rock and not more than 150 yards east of it. The laminated rock is seen in contact with the syenite, which here lies north of it, about 50 yards north of the stream. It is here shown by No. 395A, which has considerable sericitic material developed in it. Eight inches north of this occurs the actual contact between the two rocks; the hand specimens No. 396 show this. The line between the two is distinct, but the syenite holds considerable of the material of the other rock. Six inches north of this the syenite is shown by No. 397; seven inches beyond by No. 398; eighteen inches from this by No. 399, and four feet further north it has its usual character and appearance, as shown by No. 400. At this place the contact was along the strike of the laminated rock and there is nothing to show their relative ages. The syenite now extends northward for thirty feet, where it disappears under the soil as it does just to the west of this place. Boulders of massive greenstone occur just north of the syenite, but the greenstone is not seen certainly in place until a low ridge of it (No. 401) is reached fifty feet north of the syenite.

*Compare the diagrams of jointing and schistose structure in the greenstones of the Menominee river, Michigan; Bul. 62, U. S. Geol. Survey, p. 128.

The high ridge, running east and west through the N. ½ of N. W. ¼ sec. 28, is composed of massive greenstone. In places it is cut by irregular branching dykes of gray quartz porphyry. These dykes vary from an inch up to more than a dozen feet across. The principal and largest one runs about east and west along the southern edge of the top of the ridge and varies considerably in width. The contact between the porphyry and the greenstone is sharp and there is no intermingling of the two rocks. At the contact the greenstone does not appear to be much changed except that it is more broken and fissured. Pieces of the greenstone are included in the dyke. Nos. 402 and 403 represent this porphyry; the former was taken within three inches of the edge of the dyke, and the latter about four feet from the edge. This rock has a grayish groundmass in which are imbedded a few quartz grains and numerous flesh-colored and blood-red feldspars The quartz is more plentiful near the edge of the dyke (No. 402). In places the rock contains minute cavities, apparently formed by the weathering out of certain constituents of the rock. Under the microscope the rock is seen to have a micrograuitic groundmass of rather variable grain. In this are feldspars of all sizes up to pieces over a quarter of an inch in length. The crystal outlines of the feldspars are not usually distinct and most of them show no planes at all, being pieces with irregular outlines. Many of the feldspars show polysynthetic twinning lamellæ, and a large number do not. Alteration to sericite is quite common, and in some cracks and areas of considerable size in the groundmass sericite has been developed in large amount. Secondary calcite is also present. No distinction between the flesh-colored and the blood-red feldspars can be made in ordinary section,—they both appear colorless; and as yet no oriented sections of the two kinds have been studied; they appear very distinct in the hand specimen. Scattered through the rock are colorless to greenish secondary needles of chlorite or hornblende. A few areas of green hornblende, more or less altered, also occur, but it is not possible to say whether or not this hornblende was the form of the original ferro-magnesian constituent of the rock. Sphene and apatite are present in small amount. Large quartz grains are not present in the sections examined, although macroscopic grains are often seen in the hand specimens collected.

On going south from the stream into the S. E. ¼ of N. W. ¼ sec. 28, the graywacke-like rock is seen showing the characteristic lamination. Soon this rock begins to grow more crystalline, and this character becomes more and more pronounced as one proceeds southward. No. 404 shows this more crystalline facies, but in this the lamination is still distinctly preserved. Interbedded with this are beds of a less crystalline character, as shown by No. 405, which is very similar to the mica-schist found to the west in sec. 30, already described. Other facies of this rock are shown by Nos. 406, 407 and 408, which are all completely crystalline. The first of these is a distinct gneiss, and the latter show no gneissic structure, even on the most favorable weathered surfaces. Macroscopically these three specimens are seen to be composed of quartz, a light colored feldspar, biotite and some little hornblende. These rocks, while completely crystalline, can in no wise be separated from the less crystalline facies and the graywacke-like rocks already mentioned several times. They are interbedded in bands from one-half inch to two feet in thickness,—the more crystalline always in the thicker beds. They seem to grade into each other across the the strike, and in some places the less crystalline is replaced along the strike by the more crystalline,—the former fading out into the latter. The most crystalline facies contain many black lens-shaped pieces of black diorite (No. 409); these pieces are composed mostly of hornblende with some little white feldspar. The exposures above described extend south from the stream for a quarter of a mile, and beyond this is low swampy ground with no exposures. The strike at the most southerly place seen was N. 70° E., and the dip vertical or very steep toward the south.

A narrow belt of syenite (No. 410) extends along the north shore of the river in the N. ½ of N. E. ¼ sec. 29. Just north of the syenite is a range of greenstone hills running east and west. In some places the two rocks were seen within fifty feet of each other, but at no place was the junction between them seen. The syenite rises in a bold bluff at the portage in the W. ½ of N.W. ¼ of N.E. ¼ sec. 29. About one-quarter of a mile east of this portage the greenstone is cut by an irregular dyke of gray quartz porphyry (No. 411). This dyke where examined is three to ten feet wide and has a general east and west direction. It was also seen, but not visited, in the greenstone both east and west of this locality. This dyke is probably a westward continuation of that already described from the N. ½ of N. W. ¼ of sec. 28.

Coming south from the river about on the line between secs. 28 and 29, the laminated rock and gneiss similar to that described above (Nos. 404 to 408) are seen in many exposures. About one-third of a mile from the river the syenite suddenly appears. It was first seen as a belt, 100 feet in width, running parallel with the gneiss which appears on both sides of it. The gneiss preserves its usual character and distinct alternation of different bands clear to the syenite. No. 420 shows this rock within a few feet of the syenite. Nos. 421 and 422 come from within three and one inches respectively of the syenite; the latter is some more coarsely crystallized and contains many distinct hornblende grains and some red feldspar. No. 423 shows the two rocks together; the line between them is quite sharp and distinct. No. 424 is the syenite just beyond No. 423; it is quite gneissic in structure. The strike of the gneiss is N. 60° E., and the gneissic structure of the syenite stands parallel to this; the dip is 5° either side of the vertical. In some places the line between the two rocks, instead of running with the lamination, runs across the strike for a few inches. In other places the syenite is more completely granitic in structure, as shown by No. 425. A short distance south of this the gneiss is much contorted and is cut by stringers, two to three feet across, of the syenite; some of these run with the lamination of the gneiss and others cut across it. There is no gradation from the gneiss to the syenite; the line between the two is clear and sharp. Further south the syenite becomes the prevailing rock, and in many places it holds lenticular masses of the gneiss.

On the south shore of the river just west of the line between secs. 28 and 29 the laminated rock is seen. Still further west, about half way from this section line to the rapids, which are about in the N. W. ¼ of N. E. ¼ sec. 29, the syenite again appears, but less than 200 feet south from the shore it comes in contact with the laminated rock. The junction here is along the strike of the laminated rock and the syenite was not seen cutting across the strike. The line between the two was distinct and easily seen on weathered surfaces. From the rapids just mentioned west to the east line of sec. 30 the laminated rock occurs on the south shore and a high bluff of it is seen just south of the river on this section line. The little bay in the N. E. ¼ of N. E. ¼ sec. 30 has syenite on its south and greenstone on its north shore.

Mr. Wood went south from the river about on the line between secs. 29 and 30. He found the laminated rock in place all the way until nearly half a mile from the river, when the syenite was seen. No. 426 shows the laminated rock, which here approaches a mica-schist, and No. 427 is more accurately a mica-schist. This latter facies of the rock was that most commonly seen, but that seen nearest the syenite was more like No. 426.

The north shore of the river, in the N. ½ of N. W. ¼ sec. 29, is made of greenstone, but the syenite comes in at the water's edge just west of the portage in the eastern edge of this quarter section. I went north from the river on the west line of this section for one-third mile, but found no rock except massive greenstone, of which several exposures were seen. About one-fourth of a mile east of this line and just north of the river the greenstone is cut by a dyke of reddish fine grained rock (No. 428) resembling a syenite porphyry. The dyke has an east and west direction and was traced for fifty feet. The sides of it were covered by soil, and as far as seen it was not more than ten feet wide.

The point on the south side of the river, in the W. ½ of N. W. ¼ of N. W. ¼ sec. 27, is made up of the laminated rock* and is well shown by the specimens already described,—Nos. 383 to 386. The strike varies from N. 30° E. to 45 E., and the dip from 75° to 80° S. E. Along the shore just west of this point the laminæ are much contorted. The point on the north side of the little bay in the same $\frac{1}{16}$ section is also made of the same rock. The small island in this bay is composed mostly of the syenite, but the northern side has a little of the laminated rock. Near the syenite this rock changes, becoming more crystalline and acquiring some reddish feldspar (Nos. 429, 430 and 431); but this condition exists only within a few inches of the syenite, in fact the syenite, as shown by No. 432, is seen within six inches of the above specimens. The junction between the two is easily seen as a pretty distinct line on weathered surfaces. Small pieces of the laminated rock were found in the syenite; No. 433 is from one of these. On the shore just east of this the syenite is intimately mixed with the laminated rock; still the line between the two is distinct and the syenite seems to have enclosed pieces of the other rock. In one place the syenite holds a small area of a dark compact mica-schist (No. 434), which is really part of the laminated rock, and shows lamination in favorable places. No. 435 shows this rock and the syenite together; they are marked off from each other by a sharp line.

The laminated rock is again seen on both points of the promontory in the N. E. ¼ of N. W. ¼ sec. 27, but the syenite appears on the western shore of the little bay in this $\frac{1}{16}$ section and also on the south and east sides of it. At the southeastern corner of this bay the rock has a decidedly schistose structure and there are alternating bands of schistose syenite (No. 436) and rock similar to Nos. 429 and 431 which appears to be an altered condition of the laminated rock; this is shown by Nos. 437 and 438. These bands of syenite and Nos. 437 and 438 vary from one inch to one foot in width, and they are parallel to the schistosity of both rocks. This

*This is the rock described by N. H. Winchell in the 15th (1886) Annual Report, p. 352, under No 989.

is N. 40° E. and the dip nearly vertical. Nos. 437 and 438, while still retaining considerable of the sericitic material, have large quantities of reddish feldspar and some hornblende developed in them. Between these bands and almost always running parallel with them are vein-like forms of a fine grained pinkish granitic rock (No. 439) holding flesh colored feldspar phenocrysts. These veins vary from one to ten inches across and rapidly change their thickness in a short distance. They are also frequently faulted.

On the north shore of the river in the N. W. ¼ of N. W. ¼ sec. 27 the laminated rock is found, and just north of this is a belt of syenite 150 feet wide, separating this rock from the greenstone. The junction of the syenite and laminated rock was seen in one place; the phenomena at the contact are the same as those already described under Nos. 395A to 400. The line between the two rocks runs parallel with the strike of the laminated rock and is quite easily distinguished. The syenite is also seen in contact with the greenstone; the change from one rock to the other occupies one or two feet and is essentially the same as that described above under Nos. 388 to 394. In some places in this vicinity the syenite, especially when in close proximity to the greenstone, becomes very schistose, as is shown by No. 440, which is dark colored and shows a decidedly gneissic structure; but generally in this $\frac{1}{16}$ section the syenite is dark, massive and chloritic (No. 441). The syenite extends along the north shore from this place to the small bay in the S. E. ¼ of S. E. ¼ sec. 22. It forms only a narrow belt between the river and the greenstone ridge just north of it. Along this shore the syenite varies from a massive state, similar to No. 432, to a more chloritic (No. 441) and schistose condition (No. 440).

The island in the middle of the river just north of the west end of the promontory, in the N. E. ¼ of N. W. ¼ sec. 27, is composed entirely of the graywacke-like rock. The lamination is very pronounced and the strike is quite constant, being about N. 63° E.; the dip is nearly vertical. This strike would carry the rock into the north shore of the river less than a quarter of a mile east of the island, but there the syenite is seen and there is no sign of the graywacke-like rock.

On the little bay, in the S. E. ¼ of S. E. ¼ sec. 22, the graywacke-like rock is again seen just north of the south line of this section. The lamination is very distinct, and, while varying some, has a general northeasterly strike. A short distance south of this the syenite appears and extends along the north side and to the end of the point which makes the southern side of this bay. The graywacke-like rock makes up the southern half of this point; it is much twisted and crumpled. Its junction with the syenite was seen in one place; the line between this (No. 442) and the syenite (massive and similar to No. 432) was distinct. Just at the contact the graywacke-like rock showed distinct lamination in but a few small areas and here it faded out in a short distance. Away from the contact the lamination was very evident, though much twisted, and the rock was more like Nos. 383 and 384. The massive syenite is seen again on this point just east and west of the line between secs. 26 and 27.

In the N.W. ¼ of N. W. ¼ of N.W. ¼ sec. 26, the syenite is found on the shore. Just north of it the graywacke-like rock is seen; this becomes somewhat more crystalline, as shown by Nos. 443 and 444, and it seems to pass gradually into No. 445, which is a distinct gray gneiss. However, this gneiss was seen to hold sharply defined lenticular pieces of rock similar to some facies of the greenstone. No. 446 shows the gneiss and part of one of the lenticular pieces in it. The junction of the gneiss and syenite was not seen. The syenite here presents a decidedly gneissic structure, but this grades into the more massive facies within two or three feet. The phenomena here seem to be about the same as those described under Nos. 404 to 409; the gneiss (No. 445) is apparently a changed condition of the graywacke-like rock, although in some places the two are separated by a sharp line. Fifteen feet north of this the graywacke-like rock again appears; it is nearly vertical, and, while bent in some places, there is a decided general strike of N. 60° E. At times the rock is similar to Nos. 383 and 384, and again like No. 443. This graywacke-like rock continues northward for about 200 feet and then the syenite occurs. The two are separated by low ground with no exposures.

The syenite continues northeastwardly along the northwest shore of this bay (N. ½ of N. W. ¼ sec. 26) for some distance, and in it is a band of the graywacke-like rock ten feet wide. This is sharply marked off from the syenite on each side, and is distinctly laminated, striking northeast. In some places this band is similar to No. 443, but the most of it is mica-schist, as shown by No. 447. On the north side of this bay hills of greenstone are seen in the N. W. ¼ of N. W. ¼ sec. 26. The greenstone and syenite were seen within fifty feet of each other, but the junction was not found. The syenite becomes schistose and chloritic near the greenstone, as has been described farther to the west. Within 300 feet of the greenstone the syenite holds irregular sharply outlined pieces of the geenstone, which are from one to ten feet in diameter. On the weathered surfaces these pieces very closely resemble the greenstone in the hills just to the north, but on freshly broken surfaces the rock is seen to be slightly darker than the greenstone in the hills. No. 448 is from one of these pieces in the syenite. The greenstone in the hills near the syenite has a schistose structure, as shown by No. 449. This is twisted and somewhat irregular, but the general strike is N. 65° E., and the dip about vertical. The rock is lighter in color than the ordinary greenstone and contains some feldspar which weathers reddish. A short distance to the east the greenstone assumes the characteristic green color seen farther to the west, but the schistose structure does not altogether disappear. On the eastern side of the small point on the north shore of this bay the syenite occurs in a low outcrop. It is here in contact with the graywacke-like rock, but seems to enclose masses of this rock. The syenite here is mostly massive, but in a few places shows a gneissic structure which runs northeastwardly. There are pieces (a foot or so in length) of the graywacke-like rock enclosed in the syenite; most of these are facies of the rock approaching mica-schist. These pieces are mostly irregularly lenticular in shape and the lamination is parallel with their long axes, which usually lie in a northeasterly direction. Syenite occurs on the east shore of this bay.

The shores of the little bay which lies partly in the extreme southern part of sec. 23 are lined with syenite of the ordinary massive kind. About 100 yards north of the northwest corner of the bay is a hill of syenite which presents the schistose and chloritic character seen several times in close proximity to the greenstone. At the extreme eastern end of the bay the syenite is seen in contact with a dark diorite (No. 450), which is spotted by large blotches of hornblende. The contact line is sharp, as shown by No. 451, and neither of the rocks appears changed at the contact. The syenite is cut, on the eastern shores of the bay, by a coarse grained pegmatite (No. 452). This consists of large flesh-colored feldspars and small quartz grains, and often shows a true pegmatitic structure.

From this bay to the rapids, in the E. ½ of S. E. ¼ sec. 24, the north shore of the river has numerous outcrops of the ordinary massive syenite. No mica-schist or graywacke-like rock was seen along this shore, although special search was made for them.

On the south shore of the river, in the N. W. ¼ of sec. 25, there is a westerly facing gabbro cliff. On the face of the cliff was a small area, a foot square, of a reddish syenite bearing much biotite;

the specimen collected (No. 460) shows this rock and the gabbro. No other rock, except the gabbro, was found on the cliff. Just at the foot of the cliff was a large block of gray syenite (No. 461) and several small red syenite fragments (No. 462); these looked as if they had been broken off from the face of the cliff. This is possibly the line of juction between the syenite and the gabbro, but nothing more than above stated could be seen. The gabbro was the ordinary coarse grained facies.

The syenite of sec. 26 varies a little from that described from sec. 27. It is represented by No. 463, which is somewhat finer grained than the ordinary facies and is lighter in color, being more of a gray than a sed syenite, but on weathering it takes on a reddish color.

The river in the S. W. ¼ of sec. 19, T. 63–9, has two rapid channels around a small island, not shown on the township plat. The portage is along the south shore of the southern channel. At the east end of this portage gray syenite, similar to No. 463, occurs. Just beyond the portage and on the south shore of the island is a dark rock (No. 464) which seems to be intermediate between the gabbro and the syenite. It is a very compact rock of medium grain and uniform dark color, and on a freshly fractured surface shows in places yellowish color due to minute cracks; on weathered surfaces it has the appearance of the gabbro. This rock grades into the syenite (No. 467) through Nos. 465 and 466. The syenite was found at only one place, and that at the foot of a low cliff; the change from No. 464 to the syenite occupies two or three feet. This seems to be the junction of the gabbro and the syenite, but no true gabbro was found on the island, and it is not certain that No. 464 does represent the contact facies of the gabbro. Near the eastern end of the island gray syenite, shown by No. 469, is again seen. The ordinary coarse grained gabbro (No. 468) occurs on the south shore of the river just opposite this island, and on this shore no syenite was found. From this island the syenite continues along the west side of the river to the western end of the little bay in the S. E. ¼ of N. W. ¼ sec. 19, T. 63–9. The only exception to this is that on the south side of the point about the center of sec. 19, T. 63–9, the gabbro, similar to No. 468, is seen in a low outcrop. Thirty feet north of this gabbro is a gray rock (No. 470) which seems to be intermediate between the gabbro and the syenite. And 100 feet north of this the syenite is again seen. There is no continuous exposure between this syenite and the gabbro mentioned above. In places on a little island, which lies just off the end of this point, the syenite has a gneissic structure which stands about vertical and strikes N. 40° E.

On the north side of the bay, in the S. E. ¼ of N. W. ¼ sec. 19, T. 63-9, are many outcrops of a very fine grained, aphanitic grayish rock. It is shown by Nos. 471 and 472. This is apparently a facies of the greenstone.* It continues for an eighth of a mile, and probably much farther, north from the river. This rock continues along the north shore of the river for about a mile from this bay. On the line between secs. 19 and 20, a few rods back from the water (north shore of river), is an exposure of a fine grained massive diorite (No. 473). This was not, as far as seen, sharply separated from the rock shown by Nos. 471 and 472. Greenstone, or a rock intermediate between the greenstone and this diorite, was traced north on this section line for about a third of a mile.

Small lakes in T. 63-10, north of the Kawishiwi river.

Starting from the river, on the line between secs. 28 and 29, is a portage which runs north to a narrow lake, which lies in secs. 15, 16, 20 and 21. The portage crosses several greenstone ridges. These present an extremely massive appearance; this is especially noticeable towards the north end of the portage. No. 412 fairly represents this greenstone; it is a dark green aphanitic rock; it was taken from an outcrop on the portage about an eighth of a mile north of the section corner. Greenstone of the same massive kind, with no evidence of schistosity or lamination, extends along the shores of this lake in section 20. At the west end of the lake a dyke of gray granite porphyry (No. 413) cuts the greenstone. The general direction of the dyke is east and west, but not enough of it was exposed to show the exact width, though this is probably not more than fifteen feet. In the rock are many quartz and feldspar phenocrysts, some of the latter being a half an inch in length. Macroscopically this rock closely resembles No. 417, which will be described more in detail. A small island, in the W. ½ of S. W. ¼ of N. W. ¼ sec. 21, also shows more of this granite porphyry. Greenstone extends along the north shore in sec. 21, but on the point, in the N. W. ¼ of N. E. ¼ of the same section, there is a bluff of a fine grained red-weathering siliceous rock (No. 414), which is probably a facies of quartz porphyry. Just north of this bluff the greenstone occurs, but the junction of the two rocks was not seen. Greenstone appears to make the rest of the lake shore, but on the east side of the little bay (south shore of the lake), in the W. ½ of N. E. ¼ sec. 21, a dyke of quartz porphyry is seen cutting the greenstone. This dyke is fifty feet wide, stands vertical and strikes a lit-

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*This locality has been already fully described in the 15th (1886) Annual Report, pp. 345-347.

tle north of west; this strike would carry it directly into the rock No. 414, mentioned above, which is probably a continuation of this dyke. The contact between the greenstone and quartz porphyry is sharp and distinct, and the former does not seem to be especially altered near this line. The centre of the dyke is much coarser grained than the edge. No. 415 shows the greenstone within two inches of the dyke; No. 416 is the quartz porphyry two inches from the edge of the dyke, and No. 417 is the same from the centre of the dyke. The quartz porphyry (No. 417) is of a general pinkish color; it contains many quartz and feldspar phenocrysts, the latter being white and flesh-colored. A few small specks of a dark mineral are also present. The rock seems to the unaided eye to have no unindividualized ground-mass, but microscopically the rock shows a decided microgranitic ground-mass of rather small but irregular grain. Imbedded in this are numerous feldspar phenocrysts of all sizes up to those nearly half an inch in length. Most of these feldspars show their crystallographic outlines on all sides, but some few appear as fragments partially bounded by crystal planes. Zonal structure is quite common, and about half of the individuals show polysynthetic twinning lamellæ. Quartz individuals of good size are also present, but are not nearly as abundant as the feldspars. The quartzes are all corroded and show no crystal faces, and they frequently have large embayments filled in with the ground-mass. Some of the quartz shows undulatory extinction, but otherwise the rock gives no evidence of having been subject to pressure. Scattered through the ground-mass are irregularly outlined green areas composed of chlorite and epidote. What the original ferromagnesian constituent of the rock was is now impossible to determine. A few small acute rhombs of sphene are also present. The rock is properly a microgranite. Rock No. 416, from the edge of this dyke, presents the same appearance as that just described, except that the ground-mass is of some finer grain and the feldspar is mostly in fragments.

The shores of this lake seem to be made entirely of greenstone, cut in a few places by quartz porphyry dykes. The greenstone is very massive and in no place where examined shows any evidence of lamination or schistosity. It is well represented by No. 412, from the portage south of the lake, and by No. 418, from the north shore on the line between secs. 16 and 21.

From this lake there is a trail running north on the line between secs. 15 and 16 to a small lake lying in the N. W. ¼ of sec. 15 and the N. E. ¼ of sec. 16. No rock is *in situ* along this trail, but at the shore of the latter lake the greenstone is in place. The shores of the lake, as far as could be seen from the meander corner, were lined with rock which had all the appearance of greenstone. On this trail and a few yards south of the lake is a low hill, the north side of which shows many angular fragments of rock. This rock is made up of alternating bands of compact black slate and bands of almost pure magnetite. These bands vary from one-eighth of an inch to an inch in thickness. They are very regular, and on the whole the rock is very similar to some Kewatin ore described from Ottertrack lake.* The fragments of this rock were of all sizes up to those three feet in diameter, and while no pieces were exactly *in situ*, still there can be no doubt but that the rock is *in situ* just below these fragments. No. 419 represents this rock.

From the north shore of the Kawishiwi river, in the N. E. ¼ of S. W. ¼ sec. 24, a portage runs northwesterly to the southeast corner of Triangle lake. This lake lies in secs. 13, 14, 23 and 24, T. 63–10. Just north of the river the portage crosses a low ridge of gneissic syenite, and a short distance beyond is a ridge of the graywacke-like rock. This latter is shown by Nos. 453, 454 and 455. Just east of the portage this ridge is seen to better advantage; here the strike is N. 60° E., and the dip vertical. Fifty feet north of this ridge massive greenstone (No. 456) is seen. The two rocks were traced within thirty feet of each other, but the junction was covered by soil. Beyond this more greenstone ridges are seen on the portage; usually the rock is massive in appearance, but it sometimes shows an indistinct schistose structure which stands vertical and strikes about northeast. About half way over the portage is a ridge of greenish, finely laminated rock, represented by No. 457. The lamination is very distinctly seen on weathered surfaces, and in places the rock is decidedly slaty. The strike is N. 65° E., and the dip vertical. This rock seems to be a facies of the greenstone. Beyond this rock greenstone is seen in several places on the trail before reaching Triangle lake. Several outcrops on the east shore of this lake were examined, but the rock was all greenstone.

From the northeast corner of Triangle lake a portage of a few yards leads to Northwest lake, which lies in secs. 11, 12, 13 and 14, T. 63–10, and secs. 7 and 18, T. 63–9. On the south side of a small island, in the N. E. ¼ of N. W. ¼ sec. 13 (Northwest lake), is a low outcrop of altered quartz porphyry (No. 458). This rock has the ground-mass almost entirely changed to a sericitic condition, but it still contains many porphyritic quartzes and large pinkish feldspars. Some of the feldspars are an inch long; they can be read-

*17th (1888) Annual Report, pp. 112-113.

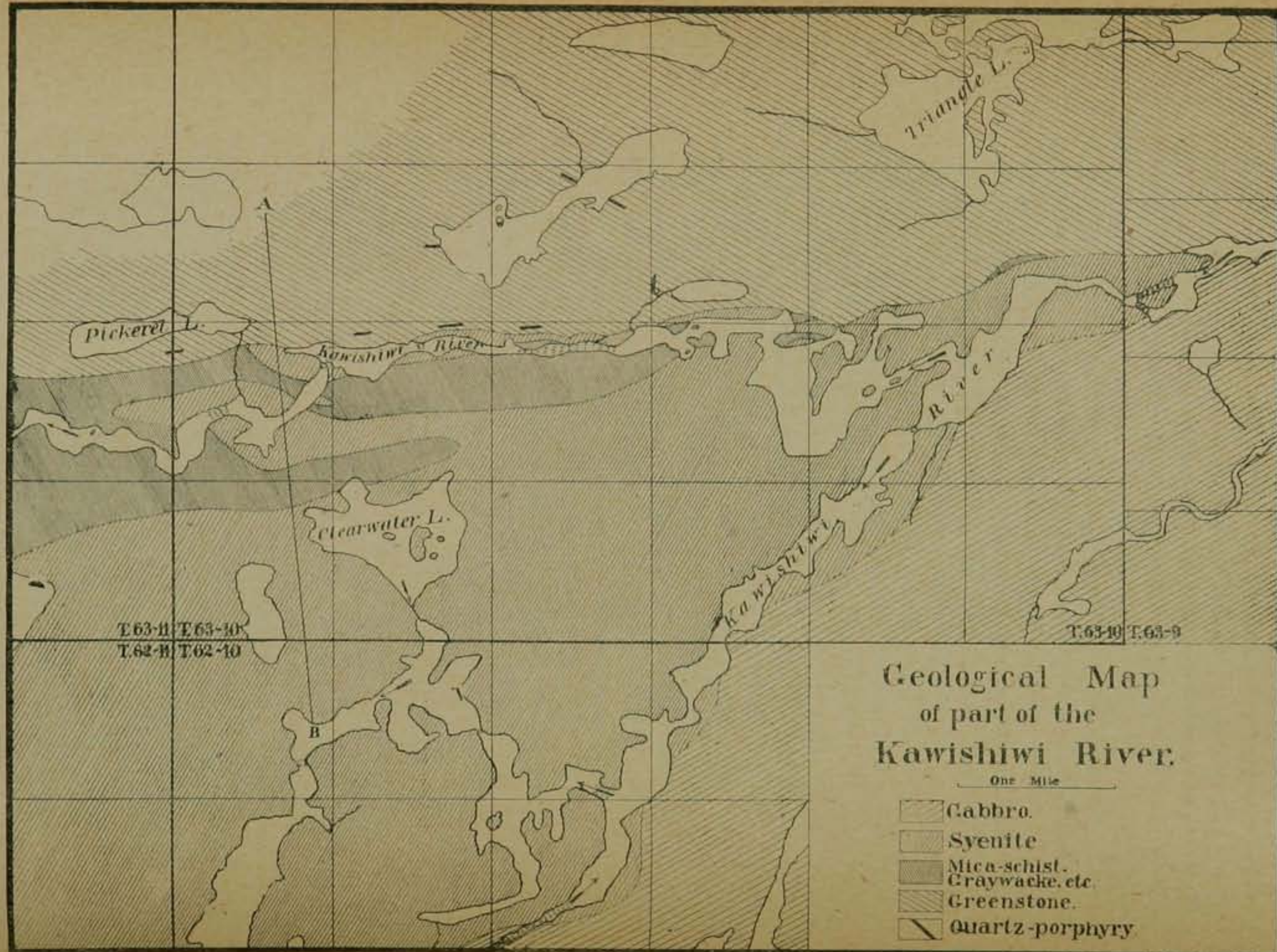
Triangle L.
A
Pickerel L.
Kawishiwi River
River
Clearwater L.
Kawishiwi
T.63-11 T.63-10
T.62-11 T.62-10
T.63-10 T.63-9
B
Geological Map
of part of the
Kawishiwi River.
One Mile
Gabbro.
Syenite
Mica-schist.
Graywacke, etc.
Greenstone.
Quartz-porphyry.

FIG. 2.

ily broken out of the ground-mass, and they show complete crystal outlines. The sericitic ground-mass gives a rough schistose structure to the rock; the strike of this is N. 60° E., and the dip about vertical. The south shore of this lake was examined in several places and the greenstone was the only rock seen; this extends to the extreme eastern end of the lake in the N. E. ¼ of sec. 18, T. 63–9. On the north side of the lake, in the N. E. ¼ of N. E. ¼ sec. 13, T. 63–10, the greenstone has a peculiarly mottled appearance. This is shown by No. 459. It is due to numerous black blotches, apparently of hornblende.

Geological map of part of the Kawishiwi river.

The distribution of the different rock masses in that part of the Kawishiwi river, described in the foregoing field notes, is shown on the accompanying map. Five distinct rock types are present, the characters and relations of which have already been briefly given. The gabbro is the most recent; it covers parts of the older rocks and is very extensively developed just to the south of the area of this map. The syenite is older than the gabbro, and is younger than the greenstone and mica-schist, both of which it cuts in a truly irruptive manner. The mica-schists, graywackes, etc., stand vertical and have a general E. N.-E. strike; they belong to what has been mapped as the Vermilion series, but there seems to be good reason for putting all of this type of rocks, in the area of this map, into the Keewatin. The greenstone is presumably of

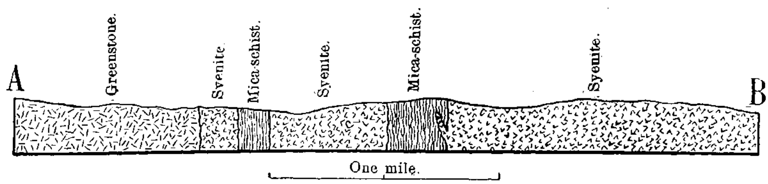

Fig. 3. Section along the line A B, of the geological map of part of the Kawishiwi river.

Keewatin age and is probably younger than the mica-schists, graywackes, etc. Quartz porphyry dykes are found cutting the greenstone in several places, but they have not yet been seen in the other rocks in this immediate vicinity.

B. SNOWBANK LAKE AREA.

The outlines of the granite on this lake were traced much less minutely than those of any other of the areas visited. In fact but a short time was spent in this vicinity, and the only things to which much attention was given were the nature of the granite and its relations to the surrounding rocks.

Portage from the Kawishiwi river to Snowbank lake.

This portage starts from the river in the N. E. ¼ of N. W. ¼ sec. 15, crosses the S. E. corner of sec. 10 and reaches Snowbank lake at its southwestern corner in the S. E. ¼ of N, E. ¼ sec. 11; all in T. 63-9. No rock but the ordinary coarse grained gabbro was seen until after reaching the S. W. ¼ of sec. 11.* About one-third of a mile east of the line between secs. 10 and 11 is a low ridge of coarse pinkish syenite (No. 474). A short distance beyond this is an outcrop of fine grained red syenite (No. 475), and farther on, just to the right of and on the portage, is a coarse pink syenite (No, 476) much resembling No. 474. A little farther is a dark colored rather fine grained diorite (No. 477), and just beyond this is another still finer grained diorite, which continues for a short distance, where it is cut by veins of a fine grained gray to reddish syenite (No. 478); at this latter place the finer diorite is represented by No. 479. On the north side of the same ridge in which the last two rocks occur a gray porphyritic syenite (No. 480) is seen. The relation of this to the other rocks could not be determined. Farther on and a short distance to the left of the trail is a low ridge of this same gray porphyritic syenite, here represented by No. 481. There are thus seen on this portage several apparently distinct kinds of syenite, but the relations between them were not ascertained, as there were but few outcrops and in no exposure did two of these syenites occur together.

Snowbank lake.

On the west shore, in the N. ½ of N. E. ¼ sec. 11, T. 63-9, a fine grained syenite (No. 482) in seen; this is quite similar in appearance to Nos. 480 and 481. Farther north syenite is again seen on the shore; here it is coarser grained and not at all like No. 482. This coarser grained syenite extends along the west shore into the northwest corner of the bay in the S. ½ of S. E. ¼ sec. 2, T. 63-9. Here it is represented by Nos. 483 and 484; the former is a dark red syenite of medium grain, and the latter is of lighter color, contains less hornblende and is the facies of the rock that is most common at this locality. Just off the point, which is in the N. W. ¼ of S. E. ¼ sec. 2, T. 63-9, is a small island made of a coarser facies of the same syenite (No. 485). This is cut by veins, of all sizes up to three feet across, of a dull reddish rather coarse grained syenite (No. 486) made up almost entirely of feldspar; the other constituent is in small amount and seems to be epidote. The point crossed

*For descriptions of the gabbro and associated rocks on this portage, in secs. 10 and 15, see the 17th (1888) Annual Report, p. 120.

by the line between secs. 35 and 36, T. 64–9, is composed of dark diorite of medium grain (No. 487); this appears in the form of a dyke, 100 feet or more in width. It runs about north and south. The syenite was seen just east of this point and also along the shore west of it; here the syenite is quite coarse grained and contains much biotite (No. 488). The point on the south shore, in the S. E. ¼ of N. W. ¼ sec. 35, T. 64–9, shows syenite of a rather fine grain (No. 489).

The bay which runs south along the line between secs. 34 and 35, T. 64–9, shows no outcrops along its shores. And on going west a short distance, near the township line, no rock was seen *in situ*.

On the west shore, in the N. E. ¼ of N. E. ¼ sec. 34, T. 64–9, a shore distance north of the portage which runs to Flash lake, is a large bluff of fine grained diabase. Farther north on the west shore of the narrow bay in the S. E. ¼ of S. E. ¼ sec. 27, T. 64–9, the fine grained greenish diabase, here represented by No. 489A, is cut by an irregular dyke of reddish porphyry (No. 490). This dyke is from two to five feet wide and was traced for at least thirty feet. Another small mass of this same rock was seen near by, but it was exposed only in one place. This porphyry (No. 490) has a reddish to purplish aphanitic ground-mass, in which are porphyritic crystals of red feldspar and small areas of chlorite. Under the microscope the ground-mass is seen to be micrographitic in structure and apparently composed of quartz and feldspar. The feldspar phenocrysts are more or less altered and the majority of them show polysynthetic twinning. Irregular areas of chlorite occur in the ground-mass, but nothing is left to show what was the mineral that originally occupied these areas. A few small apatite prisms are present, and scattered through the whole rock are minute green flakes of chlorite. The rock is probably a syenite porphyry.

No rock except that above described is seen on the shores of this narrow bay north of the south line of sec. 27, T. 64–9. But where this line crosses the east shore of the bay there is a low ridge which shows angular fragments of fine grained greenish diabase similar to No. 489A. No rock is seen in place along the southwest shore of the promontory, on which are the corners of secs. 26, 27, 34 and 35, T. 64–9, but many angular fragments of the fine grained diabase occur at the water's edge. On the sharp point, at the southern end of this promontory, angular fragments of the diabase and of porphyry, similar to No. 490, are seen. Along the shore just east of this point are angular fragments of granite, and a little further north this granite occurs *in situ*. Several outcrops of the same are seen along the shore before coming to the line between secs. 26 and 35, T. 64-9. At this place No. 491 was collected; this well represents the granite from the east shore of this promontory. It is a granite of medium grain, reddish color and compact texture; the feldspar varies from reddish to white, and the hornblende is in small grains and does not make up more than one-fifth of the whole rock. Quartz is present in small amount. Under the microscope this rock (No. 491) is seen to be a distinct hornblende granite. Quartz is present in larger quantity than is noticed in the hand specimen. The feldspar is more or less cloudy and many of the grains show a microcline structure and have a wavy extinction, as have also some of the quartz grains. The hornblende is quite fresh and of the ordinary green variety. A few scales of brown biotite are present, and also some green chlorite, which appears as an alteration product from the biotite. Bright brownish sphene is seen in considerable amount. Ilmenite, or magnetite, and apatite prisms are also present. This is the first true granite seen on this lake, but there is no reason to suppose that it is distinct from the syenite found elsewhere on the lake; in fact, everything seems to indicate that it is but an acid facies of the syenite. About 150 feet south of the above mentioned section line is a low outcrop of mica-schist, much twisted and bent. This schist is represented by No. 492, which is a fine grained compact mica-schist, and by No. 493, which is coarser and more properly gneiss. A few feet north of this the same schist is seen again; here it is cut by many granite dykes which vary from six inches to three feet in width. This granite is part of the same as that mentioned above (No. 491). The dykes in general run along between the cleavage planes of the schist, but some were seen cutting across these planes. The schist here is sometimes much changed near the contact with the granite, as is shown by Nos. 494 and 495, which are distinctly gneisses; the latter is decidedly reddish in color. There is no gradation from the schist or the gneissic parts of it into the granite; the contact between the two rocks is sharp and distinct, as is seen in No. 496. This specimen shows the two rocks, granite and schist, in contact; it was taken from the edge of a dyke one foot in width. The schist at this place is so twisted that no general strike can be made out. In places the granite includes pieces of the schist. A few yards north of this section line and back about 100 feet from the shore is quite a large exposure of the schists. These are bent some, but there is a decidedly general trend to the strike; it is N. 35° E., and the dip is almost vertical. Just beyond (north) this exposure of schist, and in the strike of part of it, is another outcrop of the granite similar to No. 491. On one of these outcrops there is a small amount, one by three feet in area and one foot thick, of purple porphyry; the contact with the granite was sharp and a distinct line, and there was nothing to show whether this rock was part of a dyke or an inclusion in the granite. This porphyry is represented by No. 497; it has a fresh unaltered appearance and seems exactly similar to that already described under No. 490, except that that the latter is not very fresh. A short distance north of the section line (between secs. 26 and 35) and about an eighth of a mile from the shore is a small island composed entirely of granite (No. 498). This island is directly in the strike of the last mentioned outcrop of schist. The granite of the island (No. 498) is of rather fine grain and holds a considerable amount of quartz, but is the same granite as that described above (No. 491). On the northeastern end of this island the granite is jointed in a very noticeable manner; the joints split the rock into parallel beds that stand vertical and strike N. 70° E.

On the south shore of the little bay, in the S. E. ¼ of S. W. ¼ sec. 26, T. 64–9, the schist is seen in many places, and the granite is seen in contact with it at a few points. The schist here is well represented by the specimens collected near the south line of this section; and where the schist is in contact with the granite it takes on the same characters as seen in Nos. 494 and 495. In one place a small tongue of the granite was seen running across the strike of the schists, as shown in the accompanying illustration (Fig. 4). Along the shore of this bay the schist is twisted so much that no general direction of strike is noticeable.

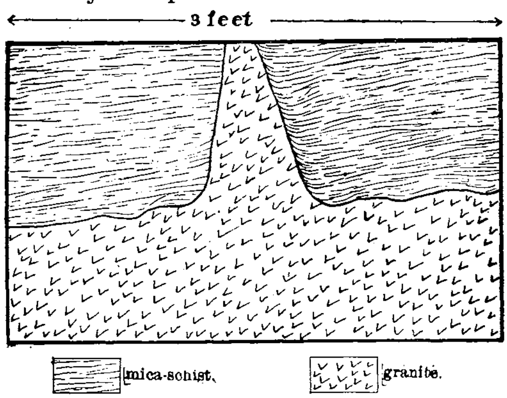

Fig. 4. Contact of granite and mica-schist; S. E. ¼ S. W. ¼ sec. 26, T. 64-9, west shore of Snowbank lake.

On the south side of this bay, near its western end and down at the water's edge, the schist is cut by a small dyke. This dyke is four feet wide, but was not exposed for over seven feet; the walls are parallel, stand vertical and strike N. 50° E. The line between the dyke and the schist is very sharp. The dyke rock is a purple porphyritic rock similar to that already described under Nos. 490 and 497; it differs from these, however, in having distinct glistening biotite scales scattered through the ground-mass. The rock may be provisionally called a syenite porphyry. No. 500 is this rock from the centre of the dyke, and No. 501 is the same from one edge of the dyke. The schist at this place has a dip of 60° towards the east, and a strike almost due north and south. The schist from near the dyke is represented by No. 499; this is a rather fine grained gray biotitic gneiss. In section this gneiss (No. 499) is seen to be a holocrystalline aggregate of interlocking grains of quartz, feldspar, biotite and hornblende. Many of the grains are elongated somewhat in one direction, this is especially true of the biotite, and there seems to be a tendency for grains of the same size and of the same minerals to be collected somewhat in irregular parallel lines. This causes a decidedly schistose structure to pervade the rock. None of the mineral grains show any evidence of a clastic origin. The quartz is clear and limpid and is in larger grains than the other minerals; it makes up about half of the rock. The feldspar, while cloudy in small areas, is usually clear; most of it is orthoclase, but some good sized plagioclases are present. The biotite is brown and fresh; it, more than any of the other minerals, is chiefly confined to certain irregular lines. The biotite is in small scales, most all of which are arranged with their long axes in the direction of the schistosity of the rock. Hornblende of the ordinary green variety is present in a few irregular areas; it appears very fresh. All the minerals of the rock present a decidedly fresh and unaltered appearance.

The granite occurs at the west end of the little bay, in the S. E ¼ of S. W. ¼ sec. 26, T. 64-9, and also along the shore for a short distance north of this place. The point in the N. E. ¼ of S. W. ¼ of the same section consists of a high ridge of green schists. These shists are hard and of a general green color; they seem to consist of mica, chlorite and silicious matter very closely intermingled. The rock has a fine lamination due to rapid alterations in the arrangement of the constituents, thus producing laminæ of different hardness and composition; this lamination is very clearly shown on weathered surfaces; it is parallel to the schistose structure of the rock. In places the schist is conglomeritic, containing pebbles of all sizes, up to a foot in length, elongated in the direction of the strike. The strike is N. 20° E. and the dip is 75° to 80° towards the east. At the east edge of this ridge the schists are in contact with the granite. The contact line is sharp and runs parallel with the strike of the schists, but the granite sends off many small dykes into the schists across the strike. No. 502 represents these green schists. No. 502A is part of one of the pebbles; it is a gray gneiss. No. 503 is the granite from one of the dykes four inches wide; this is a fine grained, reddish, hornblende granite.

The green schists extend from the point part way along the southeastern shore of the bay, in the N. W. ¼ of S. W. ¼ sec. 26, T. 64–9, but on this side of the bay, near its end, is a dark, compact, aphanitic rock holding white feldspar phenocrysts. This is probably a porphyrite (No. 504). It is massive at the shore, but on going back a few rods from the shore it becomes schistose, as is shown by No. 505. This porphyrite was traced eastward until it came within fifty feet of the green schists, but soil covered the contact. The porphyrite and the green schist at this place each had their distinct characters. The schistose structure of the porphyrite is parallel with that of the green schist. In one place the prophyrite is cut by a dyke of a fine grained syenite (No. 506). This dyke is four feet wide, stands vertical and runs east and west.

On the west side of this bay the green schists appear again and seem to get more massive on going northward, but the shore here was not carefully examined. In the S. W. ¼ of N. E. ¼ sec. 26 massive greenstone, into which the green schist seems to grade, is cut by a dyke of syenite porphyry, similar to No. 500. On the shore just north and east of this the greenstone and syenite are seen together. The greenstone here is quite massive in appearance and the contact with the syenite was seen in only one place; here it was a decidedly sharp line and two small pieces of the greenstone were seen in the syenite. At this place the syenite also cuts a gray diorite blotched with hornblende (No. 507); the relation of this diorite to the greenstone could not be determined. The syenite is itself cut by a fine grained greenstone (No. 508), in a dyke which varies from eight inches to two feet in width; this was traced for thirty feet. It may be that this is not a true dyke, but a part of the greenstone surrounded by syenite as it is decidedly similar to the greenstone and can not be distinguished from it in hand specimen. The syenite is here represented by No. 509, which is a reddish rock of rather medium grain. The greenstone is shown by No. 510.

Just north of this mica-schist is seen cut in every direction by dykes of the syenite, which vary in width from two inches to thirty feet. The mica-schist is shown by No. 511. Farther north there is a large mass of the schist exposed; here it varies from a mica-schist like No. 511, to a green schist (No. 512), which is very similar to the green schists described above. The strike here is N. 20°

E., and the dip is about vertical. These schists extend along the shore up to and beyond the line between secs. 23 and 26, T. 64–9. Sometimes they are cut by dykes of hornblende granite represented by No. 513. Near this section line the schists become very hard and compact; No. 514 from this place is a very siliceous, fine grained graywacke. Here the strike is N. 25° E., and the dip is about vertical. On a ragged bluff just north of this section line the schists are much crumpled and twisted and they become hard and very silicious. No. 515 fairly represents the schists at this place. The schists continue along the lake shore in secs. 23 and 24, T. 64–9. In places they are massive in appearance, but usually a lamination can be seen on their weathered surfaces; this, however, is much twisted in every direction, but there is a general northeasterly strike and a vertical dip. The schists in these two sections are well represented by Nos. 515, 516 and 517.

Where the line between ranges 8 and 9 crosses the north shore granite occurs, It is represented by No. 518, which is very similar to the granite and syenite found elsewhere on the lake. The granite here cuts the schists in dykes running in every direction. Some of these dykes are apparently a hundred feet wide, while others are not more than a foot. The contact between the two rocks is a very sharp line, as is shown by specimen No. 519, which was broken from the edge of a dyke eight feet wide. The schists at this place are represented by No. 520, taken within two feet of the granite; it is a fine, hard, silicious mica-schist. Here there is seen a small amount of a rather fine grained dark syenite (No. 521); this is distinct from the granite and is cut by it. The relation of this rock to the schists could not be determined. Just east of the range line the schists are seen in large amount. Here the strike is N. 70° E., and the dip southward from 70° to 80°. The schists, sometimes cut by the granite, extend along the shore to the bay in the S. W. ¼ of N. E. ¼ sec. 19, T. 64–8. On the west side of this bay the schists are graywacke schists. The strike is almost east and west and the dip varies from 65° to 80° towards the south. These schists are also seen at the north end and on the east side of this bay.

There is a small island in the N. E. ¼ of S. W. ¼ sec. 19, T. 64–8, on the eastern end of which is a large exposure of gray to reddish syenite of medium grain (No. 522). Mr. Wood went over most of this island and found it to be made of the same syenite.

Syenite from the shore in the N. W. ¼ of S. W. ¼ sec. 29, T. 64–8 is of medium grain and light gray color. Small areas of the feldspar have a peculiar yellow stain, No. 523.

Several outcrops on the east shore of the large island, which lies in secs. 30 and 31, T, 64-8, and secs. 25 and 36, T. 64-9, were examined. They are all composed of rather coarse syenite which holds large quantities of biotite. No. 524. Coarse syenite similar to this occurs on the east shore on the line between sec. 36, T. 64-8, and sec. 1, T. 63-9.

At the southwest end of the island that is crossed by the line between secs. 30 and 31, T. 64-8, there is an outcrop of fine grained biotite gneiss (No. 525).

Round lake.

This lake lies mostly in sec. 6. T. 63-8. The portage from Snowbank lake to Round lake is in the N. E. ¼ of sec. 1, T. 63-9. At the Snowbank lake end of this portage coarse syenite similar to No. 524 occurs. About half way over the portage a finer grained, reddish syenite (No. 526) is seen. But at the Round lake end of the portage is coarser syenite similar to No. 524. On the north side of the lake just west of the east line of sec. 1, T. 64-9, is a low outcrop of hardened mica-schist, cut by fine syenite veins. No. 527 shows the mica-schist and a small granite vein. The lamination of the schist is here twisted and bent, but there seems to be a general strike, No. 65° E.; however, this strike is not very pronounced. Further west on the shore are many angular fragments of syenite similar to No. 526. On the shore in the N. E. ¼ of S. E. ¼ sec. 1, T. 63-9, is an outcrop of the schist which is here more like gneiss (No. 528). In contact with this and separated from it by a sharp line is a small piece of syenite which held a small lenticular piece of the schist, or gneiss. Back from the shore is a small hill much covered by soil, but still exposing several angular fragments of rock that are undoubtedly *in situ* just below. Here a gneissic rock (No. 529) and red syenite (No. 530) were seen, and in one place they were in sharp contact; in other places they seem to grade into each other through No. 531 and 532; but nothing definite as to the relation of the syenite and gneiss could be seen here. Syenite again occurs on the shore a little south of this and is seen in angular blocks along the southwestern shore of the lake. On the shore in the N. E. ¼ of N. W. ¼ sec. 7, T. 63-8, is a low outcrop of a rather fine grained, brownish syenite (?) (No. 533). On the small stream that comes into the lake in this one-sixteenth section and about 100 yards from the shore is an exposure of coarse grained syenite. No other outcrops are seen along this stream until about a quarter of a mile south of the lake; here the ordinary coarse grained gabbro of the region occurs.

A low outcrop of mica-schist similar to No. 527 occurs on the north side of the lake in the N. W. ¼ of sec. 6, T. 63–8. A little further east syenite similar to No. 526 is seen. In the N. W. ¼ of N. E. ¼ of the same section the schists again appears. Here there is a decided strike of N. 70° E.; the dip is about vertical. The schists vary from mica-schist to graywacke-schist to quartz-schist. They are seen in several places along the northeast shore of the lake and also on the east shore. In some places the schists are cut by red syenite veins or dykes (No. 534). The most southern exposure of schists seen was on the east shore of the lake on the south line of sec. 6.

In the N. W. ¼ of N. E. ¼ sec. 7, T. 63–8, just south of the lake is a northerly facing gabbro bluff and at the base of it syenite is seen. The gabbro is the usual coarse grained gabbro common to this region. The position of the two rocks would indicate that the gabbro was the younger and overlay the syenite, but no positive proof of this was to be seen, as soil covers the junction of the two rocks. In the syenite a small dyke, ten inches wide, of a fine grained gabbro (?) occurs; this was exposed for only three feet in length. The contact with the syenite was a sharp line as is shown by No. 535. The dyke rock is represented by No. 536. The gabbro proper retained its coarse grained character as near to the syenite as it was exposed. No. 537 is the gabbro in the exposure nearest the syenite.

Disappointment lake.

This is also called Cheadle's lake. It is an irregular lake lying in secs. 3 and 4 of T. 63–8 and secs. 27, 28, 32, 33 and 34 of T. 64–8. Mica-schist occurs on the portage from Round lake. At the east end of the portage in the N. W. ¼ of S. W. ¼ sec. 3 is a low outcrop of schists, almost argillaceous in places. The strike here is N. 15° E., and the dip is vertical. The western shore of the lake has many large exposures of conglomeritic mica-schist cut in many places by fine red syenite. This syenite occurs in some amount on the portage to Snowbank lake (S. ½ of S. W. ¼ sec. 32) and is here seen cutting a peculiar gray rock. This gray rock (No. 539) seems to be a holocrystalline aggregate of gray feldspar grains among which are scattered hornblende prisms. In one place this gray feldspathic rock held many pieces of a darker rock, apparently a diorite; this is well shown by the specimen collected (No. 539). These pieces of diorite are of irregular shapes and all sizes up to those ten inches in diameter; none of them are lenticular in shape and they do not present the rounded outlines of pebbles. This gray rock lies to the north of the portage and is between two ridges of mica-schist, but was not seen in contact with the schist. No. 539 is the fine red syenite which cuts the gray rock.

North of Disappointment lake

Two small lakes, one lying in the N. ½ of sec. 27 and the other in the S. E. ¼ of sec. 21, T. 64–8, were passed through. The rock on the shores of both of these small lakes was massive in appearance and varied from a very siliceous graywacke to a hard, fine grained green rock, resembling the ordinary greenstone of the region. Most of the shore line of the former of these lakes was examined, but no rock was seen excepting that just spoken of.

C. KEKEQUABIC LAKE AREA.

South of Kekequabic lake, in secs. 11 and 14, T. 64–7.

On the portage, in the N. E. ¼ of N. W. ¼ sec. 11, is a ridge of soft dark greenish rock, which is composed largely of biotite (No. 540). An irregular lake, lying in the centre of sec. 11, has been called River lake. Its shores are made of a fine grained gabbro-like rock. This varies from No. 541, a rather coarse facies from the west end of the lake, to No. 542, of finer grain from the portage in the N. E. ¼ of S. E. ¼ sec. 11. Most of the rock, however, is finer grained than No. 541. In places this rock has small veins or streaks running through it; these are composed mostly of biotite. At times they are quite close together, as shown by No. 543, and again very few of them are seen. No general direction for these black streaks could be seen. On the north side of the central western arm of this lake the gabbro-like rock held many angular and twisted fragments of a reddish syenite similar to that found on Kekequabic lake, and also of a fine grained greenstone (No. 544). These fragments are of all sizes up to those a foot in diameter; they are very irregular in outline, none of them are rounded, and they are often much twisted and stretched. No. 545 shows some of the fragments in the enclosing rock.

A few rods back from the shore, on the south side of River lake and near the entrance to the southern of the western arms of the lake, is a westerly facing bluff made up mostly of the fine gabbro-like rock. In the face of the bluff is a small area of syenite (No. 546). This is rather fine grained and is composed of pinkish feldspar, hornblende and some biotite. The syenite was seen within six feet of the other rock, but at this place neither of them showed any change from their normal condition.

On the east shore of the lake, near the centre, is a very micaceous facies of the gabbro-like rock (No. 547). Just south of this is a gray condition, probably of the same rock (No. 548); this weathers reddish.

The shores of Shoofly lake, which lies mostly in the S. E. ¼ of sec. 11 and the N. E. ¼ of sec. 14, are made of the ordinary gabbro of the region; this is rather finer, especially near the northern end of the lake, than the main mass of the gabbro. In one place, on the north side of the western arm of the lake, is a rock similar to that which makes most of the shores of River lake. South of Shoofly lake, and about in the centre of the N. ½ of sec. 14, is a large hill of white or grayish weathering gabbro.

Kekequabic lake.

On the south side of the little bay which extends into the N. E. ¼ of N. W. ¼ sec. 11, T. 64–7, is an outcrop of what has been called, in the former reports of this survey, chloritic syenite and chloritic gneiss. This rock has a considerable development on the shores of Kekequabic lake. Under the microscope it is seen to be a *pyroxene granite.* It is of a rather medium or fine grain and reddish color, and will be frequently referred to below. South of this outcrop and about 200 yards from the lake is an east and west running ridge made of a dark green biotite rock, similar to No. 540, which was taken from this ridge a short distance to the east. The pyroxene granite is again seen in low outcrop on the south side of the point, in the S. E. ¼ of S. W. ¼ sec. 2, T. 64–7. These two are the only exposures on the west side of the bay mentioned above. On the west side of this little point is a large outcrop of the pyroxene granite; it varies considerably within a few inches as to the amount of the pyroxene constituent. No. 549 shows the lightest colored and coarsest grained facies from this place. The rock presents an irregular layered appearance. These layers vary from an inch to ten inches in thickness, and even the same layer varies in thickness within a short distance. No difference in composition between the different layers could be made out, nor is there any arrangement, macroscopically visible, of the constituent minerals in such a manner as to cause splitting along certain lines. The rock did not show a tendency to split up into fine layers parallel to the larger ones. The rock has not yet been carefully studied in regard to the origin and significance of this structure. Fig. 5 represents the face of a small exposure of this granite and shows the regularity of the layers. The layers at this place dip from 10° to 15° towards the south.

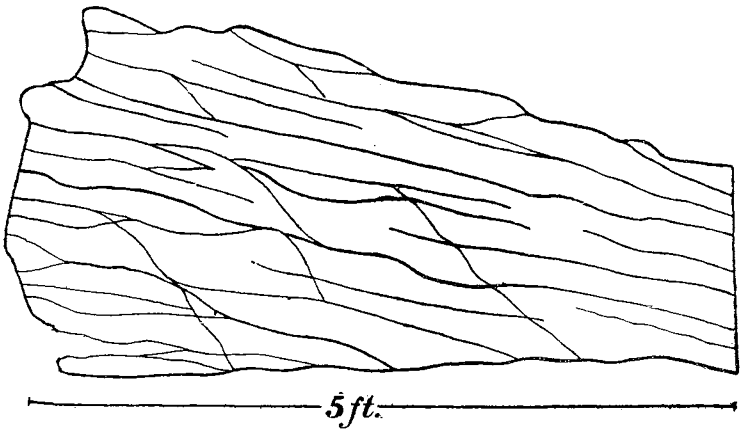

Fig 5. Sketch showing the parallel layers into which the pyroxene granite is broken in the S. E. ¼ S. W. ¼ sec. 2, T. 64-7, south shore of Kekequabic lake.

No other outcrops are seen along the south shore in sec. 2 and the S. E. ¼ of sec. 3, T. 64-7. On going south from the lake for a quarter of a mile, on the line between secs 2 and 3, no rock is seen *in situ*, although the ground rises very rapidly from the lake shore. In the S. E. ¼ of S. W. ¼ sec. 3, on the shore, is a dark colored fine grained chloritic rock (No. 550), which extends westward and seems to become the angular weathering chlorite-biotite rock described in the 15th (1886) Annual Report, page 364.

The little promontory (not shown on the plat), in the S. W. ¼ of S. W. ¼ sec. 3, T. 64-7, is made of the pyroxene granite, which here contains distinct porphyritic reddish feldspars. The rock is well represented by No. 551. There is in the granite a division into layers similar to that described above, but coarser and less noticeable, which here dips northward 15° to 20°. At the base of this promontory is a low outcrop of a dark aphanitic rock (No. 552) which resembles some of the hardened argillyte slates of Knife lake. Just west of the promontory the chlorite-biotite rock is again seen, and this extends along the shore in sec. 4 and out to the end of the point in the S. W. ¼ of N. W. ¼ sec. 3, T. 64-7. On this point the pyroxene granite is seen in contact with this chlorite-biotite rock. A piece of the granite was seen, apparently surrounded by the other rock, but no positive evidence as to the relative age of the two could be seen, although the granite seems to be the older. The contact between the two rocks is a pretty well defined line. No. 553 shows the granite from this place; No. 554 the contact; and No. 555 the chlorite-biotite rock, which here holds a small amount of red feldspar, not seen in it elsewhere. On the north side of this point the granite occurs in a large exposure. It is here finer grained than No. 553, and is represented by No. 556. It varies much, especially towards the west end of the exposure, and becomes darker colored and much finer grained, as is shown by No. 557. The chlorite-biotite rock is again seen at the extreme eastern edge of this point and in one place it is in contact with a small piece of the granite. On the north side of this point, near its base, is an uninterrupted exposure extending along the shore for thirty-five feet, and just east of it are other small exposures within a few feet of each other. Here there is a gradual change from a gray aphanitic rock much resembling some of the gray slate of this vicinity to the pyroxene granite, as represented by Nos. 556 and 557. The gray rock, however, shows no evidence of lamination or any definite slaty cleavage; it may be a very fine grained facies of the granite in which the porphyritic feldspars are lacking. As yet these specimens have not been studied microscopally. Nos. 601 to 615 represent this gradation; No. 601 is the gray rock; the specimens up to No. 612 were taken within distances of one to four feet going eastward from No. 601; Nos. 613, 614 and 615 occurred thirty to forty feet further east, and these pass into the facies of the granite represented by Nos. 556 and 557. From this point northward the rest of the west shore in sec. 4, T. 64–7, and the north shore in sec. 34, T. 65–7, were explored carefully for any trace of the pyroxene granite, but none was found.

The little island just northeast of the end of this point (S. W. ¼ N. W. ¼ sec. 3, T. 64–7,) has on its western end numerous angular fragments of dark aphanitic rock holding red feldspar crystals (No. 558). And on the south side of the island, and in some places on its west end, are also fragments of a dark conchoidally breaking argillyte (No. 559) very similar to No. 552 described above. These two rocks (Nos. 558 and 559) are undoubtedly in place just below the angular blocks. On the east end of the island is a small outcrop of a gray rock which has a fine grained granitic ground-mass holding very small porphyritic crystals of pyroxene and large ones of feldspar. This rock is numbered 560. It is the same rock as is found in considerable amount farther east on the shores and islands of this lake. This rock is found to be a very fine grained *pyroxene granite porphyry*, and will be spoken of in this report as such, or simply as *granite porphyry*. This rock was seen in sharp contact, in a loose block, with the black argillyte. Rocks Nos. 558 and 560 are probably different facies of the same rock; apparently intermediate stages were seen.

The island nearest the end of this point has a good sized bluff of granite near its centre; this is well represented by the specimens described above, Nos. 556 and 557; it occupies the north half of the island. On the south shore is a dark rock with a green chloritic ground-mass in which are blotches of hornblende (No. 561); this seems to pass into a fine grained condition (No. 562) which is seen in sharp contact with the granite, but the relative ages of the two was not determined.

On the east shore of the little bay which lies at the southern side of the base of this point (S. W. ¼ N. W. ¼ sec. 3, T. 64–7,) is a slaty rock which, however, appears perfectly massive, except in weathered fragments where the slaty structure is brought out; no evidence of lamination was seen. At the northeast corner of this bay the slate is a black almost conchoidally breaking argillyte. Here on the weathered surfaces appears a fine lamination which strikes N. 20° E. and dips 75° toward the east. This rock is similar to No. 559, and it is peculiarly spotted by small gray to whitish blotches. These spots are not very numerous, but are often quite distinct; they are of all sizes up to those five mm. in diameter. No. 563 shows this spotted slate. Going west along the north shore of this little bay the black slaty rock is seen in several low outcrops; it is cut by small veins which stand out above the surface of the rock on weathered surfaces. Near the west end of the bay, in the S. E. ¼ N. W. ¼ sec. 4, T. 64–7, is a soft green schist (No. 564), which strikes northeast and dips 70° toward the northwest. This rock shows no lamination, but has a very pronounced schistose structure. Just west of this, near the northwest corner of the bay, is the green chlorite-biotite rock.

The large island in the E. ½ of sec. 3, T. 64–7, and the three smaller islands that lie just west and northwest of it are composed of the pyroxene granite. The rock varies somewhat in grain and in the amount of the pyroxene constituent present. No. 565, from the east end of the smallest of the three smaller islands, shows about the normal condition of this granite. No. 566 is a coarser grained facies from the southern end of the largest and most northerly of the three smaller islands. On the north shore of the large island, near its western end the granite varies from a fine grained condition, like No. 565, to a dark, fine grained facies (No. 567). At this place was also seen a small band or inclusion of a gray and black slaty rock (No. 568) in the granite.

On the east shore of the bay in the N. E. ¼ of N. W. ¼ sec. 11, T. 64–7, is a fine grained green chloritic rock (No. 569). This is roughly schistose in places and at the water's edge is seen to be conglomeritic. The pebbles are rounded and do not appear dis tinct on fresh surfaces, but where the rock is waterworn they are quite prominent. From this exposure a ridge runs eastward and a short distance from the shore the rock is distinctly laminated, as shown by No. 570. This exposure may have been a little displaced, but to all appearances it has not been. The dip is about vertical and the strike is N. 80° W. Just north of this and also in the S. W. ¼ of S. E. ¼ sec. 2, T. 64-7, are hills of fine grained pyroxene granite (No. 571). In the granite are a few dark inclusions of irregular outline; No. 572 is from one of these. The same fine grained pyroxene granite is seen in several places along the shore of the bay which lies in the E. ½ of S. W. ¼ sec. 2, T. 64-7, and the high hills just east of this bay are apparently composed of the same rock. These hills were visited in the E. ½ of S. W. ¼ of S. E. ¼ and N. E. ¼ of N. W. ¼ of S. E. ¼ sec. 2, and were found to be made of the same granite, well represented by No. 571. Syenite is also seen on the west side of the northward extension of this bay and on the point in the N. E. ¼ of S W. ¼ sec. 2. No other outcrops are seen northward along the shore in sec. 2, but on the point in the S. W. ¼ of S. E. ¼ sec. 35, T. 65-7 is a low exposure of a very fine grained facies of the granite (No. 576).

There is an island in the N. W. ¼ of N. W. ¼ sec. 2, T. 64-7, which is made up mostly of the pyroxene granite (No. 573); this varies somewhat in grain, but none was seen as fine as No. 571; it is noticeably porphyritic with reddish feldspars. On the west side of the island near the north end is a rock with a green aphanitic ground-mass in which are numerous glistening biotite scales,—No. 574. This rock is seen in contact with the granite; the contact line is sharp and distinct. The green rock is cut by many vein-like forms of a purple rock which is seen to be part of the granite, but they were not, actually, traced into the granite. No. 575 shows this rock in contact with the green rock. On a microscopic examination No. 575 is seen to be part of the granite. The two rocks were not apparently changed near the contact. Many angular and rounded fragments of the green rock are seen in the granite and a few fragments, or what appear to be such, of the latter, are seen in the green rock. The evidence of this exposure points to the more recent age of the granite.

About the foot of the shallow bay in the S. E. ¼ of S. E. ¼ sec. 35, T. 65-7, is an outcrop of a very light colored facies of the pyroxene granite porphyry (No. 577). Down at the water's edge this rock held a piece of a dark chloritic rock, similar to No. 574; this is probably an inclusion in the porphyry, but not enough was exposed to show this positively. A short distance east of this place a purplish condition of the granite porphyry is seen (No. 578). In fragments from the side of this exposure there is a distinct arrangement of the porphyritic feldspar crystals in approximately parallel position. This could not be seen very well in the rock *in situ*, but at one favorable place this arrangement was in planes, or apparently so, running about east and west and dipping N. about 45°. That this direction is constant in this place is not clearly shown. The rock contains few pyroxene prisms, but a few were seen one-eighth to one-quarter of an inch in length. A short distance further east, in the S. W. ¼ of S. W. ¼ sec. 36, T. 65–7, is an outcrop of fine grained pyroxene granite, similar to No. 571.

On the main shore, just south of the west end of Stacy island (the island just off the shore and near the center of the N. ½ of S. W. ¼ sec. 36), a few feet from the water, is a low knoll of the granite porphyry well represented by No. 578, although here the porphyritic crystals are not quite as abundant as in that number. A few rods back from this knoll a high, precipitous hill rises, probably 200 feet above the lake; this hill extends along the lake shore in the S. ½ of sec. 36, T. 65–7. Mr. Wood went to the top of the hill, but found it to be all made of the same rock as is seen at its base,—a fine grained facies of the pyroxene granite (No. 579). This granite and the granite porphyry were traced within 150 feet of each other, but no nearer. Nothing was seen to indicate a gradation between the two rocks.

The granite porphyry occurs on the south shore of the lake in several places in the S. ½ of N. E. ¼ sec. 36, T. 65–7 and S. W. ¼ N. W. ¼ sec. 31, T. 65–6. Careful search was made for any general direction for the long axes of the feldspar crystals in this porphyry, but none could be found. In the S. W. ¼ of N. E. ¼ sec. 36, T. 65–7, just back from the shore, is a cliff about eighty feet high. The lower half of this is composed of the granite porphyry, and the upper half of a green conglomerate similar to that described half a mile southwest from this place on Stacy island.* The exact line of contact between the two rocks was seen in only one place, but the two were traced within two to five feet of each other for some distance along the face of the cliff. The contact line remains nearly horizontal for some distance and then suddenly runs upward. There seemed to be no blending of the two rocks at their junction, but the porphyry was roughly schistose and softer than usual, while the conglomerate seemed harder and more crystalline. No. 580 represents the porphyry and No. 581 the conglomerate at the contact; these two specimens were taken within two inches of each other. No. 582 shows the porphyry about four feet from the

* 15th (1886) Annual Report, pp. 150-151.

conglomerate. The dip of the conglomerate seemed to be toward the south, but nothing definite could be determined about this. The southwest side of Stacy island has quite an extensive exposure of the granite porphyry, but the junction of this and the conglomerate and the diabase on the island was not found. The porphyry here is rather coarser grained than usual and carries considerable biotite,—No. 583. The island just west of this shows many outcrops of the porphyry along its shores, in fact, this was the only rock seen on the island.

On the northwest end of the little point in the S. W. ¼ of N. W. ¼ sec. 31, T. 65–6 (south side of the lake) there is a dark, medium grained diabase. And on the northeast corner of this point is a low outcrop of a fine grained, gray, apparently holocrystalline rock; the ground-mass is grayish and in it are small, black needles, probably of hornblende, and a few scattered, rather irregularly outlined, feldspar individuals. There are also a few rounded pebbles, up to those two inches in diameter, scattered through the rock. The specimens collected (No. 593) show some of the pebble forms. Some of these pebbles are seen to be sub-angular, but most of them are rounded. They seem to be scattered irregularly through the rock and lie in no definite planes or layers; there is nothing in the rock to show any sedimentary lamination or bedding; it appears perfectly massive. This rock is seen in several outcrops in the N. E. ¼ of S. W. ¼ sec. 31, T. 65–6, and the shore is here usually lined with fragments of it. In the eastern part of this one-sixteenth section is quite an extensive exposure a short distance back from the shore. Here the pebbles, which have been steadily increasing in abundance eastward from the first mentioned outcrop, are very numerous. It would be almost impossibe to find any surface a foot square in the rock at this place which would not contain one or more pebbles, and many areas of this size would include as many as twenty. The rock is here represented by No. 594 and pebbles from it by 594A. This rock extends along the shore in a few outcrops nearly to the east line of sec. 31. The pebbles grow less abundant on going east from No. 594. No. 595 shows a more highly crystalline condition of this rock from the S. E. ¼ N. E. ¼ sec. 31. The noticeable features of this rock are its sharply outlined, rounded and sub-angular pebbles and the few scattering, white, apparently porphyritic, feldspar crystals, sometimes a quarter of an inch in length. No bedding, lamination or definite arrangement of the pebbles could be seen in the rock. It seems that this rock is a metorophosed conglomerate, and it strongly reminds one of certain facies of the Ogishke conglomerate. In one place in the last mentioned one-sixteenth section there is a rough, parallel jointage in the rock; these joints dip southward about 25°.

In the eastern side of the above $\frac{1}{16}$ section is a low bluff of fine grained diabase and granite porphyry. The two rocks are seen in contact; the line between them is sharp and about vertical, but quite irregular, angles of each projecting into the other. There was nothing seen to determine the relative ages of the two rocks. No. 596 shows the granite porphyry about three feet from the contact; No. 597 is the same at the contact. No. 598 is the diabase at the contact, and No. 599 is the same six feet from the contact. No. 600 shows a coarser grained condition of the same also six feet from the contact. These last three grade into each other. It may possibly be that the specimens Nos. 598 and 599 are altered black slate, but this cannot be told macroscopically, and to all appearances they are continuous with and not to be separated from No. 600, which is a distinct diabase. The south shore of the lake, from this place to its extreme eastern end, was examined carefully for other outcrops of the granite porphyry, but none were found.

On the north shore of the lake, in the W. ½ of N. E. ¼ of N. W. ¼ sec. 31, T. 65-6, there is an exposure of the granite porphyry which has above it, and on both sides of it at the water's edge, a green rock seemingly the same as the green schists found a short distance to the west. Here the green rock appears perfectly massive, except in a few places, where there is a very indistinct lamination, which is not sufficiently developed to enable one to determine the strike and dip. No. 616 is the porphyry thirty feet from the green rock; the porphyry holds a few small rounded areas of greenish material with rather indistinct outlines; one of these is shown in the specimen of the porphyry collected here (No. 616). The two rocks were traced within two feet of each other, but the exact contact was not seen. Nearest to the green rock the porphyry seemed to be finer grained (No. 617). No. 618 shows the green rock within thirty inches of No. 617, and the ill-defined reddish blotches which are seen in the green rock near the porphyry. No. 619 is the green rock about fifty feet from the porphyry. On the east side of this exposure the two rocks are seen close together. Here the porphyry held pieces of greenish material (No. 620) up to ten inches across; there was no very sharp line between these and the porphyry, but owing to the moss and lichen covered condition of the rock these green areas could not be well outlined. Search was here made for some general direction for the long axes of the feldspar crystals of the porphyry, but none could be found.

With the exception of a small area of fissile green schist on its western side, the point on which are the corners of secs. 29, 30, 31 and 32, T. 65–6, is made entirely of the granite porphyry. It here reaches its most typical development. This is the first exposure of the porphyry on the north side of the lake east of that described just above. Green slate is seen just north of this point, but between this and the porphyry there are no exposures; however, at the nearest point to these green slates the porphyry is finer grained than usual, as is shown by No. 621. A number of the largest pyroxene crystals were collected from the rock on this point, and also some of the feldspars, which showed dark centres. Very few inclusions were found here; probably not more than thirty were seen; these varied from half an inch to ten inches in diameter. They are mostly greenish in color and are not very sharply outlined, as is shown by No. 621A. No. 621B is from an irregularly but sharply outlined piece ten inches across. No. 621C is from an oblong piece, ten by five inches in area; around this piece there is distinct evidence of flowage, as is shown by the arrangement of the porphyritic feldspars.

Just south of the corner of the bay in the S. E. ¼ of S. W. ¼ sec. 36, T. 65–7, is a large ridge of pyroxene granite, spoken of before. (See No. 579 and accompanying description.) The eastern end of this ridge is made of a fine grained, flesh-colored rock (No. 622), a condition of the slates of the region, but no structural planes can be seen in it. This is in contact with the granite; the line between the two could not be clearly seen, but it seemed to run about vertical. No. 623 is the granite about thirty feet from the contact. No. 624 is the same at the contact, and No. 625 shows the slate at the contact. The last two specimens were taken within an inch of each other. This slate continues eastward and northeastward for about two hundred yards; it varies somewhat, as shown by Nos. 626 and 627. The relation between this rock and the dark, hard slates on the shore just north of this could not be determined.

In the N. E. ¼ of N. E. ¼ sec. 36, T. 65–7, where the granite porphyry overlies the greenstone,* two specimens of the former were collected. No. 628 is fine grained and was taken just at the contact of the two rocks; No. 629 is coarser grained, taken fifty feet from the contact. Careful search was made for some general direction of the long axes of the porphyritic feldspars, but their directions varied much; however, there were more places in which they ran about east and west than where they ran in other directions.

*This place has been described and figured in the 15th (1886) Annual Report, pp. 154, 367.

South from Kekequabic lake in sec. 31, T. 65–6, and secs. 6 and 7, T. 64–6.

A trip was made south from the lake through the S. E. ¼ of sec. 31, and through the E. ½ of sec. 6 to the little pond on the south line of this section east of the quarter post. From this pond I went through sec. 7 to the lake which lies in the S. ½ of this section and the N. ½ of sec. 18. The description will begin at Kekequabic lake and go southward over the high hill in the N. E. ¼ of sec. 6 to the lake just mentioned.

At the shore, in the S. W. ¼ N. E. ¼ sec. 31, the conglomerate, already described under Nos. 593, 594 and 595, is seen; this continues southward for at least an eighth of a mile. The pebbles become less numerous, but no less sharply outlined, on going away from the lake, and the rock becomes more coarsely crystalline and holds more of the apparently porphyritic white feldspars,—No. 630. No evidence of bedding was seen in this conglomerate. Beyond this and within fifty yards of the last exposure of conglomerate there are outcrops of slate. This slate varies from a dark almost black argillyte to one that is quite light gray. The lamination of the slate was twisted in some places, but as a rule this coincided with the slaty cleavage. The dip and strike were taken in many places before reaching the top of the large hill, whose summit lies in the N. E. ¼ of sec. 6; the dip was vertical and the strike varied from N. 35° E. to N. 55° E. The slate was intimately interbedded with a dark gray to greenish grit, but the lines between the two rocks were quite distinct. The bands of each varied from those a fourth of an inch across to those that were fifty feet or more in width. The grit held angular fragments of the slate and bands of the slate that were abruptly cut off; there were also places where bands of the slate were faulted and the grit existed between the faulted and broken ends of the slate bands. This grit makes up about half of the exposures to the hill top, but no exposure was composed entirely of this or of the slate alone. No. 631 is the black slate; No. 632 the grit, and No. 633 shows, as well as a hand specimen can, the intimate interbanding of the two. At the top of the high hill the grit is coarser grained than usual, as is shown by No. 634. The strike continues to be northeasterly until coming into the S. E. ¼ sec. 6, where it changes to N. 20° E., and a short distance farther south to direct north and south; the dip still remains vertical. This north and south strike continues to the pond which lies on the south line of section 6 east of the quarter post. No. 635 shows another condition of the grit resembling graywacke from just north of this pond. In this there is seen indistinct lamination, but the other specimens of the rock do not show it; the rock (grit) elsewhere appears perfectly massive except for its interbanding with the slates. South of this pond the strike again swings round to northeast and the dip remains vertical.

About a quarter of a mile south of this pond is an outcrop of a porphyritic rock which is probably the same as the granite porphyry of Kekequabic lake. About seventy-five feet of this rock was exposed, the slates occurring both north and south of it within less than a hundred feet. The porphyry is numbered 636. The weathered surfaces of it show a rough schistose structure which runs N. 35° E. and stands vertical; however, this structure is not seen on freshly broken surfaces. The feldspar crystals are often arranged with their long axes parallel to the direction of the schistosity. The northeast strike of the slate and grit continues as far as they were seen,—*i. e.* almost to the lake which lies in the S. ½ of sec. 7 and the N. ½ of sec 18. We struck this lake about the centre of its north shore in the S. E. ¼ S. W. ¼ sec. 7. A short distance before reaching this lake the slate disappears and the grit, similar to Nos. 632 and 635, both of which facies here often show fine lamination on weathered surfaces, becomes in places conglomeritic and harder (No. 637). The pebbles are mostly rounded, some few are subangular, and they are chiefly of slate and a reddish granite porphyry, a pebble of which is shown in the specimen collected. This conglomerate shows no signs of lamination or schistosity. A short distance further south and almost at the lake shore is a more crystalline conglomerate holding pebbles of the same or similar reddish granite porphyry, and also of a fine grained red granite or syenite which resembles the pyroxene granite already mentioned so often. This conglomerate is shown by No. 638. In this rock, and also in No. 637, the pebbles varied from quite small ones up to those eight inches in diameter, but most of them were one to three inches across. In some places the pebbles were quite numerous and in others there were but a few to be seen. No definite arrangement of the pebbles in planes nor any elongation of them in one direction was seen.

The eastern half of the north shore of this lake (lying in the S. ½ of sec. 7 and N. ½ sec. 18) has some outcrops of the conglomerate represented by No. 638. On the east shore of this lake there are no outcrops until coming nearly to the south line of sec. 7. A short distance north of this line the ordinary gabbro of the region is seen. It is somewhat finer grained here than is usual, as is shown by No. 639. On going south along the shore a little farther the gabbro becomes coarser, similar to the usual coarse grained gabbro of the Mesabi range.

The object of this trip south from Kekequabic lake was to find how far south the conglomerate, described under Nos. 593, 594 and 596, extended, and to look for an eastern extension of the pyroxene granite which is seen in the E. ½ of sec. 2, T. 64–7. However, no granite nor any trace of it was seen. Numerous exposures of rock were seen, and there was probably no distance of a hundred yards where outcrops were wanting, until just before coming to the small lake mentioned above. And here there were not enough exposures to satisfactorily trace the conglomerate represented by No. 637 into that represented by No. 638. Still everything, except the more crystalline condition of No. 638, seems to point to their identity. The high hill passed over just south of Kekequabic lake seems to be at least 350 feet above the lake. This was thought to be the case on comparing it with Mallman's peak, which is 250 feet above the lake.*

Small lake in the S. E. ¼ of sec. 36, T. 65–7.

On the hill just north of the east end of this lake is a fine grained diabasic rock (No. 584). In places this is massive and again slaty. The strike of the slaty structure is N. 80° W., and the dip is towards the north 65° to 70°. Toward the base of this hill is a gray porphyritic rock with indistinct white feldspars in it (No. 585). This was seen in contact with the diabase rock and is found both above and below it, but the exact contact was seen in but one place where the two rocks were separated by a sharp line. Farther up on the hill the porphyry is represented by No. 586, which much resembles the pyroxene granite found a mile to the west. There were some apparently intermediate stages between Nos. 586 and 585, but no continuous exposures connected them. No. 587 represents another facies seen in contact with the slaty diabase (No. 584); this was apparently a stringer of the porphyry in the diabase. The same porphyry is again seen in a hill north of the centre of the lake and is in sharp contact with the slaty diabase. The latter is confined mostly to the upper part of the hill while the porphyry occurs near the water. No. 588 represents this porphyry from the north side of the lake.

At the northwest corner of the lake black argillytes are seen. They show no distinct bedding. On the west side of the lake near the north end is an exposure of the fine grained pyroxene granite (No. 589). And a short distance farther south is a hill whose base is made of the same granite, but of somewhat coarser grain (No. 590).

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*The lake described above as having gabbro on its south shore is in the N. ½ of N. E. ¼, T. 64-7, and not in secs. 7 and 8, T. 64-6.

There is only one outcrop on the south side of the lake; this is a fine grained granite porphyry (No. 591) similar to that described from Kekequabic lake as pyroxene granite porphyry. I looked carefully for a definite arrangement of the feldspar crystals here, but none could be seen. Those, however, as seen in many places on Kekequabic lake, seemed to show evidence of a flowage in the rock before solidifying. On the east shore of the lake is a porphyry similar to No. 588. Here are a few irregularly shaped inclusions in the porphyry; No. 592 is from one of these. No rock intermediate between Nos. 588 and 591 was seen.

East of Kekequabic lake in secs. 28 and 29, T. 65–6.

A portage runs eastward from the most easterly point of Kekequabic lake to a small lake in the W. ½ of S. W. ¼ sec. 28. On this portage the hard black and gray argillytes, found just to the west, are also seen. The strike and dip were taken in one place; the former was N. 20° E. and the latter about vertical. On the east end of the portage is an aphanitic dark gray rock holding white feldspar crystals (No. 640); it also holds a few rounded pebble-like forms of rock similar to itself. On this portage and a short distance from the shore of the small lake this rock becomes softer and schistose and is not so distinctly porphyritic,—No. 641. It holds many rounded and subangular pebbles of fine grained granite, gray argillyte and a rock similar to No. 640. These pebbles present all the appearances of being water-worn and rounded; they are in places arranged in rough planes that run N. 25° E. and stand vertical. On the east side of the lake is an exposure of rock similar to No. 540, and on the same side nearer the north end is a large exposure of a peculiar gray granitic rock holding many small feldspars (No. 642). This is probably a metamorphosed grit. Back from the shore a little ways this rock becomes finer grained and darker in color, and is seen in sharp contact with a fine grained diabase (No. 643), which is probably in the form of a dyke. No. 644 shows this granitic rock at the contact, but this may be part of the rock similar to No. 641. North of this and extending to the portage is rock similar to No. 641; it is decidedly conglomeritic. I noticed a few scattered greenish inclusions or pebbles in No. 542.

From this lake is a portage running north for about fifty yards to another small lake. According to the plat this ought to be Zeta lake, but very probably the bay that is represented at the southwest corner of Zeta lake is separate from that lake. On the portage from this small lake to Zeta lake the argillaceous slates again occur; they here strike N. 20° E. and dip 80° to 85° towards S. 20° E.

D. SAGANAGA LAKE AREA.

The work on this area was confined mostly to its southwestern and western borders. The limits of the granite were traced pretty accurately from the east side of sec. 15, T. 65–5, west and northwest to the E. ½ of sec. 24, T. 66–6, where the western line of the granite crosses the international boundary.

West Sea Gull lake.

The southwest corner of the point that is crossed by the south line of sec. 8, T. 65–5, is composed of a coarse grained gray granite (No. 645). Just east of this the rock is much decayed and very schistose, as shown by No. 646. This is undoubtedly only a decayed portion of the granite, and the two are not separated by any line. East of this the granite, like No. 645, is again seen, and it also outcrops on the north side of a little island just south of this point. There are no outcrops at the end of the little bay in the N. W. ¼ of N. E. ¼ sec. 17, but a short distance to the east are rounded knolls of granite. Here the rock is darker colored and carries less quartz than most of the granite on the lake; this facies is shown by No. 647. On the south shore of this bay and near its eastern end is a low outcrop of the ordinary granite, and a short distance to the west are large, bare, rounded domes of a dark green slaty rock which appears massive in places. At the water's edge the granite was seen in contact with the slaty rock, and it also held angular fragments of the same. The granite at the contact was coarse grained and similar to No. 645. The green slaty rock is represented by No. 648. The rounded domes of the green slate are cut by numerous branching veins or dykes of granite, which is coarse grained and similar to No. 645; it is shown by No. 649. These veins are of all sizes up to those twenty feet in width; the sides of them are not finer grained than the centres. A second set of granite veins, few in number, also cut the green rock and the coarse granite veins; this second series is composed of a fine grained reddish granite (No. 650), and these veins are of finer grain near their edges than at the centre. This same rock was seen cutting the ordinary granite on the north side of the bay. On the west shore of the bay in the N. E. ¼ of N. W. ¼ sec. 17, is a massive aphanitic greenstone (No. 651). On going north along this shore this rock seems to pass into a massive diabasic rock, which comes in contact with the granite, which holds pieces of the diabase and sends stringers into it. No. 652 is the diabase from the granite contact. Granite occurs in a few outcrops along the shore in the

N. W. $\frac{1}{4}$ of the last mentioned $\frac{1}{16}$ section, but before coming to the north line of sec. 17 the aphanitic greenstone again appears. This is seen where this section line cuts the shore, and also in several places in the S. W. $\frac{1}{4}$ of S. W $\frac{1}{4}$ sec. 8, T. 65–5. It varies from a rock like No. 651 to one that is harder and gray to greenish in color and resembles a very compact and fine grained graywacke (No. 653). Granite is again seen on the blunt point which is touched by the west line of sec. 8 south of the quarter post.

On the shore in the N. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 8, T. 65–5, and also at the west side of the same $\frac{1}{64}$ section, where the west line of the section crosses the shore, are outcrops of conglomerate. The matrix of the conglomerate is gray to greenish in color, quite coarse and full of quartz grains. In this matrix are many pebbles, among which red jaspilyte is conspicuous. No. 654 shows this conglomerate. It is part of the Ogishke conglomerate which is seen in so extensive development to the southwest on Ogishke Muncie lake. There is nothing at this place to definitely show the dip and strike˙ This conglomerate rises in a ridge just west of the shore, and in places the matrix is entirely free from pebbles and quite schistose. This schistose structure runs N. 35° E and stands vertical. A short distance further west, but separated from the conglomerate by low ground where there are no exposures, is a ridge of granite running northeast and southwest. This granite does not differ materially from that found at the lake shore; it is represented by No. 655. This granite ridge is about 100 feet wide; beyond it the conglomerate again appears and extends westward for at least a quarter of a mile from the lake. Beyond this is low ground with no exposures. On this last ridge the granite and conglomerate are seen in contact. The granite runs in bands in the conglomerate, thus giving the appearance of "interbedded" granite and conglomerate. These bands of granite vary from one to thirty feet in width, and about a dozen of them were seen. The contact lines between the granite and conglomerate are distinct, but rather irregular; however, they do not run across the strike of the conglomerate for more than six inches at a time. In some places it is rather difficult to tell which rock is under foot, but when the two rocks are seen together they are easily distinguished. The granite does not vary in grain, especially at the contact, but is of a uniformly coarse grain. No. 656 shows the conglomerate at the contact, and No. 657 is the granite from the same place. No. 657A is the granite four feet from the contact. No. 658 shows a more crystalline condition of the conglomerate matrix. Interbedded with the conglomerate is a small amount of argillaceous slate. The matrix varies from that shown by No. 654 to a fine grained green facies shown by No. 659. Bands of the matrix free from pebbles are common, and in such cases the rock is occasionally laminated. The strike at a place 100 yards east of the granite bands is N. 10° E., but near these bands it varies from N. 10° W. to exact N. and S.; the dip in all cases is vertical.

The granite is again seen on the northeastern side of the round point in the S. W. ¼ of S. W. ¼ of N. W. ¼ sec. 8, and also on the point just east of this. At the southwest corner of the bay, which runs into the S. E. ¼ of N. E. ¼ sec. 7, is a green rock similar to No. 651; it is cut by the granite and is also seen in sharp contact with a fine grained purplish porphyritic rock, which seems to be in the form of a dyke, although this could not be definitely seen. This porphyritic rock is the same as Nos. 660 and 661. On the northwest shore of this bay is a ridge of granite. Granite is also seen in several places on the north shore of the bay, and in one place is in contact with a purplish rock, which is much decayed and resembles a porphyrite. The line between this rock and the granite is very distinct, and the former seems to cut the latter in the form of a dyke. The granite is unchanged at the contact, but the other rock here seems to be finer grained than usual. No. 660 shows this porphyrite (?) from the contact, and No. 661 is the same twenty feet from the granite.

Along the west shore of the lake the granite is seen in several outcrops in the N. E. ¼ of N. W. ¼ sec. 8 and S. W. ¼ sec. 5. Near the end of the point in the N. E. ¼ S. W. ¼ sec. 8 is a diabase dyke in the granite. This dyke is also seen in the bay on the west of this point. No. 662 represents the diabase of this dyke; it is finer grained near the edge. The same dyke is also seen on the west and east sides of the end of the point in the N. ½ of S. E. ¼ sec. 5. It has an east and west direction and varies from thirty to forty feet in width. On going west from the southwest side of the bay in the N. W. ¼ S. W. ¼ sec. 5 the same dyke is again seen in contact with the granite, and both rocks form a ridge that runs west from the lake for an eighth of a mile. Beyond this (west) is a swamp with no exposures, and then not less than a quarter of a mile from the lake is a ridge running northeast and southwest. This ridge is made of a fine grained laminated slate (No. 663), which varies from a gray to a green argillyte. The lamination and slaty structure coincide and strike N. 15° E. and stand vertical. South of this ridge a few rods is another composed of a green to gray grit (No. 664), which is like the matrix of the conglomerate above described—Nos. 654 and 659. No pebbles are visible in this rock, nor is there any lamination, but in it are a few narrow bands of slate similar to No. 663. These stand vertical and strike N. 30° E.

The granite is seen in several outcrops on the shores of the bay in the centre of the N. ½ sec. 5, and also on the point on the east side of this bay. The east shore of the point in the S. E. ¼ S. E. ¼ sec. 8 was also examined and found to be composed of granite.

The granite of West Sea Gull lake varies considerably in grain and also in the amount of chlorite or hornblende present. The fresh rock is a hornblende granite, but in many places this has been completely changed to chlorite. There seem to be two feldspars present,—a yellow and a pink one. No. 675 is as fresh as any of the granite of this lake and may be taken as a typical example of it. This specimen was taken from the east side of an island in the S. W. ¼ S. E. ¼ sec. 8.

Small lake in the N. W. ¼ of N. W. ¼ of sec. 8, T. 65–5.

This lake is not shown on the government plat. On the east and north shores of the lake no rock exposures were seen. On the west shore near the north end is a ridge composed of the Ogishke conglomerate similar in every respect to that described from West Sea Gull lake in this same section. The conglomerate was traced west over the ridge for a short distance; the pebbles became fewer in number and the rock in places was slaty, almost exactly like No. 663. At one place the slaty rock was crumpled as if it had been pressed in a direction parallel to the strike; this was seen for only a short distance. In places the matrix showed a lamination and again it was broken into long flags. The lamination, the long direction of the flags and the banding and slaty cleavage of the slaty areas were all parallel and stood vertical; the dip was N. 15° E.

On the west side of the lake near the south end the granite is seen at the shore. It is chloritic and holds large quartz grains and reddish feldspars,—No. 665. The conglomerate is seen not more than an eighth of a mile west of the shore, but the junction of it and the granite was not found. What is said about the conglomerate in the last paragraph will apply equally well here, except that the strike is N. 20° E. Back from the shore the granite becomes schistose in places; this schistose structure stands vertical and strikes N. 20° E. Here the rock is similar to No. 665, excepting for this schistosity. A little further west the granite has changed to a yellow rock holding large quartz grains,—No. 666.

This and the conglomerate were separated by several yards of soil where there was but one exposure. This exposure is within twenty feet of the conglomerate; the rock is shown by No. 667, which appears to be a more decayed part of the granite. On the west side of this exposure there seems to be, although this could not be distinctly made out, an interbanding of rock similar to No. 667 and a rock similar to this, but finer grained and greener. It is, however, possible that this last is but a less weathered condition of the former, and that they are both decayed conditions of the granite. The two rocks (if there are two) are shown by No. 668. Twenty feet west of this is the conglomerate with the matrix like No. 664.

No other rock exposures occur on this lake, but between its southeast corner and West Sea Gull lake is a knoll of the ordinary granite.

Small lake in the S. ½ of N. W. ¼ of sec. 16, T. 65-5.

From the foot of the bay of West Sea Gull lake, in which are the corners of secs. 8, 9, 16 and 17, a portage leads south to this small lake. The ordinary granite is seen in two or three places on and near this portage trail. Granite also occurs where the west line of sec. 16 cuts the north shore of the little bay that projects into the S. E. ¼ N. E. ¼ sec. 17, and also a short distance on either side of this line. On the west side of this little bay is a rounded hill, the northern part of which is composed of granite and the southern part of a hardened mica-schist (No. 669), which in places looks almost like a fine diabase. The granite is in sharp contact with this rock and cuts it with many vein-like forms. These veins are like the granite elsewhere and differ only in being finer grained in places. The whole exposure much resembles that seen in the N. W. ¼ N. E. ¼ sec. 17, West Sea Gull lake, and described under Nos. 647 to 650.

Back from the shore at the southwest corner of this little bay the same hardened mica-schist is seen, and it occurs again within a few feet of where the west line of sec. 16 cuts the south shore of this bay. Continuing along the southwestern shore of the lake more of the hardened mica-schist is seen; it varies to a green slaty rock and also to a green siliceous schist (No. 670). These were all cut by granite veins. On the south shore near the east end of the lake the granite is seen in a large outcrop. No outcrops were seen on the north shore of this lake excepting on the little point in the centre of the N. ½ S. W. ¼ N. W. ¼ sec. 16, and on the small island just off this point; here the rock was granite.

A small stream flows from this lake east to Sea Gull lake, in the S. E. ¼ N. W. ¼ sec. 16, and just south of the stream is a short portage between the two lakes. Granite occurs a few feet south of this portage.

Sea Gull lake.

The western shore of this lake, in sec. 16, T. 65–5, was rather carefully examined. There were many exposures, but these were all granite except on the south side of the bay in the N. E. ¼ S. E. ¼ sec. 16, and on the shore in the S. E. ¼ S. E. ¼ sec. 16. Here were outcrops of the same hardened mica-schist, varying to a green slaty rock, as described above. (Compare Nos. 669 and 670.)

Where the east line of sec. 16 cuts the south shore the granite is seen; here it is chloritic, rather decayed and somewhat schistose,—No. 671. Back from the shore a few rods and just west of the section line is a ridge of fine grained mica-schist, varying to chloritic schist. Farther south and on the north side of the east and west ridge, on which is the southeastern corner of sec. 16, is a small amount of fine grained granite (No. 672), probably a stringer from the main granite mass. The south side of this ridge is made up of a greenish mica-schist (No. 673); here the strike of the schistose structure is N. 70° W. and the dip is vertical. A short distance further south is another ridge of the same rock. No lamination was seen in this schist; it varies from a fine mica-schist, like No. 673, to rock similar to Nos. 651 and 670. On this last ridge is a small amount of a gray quartz porphyry in the schists; this appeared like a band running parallel with the schists;—No. 674.

Red Rock lake.

The outcrops on the west end of the bay that projects into the N. E. ¼ N. E. ¼ sec. 5, T. 65–5, are all granite. The bay which lies in the E. ½ N. E. ¼ sec. 32 and W. ½ N. W. ¼ sec. 33, T. 66-5, was examined. Here there are several outcrops of the ordinary granite.

On going north from West Sea Gull lake the granite becomes coarser in grain and more pink in color; it is hornblendic rather than chloritic. The quartz grains are especially large,—commonly a quarter of an inch across and sometimes as much as half an inch. Frequently one-third of the rock is made up of these large quartz grains.

Saganaga lake.

The coarse grained granite of Red Rock lake is found also on Saganaga lake. No. 686 from the point in the S. W. ¼ N. E. ¼ sec. [illegible], T. 66–5, fairly represents the granite of the main part of Saganaga lake. It is of decidedly coarse grain and of a pinkish color. The large irregular areas of quartz are very noticeable. The feldspar is pinkish and sometimes yellowish. Hornblende is present in considerable amount and is more or less changed to chlorite.

On the east end of a long island which lies just south of the point in the S. W. ¼ N. E. ¼ sec. 22, T. 66-5, is a a diabase dyke in the granite. This dyke is ten feet in width and has a north and south direction.

The island which lies mostly in the S. E. ¼ N. W. ¼ sec. 14, T. 66-5, is composed of a rock which varies from a fine grained syenite, made up almost completely of feldspar and very little hornblende, to a very coarse grained syenite of the same kind, and again to a rock composed mostly of feldspar and quartz, the latter in very large grains. In places it is porphyritic and has a reddish feldspathic ground-mass, in which are red feldspar crystals and sometimes quartz crystals. Disseminated through the rock in veins, and also in small grains, is a dark violet fluor spar. There are also some few small yellow grains in the rock which resemble talc. At the north side of this island is a large mass of white quartz which extends along the shore for over a hundred feet. This quartz mass was not seen in other places on the island. Mixed in with the quartz are fluor spar, yellow talc and red feldspar; the latter often shows cleavage faces eight or ten inches across. Small quartz crystals are seen in cavities; these crystals vary from colorless ones to those that are purple and even black. The rock from this island is represented by Nos. 676, 677 and 678.

In the N. E. ¼ N. W. ¼ sec. 14, T. 66-5, south side of the large island crossed by the north line of this section, the rock appears to be porphyritic with large quartzes; this is probably a decayed condition of the ordinary granite, the quartz being the only mineral unaltered. This rock is represented by Nos. 679 and 680. This rock is seen further east in the same $\frac{1}{16}$ section along the shore of the island. In the S. W. ¼ S. E. ¼ sec. 11, the ordinary granite occurs, and this is also seen in several places in the S. ½ of sec. 11, on the west shore of this large island.

All the outcrops seen along the shore in secs. 10 and 9, T. 66-5, were of the usual coarse grained granite. On the little island in the extreme southeast corner of sec. 8 the granite is seen in contact with a fine grained reddish aplite, which seems to be in the form of a dyke. The granite did not appear to be changed at the contact, but the other rock was finer grained. No. 682 shows this aplite ten feet from the contact, and No. 681 is the same from the contact. The shore was followed pretty closely in secs. 17, 18 and

19, T. 66–5, and many exposures were seen. No. 683, from the small island in the mouth of the bay which projects into the N. E. ¼ N. E. ¼ sec. 19, well represents the rock in sec. 17 and the S. E. ¼ of sec. 18. On the west side of the point in the extreme southeastern corner of N. E. ¼ S. E. ¼ sec. 18, the rock is decayed and the feldspar no longer shows distinct cleavage faces,—No. 684. Along the points in the S. W. ¼ S. E. ¼ sec. 18, the rock is much decayed and broken, but it still seems to be part of the granite,—No. 685. Just north of this, on the Canadian side and not more than two hundred feet distant, the ordinary granite similar to No. 683 is seen.

Outcrops of granite, similar to No. 683, continue along the east, south and west shores of the bay, which lies in the W. ½ of sec. 19, T. 66–5, almost to the west line of this section. At this line the rock is decayed, as shown by No. 687. On the Canadian side, just north of this, apparently the same rock is seen in a very schistose condition; it is also broken into well defined flagstones from one to four inches in thickness. These flagstones stand parallel to the schistosity, which strikes N. 40° W. and dips 70° towards the southwest. Similar rock, but with less schistose structure, is seen on the Minnesota side near this section line. The specimens collected from the Canadian side, Nos. 688 and 689, are not as full of large quartz grains as most of the rock here, but they are the soundest pieces that could be obtained. No. 689 is but a weathered condition of No. 688, as is shown by one of the specimens marked 689. It is not absolutely certain that this rock is part of the granite, but all indications seem to point that way. It is seen in many places in this vicinity and will be spoken of as altered granite.

Along the east shore of the bay in the S. E. ¼ sec. 24, T. 66–6, the rock is similar to Nos. 688 and 689, although sometimes of coarser grain. The rock along this shore in the E. ½ N. E. ¼ of the same quarter section is well represented by the last two numbers, by No. 690 and by Nos. 693 and 694, to be described below. In this subdivision of sec. 24 the altered granite is seen in contact with slates. There is, however, only a small mass of the slate in contact with this altered granite, but large amounts of it appear just to the south of this place. The contact is sharp and well defined. No. 691 shows the slate, which is a gray to a black argillyte No. 692 is the altered granite at the contact. These two specimens were taken within three inches of each other. The lamination and slaty cleavage of the slates are practically parallel, although the specimens collected (No. 691) do not show it. The strike is N. 34° W., and the dip is 68° towards S. 56° W. Rock No. 692 passes gradually into Nos. 693 and 694, and these three numbers were taken within a distance of four feet. No. 695 is from the slates about a foot from the contact; it is probably an interbedded band of graywacke. A small bed of slate, six inches wide, is seen with the altered granite on each side of it; this slate (No. 696) is very fissile and of a drab color, appearing considerably different from the ordinary slate (No. 691). The contact between the two rocks in both places is parallel to the strike of the slate, and the altered granite at the contact is finer grained, like Nos. 692 and 693, but grades off rapidly into a coarser grained facies, like No. 694. There seems to be no line between the ordinary granite (No. 683) and the rocks numbered 688, 689, 690, 692, 693 and 694, but there is a very evident line between the slates and these rocks. This altered granite is light gray or greenish gray in color when not weathered, but on weathering becomes brownish and seemingly coarser grained. This weathering in places does not extend more than a quarter of an inch into the rock, and in other places it goes as far as three inches from the surface; (compare specimens Nos. 688 and 689.)

On the east shore of the bay in the S. E. ¼ sec. 24, T. 66-6, just north of the little stream which flows from the lake to the south, the altered granite and slate are again seen in contact. Here there are three bands, three to six feet wide, of the altered granite, or what appears to be such, in the slate; the rock of these bands is shown by No. 727. This rock is sharply separated from the slates; in places it becomes coarse by the addition of large quartz grains. Just away from the contact are bands of grit in the slates like Nos. 729 and 730. Near the contact the slates hold bands, from one-half to six inches wide, of a fine grained graywacke (No. 728). It is hard to distinguish in some cases between the grit and the altered granite near the contact between this latter rock and the slates; almost the only difference to be seen is in the peculiar weathering, mentioned above, of the altered granite, but when this rock is in large masses it can be easily distinguished. The strike of the slates at this place varies from N. 90° W. to N. 20° W., and the dip from 70° to 80° towards the south. The lamination and slaty cleavage are parallel, but the rock has been much twisted. In some of the slaty beds there is a distinct schistose structure, which is different in direction from the slaty cleavage; this schistosity strikes from north and south to N. 5° E., and dips 70° to 80° towards the east. South of this little stream the dip and strike are rather constant; the latter is 75° towards S. 60° W., and the strike N. 30° W. Here was seen a bed of the grit, shown by No. 729, which held twisted fragments of slate. A little further south was another bed of the same, which had one side a very irregular line and one end was abruptly cut off by the slate. The grit from this place is shown by No. 730. The east shore of this bay was carefully examined south of the above mentioned stream. Many places were found where the grit held angular and twisted fragments of the slate. These fragments were in most cases entirely disconnected from the slàty bands and completely enclosed in the other rock. Nos. 731 and 732 are samples of the rock which held the slate fragments. In other places rock like this gradually passed into the slate. These bands of slates and grit continue along the south and west shore of this bay nearly to its north end, where the altered granite is again seen, at first holding beds of the slate. The phenomena here seem to be the same as described above. The strike of the slates was taken in several places; it averages N. 30° W., and the dip was 70° to 80° towards the southwest. However, there were some local variations in the strike; these varied from N. 20° W. to N. 45° W.

On the west shore of the bay in the W. ½ of sec. 19, T. 66–5, near the west line of this section, a series of specimens was collected representing the change from the granite to the so-called altered granite. These specimens were taken within a distance of fifteen feet; they are numbered from 717 to 725 inclusive. No. 720 seems to be only a decayed condition of No. 721. The exact order of the specimens to show the steps of this gradation is not certain, as the rock exposed was much broken into angular fragments, some of which were displaced a few inches. At this place the granite held one inclusion of a fine grained greenstone (No. 726).

At the portage from Saganaga west to Oak lake the altered granite is again seen, and also just west of this on the south shore of Oak lake. Here it holds small grains of white feldspar, No. 733. Farther west on the south shore the slates are seen holding bands of what appear to be the altered granite,—No. 734. Here the strike is N. 35° W., and the dip about 80° towards the southwest. The slate formation becomes well established before reaching the west end of Oak lake.

Wind lake and vicinity.

This lake lies in the E. ½ E. ½ sec. 25, T. 66–6, and the W. ½ W. ½ sec. 30, T. 66–5, with a small bay projecting into the S. W. ¼ S. W. ¼ sec. 19, T. 66–5. It is connected with Saganaga lake by a small stream which flows from the north end of this small bay into the bay of Saganaga lake, which lies in the S. E. ¼ of sec. 24, T. 66–6.

On the west side of Wind lake, in the S. E. ¼ N. E. ¼ sec. 25, the rock is composed of intergrading and interbedded bands of a greenish slate (No. 697), a graywacke (No. 698) and a grit (No. 699). The banding and slaty cleavage coincide in direction. The strike is almost exactly north and south, and the dip is 75° to 82° towards the west. Back from the shore a hundred yards is a bluff composed mostly of graywacke and grit; here the general strike is north and south, although there is much local twisting. On the surface of the rock the glacial striæ are very distinct and run very nearly south. A short distance further south on the west shore, in the N. E. ¼ S. E. ¼ sec. 25, the rock at the shore appears almost massive and is broken up into angular blocks. There are many narrow bands, one to four inches wide, of slate in the rock, which strike N. 15° W. and dip W. 82°. The slate is laminated in places and is almost exactly similar to No. 691. The main mass of the rock varies from a graywacke, like No. 698, to a grit, like No. 699, and is very hard and compact. Frequently the slaty bands grade into the other rock. This exposure is at the north entrance to the little bay in the same $\frac{1}{16}$ section. At the west end and at the south entrance to this bay are exposures of the same rock, but with fewer slaty bands. The strike is rather imperfectly shown, but seems to be N. 20° W. No. 700 is the graywacke from the west side of this bay; it somewhat resembles some facies of the altered granite found in contact with the slate on Saganaga lake. South of this bay no exposures are seen on the west shore, and there are none on the south shore. On the east shore near the south end of the lake, and back a few yards from the water, is a large exposure of the graywacke, in which the lamination is indistinct. On the southwest side of this exposure of graywacke is an area of black to gray slate about eight feet wide and twenty-five feet long, and exposed for six to seven feet in hight. The slaty cleavage is distinct, striking N. 50° W. and dipping 85° S.W. The lamination is extremely distinct; it has the same strike but dips 52° towards the northeast. This lamination fades out gradually into the graywacke. The slate is to all appearances the same as that seen on the west side of the lake. No. 701 shows in a small way this discordance of slaty cleavage and lamination. This exposure is in the S. E. ¼ S. W. ¼ S. W. ¼ sec. 30, T. 66–5.

Several outcrops of rock varying from slate to graywacke occur on the east shore in S. W. ¼ sec. 30. The slaty cleavage and the lamination, where seen, always coincide. The strike on the little point in the W. ½ N. W. ¼ S. W. ¼ sec. 30 is N. 5° W. and the dip is 70° W. The little island just off the point in the S. W. ¼ N.

W. ¼ sec. 30 has a fine exposure. Here the bedding of the graywacke is seen to good advantage; strike N. 22° W. and dip 70° towards S. 68° W. On the point at the west entrance to the bay in E. ½ S. W. ¼ N. W. ¼ sec. 30 the strike is N. 22° W. and the dip 70° to 76° towards S. 68° W. The shores of this bay are low and show no outcrops, but on the shore about 300 feet east of the last named point is an outcrop of altered granite like No. 689. It is roughly schistose; this structure is vertical and runs north and south. Less than fifty yards east of this is a ridge of the same rock very coarse grained. A little further north (in the E. ½ N. W. ¼ sec. 30) the rock at the shore is the same as in the ridge. In places four-fifths of the rock is composed of quartz as is shown by No. 702. Apparently in this altered granite was a small, illy exposed area of brownish fissile slate. No. 703 shows this slate and No. 704 a condition of it near the ordinary altered granite. It appears as if this slate is part of the slate formation of the region enclosed in the other rock, but nothing definite could be made out concerning it.

The altered granite extends along the east shore in the N. W. ¼ sec. 30, and to the extreme northern point of the lake. Here, on the east side of the stream which flows into Saganaga lake, the rock is altered granite, but on the west side of this stream the slate and graywacke formation appears. The slates hold bands of what seem to be the altered granite, and also of graywacke and grit. It is here impossible to distinguish between these rocks, in fact it seems as if the so-called altered granite was a part of the grit and graywacke. Nos. 705, 706 and 707, from the east end of this exposure, show facies of the altered granite or of the grit and graywacke. No. 708 certainly seems to be grit; it was taken over fifty yards from the main mass of the altered granite. In one place one of these questionable bands was seen to hold fragments of slate near its edge,—No. 709. In no place did I see any of the so-called altered granite bands cutting across the strike of the slates. Nearest the main mass of altered granite the slates are brownish, as those found inclosed in the other rock (see Nos. 704 and 705) and are shown by No. 710.

The slaty formation extends along the north and west shores of of Wind lake. Northwest from the northwest corner of the lake is a high bluff composed mostly of grit and graywacke, the former apparently somewhat re-crystallized (No. 711). Here the dip is 75° to 80° towards S. 60° W. About a quarter of a mile south of this bluff the dip is 80° towards S. 70° W.

On going east from the south end of the lake to the small lake which is crossed by the south line of sec. 30, east of the quarter post, only a few outcrops were seen. These were of the same slate formation as exists on the shores of Wind lake. On the west shore of this small lake the strike is N. 20° W. and the dip 80° towards S. 70° W., but at an outcrop about an eighth of a mile west of this the strike is N. 25° E. and the dip is probably 80° towards N. 65° W., but the dip could not be accurately determined, as only a smooth glaciated surface was exposed. An outcrop on the east shore of this small lake appears to be of the same slaty formation, but it was not visited. In the E. ½ of N. W. ¼ sec. 30, the altered granite similar to No. 702 is seen.

South of Wind lake a short distance are a few outcrops of the slate formation. Here the beds are twisted somewhat, but the general strike is a little west of north. Southeast from the lake the slate outcrops extend for a quarter of a mile. The dip taken on one outcrop was vertical and the strike N. 25° W. We went east-southeast from the southeast end of Wind lake, but after passing the above mentioned outcrops of slate no other rock was seen *in situ* until coming into about the N. E. ¼ S. W. ¼ sec. 32, T. 66-5. Here the ordinary coarse grained hornblende granite occurs, but of not quite as coarse grain as that usually seen on Saganaga lake. Farther on, probably in the S. W. ¼ S. E. ¼ of the same section, granite is again seen.

On going east from Wind lake about the centre of the N. W. ¼ sec. 30, an apparent gradation is seen between the altered granite and the ordinary granite. The latter was found in the midst of the former and not separated from it by any line or sudden change. Nos. 712 to 716, together with the finer grained conditions of this rock already described, show this gradation into the ordinary granite. In its coarsest condition the altered granite is much weathered and decayed, and it is difficult to get good specimens of it. I also went east from the lake a short distance on the north line of sec. 30, and then northeast to the bay of Saganaga lake in the S. W. ¼ sec. 19, T. 66-5, and saw essentially the same gradations. In places the altered granite has irregular areas in which the large quartz grains are lacking and the rock is almost entirely composed of a fine greenish material, as seen in specimens Nos. 688 and 689. In a few places the large quartz grains were arranged along definite, distinct lines or "beds," and this arrangement faded off into the main mass of the rock where no arrangement of the grains could be seen. These "beds" ran from 10° to 30° W. of N. and seemed to stand vertical.

PART II.—CATALOGUE OF ROCK SPECIMENS

COLLECTED BY ULYSSES SHERMAN GRANT IN 1891.

This is a continuation of the list ended on page 215 of the 17th (1888) Annual Report. The page references refer to the places where the specimens are described in this report.

KAWISHIWI RIVER AREA.

299. Greenstone. Just south of Pickerel lake, on the east line of sec. 25, T. 63–11. P. 39.

300. Quartzless porphyry. A short distance south of the last. P. 39.

301. Contact of the last with the greenstone. Same locality. P. 39.

302. Greenstone. S. E. ¼ N. W. ¼ sec. 25, T. 63–11, portage from Kawishiwi river to Pickerel lake. P. 39.

303. Schistose graywacke. Same locality. P. 39.

304. Greenstone. S. E. ¼ N. W. ¼ sec. 25, T. 63–11, Pickerel lake. P. 39.

305. Greenstone. N. W. ¼ N. E. ¼ sec. 25, T. 63–11, south shore of Pickerel lake. P. 39.

306. Siliceous greenstone. N. W. ¼ N. E. ¼ sec. 25, T. 63–11, south shore of Pickerel lake. P. 39.

307. Greenstone. N. E. ¼ N. W. ¼ sec. 30, T. 63–10, south shore of Pickerel lake, at the outlet. P. 39.

308. Greenstone. N. E. ¼ N. W. ¼ sec. 30, T. 63–10, east end of Pickerel lake. P. 39.

309. Greenstone. S. W. ¼ S. W. ¼ sec. 19, T. 63–10, north shore of Pickerel lake. P. 39.

310. Sericitic schist. East line of sec. 19, T. 63–11, north of the quarter post. P. 39.

311. Coarse gneissic syenite. A short distance farther south and just north of the quarter post. P. 39.

312. Fine granite. Same locality. P. 39.

313. Dark gneissic syenite. East line of sec. 19, T. 63–11, south of the quarter post. P. 39.

314. Mica-schist. Same locality. P. 39.

315. Fine biotite granite vein rock. Same locality. P. 40.

316. Mica-schist. S. W. ¼ N. W. ¼ sec. 30, T. 63–10, little point on north side of the Kawishiwi river. P. 40.

317. Fine vein granite. Same locality. P. 40.

318. Mica-schist. South of the Kawishiwi river, about on the west line of sec. 31, T. 63–10. P. 43.

319. Green schist. Same locality. P. 43.

320. Red syenite. N. E. ¼ S. W. ¼ sec. 30, T. 63–10, south shore of the Kawishiwi river. P. 43.

321. Dyke rock in the syenite. Same locality. P. 44.

322 to 325. Syenite near the contact with the mica-schist. Same locality. P. 44.

326 to 328. Mica-schist near the contact with the syenite. Same locality. P. 44.

329. Syenite and mica-schist in contact; not *in situ*. Same locality. P. 44.

330. Fine diorite dyke rock. S. W. ¼ N. E. ¼ sec. 30, T. 63–10. P. 44.

331. Hornblende gneiss; inclusion in syenite. Same locality. P. 44.

332. Siliceous schist; inclusion in syenite. Same locality. P. 44.

333 to 336. Specimens showing change from mica-schist to syenite. S. E. ¼ N. E. ¼ sec. 30, T. 63–10, east shore of Kawishiwi river. P. 44.

337. Syenite showing "flowage structure." S. W. ¼ N. W. ¼ sec. 32, T. 63–10, south shore of Clearwater lake. P. 40.

338. Red syenite. Same locality. P. 40.

339. Coarse syenite. S. W. ¼ S. E. ¼ sec. 29, T. 63–10, north shore of Clearwater lake. P. 40.

340. Fine syenite. West line of sec. 32, T. 63–10, north shore of Clearwater lake. P. 41.

341. Mica-schist and syenite in contact. N. E. ¼ N. E. ¼ sec. 31, T. 63–10, north shore of Clearwater lake. P. 41.

342. Red syenite near contact with mica-schist. Same locality. P. 42.

343. Coarse black diorite. E. ½ N. E. ¼ sec. 31, T. 63–10, west shore of Clearwater lake. P. 41.

344. Red syenite cutting the above diorite. Same locality. P. 41.

345. Gray syenite cutting the above diorite. Same locality. P. 41.

346. Trap dyke rock. Same locality. P. 41.

347 and 348. Red syenite. West line of sec. 5, T. 62–10, north of the Kawishiwi river. P. 41.

349. Hornblende vein rock. Same locality. P. 41.

350. Dark red syenite. Near the west line of sec. 5, T. 62–10, north shore of the Kawishiwi river. P. 42.

351. Dark coarse syenite. Same locality. P. 42.

352 to 354. Coarse dark diorite. S. W. ¼ N. W. ¼ sec. 5, T. 62–10, north shore of the Kawishiwi river. P. 42.

355. Syenite. S. E. ¼ N. E. ¼ sec. 5, T. 62–10, Kawishiwi river. P. 42.

356. Red hornblende granite. N. W. ¼ S. W. ¼ sec. 9, T. 62–10, south shore of the Kawishiwi river. P. 42.

357. Gabbro. S. W. ¼ S. W. ¼ sec. 9, T. 62–10. P. 42.

358. Fine grained biotite granite. Same locality. P. 42.

359. Biotite syenite. Same locality. P. 42.

360. Red aplite. Same locality. P. 42.

361. Fine micaceous syenite. S. W. ¼ sec. 9, T. 62–10, east shore of the Kawishiwi river. P. 42.

362. Fine gray syenite. Same locality. P. 42.

363 and 364. Intermediate between gabbro and syenite. Same locality. P. 42.

365. Purple porphyrite (?). Same locality. P. 43.

366. Dark syenite. Sec. 34 (?), T. 63–10, west shore of the Kawishiwi river. P. 43.

367. Syenite. Same locality. P. 43.

368. Coarse syenite. S. W. ¼ sec. 34, T. 63–10, west shore of the Kawishiwi river. P. 43.

369. Coarse diorite. Just north of the centre of sec. 26, T. 63–10, south shore of the Kawishiwi river. Pp. 44–45.

370. Trap dyke rock. Same locality. P. 45.

371. Fine red granite. Same locality. P. 45.

372. Fine gray granite. Just west of the last. P. 45.

373. Diorite. Same locality. P. 45.

374. Diorite and granite in contact. Same locality. P. 45.

375. Coarse diorite. S. W. ¼ sec. 26, south shore of the Kawishiwi river. P. 45.

376. Diorite, fine grained. N. W. ¼ S. W. ¼ sec. 26, T. 63–10, south shore of the Kawishiwi river. P. 45.

377. Coarse red syenite. S. W. ¼ S. W. ¼ sec. 26, T. 63–10, south shore of the Kawishiwi river. P. 45.

378. Gneiss inclusion in the syenite. Same locality. P. 45.

379. Greenstone. West line of sec. 22, T. 63–10, north of the Kawishiwi river. P. 45.

380. Greenstone. Same locality. P. 45.

381. Quartz porphyry. Same locality. P. 45.

382. Greenstone. West line of sec. 22, T. 63–10, ¾ mile north of the Kawishiwi river. P. 46.

383. Fine graywacke. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 46.

384. Coarser graywacke. Same locality. P. 46.

385. Coarse graywacke. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 46.

386. Finer graywacke; Same locality. P. 46.

387. Gneissic syenite. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, portage along north side of the Kawishiwi river. P. 46.

388. Fissile greenstone. N. W. ¼ N. E. ½ sec. 28, T. 63–10, portage along north side of the Kawishiwi river. P. 46.

389 to 394. Specimens illustrating passage from greenstone to syenite. Same locality. P. 47.

395. Finely jointed greenstone. Same locality. P. 47.

395A. Sericitic graywacke. N. E. ¼ N. W. ¼ sec. 28, T. 63–10, portage along the north side of the Kawishiwi river. P. 47.

396. Contact of graywacke and syenite. Same locality. P. 47.

397 to 400. Facies of the syenite near the contact. Same locality. P. 47.

401. Greenstone. Same locality. P. 47.

402. Quartz porphyry from edge of dyke. N. ½ N. W. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 48.

403. The same from center of dyke, Same locality. P. 48.

404. Gray gniess. S. E. ¼ N. W. ¼ sec. 28, T. 63–10, south of the Kawishiwi river. P. 48.

405. Sericitic schist. Same locality. P. 49.

406 to 408. Gray gneiss. Same locality. P. 49.

409. Diorite in the gneiss. Same locality. P. 49.

410. Red syenite. N. E. ¼ N. E. ¼ sec. 29, T. 63–10, north shore of the Kawishiwi river. P. 49.

411. Quartzporphyry. N. ½ N. E. ¼ sec, 29, T. 63–10, north shore of the Kawishiwi river. P. 49.

412. Greenstone. West line of sec. 21, T. 63–10, one-eighth mile north of the S. W. corner of this section. P. 56.

413. Gray granite porphyry. N. W. ¼ S. E. ¼ sec. 20, T. 63–10, west shore of lake. P. 56.

414. Quartzporphyry (?). N. W. ¼ N. E. ¼ sec. 21, T. 63–10, north shore of lake. P. 56.

415. Greenstone near dyke walls. N. ½ N. E. ¼ sec. 21, T. 63–10, south shore of lake. P. 57.

416. Quartz porphyry at edge of dyke. Same locality. P. 57.

417. The same from center of dyke. Same locality. P. 57.

418. Greenstone. South line of sec. 16, T. 63–10, north shore of lake. P. 57.

419. Magnetite slate. East line of sec. 16, T. 63–10, a short distance north of the quarter post. P. 58.

420 to 422. Sericitic gneiss near syenite contact. Near the west line of sec. 28, T 63–10, one-third mile south of the Kawishiwi river. P. 50.

423. Gneiss and syenite in contact. Same locality. P. 50.

424. Gneissic syenite near the contact with the gneiss. Same locality. P. 50.

425. Red syenite. Same locality. P. 50.

426. Sericitic schist. Near the west line of sec. 29, T. 63–10, south of the Kawishiwi river. P. 50.

427. Mica-schist. Same locality. P. 50.

428. Syenite porphyry (?). N. ½ N. W. ¼ sec. 29, T. 63–10, north of the Kawishiwi river. P. 51.

429 to 431. Gray gneiss. Small island in the bay in the N. W. ¼ N. W. ¼ sec. 27, T. 63–10, Kawishiwi river. P. 51.

432. Reddish syenite. Same locality. P. 51.

433. Schist inclusion in syenite. Same locality. P. 51.

434. Mica-schist from inclusion in syenite. East shore of the same bay. P. 51.

435 Mica-schist and syenite in contact. Same locality. P. 51.

436. Schistose syenite. S. E. corner of bay in N. E. ¼ N. W. ¼ sec 27, T. 63–10, Kawishiwi river. P. 51.

437. Gneissic syenite (?). Same locality. P. 51.

438. Gneiss. Same locality. P. 51.

439. Granite vein rock. Same locality. P. 52.

440. Schistose syenite. N. ½ sec. 27, T. 63–10, north shore of the Kawishiwi river. P. 52.

441. Chloritic syenite. Same locality. P. 52.

442. Dark gneiss. N. E. ¼ N. E. ¼ sec. 27, T. 63–10, north shore of the Kawishiwi river. P. 53.

443 and 444. Sericitic gneiss. N. W. ¼ N. W. ¼ N. W. ¼ sec. 26, T. 63–10, north shore of the Kawishiwi river. P. 53.

445. Gray hornblende gneiss. Same locality. P. 53.

446. Gneiss and green inclusion. Same locality. P. 53.

447. Mica-schist. N. W. ¼ N. W. ¼ sec. 26, T. 63–10, north shore of the Kawishiwi river. P. 53.

448. Greenstone inclusion in syenite. N. W. ¼ N. W. ¼ sec. 26, T. 63–10, north of the Kawishiwi river. P. 54.

449. Schistose greenstone. Same locality. P. 54.

450. Diorite. East shore of the bay which is crossed by the south line of sec. 23, T. 63–10, Kawishiwi river. P. 54.

451. Diorite and syenite in contact. Same locality. P. 54.

452. Pegmatite. Same locality. P. 54.

453 to 455. Siliceous schist. N. E. ¼ S. W. ¼ sec. 24, T. 63–10, portage from the Kawishiwi river to Triangle lake. P. 58.

456. Greenstone. Same locality. P. 58.

457. Green slate. S. E. ¼ N. W. ¼ sec. 24, T. 63–10, same portage. P. 58.

458. Altered quartz porphyry. N. E. ¼ N. W. ¼ sec. 13, T. 63–10, south side of small island in Northwest lake. P. 58.

459. Mottled greenstone. N. E. ¼ N. E. ¼ sec. 13, T. 63-10, north shore of Northwest lake. P. 58.

460. Gabbro and biotite syenite in contact. N. W. ¼ sec. 25, T. 63–10, south shore of the Kawishiwi river. P. 55.

461. Gray syenite. Same locality. P. 55.

462. Red syenite. Same locality. P. 55.

463. Gray syenite. Sec. 26, T. 63–10, Kawishiwi river. P. 55.

464. to 466. Rock intermediated between syenite and gabbro. N. ½ S. W. ¼ sec. 19, T. 62–9, island in the Kawishiwi river. P. 55.

467. Syenite. Same locality. P. 55.

468. Gabbro. N. ½ S. W. ¼ sec. 19, T. 63–9, south shore of the Kawishiwi river. P. 55.

469. Syenite. Same locality as No. 467. P. 55.

470. Rock intermediade between gabbro and syenite. Near the center of sec. 19, T. 63–9, point on north side of the Kawishiwi river. P. 55.

471 and 472. Greenstone. S. E. ¼ N. W. ¼ sec. 19, T. 63–9, north shore of the Kawishiwi river. P. 56.

473. Diorite. West line of sec. 20, T. 63–9, north of the Kawishiwi river. P. 56.

SNOWBANK LAKE AREA.

474. Coarse syenite. Sec. 11, T. 63–9, portage from the Kawishiwi river to Snowbank lake. P. 60.

475. Fine red syenite. Same locality. P. 60.

476. Syenite. Same locality. P. 60.

477. Diorite. Same locality. P. 60.

478. Fine syenite. Same locality. P. 60.

479. Fine diorite. Same locality. P. 60.

480 and 481. Gray porphyritic syenite. Same locality. P. 60.

482. Fine syenite. N. ½ N. E. ¼ sec. 11, T. 63–9, west shore of Snowbank lake. P. 60.

483. Dark red syenite. S. ½ S. E. ¼ sec. 2, T. 63–9, west shore of Snowbank lake. P. 60.

484. Gray Syenite. Same locality. P. 60.

485. Syenite. N. W. ¼ S. E. ¼ sec. 2, T. 63–9, island in Snowbank lake. P. 60.

486. Reddish syenite vein rock. Same locality. P. 60.

487. Diorite. West line of sec. 36, T. 64–9, south shore of Snowbank lake. P. 61.

488. Coarse syenite. S. E. ¼ sec. 35, T. 64–9, south shore of Snowbank lake. P. 61.

489. Fine syenite. S. E. ¼ N. W. ¼ sec. 35, T. 64–9, south shore of Snowbank lake. P. 61.

489A. Fine diabase. S. E. ¼ S. E. ¼ sec. 27, T. 64–9, west shore of Snowbank lake. P. 61.

490. Syenite porphyry. Same locality. P. 61.

491. Fine reddish hornblende granite. North line of sec. 35, T. 64–9, west shore of Snowbank lake. P. 62.

492. Mica-schist. N. E. ¼ N. W. ¼ sec. 35, T. 64–9, west shore of Snowbank lake. P. 62.

493. Gneiss. Same locality. P. 62.

494 and 495. Gneiss near granite contact. Same locality. P. 62.

496. Gneiss and granite in contact. Same locality. P. 62.

497. Syenite porphyry. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 63.

498. Hornblende granite. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, island in Snowbank lake. P. 63.

499. Gray biotite gneiss. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 64.

500. Syenite porphyry from centre of dyke. Same locality. P. 64.

501. The same from edge of dyke. Same locality. P. 64.

502. Hard green schist. N. W. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

502A. Gneiss from pebble in the schist. Same locality. P. 65.

503. Fine hornblende granite. Same locality. P. 65.

504. Porphyrite. N. W. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

505. Schistose condition of the same. Same locality. P. 65.

506. Fine syenite dyke rock. Same locality. P. 65.

507. Mottled diorite. S. W. ¼ N. E. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

508. Greenstone. Same locality. P. 65.

509. Red syenite. Same locality. P. 65.

510. Greenstone. Same locality. P. 65.

511. Mica-schist. N. E. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

512. Green schist. Same locality. P. 65.

513. Hornblende granite. Same locality. P. 66.

514. Graywacke. Near the north line of sec. 26, T. 64–9, west shore of Snowbank lake. P. 66.

515. Siliceous schist. S. E. ¼ S. E. ¼ sec. 23, T. 64–9, west shore of Snowbank lake. P. 66.

516. Green schist. Sec. 24, T. 64–9, north shore of Snowbank lake. P. 66.

517. Siliceous schist. Same locality. P. 66.

518. Hornblende granite. East line of sec. 24, T. 64–9, north shore of Snowbank lake. P. 66.

519. Contact of schist and granite. Same locality. P. 66.

520. Siliceous mica-schist near granite contact. Same locality. P. 66.

521. Fine dark syenite. Same locality. P. 66.

522. Syenite. N. E. ¼ S. W. ¼ sec. 19, T. 64–8, island in Snowbank lake. P. 66.

523. Light gray syenite. N. W. ¼ S. W. ¼ sec. 29, T. 64–8, east shore of Snowbank lake. P. 66.

524. Coarse biotitic syenite. Near south line of sec 30, T. 64–8, east shore of the largest island in Snowbank lake. P. 67.

525. Biotite gneiss. N. W. ¼ N. E. ¼ sec. 31, T. 64–8, south end of island in Snowbank lake. P. 67.

526. Reddish syenite. N. E. ¼ sec. 1, T. 63–9, portage from Snowbank to Round lake. P. 67.

527. Mica-schist cut by syenite veins. N. E. ¼ S. E. ¼ sec. 1, T. 63-9, north shore of Round lake. P. 67.

528 and 529. Gneiss. N. E. ¼ S. E ¼. sec. 1, T. 63–9, west shore of Round lake. P. 67.

530. Fine red syenite. Same locality. P. 67.

531 and 532. Gneiss. Same locality. P. 67.

533. Brown syenite (?). N. E. ¼ N. W. ¼ sec. 7, T. 63–8, south shore of Round lake. P. 67.

534. Fine red syenite. E. ½ sec. 6, T. 63–8, east shore of Round lake. P. 68.

535. Syenite and fine gabbro (?) in contact. N. W. ¼ N. E. ¼ sec. 7, T. 63–8, south shore of Round lake. P. 68.

536. Fine gabbro (?). Same locality. P. 68.

537. Gabbro. Same locality. P. 68.

538. Gray syenite (?). S. ½ S. W. ¼ sec. 32, T. 64-8, portage between Disappointment and Snowbank lakes. P. 68. [Note: No. 539, on p. 68, should be No. 538.]

539. Fine red syenite. Same locality. P. 69.

KEKEQUABIC LAKE AREA.

540. Soft green biotite schist. N. E. ¼ N. W. ¼ sec. 11, T. 64-7, portage south of Kekequabic lake. P. 69.

541. Fine gabbro (?). W. ½ sec. 11, T. 64-7, west end of River lake. P. 69.

542. Finer facies of the same. N. E. ¼ S. E. ¼ sec. 11, T. 64-7, portage from River to Shoofly lake. P. 69.

543. Streaks of biotite in the same. S. E. ¼ N. W. ¼ sec. 11, T. 64-7, River lake. P. 69.

544. Greenstone from the fine gabbro (?). S. E. ¼ N. W. ¼ sec. 11, T. 64-7, River lake. P. 69.

545. Fragments of syenite in the fine gabbro (?). Same locality. P. 69.

546. Gray syenite. N. E. ¼ S. W. ¼ sec. 11, T. 64-7, south shore of River lake. P. 69.

547. Fine biotitic gabbro (?). S. E. ¼ N. W. ¼ sec. 11, T. 64-7, east shore of River lake. P. 70.

548. Fine gray gabbro (?). Same locality. P. 70.

549. Pyroxene granite. S. E. ¼ S. W. ¼ sec. 2, T. 64-7, south shore of Kekequabic lake. P. 70.

550. Diorite (?). S. E. ¼ S. W. ¼ sec. 3, T. 64-7, south shore of Kekequabic lake. P. 71.

551. Porphyritic pyroxene granite. S. W. ¼ S. W. ¼ sec. 3, T. 64-7, south shore of Kekequabic lake. P. 71.

552. Hardened black slate. Same locality. P. 71.

553. Pyroxene granite. S. W. ¼ N. W. ¼ sec. 3, T. 64-7, west shore of Kekequabic lake. P. 71.

554. Contact of diorite and granite. Same locality. P. 71.

555. Diorite. Same locality. P. 71.

556. Pyroxene granite. Same locality. P. 72.

557. Finer facies of the same. Same locality. P. 72.

558. Granite porphyry (?). S. W. ¼ N. W. ¼ sec. 3, T. 64-7, small island in Kekequabic lake. P. 72.

559. Black argillyte. Same locality. P. 72.

560. Granite porphyry. Same locality. P. 72.

561. Coarse diorite. S. W. ¼ N. W. ¼ sec. 3, T. 64-7, small island in Kekequabic lake. P. 73.

562. Finer diorite. Same locality. P. 73.

563. Spotted black argillyte. S. W. ¼ N. W. ¼ sec. 3, T. 64–7, west shore of Kekequabic lake. P. 73.

564. Green schist. S. E. ¼ N. W. ¼ sec. 4, T. 64–7, west shore of Kekequabic lake. P. 73.

565. Fine pyroxene granite. S. E. ¼ N. W. ¼ sec. 3, T. 64–7, small island in Kekequabic lake. P. 73.

566. Coarser pyroxene granite. Another island in the same $\frac{1}{16}$ section. P. 73.

567. Fine dark facies of the granite (?). S. W. ¼ N. E. ¼ sec. 3, T. 64–7, north shore of largest island in Kekequabic lake. P. 73.

568. Black slate in the granite. Same locality. P. 73.

569. Chloritic conglomerate. N. E. ¼ N. W. ¼ sec. 11, T. 64–7, east shore of Kekequabic lake. P. 73.

570. Green schist. Same locality. P. 74.

571. Fine pyroxene granite. S. W. ¼ S. E. ¼ sec. 2, T. 64–7, just east of Kekequabic lake. P. 74.

572. Inclusion in the granite. Same locality. P. 74.

573. Porphyritic pyroxene granite. N. W. ¼ N. W. ¼ sec. 2, T. 64–7, small island in Kekequabic lake. P. 74.

574. Mica diorite (?). Same locality. P. 74.

575. Contact of the last two. Same locality. P. 74.

576. Fine pyroxene granite. S. W. ¼ S. E. ¼ sec. 35, T. 65–7, south shore of Kekequabic lake. P. 74.

577. Pyroxene granite porphyry. S. E. ¼ S. E. ¼ sec. 35, T. 65–7, south shore of Kekequabic lake. P. 74.

578. Purple granite porphyry. Same locality. P. 74.

579. Fine pyroxene granite. S. E. ¼ S. W. ¼ sec. 36, T. 65–7, just south of Kekequabic lake. P. 75.

580. Granite porphyry at contact with conglomerate. S. ½ N. E. ¼ sec. 36, T. 65–7, south shore of Kekequabic lake. P. 75.

581. Conglomerate at contact with granite porphyry. Same locality. P. 75.

582. Granite porphyry. Same locality. P. 75.

583. Granite porphyry carrying biotite. N. ½ S. W. ¼ sec. 36, T. 65–7, Stacy island, Kekequabic lake. P. 76.

584. Fine diabase. S. E. ¼ N. E. ¼ sec. 36, T. 65–7, northeast shore of small lake. P. 81.

585. Granite porphyry. Same locality. P. 81.

586. Granite porphyry. Same locality. P. 81.

587. The same from contact with diabase. Same locality. P. 81.

588. Granite porphyry. S. E. ¼ N. E. ¼ sec. 36, T. 65–7, north shore of small lake. P. 81.

589. Fine pyroxene granite. N. W. ¼ S. E. ¼ sec. 36, T. 65-7, west shore of small lake. P. 81.

590. Fine pyroxene granite. A short distance south of the last. P. 81.

591. Gray granite porphyry. N. E. ¼ S. E. ¼ sec. 36, T. 65-7, south shore of small lake. P. 82.

592. Inclusion in granite porphyry. N. E. ¼ S. E. ¼ sec. 36, T. 65-7, east shore of small lake. P. 82.

593. Metamorphosed conglomerate. S. W. ¼ N. W. ¼ sec. 31, T. 65-6, south shore of Kekequabic lake. P. 76.

594. Metamorposed conglomerate. N. E. ¼ S. W. ¼ sec. 31, T. 65-6, south shore of Kekequabic lake. P. 76.

594A. Pebbles from the same. Same locality. P. 76.

595. Metamorphosed conglomerate. S. E. ¼ N. E. ¼ sec. 31, T. 65-6, south shore of Kekequabic lake. P. 76.

596. Granite porphyry. E. ½ S. E. ¼ N. E. ¼ sec. 31, T. 65-6, south shore of Kekequabic lake. P. 77.

597. Granite porphyry at contact with diabase. Same locality. P. 77.

598. Fine diabase at contact with granite porphyry. Same locality. P. 77.

599. Fine diabase. Same locality. P. 77.

600. Coarser condition of the same. Same locality. P. 77.

601 to 615. Specimens showing gradations from a gray slate (?) to the pyroxene granite. S. W. ¼ N. W ¼ sec. 3, T. 64-7, west shore of Kekequabic lake. P. 72.

616. Granite porphyry. W. ½ N. E. ¼ N. W. ¼ sec. 31, T. 65-6, north shore of Kekequabic lake. P. 77.

617. Granite porphyry near contact with greenstone. Same locality. P. 77.

618. Greenstone near contact with granite porphyry. Same locality. P. 77.

619. Greenstone. Same locality. P. 77.

620. Inclusion in granite porphyry. Same locality. P. 77.

621. Granite porphyry. S. W. ¼ S. W. ¼ sec. 29, T. 65-6, north shore of Kekequabic lake. P. 77.

621A, 621B and 621C. Inclusions in granite porphyry. N. W. ¼ N. W. ¼ sec. 32, T. 65-6, north shore of Kekequabic lake. P. 77.

622. Purple slate. N. E. ¼ S. W. ¼ sec. 36, T. 65-7, south shore of Kekequabic lake. P. 78.

623. Pyroxene granite. Same locality. P. 78.

624. Pyroxene granite at contact with purple slate. Same locality. P. 78.

625. Purple slate at contact with granite. Same locality. P. 78.

626. Hardened slate (?). Same locality. P. 78.

627. Gray slate. Same locality. P. 78.

628. Granite porphyry at contact with greenstone. N. E. ¼ N. E. ¼ sec 36, T. 65–7, north shore of Kekequabic lake. P. 78.

629. Granite porphyry. Same locality. P. 78.

630. Metamorphosed conglomerate. N. W. ¼ S. E. ¼ sec. 31, T. 65–6, south of Kekequabic lake. P. 79.

631. Black slate. N. W. ¼ S. E. ¼ sec. 31, T. 65–6, south of Kekequabic lake. P. 79.

632. Grit. S. W. ¼ S. E. ¼ sec. 31, T. 65–6. P. 79.

633. Grit and slate interbanded. Same locality. P. 79.

634. Grit. N. W. ¼ N. E. ¼ sec. 6, T. 64–6. P. 79.

635. Grit. S. W. ¼ S. E. ¼ sec. 6, T. 64–6. P. 79.

636. Granite porphyry (?). S. W. ¼ N. E. ¼ sec. 7, T. 64–6. P. 80.

637. Green conglomerate. N. E. ¼ S. W. ¼ sec. 7, T. 64–6, north of small lake. P. 80.

638. Crystalline conglomerate. S. E ¼ S. W. ¼ sec. 7, T. 64–6, just north of small lake. P. 80.

639. Gabbro. S. ½ S. E. ¼ sec. 7, T. 64–6, east shore of small lake. P. 80.

640. Porphyritic (?) conglomerate. S. E. ¼ S. E. ¼ sec. 29, T. 65–6, east end of portage. P. 82.

641. Green conglomerate. Same locality. P. 82.

642. Metamorphosed grit (?). S. W. ¼ S. W. ¼ sec. 26, T. 65–6, east shore of small lake. P. 82.

643. Fine diabase. Same locality. P. 82.

644. Metamorphosed grit (?) at contact with diabase. Same locality. P. 82.

SAGANAGA LAKE AREA.

645. Coarse gray granite. N. E. ¼ N. W. ¼ sec. 17, T. 65–5, West Sea Gull lake. P. 83.

646. Decayed granite. Same locality. P. 83.

647. Coarse granite. N. E. ¼ N. E. ¼ sec. 17, T. 65–5. P. 83.

648. Green slate. N. W. ¼ N. E. ¼ sec. 17, T. 65–5, south shore of West Sea Gull lake. P. 83.

649. Coarse granite vein rock. Same locality. P. 83.

650. Fine reddish granite vein rock. Same locality. P. 83.

651. Greenstone. N. E. ¼ N. W. ¼ sec. 17, T. 65–5, south shore of West Sea Gull lake. P. 83.

652. Diabase. Same locality. P. 83.

653. Fine graywacke. S. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 8, T. 65-5, west shore of West Sea Gull lake. P. 84.

654. Ogishke Muncie conglomerate. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 8, T. 65-5, west shore of West Sea Gull lake. P. 84.

655. Granite. N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 7, T. 65-5, just west of West Sea Gull lake. P. 84.

656. Ogishke Muncie conglomerate at contact with granite. N. W. $\frac{1}{4}$ N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 8, T. 65-5. P. 84.

657. Granite at contact with conglomerate. Same locality. P. 84.

657A. Granite. Same locality. P. 84.

658. Matrix of conglomerate. Same locality. P. 84.

659. Fine green matrix of conglomerate. Same locality. P. 85.

660. Purple porphyrite (?) at contact with granite. N. $\frac{1}{2}$ S. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 8, T. 65-5, west shore of West Sea Gull lake. P. 85.

661. Purple porphyrite (?). Same locality. P. 85.

662. Diabase from dyke. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 5, T. 65-5, west shore of West Sea Gull lake. P. 85.

663. Green slate. E. $\frac{1}{2}$ N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 6, T. 65-5. P. 85.

664. Grit. Same locality. P. 85.

665. Granite. W. $\frac{1}{2}$ N. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 8, T. 65-5, west shore of small lake. P. 86.

666. Decayed granite. W. $\frac{1}{2}$ N. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 8, T. 65-5, just west of small lake. P. 86.

667. Decayed granite. Same locality. P. 87.

668. Decayed granite (?). Same locality. P. 87.

669. Hardened mica-schist. E. $\frac{1}{2}$ S. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 17, T. 65-5, west shore of small lake. P. 87.

670. Green siliceous schist. S. $\frac{1}{2}$ S. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 16, T. 65-5, south shore of small lake. P. 87.

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683. Coarse hornblende granite. S. ½ S. E. ¼ sec. 18, T. 66-5, island in Saganaga lake. P. 90.

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688. Green altered granite. Canadian shore, just north of the last. P. 90.

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690. Altered granite. E. ½ N. E. ¼ S. E. ¼ sec. 24, T. 66-6, east shore of bay of Saganaga lake. P. 90.

691. Gray slate. Same locality. P. 90.

692 to 694. Altered granite. Same locality. Pp. 90, 91.

695. Graywacke. Same locality. P. 91.

696. Drab fissile slate. Same locality. P. 91.

697. Green slate. S. E. ¼ N. E. ¼ sec. 25, T. 66-6, west shore of Wind lake. P. 93.

698. Graywacke. Same locality. P. 93.

699. Grit. Same locality. P. 93.

700. Graywacke. N. E. ¼ S. E. ¼ sec. 25, T. 66-6, west shore of Wind lake. P. 93.

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703. Brown fissile slate. Same locality. P. 94.

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705 to 707. Altered granite (?). S. W. ¼ S. W. ¼ S. W. ¼ sec. 19, T. 65-5, north shore of Wind lake. P. 94.

708. Grit. Same locality. P. 94.

709. Grit (?). Same locality. P. 94.

710. Brown fissile slate. Same locality. P. 94.

711. Grit. S. E. ¼ S. W. ¼ S. W. ¼ sec. 24, T. 66–6, just northwest of Wind lake. P. 94.

712 to 716. Specimens showing gradation from the altered granite to the ordinary granite. N. W. ¼ sec, 30, T. 66–5, east of Wind lake. P. 95.

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729 to 732. Grit. Same locality. Pp. 91, 92.

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IV.

THE MESABI IRON RANGE.

HORACE V. WINCHELL, F. G. S. A.

CONTENTS.

THE MESABI IRON RANGE.

DISCOVERY OF THE ORE.

On the sixteenth day of November, 1890, workmen under the direction of Capt. J. A. Nichols, of Duluth, Minnesota, encountered soft hematite in a test-pit on the northwest quarter of section three, township fifty-eight, range eighteen, west of the fourth principal meridian. This mine, now called the Mountain Iron, was the first body of soft ore discovered on the Mesabi iron range. Hard ore, chiefly magnetic, had been known for many years on the Mesabi, and explorations made by Mr. E. W. Griffin, of Minneapolis, near the falls of Prairie river in townships 56–24 and 56–25, had revealed some hard hematite interbedded with quartzyte and low grade soft ore. This, however, was the first merchantable deposit of hematite found on the new range. Capt. Nichols had been doing more or less exploring work along the range for some two years prior to this discovery. The Merritt brothers, of Duluth and Oneota, were not to be discouraged by the reports of explorers and miners added to those of experts and geologists who had condemned the range ever since 1875. To these Duluth pioneers the Mesabi was an attractive and promising district and their faith in it was never shaken, even though their ready cash was spent vainly and two years' searching remained unrewarded. To them belongs the credit for persisting in the hunt for ore and the final discovery of it, and to them rightfully and properly have large rewards already been granted.

WHAT EARLY EXPLORERS HAD SAID.

The Mesabi range attracted attention to its iron belt as early as 1875, and several iron experts of good repute were sent to examine the various outcrops of ore known at that time. The journey was an arduous one into a dense wilderness, and there is no wonder they did no test-pitting or drilling. They were sent to examine outcrops which they properly enough condemned, for the only iron to be seen was in thin strata of magnetite banded with jaspery quartzyte, under which, in some places, could be seen the rocks of the Archean.

Professor A. H. Chester, of Hamilton, N. Y., was one who visited the Mesabi in 1875. His account of the ores and rocks there may be found in the eleventh annual report of the Minnesota geological survey, pages 154 to 167.

Capt. A. P. Wood and others were sent to the very property now owned by the Mountain Iron Company, about eight years ago, and seeing nothing but the lean outcrops mentioned above reported adversely on it.

In fact the opinion of these early explorers was unanimously unfavorable to the range. Some of them found the titaniferous ore of the gabbro and drew the hasty conclusion that all the ores on the range would be worthless on account of titanium. The impression gained ground after the mines on the Vermilion range were opened that there was no ore worth mining on the Mesabi, because it consisted of nearly horizontal strata, or, in miner's parlance, was a "blanket formation." The ore deposits in the ranges on the south shore of lake Superior are all inclined at high angles, and a flat deposit of ore of any considerable purity and thickness was unknown in this country. In spite of all this unfavorable opinion on the part of those who should be competent to judge, and against the advice of their friends, the Merritts continued to look for outcrops and dig holes in the ground, and never ceased to dream of hidden stores of iron treasure.

It should here be stated that the opinion of the State Geologist and his assistants was again and again expressed in conversation and put on record in various reports to the effect that the Mesabi was likely to yield large quantities of good ore. It was shown by diagrams that the formation, although a flat one, did contain good ore, and it was indicated where the ore would occur in relation to the other rocks of the range. The order of stratification was studied and explained two or three years before any ore was discovered, and finally we even went so far as to hazard the prediction that the Mesabi range was likely to produce more ore even than the Penokee-Gogebic.*

This and many other statements of similar import put the geological survey on record as favoring the Mesabi, against the opinion of nearly all the actual mine operators and scientists who had examined it.

If the geology of the range as it was described in the annual reports of 1887 and 1888 were better understood by the explorers on the range at the present time there would be fewer test-pits sunk in greenstone, granite and quartzyte and more dollars in the pockets of those who are still vainly searching for ore.

*Bulletin No. 6, p. 160.

It is not the province of the state geological survey to find iron mines; that is the business of the explorer. A geologist's duty is by study and observation to indicate the proper conditions for ore deposits and the geographic limits of the formations in which those conditions may exist. The intelligent and unbigoted explorer will assimilate these ideas and apply them in discovering the stores of hidden wealth. The work of sinking test-pits is work of exploration, not geological work. As soon as a geologist begins to apply his ideas and dig holes he becomes an explorer, and in that work is a geologist no longer. We confess that we take considerable pride in the fact that our predictions in regard to the Mesabi are now in such rapid process of fulfillment.

There are several prominent citizens of Duluth and others who took an early interest in the Mesabi and assisted largely in its rapid development. It is due to their energy and confidence in the new range that there has been begun the exploitation of the greatest iron range in the world, in the most wonderfully rapid and unprecedented fashion. Among these pioneers of development should be mentioned judge J. T. Hale and his partner, E. C. Gridley; A. E. Humphrey, Geo. E. Milligan and others in the firm of A. E. Humphrey & Co., who undoubtedly were engaged in the largest transactions consummated on the range during the first year of its discovery, and whose exertions have resulted in the most extensive discoveries, perhaps several years in advance of the natural process of development; Frank Hibbing, A. J. Trimble, James Billings, John, William and Duncan McKinley, D. T. Adams, J. T. James, Hon. O. D. Kinney, Joseph Sellwood, J. G. Cohoe, P. L. Kimberley, J. T. Jones, J. A. Crowell, James Sheridan, and many others whose names are not now recalled. Judge Hale, especially, through the observations of John McCaskill and B. T. Hale, began exploration work in a systematic and thorough manner. McCaskill's keen eye discovered ore clinging to the roots of an upturned tree on the Cincinnati property, and by tracing out from there the approximate course of the green schist ridges enabled judge Hale and his coöperators to early select and secure possession of some of the best lands in 58–16. The value of clear and accurate observation and shrewd deduction from the facts observed, as to the best location for iron ore deposits and the situations in which they were most likely to occur, was soon made apparent on this range. Those who selected lands by chance, even though they purchased whole sections, did not get as much iron ore as those who applied what knowledge was to be obtained in the selection of promising pieces. The difficulties of becoming acquainted with such a wilderness and the new conditions to be met with, are incomprehensible to one not familiar with the region, and form some excuse for the great waste of money in the buying of lands and working them during the earlier months. Travel was perforce on foot, and supplies were carried on men's backs through swamps and dense forests for many weary miles. The range of vision is limited in the bushes, and the mantle of glacial drift conceals the rocks, especially the flat formations of the Mesabi. It is no wonder then that a narrow belt of ore should remain undiscovered for so many years in the vast region stretching between Duluth and the Giant's range. Few explorers were hardy and persistent enough to spend the time and undergo the hardships involved in a long search for ore on the much-condemned range. Even after the discovery of large deposits of fine ore it is a matter of great difficulty and expense to take men and supplies into the new regions twelve to forty miles from any railroad. It is highly important that good wagon roads be built through this mining region at once. The roads at present are almost impassable, and the cost of transporting mining outfits enormous, while the delay is a serious matter in many instances. It is a matter of interest to the entire state to have these new ore fields developed, and the first thing to be done is to construct passable roads.

Extent of the Range.

The ore formation of the Mesabi range extends from the Canadian boundary line in Minnesota, in a direction a little south of west to and beyond the Mississippi river in township 56-25, a distance of 140 miles or more. Part of this distance the ore-bearing rocks are concealed from sight by the later gabbro overflow.

The width of the ore belt at any one place probably does not exceed two miles, and will be found to be generally less than one. The ore lies in nearly flat beds, having a variable depth or thickness up to 100 feet. It is not to be inferred that there is a continuous belt of ore half a mile to a mile or more wide and 40-80 feet thick extending for 140 miles on this range. That would be far from true. The ore deposits are found at intervals over this area where the conditions necessary for their formation and accumulation exist. What these conditions are will be explained later. The ore on the eastern end of the range is hard, black and magnetic, all probably owing to the heat of the gabbro overflow. On the central and western portions of the range the ore is soft hematite, limonite and gœthite with hard hematite and limonite streaks of variable thickness.

Ore in merchantable quantity has already been found—June, 1892—on the central part of the range in seven townships, over a length of forty miles. There is good reason to believe it will be found in many places where no work has been done yet, as well as in some sections where hasty or misdirected exploration has so far failed to find it. Township 58-17 especially is likely to produce many more mines.

EXTENT OF OTHER RANGES.

The iron mines worked on the Vermilion range at present are at two points only, Tower and Ely, twenty-three miles apart. Other lake Superior ranges have an extent as follows:

Marquette, from Goose lake to Three lakes, thirty-four miles.

Menominee, from the Breen mine to the Nanaimo, fifty miles.

Penokee-Gogebic, from Sunday lake to Upson on the Wisconsin Central R. R., thirty miles or less.

It is thus evident that there is an opportunity on the Mesabi range, considering merely the area of the iron formation, for a much larger quantity of iron ore than on any other range in the lake Superior district, which is admitted to be the greatest iron district of the globe.

In favorable situations the ore deposits on the Mesabi may have a width of a mile and a length of two miles. The width of ore-bodies here corresponds to the depth on other ranges. Hence there may be in one ore deposit on the Mesabi as much ore within one hundred feet of the surface as on the Vermilion or Marquette range down to the depth of one mile. When this idea is once comprehended and its truth admitted the great advantage of this new range over all other known ranges is at once recognized.

There is always the possibility that the ores of the Mesabi will be found to extend indefinitely to the south under the black slates of the Animikie, and even under the gabbro and trap rocks of the lake Superior basin, until it reappears in the Penokee-Gogebic range on the south shore. In that case the supply of iron which may be counted on for future production is simply incomprehensible and inexhaustible. The greatest and deepest mines of the world will be developed here, and the industry of iron mining and manufacture in this state will continue to grow until iron is no more an article of consumption.

But, while we admit this possibility, we must confess that we do not consider it likely to be the case. The nature of the ore, its probable method of origin as explained later on, its porous texture and hydrated composition, combined with our general geoscopy, force us to the opinion that the merchantable ore beds are narrow and only locally developed. If here and there ore is found at a considerable depth under the black slates it will be due to some local conditions which cannot be expected to prevail over a wide region, and will be correspondingly accounted for.

GEOLOGY OF THE MESABI RANGE.

The geology of the Mesabi has been discussed in the various annual reports of the Minnesota survey which have described field work in the northern part of the state. The U. S. geological survey has also added considerable to the literature of the range and its geology. The views of different geologists, as expressed in these and other publications, will be found referred to in the report on "The Iron Ores of Minnesota," Bulletin No. 6, Geol. and Nat. Hist. Sur. I shall here give merely an outline of the views entertained at present by myself.

GEOGNOSY OF THE RANGE.

This iron range presents one of the most interesting chapters in the life-history of that part of the earth's crust which is embraced within the boundaries of Minnesota. We have here the phenomenon of a series of strata, wide-spread and of immense thickness, entirely confined to the south side of a range of granite and syenite hills. Although the country is at the present time much lower, no trace of the Mesabi range rocks has been reported north of the Giant's range granite in this state. The altitude of the various portions of the range is not the same. Elevations or depressions amounting to hundreds of feet have taken place, and the horizontal Taconic strata of the Mesabi have simply sunk or been elevated with the granite and schist which sustain them. On the southern slope of the granite range, whose summits form blue hills visible for thirty miles either south or north, there are accumulated strata of quartzytes, iron slates, quartz slates, cherts and argillytes with flows of gabbro and trap rocks thousands of feet in thickness. Yet only the gabbro eruptives appear to have extended north of the lofty Giant's range, and that very seldom. It is not credible that the Taconic strata once existed north of the granite and have since been entirely swept away by erosion—glacially or otherwise. The sharp, deep gorges in the folded crystalline and earthy schists of the Vermilion range, which lies at the foot of the Giant's range to the north, would surely retain some traces of sediments which formerly filled them. And if the huge granite range was such a protection for the soft ores and slates which lie on its southern slope as to leave those extensive deposits of soft iron ore, which are now being discovered just beneath the drift mantle, surely there would be some protection afforded to similar rocks by the lesser parallel ridges farther north, and some remnants of the slates would remain.

Look, too, at the difference in the topography on the two sides of the Giant's range, especially west of the gabbro sheet. On the north abrupt ridges and narrow gorges in the vertical eastward-trending folds of the Keewatin; on the south a smooth plain of black slates covered by till, sloping gently southward for fifty miles. North of the granite, on the Duluth and Iron Range railroad, rock-cuts are frequent; south of it, on the Duluth, Missabe and Northern, there is not a rock-cut for forty miles. These differences can be explained in only one way—the limitation of the early Taconic ocean by this granite shore.

Date of the Giant's Range Uplift.

An examination of the granite range, which lies just north of the Mesabi iron belt, makes it evident that the granite hills have been uplifted—undoubtedly without much accompanying metamorphism or other disturbance—since the superincumbent Taconic strata were deposited.

Proof of this is found in the vicinity of Birch lake. Here the quartzyte of the Taconic is seen north of the summit of the Giant's range, but 600 feet below, on the shores of the lake and still confined to the south of the granite belt.

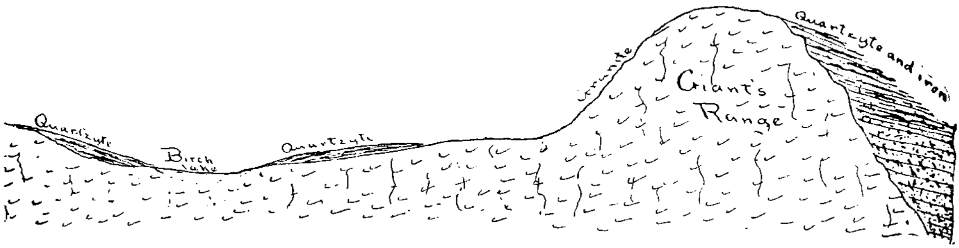


Fig. No. 1. Section from Birch lake to the Mesabi range.

It has been remarked that the quartzyte and magnetite strata which lie on the granite south of Birch lake are almost up to the very summit of the Giant's range.* The force of the ice sheet must have been very strongly felt on this exposed ridge, and erosion would be carried to a greater depth here than elsewhere. The fact that the Taconic strata are still found in such an exposed

*Seventeenth annual report Minn. Survey, p. 85.

situation is proof that the entire ridge was formerly covered by a considerable thickness of these rocks, and must have been elevated in that condition.

At the same time it is true that the fact that the Taconic strata do not extend north of the Giant's range, is an indication that there was a ridge of some sort there during Taconic time. It thus appears probable that the entire region north of the granite may formerly have been higher than now—perhaps even higher than the granite ridge—and has since subsided to its present level. The elevation of the granite hills was thus accompanied by a depression both south and north.

Cause of the Giant's Range Uplift.

In searching for an explanation of the gradual elevation of the Giant's range it is natural to look to the south, towards the lake basin, which is its apparent complement. The immense load of eruptive rock piled up on the north shore of lake Superior could scarcely fail to produce a sinking of the crust in that region. A depression in one part of the crust must be followed or accompanied by a corresponding change in contour and an elevation at some other place. Hence the most natural explanation of the hill range, which now forms the chief water-shed of Minnesota, is in the formation of the lake Superior basin and the outflow of great sheets of trap and gabbro.

These eruptions did not all occur at one time, part of them being found as inter-bedded or laccolitic sheets in the Taconic strata. The upward movement of the range was gradual, corresponding to the gradual accumulation of sediments and flows further south. There is not found in the quarzytes and slates, which now lie upon the granite hills at an elevation of fourteen hundred feet above the water of lake Superior, any stratigraphic deformation or mineralogic alteration which requires the supposition of rapid elevation. From this it follows that the petrographic nature of the Giant's range was practically the same as it is now, at the commencement of Taconic time. Metamorphism intense enough to produce the crystalline rocks of the range, would have had a similar effect on any strata resting upon them. But the slates and other rocks of the Mesabi do not show any evidence of metamorphosing agents aside from the superincumbent gabbro. The stratification is not destroyed, nor disturbed to any considerable extent, while the mineralogical changes observed are more likely to be the result of aqueous than of igneous action.

We have here a simple chain of reasoning from which to infer the solution of the as yet unsettled question of the stratigraphic position of the gabbro:

1st. The elevation of the Giant's range to its present position is post-Taconic.

2nd. The elevation of the Giant's range was caused by the gabbro, hence

3rd. The gabbro is post-Taconic.

This agrees with the observations and conclusions of R. D. Irving in the vicinity of Gunflint and Loon lakes. He has given a section south of these lakes which shows the olivine gabbro lying on top of the Animikie black slates and traps.*

ORDER OF STRATIGRAPHY ON THE MESABI.

The rocks exposed on the Mesabi are the following, in descending order:

1.	Gabbro unconformable on all the following,	Taconic.
2.	Black slates—Animikie, - - - -	Taconic.
3.	Greenish siliceous slates and cherts, -	Taconic.
4.	Iron ore and taconyte horizon, - - -	Taconic.
5.	Quartzyte unconformable on 6 and 7, -	Taconic.
6.	Green schists of the Keewatin, - - -	Archæan.
7.	Granite or syenite of the Giant's range,	Archæan.

It will be proper to give a brief description of the appearance and occurrence of each of these divisions. It is essential for economical exploration on the range, that these different rock horizons be recognized and distinguished from each other. The object of this sketch of the Mesabi range is more for the purpose of furnishing a reliable and simple account which will be understood and applied in future development, than a scientific discussion of the subject. To the explorer the difference between the green slates of the Taconic and the green schists of the Keewatin is of the utmost importance. The former lie, for the most part, above the ore horizon and the latter entirely beneath it. If he cannot distinguish them at sight he cannot tell which way to direct his line of test-pits, nor when to stop work in any one of them. If he calls the chert "quartzyte," and then concludes that he is below the ore because the quartzyte lies below it, he again makes a mistake and one which may be very costly or result in his missing his ore body entirely. Many similar instances have come under my observation. It is by determining such questions as

*Seventh annual report, U. Geol. Sur., p. 421.

these that geology aids the explorer and miner. Although an elementary knowledge of mineralogy and the composition of the more common rocks would assist in an understanding of the next few paragraphs, yet the principles laid down are so universal and the distinctions so obvious, that it is believed they can be understood and applied by anyone who reads them.

7. Granite of the Giant's Range.

The granite or syenite of the Giant's range lies north of the iron belt of the Mesabi. It forms high rounded ridges of pink or gray crystalline rock. It is composed of rather coarse crystalline grains of gray or flesh-colored feldspar, bluish translucent quartz and black mica or hornblende. It usually possesses no bedded structure and can be broken with almost equal ease in any direction. It is older than the rocks of the iron formation proper, and lies beneath them from the Mountain Iron mine westward. It has on the north a belt of crystalline mica and hornblende schists, and on the south seems to have a direct transition into

6. Green Schists of the Keewatin.

These schists constitute the rock commonly called "greenstone," or "dioryte" by explorers. They are gray to green in color, softer than the granite and have an earthy appearance instead of a bright crystalline lustre like the mica schists. The green schist has a cleavage which is nearly vertical—when it is not massive. It never occurs in horizontal layers like the quartzyte and slate. The lower bed of the Mesabi ore formation, *i. e.*, the basal quartzyte,—always rests upon this Archæan green schist or upon the granite, and the nature and extent of the ore bodies seem to be entirely independent of the underlying rock.

The green schist does not always follow the course of the granite range. It diverges and forms minor ridges, uplifting the quarzyte and iron strata for a distance of several miles from the main ridge. The presence of these ridges of granite or green schists, whether exposed or not, is one of the essentials to the existence of a body of soft ore, as we shall see later. This green schist is the same as that of the Vermilion iron range, and it is not impossible that lenses of hard iron ore may be discovered in it in some place beneath the ore of the Mesabi. These schists are covered in many places by

5. Quartzyte Unconformable on the Schists and Granite.

This rock is the lowest member of the Taconic strata which constitute the Mesabi iron formation. It is white, gray, green, pink or purple, and is composed of rounded grains of sand, mostly silica. It never has a high dip so far as seen on that portion of the range west of the gabbro overflow. Where it lies upon granite it is pink or white, or may be stained red by iron oxide. Where it rests on green schist it is finer grained, usually in thinner strata and gray or greenish in color. Near the bottom it often contains pebbles of quartz and granite, as well as jasper and greenstone. It has also been observed to contain white or pink mica in horizontal scales as large as half an inch across. In some thin sections the secondary enlargement of the quartz grains is well shown. In others the grains fit closely together and there are few interstitial spaces, although the quartz is crystalline. Where it is found in test-pits under the ore it has usually lost its character of hard vitreous quartzyte for some distance below the contact, and is a soft, coarse, crumbling sandstone, white or iron stained. No merchantable iron ore is found in or below this quartzyte, unless it should be in the green schist, and when this rock is encountered in a test-pit work should be discontinued as quickly as it would be in the granite or green schist. This quartzyte lies immediately under the taconyte horizon.

Its position with reference to the black slates has been a matter of some difference of opinion, and the writer formerly believed it to belong above them. There seems to be no question now, however, that this is the same as the Pewabic quartzyte at Gunflint lake and the Pokegama quartzyte of the Mississippi river, and that it is the lowest member of the Taconic. It has been assigned to the Cretaceous, Potsdam and Huronian by different geologists. Prof. N. H. Winchell believes it to be the equivalent of the Potsdam quartzyte of New York. It occurs at Sioux Falls, South Dakota, and at Baraboo, Wisconsin, in similar association with underlying granite and overlying iron bearing rocks.

4. Iron Ore and Taconyte Horizon.

Resting immediately upon the basal quartzyte, and apparently conformable with it, is a series of strata which present very different appearances in different localities, and which constitute the iron ore deposits in situations favorable for their accumulation. These strata consist of siliceous and sometimes calcareous rocks banded with oxide of iron or iron ore. The ore occurs in streaks or beds of indefinite length and thickness. It is sometimes magnetite, sometimes hematite, hard or soft. The rock which encloses these bands may be called a jaspery quartzyte, but it contains much besides silica. It is of various colors, but usually gray. It is occasionally cherty, often brecciated and sometimes conglomeritic. There are layers of jasper having a peculiar mottled and streamed appearance; there are others of fine quartz grains more or less mingled with grains of iron oxide; others again are so fine grained as to be flinty, with amorphous silica, which evinces great readiness to dissolve and leave cavities or soft porous streaks in the ledge. In its fresh gray condition one portion of it does not present macroscopically individualized constituents. The silica is clouded with some grayish or greenish element which appears to contain a percentage of lime or iron carbonate. This rock is widely spread over the whole length of the Mesabi, and being different from anything found elsewhere and peculiar to this horizon of the Taconic, has been called *taconyte* by the writer. It has not been studied microscopally or chemically as yet. The examination of specimens now on hand will probably yield further interesting information as to its nature and origin.

This banded jaspery quartzyte or taconyte horizon is not of great thickness. There is a rather abrupt transition below into quartzyte, but a more gradual one into the siliceous slate and chert member above.

The percentage of iron in this rock as it occurs unaltered is seldom sufficient to make it a merchantable ore, though there may be found layers of ore in it thick enough to work profitably like those west of Gunflint lake in T. 65–4. It is not to be expected that there will be any mines of magnetic ore on the central portion of the range. The taconyte, however, is found in all degrees of alteration into good iron ore. The nature of this alteration will be explained later. It is only necessary to add here that this is the horizon to follow in the search for ore. It is the rock which contains and produces the ore, and test-pits which reveal this member of the Taconic formation are not discouraging. Having found it the next thing is to find some uniform, even slope of considerable descent and let the test-pits follow it down, be it north, east, south or west.

3. Greenish Siliceous Slates and Cherts.

These strata constitute a sort of transition stage between the rocks of the iron horizon and the black slates. There is no proof of any unconformity either above or below this member, but lithologically it is distinct from the rest. There is a considerable mixture of greenish material, apparently of eruptive origin, either intimately mixed with the silica and fine argillaceous matter or in separate streaks. Even the extremely siliceous cherts which constitute the upper part of this horizon occasionally present a green ish appearance due to intermixture with this basic element. There is sometimes found a layer of dense but soft black argillyte in this zone, which seems to be an indication of the great thickness of similar rocks to be deposited later.

The chert is red, yellow, black, white or green, and in the Thunder Bay region has a thickness of two or three hundred feet. It is not known how thick it is on the central Mesabi. It is not strictly confined to this member of the Taconic, but is occasionally found as low as the basal quartzyte, and above high up in the slates. Its content of silica varies greatly. Now it will have the appearance of pure translucent chalcedony, and again it is mixed with oxide of iron or some carbonate of lime and iron. It frequently possesses a peculiar brecciated appearance, having been thoroughly shattered into angular fragments which are re-cemented by the same amorphous silica.

This angular fracturing or jointing is also visible in the iron ore, even when it is soft enough to excavate with pick and shovel. It is more difficult to account for the large amount of silica in these cherts, which lie above the iron ore horizon, than for that which has enlarged and cemented the grains of the quartzyte below the ore. In the latter case the silica has been removed in carbonated solutions from the ferriferous layers down into the quartzyte and there deposited. How it came to be accumulated in such quantity at the chert horizon is a matter for future study. When the explorer finds this flinty slate formation it is safe to conclude that he is above the ore horizon (that is, above where the ore is, if there is any there) and must go deeper or farther *up* the general slope of the region.

2. Animikie Black Slates.

The upper slaty strata of the last division soon pass into this, which, so far as examined on the central part of the range, consists entirely of several hundred feet of carbonaceous argillytes. Diamond drill records do not show the presence of the interbedded traps which are seen in the same horizon around Gunflint lake and eastward. It is possible that these eruptives may be higher up in these slates and will be discovered by future drilling farther south. These slates have the usual dip of the entire Taconic series on the

Mesabi, viz., from horizontal to 20° to the south or southeast. The dip is locally as high as 45° in some of the ore deposits where they lie close to the green schist.

These slates are supposed to extend southward under the gabbro to the St. Louis river, and then to appear again with a high dip and somewhat distorted stratification. If the St. Louis river slates are Animikie, as supposed, it is quite likely that the lower horizon of iron ore and quartzyte may also come to the surface in the same vicinity, and thus still another iron range may be discovered, still nearer Duluth. It is obvious, however, that with the high dip of the St. Louis slates the ore deposits would soon lead to deep mining and lose the advantages which the Mesabi possesses in lying in flat deposits.

The practical inference to be drawn from black slate outcrops on the Mesabi is that they are always *above* the iron ore horizon, and surface exploration must be pursued in the direction contrary to the dip.

The task of test-pitting through the black slates is almost a hopeless one, for the dip is sufficient to make a depth of several thousand feet in a few miles. In case of diamond drilling, where the property is all within the slate area, the only general advice is to get as near the north side of the property as possible, for if there is any ore under the slate it will be found in a shorter vertical distance there than farther south.

1. Gabbro.

This rock is sometimes called "granite" by explorers. I have heard some of them say that there is granite on both sides of the ore belt in 59–14. But the average explorer knows the difference between granite and gabbro. Granite has a pink color and contains crystalline grains of lavender blue quartz, together with mica or hornblende.

Gabbro is gray—seldom if ever pink, and contains no free quartz. It is almost wholly composed of gray feldspar (labradorite), which has pearly and often striated cleavage planes and is softer than quartz. The hills south of the iron belt in 58–16 are composed of this gabbro, which probably lies above the black slates and underlying iron rocks. The gabbro poured out of the earth's surface like lava and flowed north over the surface of the country, tipping the rocks up on edge and sometimes floating along huge slabs of the Taconic strata several hundred feet long, which are now found standing at various angles surrounded by the cooled gabbro.

From Birch lake eastward for several miles the gabbro flowed so far north as to cover the iron belt completely and we now find it lying on the granite. The effect of the heat of this molten gabbro was to make the iron ore, which already existed in the rocks, hard and magnetic, and this effect seems to have been felt for miles away from the edge of the gabbro.

Other minerals besides iron were changed by the same agency, and even so hard a rock as the quartzyte was so changed that samples of it have recently been designated "altered gabbro" by an eastern petrographer.

There is good reason to believe that the iron ore deposits in their present condition have been formed principally since the gabbro overflow. There was a certain amount of iron in the rocks originally, but this has been greatly augmented and concentrated in more recent times.

Accompanying the gabbro is frequently more or less black magnetic ore, which carries an injurious amount of titanic acid. This black ore occurs in grains in the rock nearly everywhere, and sometimes forms large deposits. It has a dull lustre and is not finely granular like the magnetite of the Taconic strata. It also lacks the evidences of stratification everywhere visible in the quartzyte and associated ores.

The northern and western boundaries of this gabbro sheet are approximately shown on the geological map accompanying Bulletin No. 6 of the geological survey. It will there be seen that there is no trace of this rock known west of range 16, and it is to be expected that the slates will be found immediately under the glacial drift west of the gabbro. The ore also loses its magnetic quality as we approach the Mississippi river, and at Prairie river it is nearly all hematite.

Although parties of explorers have recently gone into the gabbro area on Partridge river, equipped for test-pitting, it is scarcely necessary to say that there is no good reason to expect merchantable iron ore deposits in or under this eruptive flow in any place but along the northern edge, where it covers the ore belt. Farther south it reaches a thickness of hundreds of feet, and the slates below are still hundreds of feet above the ore horizon.

The advice in general is: Keep away from the gabbro. The ore found under it will be magnetic, may be titaniferous and is sure to be mixed with lean siliceous portions which will interfere with cheap mining.

OCCURRENCE OF THE ORE.

In the foregoing pages it has already been indicated how the ore occurs. Among explorers and miners on the range there is great confusion of ideas on this point. It is said to be in veins, and many are still searching for a hanging wall and predicting that the flat portions occurring without one, are what they term "slop-overs." It is quite common to be told that the vein will soon take a high dip to the south and go down at an angle of 60°, more or less, to a great depth. Those who entertain this opinion go still farther and look for the continuation of the "vein" to an indefinite distance across the country in one direction. The proper direction is often rather absurdly ascertained by drawing a line through the locations of two or more mines on the map and extending it across adjacent property for miles. The amount of money already spent in extremely unpromising locations that have been selected in this way would buy several good mines. Others say that the ore is a surface "wash" which has settled in waters of very recent date in troughs or valleys. Still again it is said that the ores are eruptive, and the shiny limonite coating in some cavities is pointed to as unmistakable evidence of fusion and rapid cooling.

The most ancient of ideas is held by some that the ore deposits date from the creation of the world, and those who hold this idea say wisely: "Where it is there it is, and you cannot see any further into the ground than any of us, nor tell us where the ore is likely to occur." It would be extremely rash to deny the truth of the old Cornish saying, but repeated experience has proven that a knowledge of the geology of a region will and does enable us to tell where the ore *probably* exists and where it does not.

The occurrence of the Mesabi ores is not in veins or lodes. No hanging and foot wall proper are to be found. The deposits lie on quartzyte, and for convenience that may be called the foot wall, but it has not the same significance nor does it bear the same relation to the ore body that a true foot wall bears to a true vein. In rare instances the ore will be found with a "capping" of jaspery quartzyte or taconyte varying in thickness from a few inches to thirty feet or more. This will be called a hanging wall, but not properly. Moreover, the course of the ore deposits is not persistent in one direction unless the slope of the ridge on which they lie has a straight trend. The soft ore bodies follow the slopes, and when they change direction the ore deposit usually either comes to an end or changes also. This can be seen at several places, but especially marked at the Mountain Iron mine. The ore first discovered lies in a horse-shoe basin, the sides of which are high and have a steep slope. The ore follows the side of this basin and is discovered in pits which follow the slope around to the northwest, as well as on a subordinate ridge which runs south and southeast for half a mile. There is no principle more universal on the range than this: the presence or absence of an ore body depends on the presence or absence of an elevation, on the slope of which the proper horizon of Taconic strata occurs. This idea will be further explained in discussing the origin of the ore.

The ore deposits are not likely to assume a high dip and thus to extend to great depths. On the contrary, as we go south away from the granite and green schist ridges, the entire formation flattens down and the dip is hardly perceptible. This fact is not indicative of the existence of soft ore deposits under the slates at great distances south from the iron belt, as at present defined.

The ideas of surface "wash" and eruptive flows are also necessarily discarded. The existence of oceanic stratification and the frequent transition from soft ore into the rock strata of the ancient Taconic are alone sufficient to disprove both of these ideas. Moreover, there is no trace of the chemical action which would have taken place if the ores were eruptions, nor does the physical character of the ore harmonize with this idea. The deposition of limonite in shiny coatings in crevices and elsewhere, is by the action of aqueous solutions, and instead of being an indication of heat is just the reverse.

Ore Deposits Occur in Beds.

The Mesabi ore deposits are in regular *beds*. They constitute part of the Taconic strata and are still in almost their original position. They are part of the horizon which lies next above the basal quartzyte. They grade into the rocks of this horizon in all directions laterally, and occasionally both above and below. As a rule, however, the ore lies directly on the softened and disintegrated basal quartzyte which does not contain much iron oxide. The bedding planes of the original strata are perfectly preserved in the ore, as are the joints and even the differences in texture of the various layers of jasper, chert, coarse and fine taconyte and slate.

The ore deposits thus far discovered on the Mesabi, with few exceptions, lie just below the glacial till, which varies in depth from a few inches to one hundred feet. The ore body has a depth equally as great, and usually is wedge-shaped with the narrow end or side lying toward the top of the slope and the thickest portion farther down. There may be occasionally a knoll or ridge of jaspery quartzyte lying above the surface plane of the slope. In this case the ore generally passes under the knoll, which thus forms a capping; but occasionally this hard knoll or ridge extends downward unaltered to the basal quartzyte and constitutes a "horse" in the ore body. These "horses" are called "dykes" by some explorers. They are not true dykes, however, but parts of the general formation which do not cut through the quartzyte below the ore, as eruptive dykes would.

True dykes are not common along the range, and their absence constitutes one of the chief points of difference between the Mesabi and the Penokee-Gogebic. The accumulation of the Mesabi ores cannot be due in any way to dykes, for there are none associated with the ore, and no ore where dykes are found. This fact indicates that perhaps the ore deposits on the Penokee-Gogebic, instead of being produced through the agency of the dykes in forming troughs in which the ore was deposited, have been formed *in spite* of the dykes and would have been much deeper and more extensive had it not been for them. From what can be seen on the Mesabi, dykes and even troughs are unnecessary features, the ore being due to a replacement and concentration process which has proceeded on all uninterrupted slopes of sufficient pitch where the proper rocks exist for such a change. This operation or process of replacement, moreover, extended as far down the slope as the local conditions have permitted since the rocks were elevated to their present position. If the slope was a long one, and in the shape of a large basin, the ore deposit is large. If it was narrow or interrupted by numerous gorges or ridges, the ore is apt to be limited in quantity and of poorer quality. Where there was an opportunity for the greatest freedom of drainage and the most extensive percolation of solutions through the rocks for a considerable thickness, and over a considerable area, there are found the purest and largest accumulations of ore.

It is quite possible that there may be in places two or more parallel lenses of ore separated by ridges of unaltered taconyte. This might easily occur where the taconyte horizon is uncovered over a considerable area and where the surface consists of an undulating succession of ridges with gradual slopes. The usual dip of the Taconic rocks on the Mesabi is so slight that it does not always exceed the general slope of the surface of the country south of the Giant's range. For this reason there may occasionally be a succession of elevations, on the sides of which are ore deposits; and since the elevated portions of these ridges are usually magnetitic and the ore bodies are not, a dip needle may be used to advantage in locating the ore. Fig. 2 illustrates this idea.

The nature of the lateral and lower boundaries of the ore deposits will be more or less a matter of speculation until some are mined out. The extensive developments and the large production of ore already arranged for, promise interesting revelations within the next two or three years. At the present time, however, some idea of the appearance of the open pits, when the ore has been mined out, can be gained from a consideration of its mode of occurrence, as already known.

The upper edge is generally thin and rather the poorest ore. If this part of the ore is stripped and taken out it will leave the basal quartzyte exposed, dipping south at an angle of 10° to 40°. The lower side of the ore bed is more or less mixed with sand from this quartzyte. Hence the bottom of the open pits will be an almost plane surface dipping as the quartzyte dips, and at a short distance resembling soft ore more than quartzyte. The ore will gradually deteriorate below a certain depth in all pits and in an excavation until it becomes too poor to be mined.

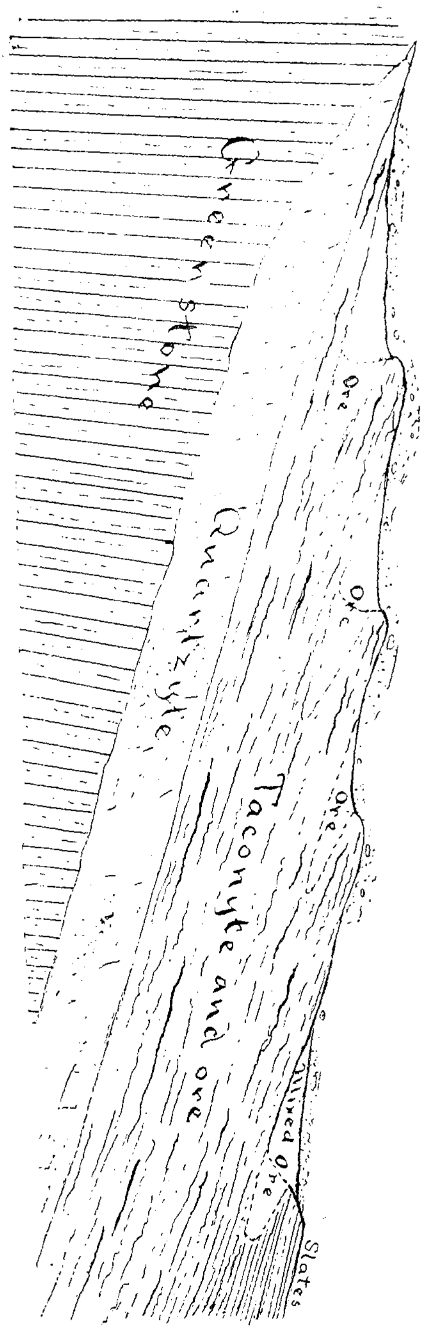


Fig. 2. Possible method of occurrence of parallel lenses of ore.

The sides of the ore bodies will present rather abrupt transitions into the jaspery quartzyte of the iron ore and taconyte horizon. It is not to be supposed that the limits of the soft ore will be marked by a wall or definite boundary plane on any side or at the lowest edge. It is rather to be believed that the ore extends into the rocks in sheets of variable thickness, and that when followed up and mined out, the lower edge of the remaining open pit will have a very ragged appearance something like the following, figure 3.

The ore on the lower, thicker edge may also be expected to deteriorate and become more like paint rock and earthy than the lower strata, which are mixed with sand. The capping or hard ridges already mentioned may present some interesting examples of the process of the replacement of silica by oxide of iron, which can be easily examined and studied when the surrounding ore is removed.

There are other interesting phenomena which can only be explained fully when the ore in their vicinity is removed. There appears to be a gorge on the Lone Jack and Missabe Mountain properties, excavated to the depth of sixty feet in the soft ore by some preglacial stream and subsequently filled with rounded, water-worn pebbles of hard ore. Test-pits on each side of this gorge filled with ore-gravel encounter fine, soft hematite just below the glacial drift, which does not here exceed twenty feet in depth. At the bottom of this ore gravel is a stratified layer or series of layers of white kaolin, more or less stained and mingled with fine red iron ore. This layer varies from a few inches to twelve feet in thickness and its true nature has not been ascertained. Below it is found the same blue hematite which occurs in the test-pits on both sides of the gorge sixty feet nearer the surface.

There are also gorges apparently scraped out by solid ice and filled by sand and gravel. On the Berringer forty, sec. 4, 58–16, a test-pit seventy-two feet deep has been sunk at the edge of one of these gorges. The east half of the pit passes down through soft blue hematite from the depth of forty-eight to seventy-two feet, while the west half of the pit is sand and gravel for the same distance. The wall of the ore is nearly perpendicular and seems to have been planed off. A short distance farther west there is a test-pit nearly one hundred feet deep, which did not strike anything but glacial till. These facts are an indication that the soft ore was essentially in its present condition at the time of the last glacial epoch.

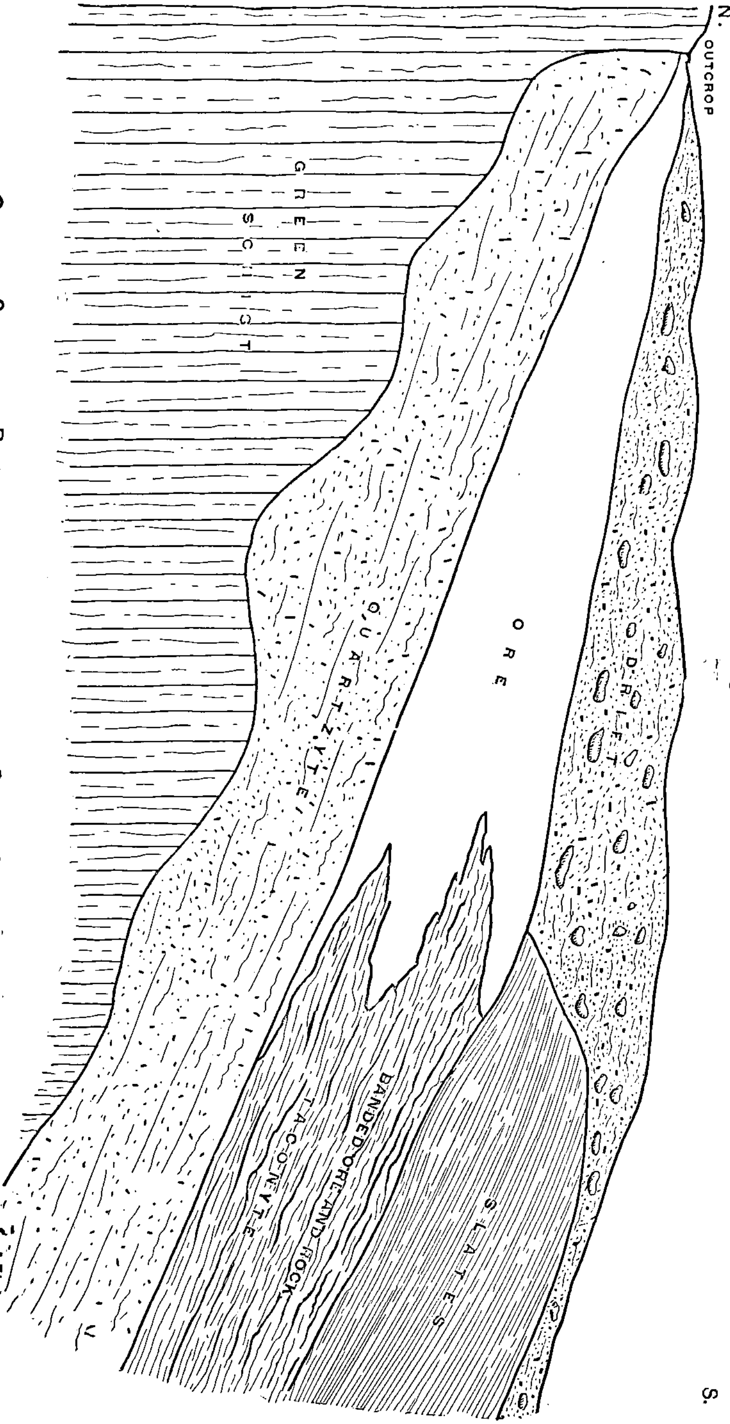


Fig. 3.

GENERAL SECTION AT BIWABIK, SHOWING RELATION OF ORE TO SURROUNDING ROCKS.

Am. Bank Note Co. N.Y.

VARIETIES OF MESABI IRON ORE.

MAGNETITE.

The ore of the eastern portion of the Mesabi probably owes its magnetic properties to the heat of the gabbro overflow upon the hematites which were deposited in the rocks at the time of their formation in the oceanic waters.

Where this ore is associated with the lower beds of the Taconic it is rather coarsely granular and shiny. The ore which occurs higher up in the horizon is fine grained and compact, having a high specific gravity. Individual samples of this ore show a high percentage of iron and a low content of phosphorus and sulphur. Unfortunately it seldom occurs in beds of sufficient depth to render it valuable without concentration.

It is noticeable that there is a small percentage of magnetic grains in the blue-black, soft, granular hematite of the central portion of the range. A magnet will pick out grains from a handful of this ore from almost any test-pit in which it occurs. Its presence adds somewhat to the percentage of iron in the ore and does not produce any deleterious effect.

Small streaks of black, shiny, crumbling grains were noticed first in the test-pits on the Cincinnati property. They were at once seen to be magnetite, but their occurrence at the depth of sixty feet in solid strata of limonite and hematite was a surprise. The only well known means of producing magnetism in oxide of iron is by a considerable degree of heat. It is evident that it would be impossible to apply heat to a particular streak a couple of inches thick in the depths of such a deposit as that without also heating adjacent strata. Had the heat come from above all that portion of the deposit lying above this particular layer would also be affected by it. Had it been heated in some way from below there would be no hydrated ore left below it.

There are three possible hypotheses:

1. There may be some way to render ores magnetic aside from heating them.

2. This streak may have been heated and magnetized after deposition in its present position before the adjacent strata had their present chemical composition.

3. The ore may have been deposited here as magnetite originally.

In the Tenth Annual Report of the U. S. Geological Survey Prof. Van Hise has advanced the idea of the formation of magnetites by chemical processes during the oxidation and concentration of iron carbonates. He supposes that in the presence of an insufficient amount of oxygen, siderite may have been altered directly into magnetite. As a proof of this he mentions the fact that some of the magnetite is pseudo-morphous after siderite, and also that the hematite and magnetite are intimately mingled in the rocks of the Penokee-Gogebic range. He even states that it is exceedingly probable that all the magnetite is of secondary origin by chemical alteration of siderite at a low temperature.

In the case of the Mesabi magnetites we may admit that a portion of the magnetic grains may have been produced in this way. It is, however, not admitted that it is wholly due to such action. There are abundant evidences that much of this iron ore is an original constituent of the rocks, as siderite, magnetite, or sesquioxide of iron, probably the latter. The effect of a gabbro overflow would certainly be to render this original ore magnetic, if it were not already so, and less liable to chemical decomposition than the hematite and limonite. The magnetic oxide of iron is its most stable natural compound. It is often found unchanged by atmospheric agencies in exposed situations where other minerals have been deeply eroded and considerably decomposed. While the oxidation of magnetite into hematite is possible and has been observed in certain localities, it is not so common as the series of changes from siderite through limonite and hematite to magnetite. The pseudomorphs of magnetite after siderite mentioned above may be hematite pseudomorphs rendered magnetic by heat.

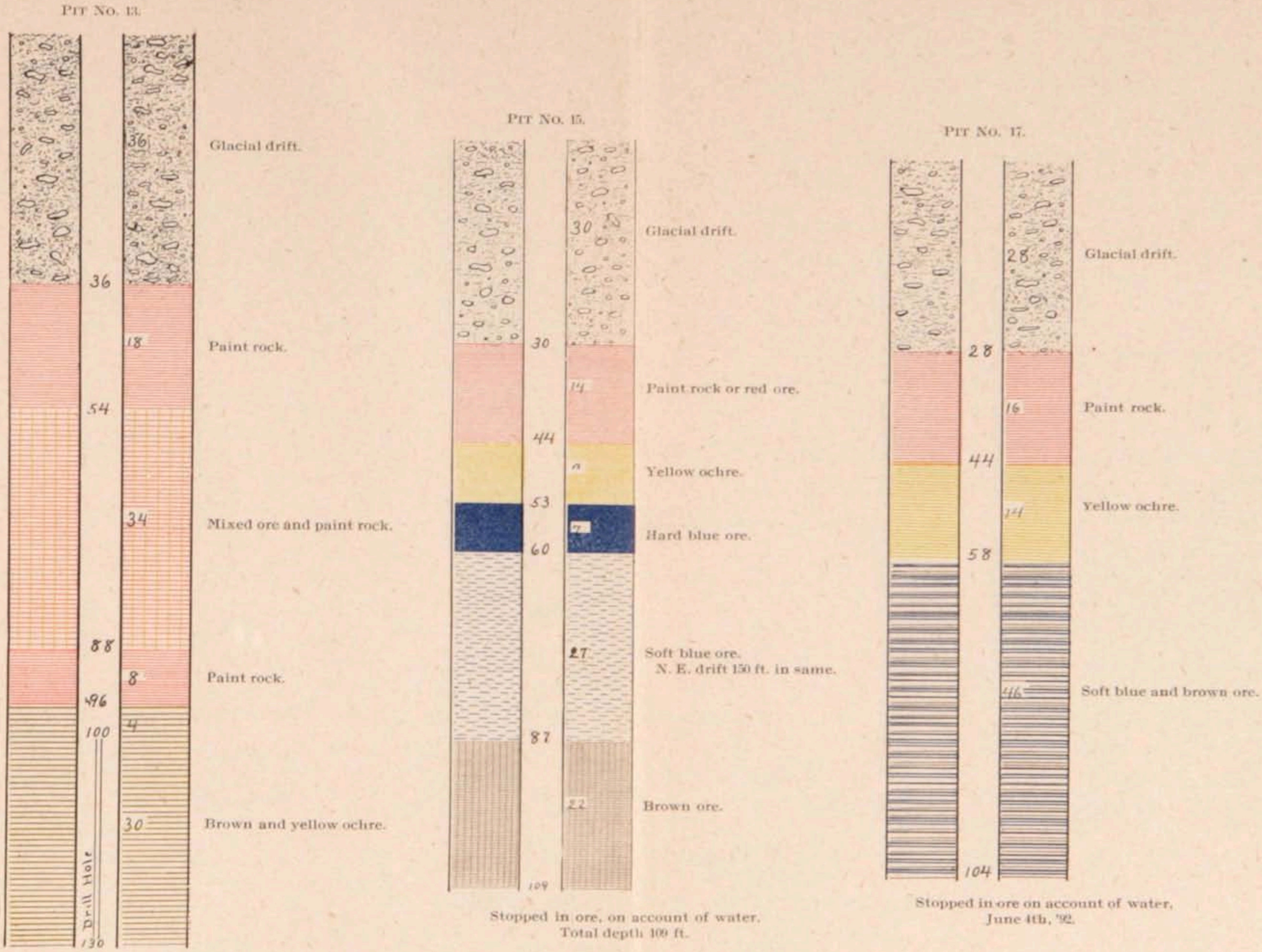
One difficulty in the way of an acceptance of the idea of this method of the formation of magnetite on the Mesabi is the fact that the magnetic strata are found near the surface of the ground where all chemical changes for a great space of time have been accompanied by an abundance of oxygen. Prof. Van Hise supposes that hundreds of feet, perhaps even thousands, of solid rock have been removed by erosion above the present surface on the Penokee-Gogebic range. There is strong evidence that no such depth of erosion has taken place on the Mesabi. The iron ore beds are essentially surface products, and do not occur under any great thickness of rock strata. The principal agent of erosion is glacial action. The freshness of glacial striæ and the drift mantle covering the rocks show that no postglacial erosion has taken place, and it is not likely that preglacial erosion was conducted to such a great depth. Moreover, it is only by the exposure of the very strata now found at and near the surface during all the ages since the gabbro overflow, that such extensive alteration deposits can be accounted for. Hence, unless the presence of some powerful reducing agent can be proven, the magnetic element of the rocks must be explained in some way which admits the presence of an excess of oxygen. It is not known at present whether the magnetite extends to any depth under the slates southward or not. All the facts we possess indicate that it does not. The heat of the gabbro cannot be supposed to account for the existence of magnetic ore in the rocks twenty miles or more distant. It may be that simple surface weathering of long duration is able to produce magnetic oxide from sesqui-oxide. It cannot be derived from a carbonate, for the resultant of surface alteration of siderite is always a sesqui-oxide. Admitting, then, that further study is necessary to account for the magnetic strata in the rocks between the Mountain Iron mine and the Mississippi river, we must still affirm our belief that the magnetic streaks in the pits of the Cincinnati represent ore that was originally deposited in the rocks as a hydrated sesqui-oxide and was rendered magnetic by the gabbro overflow. These streaks represent all the iron there was in the rocks at that time. The effect of the gabbro eruption was to elevate the Giant's range, and from that time until the present the process of ore deposition in these rocks by the decomposition of carbonates, if any were present, and the replacement of silica by ferric oxides, has been progressing. The result has been the formation of large deposits of pure ore in which the magnetite layers are interbedded with the more recent non-magnetic ores.

The titaniferous magnetites have already been mentioned. They occur in the gabbro, and are valueless at present. Their manner of occurrence and chemical composition are described fully in Bulletin No. 6, Minn. Geol. Surv.

GŒTHITE.

This ore is the first to be found below the glacial drift in many test pits on the Hale, Kanawha, Cincinnati, Canton and Biwabik. It is soft, homogeneous yellow ore and occurs in layers several (six to twenty) feet in thickness. It was at first called limonite, but its high percentage of iron, as revealed by several analyses, together with the large amount of combined water showed that it is gœthite. As a rule it is non-bessemer. It is called "yellow ochre" by the miners and is frequently thrown out as poor ore. Its composition when absolutely pure is sesqui-oxide of iron 89.9, water 10.1, metallic iron 62.9. It occurs in such large quantities on this range that the term "Mesabite" may appropriately be applied to it to distinguish it in the iron trade. The following analyses show its purity:

Berringer yellow ochre, Iron 60.65, Phos. .070.

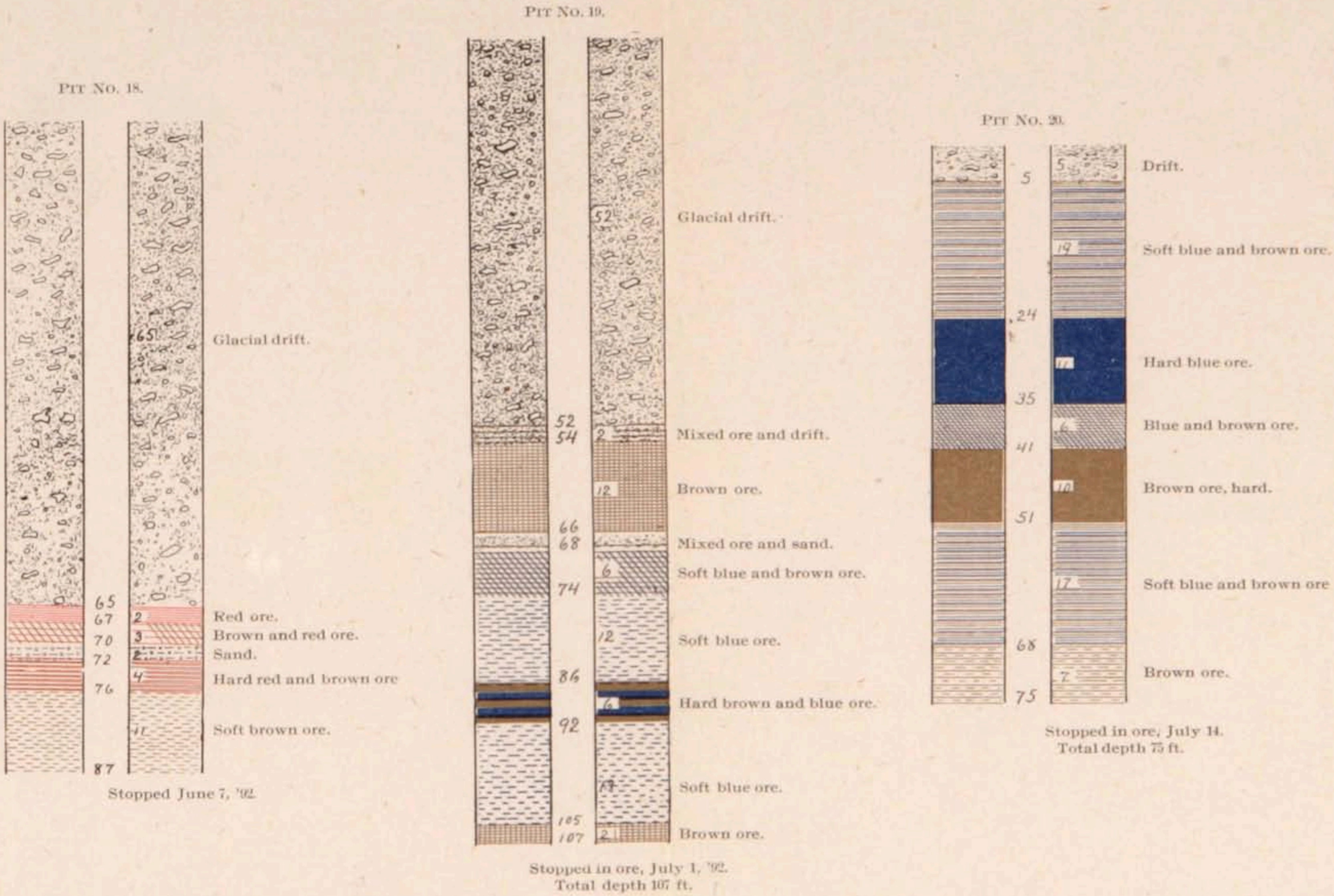


Pit No. 13: Stopped in ore, June 15, '92, in yellow ochre. This is the same ore that overlay the blue ore in No. 15. Shaft stopped on account of water. Total depth 130 ft.

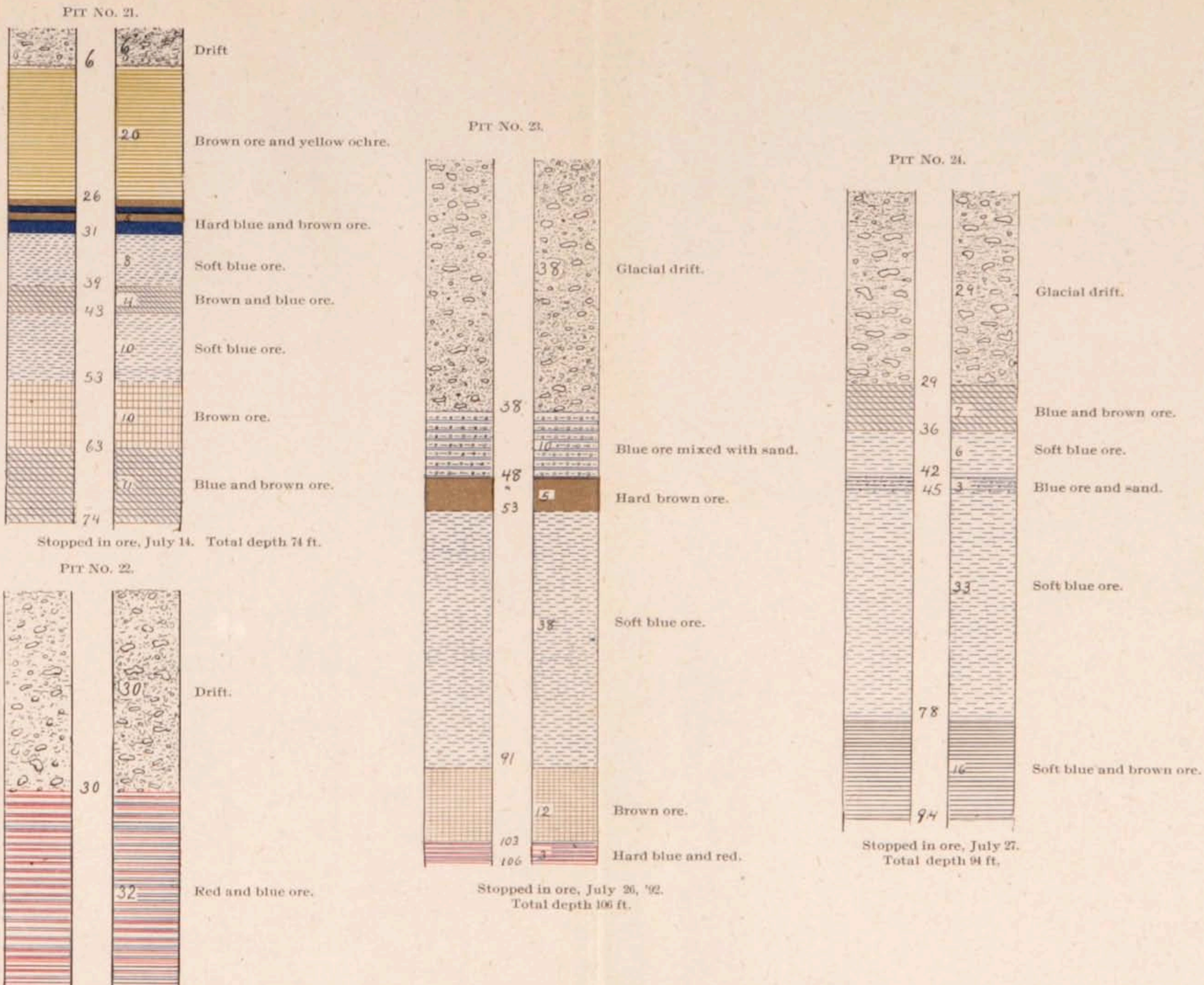
Pit No. 15: Stopped in ore, on account of water. Total depth 109 ft.

Pit No. 17: Stopped in ore on account of water, June 4th, '92.

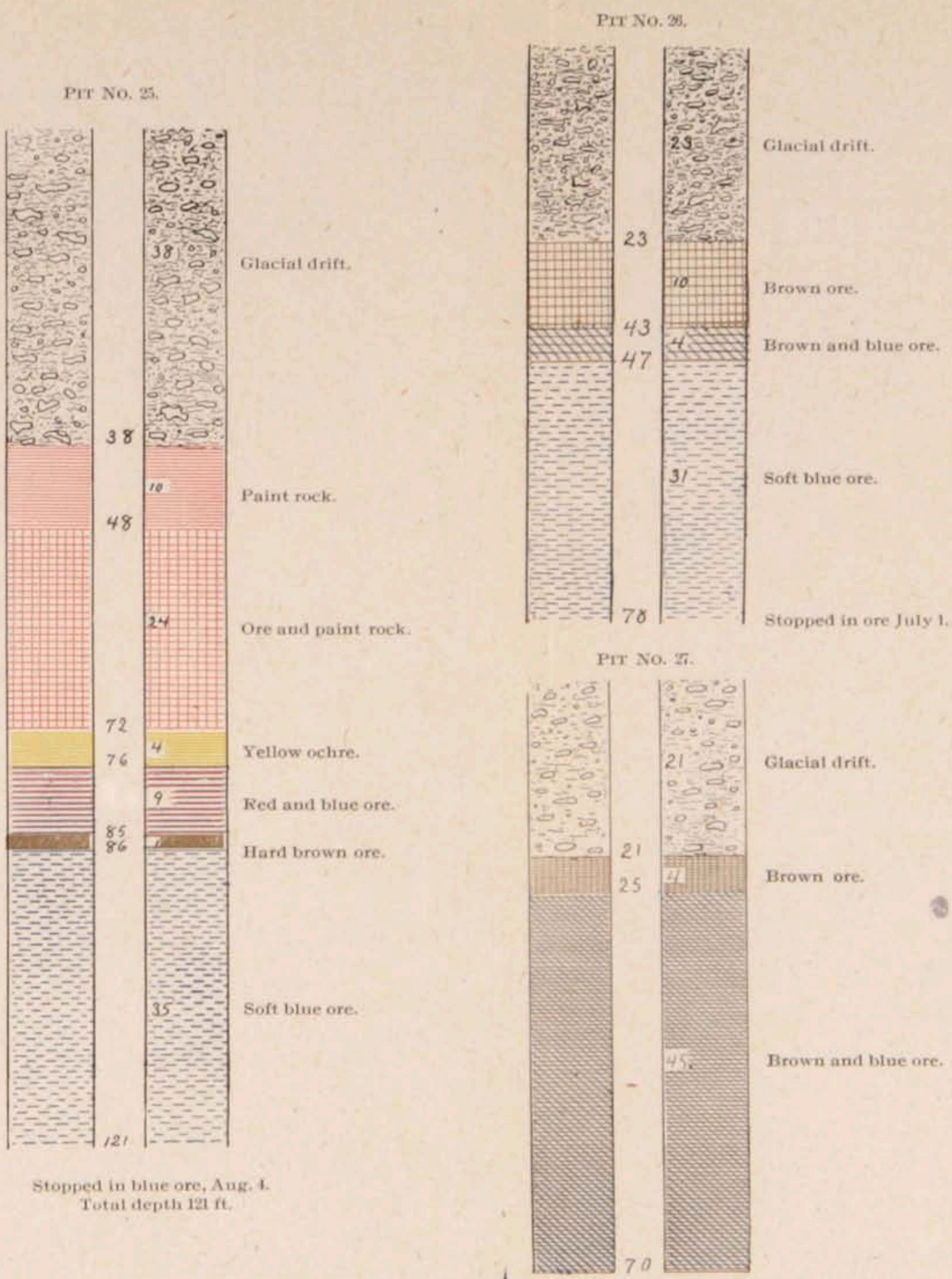
TEST PITS AT THE BIWABIK MINE.



TEST PITS AT THE BIWABIK MINE



TEST PITS AT THE BIWABIK MINE.



TEST PITS AT THE BIWABIK MINE.

Canton yellow ochre, Iron 60.65, SiO_2 2.09, Phos. .105, Comb. H_2O 8.04. Free H_2O 9.86.

Canton yellow ochre, Iron 60.75, SiO_2 1.85, Phos. .065, Comb. H_2O 10.05. Free H_2O 12.77.

Canton yellow ochre, Iron 60.90, SiO_2 4.85, Phos. .029. Some analyses indicate 61.5 per cent. of iron.

This ore will perhaps be of more value for the manufacture of mineral paints than for use in the furnace. It can be obtained cheaply and in large quantities.

LIMONITE.

Hard masses and layers of brown hematite are found in many pits on the Mesabi. The ore is inclined to be siliceous and rather high in phosphorus. Many cavities are lined or filled with grape and pipe limonite ore. It seems to occur in portions of the ore bodies where considerable streams of water flow, continually or at certain seasons of the year, through the rocks and ore. Only a small percentum of all the ore in any mine so far discovered has been shown to be of this mineral. It is perhaps the least valuable of any except the titaniferous ores on the range.

HEMATITE.

By far the larger part of Mesabi ores are hematites, as the term is used by mineralogists, *i. e.*, anhydrous sesqui-oxide of iron, whether hard or soft, crystalline, massive or earthy, red, blue, purple, brown, green or black. All varieties and all textures occur on this new range. The variation in appearance is remarkable, but the uniformity of composition is equally so. It is only after considerable experience in the ores of the range, and a careful examination of each variety by a hand-glass that the ore expert can tell which ore is the best and approximate its percentage of superior excellence. To be sure there are high and low grade ores here as on any other range, but samples of ores of at least ten totally different macroscopic characteristics can be selected that will not vary two per cent. in iron content. The process of ore formation here has been a discriminating and selective process, and has progressed regardless of color, hardness or texture.

The best grade of hematite is the blue-black soft ore found at many of the mines. Where this ore is in perfectly crystalline grains which possess little adherence to each other and will not "pack" in one s hand as do the more earthy ores, the percentage of iron reaches almost absolute purity. One sample of thirty feet of this ore from pit No. 15 on the Biwabik, taken by E. P. Jennings, yielded an analysis of 67.90 per cent. iron, 1.8 per cent. silica and

.016 per cent. phosphorus. Such ore as that is not excelled anywhere. It is this exceedingly pure ore that brings up the average of Mesabi ores. Without it there are several properties which would be non-bessemer; with it they are a good bessemer.

The general order of succession of the various kinds of ore is indicated by the plates of sections (Plates I, II, III, IV, V) from the Biwabik, furnished me by Mr. Jno. T. Jones and P. L. Kimberley.

Manganiferous Ores.

Black oxide of manganese is found in hard and soft streaks in the ore of many mines on the range. As yet it has not been found in sufficient quantities to guarantee any considerable production of manganese ore or manganiferous iron ore. It will be strange, however, if some such ore is not produced from the range, since so many indications are met with, and the conditions are so favorable for its accumulation. Moreover, such ore is mined in limited quantity on the Penokee-Gogebic range, which is the undoubted equivalent of the Mesabi.

ORIGIN OF MESABI ORES.

In Bulletin No. 6, on the Iron Ores of Minnesota, the idea was advanced that the bands of ore found interstratified with the Taconic rocks of the Mesabi are due to oceanic precipitation as hydrated sesqui-oxides at the time the sediments were deposited. Subsequent pressure and heat are supposed to have dehydrated the ores and the gabbro outburst to have rendered them magnetic. This idea is still maintained and has been strengthened by recent observations. But it accounts for only one portion of the Mesabi ores. Those original bands of iron were of limited thickness and were interstratified with rock material. The ore deposits recently discovered have none of these rock strata left. They were either never present or have been removed. On page 146 of the report referred to above is also found the following statement:

"We are quite ready at this time to adopt the theory that has been referred to originating with Prof. Edward Hitchcock, and more recently adopted by Prof. J. D. Dana and Prof. R. D. Irving, that these carbonated beds may be changed, and have been, on a large scale in the Taconic rocks of New England and of the Penokee-Gogebic range, by infiltrating waters, that their alkaline constituent has been carried away and their iron has been redeposited or concentrated in a residual condition as ferric oxides, and that by this concentration large beds of iron ore have been formed. It is because of this that we state our belief that possibly important beds of limonite or hematite, originating in this way, may yet be found in the Taconic region of Minnesota, the parallel of those that have recently been opened up in northern Wisconsin." This is a partial statement of the theory adopted by the writer for the ore deposits under discussion. From careful personal examination of the work on all parts of the Mesabi during its entire process of development, the idea has become stronger and more firmly fixed in his mind that these deposits are mainly due to chemical alteration and replacement of some mineral by oxide of iron. There is a general harmony of facts and phenomena observed which go to support this idea, and which apparently are not in consonance with any other theory. The usual conditions existent at the different mines on the range, so far as they have been exploited, are the following:

1. There is a deposit of ore situated on some hill-side or in some basin.
2. This ore is regularly stratified.
3. The planes of stratification dipping less than 30° pass from the ore into and through the banded jaspery quartzyte or taconyte horizon in three directions and occasionally on all four sides.
4. The ore strata correspond in texture with the rock strata which appear to be their continuation.
5. Underlying the ore is usually a quartzyte horizon.
6. Just beneath the ore this quartzyte is decomposed into a crumbling sandstone, but it becomes vitreous a few feet below.
7. This quartzyte is impervious and presents an absolute barrier to surface infiltration. This fact is shown (1) by microscopic examination of the vitreous quartzyte, (2) by test-pits sunk into it, (3) by the large amount of surface water in the ore as the boundary between the ore and quartzyte is approached. The ore is porous and permits the water to filter through it. Test-pits are sunk through dry ore to the depth of nearly one hundred feet, where the ore body covers a considerable area, but water in large quantity is invariably encountered a few feet above the quartzyte.

Exceptional occurrences which tend still further to prove the replacement theory are, (1) the existence of deposits of half ferrified rocks with ore in bands and in isolated centers of deposition. In such situations the process of ore production, or natural manufacture, so to speak, can be observed in all stages of progression. (2) The occurrence of knolls of taconyte lying on top of the ore deposits, having been above the course of the chemical percolations, and thus having remained unaltered.

It is a fact confirmed by abundant observation that the iron ore occurs precisely at the taconyte horizon. It lies neither above nor below it, but in it and of it. It is natural that the process of this transformation into ore should be limited by the local environments. If the angle of the slope down which surface waters have flowed be too steep or too flat there is no resultant ore body, if it is moderate the ore deposit may have been produced to a great depth and width. If the basal quartzyte comes to the surface at the upper side of the slope the atmospheric waters appear to have flowed down along the line of separation between the taconyte and quartzyte. In this case it may happen that the process of replacement extended but a short distance above the quartzyte and there may be an unaltered capping of taconyte above the ore. If the hill side and top are covered with the jaspery quartzyte and banded ore formation the infiltrating waters sometimes seem to have worked a change downward into these rocks and there may or may not be an unaltered remnant of the taconyte horizon below, according to the original thickness and the natural facilities for chemical action.

There is even a third case seen on the Chicago property, in which a body of soft ore nine feet thick has been produced in the taconyte formation, and is seen graduating into the hard banded rock on all sides.

The process of replacement is of two or three varieties. Certain strata seem to be more easily ferrified than others, and instances are common where the wavy line of ferruginization is seen encroaching upon the blue or gray unaltered taconyte. This may often be followed in a single hand sample from taconyte to ore, while the stratification, texture and often appearance remain the same. The remarkable part of it is that all the original mineral elements have gone and the result is such pure oxide of iron. There is much silica of a chalcedonic or amorphous nature in the taconyte, and occasionally layers of quartzyte, but all these can be observed in the actual process of replacement by iron ore.

On the Cincinnati property it even appears that some of the basal quartzyte has been replaced by iron oxide. Samples taken from here show a complete transition from quartzyte to iron ore. In some of the intermediate samples the individual grains can be seen in all stages of removal. There are many encased in a shell of hematite, which can be seen increasing in thickness until on breaking the black grain no white silica grain is found. It has all been removed. With a specimen of this sort in hand it is impossible to doubt that here is an instance of the removal of silica and its replacement by sesqui-oxide of iron.

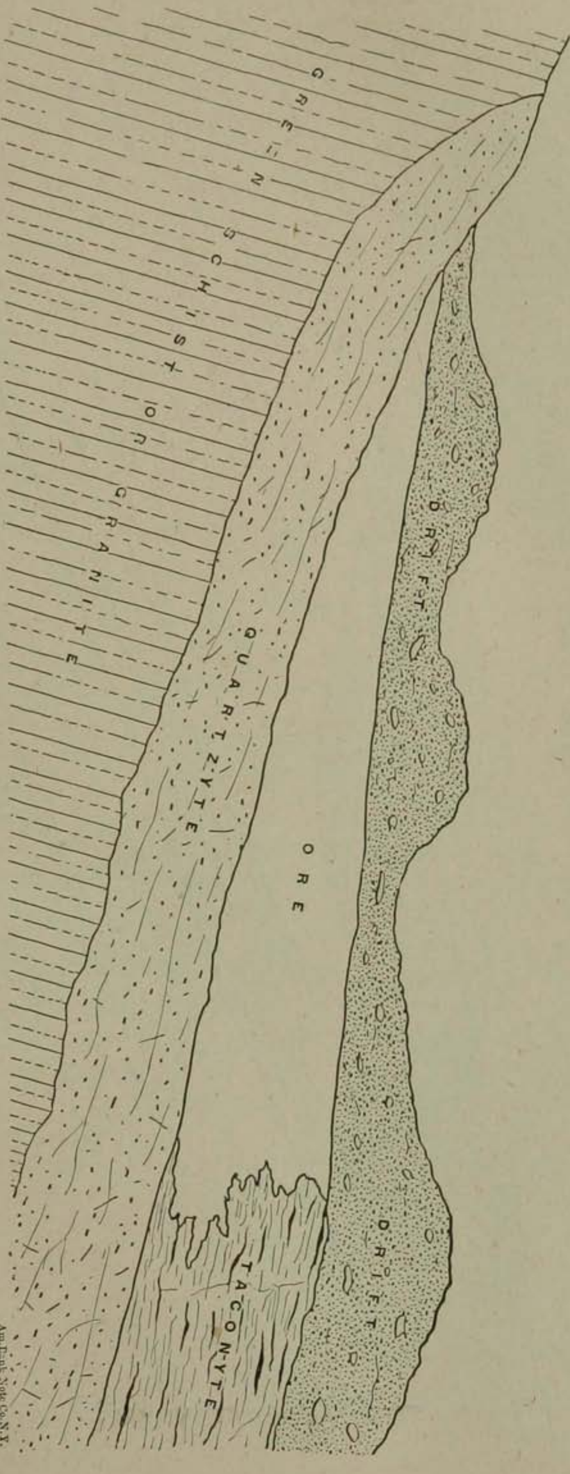
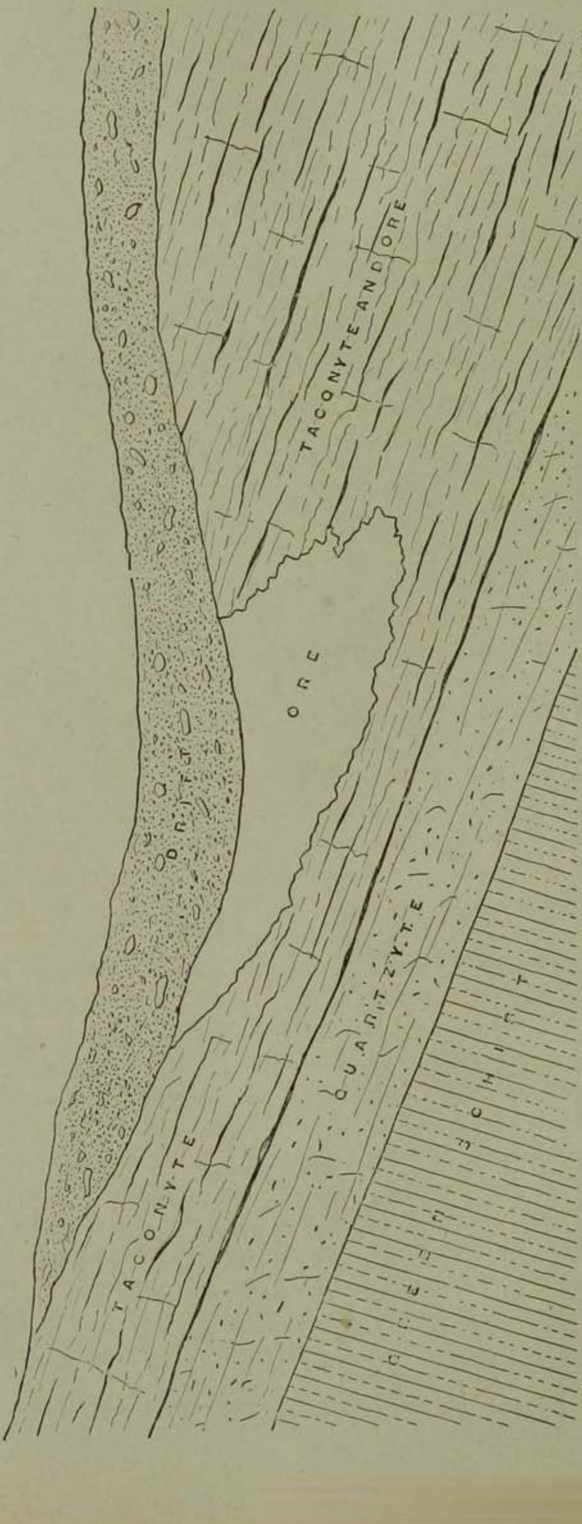


Fig. 4.

USUAL OCCURRENCE OF ORE BELOW DRIFT AND RESTING ON QUARTZYTE

Am. Bank Note Co. N.Y.

Fig. 5.



Possible Method of Occurrence of Ore on Taconyte

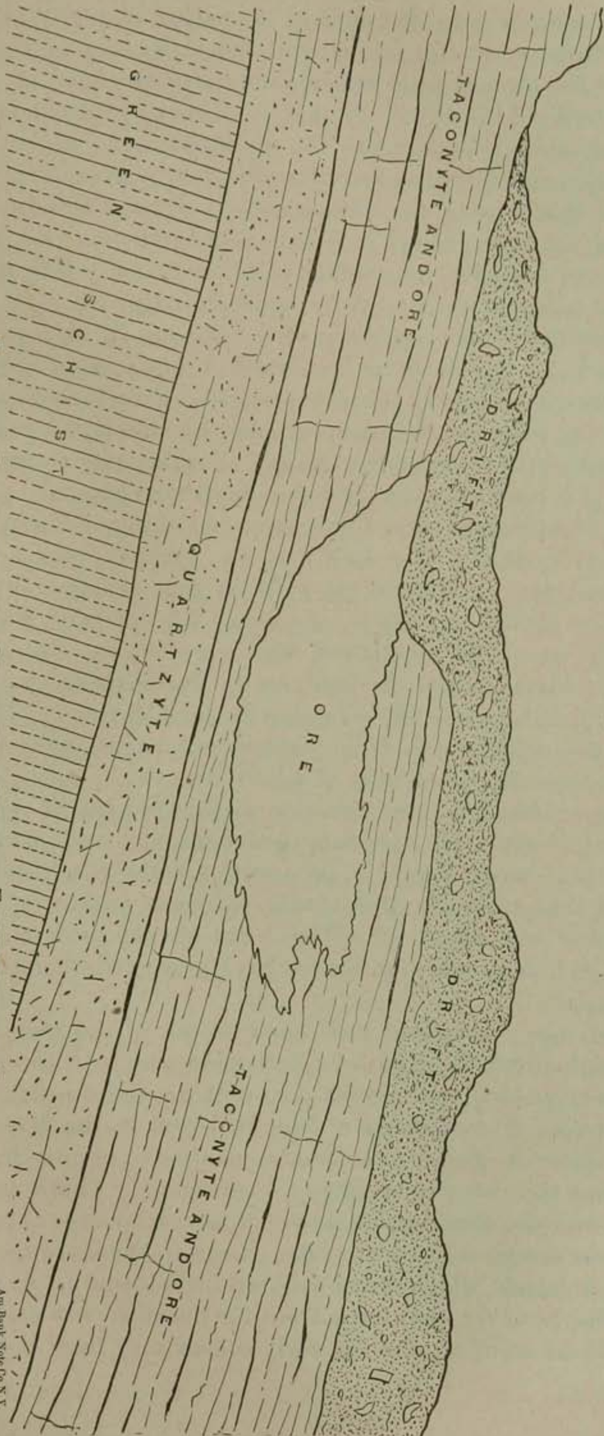


Fig. 6.

POSSIBLE OCCURRENCE OF ORE SURROUNDED BY TACONYTE AND ORE.

Still another proof is found in the nature of the transition back again from ore to the taconyte on the lower edge of the deposits. This has already been referred to under the head of "Mode of Occurrence of the Ore." If this ore be not a replacement product it must continue underneath the rocks belonging higher up in the formation and will ultimately be mined to a great depth. There is no absolute proof that this is not so. On the Biwabik and Cincinnati, however, the ore is seen to degenerate and pass into a low grade ore and then into "paint rock" and finally into the regular banded taconyte horizon on the southern edge.

There have been reports of the discovery of soft ore at great depths under the slates to the south of the present deposits, but these reports are not as yet authenticated. Even if they should be at one or two places in the basins of lakes like the Embarrass it would not weaken the replacement theory. For it is only natural that the effect of a body of water pressing downward through and into a series of soft slates would have some softening, oxidizing and disintegrating effect. The carbon of the graphitic slates would be dissolved and silica removed by it so that replacement deposits might be formed in such a place even at a depth of five hundred feet. It should be mentioned, moreover, that the glacial drift exceeds one hundred feet in depth on the southeast shore of Embarrass lake and may be twice as deep in the lake basin. This would make the actual depth from surface influences very much less and increase the likelihood of an ore deposit.

In searching for an explanation of this process of replacement we are met with many puzzling questions, and it is just as well to admit that more study is necessary for their solution. What started this process? How could so much quartz be removed? What has become of it? Where did all the iron come from? These and many other questions have presented themselves time and again.

It has been advocated that the iron ore of the Gogebic range was originally in the form of a carbonate which in the process of oxidation yielded the necessary solvent for the quartz. We find some traces of carbonates of lime and iron in the Mesabi rocks, but it does not appear in sufficient quantity to permit the assumption that the ore was originally a carbonate. There are not yet discovered any considerable non-oxidized carbonaceous portions of the rocks associated with the ores, except in the more recent slates of the Animikie, which are now found further south. It does seem probable, however, that the solvent for the silica was carbonic acid in aqueous solution, and its early source may have been (1) the atmosphere, (2) the black slates, which may have covered the ore horizon at one time and have since been eroded. (3) More recently decaying vegetation must have supplied a considerable amount.

The amount of carbonic acid gas in the atmosphere at the beginning of Silurian time is stated by different writers to have been far greater than at présent. It is supposed that the Carboniferous was a period of dense atmospheres and warm temperatures. Dana states that in Archæan time the effects of carbonic acid must have been much greater than now owing to its much larger proportion in the atmosphere, and that it has gradually diminished in quantity up to the present time. He states after Hunt that the excessive proportion of carbonic acid in the atmosphere was the most efficient of all agents in rock destruction. Manual of Geology, p. 156. T. S. Hunt states that "all carbonates of lime, whether directly formed by the decay of calcareous silicates or indirectly through the intervention of carbonates of manganese, or alkalies, derive their carbonic dioxide from the atmosphere. The same must be said for the dolomites, magnesites and siderites, * * * the earth contains fixed in the form of carbonates, a quantity of carbonic dioxide, which if liberated in a gaseous form, would be equal in weight to one hundred if not two hundred atmospheres like the present." Min. Phys., pp. 37-38. Here, then, may be the explanation of the removal of silica in such large quantity. If the rocks which produced the present iron ore deposits have been uplifted and exposed to surface action since primordial time, the carbonic dioxide used in the removal of silica must have been derived, at least in part, from the atmosphere. This process would have been carried on to a considerable depth, and may have produced an appreciable effect, even below several hundred feet of sediments which may have since been eroded.

But if these iron bearing strata were ever covered by the slates which belong above them, we can find an abundance of carbon in these very black slates, and though it is not now in the form of carbonates, yet the action of surface waters would be such as to extract sufficient to make a carbonic acid solution powerful enough to take iron and silica into solution. Moreover, Hunt says "the removal of silica in soluble form does not depend on the intervention of alkalies." And the carbon in the graphitic Animikie slates may have been at earlier times in some form more readily taken into solution. Having thus hinted at an answer to the first two or three questions which naturally arise in this connection, let us consider another one.

What has become of all the silica supposed to have been removed from the present location of the iron ores?

The answer to this is short. It was re-deposited in the rocks lying below and farther down the slope. (1) There is need of a source for an enormous amount of silica which has been added to the grains of quartz in the quartzyte, making it vitreous and filling all interstitial spaces. (2) There are considerable amounts of chalcedonic and flinty silica found associated with the quartzyte, and in the other rocks associated with the ores. This silica may be largely from a different source, but it may be partially derived from the leaching of the ore beds. (3) There are deposits of silica in all the cracks and fissures of the slates which lie at a lower elevation but stratigraphically above the ore horizon. Test-pits, for instance, on the Rouchleau, south of the Biwabik, encountered black slates and found no ore. These slates had been more or less jointed and the joints were filled by a bluish silica, sometimes mammillated, sometimes drusy. It is apparent to an observer that the most natural source for this silica is in the ore deposits farther up the hill to the north. Future researches will throw more light on this subject, and will perhaps show other ways in which the removed silica has been re-deposited.

As for the source of the iron, it is believed to have been largely the result of oceanic deposition, both chemical and mechanical, and to have been simply concentrated in its present situations.

There was also a removal of iron in solution. It was brought down to supply the places whence the silica was taken. These solutions followed the natural drainage courses. Elevation of the strata produced general jointing. The rocks on top of an elevated knoll were cracked full of joints, and the waters had free and abundant opportunity to percolate downward even in some places where the slope was not sufficient to accomplish it otherwise. The iron now being mined may formerly have been disseminated through rocks now completely removed by erosion.

QUALITY OF MESABI IRON ORE.

For some unknown reason the opinion prevailed for several months after the discovery of many of the best mines on the range, that the ore was of inferior quality. This may have been due to false reports purposely circulated by those who had no desire to see a new range discovered and exploited in competition with the mines in which they were interested; or it may have been due to honest but incorrect sampling. Each addition to the family of lake Superior iron ranges is received more unkindly by the older brothers and sisters. Dame Nature seems to have bestowed her best favors on her youngest children. The Vermilion, Gogebic and Mesabi ranges have each in turn revealed newer and greater riches. It was with extreme reluctance that the proprietors of mines in other districts recognized the importance of the Mesabi. Indeed they have not yet done so, nor will they until next year, when the ore finds its way to the markets and furnaces of the East.

It is true that the first test-pits were sunk on the thin upper edge of the ore, and the upper strata are not so rich as those lower and farther down the slope on which the deposits lie. The analyses first obtained, however, were sufficient to convince an unprejudiced person of the importance of the new district. The average of a large number of samples taken in January and February, 1892, indicated that the ore would yield about sixty per cent. metallic iron and that seventy-five per cent. of it would be within the bessemer limit as to phosphorus. Since then the test-pits have been increased in depth and number and the quality of the ore taken out has improved, as will be seen from the analyses which follow. There has been still further improvement since these samples were taken.

METHOD OF SAMPLING.

The most reliable samples are "pit samples." The usual method of obtaining them is by standing in a barrel or bucket, pick in hand, and while being lowered from the top to dig out a groove in the side of the pit from top to bottom, letting the ore fall into the barrel. Upon reaching the top the ore is broken into small fragments if it is not already fine, and carefully mixed and quartered down to a sample of eight or ten pounds. Taken in this way the samples should fairly represent the ore that will be shipped from that pit. All the hard layers must be grooved out as deeply as the soft ones, for the percentage of iron may vary; and, of course, sand streaks must be included, for they cannot be eliminated in mining. It is remarked by all new-comers that the ore has a sandy appearance and feel. There are occasional small streaks of sand in it, and near the bottom small grains of white silica are common, and can be seen by a hand glass. Analyses are surprising to these ore experts as revealing but a small per cent. of silica. The sandy feel is due to the nature of the ore, which is largely made up of crystalline grains of hematite.

The habit, quite general on the range, of dumping successive bucket-fulls of ore on a circular stockpile and spreading it around evenly renders dump samples rather unreliable. It is evident that the last ore mined is on the top of the dump, and as it is not feasible to dig to the center of a dump twenty or thirty feet across, the sample taken will represent but a part of the ore penetrated by the pit. To be sure the sample is as likely to vary one way as the other, but it is not satisfactory unless the pit is quite uniform or the ore has been divided as it was taken out.

The following table of analyses does not do full justice to all of the mines represented. The Berringer, Canton, Lake Superior, Lone Jack and New England have already made developments showing a higher grade of ore, and there is no doubt that some of the others will improve with further development.

Analyses of Mesabi Iron Ores.

BERRINGER MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
0.	E. P. Jennings	57.50	10.33	.108			
4. First 10 ft.	J. A. Crowell	60.70		.069			
4.	J. A. Crowell	62.15		.049			
4. Dump	J. A. Crowell	63.10		.032			
4.	W. J. Rattle	61 90		.051			
?. Ochre	J. A. Crowell	60.95		.070			
?. 60 ft. ore	E. P. Jennings	59.20	4.41	.111			
4. 35 ft. ore	E. P. Jennings	62.60	3.58	.049			
Average		60.97	6.05	.067			

BIWABIK MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. Dump	J. T. Jones	55.55	9.77	.107		6.64	12.21
1. 22 ft. ore	J. T. Jones	58 25	4.49	.112		7.05	6 63
2.	D. H. Bacon	60 32	5.07	.121	.37		5.37
9.	P. L. Kimberley	61.95	2.92	.090		6.48	7.50
11.	J. T. Jones	61.05	4.42	.075		5 35	2.93
11.	D. H. Bacon	61.44	3.59	.076	.17		6.33
11.	W. J. Rattle	61.50	4.01	.075	.957		
11.	E. P. Jennings	59.30	8.57	.075			
11.	H. V. Winchell	61 58	4.07	058	.16	6.48	5.59
11. 58 ft. ore	J. T. Jones	61.95	2.92	.092			2.50
13.	P. L. Kimberley	55 25	7.36	.039		6.25	11.85
15. Blue ore	J. T. Jones	66 50	1.57	.015	.21		
15. Upper 6 ft.	J. T. Jones	67.90	1.23	.010			
15. Lower 10 ft.	J. T. Jones	66.60	2.04	.012			
15. Whole pit	H. V. Winchell	64 30	3 20	.038	.349		
15. Blue ore	W. J. Rattle	66 70	1 84	.022	.442		
15. Brown ore	W. J. Rattle	62.90	3.35	.047	.587		
15. Red-brown	W. J. Rattle	62.90	2 59	.045	.331		
15. Selected	H. V. Winchell	68 15	1.025	.011			
15. 30 ft. blue	E. P. Jennings	67.90	1.80	.016			
15. *Drift	E. P. Jennings	64.40	4.36	.027			
15. *Drift	J. T. Jones	65.80		.034			
15. Brown-blue	E. P. Jennings	65.90	2.70	.042			
15.	J. T. Jones	67 50		.010			
15. First 20 ft.	J. A. Crowell	61 85		.057			
15. Last 16 ft	J. A. Crowell	63.20		.032			
15. 30 ft. blue	E. P. Jennings	64 50		.018			
15. First 10 ft drift	J. A. Crowell	67.25	1.88	.010			
15. 0-20 ft. drift	J. A. Crowell	67.00		.020			
15. 20-30 ft. drift	J. A. Crowell	65.80		.034			
15. 30-40 ft. drift	J. A. Crowell	66.20		.039			
15. 40-50 ft. drift	J. A. Crowell	66 00		.038			
15. 70-80 ft. drift	J. A. Crowell	66.50		.015			
15. 80-90 ft. drift	J. A. Crowell	66 60		.012			

*From 150 foot drift at depth of sixty-five feet.

BIWABIK MINE.—*Continued.*

PIT NUMBER.		SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
15.	90-100 ft. drift......	J. A. Crowell.....	66.00	....	.015	....	....	....
15.	100-110 ft. drift.....	J. A. Crowell.....	66 20	....	.013	....	....	....
15.	Dump	H. M. Curry......	65 850	2.450	.022	.160	2.2	....
17.	....	J. T Jones	63.25	....	.056	....	....	....
17.	....	J. T. Jones	58.60	....	.069	....	....	....
17.	Brown	E. P. Jennings ...	63.40	5.04	.033	....	....	....
17.	97-107 ft...........	J. T. Jones	64.15	....	.023	....	....	....
17.	67-77 ft...........	J. T. Jones	64 00	....	.026	....	....	....
17.	....	J. T. Jones	63.25	....	.056	....	....	....
17.	72 ft. ore...........	J. T. Jones	65.34	....	.035	....	....	....
17.	63 ft. ore....	W. H. Smith......	67.20	1.27	.017	.130	2.06	....
19.	30 ft. ore, 56 ft. deep	H. M. Curry......	64 20	2.070	.054	.110	5.00	....
19	18 ft. hard ore and soft ore 86½ ft. down............	H. M. Curry......	66.25	1.63	.034	.250	2.70	....
19.	2½ ft. brown ore at bottom	H. M. Curry......	64.75	1.450	.072	.290	5.67	....
20.	....	E. P. Jennings ...	62.60	5.83	.064	....	....	....
20.	First 15 ft..........	J. T. Jones	62.40	....	.065	....	....	....
20.	15-25 ft.............	J. T. Jones	62.40	....	.068	....	....	....
21.	First 15 ft..........	J. T. Jones	50 85	....	.097	....	....	....
21.	15-25 ft.............	J. T. Jones	62.50	....	.063	....	....	....
21.	....	E. P. Jennings ..	57.40	11.04	.093	....	....	....
23.	Blue ore 7 ft. from bottom...........	H. M. Curry......	67.35	1.85	.015	.130	1.10	....
24.	Bottom ore	H. M. Curry......	64.050	1 71	.027	.240	4.88	....
25.	Dump ore, just under surface...	H. M. Curry......	63.45	2.85	.028	.370	4 6	....
26.	37 ft. at base	H. M. Curry......	65.50	1.73	.049	.060	3.3	....
26.	5 ft. at bottom.....	H. M. Curry......	66.40	1 63	.043	.080	2.4	....
26.	Blue ore at base .	H. M. Curry......	63.25	2.75	.042	.300	3.1	....
	Average	....	63 70	3.46	.0455	.284	3.01	6·76

CANTON MINE.

PIT NUMBER.		SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
3.	....	D. H. Bacon......	57 22	7.47	.083	......	....	9.50
...	North pit..........	D. H. Bacon......	63.13	2.29	.030	....	....	7.65
?.	Yellow ochre ...	J. T. Jones	60.65	2.09	.105	....	8 04	9.86
?.	20 ft. sur., 45 ft. ore	J. T. Jones	59 15	4.31	.048	....	9 21	10.22
?.	Yellow ochre	E. P. Jennings ...	60.90	4.85	.029	....	10.05	....
	Average..........	....	60.21	4.20	.059	....	9.10	9.307

CINCINNATI MINE.

PIT NUMBER.		SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1.	"Poor ore"	P. L. Kimberley .	54.85	15.06	.026	....	2.35	8.09
2.	....	J. T. Jones........	59.95	8 35	.032	....	3.16	8.44
2.	....	W. J. Rattle	60 10	8 60	.040	.475	....	....
3.	....	J. T. Jones........	61.65	5.39	.031	....	3.24	4.80
3.	....	W. J. Rattle......	59.80	8 40	.040	.497	....	....
3.	....	H. V. Winchell ..	59.24	10.25	.046	....	....	4.01
4.	....	E. P. Jennings ...	62.50	4 89	.087	....	....	....
5	[Biwabik].........	P. L. Kimberley .	63.00	3.84	.029	....	5.03	3.16
5.	[Biwabik].........	W. J. Rattle......	61.50	4 83	.039	1.98	....	....
5.	[Biwabik]	E. P. Jennings ...	63.50	5.37	.039	....	....	....
5.	[Biwabik] dump.	H. V. Winchell...	59.00	7.65	.050	....	....	....
7.	....	W. J. Rattle......	57.80	....	.038	....	....	....
8.	....	E. P. Jennings ...	54.50	14.13	.028	....	....	....
8.	....	J T. Jones	60.70	8.10	.034	....	2.85	10.96
8.	Dump.............	J. T. Jones	58.50	8.90	.045	....	5.39	7.55
8.	....	W. J. Rattle.....	54.90	16.0[illegible]	.040	.515	....	....
9.	....	E P. Jennings ...	54.40	14.13	.028	....	....	....
9.	....	W. J. Rattle......	54.50	9.08	.078	.460	....	....
10.	....	E. P. Jennings ...	55.70	9.06	.112	....	....	....
10.	....	W. J. Rattle	55.10	8.68	.110	.810	....	....
10.	Dump.............	H. V. Winchell...	55 75	7.38	.078	....	....	....
12.	....	E. P. Jennings ...	56.80	6.00	.063	....	....	....
...	Second from north	E. P. Jennings ...	57.20	12.88	.034	....	....	....
	Average..........	....	58.30	8.95	.0498	.791	3.67	6.71

GREAT WESTERN MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
4.	J. A. Nichols	65 02	....	.024	....	....	....
5.	J. A. Nichols	63.71	....	.020	....	....	....
Average	....	64.36	....	.022	....	....	....

HALE MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1.	D. H. Bacon	61.16	2.89	.063	.40	....	7.05
2.	W. J. Rattle	61.48	3.60	.088	1.20	....	....
3.	W. J. Rattle	61.10	4.92	.067	.849	....	....
4.	W. J. Rattle	62.10	2.92	.075	1.29	....	....
5.	W. J. Rattle	57.60	5.95	.077	1.657	....	....
Average	....	60.67	4.05	.074	1.079	....	7.05

KANAWHA MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
2.	J. T. Jones	64.45	3.32	.050	....	5.29	11.76
2.	W. J. Rattle	60.65	4 90	.051	.644	....	....
3.	W. J. Rattle	59.60	6 40	.081	.754	....	....
4.	W. J. Rattle	59.10	7.48	.084	.405	....	....
Average	....	60.95	5.52	.066	.600	5.29	11.76

LONE JACK MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1.	D. T. Adams	59.415	7.55	....	.251	3.05	....
1. Bottom	H. M. Curry	58.565	6 75	....	.348	3.15	....
1.	E P. Jennings	55.00	9.29	.096	....	....	....
2.	D. T. Adams	60.806	4 78	....	.775	2.05	....
2. Bottom ore, dump	H. M Curry	60.225	3.716	.089	.540	2.08	....
Average	....	58.402	6.417	.092	.478	2.55	....

McKINLEY MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1.	D. H. Bacon	60.32	10.72	.024	.770	....	1 89
2.	D. H. Bacon	61.48	9.27	.022	....	....	1.64
?.	J. M. Clifford	65.60	4.10	.017	....	....	....
Average	....	62.46	8.03	.021	.770	....	1.76

MISSABE MOUNTAIN MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1.	J. T. Jones	63.30	3.617	.051	....	1.85	....
1. Upper 10 ft	H. M. Curry	56 80	7.20	.041	.580	3.30	....
1. [?]	J. T. Jones	62.40	4 80	.026	.270	1.78	9.80
1. [?]	J. T. Jones	62 89	3.38	.061	....	2.92	....
1.	C. F. Howe	65.21	3.83	.037	....	2.26	....
1. 45 ft. ore	H. V. Winchell	64.03	3.094	.053	.337	1.75	6.70
3.	H. M. Curry	60 05	4.65	.075	1.090	3.40	....
3. Dump	W. H. Smith	62 33	5.53	.027	.840	1.15	....
4. Top of dump	H. M. Curry	61.304	5 40	....	.503	5.10	....
4. Dump	H. V. Winchell	60 90	3.14	.080	....	....	....
5. Dump	H. M. Curry	56.817	11.967	.050	.180	1.76	....
?.	E. P. Jennings	64.30	4.36	.077	....	....	....
?.	E. P. Jennings	62.50	4.89	.087	....	....	....
Average	....	61.73	5.066	.055	.542	2.52	8.25

MOUNTAIN IRON MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. [Old number]	D. H. Bacon	62.43	5.70	.047			4.15
2. [Old number]	D. H. Bacon	59.12	11.48	.048			2.74
1. [New number]	— Joyce	65.60		.052			
2. [New number]	W. H. Smith	62.250	6.820	.038	.116	2.50	
1.	Geo. Sutherland	63.98		.029			
2. 18 ft. ore	H. M. Curry	57.68	13.35	.054	.130	2.20	
2.	Geo. Sutherland.	66.19		.068			
3. 14 ft. ore	W. H. Smith	64.93	3.70	.057	.238	1.88	
2.	L B. Miller	61.90	5 82	.048			
3.	H. M. Curry	65.14	4.11	.048			
3.	Geo Sutherland.	65 14		.048			
4.	H. M. Curry	65.55	4.14	.037			
4.	L. B. Miller	65.00	3.51	.033			
4. 23 ft. ore	H. M. Curry	64.242	4.98	.035	.232	2.80	
6.	Geo. Sutherland.	66.52		.031			
4. 18 ft. ore	W. H. Smith	59.81	8.66	.057	.155	3.99	
7.	L. B. Miller	65.30	3.08	.053			
?. Lammers, Chem.	?.	63.68	6.77	.041			
8.	L. B. Miller	65.30	3.07	.054			
?. Lammers, Chem.	?	62.52	2.74	.031			
9.	L. B. Miller	66.00	2 49	.046			
?. Lammers, Chem.	?	62.65	5.20	.056			
Average		63.22	5.64	.050	.155	2.674	3.495

NEW ENGLAND MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. 26 ft. ore	E. P Jonnings	58.30	5.99	.084			
2.	E. P. Jennings	62.60	5.64	.037			
3. 20 ft. ore.	E. P. Jennings	61.80	6.44	.029			
Average		60.90	6.02	.050			

OHIO MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
3.	E. P. Jennings	63.20	5.07	.032			
3. Pit. last 20 ft.	J. T. Jones	64.53	4.20	.047	.414	1.91	
4. 26 ft. ore	E. P. Jennings	64.45	3.03	.037			
3. Dump, last 20 ft.	J. T. Jones	61.25	8.783	.020	.450	1 48	
Average		63.16	5.34	.036	.432	1.695	
Average of averages		61.46	5.92	.0528	.667	4.063	6.886

COMPARISON WITH OTHER ORES.

Until there shall have been a large consumption of the Mesabi ores it will be impossible to tell exactly how they compare in all respects with the ore of other districts. There are high and low grades of ore on all ranges, and the average tonnage purity of an entire range has never been determined. By this is meant the average quality of the ore taking into consideration the number of tons of each grade mined. Some idea of the comparative excellence of Mesabi ores, however, can be gained by a consideration of the analyses already given and the actual results obtained in other instances.

The output of the Minnesota Iron Company from the Vermilion range in 1891 is classified in the following table. This ore is well-known as some of the finest hard hematite obtainable, and yet only forty-seven per cent. of the product was bessemer.

TABLE SHOWING PRODUCT OF THE MINNESOTA IRON COMPANY IN 1891.

SHAFT.	Vermilion.	Soudan.	Red Lake.	Minnesota.	Nipigon.	Total.
No. 1	2,813	24,379	6,581	14,615	......	48,388
No. 3	298	10,939	1,065	46,382	646	59,330
Alaska	....	....	14,243	....	....	14,243
No. 5*	....	21,779	6,655	159,836	3,983	192,253
No. 7	....	46,174	6.324	5,068	....	57,566
No. 8	92,464	591	10,073	....	....	103,128
No. 9	154	5,683	2,423	11,126	425	19,811
No. 10	....	15,341	742	....	....	16,083
No. 10 Scram	....	1,177	82	....	....	1,259
No. 17	....	377	834	676	....	1,887
No. 13	....	2,319	913	....	....	3,232
No. 12	....	21	91	....	....	112
No. 19	....	....	278	....	....	278
Total	95,729	128,780	50.304	237,703	5,054	517,570

*Includes Montana, Butte, Armstrong and No. 6 Shaft.

Pickands, Mather and Co., the Cleveland agents for these grades of ore, give the following average analyses for 1891, and guarantees for 1892.

COMMERCIAL GRADES OF ORE FROM VERMILION IRON RANGE, 1891.

COMPOSITION.	Vermilion.	Soudan.	Red Lake.	Minnesota.	Chandler.	Long Lake.
Iron	67.75	65.96	63.49	68.14	63.91	60.06
Silica	1.58	2.27	5.00	1.30	5 10	7.20
Phosphorus	.157	.102	.111	.049	.041	.044
Manganese	.29	.14	.19	trace	.69	.61
Alumina	.98	1.80	.90	1.10	2.90	2.87
Sulphur	trace	trace	.026	trace	trace	.043
Magnesia	trace	.30	.30	.13	trace	.19
Lime	1.00	.54	.71	.56	.37	.31
GUARANTEES.						
Iron	66.66	65.00	62.00	66.66	63.00	60.00
Phosphorus	....	.12	....	.055	.05	.05

In 1891 the Chandler mine produced 354,993 tons of Chandler ore and 20,873 tons of Long Lake ore. The entire product of this mine is bessemer. In some respects this is the greatest mine in the world. Occupying but eighty acres its production for 1892 will be nearly 650,000 gross tons of remarkably uniform ore. Cargo after cargo is sampled at Cleveland that will not vary half of one per cent. in iron content. Under the able direction of Joseph Sellwood the cost of mining has been reduced to less than $1.00 per ton at the depth of 450 feet. It is believed that there is a profit of $1.00 per ton on this ore, providing it brings $4.85 at Cleveland, as it is said to have done in 1892. This estimate is based on the following details:

Cost of Mining,	$1.00
Royalty,	.35
R. R. Freight to Two Harbors,	1.00
Lake Freight to Cleveland,	1.20
Insurance, Commission, etc.,	.25
	$3.80

These figures are approximate and are given merely for the sake of indicating the entire feasibility of mining at a profit on the Mesabi, where the cost of mining will be considerably less than at the Chandler, with higher royalties.

The average of the analyses given of the Biwabik ore indicates that in quality it is nearly equal to the Chandler ore. If the expense of placing it on the car, including royalty, were equal, there would be a slight difference [equal to the freight from Ely to Tower, perhaps] in favor of the Biwabik. It might even be possible to sell the ore at $4.00 per ton and still have a nice profit. If in addition to this there are any other directions in which the Biwabik ore can be produced more cheaply than the Chandler, such as smaller mining cost, there is so much more profit. This point will be discussed later.

The analyses of certain standard grades of ore from the other lake Superior ranges is given in the following table.

Analyses of Lake Superior Iron Ores.*

MARQUETTE DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
American	65.00	0.045	4.50	......	......	......	......	......
Angeline—Hard	65.50	0.009	......	......	......	......	......	......
Angeline—Hematite	66.38	0.032	......	......	......	......	......	......
Barnum	65.00	0.098	4.70	0.20	0.20	0.35	trace	......
Buffalo	62.33	0.120	6.80	0.37	1.61	0.06	......	......
Cambria	60.00	0.064	7.26	0.37	3.81	0.33	0.62	0.042
Champion, No. 1	67.00	0.040	3.00	......	......	......	......	......
Cleveland, No 1	65.60	0.104	3.06	0.21	0.99	0.18	0.37	0.037
Cleveland Hematite	60.00	0.050	6.74	0.33	2.35	0.12	0.12	0.011
Cliff Shaft	62.70	0.109	3.45	0.52	1.55	1.15	1.61	0.025
Comrade	60.50	0.100						
Detroit	58.60	0.056	8.00	......	......	......	......	......
East New York	60.10	0.055	11.64	0.41	1.11	0.31	0.12	0.029
Humboldt	65.00	0.120	5.00	0.12	0.72	0.26	0.64	0.020
Imperial	57.50	0.280	5.30	0.03	1.71	0.41	1.16	0.045
Jackson	62.00	0.090	......	......	......	......	......	......
Lake Superior, No. 1A	64.00	0.116	......	......	......	......	......	......
Lake Superior, Slate	66.00	0.080	3.00	0.03	1.22	0.12	0.48	0.045
Lillie	59.00	0.084	8.69	......	......	......	......	......
Lucy	53.50	0.045	12.05	4.25	......	......	......	......
Michigamme	65.50	0.114	4.57	0.01	0.51	0.11	0.07	0.030
Michigamme, No. 1	62.00	0.055	7.00	0.60	0.80	0.30	1.35	0.030
Milwaukee	62.05	0.105	4.32	0.45	0.60	0.90	1.10	0.080
Mitchell	60.95	0.131	6.85	0.62	1.35	0.30	0.42	0.020
Negaunee	60.00	......	......	......	......	......	......	......
Prince of Wales	62.56	0.106	5.51	0.37	1.70	0.17	0.59	0.053
Prout	53.02	0.041	17.65	......	......	......	......	......
Queen	62.60	0.112	4.65	0.41	1.11	0.31	0.12	0.029
Republic, Magnetic	69.77	0.051	1.78	......	......	......	......	......
Republic, Specular	67.50	0.043	3.01	0.04	0.85	0.07	0.41	0.012
Salisbury Bess	62.00	0.045	4.00	0.22	0.50	0.60	1.00	0.012
Sharon	61.00	0.090	8.00	0.12	0.72	0.26	0.84	0.012
Sheffield	61.00	0.015	......	......	......	......	......	......
South Buffalo	63.80	0.100	4.10	0.31	1.49	0.34	0.82	0.049
Volunteer	60.10	0.070	......	......	......	......	......	......
Winthrop	63.40	0.109	5.37	0.85	0.81	0.11	0.24	0.028
Average	62.33	0.079	4.72	......	......	......	......	......

MENOMINEE DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Aragon	65.20	0.038	4.68	0.02	0.33	0.01	0.36	0.034
Armenia	60.80	0.188	8.69	0.11	1.33	0.39	0.66	0.022
Chapin	62.13	0.068	4.20	0.26	1.08	2.71	0.81	0.001
Commonwealth	57.70	......	......	......	......	......	......	......
Corbett	58.20	0.675	4.37	0.31	3.10	0.62	0.78	0.041
Crescent	64.55	0.044	3.35	0.15	0.67	1.64	0.50	......
Cyclops	61.00	......	......	......	......	......	......	......
Dunn	60.60	0.344	4.81	0.22	2.98	0.81	0.97	0.036
Eagle	55.20	0.547	5.03	0.02	......	0.81	0.91	0.061
Florence	60.50	0.257	4.05	0.22	0.81	0.64	1.18	0.041
Great Western	......	......	......	......	......	......	......	......
Iron River	59.80	0.356	5.29	0.37	3.41	0.37	0.69	0.028
Ludington	64.59	0.070	......	......	......	......	......	......
Manganate	54.00	0.612	6.00	3.50	......	......	......	......
Mansfield	63.40	0.025	3.56	......	......	......	......	......
Mastodon	58.36	......	......	......	......	......	......	......
Millie	64.06	0.027	3.00	0.08	1.30	0.95	1.10	0.035
Norway	58.00	0.120	12.00	......	......	......	......	......
Paint River	56.40	0.502	3.48	0.37	6.12	0.72	5.58	0.068
Pewabic	65.00	0.010	......	......	......	......	......	......
Rex	55.78	0.080	6.85	......	1.67	......	......	......
Shafer	59.00	......	......	......	......	......	......	......
Vulcan	62.00	......	......	......	......	......	......	......
Youngstown	52.18	0.642	6.00	3.50	......	......	......	......
Average	59.93	0.253	5.33	......	......	......	......	......

*Geo. W. Goetz, Trans. Am. Inst. Min. Eng., vol. xix, p. 59.

VERMILION DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Braddock	65.17	0.052	4.50	0.13	0.48	0.16	0 56	0.020
Chandler	64.15	0.044	4.30	0 14	2.25	0.19	0.25	0.040
Long Lake	60.20	0.053	7 00	0.54	2.75	0.19	0.25	0.047
Minnesota	67.54	0.051	1 97	0.15	0.04	0.14	0.53	0 020
Nipigon	63.01	0.053	6.75	0 14	0.65	0.20	0.60	trace
Red Lake	62.86	0.099	6.95	trace	0.65	0.20	0 60	trace
Soudan	65.77	0.102	4.25	0.16	0.38	0.17	0 56	0.020
Vermilion	67 31	0.091	2.15	0.15	0.35	0.15	0.02	....
Average	64.50	0.068	4.46	....	....	....	....	....

GOGEBIC DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Anvil	61.54	0.053	....	....	....	....	....	....
Ashland	63 82	0.038	....	....	....	....	....	....
Aurora	63.36	0.034	4.00	0.03	1.98	0.12	0.04	0.033
Brotherton	62 50	0 037	6.13	0.49	2.98	0.39	0.16	0.070
Cary	58.84	0 062	5.20	....	....	3.66	....	....
Eureka	62.00	0.076	6.64	0.48	3.69	0.16	0.15	0.015
Germania	59 19	0.058	....	....	....	....	....	....
Hennepin	65.45	0.048	3.53	0.02	0.31	0.02	0.02	0.022
Iron Belt	62.75	0.042	6.33	....	2.44	....	....	....
Ironton	60 55	0.058	....	....	....	....	....	....
Montreal	64.22	0.053	....	....	....	....	....	....
Mount Hope	62.32	0.029	....	....	....	....	....	....
Norrie	63.72	0.043	3.40	....	....	....	....	....
Pabst	62 34	0.037	4.50	....	....	....	....	....
Palms	62.43	0.049	....	....	....	....	....	....
Ruby	62 50	0.045	4.20	0.49	....	0.16	0.45	....
Section 33, North	64.82	0.045	....	....	....	....	....	....
Sunday Lake	62 00	0.036	....	....	....	....	....	....
Trezona	62.55	0.061	4.44	0.02	0.97	0.03	0.02	0.031
West Cary	54.95	0.054	5.35	7.41	....	....	....	....
Windsor	62.00	0.051	6.30	0.81	3.45	0.31	0.40	0.025
Average	62.09	0.048	5.00	....	....	....	....	....
Average of averages	62.46	0.062	4.88	....	....	....	....	....

It will be noticed that the average of the grades given is higher in iron, but also higher in phosphorus than that of the large number of samples of Mesabi ore in the foregoing table. It is not claimed that this average is a correct one of the product of the ranges represented, but it is claimed that it is similar to the average obtained from the various Mesabi analyses, and the comparative high grade of the latter ores is shown thereby. It is unlikely that any ore will ever be shipped to Cleveland of as low grade as the lowest in the table, but it is certain that there will be grades of Mesabi ore as low in phosphorus and as high as or even higher in metallic iron than any hematite ore in the list, and that in large quantity.

It is hardly necessary to refer to the fact that southern ores are very much lower grade than lake Superior ores. Their proximity to the coal field and the furnace is the only feature that enables them to compete with the northern ores at present, and if an unlimited amount of high grade lake Superior ore can be profitably deposited in Cleveland at a reduction of fifty cents per ton below the present market price, most of the southern furnaces will be forced to suspend operations.

From recent experiments in New York and New Jersey it appears probable that a large amount of concentrated iron ore may be put upon the market in the next few years and become an active and important competitor of the lake Superior district. It is also reliably reported that the Sigua and Juragua districts of Cuba will soon ship several hundred thousand tons per annum of high grade ore to this country, and that they can do it at a profit with the present duty of 75 cents per ton. When shipped to this country for manufacture and exportation, foreign ores may obtain a rebate of the tariff paid for importation. This will be done to a considerable extent in the future.

All these facts indicate that the price of bessemer ore will tend to be lower rather than higher, and Mesabi mine owners may well be congratulated that to the excellent quality of their ore is added the combination of great abundance advantageously situated for very cheap mining.

METHOD OF PROSPECTING.

There is nothing particularly novel or original in the manner in which prospecting is conducted on the Mesabi. An illustration in Agricola's De Re Metallica of a test pit in the sixteenth century shows a windlass operated by a crank at each end almost identical with those employed here three hundred years later. The ancients used two buckets to save time and labor in hoisting. Fig. 7.

The pits are rectangular and vary greatly in diameter. They are seldom timbered below the top of the ore unless very deep and wet. During the winter time pits are sunk in favorable situations to the depth of more than one hundred feet with pick and shovel unaided by a single drill hole or blast of powder. In the spring, however, surface water bothers greatly and pumps are needed. At times there are strata of hard ore or a capping of rock to be penetrated. Drilling and blasting are then resorted to.

The ore is hoisted out in buckets and piled up around the mouth of the pit in a circular dump or stock pile. Plate No. V. is an illustration of a windlass and dump. When the pit is more than one hundred feet in depth the operation of hoisting by hand is a very slow one, and a "bent" is sometimes arranged for hoisting by horse power and dumping into a tram car. This method was first employed on the Mesabi at the Biwabik in the northeast drift at pit No. 15. On Plate No. V. is also an illustration of the bent.

TEST-PITTING AT THE BIWABIK MINE.

CAMPS AT THE WYOMING MINE.

If the ore deposit lies in a rock-rimmed basin there is considerable water in the ore. If it lies on a hillside and is of considerable extent the water filters down through the ore to the basal quartzyte and the upper part of the ore body is quite dry even in very wet seasons. From this it follows that the presence of water in an ore

Fig. 7. Test-pitting in the sixteenth century.

pit is simply an indication that it cannot get away, while its absence is a sign that it can escape, probably by filtering down in the ore, which is therefore concluded to be of considerable amount. The significance of the various rocks and their usual appearance have already been discussed.

Mines Now Opened Up.

Biwabik.

After the discovery of the Mountain Iron mine in 1890, described in the first portion of this article, no further discoveries of importance were made until about a year later, when an explorer named John McCaskill saw traces of soft ore in the roots of an over-turned tree in section three, T. 58–16. This led to the discovery of the Biwabik, Cincinnati, Canton, Hale and Kanawha mines. Credit for the actual discovery of the ore deposit on the Biwabik must be given to Capt. J. A. Nichols. He directed the work which succeeded in making this discovery in August, 1891. Capt. J. G. Cohoe was put in charge of the work here and sunk fifteen test pits during the winter of 1891-'92. It would be somewhat peculiar if the first and second mines to be discovered should turn out to be the best two mines on the range.

In the last part of April the Biwabik Mountain Iron Company leased three forties in sections two and three, T. 58-16, to Mr. P. L. Kimberley, of Sharon, Pa. The lessees are required to mine at least 300,000 tons per annum and to pay a royalty of 50 cents per ton. This deal was the result of an examination of the early developments on the range made by Mr. J. T. Jones, the superintendent of the Hamilton Ore Company, of Iron Mountain, Mich. Work of exploration was continued in a systematic manner and soon became the model for such work on the range. The test pits were rapidly increased in depth and number, and the result showed the wisdom and foresight of Messrs. Jones and Kimberley in the selection of this property out of all those so far discovered on the range. Records of some of their test pits may be seen on page 138. By the time these test-pits were completed it was evident to the unprejudiced observer that here is the greatest deposit of ore known on the range if not in the whole Lake Superior district. Millions of tons of soft hematite, averaging 63 per cent. iron and .045 phosphorus, are here found within one hundred feet of the surface of the ground. It is safe to say that this mine under its present management will eclipse all former records for cost of mining and number of tons produced in a given length of time. There may yet be larger deposits found on the Mesabi, but so far the Biwabik is chief. The Mountain Iron may prove to be its equal, and at present is a good second, but the number of cubic feet of ore reasonably to be estimated as "in sight" at the Biwabik exceeds that of any two other mines yet opened up.

Cincinnati.

Adjoining the Biwabik on the east is the Cincinnati. This is also a fine property. It does not seem to get the credit it deserves among those familiar with the range, perhaps because it happens to suffer somewhat in comparison with the Biwabik adjoining, which is a larger property and has been more extensively developed. For several months no property on the range could make a better showing as to quantity and quality of ore than the Cincinnati. Subsequent development revealed others equally as good, but that was only to be expected. Later development on this property also showed the ore to be more extensive than the owners themselves believed it originally.

This mine is leased to the Standard Ore Company, who have agreed to mine at least 150,000 tons each year at a royalty of 55 cents per ton.

The development of this property was largely under the charge of Capt. Edward Florada and Capt. Carlin.

Canton.

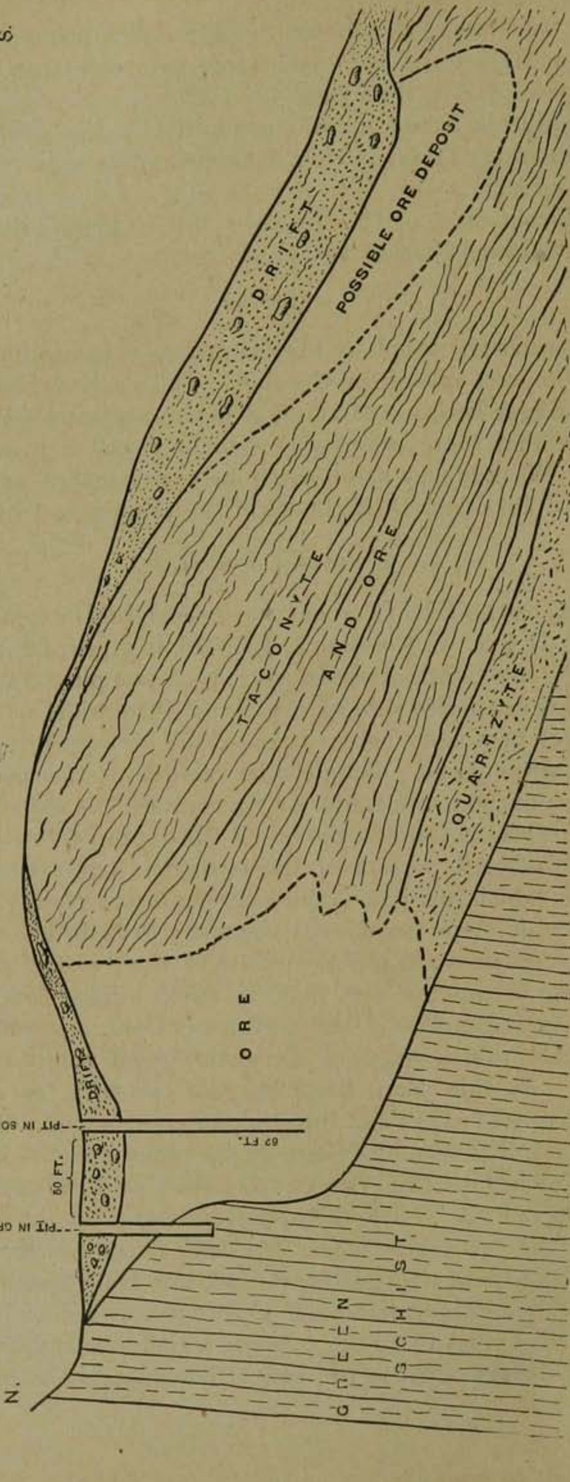
This property, owned by the Minnesota Exploration Company, lies on the west side of the Biwabik. The ore here was discovered by Mr. Edgar Brown. Much of it is non-bessemer gœthite. It is probable that there is better ore to be found here at a greater depth. Work is now being vigorously prosecuted under the direction of President D. H. Bacon of the Minnesota Iron Company.

Kanawha and Hale.

The Kanawha Iron Company did considerable exploration work in the S. E. ¼ N. W. ¼ section 1, T. 58–16, in April, 1892, and found a considerable depth of ore in a series of test pits located east and west along the north side of the forty. The width of the deposit is not yet proven to be great here, the ore appearing to lie in a rather narrow gorge. The peculiar relation of the ore deposit at this place to the green schist or "greenstone" is shown by Fig. 8.

Pit No. 1 went through the ore at the depth of thirty-eight feet into an unaltered portion of the taconyte. On this property and the Hale, which lies just to the east, the fact is plainly shown that the drainage slope considered necessary to facilitate the replacement process does not always consist of the rocks of the Taconic formation above the ore deposit itself. The flow of waters which has accomplished the replacement and concentration may have come from a ridge of Keewatin green schist or Archæan granite. At this place there are two pits fifty feet apart, one in fifty-five feet of ore and the other in green schist. The schist is the same as that seen elsewhere on the range and lies unconformably beneath the Taconic rocks. It dips here N. 85°, while the dip of the ore is S. 10°. The ore occupies a gorge at the contact line between the two formations. The same deposit in the same relative position extends eastward across the Hale forty. The bare ridges of green schist rise much higher northward, and drainage is off the schist ridges into the valley in which the ore is found. The fact that the ore on these two properties is largely a non-bessemer

Fig. 8.



SITUATION AT THE KANAWHA AND HALE.

Am. Bank Note Co. N.Y.

gœthite is an indication that the replacement is not so perfect in this situation as when the entire slope is composed of the Taconic iron formation.

Missabe Mountain.

A pit located with very good judgment by Capt. J. G. Cohoe, one of the earliest and best explorers on the range, encountered ore on this property, N. E. ¼ section 8, T. 58–17, in the first pit sunk, at the depth of thirteen feet. This was in the last of March, 1892. The first ore discovered in this township was on this property. Other pits on the same land revealed a large deposit of ore of good quality, and in about four months a lease was made to H. W. Oliver, of Pittsburgh, on a guaranteed output of 400,000 tons annually, at the high royalty of 65 cents per ton. The income of this company is thus assured to be more than a quarter of a million of dollars from this property alone. An advance royalty of $75,000 was paid by Mr. Oliver. So quickly are iron mines developed and turned into cash on the Mesabi.

Ohio.

The Ohio Iron Company moved their workmen to the corner of their property nearest the first pit on the Missabe Mountain in April, and were rewarded by finding soft blue hematite of excellent quality in several pits. Early in June this property was leased to James Sheridan, of Duluth, and others, who agreed to pay $97,500 a year in royalties at the rate of 65 cents per ton.

Lake Superior.

In February or March ore was found in the northeast quarter of section 22, T. 58–20, on the land of the Lake Superior Iron Company. This was the fourth township in which ore had been found and its discovery added greatly to the already intense excitement in Duluth. The statement was often made that the whole country was full of iron ore and that a test-pit could hardly fail to find it. Some were of the opinion that iron ore would be so abundant as to be worthless, and that the mines were equally so. It is needless to say that this opinion was held by those who were ignorant of the immense consumption of iron in this country. It is also superfluous to add that this idea was exaggerated beyond all bounds.

Several test pits found ore on the property of this company, both at the first location and at another farther west. As yet no sublease has been made by this corporation, and their intention may be to do their own mining.

At the Mountain Iron mine the quartzyte is underlain by granite as it is also at the Lake Superior.

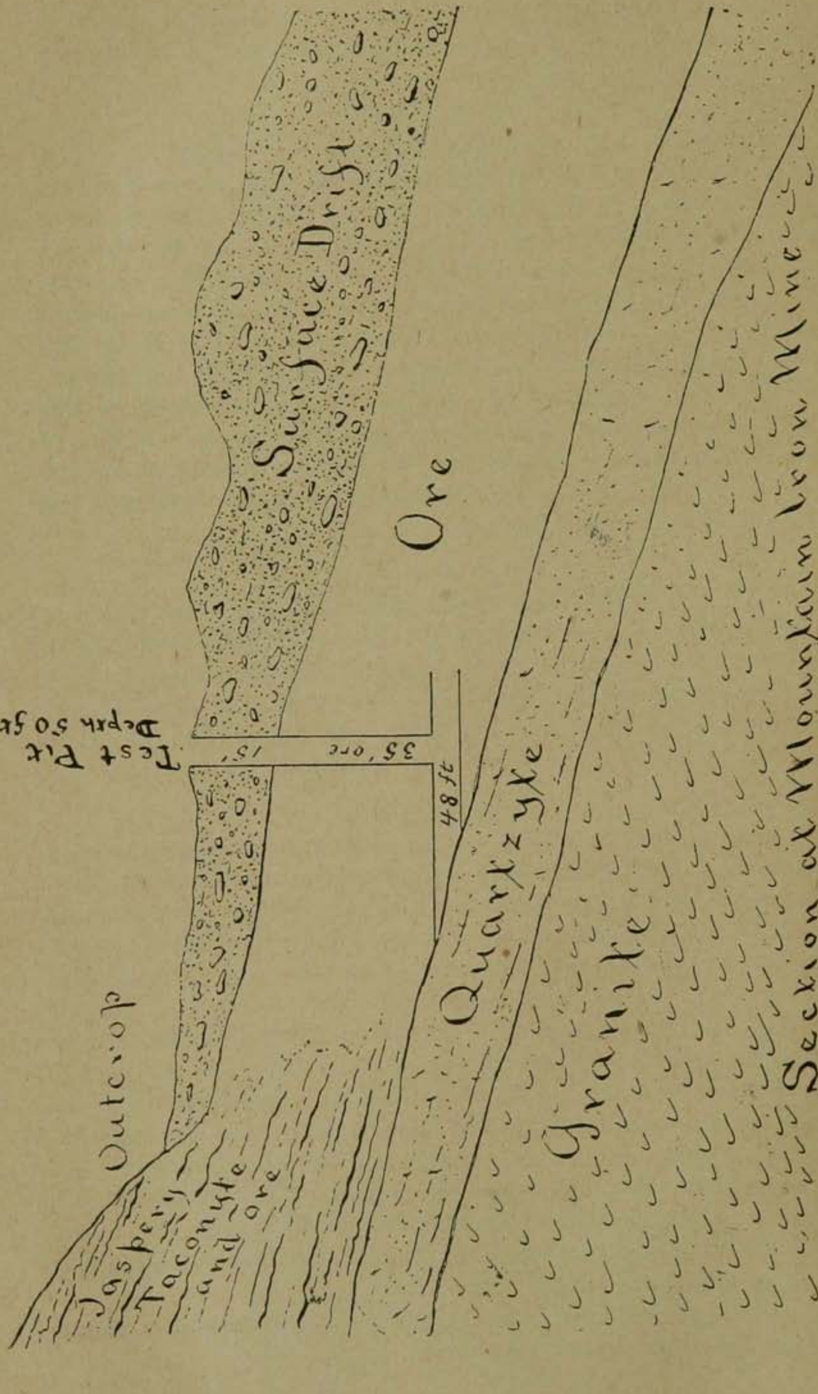


Fig. 9. Section at the Mountain Iron mine.

New England.

In May a fine body of ore was discovered by John Owens on the property of the New England Iron Company, N. W. ¼ N. W. ¼ section 9, T. 58–17. Later developments have shown the existence of nearly forty acres of ore, and most of it is the peculiar soft blue ore, which is the best on the range. In August this property was subleased to Capt. N. D. Moore and others at a royalty of 55 cents per ton and an advance royalty of $50,000. This company controls other lands favorably situated for the existence of merchantable ore bodies.

Virginia.

The Virginia Iron Company also found ore in the N. E. ¼ S. E. ¼ section 8, T. 58–17, during the month of May. This property was leased in August for a valuable consideration. A number of test pits indicate that there is ore over a large area on the land of this company. Like the New England, Wyoming, Lone Jack, Kanawha and others, it belongs chiefly to A. E. Humphreys & Co., who were fortunate in their selection of lands and who spared no expense in the rapid and thorough exploration of them. The phenomenally quick development of the new range is due perhaps more largely to their efforts than to those of any other single firm or individual. Their confidence in the district and their earnest efforts to develop it deserve abundant thanks and reward.

"Paddack's."

Ore was found on the S. W. ¼ N. E. ¼ section 3, T. 58–18, east of the Mountain Iron mine, in May. This was the second property in this township to show a good body of ore. The glacial drift here exceeds fifty feet in depth and water is troublesome, but the body of merchantable ore appears to be of considerable extent.

Lone Jack, Wyoming, Security, Great Western and Rouchleau.

Along in May ore was found on the above properties, all situated in T. 58–17. There is a large bend in the green schist ridge in this township and the largest group of mines on the range is situated on the flanks of this loop or bend. As will be seen from the map these mines follow the curving line of the greenstone ridge, and occur on its flanks, irrespective of the direction it may happen to assume. No detailed description of each property and its develment will be given here, for the work is not sufficiently advanced to warrant it and the main features are similar to those already described on other properties.

There is, however, one peculiar occurrence on the Lone Jack and Missabe Mountain to which reference has already been made.

There appears to be a pre-glacial gorge formerly excavated by some stream flowing in a westerly direction down from the green schist ridge across the Lone Jack and Missabe Mountain into the valley in the southwest part of the township. This gorge was in some way filled with gravel, at the present time composed principally of round, water-worn fragments of hard ore. The drift mantle was subsequently spread over the top of the filled gorge and the ore on both sides of it. At the bottom of this gravel-filled gorge is a stratified layer of light colored kaolinic material which varies in thickness from a few inches to twelve feet. Beneath this stratum of kaolin is soft blue hematite similar to that found by test pits north and south of the supposed gorge on both the Lone Jack and Missabe Mountain. The depth of this ore gravel in the gorge is more than sixty feet. The test-pits sunk on both sides of it encounter ore at the depth of from eight to fifteen feet as the thickness of the drift varies. The so-called ore-gravel is mostly hard, dark colored hematite and is cemented by a soft ferruginous paste containing more or less of the kaolinic matter. It is not certain that this gravel was ore when it was deposited in its present position, but it does appear likely that it is not a constituent part of the Taconic strata. The fine deposit of kaolin which separates it from the blue ore below and on the sides was perhaps derived from the detritus of the feldspathic green schist, although it is similar to material found elsewhere at the base or lower edge of deposits of ore, and may thus be a product of chemical alteration *in situ*.

McKinley.

In December, 1891, ore was found on the McKinley, N. W. ¼ S. E. ¼ section 8, T. 58–16. During January work progressed rapidly under the direction of Mr. D. McKinley. Three pits were sunk in good soft blue hematite. Having proven the existence of a good mine here work ceased, until railroad facilities could be obtained, before the full extent of the deposit was revealed. The property is a large one and there is abundant opportunity for a very fine deposit of ore.

During the winter of 1891–'92 work was vigorously prosecuted on all these properties, and the discovery of such a large amount of ore produced quite an excitement in Duluth and among northwestern iron miners, in the months of January, February and March, 1892. Many new companies with a very large capital stock were organized, and the work of searching for iron deposits was begun in dozens of camps in the dead of winter. Log camps were erected and tons of supplies were taken on runners to the various locations west of Mesaba station on the Duluth and Iron Range railroad. The organization of these companies was a matter of speculation. The lands were held under State or private lease at a royalty of 25 or 30 cents per ton, or in fee, and were selected without any knowledge of the region or the properties or the possibility of the discovery of ore thereon. It was to be expected that many companies would be disappointed in the search for ore and that the expense of operating would soon drain the exchequers of others. This was in fact the case, but it must be admitted that the number of successful ones was surprisingly large.

Other discoveries of ore.

There are authentic reports of the discovery of merchantable ore in townships 58–20, 58–21 and 57–22, on the lands of the Washington, Mesabi Chief and Lake Superior Iron companies, as well as on land under lease to J. M. Longyear. These have not been visited recently by the writer. Neither has the Diamond mine in 56–24. This mine has been operated for several years under the superintendence of Mr. E. W. Griffin, of Minneapolis. The results were not at first satisfactory, and considerable trouble was experienced with water. It is reported that the work is at present being conducted in a body of good soft ore. The Gunflint Lake Iron Company, under the direction of Mr. John Paulson, is preparing to mine the magnetic ore on the eastern end of the Mesabi range in township 64–5. The Port Arthur, Duluth and Western railroad is in operation to a point near these deposits.

LIST OF SUB-LEASES ALREADY MADE.

Mine.	Royalty.	Advance royalty.	Minimum output, tons.
Cincinnati. [To Standard Ore Co.]	$.55	$25,000	150,000
Biwabik. [To P. L. Kimberley.]	.50	......	300,000
Biwabik. [To Berringer et al.]	.50	......	*100,000
Virginia. [To Weimer et al.]	.50	25,000	50,000
Wyoming. [To A. J. Decker.]	.30	40,000	25,000
Wyoming. [To. J. T. Jones.]	.50	......	25,000
Wyoming. [To Parkersburg Iron Co.]	.50	30,000	50,000
New England. [To N. D. Moore.]	.55	50,000	150,000
New England. [To J. B. Weimer.]	.50	25,000	50,000
Lone Jack. [To Moore & Foley.]	.65	......	50,000
Missabe Mountain. [To H. W. Oliver]	.65	75,000	400,000
Ohio. [To Jas. Sheridan et al.]	.60	......	150,000
Hale. [To F. A. Bates and H. P. Barbour]	.50 & .40	.....	50,000
			1,550,000

*50,000 tons each alternate year.

LIST OF MINING COMPANIES INCORPORATED IN MINNESOTA DECEMBER 1, 1890, TO SEPTEMBER 1, 1892.*

[The name of the company is followed by the place of its principal office, the amount of capital stock, number of shares, date of incorporation and names of incorporators.]

Alaska Mexican Gold Mining Company; St. Paul; $1,000,000; 200,000 shares; Nov. 17, 1891. S. M. Magoffin, F. S. Kirkpatrick, J. T. Rogers.

Allegheny Iron Mining and Milling Company; Duluth; $1,500,000; 150,000 shares; May 11, 1892. C. C. Merritt, W. O. Tillotson, P. Hamil, Grant Wyatt, D. W. Evans.

American Mining Company; Minneapolis; $3,000,000; 30,000 shares; March 1, 1892. D. M. Clough, J. B. Sutphin, R. Jamison, F. G. James.

Anderson Iron Company; Duluth; $1,000,000; 40,000 shares; July 16, 1891. A. R. Macfarlane, W. C. Sherwood, J. T. Hale.

Athens Iron Company; Duluth; $3,000,000; 30,000 shares; March 3, 1892. L. Merritt, A. Merritt, R. H. Palmer.

Atikokan Iron Company; Duluth; $250,000; 2,500 shares; Jan. 19, 1892. S. Meniece, A. Snyder, W. Getty, E. J. McLaughlin, M. McManus, J. I. Gilbert, W. McRae, A. P. Cook.

Aurora Iron Company; Duluth; $3.000,000; 30,000 shares; April 8, 1892. J. McKinley, A. E. Humphreys, P. S. Bemis, J. Billings, G. N. Bissell.

Bessemer Iron Development and Mining Company; Duluth; $100,000; 1,000 shares; Aug. 23, 1892.

Bessemer Iron Company; Duluth; $3,000,000; 120,000 shares; Feb. 27, 1892. L. J. Hopkins, G. H. Claypool, H. S. Mahon, C. J. Kershaw, A. E. McCordic, W. B. Silvey, W. G. Crosby, E. C. Jones.

Biwabik Mountain Iron Company; Duluth; $2,000,000; Oct. 9, 1890; $3,000,000; 30,000 shares; Oct. 17, 1891. L. Merritt, E. H. Hall, J. J. Wheeler.

Boston Iron Company; Duluth; $2,000,000; 20,000 shares; March 1, 1892. J. McKinley, G. W. Buck, G. F. Piper, J. T. Hale.

Boston Iron Company; Duluth; $3,000,000; June 16, 1892. Changed to McCaskill Mining Company.

Bradley Iron Company; Duluth; $2,000,000; 20,000 shares; March 1, 1892. H. C. Hanford, G. F. Piper, E. L. Bradley.

Buckeye Iron Company; St. Paul; $3,000,000; 30,000 shares; March 4, 1892. F. Barrett, E. D. Sawyer, J. H. James, W. W. Braden, J. H. Baker.

Buffalo Land and Exploration Company; Duluth; $125,000; 125,000 shares; July 27, 1892. W. E. Richardson, C. Adams, J. T. Hale, H. W. Coffin, O. H. Hewit, D. G. Cash, J. D. Stryker.

* For a list of all the companies previously incorporated in Minnesota for the purpose of mining see Bulletin No. 6, "The Iron Ores of Minnesota," p. 335.

Camden Iron Company; Duluth; $1,000,000; March 25, 1892; $1,200,-000; 12,000 shares; April 5, 1892. J. G. Williams, J. B. Lovell, H. G. Ingersoll, A. J. Decker.

Carnegie Mining Company, The; Duluth; $1,000,000; 10,000 shares; April 4, 1892. S. P. Davidge, E. Zohrlaut, R. F. Fitzgerald, T. E. McGarr, J. R. Bell.

Central American Mining and Improvement Company; St. Paul; $100,000; 20,000 shares; Jan. 4, 1892. W. M. Davis, P. Fletcher, S. M. Magoffin.

Central Vermilion Iron Company; St. Paul; $800,000; 80,000 shares; March 22, 1892. E. A Hendrickson, A. Scheffer, E. J. Hodgson, C. W. Cox, L. E. Judson, Jr.

Champion Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. W. McRae, J. I. Gilbert, C. F. Howe.

Charleston Iron Company; Duluth; $2,000,000; 20,000 shares; Feb. 11, 1892. J. McKinley, F. Cox, A. E. Humphreys.

Chicago Iron Company; Duluth; $5,000,000; 50,000 shares; Feb. 15, 1892. A. E. Humphreys, E. C. Gridley, J. McKinley, J. T. Hale.

Cincinnati Iron Company; Duluth; $3.000,000; 120,000 shares; Nov. 24, 1891. L. Prichard, F. Woodman, A. E. Humphreys, J. McKinley, J. T. Hale.

Clark Iron Company; Duluth; $3 000,000; 30,000 shares; March 7 1892. M. J. Clark, F. Jewell, M. W. Bates, G. F. Piper, A. B. Upton, C. F. McComb.

Cleveland Iron Company; Duluth; $200,000; 2,000 shares; Jan. 28, 1892. J. McKinley, G. J. Atkins, M. O. Brooks.

Columbia Iron Company; Duluth; $3,000,000; 30,000 shares; March 14, 1892. J. McKinley, D. McKinley, G. S. Ostrum, J. E. Lobdell, S. O. Brooks, T. E. Yerxa, E. B. Swygart, G. M. Bissell, A. C. Clauson.

Columbus Iron Company; St. Paul; $2,000,000; 20,000 shares; March 23, 1892. F. Barrett, W. W. Braden, M. Clark, J. McCarthy, A. S. Bates, M. O. Brooks.

Comstock Iron Mining Company; Duluth; $5,000,000; 50,000 shares; March 11, 1892. G. T. Porter, F. W. Merritt, G. A. Elder, A. D. Thomson, M. Simpson, W. M. Holbrook.

Consolidated Missabe Iron Company; Duluth; $3,000,000; 30,000 shares; March 14, 1892. G. M. Nelson, L. Merritt, R. Jamison, A. Erwin. J. Mather, K. D. Chase.

Cosmopolitan Iron Company; Duluth; $4,000,000; 40,000 shares; March 11, 1892. J. McKinley, F. W. Winship, A. E. Humphreys.

Dayton Iron Mining Company; Duluth; $1,000,000; 10,000 shares; Feb. 29, 1892. J. C. Semple, J. W. Earl, W. P. Strickland, J. F. Landry, N. A. Gearhart, C. A. Long, W. A. Barr, H. P. Haskell, G. F. Copeland.

Detroit Iron Company; Duluth; $3,000,000; 120,000 shares; Feb. 18, 1892. J. T. Hale, F. E. Kennedy, J. M. Root.

Diamond Iron Mining Company, The; Minneapolis; $100,000; 1,000 shares; Aug. 20, 1892. G. F. Warner, A. Richardson, H. H. Smith.

Donald Grant Mining Company; Duluth; $50,000; 500 shares; March 14, 1892.

Duluth Iron Mining Company; Duluth; $200,000; 2,000 shares; March 3, 1892. F. Cox, S. W. Eckman, A Howell.

Duluth Mining Investment Company; Duluth; $50,000; 500 shares; March 16, 1892.

Duluth Ore Company; Duluth; $100,000; 4,000 shares; May 16, 1892. J. R. Berringer, A. H. Stevens, J. B. Weimer.

Elk Iron Mining Company, The; St. Paul; $3,000,000; 30,000 shares; April 13, 1892. C. R. Groff, D. D. Merrill, Jr., W. B. Richards, J. L. Stack.

Gowan Mining Company; Minneapolis; $500,000; 100,000 shares; May 26, 1892. A. H Linton, R. B. Langdon, R. B. Conkey, C. S. Langdon, J. A. Gowan.

Great Northern Mining Company; Duluth; $2,000,000; 20,000 shares; Jan. 2, 1892; $3,500,000; 35,000 shares; April 2, 1892. G. L. Robbins, E. T. Merritt, J. T. Culbertson, N. B. Merritt, E. R. Brace, T. A. Merritt, R. W. Allnutt, F. W. Merritt, H. A. Wing.

Great Western Mining Company; Duluth; $6,000,000; 60,000 shares; March 5, 1892. A. Merritt. L. Merritt, G. L. Robbins, J. Culbertson, E. T. Merritt, F. W. Merritt, N. B. Merritt, C. C. Merritt, D. B. Searle, C. A. Gilman, M. Simpson.

Guaranty Silver Mining Company; Minneapolis; $500,000; 500,000 shares; June 5, 1891. A. C. Dunn, J. G. Ricke, A. D. Westby, C. D. White, E. Robinson.

Gunflint Lake Iron Company; Duluth; $100,000; 1,000 shares; Mar. 24, 1892. J. Paulson, K. Kortgaard, O. D. Kinney.

Hale Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 2, 1892. J. T. Hale, E. C. Gridley, J. Norton.

Henderson Mountain Mining and Milling Company, The; St. Paul; $100,000; 1,000 shares; July 27, 1892. W. E Nichols, H. J. Chittenden, L. Blanden, W. A. Jones.

Henrietta Iron Company, The; Minneapolis; $50,000; 500 shares; April 27, 1892. G. F. Moulton, O. J. Nevitt, J. Paulson, G. A. Morse, W. H. Cooper.

Hidden Treasure Silver Mining Company; Minneapolis; $100,000; 100,000 shares; Dec. 28, 1891. D. McKenzie, N. Campbell, L. Kimball, F. W. Nevens, W. R. Steadman.

Horton Mining Company; Duluth; $500,000; 50,000 shares; Jan. 28, 1892; $1,000,000; 100,000 shares; Feb. 20, 1892. G. W. Horton, S. G. Wightman, R. H. Harris, W. E. Worden, S. S. Smith, H. B. Moore, W. D. Edson, R. P. Edson.

Imperial Mountain Iron Mining Company, The; St. Paul; $1,000,000; 10,000 shares; April 11, 1891. J. P. Heatwole, J. Roach, A. B. Kelly, S. Finkelson, L. D. Baird, W. B. Joyce, J. J. Furlong.

Iron Belt Mining Company; Duluth; $1,000,000; 40,000 shares; Mar. 1, 1892. A. J. Trimble, F. Hibbing, L. E. Judson.

Iron Cliff Mining Company; Duluth; $3,000,000; 30,000 shares; March 5, 1892. H. Keller, J. C. Flynn, J. Kraker, S. S. Titus, J. R. Howes, W. N. Holbrook, M. Johnson, A. B. Plough, T. G. Alvord, N. C. Thrall, J. B. Sutphin, *et al.*

Kakina Iron Company; Duluth; $1,000,000; 40,000 shares; Dec. 4, 1891. W. H. Fisher, D. Grant, D. H. Merritt.

Kaministique Iron Company; Minneapolis; $100,000; 10,000 shares; Dec. 3, 1891. S. H. Hall, H. S. Smith, G. A. Castle, R. D. Arundell, C. L. Stacy, A. M. Hillman, E. W. Ginter.

Kanawha Iron Company; Duluth; $2,000,000; 20,000 shares; Feb. 15, 1892. A. E. Humphreys, J. T. Hale, G. E. Milligan.

Kentucky Iron Company; Duluth; $1,000,000; 10,000 shares; March 8, 1892. F. W. De Vey, W. H. Smallwood.

Keystone Iron Company; Duluth; $3,000,000; 30,000 shares; March 4, 1892. C. Markell, A. C. Otis, F. G. Stevens, W. E. Richardson, H. W. Pearson, E. R. Brace, F. B. Lazier, J. T. Hale, C. L. Codding.

Lackawanna Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 3, 1892. F. L. De Forest, W. G. Park, M. J. Davis, E. F. Clark, J. A. Taylor.

Lake Superior Iron Company; Duluth; $5,000,000; 200,000 shares; March 17, 1892. A. J. Trimble, W. D. Vernam, W. H. Buffum, F. Hibbing, W. Munro.

Licking Mining Company; St. Paul; $3,000,000; 30,000 shares; April 22, 1892. F. Barrett, W. W. Braden, A. W. Thurman, W. V. Marquis, J. H. Newton.

Lincoln Iron Company; Duluth; $3,000,000; 30,000 shares; March 19, 1892. H. H. Myers, F. Cox, A. Howell.

Little Mesabi Iron Company; Minneapolis; $3,000,000; 30,000 shares; March 15, 1892. R. W. Cavenaugh, E. S. Bean, G. H. Dodge, E. F. Dodge, A. C. Paul.

Lone Jack Iron Company; Duluth; $500,000; 5,000 shares; Aug. 26, 1892. A. E. Humphreys, G. E. Milligan, A. Howell.

Lucky Hit Mining and Milling Company; Minneapolis; $250,000; 250,000 shares; March 11, 1891. S. Parker, W. F. Albee, J. L. Parker.

Mallmann Iron Mining Company; Duluth; $1,000,000; 100,000 shares; March 5, 1892. A. H. Viele, A. J. Trimble, F. L. Cowen. Increased capital stock.

McCaskill Mining Company; Duluth: $3,000,000; 30,000 shares; June 16, 1892. Changed from **Boston Iron Company.**

McKinley Iron Company; Duluth; $5,000,000; 50,000 shares; May 25, 1892. W. McKinley, J. Charnley, J. McKinley, G. N. Bissell, D. McKinley, J. Billings.

Merritt Nickel Mining Company; Duluth; $2,000,000; 20,000 shares; May 24, 1892. F. W. Merritt, G. W. Mann, W. H. Prescott.

Mesabi Chief Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. W. B. Gardner, J. C. Mishler, S. G. Wightman, R. F. Willcuts, C. D. Smith.

Mesabi Iron Range Mining Company; St. Paul; $4,000,000; 40,000 shares; March 27, 1892. S. McClure, S. Matthews, J. J. Howe.

Minawa Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

Minneapolis and Webb City Mining Company; Minneapolis; $100,000; 10,000 shares; Aug. 18, 1891. F. A. Fisher, W. H. Mitchell, W. M. Barrows, D. G. Michell, S. P. Channell, J. A. Bowman, S. A. Reed, J. B. Starkey, J. H. Clark.

Minneapolis Iron Company; Minneapolis; $3,000,000; 30,000 shares; Feb. 23, 1892. E. M. Mabie, A. R. McGill, G. L. Becker, C. N. Smith, W. S. Milnor, J. J. Ankeny.

Minneapolis Mineral Land Company; Minneapolis; $50,000; June 19, 1891. J. I. Best, J. S. Lane, C. E. Brewster, L. M. Lane, J. F. Calhoun, M. McKinney, W. Miller, E. J. Edwards, E. I. Ewing, O. Jones, O. F. Schmid.

Minneapolis Mining and Milling Company; Minneapolis; $500,000; 500,000 shares; Dec. 26, 1891. J. Pye, S. Parker, W. Hartley, W. F. Albee, J. L. Parker.

Minnehaha Mining and Milling Company; Minneapolis; $500,000; 500,000 shares; April 26, 1892. G. Danforth, L. P. Crevier, F. H. Wendell, K. E. Brewster, D. F. Strobeck.

Minosin Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, J. H. Upham, D. H. Merritt, L. Merritt, W. A. Barr.

Missabe Central Land and Exploration Company; Duluth; $100,000; 10,000 shares; Jan. 2, 1892. A. Merritt, R. H. Palmer, J. Helmer.

Missabe and Northern Townsite Company; Duluth; $50,000; 500 shares: March 17, 1892. L. Merritt, R. H. Palmer, N. B. Merritt, A. Merritt.

Missabe Mountain Iron Company; Duluth; $3,000,000; 30,000 shares; Feb. 4, 1892. L. Merritt, J. E. Merritt, K. D. Chase.

Missabe Monarch Iron Company; Duluth; $3,000,000; 30,000 shares; March 12, 1892. L. Merritt, R. H. L. Jewett, W. P. Jewett.

Missouri Iron Company; Duluth; $50,000; 5,000 shares; Aug. 4, 1892. L. J. Taussig, A. W. Taussig, T. Bloomfield.

Myrna Iron Mining Company; Duluth; $200,000; 100,000 shares; Feb. 14, 1891. T. H. Pressnell, F. Hibbing, R. D. Mallet, A. J. Trimble, F. I. Tedford.

New Castle Iron Mining Company; Duluth; $250,000; 25,000 shares; April 4, 1891. A. E. Humphreys, F. I. Tedford, F. Hibbing, T. H. Pressnell, J. A. Boggs.

New England Iron Company; Duluth; $3,000,000; 30,000 shares; March 15, 1892. A. E. Humphreys, J. McKinley, A. J. Blethen, L. Swift, Jr., W. H. Lynn.

New York Iron Company; Duluth; $3,000,000; 120,000 shares; Mar. 1, 1892. C. C. Merritt, A. R. Merritt, H. W. Coffin, J. T. Hale, E. T. Merritt.

Nibiwa Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, J. H. Upham, D. H. Merritt, L. Merritt, W. A. Barr.

Northern Light Iron Company; Duluth: $2,000,000; 20,000 shares; March 31, 1892. A. Michaud, A. I. Scarlett, S. Clark, A. M. Cox.

Ohio Iron Company; Duluth; $50,000; 2,000 shares; Aug. 12, 1892. J. Sheridan, J. T. Jones, J. B. Weimer.

Ohio Mining Company; Duluth; $1,000,000; 100,000 shares; Feb. 1, 1892; $3,000,000; 30,000 shares; April 18, 1892. J. E. Campbell, E. D. Sawyer, W. J. Hilands, C. F. Nester, R. S. Munger, M. R. Baldwin, T. H. Pressnell, J. K. Persons, F. Barrett, S. R. Ainslie.

Oneota Iron Mining Company; Duluth; $1.500,000; 15,000 shares; March 1, 1892. F. W. Merritt, J. Frazer, G. W. Mann, G. Wyatt, J. M. McLennan, E. F. Clarke.

Outcrop Iron Mining Company; St. Paul; $500,000; 5,000 shares; May 10, 1892. C. A. Hutchinson, G. Lill, J. F. Whiting, D. M. Case, F. Barrett.

Pacific Mining Company, The; Duluth; $500,000; 5,000 shares; May 6, 1892. A. Erwin, G. N. Baxter, E. H. Hall, G. N. Nelson, R. Jamison.

Palisade Mining Company; Minneapolis; $250,000; Oct. 21, 1891. J. F. Calhoun, L. M. Lane, J. S. Lane, M. McKinney, E. J. Edwards.

Parkersburg Iron Company; Duluth; $100,000; 1,000 shares; Sept. 5, 1892. J. Billings, P. S. Bemis, F. Cox.

Pennsylvania Iron and Steel Company; Duluth; $3,000,000; 30,000 shares; March 5, 1892. Nels Hall, D. W. Evans, S. W. Clark, A. T. Scarlett, N. A. Gearhart, A. C. Pearsons, G. Wyatt.

Pipe Lake Nickel Mining Company; Duluth; $500,000; 50,000 shares; June 9, 1891. R. Forbes, G. N. Stevenson, W. H. Trescott, J. T. Watson, M. Douglas.

Pittsburgh Iron Company; Duluth; $100,000; 4,000 shares; Dec. 12, 1891. W. McKinley, J. McKinley, A. J. Trimble.

Poca Iron Companv; Duluth; $50,000; 500 shares; June 9, 1892. F. Cox, A. Howell, S. W. Eckman.

Portage Red Sandstone Company; Duluth; $100,000; 1,000 shares; July 7, 1891. J. D. Lloyd, F. B. Chew, J. H. Hellyer, C. W. McFadden, C. T. Le Tourneau.

Putnam Iron Company; Duluth; $3,000,000; 30,000 shares; March 2, 1892. J. T. Hale, E. C. Gridley, S. R. Payne, J. P. Morrow, E. G. Chapman, H. S. Stearns, J. Sheridan, C. d'Autremont.

Republic Iron Company; Duluth; $3,000,000; 120,000 shares; March 22, 1892, P. M. Graff, F. W. Eaton, J. G. Brown, R. J. Ryan, A. Erwin, G. M. Nelson, R. Jamison.

Rouchleau Iron Company; Duluth; $5,000,000; 50,000 shares; Mar. 18, 1892. L. Rouchleau, F. W. Higgins, G. Gilbert, G. F. Piper, C. E. Shannon, G. W. Buck, T. B. Mills.

Securitv Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. T. Hale, E. T. Merritt, G. W. Buck, G. F. Piper, R. H. Palmer.

Security Land and Exploration Company; Duluth; $100,000; 10,000 shares; Dec. 30, 1891. G. W. Buck, G. F. Piper, J. T. Hale, N. B. Merritt, R. H. Palmer.

Shaw Iron Company; Duluth; $3,000,000; 30,000 shares; Dec. 21, 1891. D. W. Scott, J. E. Davies, A. R. Merritt, N. B. Merritt, R. H. Palmer.

Sheridan Iron Company; Duluth; $1,000,000; 100,000 shares; Dec. 8, 1891. C. E. Shannon, W. C. McComber, R. H. Harris, J. H. Harris, C. M. Gray, A. C. Otis, G. R. Laybourn.

Silver Chief Mining Company, The; Minneapolis; $500,000; 500,000 shares; Aug. 18, 1892. M. N. Price, B. F. Moore, C. L. Mendel, F. M. Hutchinson, F. L. Favor, F. E. Mix, W. F. Thayer.

Southern California Smelting and Refining Company, The; Los Angeles; $500,000; ——— shares; Sept. 5, 1892.

Standard Ore Company, The; Duluth; $1,500,000; 60,000 shares; Aug. 5, 1892. H. W. Oliver, F. A. Bates, H. P. Barbour, A. D. Thompson, B. C. Church, C. A. Congdon.

Steep Rock Mining and Improvement Company; Duluth; $50,000; 500 shares; May 13, 1892. L. S. Franklin, H. C. Ash, A. E. Walker.

Stowell Iron Company; Duluth; $1,000,000; 100,000 shares; Feb. 16, 1891. W. H. H. Stowell, B. E. Baker, G. F. Long, A. C. Jamison, T. H. Pressnell, S. F. Boyce, F. I. Tedford, J. Zimmermann, L. W. Hizar, F. Barrett.

St. Paul and Duluth Mining Company; St. Paul; $1,000,000; 100,000 shares; April 23, 1892. S. S. Smith, W. H. Squier, J. C. Southall, W. Ruan, W. P. Curtiss, R. H. Edwards, P. P. McVeigh, Jr.

Swan Lake Iron Mining Company of Minneapolis; Minneapolis; $1,000,000; 40,000 shares; April 4, 1892. G. H. Warren, W. G. La Rue, D. Waite.

Swedish American Iron Company; Duluth; $2,000,000; 20,000 shares; Feb. 23, 1892. C. A. Smith, O. N. Ostrum, N. O. Werner, J. Peterson, L. M. Erickson, A. Nelson, N. Hall, J. J. Eklund, N. A. Linderberg, J. A. Carlson.

Towanda Iron Company; Duluth; $3,000,000; 30,000 shares; March 2, 1892. J. T. Hale, B. T. Hale, J. Sullivan, R. H. Palmer, A. Merritt.

Twin City Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. McKinley, A. E. Humphreys, G. E. Milligan.

Vermilion Iron and Land Company of Duluth; Duluth; $1,000,000; March 8, 1892. Changed name to **Kentucky Iron Company.**

Virginia Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. McKinley, G. F. Piper, A. L. Warner.

Vulcan Iron Company; Duluth; $1,000,000; 100,000 shares; Feb. 29, 1892. F. Walker, A. H. Morris, M. A. Morris, C. O. Munns, R. H. Harris.

Wabigon Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

Wahkootah Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 14, 1892. L. Merritt, E. H. Hall, R. Jamison, J. Mather.

Washington Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 2, 1892. T. B. Mills, G. F. Piper, J. Spencer, R. A. Taussig, A. B. Upton, D. S. Culver, W. B. Welles, G. A. Leland, C. F. McComb, J. K. Redington, C. K. Lawrence, M. W. Bates.

Wenona Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

West Gogebic Iron Land Company; Minneapolis; $60,000; April 20, 1891. M. W. Lewis, J. A. Wolverton, F. B. Lewis.

Wyoming Iron Company; Duluth; $300,000; 3,000 shares; April 23, 1892. F. Cox, S. W. Eckman, W. F. Gore.

Youngstown Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. A. Merritt, N. B. Merritt, A. L. Warner, C. C. Merritt, B. T. Hale.

Zenith Iron Company; Duluth; $2,500,000; 100,000 shares; March 28, 1892. G. F. Piper, H. H. Hanford, L. E. Judson, Jr.

Method and Cost of Mining on the Mesabi.

The excellent quality of the Mesabi ore and the large amount of it have been commented upon in the preceding pages. A few words as to the expense and probable method of extracting this ore from its bed and placing it on the cars ready for transportation to the furnace will be of interest. In an article in the Cleveland Iron Trade Review, July 21, 1892, the writer made the following statements:

"The most important feature of the Mesabi, in view of its distance from the furnace and forced competition with other ranges, is the cheapness of mining. A few estimates will make this clear. Old methods and old calculations will not answer on this range.

"Soft ore, large areas near the surface and horizontal deposits are not to be handled by deep shafts, air-compressors, timbering and costly pumps. It is the exception to find the ore covered by rock, and it is unusual to find more than fifty feet of glacial drift lying upon it. It is not to be supposed that there will be only a single method of mining here. Different men will have different ideas, and different properties will present different problems, but it is plain that the most of the mines will be worked as open pits, with the surface stripped off.

"Estimates of the cost of removing earth, sand, clay and gravel and boulders can be obtained from any railroad contractor. The estimated cost per cubic yard varies from six to forty cents according to the material and the facilities for removing it. With a railroad at hand a steam shovel will remove ordinary sand and gravel for six cents a yard. By hand work, without railroad facilities, it will cost from twenty-five to forty cents a yard.

"When the surface is stripped off, the ore is found in flat deposits covering twenty to sixty or more acres, and from twenty to ninety feet thick. Test pits are sunk in places one hundred and seventeen feet deep by pick and shovel, without a single drill hole or blast of powder. In other spots there may be twenty or thirty feet in a pit which is too hard to pick. This can be thrown down in large quantities when there is once a face on it, and can then be loaded by hand or steam shovel. Where no blasting is required, the expense of loading cars by hand labor will not exceed twenty-five cents per ton; by steam shovel it may reach ten cents. Where the ore is hard enough to blast, the expense of excavating and loading on cars may reach forty cents. It is not necessary to reckon into our calculation any interest on a large investment, for that is covered by royalty. No expensive plant is depreciating on our hands. Fewer damage suits arise from injuries received, because our men work by daylight.

"Let us now, with these figures before us, make a theoretical estimate of the cost of mining ore on almost any property on the Mesabi which has been developed enough to show the depth of ore and the amount of stripping. One cubic yard of ore weighs about two and one-half tons, one yard of earth about one ton. The average depth of ore so far revealed on several properties is seventy feet, and the surface thirty-five feet. In other places the ore is sixty or even eighty feet thick and the surface only twenty, but for the sake of estimation let us consider the ore only twice as thick as the surface. There are then two cubic yards of ore for each cubic yard of surface. But as each yard of ore weighs two and one-half tons there are five tons of ore for each yard of surface, and if the stripping costs the maximum of forty cents per yard the cost for each ton of ore is eight cents. At the minimum of six cents per yard for stripping, the stripping cost is only one and one-fifth cents for each ton of ore.

"When the surface is removed the ore is practically in a huge stockpile, containing in some instances several millions of tons. At the maximum cost of mining this by hand and in hard ore the cost of stripping and placing ore on cars is forty-eight cents per ton. The minimum cost at the figures given above is eleven and one-fifth cents. The average is about twenty-nine and one half cents. But as there is more soft ore than hard the average may be expected to be about twenty-five cents. The cost of timbering alone in many mines on the south shore of lake Superior exceeds the total cost of mining millions of tons of ore on the Mesabi."

If the cost of mining is 25 cents the approximate cost of the ore delivered at Cleveland will be $3.10, distributed as follows:

Cost of mining,	$ .25
Royalty,	.60
Railroad freight to the lake,	.80
Lake freight to Cleveland,	1.20
Insurance, commission, etc.,	.25
	$3.10

These items will vary somewhat. The lake tariff at present is but $1.00 to Cleveland, and in some cases the last item will be only 15 cents. The royalty, too, will vary, and will average less than 60 cents. Different methods of mining will vary in expense. The above estimate is for mining by steam shovels and stripping off the surface. If the method of underground mining is adopted the cost will exceed the figure given above.

The average price for 60 per cent. bessemer ore is not far from $4.25 at Cleveland. If the large amount of Mesabi ore made suddenly available should force the price down to $3.75 per ton, there will still be a profit for the average Mesabi mine operator.

Quantity of Ore on the Mesabi.

How much ore is there on the new range? How long will it last? These are questions of importance and are frequently asked. The answer must be in the nature of an estimate at present. Different experts of equal skill would arrive at different results in an attempt to compute the ore in sight. Figures that represented anything like the truth, even though they were made by a competent and disinterested person, would be received with incredulity by those not familiar with the actual developments. Besides, there is no doubt that much more ore will yet be discovered; how much is merely a matter of speculation. Hardly a week passes now without the announcement of a new find, and new areas are continually being tested and found productive on the properties already under development. The Biwabik company has quite recently been presented with another mine on section 36, T. 56–18, by the good judgment and industry of their explorer, Capt. J. G. Cohoe. The number of known merchantable deposits already exceeds twenty and many other promising localities have not yet been explored.

It is evident that there is ore in store for many years to come, and that permanent investments and improvements of the most extensive nature can safely be made, based on an expectation of the sufficiency and quality of this ore-supply. As already stated contracts have been made calling for the minimum production of one and a half million tons per annum. This is eighty per cent. more than has ever been produced by the Vermilion range in one season, and is about one-sixth of the entire lake Superior product. The yield of some of the largest mines, like the Mountain Iron, McKinley and Lake Superior, is not included in this minimum figure, nor are some others like the Canton, Kanawha and Great Western. It is moreover likely that some companies will ship more than their minimum amount. It may not be within the first two years, but after they are quite ready.

TRANSPORTATION.

Extensive railroad and vessel equipments are necessary for handling the product of an iron range. It seems rather questionable whether the railroads running to the Mesabi will be able to handle the ore which will be offered them in 1893. The iron mines are situated sixty to eighty miles from lake Superior. At the beginning of 1892 there was but one railroad, the Duluth and Iron Range, which crossed the Mesabi, and that was twelve miles from the nearest mine. The Duluth and Winnipeg, in running west from Duluth, formed an acute angle with the Iron Range and crossed it at Grand Rapids, on the Mississippi river. During the first nine months of this year, however, two roads were constructed and put in daily operation between Duluth and the new range.

The first road completed was the Duluth, Missabe and Northern. From the Duluth and Winnipeg, at Stony Brook, this road runs north over a level, drift-covered region for forty-two miles to the Mountain Iron mine. The road-bed is excellent, and curves and grades being few the operating expenses will be light. It was chiefly through the efforts of the late M. B. Harrison, Leonidas Merritt, K. D. Chase and Donald Grant that this road was built. It was put in operation during the first week in October. By its contracts with the owners and lessees of several of the largest mines this railroad is already assured of large business. A considerable number of ore-cars and heavy locomotives are now being constructed for this company.

The ore brought down over the Duluth, Missabe and Northern will be handled by the Duluth and Winnipeg between Stony Brook and the docks on Allouez bay. This road will also handle ore which will be delivered to them by other branch roads to be constructed farther west. One of these roads is now being built by the Swan River Logging Company from the crossing of Swan river to the mines in townships 57–22 and 58–20.

The Duluth and Iron Range branch to the Biwabik, Canton and other mines near the town of Merritt was also completed in October, 1892. In spite of many serious natural obstacles, such as heavy grades, this road has as fine a track and equipment and is as well managed as any road in the state. Its traffic is already large from the Vermilion range, and will manifestly be increased by the large output of the Mesabi. It is expected that both the Iron Range and Missabe and Northern will construct lines along the range connecting the various towns and mines.

For assistance in many ways, for valuable information and repeated courtesies, the officers of the geological survey are indebted to the Duluth and Iron Range, the St. Paul and Duluth, and the Duluth, Missabe and Northern railroad companies. The extension and successful operation of these roads, as well as others, is for the welfare and development of the wealth of the state, and they are factors perhaps second to none in forwarding its prosperity.

Value to the State.

The best gauge of a nation's commercial and political rank among the nations of the world is found in the record of its mining and manufacturing achievements. The country that makes the largest use of its natural products is the leader in all that constitutes national greatness. One good reason for the decadence of nations formerly foremost in the world and now of but little importance is the want of mineral resources or the ability to utilize them.

We may go farther and say that of all natural resources there is none which, properly developed and applied, confers such great riches and commercial importance on its possessor and user as ron. Gold and silver mines are valuable and their possession enriches nations as well as individuals, but "he who possesses iron will soon be master of the gold," and its benefits to civilization are greater and far more lasting.

Which are the leading countries in the world to-day? The United States and England are probably foremost in all that denotes prosperity and greatness. Which are the largest producers and consumers of iron ore? The same two by long odds, having yielded together more than fifty per cent. of the world's output in the year 1889.

The same truth is borne out by a consideration of the different States of the United States. The four most populous and wealthy States in the Union are New York, Pennsylvania, Illinois and Ohio. In 1890 these four States ranked respectively fifth, first, fourth and third in the production of pig iron, having produced in the aggregate 73.5 per cent. of the entire yield of the United States. In the production of steel they ranked in the same order.

In Michigan, Wisconsin and Minnesota there was an average increase in population amounting to forty-one per cent. in the decade from 1880 to 1890. In these States the production of iron ore increased in a more than corresponding ratio. The average increase of Michigan and Wisconsin was 1210 per cent., while Minnesota, which did not appear as a producer in the tenth census, ranks *fifth* among the States in the eleventh. These commonwealths have not derived their full benefit from this large production of iron ore for two reasons. First, they have been producers but a few years. Second, their ore has been shipped away to be consumed in other regions; and it is not merely the production of iron ore, but the combined production and consumption or manufacture of iron that results in the greatest growth and prosperity.

With the exploitation of the mines on the Mesabi there will arise communities of inhabitants who will populate the northern portion of the state more rapidly than would be the case for almost any other reason. All the industries connected with mining and the support of a large number of people will be rapidly promoted. But the greatest good will come only from the establishment of furnaces to reduce the ore and factories to make finished articles for shipment to the western markets.

Minnesota has within her borders the greatest iron district known in the world to-day. It lies within her power to become the leading state in America. With these facts before them it is incumbent upon the citizens of this commonwealth to consider most seriously how to derive the greatest benefits from her mineral wealth. It is a sober fact that more merchantable iron ore is already known to exist on the Mesabi range than has been produced from all the other mines in the lake Superior region since they were first discovered. With this possibility of unprecedented prosperity and industrial growth every facility and inducement should be extended to those who may establish furnaces and factories within our boundaries.

Discoveries of ore on lands owned and leased by the State already promise an annual income of a quarter of a million, to be paid directly into the State treasury in the shape of royalties. The erection of blast furnaces to consume this ore would result in benefits to the state at large equal to several times the amount of these royalties. It might be a wise move on the part of the State to pay a bounty on each ton of ore reduced within her limits. If this bounty were simply enough to offset the royalty it would be a considerable inducement for the establishment of furnaces, and would be a paying investment for the State.

CLASSIFICATION OF THE THEORIES OF THE ORIGIN OF IRON ORES.‡

In discussing the various theories proposed for the origin of iron ores in Bulletin No. 6, the scheme or order adopted by Prof. A. A. Julien was followed. It has not proven entirely satisfactory, being often inconvenient and confusing. The following classification may be used in the study of the subject with a clearer understanding of the differences in the ideas entertained by geologists on this interesting question:

A. MECHANICAL.
- a. Extra-terrestrial or cosmical.
  - 1. Meteoric fall. [1.]†
- b. Terrestrial.
  - 1. Subterranean—eruption in dykes or accompanying basaltic flows. [2.]
  - 2. Superficial action.
    - *a.* Violent abrasion and transport. [13.]
    - *b.* Ordinary erosion. { 1. Concentration of iron sands. [14.] 2. Oceanic sedimentation. [8.]

B. CHEMICAL.
- a. Changes in situ.
  - 1. Change in the kind or quantity of iron already present in the rocks.
    - *a.* Alteration of diffused ferric oxide into ferrous carbonate. [10.
    - *b.* Metamorphism of bog ore. [11.]
    - *c.* Metamorphism of lake ore. [12.]
    - *d.* Alteration of ferrous carbonate or sulphide into ferric oxide. [8 in part.]
  - 2. Change in the kind or quantity of other minerals.
    - *a.* Substitution of iron oxide for some non-ferriferous mineral. [17.]
    - *b.* Concentration, by removal of other constituents. [4.] Similar to B a 1.

‡American Geologist, Nov., 1892, Vol. X., No. 5, p. 277.

†Figures in brackets refer to the theories as numbered and discussed in "The Iron Ores of Minnesota," Bulletin No. 6, Minn. Geol. Survey.

c. Electro-telluric action. [16.]

b. Removal by chemical action and subsequent deposition.

1. By action of heat—sublimation. [3.]
2. By action of water.
    - *a.* In drainage basins.
        - 1. Oceanic precipitation. [8 in part.]
        - 2.
            - a. Secondary product of the decomposition of basic rocks [18.]
            - b. Secondary product from the decomposition of pyrite. [7.]
    - *b.* In the rocks.
        - 1. Saturation of porous strata. [5.]
        - 2. Infiltration into cavities. [6, 15.]
    - c. Deposit by springs. [9.]

COAL IN NORTHERN MINNESOTA.

During the past year there have been frequent reports of the discovery of coal in the region north of Duluth. The development of such extensive iron mines and the great desirability of coal deposits that can be used in connection with the iron has added to the interest with which such reports are usually received.

The opinion of the state geologist and the writer has been frequently expressed that the only coal of any sort in the northern part of the state is in thin seams of brown coal, occuring in Cretaceous shales, which were found in patches on the Little Fork river by the writer in 1888. This coal is not of good quality and the discovery of large amounts in thick beds would not be of such great importance as the newspapers would have us believe.

At the same time lignite is used to a considerable extent in treeless regions as fuel for ordinary heating and cooking purposes. In Texas and Dakota such coal is mined in considerable quantities. Grates of a particular pattern are devised in which to burn this coal and it plays quite an important part in the domestic economy of those regions. It is used in the form of briquettes in Germany. These briquettes are made by drying the brown coal until the water it contains is nearly all driven off and then subjecting a mass of it to a pressure of fifteen hundred to two thousand atmospheres. The resulting briquette is elliptical in form, about six inches long and one inch thick. It is so hard that it will not absorb moisture even though laid in water for some time. This coal is too fine-grained and not compact enough to use in blast furnace practice. If this brown coal should be found dehydrated and consolidated by heat or pressure consequent on eruptions or excessive faulting in the rocks, it would have a much greater value. It is not impossible that such deposits may be found in some of the large areas northwest of Duluth as yet but little explored by the geological survey. It is quite desirable that some further examination be made of this region in connection with more thorough and careful mapping of the rocks of the Mesabi range. The value of good coal deposits cannot be overestimated, and if we have such in Minnesota the sooner we know it the better.

V.

SKETCH OF THE

Coastal Topography of the North Side

OF

LAKE SUPERIOR.

With Special Reference to the Abandoned Strands

OF

LAKE WARREN

(The Greatest of the Late Quaternary Lakes of North America)

BY ANDREW C. LAWSON,

Associate Professor of Geology and Mineralogy in the University of California.

CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

The prosecution of geological investigations for the Geological Survey of Canada in the region northwest of lake Superior afforded the writer annual opportunities of obtaining cursory glimpses of the coast of the great inland sea itself, and on a few occasions of making a very limited reconnaissance of particular portions of it. He never, however, had the good fortune to be able to examine its geological features in detail. Those features, even to his limited acquaintance with them, appeared ever both grand and simple, and seemed to yield to mere inspection an exposition of the great principles of physical geology, which in force and clearness was second to none he had met with either in reading or in traveling.

Working gradually eastward, therefore, the writer had before him the prospect of some day entering upon the investigation of that interesting and rarely paralleled line of accessible rock exposure, the "north shore" of lake Superior, and of presenting a detailed account of the relations there revealed as a contribution to geological science. The severance of his connection with the Canadian survey in the spring of 1890 obscured this prospect, but the writer's thoughts still turned in that direction. In the following year after having settled at the University of California, it seemed to be advisable, before engaging in new investigations on the Pacific coast, to revisit lake Superior for the purpose of procuring information relative to some minor geological problems, which had been suggested to the writer in the course of such partial and unsatisfactory examinations as he had formerly been able to make. Among these problems was an inquiry into the character of the ancient shore lines of the lake. Stimulated by the interesting results obtained by Upham and Tyrrell in the lake Agassiz basin to the west and by Gilbert and Spencer in the lake Ontario (Iroquois) region to the east as to the deformation of ancient shore lines, the writer had been particularly attracted by the evidence of former high elevations of the lake; and had made some effort to gain definite information as to the distribution of terraces and beaches, and as to the probability of a detailed inquiry yielding sufficient data for purposes of generalization.

The interest and importance of such an inquiry lies, of course, in the evidence which it affords of local instability of the crust of the earth. On oceanic coast lines evidences of recent differential movements of the crust are ordinarily not difficult to observe. Such movements are not confined to the vicinity of these coasts but are probably common in the interior as well as on their periphery. But the evidence which makes this statement possible has until recent years been very meagre, and indeed, scarcely sufficient to satisfy the demands of exact knowledge. In the interior of the continents there is no absolute datum such as is offered by the surface of the ocean to which may be conveniently referred the altitudes of the land. There is not a set of agencies, such as the shore action of the sea, to score on the slopes a definite horizon that may be readily recognized as out of place when lifted beyond the reach of those agencies. The allied action of lake shores produces similar horizontal impressions, but the lake may go up or down with the portion of the continent in which it lies and otherwise share its movements, so that when such horizontal shore lines are seen high above the waters of a lake they are usually left there by the mere subsidence of the level of the lake. Thus there is no means of measuring the *absolute* vertical movement of any portion of the interior of a continent, except by the laborious and costly method of carrying lines of levels to the sea shore. But for the more immediate purposes of geological science the absolute measure of such movements is not needed. The science will be enriched in proportion as means are discovered recognizing the fact of recent *differential* vertical movements of the crust in regions remote from the sea and of affording some approximate measure of their extent without reference to any absolute datum. Such a means has been supplied by the modern study of the development of topographic forms, a study that, thanks to the masterly lines that have been laid down by Gilbert, Davis, McGee, Chamberlin and other leaders of the present time, bids fair to become one of the most important fields of research to engage the attention of the coming generation of American geologists.

As one result of such topographic studies it appears that in interior regions we may have good evidence both of the fact and of the measure of differential movements of the crust in (1), the character of stream erosion and deposition, and (2), the deformation of the abandoned shore lines of lakes. It is now generally recognized that streams are extremely sensitive to any change in the slope of their trenches or of any portions of them. There is a uniform minimum slope which they constantly seek to establish and maintain. Any movement of the land leaves its record in a change in the intensity of the action of the stream, whether it be cutting or depositing; and in non-glaciated regions streams are now systematically inspected by geologists for the purpose of ascertaining whether the country traversed by them has been uplifted or depressed, or has maintained a fairly constant altitude. Evidence of this kind is, however, not always available.

The peculiar topography of certain regions is due to the fact of their having been occupied in comparatively recent times by lakes which have now wholly or partially disappeared. One of the characteristic features of such a topography is the presence of ancient shores of the lake at various altitudes on the slopes of the basin, marking as many stages of the water. These strand lines are often traceable as contours for hundreds of miles, and in some cases, as for example on lake Bonneville, the highest of such strand lines is a sharp demarkation between two classes of topography, the one that of the once submerged basin and the other that of the hills above the highest level of the lake. These strand lines were once of course horizontal. At the present day they are frequently found to vary from horizontality in a marked degree, and in this case they are said to have suffered deformation. This deformation affords us at once a proof and an approximate measure of the local differental movements of the crust. Among the most remarkable instances of such deformation of ancient shores are the cases of lakes Agassiz and Iroquois; the former a glacial or post-glacial extension of lake Winnepeg, and the latter a corresponding extension of lakes Ontario, Erie and Huron.

The ancient shore lines of lake Agassiz have been traced by Upham and Tyrrell on the front of the Pembina escarpment in practical continuity for many hundreds of miles on the open prairie, and are found to ascend to the northward at the rate of from six to sixteen inches to the mile.

The measurements of Gilbert and Spencer on the ancient strand lines of lake Iroquois show that they slope in a similar fashion. Thus there is very explicit evidence of the differential movement of the land surface of North America in two extensive regions lying on either side of the lake Superior basin. In view of this fact it becomes a matter of very considerable interest to ascertain what evidences the ancient strand lines of lake Superior afford of differental crustal movements. This was the motive of the present inquiry. The fact of the former high elevation of lake Superior has long been known, though not to the extent to which the writer is now able to establish.

Logan in his report of the geological survey of Canada, 1847, records the occurrence of terraces below the Petits Ecrits (Terrace bay) rising to an elevation of 331 feet above the lake. Terraces rising to nearly 100 feet on the south side of the lake were described and their significance appreciated in Foster and Whitney's "Report on the Geology and Topography of a portion of the Lake Superior Land District," Part I, 1850, and Agassiz in his "Lake Superior," 1850, discusses the terraces observed by him in his trip around the "north shore" and cites Logan's measurements.

But while the former high elevation of the lake was known, no effort whatever had been made to trace the strands around the coast and no suggestion had been offered as to whether they maintained their original horizontality or had been thrown into inclined attitudes. There was thus a serious gap in our knowledge which, it is hoped, will be in some measure filled by the information contained in this paper.

At the outset of the inquiry it was proposed simply to secure accurate data as to the altitude of the various strand lines at as many points as possible and to gather evidence which would help to trace particular strands around the coast. As soon as the work was begun, however, a comparison was naturally instituted between the characters of the present strand and those of the ancient and abandoned strands, the altitudes of which were sought.

This led to a consideration of the topography, not only of the immediate shore line, but also of the general coast of the north side of the lake. It was found that the coast presented very striking contrasts of topographical character which were due to marked differences in the petrographical and structural geology of its different portions. Thus, in the course of the search for elevated beaches and terraces, sufficient information was gained to serve for a general sketch of the topography of the north coast of the lake from Duluth to Sault Ste. Marie. The ancient strands of the lake are now simply topographic features which are, for the most part, displayed along the coast at no great distance from the shore. It seemed best, therefore, to include the discussion of these special features in a more general discussion of the topography of the coast. This discussion does not pretend to be in any sense exhaustive. It is a mere sketch which would be unwarranted were there any satisfactory account of the topography of the north side of lake Superior to be found in geological literature. Even as a sketch this description of the general topography of the coast suffers from the haste in which the work was done, the entire trip from Duluth to Sault Ste. Marie occupying only two months; and also from the fact that the writer had no special qualifications for the work other than his general familiarity with the geology of a portion of the region. It is hoped, however, that the exact data which have been obtained regarding as many of the ancient strands of the lake as could be seen from off its present shore will compensate for what may be lacking in the general account of the coast; and that what is here set forth may be an incentive to others to make more detailed and therefore more valuable examinations of its various parts.

GEOLOGICAL PROVINCES FRONTING ON LAKE SUPERIOR.

There is a very evident relationship between the general topography of the north side of lake Superior and the geological conditions which obtain in different portions of its extent. Between Duluth and Sault Ste. Marie there are four great geological provinces fronting on the lake. These are the Keweenian, the Animikie, the Archæan and the Potsdam.

The Keweenian occupies the entire Minnesota coast from Duluth to Grand Portage. Beyond this point the various formations of the Keweenian are probably geologically continuous around the whole of the north shore, but the out-crop of the rocks is mostly confined to the islands which fringe the coast and to the peninsulas terminating in Thunder cape and Magnet point, which are here regarded as part of the island fringe rather than of the main land. A few outlying patches are also found at different points on the main shore, but these are quite limited in extent except in the vicinity of Nipigon, where a neck of these formations connects the lake Superior Keweenian basin with the extensive interior Keweenian basin of lake Nipigon.

The Animikie rocks occupy the main shore of the lake uninterruptedly from Grand Portage to Port Arthur and also the chain of islands which stretches from Pigeon point to Thunder cape. From Port Arthur onward to the meridian of the Slate islands the Animikie formations are geologically continuous, but are much interrupted along the shore by projecting areas of the underlying Archæan, and, on the peninsulas between Thunder bay and Nipigon bay, by overlying sheets of the Keweenian.

The Archæan shares the coast line with the Animikie and Keweenian from the vicinity of Port Arthur to the eastern end of Nipigon bay. Beyond Nipigon bay as far as the outlet of the lake the coast yields to the rugged dominion of the Archæan; the only exceptions being the Keweenian outliers of Gargantua and Mamainse and the flat-lying patches of Potsdam in the vicinity of Goulai's bay and Sault Ste. Marie.

These Potsdam formations constitute the fourth geological province; and, although its extent on the lake shore is very limited, the rocks composing it have an extensive distribution as is shown by their presence on several of the larger islands off this part of the coast, and much of the character of the southeasterly part of the lake is due to their presence. The Potsdam sandstones are also of peculiar interest, inasmuch as they form the dam in the St. Mary's river which holds the waters of the lake at their present level;—a dam which has evidently only recently been rendered functional by the lowering of the waters of lake Huron below the level once occupied in common by that lake and lake Superior.

Corresponding to each of these great geological provinces, there is a distinct type of coastal topography. And here it may be well to draw a distinction between those elements of the topography, which from Gilbert's classic work have come to be regarded as the "topographic features of lake shores" and what may more comprehensively be designated the *coastal topography*. On any rocky coast line of a lake there may be developed certain topographic elements, the perfection of form of which may be evolved practically independently of the varying character of the geological conditions of the coast. Of these topographic elements we have beaches, bars, spits, terraces, sea-cliffs, caves, pot holes, etc. These are the direct product of wave action along the shore and may be common to all lakes. They will therefore be referred to briefly as the "shore features." The term "coastal topography" embraces these and also those features which, though not necessarily developed by shore action, are well displayed along the coast line and are of a local character and peculiar to any given lake or to several lakes existing under similar geological and physiographic conditions.

Just what should be comprised under the designation "coast" is somewhat difficult of definition. That there is, however, a definite belt of the land extending back from the shore to a varying extent, which is commonly recognized as the coast, goes without saying. The area recognized by the U. S. coast and geodetic survey as the "coast" appears to be that portion of the land visible from a ship sailing within easy distance of the shore. It may also be generally described as the more or less rudely beveled edge of a continental tract where it breaks away in altitude to form the margin of a topographic basin occupied by water.

The coastal topography, then, of lake Superior, as thus understood, is determined in each geological province by the conditions peculiar to that province. Even the common "shore features," such as beaches and wave built terraces, although found in equal perfection of form in different provinces, are clearly affected by the geological conditions, and their development is not always simply a question of a given amount of wind and water and time. The material of which they are constructed is, for example, largely extra-lacustrine in its derivation. The waves supply themselves often with but a subordinate proportion of the materials which they employ in the construction of topographic forms, particularly along the front of the Archæan province. The great bulk of the material is brought down by stream action and sub-aerial agencies. The abundance of this material and, therefore, the number and aggregate extent of beaches, bars, spits and terraces, varies directly with the character of the rocks and with the presence or absence of morainic accumulations.

The depth of water and the angle of the sub-aqueous slope also are conditions which materially affect the development of such structures, and both of these conditions vary with the geological character of the shore. It will thus be found that the "shore features" proper vary as to their abundance and extent according to the readiness with which the rocks of any given province yield the materials for construction, and according as the sub-aqueous slope is favorable or the reverse. Other conditions are the character of the streams entering the lake and the time during which the lake has remained at the same level. The latter is, however, a condition which is a constant quantity for all parts of the shore of the lake. But these "shore features" proper are but small and subordinate elements of the sum total of the coastal topography of the north shore of lake Superior.

A very important feature of the topography, and one strictly dependent upon the character of the rocks, is the shore contour or the line of intersection of the coastal slope and the surface of the water. This embraces both the general form of the lake or the trend of its shores, and the sinuosities and indentations subordinate to that general trend. The general trend of the north shore of lake Superior, although a dominant element of the topography, has practically no relation to littoral forces; and even the detailed forms and minor sinuosities of the contour are ascribable on these rocky coasts only in part to differential erosion, a major portion representing simply a horizontal section through pre-existing forms.

Another feature of scarcely less prominence on the coast is that which becomes apparent in longitudinal profiles along the mean local trend of the shore. Such profiles indicate the hight and boldness of the promontories, headlands and minor projections of the coast. The breadth of such features is also shown, but this dimension is better read off from the shore contour where the variation is apparent. The character of the profile may, like the details of the shore contour, be due either to differential shore erosion or to the submergence of pre-lacustrine forms. On lake Superior these profiles are for the most part vertical sections of partially submerged forms which antedate the lake, and their aspect is peculiar to each of the geological provinces.

Still another feature of the coastal topography, and the most important for the purposes of an inquiry into ancient shore lines, is that which is best represented by series of profiles transverse to the shore. It is that element of the topography which is dependent upon the hight of the land in the vicinity of the shore contours and upon the shoreward slope, which slope may be modified by the presence of shore features developed at levels of the lake now abandoned. For very considerable stretches of the coast, however, these modifying features are absent, the bald rocky slopes having retained no impression of former occupation by the waters of the lake; and in this case the transverse profile is practically independent of littoral action. In order to make clear to what extent these various elements of the coastal topography are dependent upon the conditions peculiar to each geological province, it will be necessary to review briefly the structure of the entire coast.

GEOLOGICAL AND PHYSIOGRAPHIC CONDITIONS PECULIAR TO EACH PROVINCE.

The Keweenian from Duluth to Grand Portage consists essentially of a well stratified series of volcanic flows, having a gentle, but very constant, lakeward dip, which does not exceed as a general rule ten degrees. The sedimentary formations are represented also in the series, but only to a very limited extent, and occupy less than one-half per cent. of the coast line between the points above mentioned.

The pre-Keweenian surface upon which the series rests is exposed at a number of points on the shore, but its exposure at any one place is comparatively small. The rocks of which it is composed are massive, coarse-grained, granular aggregates of labradorite *and are similar to rocks which are well known in the Archæan. They are doubtless Archæan inliers within the Keweenian province, and they exhibit all the evidences of profound erosion and rounding which the Archæan shows at other points on lake Superior where overlapped by the Keweenian.

Since the time of their outflow over this surface of presumably Archæan rocks, the Keweenian strata have not suffered any disturbance sufficient to fold or even to tilt them to any noteworthy extent. The prevaling lakeward dip at low angles is probably partly due to the altitude of the slope over which the lavas flowed, rather than entirely to a differential movement of once horizontal strata.

But, while the Keweenian formations have remained almost exempt from disturbances of this kind, they have been profoundly affected in another way, and the geological structure is more complex than might be inferred from the simple statement of the composition of the series as above given.

The series has been invaded by very many later intrusive masses, which appear along the line of the present coast either as dykes, or, more commonly, as injected sills; while there are also not a few masses of igneous rocks which, considering the very limited study that has been given to the geology of the coast, it would be rash to place definitely either with the regular bedded constituents of the series or with the later masses which cut it, although they doubtless belong to one or the other of these categories. The dykes usually do not vary much from the vertical, and the intrusive sills coincide with the planes of stratification of the bedded flows.

Very large portions of the rocks of the Keweenian series are vesicular or amygdaloidal in character, and many, particularly those of an acid composition in which the vesicular structure is not as well developed as in the more basic flows, are traversed by irregular joints to so remarkable a degree that it is scarcely possible to secure the smallest hand specimen the form of which is not conditioned by joint planes.

There appears to be no great contrast in hardness or in power of resisting disintegration between the Keweenian strata and the intrusive masses which cut them. The basic intrusives afford evidence, however, of being more decomposable and the acid masses

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*These rocks, here styled Archæan, are in the horizon of the gabbro and its associated crystallines, included by the Wisconsin and Minnesota geologists in the base of the Keweenian; although, by the Canadian geologists, generally considered "Laurentian." See A. A. A. Sci., Boston, 1880, p. 425, and ninth Ann. Rep., Geol. and Nat. Hist. Survey Minn., p. 387. [N. H. W.]

of being less so, than the bedded rocks. Faults which can be clearly recognized as such are not prominent, although certain blocks of strata with precipitous fronts and gently sloping backs, which are observable some miles inland in the vicinity of Poplar river, suggest the presence of faults with oragraphic tilting. It is not improbable, moreover, that the entire Minnesota shore with its persistent line of cliffs follows the line of a fault scarp. The intrusive sills usually appear at an altitude which is about the present level of the lake or but slightly above it.

To these broad geological features there remains to be added a statement of three important physiographic facts in order to have before us the salient conditions which have controlled the development of the peculiar topography of the Minnesota coast. The first of these is that, if we except the drainage of the St. Louis river, the hydrographic area of Minnesota which is tributary to lake Superior is a comparatively narrow strip parallel to the shore of the lake, the water shed being a high ridge not many miles inland. As a consequence of this the streams flowing into the lake, although all rapid, and though actively deepening their trenches, are insignificant in size and bring but a small amount of material to the shore. The second physiographic condition alluded to is the rapid deepening of the water off the Minnesota coast.

The third condition is the exposure of the shore to the open expanse of the lake without the protection of any material breakwaters.

The Animikie rocks are geologically older than the Keweenian and underlie them. The emergence of the Animikie from beneath the Keweenian may be easily observed in the vicinity of Grand Portage as has been well described by Irving. The lower series presents several striking contrasts with the higher, the most important of which is due to the diverse character of the rocks. While the Keweenian is made up almost entirely of volcanic flows, the Animikie is composed altogether of sedimentary strata with no trace of contemporaneous volcanic formations. The series consists essentially of uniformily fine grained gray sandstones which locally are quartzytes, black more or less carbonaceous shales or slates, certain cherts and jaspers, beds of carbonate of iron, hematite and magnetite, a very sparing proportion of conglomerate, and occasional lenses of non-ferruginous carbonate in the slates. These rocks occur in strata which, except in local instances, as in the town of Port Arthur and near Gunflint lake, have been dis turbed very little from the horizontal, the average dip of the strata being in a southeasterly direction at angles probably not exceeding five degrees; and they are frequently quite flat or very gently undulating. The rocks of the entire series, with the exception of certain of the cherts, the carbonates and the hematites and magnetites, which together form but a small proportion of the total volume, are characterized by a strongly pronounced shaly or slaty structure, the cleavage of which is parallel to the planes of bedding. This fissile character of the rocks renders them liable to rapid erosion. Were they not protected in a peculiar way little of them would have remained to the present time, and instead of forming parts of the highest and boldest cliffs on the lake they would long ago have been planed down to flat shelving forms, few of which would remain above the surface of the water. The protection which has so effectually, over large areas, enabled these rocks to withstand the active disintegration to which they are subjected, is afforded by the later intrusive masses which have invaded the series. These intrusive rocks are all basic in composition and are of the character of diabases and gabbros. They appear in the series in two distinct ways: (1) as intrusive sills or sheets lying horizontal or parallel to the stratification and resembling contemporaneous beds, for which they have by earlier observers been mistaken; (2) as vertical dykes. Some of the dykes have been observed in continuity with the sills and evidently represent the canals by which the material for the sills came up from deep sources. The most of them, however, are of later origin than the sills and intersect the latter.

The dykes have two chief trends, viz: N. E. and S. W. for the larger and more important, and about N. W. and S. E. for the smaller and less numerous dykes.

The dykes are very abundant in the vicinity of Pigeon river, and for some few miles northeast along the Canadian coast and on the islands as far as Pie island, constituting the dominent structural feature. From McKellar's point on to McKay's Mt., however, the dykes are not so prevalent and the horizontal sills have been the controlling factor in the development of the topography. These sills have very commonly a thickness of about 100 feet and in places reach 400 feet. Their altitude in the vertical column of strata varies from a position at the water's edge to elevations of over 1,000 feet, and ordinarily their position is several hundred feet above the lake.

Both dykes and sills have usually a distinct columnar structure, the columns in the former case being horizontal and in the latter vertical. This structure, of course, facilitates disintegration, but these intrusive rocks, notwithstanding this feature, are either in the form of sills or of dykes, prominently harder and more durable than the shaly strata which they penetrate.

Faulting is much more clearly recognizable in the Animikie province than in the Keweenian and is a common occurrence, many scarps being due primarily to this cause.

In this physiography the front of the Animikie province between Grand Portage and Thunder bay presents as interesting contrasts as does the geological structure. There are two considerable streams flowing into the lake over these rocks, viz: the Pigeon and the Kaministiquia, besides some minor brooks. The Pigeon contributes very little to the shore drift since its sediment is largely intercepted by lakes. The Kaministiquia has on the other hand brought down much sediment which has served for the construction of very important features. The divide is much farther removed from the lake than in Minnesota. The water off shore is also much shallower as a rule than on the Minnesota coast and there is frequently a shelving bottom. Added to this shoal water condition is the presence of a chain of islands, which form a very effectual breakwater and protect the shore from the violent action of the open lake.

The Archæan forms the basement upon which the Animikie rests in glaring unconformity. The actual superposition of the Animikie upon the well eroded Archæan surface may be observed at several points, with the Keweenian lying flat on the former. Very frequently, however, the Animikie is absent and the Keweenian is imposed directly upon the Archæan. But, whether the Archæan emerges from beneath the Animikie or the Keweenian, the contrast which its rocks present to the formations of either of the latter series is equally profound. The petrographical character and general structure of the Archæan is so different from that presented by the newer rocks which rest upon it, that comparisons on parallel lines of observation are difficult to make. Antitheses of conditions meet one at every point of view, and the topographic forms evolved under these conditions, save those due solely to wave action, present correspondingly marked contrasts.

The Archæan complex of this coast is readily resolvable into two broad divisions: (1), a great volume of profoundly altered sedimentary and volcanic rocks, characteristically schistose or in the form of massive greenstones, which have suffered intense disturbance and which correspond to what has been designated the Ontarian system*, and (2), immense batholites of irruptive gneiss

*Bull. Geol. Soc. Am., Vol. I, pp. 175-194.

and granite, which have invaded the rocks of the Ontarian system from below in the most irregular fashion, corresponding to that division of the Archæan which is commonly recognized as Laurentian. These Laurentian rocks exhibit only to a very subordinate extent those evidences of disturbances and deformation which are so abundantly apparent in the schists which they have invaded. The Laurentian gneisses and granites occupy much more of the shore than do the metamorphic and schistose rocks of the Ontarian; and each of these divisions of the Archæan province has its own peculiar phases of a topography of a general type. The entire surface of this province presents a remarkably hummocky or mammilated aspect due to pre-Paleozoic erosion* modified by the glacial action of the Pleistocene.† The rocks are fresh and free from the mantle of rotten rock arising from secular decay which covers similar crystalline rocks in some regions. The granites and gneisses, being in this fresh condition at their surface, practically homogeneous, remarkably free from divisional planes due to pressure and movement, and having prelacustrine hummocky or rounded forms which are least affected by erosive agencies, condition a topography which to a very large extent is independent of shore action. Where cut terraces are present on the coastal slopes of these rocks they have usually been carved out of morainic material or notched in the face of embankments formed early in the history of the lake. These embankments are rarely sufficiently continuous to obscure the broad aspects of the rocky slope. The schistose and greenstone rocks of the Ontarian traverse the region in curvilinear belts or zones, separating neighboring Laurentian batholites. These belts sometimes emerge on the coast in the form of great ridges, the extremities of which form promontories. They condition a much more jagged and linear aspect of topography; and along the present shore, at least, the rocks of which they are composed yield to the cutting action of the waves much more readily than do the granites and gneisses. Sometimes the trend of the coast coincides with the strike of these belts for a distance, when preciptious cliffs face the lake, which, however, are not necessarily sea-cliffs. The essentially Archæan conditions of this province are modified somewhat by a great system of diabase dykes which traverse the region and which were noted by Agassiz‡; they coincide remarkably closely with the trend of the coast. This coincidence of coastal trend is best seen between Nipigon and Peninsula.

*i. e. Pre-Algonkian. (Algonkian = Animikie + Keweenian.)
†Bull. Geol. Soc. Am., Vol. I, pp. 163-174.
‡Lake Superior, its physical character, etc., 1850.

Between Peninsula and Otter head the dykes are very numerous and only a portion of them coincide with the general trend of the coast. The majority cut the line of the coast obliquely. Between Otter head and Michipicoten harbor the dykes are both parallel and transverse to the trend of the coast, there being apparently two distinct systems of fissures. The dykes do not as a rule exceed one hundred feet in width and are vertical or nearly so. When occurring in the Laurentian and where degradation has proceeded more rapidly than the country rock, a distinct trench marks their occurrence. When they traverse the Ontarian rocks they are less recognizable and less important topographically, their color being more nearly that of the country rock and their susceptibility to degradation not markedly different. Whether these lines of dykes are also fault lines has not been clearly made out. It is impossible, as has been suggested, that their origin is associated to some degree with the depression which gave rise to the lake Superior syncline.*

There is much morainic drift scattered over the coast of the lake, chiefly in the form of boulders. There are also protecting distinct morainic accumulations, although the form of these moraines is difficult to recognize on account of the timber and also from their having been modified by shore action at various stages of the lake and degraded by stream action. There are numerous streams entering the lake along the front of the Archæan province. Most of these are, however, small and the watershed is not far distant from the coast. The entire coast is well exposed to southerly and westerly storms.

The rocks of the Potsdam province are undisturbed, flat, or nearly flat, shaly sandstones, generally of a red color. These sandstones extend out from the base of the Archæan hills, which they encircle in a level plain. They have not been observed on the north side of the lake at elevations exceeding fifty feet above its level. These rocks appear to occupy an extensive tract beneath the waters of the lake in its southeastern portion. Whether on the islands or on the main land these rocks, by their petrographical uniformity, their stratigraphical simplicity and the proximity of their summits to the local base level of erosion, condition a simple and mature topography. The coast along which they are found is mostly protected from the full sweep of the lake in storms, and the water off shore is comparatively shallow.

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*Lake Superior, its physical characters, etc., 1850.

SHORE FEATURES OF THE PRESENT STRAND.

It has been stated at the beginning of this paper that there is a very evident relationship between the coastal topography of the north side of lake Superior and the geological conditions which obtain in the various provinces which have been outlined as fronting on the lake. The shore features of the present strand constitute an important element of the general topography of the coast, and the relationship alluded to becomes very apparent in a consideration of some of these features. It is here proposed to sketch very briefly the character of the leading shore features and to compare those pertaining to the different provinces with one another, having reference chiefly to the geological conditions which have controlled the development of the shore.

SEA CLIFFS.

Among the most striking of the shore features which engage the attention on the Minnesota coast are the lines of the low sea-cliffs, which rise abruptly from the water, ranging in elevation from a very few feet in some places up to as much as 210 feet of vertical precipice at the Palisades. These cliffs are remarkable for their great continuity, their general uniform hight and for the general scarcity of shore drift along their base. The most striking feature of the shore coutour,—viz: its simple unbroken trend,—is also a character of the cliffs and must necessarily be taken into account in a description of them. These cliffs are *seemingly* the direct product of shore action and appear from their abruptness to be in active recession; yet they are not receding altogether by reason of the process of battering and undermining to which the recession of cliffs is usually ascribable. The products of the mechanical disintegration of the cliffs do not as a rule lodge at the base of the cliff and become the tools for the further cutting of its base. Wherever such detritus lodges and is handled by the waves as a battery there is usually a little notch or vertical gash established in the cliff wall. As a rule, moreover, it is to be noted that the cliffs, independently of any softening or rounding of their brink by atmospheric agencies, are not strictly precipitous except where the rock of which they are composed is uniform from top to bottom. On the contrary, although the general effect is that of precipitous cliffs, the base is nearly always more projecting than the higher portions and the cliff rises in a series of rude steps, the front of each step being usually nearly vertical, while its surface slopes gently lakeward. The explanation of this character of cliff lies in the nature of the rocks and their structural features. As has been stated, the rocks of the coast, with some local exceptions, are volcanic flows, frequently of no great thickness, associated with which are sheets, probably injected as sills, and a few dykes. The volcanic rocks are very commonly, when basic, vesicular or amygdoloidal and, when acid, are of the nature of a dense red porphyry which disintegrates mechanically with the greatest readiness. These bedded and regularly stratified volcanic rocks have a constant lakeward dip along the whole coast, the inclination usually not exceeding ten degrees. It is these petrograpical and structural features which seem to be the real conditioning causes in the development of this remarkable line of cliffs in so far as it is actually receding, and the shore action a minor and, as it were, the determining or precipitating cause of the degradation. The bedding planes, the intricate jointage, the columnar structure of some of the beds, the porous character of many others, and lastly, the lakeward dip, all favor the loosening and dislodgement of blocks under the influence of an abundant supply of water by the waves and the changing temperature of the climate; and so the cliff recedes, being only to a limited extent worn down by the battery process. But the total recession has been very small as is evidenced by the fact that for many parts of the shore only a very narrow subaqueous shelf, disproportionate to the size of the cliff, has been formed, or none at all. And indeed there are grave doubts, amounting almost to certainty, that, although this line of precipice is now functionally a sea-cliff of the present strand, it is not primarily and genetically a sea-cliff. The way in which the cliff rises from deep water as the upward continuation of a very pronounced subaqueous cliff [See Pl. XI, Fig. 1.] indicates very clearly that its origin is essentially pre-lacustrine or at least extra-lacustrine; and the suggestion can scarcely be resisted that primarily the cliff of the Minnesota coast is a great fault scarp. Two facts may be cited which harmonize with this suggestion. (1) The trend of the coast is in direct line with the great linear series of dykes which extends from Pigeon point to Thompson island, and which probably is continuous with the similar series of dykes having the same trend on the islands and points on the south side of Thunder cape. (2) Mr. Peter McKellar has informed the writer that a great fault is observable near the head of Thunder bay in the line of the east side of the bay, and that the cliff which forms this side of the bay is without doubt a great fault scarp. This scarp would parallel the one suggested as determining the line of the present Minnesota shore, or converge upon it very obliquely.

FIG 1. NATURAL ARCHWAY AT POINT OF GREAT PALISADES. ILLUSTRATING CLIFF WITH BASE BELOW WATER LEVEL. (PP. 198 AND 214.)

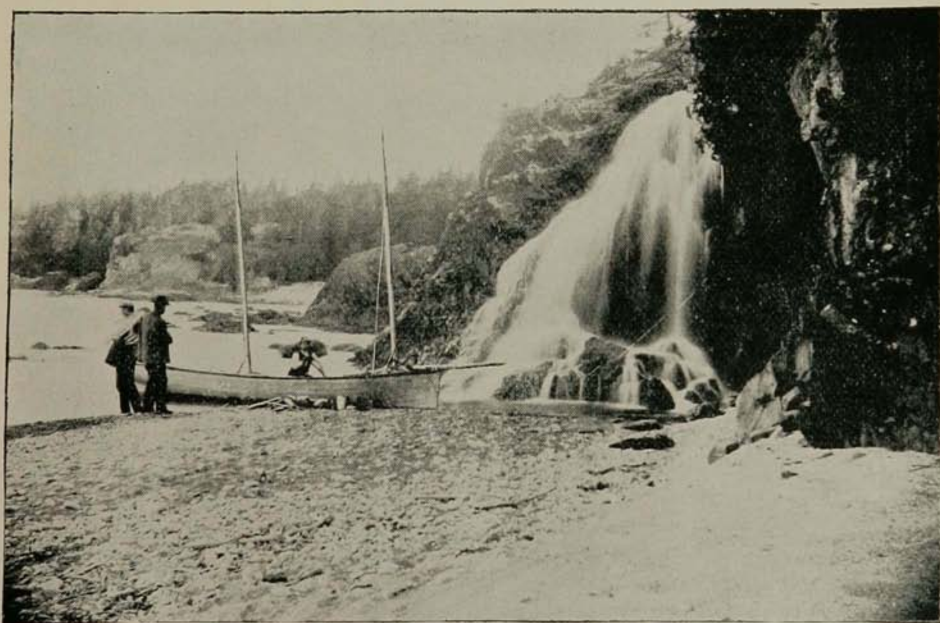

FIG. 2. SCENE AT OTTER COVE, NORTH SHORE OF LAKE SUPERIOR

Along the front of the Animikie province true sea-cliffs are not prominent or common features of the present strand. There are, indeed, numerous precipices rising from the water, but they are not all sea-cliffs in the strict sense of the term. Two types of these coastal precipices may be mentioned: (1) where the rock of the shore is that of one of the great trap dykes which intersect portions of the coast, particularly in its southwestern portion; and (2) where the thick sheets of columnar trap, which have been intruded between the nearly flat Animikie beds, descend by a gentle local dip to the water's edge. In both of these cases precipices are formed, those of the columnar flat sheets being more nearly vertical than those of the dykes. But in neither case, so far as the observation of the writer goes, are these cliffs ever functional as sea-cliffs in the sense that they are receding by reason of wave action and have a wave cut terrace at their base. Usually they rise from deep water and have no shelf at the water line. Their origin as topographic forms long antedates the lake and is ascribable to the process of erosion, which, in conjunction with orographic movements, is responsible for the basin in which the lake lies. There is, however, a type of precipice which is in its functional relations to the present strand, a true sea-cliff, although, as seems probable in the case of the Minnesota shore, the locus of the cliff was determined by other agencies than shore action. The cliff referred to is best seen on the east side of Thunder bay, above Sawyer's bay. Here the shore is at the base of a long uniform line of vertical cliff which is in active recession and which has a boulder-strewn, sub-aqueous shelf at its base. Here the face of the cliff is composed of horizontal Animikie slate, which yields readily to the battery which plays on its lower part during westerly storms. The recession is so active that it is encroaching upon a terrace of a higher stage of the lake where a similar cliff has been developed. The initiation of this line of cliff, now a sea-cliff, is, in the opinion of Mr. McKellar, expressed in conversation with the writer, due to a fault, the displacement of which is apparent near the head of Thunder bay. But these rocky precipices, whether sea-cliffs or not, do not form any very extensive portion of the shore of the Animikie province. By far the greater part of the shore is along the talus slopes of the magnificent cliffs of differential degradation, which surround the Thunder bay district and have made its topography famous. On these talus slopes earlier shores have in places constructed embankments. But, whether the present strand lies along the primary talus or along these secondary embankments, there has been no important cutting of sea-cliffs. There are a few minor instances where the shore has eaten back somewhat and given rise to a small cliff.

Along the front of the delta of the Kaministiquia there is a low but abrupt rise above the shore which is also to be interpreted as a sea-cliff. A low cliff of a very few feet encircles some of the islands, such as Flatland island, which have a small altitude above the lake in consequence of the absence of protecting dykes or sheets of trap to restrain the slates from yielding rapidly to erosion. Some of the small islets of Thunder bay also may be but the remnants of larger islands truncated at the shore line by the process of cliff-making.

Along the strand of the Archæan province rocky declivities are an almost constant feature of the shore. The coast is bold, bare and rugged; but true sea-cliffs are remarkably scarce. The rocky slopes descend to the water with usually no break in the profile and most frequently with no embankment of shore drift or appearance of shelf at their base, except in the bays where sea-cliffs in rock are not ordinarily developed on any shore. Where the shore is occupied by the Laurentian gneiss and granite practically no incision has been made in the face of the rocks at the shore line,and the surface of rock which plunges beneath the waters of the lake has with little or no qualification the precise form and slope which it had, when, earlier in the history of the lake, it was covered by several hundred feet of water, and which it had, indeed, before the existence of the lake. The entire coast has been glaciated and the glacial markings, grooves and hollows are frequently seen to pass down beneath the water's edge without an abrasion to dim their sharpness. The hummocky, rounded forms of rock which are so well displayed on many parts of the coast are the same which are found throughout the region far removed from shore action; and many of the slopes which descend to the water, whether steeply precipitous, or gently inclined or rounded in hummock form, may be indisputably recognized as precisely the slopes upon which Animikie or Keweenian sediments were deposited or over which the Keweenian lavas flowed. The basin of lake Superior is very ancient, more ancient than some glacialists have dreamed of in their philosophy. It is perhaps hardly necessary to go into the causes of this scarcity of sea-cliffs on a coast where one would at first thought expect to find them abundant, but the chief of these may be enumerated as follows: (1). The obdurate, tough and resistant character of the rocks which prevents their yielding shore drift for battering purposes. (2). The steepness of the original slope of the coast and the consequent depth of water near shore, which prevents the lodging of such shore drift as is available and hinders the building up of embankments which would facilitate the transport of shore drift to where it could be effectively used by the waves. (3). The shortness of the time at which the shore has been at its present level. Given time sufficient and the two other adverse causes would be overcome and we should have sea-cliffs around the entire coast. Where the shore lies along the schistose rocks of the Ontarian system of the Archæan, such sweeping statements as to the absence of sea-cliffs cannot be made. These rocks have certainly yielded appreciably to the cutting action of the shore and the original profiles of the pre-lacustrine forms have been notched. But the shore notch is not heavy and the recession of the fresh cliffs has usually been so slight as to modify the original profile but little, and the steep slope to the water which these schistose rocks commonly present is essentially that of the pre-lacustrine form. These cliffs in the schistose rocks may be best seen along the shore east of Otter head. On this coast, also, to the east of Dog river, may be observed a very interesting instance of the active formation of sea-cliffs in soft material, by the waves cutting into the shore embankments which have been built up at higher stages of the lake. The cliff of the present shore has been receding so rapidly that a portion of a terrace 16 feet above the level of the lake has been entirely undermined and obliterated back to and beyond its own original sea-cliff, affording a very clear picture of how gaps in the series of ancient shore lines may occur. [See Fig. 15, in descriptive notes under Dog river.]

On the shore of the Potsdam province the sea-cliff which commonly separates the shore from the plain formed by the upper surface of the flat sandstones is frequently worn down and is not always a prominent feature of the shore. It probably tends to recede more rapidly by atmospheric and organic degradation in many portions of its extent than by the attack of shore forces, so that its edge or brink is rounded and softened and the lakeward slope of the cliff is rather low. It is not precipitous on the islands.

BEACHES, BARS, SPITS, ETC.

Boulder, pebble and shingle beaches are common features of the north shore of lake Superior, and some of these are of magnificent proportions as regards their cross profile. They are all, however, limited in their horizontal extent, except in the Potsdam province, to the pronounced indentation of the shore line. They are least abundant in the Keweenian province and most abundant in the Animikie. In the Archæan province they are only of local occurrence chiefly in the vicinity of the mouths of streams, there being extensive portions of the shore along the front of this province which yield no shore drift for the formation of such embankments. The shore of the Potsdam province presents either a continuous beach or a boulder strewn shore, but, as the Potsdam rocks are of very limited occurrence on the north side of the lake, the extent of these simple beach or bouldery strands is even here small when compared with the total length of the shore.

The extensive lines of cliffs along the shore of the Keweenian province on the Minnesota coast would seem to presuppose the occurrence of more extensive beach accumulations than are actually found; the simplicity of the shore contour, however, and its remarkable freedom from indentations in which the shore drift could lodge, militate against the development of beach embankments. The shelving character of the rocks with their constant lakeward dip, and the depth of water immediately off shore, are also effective causes in preventing accumulations of shore drift except in the most favored localities. Such localities are not wanting along the coast of Minnesota, and a few of these may be referred to.

The finest of all the lake Superior beaches is of course the bar which spans the head of the lake from Duluth to Superior City. This is so well known already that nothing more than a mere mention of it is here required. Beyond Duluth the first important beach is that which forms the bar across the mouth of the Knife river. The river has at its mouth developed a small delta in the shelter of a low point of rock. This delta material is chiefly sand, but there is mixed with it drift from the shore to the eastward. This accumulation has extended outward till it is now even with the protecting rocky point, and here it is probably stationary, having ceased its lakeward expansion by reason of the surplus being carried beyond the point. The front of this delta extends as a well defined bar almost entirely across the mouth of the stream and the waves have banked it up in the form of a broad beach.

The shore of Agate bay and that of the adjoining Burlington bay has a beach embankment of considerable extent, the pebbles being mostly of local derivation. Among these, however, were found two fragments of cream colored limestone containing fragments of fossils indicating that some of the beach material is derived from morainic accumulations.

FIG 1. GRAND MARAIS. FROM TWO HUNDRED FOOT BLUFF WEST OF THE HARBOR. (PP. 203, 246.)

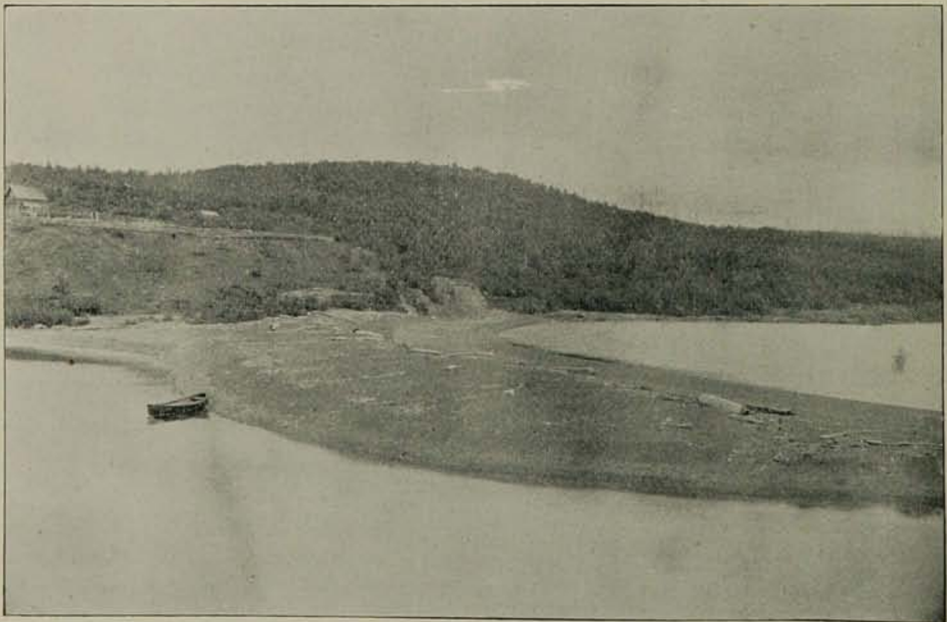

FIG. 2. SPIT AT THE MOUTH OF BEAVER RIVER. (PP. 203, 238.)

Gooseberry river discharges into a small bay which is somewhat protected by a jutting point of rock, and the shore in the vicinity of the stream presents a finely built beach of small uniform gravel of a red acid volcanic rock, which occurs in the neighborhood and which is easily broken down into small fragments without undergoing chemical decay or losing its hardness. The mouth of Split-rock river is similarly protected by Split-rock point and a beach shuts off from the lake the marshy flood plain of the stream.

The mouth of Beaver river is also well protected by a point of rock and between the stream and Beaver bay there has been thrown out a spit composed almost entirely of sand brought down by the stream. The spit is parallel to the stream and is only a few hundred yards long. The waves have built it up into a broad low arched beach. The river side of the spit is being constantly corroded by the stream and the material thus worn down is carried into the bay where it is added to the outer or lakeward side, where by the action of the wind and waves it is soon carried again over to the river side, again to be undermined by the stream. Thus there is a constant undermining on one side and up-building on the other side of the spit, while in position it remains constant. [See Pl. xii, Fig. 2.]

Between the Palisades and the mouth of Baptism river a beach of greater length than is usual on this shore has been thrown across an embankment. The material is chiefly derived from the cliffs of the vicinity, supplemented by gravel from the Baptism river, the rock there being the same red porphyry which supplies so much of the gravel of the shore drift.

At Good Harbor bay some soft sedimentary shales protected on the lakeward side by a ridge of hard igneous rock have afforded conditions favorable for shore erosion, and the bay is the result. The cliffs at the back of the bay, being of this soft shale in nearly horizontal attitudes, are actively receding and a shingle beach has been piled up along the base of the material which has not yet been reduced to clay and carried out to deep water. The beach is not large and in violent storms is doubtless entirely moved. A few miles farther on Grand Marais harbor presents a fine pebble and shingle beach which extends in the form of a broad based spit connecting the island on which the lighthouse stands with the main shore. [See Pl. xii, Fig. 1.] The material of this beach is again the same red quartz porphyry which has been so often referred to as a source of supply of shore drift. The cliff from which it is in this case derived is a little to the east of Grand Marais.

Fish-hook point, the mouth of Brule river, and Deronda bay are the only other places along the Keweenian of the Minnesota shore where notable beaches occur, and in all these cases they are found in the immediate vicinity of cliffs of red quartz porphyry and the embankments are nearly altogether composed of this material.

These beaches thus briefly alluded to are the only very prominent ones that attract attention in coasting along the shore from Duluth to Grand Portage. The longest of them is probably not more than one-eighth of a mile in length; and, if it is borne in mind that these are distributed over a shore of nearly 150 miles, their mere enumeration is sufficient to indicate the meagerness of beaches along its extent. It is not intended by this explicit allusion to these beaches to imply that there are not others. There are many small coves along the shore, so small that they afford no shelter for a row-boat, and also short stretches of open shore between jutting points, where local detritus has accumulated and has been thrown up into beach form. The proportion of these, however, to the total length of coast is very small. There are also stretches of shore which are essentially bare shelving rock, but which in patches are encumbered with boulders. In general the impression received by inspection of the Keweenian shore from a row-boat is that of a wonderful dearth of shore drift and a great extent of bare rock, and one is constantly struck by the association of the more important beach accumulations with the occurrence of a red quartz porphyry and an allied and quite similar rock in which quartz can not be detected macroscopically. This association depends upon the property which this rock has of yielding pebbles by reason of its shattered jointage structure, the resulting fragments being hard and resistant.

In passing from the Keweenian to the Animikie province along the shore of the lake one is impressed by the great contrast which is presented in the relative abundance of beaches. Along the Animikie shore beaches are the rule except where the great dykes occupy the water's edge. The reason for the difference lies in the diverse petrographical characters of the two formations. In the Keweenian the only rock capable of yielding shore drift in abundance, the red porpyrhy, is of limited occurrence, and it is prevented from yielding large quantities by its association with harder rocks which keep the line of the shore from receding. In the Animikie province it is far otherwise. The Animikie slates and slaty sandstones and quartzytes occur along the entire Animikie coast and have yielded an overwhelming amount of material eminently suitable for the formation of shingle beaches. As has been already pointed out the topography of the Animikie coast varies according as the igneous rocks which invade the slates are prevailingly dykes or prevailingly horizontal sheets or sills. At the southwestern part of the Animikie coast, in the vicinity of Pigeon river, the dykes prevail and the country is intersected by a great plexus of immense dykes, with limited patches of slates in horizontal attitudes lying between. This condition obtains also on the islands which stretch from Victoria light to, but not including, Pie island. In the portion of the coast thus affected, the dykes usually extend lakeward and as bold promontories marking off well defined bays; and the water being deep off the extremity of these promontories, the beaches are confined to the bays, so that there is not a long continuous beach on this part of the coast, although the various individual beaches in the bays are of considerable extent. Where the sides of the dykes occupy the shore, as on the north side of Pigeon point, Victoria island and Thompson island, the water is usually deep, and there is no shore drift nor beach accumulation, the cliffs (pre-lacustrine) rising precipitously from the depths of the lake. Passing into that portion of the Animikie coast where trap sills prevail and the dykes play only a very subordinate role or are absent, we find practically continuous beaches interrupted occasionally by precipitous headlands. This feature of the shore is associated with an almost entire absence of sea-cliffs. This statement may be surprising to readers familiar with the famous Thunder bay landscape with its beetling cliffs. The vertical precipices of Thunder bay overlooking the lake are not sea-cliffs of the present shore. They are primarily cliffs of differential degradation of pre-lacustrine origin, and the topographic masses which they limit are true mesas. At some of the higher stages of the lake they have been functional as sea-cliffs, but at present the subsidence of the lake has brought the shore in most cases low down on their talus slopes, and the cliffs have returned to their former condition of cliffs of differential degradation. As an exception to this last statement may be mentioned the cliffs which occupy the shore immediately to the northeast of Little Trout bay, where the main trap sheet or cap descends below the level of the lake, and its edge rises vertically 100 feet or more above the water, and there is no beach or visible talus. From these statements it will be apparent that, although beaches abound on the Animikie shore, the material of which they are composed is not derived immediately from neighboring sea-cliffs. It comes entirely from the old talus of the cliffs not now affected by shore action and much of it has come from earlier beach embankments higher up on the same talus slope.

Thus in our comparison of the Keweenian and Animikie shores we arrive at the seemingly paradoxical statement that along the former, although there are extensive lines of functionally active sea-cliffs, there is a scarcity of beaches; while along the latter, although there are practically no sea-cliffs shedding fresh detritus, shingle beaches abound.

Intermingled with the local drift of the beaches of the Animikie province there are, it should be mentioned, numerous boulders of glacial derivation. There are also many more or less angular boulders of trap from sills and dykes, and some parts of the shore are thickly strewn with such boulders to the exclusion of the ordinary pebbles and shingle.

A general statement respecting the distribution of beaches along the shore of the Archæan province is difficult to formulate. Beaches are common, but they are due to local causes and are not uniformly distributed. The intricate indentation of the coast affords everywhere ample opportunities for the lodging of shore drift and the piling of it up into beach embankments, but the supply of shore drift is very small. Where the Laurentian granite and gneisses occupy the coast shore action has been impotent both at the present and all earlier stages of the lake to affect the sculpture of sea-cliffs, which would supply the drift necessary for the accumulation of important lines of beach embankments. The schistose rocks of the Ontarian system have been more yielding, but still supply a comparatively small proportion of the shore drift. The petrography and structure of the province preclude the possibility of cliffs of differential degradation having at any previous period in the history of the region afforded a supply of talus material which might be seized by the waves and wrought up into embankments. This poverty of general shore drift and the prevalent separation of the bays by bold headlands, preventing the drift of one bay from passing around into its neighbors,conditions a shore whose beaches are dependent upon local and extra lacustrine sources of supply. These sources are chiefly two, viz: (1) stream deltas, and (2) glacial drift; and both of these are variable. The result is that the shore is a long succession of small bays, some of which have beaches and some of which have not. In the vicinity of the streams, deltas have been developed usually of small size consisting chiefly of stream pebbles, and these afford material for beaches as described in the reference to wave-built terraces. Where there are no streams the beaches, when present, consist chiefly of erratic boulders with but a sparing proportion of smaller pebbles and gravel. Thus a very small proportion of the beach material of the Archæan province is of local origin. One other source of beach material on this part of the shore remains to be mentioned. At higher levels of the lake, the streams, not having well-defined trenches of their own cutting, but following the depressions between the hummocks and hills of this mammillated region, emerged on the coast in some cases at places more or less distant from their present point of discharge, and the embankments which accumulated at these old outlets have been cut into by lower stages of the lake and the whole or part of their material carried down to lower portions of the rocky slope; and some of it enters into the composition of the modern beaches. Even when the point of discharge has not materially changed, the shore contour at higher stages was in certain other cases such that the stream detritus brought down to the lake was much more extensively distributed than at the present stage. So that not a little of the pebbly material which enters into the composition of the modern beaches is derived from the streams of the neighborhood, although this is not apparent at the first glance.

Of the beaches of the Potsdam province little remains to be said. The rocks of the Potsdam are uniformly flat, or nearly flat, often shaly sandstones; and the effect of wave action upon such rocks has been the development of a uniform and continuous shelf which is coextensive with the occupancy of the shore by these rocks, and which is now frequently occupied at the shore by a low beach. The profile of the beach of course varies according as it is sheltered or is exposed to an open expanse of water. The water off these shores is generally shallow, and wave action therefore feeble on the immediate shore, so that high beaches do not prevail. Scarps or cliffs of importance are not common, although a few good sea-cliffs occur, especially on the islands. An occasional abrupt rise of the ground may perhaps be interpreted as a cliff, genetically considered, but the rocks seem to yield readily to the degrading influence of the weather and vegetation. The shallow off shore water and the shore itself is frequently strewn with boulders which the waves are unable to handle. These boulder strewn shores are regarded as a phase of beach. Under other condidions, which would allow the access of more potent waves to the shore, these boulders would undoubtedly be ridged up together in beach fashion. The sweeping contour of the shore, the low, continuous beaches and the degradation of the cliffs, all give the shore, as has been said, an aspect of great maturity.

DELTAS AND WAVE-BUILT TERRACES.

On the north shore of lake Superior deltas and wave-built terraces are naturally associated. The *sine qua non* of a wave-built terrace is the accession to the shore of more detritus than the forces of the shore can either transport or pulverize. On a shore where the development of cliffs has not proceeded sufficiently to yield an abundance of detritus, the only place where such a congestion of shore drift is liable to occur is in the vicinity of streams which are bringing down pebbles and boulders to the lake and there dropping them to build up a delta. Thus it happens that along the present strand of lake Superior, where the sea-cliffs are not largely developed, the chief wave-built terraces are found on the outer margins of the deltas of certain streams which are transporting coarse material, and in the vicinity of certain rocks of limited distribution which disintegrate rapidly and shed an abudance of hard fragments, as in the case of the red porphyry rocks of the Minnesota coast. Streams which are transporting sediment in a fine state of division are also forming deltas at the lake shore, but there are no wave-built terraces associated with them. Of these the delta of the Kaministiquia is the most notable. Other streams which emerge on the open coast where the water is deep close to shore are also building up deltas, but these are entirely sub-aqueous or are barely perceptible. Still other streams have their sediments intercepted by small lakes before reaching lake Superior, and these add little or nothing to the shore drift. The fewness of the deltas and wave-built terraces on the north shore renders it difficult to compare the local influences which have controlled the development of these features in the different geological provinces. There are certain general considerations, however, which may be mentioned. The extreme meagreness of the visible delta accumulations along the shore of the Keweenian province is doubtless due to the proximity of the Minnesota water-shed to the coast and the consequent smallness of the streams, and to the exceptional depth of water close to the shore line. The scarcity of wave-built terraces, which are independent of deltas, is to be ascribed to the simplicity of the shore line, which does not favor the lodging of shore drift, and to the fact that the extensive cliffs which characterize the Minnesota shore are only effective sea-cliffs to a limited extent, being probably conditioned by a pre-lacustrine structural feature.

Along the front of the Animikie province there are only two streams of importance, the Pigeon and the Kaministiquia; and of these the former appears to be a very young stream, while the latter is probably one of the oldest streams associated with the present physiography of the lake Superior basin. The one stream has a small and insignificant delta, while that of the other is large and important, as is noted more in detail below. The sediment carried by both streams is fine, and there is no wave-built terrace associated with their deltas.

The scarcity of wave-built terraces, which are strictly ascribable to the present strand of the Animikie province, is not due to any lack of shore drift, but rather to the following fact: The more recent stages of the lake have had their shores along talus slopes or earlier shore embankments, and the general shore contour for very considerable stretches has not materially changed, although the lake has subsided through many successive stages. Thus there has been opportunity afforded for such a distribution of the shore drift to be effected as to establish a practical equilibrium without tendency to transport so long as no new accessions are made to the shore; and we have seen in our discussion of the cliffs, that for the greater part of these shores the amount of shore drift is now constant, or is diminishing slowly by pulverization. In the process of establishing this approximate equilibrium, much of the shore drift has gathered inthe bays and has been ridged up into parallel beaches; but as this has proceeded *pari passu* with the lowering of the level of the lake, the ridged terrace which has resulted differs from a simple wave-built terrace in the fact that it is not level, but *slopes*, the more lakeward ridges being lower as a rule than those farther from the lake. The additions to this sloping wave-built terrace made by the present stage of the lake are not important and usually do not exceed one or two beaches.

The delta-building streams of the Archæan province seem for the most part to draw their detritus from the earlier formed embankments of the lake, through which they have cut their way; and these embankments would seem primarily to have been built up of material derived from morainic accumulations, as true sea-cliffs supplying shore drift have never at any stage of the lake been prominent features of the shore. No well characterized wave-built terraces, dissociated from deltas, have been observed along the shore of the Archæan province. In the Potsdam province there are no deltas; and no wave-built terraces were observed, although it is possible that they may be found in the bays which were not examined. Their existence is, however, improbable. A few notes are here given on the more important deltas and wave-built terraces of the north shore, based not on a careful study of their features, but only on such cursory examination as the time devoted to the work would allow.

The Delta of the Kaministiquia.—The largest and most impressive delta of the north side of lake Superior, as well as the most accessible for study, is that of the Kaministiquia river. The lower portion of the stream for many miles back from its mouth has cut its trench down into the delta, which has been accumulating throughout the higher stages of the lake, and this trench is continued into the lake as a sub-aqueous channel, navigable for large lake craft, through the delta now accumulating out to deep water. The river has three mouths, known as Fort William river, McKeller's river and Mission river. These embrace two islands of the older delta, the river bifurcating twice in the vicinity of the town of Fort William, about three miles from the lake shore. The material brought down by the stream is all fine, and appears to consist of clay and light sand; and this has been true far back in the history of the delta, as appears from an inspection of its structure as revealed in the trench walls of the river. This section shows uniformly for many miles from the mouth a lower portion of an indefinite thickness of blue clay, over which is spread a continuous sheet of sand which forms the surface of the ground. The blue clay has a minimum thickness at a distance of fourteen miles from the shore of probably fifty feet. The sand is not quite uniform in thickness and ordinary sections show that it ranges from two to ten feet. This structure in two strata, or two sets of strata, the material in each being quite different from that in the other, becomes easily comprehensible when we consider the two main conditions attending the development of the delta, viz: (1) The extension of the delta embankment from shallow into deep water—a condition common to all deltas; and (2) the subsidence of the base-level of erosion as the level of the lake dropped, which would cause a more rapid lakeward extension of the delta than if the base-level were constant. Of the two classes of material brought down by the stream the clay would be carried out to deep water, while the sand would be dropped in shallow water. But the shallow water at any given stage of the lake, except the highest, was deep water for the preceding stages, so that the sand for this stage would be spread out over a clay bottom. The same process would of course operate with a constant base-level, but the horizontal extension of the delta would not be nearly as rapid. The process is in operation in the growth of the delta of the present shore. The shoals from the mouth of the river on either side of the channel out to the vicinity of the Welcome islands, are sandy and have a very gentle slope, so that a sailboat may ground half a mile from shore, within hailing distance of a two thousand-ton propeller steaming up the channel, as the writer has experienced. Near the Welcome islands the slope becomes steeper and out beyond the islands is clay bottom. Thus the development of the present delta is but a continuation of the same growth which has built up the great delta extending far up the valley of the Kaministiquia. At the apex of the delta, near Kaministiquia station, its structure is different, as is indicated elsewhere; but here the condititions were different, the current was powerful and coarse material was handled by the stream. The channel of the stream near the lake is so open and unobstructed that the older portion of the delta, back of the present shore, is not subject to serious overflow, and only the subaqueous portion is growing. The slope of the older delta surface is, as it should be, away from the banks of the stream, at least on the north side towards Port Arthur. The south side of the stream has not been examined. At the line of the present shore the delta is faintly terraced by the development of a low sea-cliff, as if marking a distinct drop of the surface of the lake of a few feet.

On the surface of the subaqeous delta is an exceptionally shoal linear area between the shore and Mutton island, so that it is scarcely possible for even a row boat to pass between. This linear shoal appears to be the direct product of wave action, and the final result will doubtless be a bar connecting the island with the shore.

The Delta of the Mazokamah.—At the mouth of the Mazokamah river a delta of stream gravel is at present being built up. The river is a small, rapid stream issuing directly upon the lake through a narrow cañon. The latter is a sharp V-shaped cleft in the high rocky bluffs which here front the lake. On the west side the flat-lying Keweenian rises in vertical walls, and the face of the heavy sheet of columnar trap which rests upon it frowns down on the shore from an elevation of 1,000 feet or more. On the east side the Archæan rises in scarcely less formidable hills with varying slopes and much greater complexity of form. Since the removal of the ice sheet the Keweenian cliffs have been receding, while the Archæan hills have not been sensibly modified by the agencies of erosion. Although the stream is rapid, and is lowering its trench like all streams entering the present level of lake Superior, the bulk of the material which it brings to the shore is derived from a great embankment of beach gravel which has been thrown part way across the cañon at the higher stages of the lake, and which the stream is now undermining. The slides from the cut through this embankment tend to choke the stream, and it is the purging of the channel of this slide material which supplies nearly all of the pebbles for the delta now under construction. The delta which is thus accumulating on the exposed shore of Nipigon bay is not a simple delta; for the storms have given its surface, on its outer part at least, the ridged character of a wave-built terrace; and the structure throughout, as far back as the waves originally reached, is doubless a composite of that of a simple delta and a wave-built terrace, the latter being gradually dissected and overwhelmed as the delta extended lakeward. To the northwest the delta passes into a true wave-built terrace beyond the reach of the delta overflow. The entire embankment has a width from the original shore of from one-eighth to one-quarter of a mile, and is over a mile in length, extending to Mazokamah point. It has a fairly uniform level, except near the mouth of the stream, of from three to six feet above the lake.

The Delta of Nipigon River.—The Nipigon is the largest stream flowing into lake Superior, yet its present delta is small and unimportant as a feature of the present strand. We have not far to look for the reason of this. The stream itself is the drainage of a large lake and just before it drops into lake Superior it expands into a series of small lakes, so that the sediment which it carries over the rapids at Nipigon bridge is exceedingly small in amount, and the water appears to be perfectly colorless. Just below the rapids, however, the eddy of the stream is undermining a high embankment of sand and gravel and this affords sufficient material for the silting up of the small bay or inlet of Nipigon bay which forms the last couple of miles of the stream's course.

The Delta of Gravel River.—The Gravel river is bringing to the north shore of Nipigon bay a copious supply of gravel and the accumulation of this makes the delta of the stream a prominent feature of the present shore. The area of the delta which lies out beyond the general line of the shore is probably about a mile square. It is dissected by the stream and has a uniformly level apperance, any slope that it may have being exceedingly gentle. The surface of the delta, like that of the Mazokamah has the characteristic parallel ridge structure of the wave-built terrace, and the recent formation of the outermost of these ridges is very apparent.

The Deltas of the Michipicoten and Pic Rivers.—At the mouth of the Michipicoten there is an extensive delta accumulating resembling somewhat in its mode of development that of the Kaministiquia. The portion of the delta which is accessory to the present strand is due to the continuation of the processes which have been in operation through several higher stages of the lake. At the front of the delta successive beaches have been thrown up and in turn have been cut through by the stream. There is a similar delta at the mouth of the Pic river associated with which is a long sand beach of the present shore. Neither of these deltas was examined sufficiently carefully to warrant any farther statement regarding them. They would, however, doubtless well repay careful study.

The Delta of Brulé River.—The embayment of the coast into which the Brulé river discharges is filled with a great wave-built terrace, the material of which is partly a delta accumulation of the stream and partly due to the lodging of shore drift shed from the neighboring cliffs to the south. These cliffs and the rocks through which the stream is cutting are largely acid volcanic rocks of the nature of quartz-porphyries, easily susceptible of mechanical disintegration. As they have accumulated the fragments have been from time to time thrown up into storm beaches one in front of another till the embayment has been filled out nearly even with the general trend of the shore. It is one of the few cases of simplification of shore line by filling in on the Minnesota coast.

Wave-Built Terrace at Grand Marais.—The small wave-built terrace at the harbor of Grand Marais is the only one of note on the north shore of lake Superior which is not dependent upon a stream for its supply of beach material. A short distance to the northeast of the harbor is a sea-cliff of quartz-porphyry which is shedding angular fragments of rock from its face very rapidly. The cliff is vertical, and has receded between prominent points of more resistant rock till a distinct bay has been formed. At higher stages of the lake there has been a similar supply of the same material, though not all from the same cliff. The detritus thus accumulated has lodged at Grand Marais, and the formation of the harbor at that point is due to the extension lakeward of this embankment in the form of successive storm beaches, till the latter joined with the rocky island shore on which the lighthouse stands. This junction was effected by the running out of a spit from the shore till it met the island. The construction of the wave-built terrace was begun at somewhat higher stages of the lake than the present, and is doubtless still in progress, but the growth is on one side only of the original spit, there being no new supply of beach material within the harbor.

MINOR FEATURES OF THE NORTH SHORE.

There remain to be noted as minor features of the north shore the forms known as *stacks, caves, clefts* and *pot-holes*, and these can be disposed of in a word. These features have been found only along the shore of the Keweenian province, and in all cases to a very limited extent and of exceptional occurrence. Stacks are only found where a portion of the shore, usually not more than a few hundred yards, is occupied by exceptionally soft material that is yielding rapidly to shore erosion to form a small bay or cove. The best and most characteristic stacks were observed between Baptism river and the Saw-teeth, where the rocks occupying adjoining portions of the shore are of very diverse character as regards their hardness and coherence.

Small caves a very few feet in diameter are found in the face of some of the cliffs. These are above the water line, and are not developed by the battery of shore drift against the face of the cliff, as there is no shore drift in sight; but are evidently caused primarily by some local weakness of the rock which enables simple wave action, assisted by the solvent power of the water, to wear out the cavities. Ordinary over-arched shore caves due to the battering of shore drift against the base of the cliffs are not found along the Minnesota coast, except at the Palisades, where some fine ones have been formed; and here the battering process is a small factor as compared with simple wave action acting on the infinitely jointed porphyry of the cliffs. These caves form magnificent archways, through which one may pass in a large row-boat with ease. [See Pl. XI., Fig. 1.] Ordinarily, however, the cliffs are so low that the incision made at their base is, owing to bedding and jointing planes, carried to the summit, and a distinct Λ-shaped cleft in the face of the cliff is the result. These clefts are numerous along the Minnesota shore, and there may be seen almost invariably lying on their sloping bottom the boulders and pebbles with which their sculpture is effected. There is a fine arch on the north side of Pigeon point wrought out of coarse gabbro.

Pot-holes are not commonly developed on lake shores. They are usually the products of stream action. On one part of the Minnesota shore, however, they are distinctly the product of wave action, and may be observed in process of formation. The place where they were observed is on the shore about two miles east of the mouth of the Temperance river. Here the shore is occupied by an amygdaloidal lava of uneven texture, which forms a shelving lakeward sloping platform. In this platform are numerous pot-holes, the deepest having a depth of about four feet and a diameter at the mouth of about three feet. In the bottom of the pot, unless it is very shallow or has been breached, there are always one or more hard erratic boulders, which do the work of grinding out the hole when set in motion by the waves pouring over the surface of the platform. The holes are not as symmetrical as hose formed by stream action, but there is no essential difference between them and the latter. It is to be noted that the rocks which are here susceptible of having pot-holes developed in them by wave action also afford in the canon of the Temperance river the finest, though not the largest, pot-holes to be seen in any of the streams of this coast. The canon of the river is formed by a systematic series of deep pot-holes which have breached into one another, giving the walls of the canon a concavely scalloped form.

Similar shore pot-holes are referred to by Agassiz as occurring at cape Choyye.

COASTAL CONTOURS.

THE PRESENT SHORE CONTOUR.

Of the various elements of a coastal topography the shore contour is the most constant and therefore perhaps the most essential and important. Other topographic elements may shrink into comparative insignificance and some of them may vanish entirely or may never be developed, but the shore line is always present. Like some other phenomena that belong to the category of the "ever present" it is apt to be overlooked among the factors in the total effect which constitutes the topography of a coast. The variation in the character of a shore line is a variation in quantity—in the length of the line. In quality it is practically unvarying, there being no attributes of excellence or imperfection by which we can qualify a description of it. Its shape or form of curve may be regarded roughly as a function of its length, being simple or intricate in proportion to the extent of time which traverses a circle of a given diameter and passes through to the center. The inconstancy of direction of the shore renders the possible variation of the form of the contour practically infinite. Thus the most constant feature of a coastal topography may be the most inconstant in form. But notwithstanding this variability there is usually a certain broad character peculiar to the contour of any shore developed under uniform geological conditions which, though difficult of precise description, may be distinguished readily from that of an adjoining shore developed under different geological conditions. This statement would probably be difficult to substantiate in the case of very mature shores, but it is probably only in exceptional cases where the shore of a large lake is uniformly mature, and the degree of maturity is largely dependent upon geological conditions.

When we consider the form of the shore contour of the north side of lake Superior in its relation to our four geological provinces, we are at once struck by the pronounced character peculiar to each province. In none of the other topographic features of the coast is there a more definite and unmistakable dependence upon strictly geological conditions. The moment we pass from one province to another so soon do we pass from one kind of shore contour to another. This contrast of the character of the shore contour can best be appreciated by an inspection of a map of the lake. But as maps of lake Superior on a suitable scale for such a comparison are not common, certain portions of the shore are here reproduced to illustrate the character of this feature in the different provinces. [See Figs. 1, 2 and 3.] And here it is well to recall the fact that the *apparent* simplicity of a shore line as interpreted from a map is in a measure dependent upon the scale of the map. Of the two shores both mapped as simple lines one may be serrate in minute detail while the other may be quite as simple as represented.

Shore Contour of the Keweenian Province.—The shore contour of the Minnesota coast from Duluth to Grand Portage is on the whole a remarkably simple line. It has the form of a slack bow concave to the lake. Projecting headlands and deep bays are entirely absent. Such salients and re-entrants as are worthy of note are obtuse in form and do not appreciably add to the length of the shore line. Yet in minute detail the line is frequently sharply jagged and serrate; and there is a marked absence of those sweeping sinuous curves which characterize mature shores. Shore erosion is active in the production of coves and the whole tendency of development appears to be, in this adolescent stage of the shore, the reverse of simplification. The present stage of the lake found the shore without indentations and a vigorous beginning has been made in the work of evolving them and in effecting a more intricate form of shore contour. But it is scarcely more than a beginning. The notches, clefts, and coves of the shore can only be rendered appreciable on a very large scale map and do not affect the general statement of the simplicity of the shore line considered as a whole. The shore contour of the Keweenian in the vicinity of Black bay and between that and Nipigon bay is very different from that of the Minnesota coast, and the reasons for the difference are not fully understood as the Canadian distribution of the Keweenian has not been carefully examined. This much is known, however, that in the latter district the shore contour is intricate, and is further complicated by the presence of great numbers of islands lying off shore in a fairly well defined belt. The

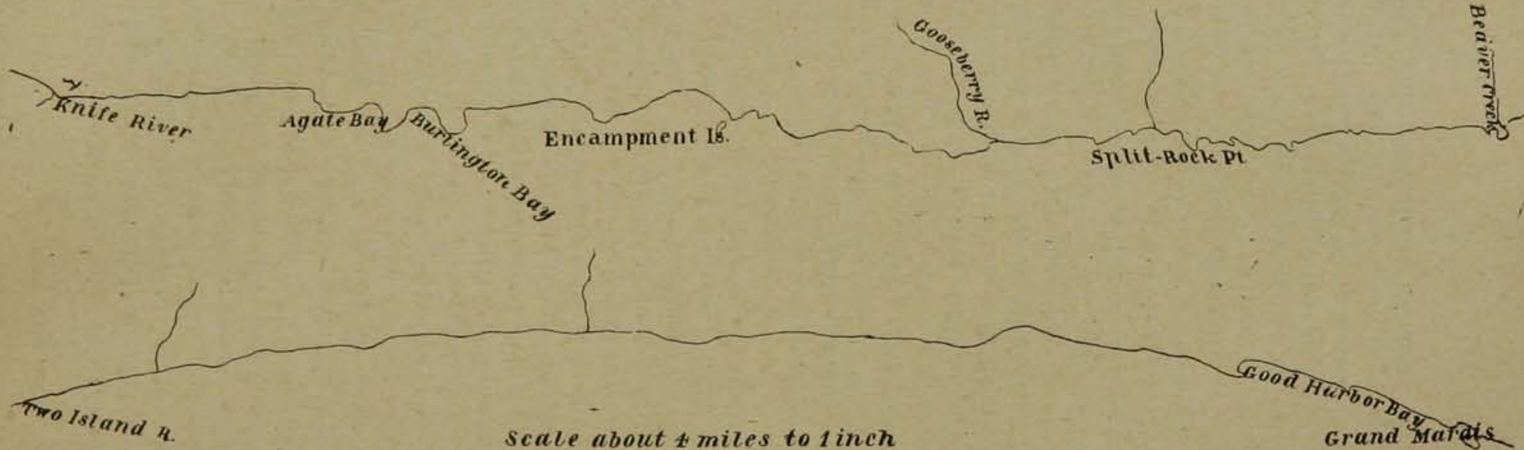

Fig. 1. Examples of the most complex and the simplest shore contours of the Keewenian Province along the Minnesota Coast.

Fig. 2. Shore contour of the Animikie Province. Scale four miles to an inch.

conditions differ from those on the Minnesota coast in the presence of a greater mixture of clastic rocks among the volcanic and in the greater abundance of dykes. These differences do not seem, however, to fully account for the great contrast in the topography of the two Keweenian areas; and the suggestion is strengthened, that the simplicity of the Minnesota coast is due to the fact that primarily it is a fault scarp.

Shore Contour of the Animikie Province.—The general trend of the shore along the front of the Animikie province is not a simple line. Deep narrow bays and prominent sharp headlands prevail, and the length of the shore line is large in proportion to the extent of the coast. The sculpture which gave rise to these bays and points is pre-lacustrine and the tendency of the shore action is, in contrast to that noted on the shore of the Keweenian province, towards simplification. The tendency in this direction is, however, not strongly marked on account of the resistant character of the extremities of the promontories which have not yet been appreciably truncated at the line of the present stage of the lake. See Fig. 2. The tendency is chiefly manifest in the filling up of the heads of the bays. While the shore contour of the Animikie province is in strong contrast to that of the Keweenian by reason of these large salients and re-entrants there is also a radical difference in the minute detail of the shore contour in the intervals between the points and along those portions of the shore which are exempt from bays. There is very little of the sharp local notching and clefting of the shore line where the shore is rocky and none of it where the shore is occupied by shingle. Thus the shore contour of the Animikie province is intricate in its general features but simple in its minute details; while that of the Keweenian is simple in its general features and serrate in its minute detail. The conditions governing the local trend of the bays and points along the Animikie front is easily recognizable and there is a prevailing parallelism in these features.

Shore Contour of the Archæan Province.—The shore contour of the Archæan province is exceedingly intricate in detail. If the shore were represented on a map of a scale sufficiently small to obliterate the detail, so that it would express merely the mean trend of the coast, it would be indicated by a fairly simple, obtusely zigzag line extending from Nipigon to Sault Ste. Marie. In this general and varying trend there may be recognized two degrees of detail: (1) Wide-mouthed bays and broad or obtusely rounded headlands which indent the mean trend of the shore to the extent

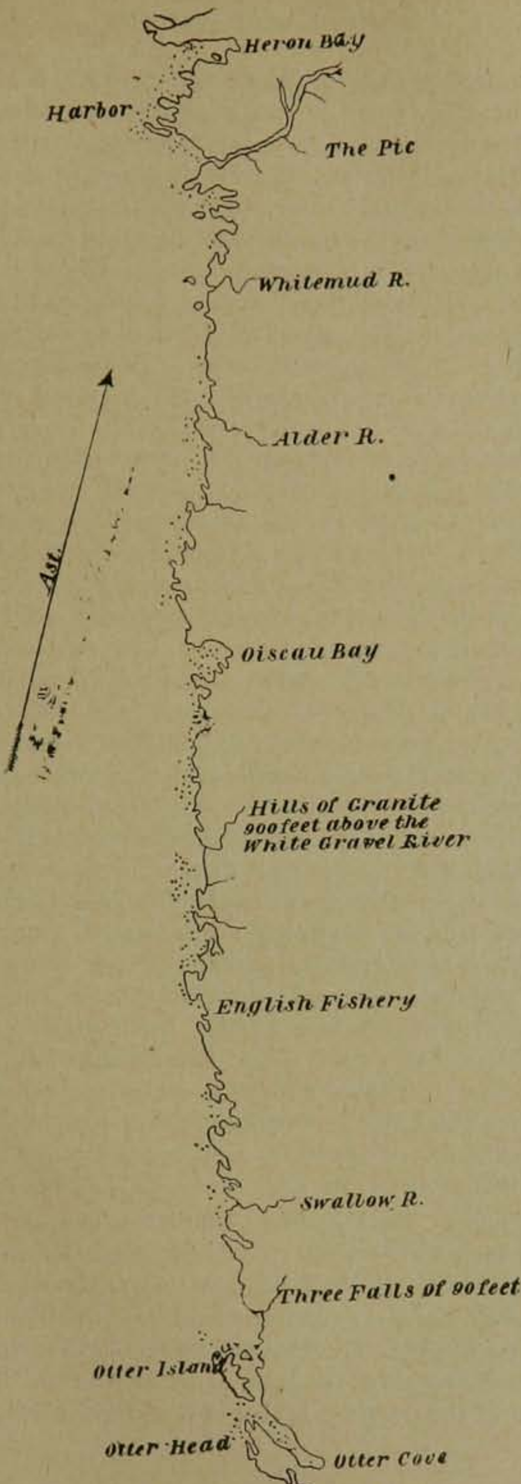

Fig. 3. "The shore contour of the Archæan Province. Scale five and one-third miles to an inch.

of from two to five miles, and (2) a much more elaborate indentation of a minor kind, which is the most characteristic feature of the shore of the Archæan. It is in this minor indentation that the shore contour is most intricate. It gives the shore, when mapped on an adequate scale a distinct *suture*-like appearance, to understand which it is necessary to remember that the shore line is produced by the submergence of a hummocky or mammilated slope. The land and water seem to interlock much as two bones of a skull do. As regards the major indentations of the shore the controlling condition of their evolution, under processes of pre-lacustrine erosion, has doubtless been the variation in the petrographical character of the formations along the line of the present coast. The green stones of the Ontarian system of rocks seem to have been more resistant than the granite and gneiss of the Laurentian and have in some cases given rise to headlands. In other cases one portion of the Laurentian was probably less susceptible to secular decay than another and so stands out as a promontory. The law controlling the evolution of the form of the minor indentations is not apparent. It is the same as that governing the forms of the *roches moutonnees* and the hummocks. In neither the major nor the minor indentations is there any semblance of parallelism, the forms and directions of the bays and points being exceedingly diverse and irregular. In spite of the excessive intricacy of detail of the shore contour, the indentations of this line are very rarely sharply angular but are rather rounded, being practically the local partial contours of the hummocks and lumpy rock masses of the coastal slope. The present tendency of shore action is towards the simplification of the shore contour, but as pointed out in another place, it is only feebly effective on account of the smooth obdurate character of the rocky points and the consequent scarcity of shore drift to fill in the bays. A characteristic feature of the Archæan coast and one which is supplementary to the minor indentation of its shore line is the presence of the fringe of rocky islets lying close in to shore. These of course are but the summits of hummocks and *roches moutonnees* which have been so far submerged as to be completely encircled by water. See Fig. 3.

Shore contour of the Potsdam Province.—The extent of the Potsdam province, on the north side of lake Superior, is so limited and so broken up into isolated patches that any generalization as to the character of its shore contour would be of questionable value, were it not that the same province has an extensive distribution on the adjoining south side of the lake, under similar conditions. The shore contour of the province is that of a mature shore. In detail it presents sweeping sinuous curves, and the few angularities are apparently due to the development of spits, or to the local accumulation of coarse glacial debris, in shallow water. The simplification of the shore line is far advanced, although there are some small bays without apparent bars across their entrance. Such bays are, however, very shallow. The general trend of the shore line is irregular, and has no dominant direction for the reason that the geological province is geographically, if not geologically made up of outliers of the more extensive formation of the same rocks on the south side of the lake.

THE HILL CONTOURS.

Inasmuch as the topography of the coast is, in its broad features, essentially pre-lacustrine, the shore contour is only a special case of the hill contours; and our consideration of this special case anticipates, in some degree, an account of the more general contours of the coastal slope. These contours, as they would appear on a topographic map, are, quite as much as the shore contour, characteristic for each province. In the Keweenian province the hill contours, inland from the brink of the shore cliffs, are prevailingly long sweeping lines, usually uniformly spaced for a constant vertical interval. On a map closed curves, indicating isolated hills, would not be numerous, and only in a very few cases, such as at Carlton Peak, would they approximate a circular form. These hill contours would not, however, have the same constancy of trend as that evinced by the shore contour of the present strand. This comparison of the shore contour with the hill contours brings into prominence the fact that at none of the higher stages of the lake has the shore of the Keweenian province been so simple a line as it presents for the existing strand. Many sinuousities, bays and headlands characterized the shores of the earlier stages of lake Superior along this portion of the coast.

In the Animikie province the hill contours would for the most part show a prevailing parallelism with the shore contour, but with a greater amount of indentation. The prevalence of mesa scarps and dykes would, as compared with the Keweenian coast, necessitate a great crowding together of contour lines; while on the tops of the mesas the same vertical intervals would be widely spaced. In their trend, also, these contours would show sudden bends and sharp angularity, features which contrast with the gentler curves of the Keweenian province. Closed curves would be even more exceptional than in the Keweenian, but would occur in the case of isolated mesas similar to Pie island.

In the Archæan province the hill contours are very distinct from those of either the Keweenian or Animikie provinces. Whatever general parallelism they may have with the present shore is obscured by their great irregularity. The hummocky character of the country would give rise to a great abundance of closed curves in contours of small interval, and these would constantly approximate circular and oval forms. The majority of the contour lines would be exceedingly serpentine in character, or suture-like as in the case of the present shore. For the same interval they would not be so uniformly spaced as in the Keweenian province, nor would they ever be so unequally spaced as in the mesas of the Animikie.

In the Potsdam province the contours, even of very small interval, would, on a map, be few in number, widely spaced, and sinuously straggling as is usual in nearly flat tracts.

COASTAL PROFILES.

Those elements of the coastal topography which are best expressed by profiles evince, as has been already remarked, a very striking dependence on geological conditions; and the profiles in each province are characteristic for it to a remarkable degree. The petrographical and structural features of the four provinces find very distinct expression in the form of the coastal slope.

The possibilities of variation in a topographic profile are seemingly great. As a matter of fact, however, there is but a limited number of *types* of profile actually met with in the inequalities of the earth's surface; and nothing would startle the geological eye more than to meet with certain profiles which are mathematically possible, and easily conceivable, but which are not developed by geological agencies.

It is not proposed here to enter upon a discussion of these types of profile in general, but a few may be enumerated as of dominant occurrence in lake Superior topography. For the sake of convenience the writer will take the liberty of specifying those different types of profile by definite names, some of which are in common use.

The Dip Profile—in which the slope is definitely conditioned by the dip of inclined strata. This profile is common as a portion of anticlinal, synclinal or monoclinal structures, and is of frequent occurrence where the full structure is not revealed. It also constitutes portions of the full profile of many tilted orographic blocks.

The Flat Profile—in which the vertical element is very insignificant; common in undisturbed horizontal strata, the upper beds of which are not much above the local base level of erosion. This would of course include base level plains of deposition. The same profile may also be found in base level plains of erosion.

The Mesa Profile—in which the vertical and horizontal elements are nearly equally effective and are manifest in the profile as actual vertical and horizontal lines respectively. Most common where table lands are wholly or partially circumscribed by cliffs of differential degradation.

The Strike Profile—the outline of a section of inclined strata taken parallel to the strike of the rocks. Theoretically the profile is characterized by a dominant horizontal line. In reality the horizontal line is usually interrupted and indented by features due to uneven erosion.

The River Trench Profile—the profile across a line of drainage, usually representing a distinct trench, the form of which varies according as the drainage is new or old—juvenile or senile—from the sharp V-shape of a mountain cañon to the broad flat-bottomed valleys of a base-leveled plain. On lake Superior the latter of these extremes is never found. With reference to their present base level all the streams are young and are actively cutting trenches. But they are mostly small and the cañons, with one or two exceptions, such as that of the Pigeon, below the falls, and the Kaministiquia, below the falls, are not imposing.

The Precipice Profile—in which the vertical element is greatly in excess of the horizontal, and which lacks the flat top of the mesa. The forms which give this profile may be developed in a variety of ways. It may be part of the fallen but not wholly revealed profile of many sea-cliffs. It is common in the forms resulting from stream erosion and along fault lines.

The Dyke Profile—usually the profile of a sharp ridge with a definite approximation to verticality on both sides, resembling two precipice profiles back to back. Frequently on lake Superior the vertical aspect of the profile is diminished by the adherence to the sides of the dyke of indurated portions of the country rock intersected by it.

The Hummock Profile—characteristic of the forms resulting from the gradual decay of massive crystalline rocks; very common in Archæan terranes where this character of surface now prevails, and also prevailed prior to the deposition of the earliest Palæozoic strata, although evidence of secular decay of the pre-Palæozoic surface is exceedingly meagre. Rotundity is the chief characteristic of the hummocks so that *convex* curves mark their profile. The arrangement of the hummocks with reference to one another is very irregular so that no two neighboring profiles exactly agree, although the general characteristic is never lost.

The Talus Profile—the slope of repose of angular fragments of rock; common on certain parts of the coast of lake Superior but always subordinate to more important profiles, usually that of the mesa; never a dominant profile as in the case of cinder cones.

All of these profiles may be observed on the coast of the north side of lake Superior. Other types also exist, but it is believed that they are of minor importance for the purpose of this discussion, which does not pretend to be exhaustive. Some of these types may exist alone or in combination with others; while some exist only in combination. They may be regarded as *primary* profiles or of prime importance in giving character to the topography of the coast, being the results of sculpture, under various geological conditions, of the beveled edge of the rocky plateau which limits the lake basin.

These primary profiles are frequently, however, locally modified by the imposition upon them of secondary profiles due to former lacustrine action. These secondary or modifying profiles are those of the various shore embankments and terraces which have been developed at stages of the lake higher than the present. And it is these modifications of the coastal topography to which special attention is directed in the sequel. But first a brief comparison will be instituted between the primary profile of the different geological provinces.

Independently of their topographic character the profiles of a coast may be classified according to the direction in which they are taken with reference to the trend of the coast as, (1) the parallel profile and (2) the transverse profile. The topographic type which these two directions of profile exhibit in the different geological provinces will now be briefly stated.

THE PARALLEL PROFILE.

The Keweenian Province.—The parallel profile of the Keweenian province is characterized by the dominance of those special types of profile which have been designated the "strike profile," modified by the "river trench profile." Generally speaking, the strike of the rocks is parallel to the shore, and a general section through the coast close to the shore line and parallel to it would show a long approximately horizontal line notched by stream trenches and the deeper coves of the shore. The vertical distance between the level of the lake and the line of the profile would be comparatively small, but would increase in proportion as the line of section was taken more and more remote from the shore.

The Animikie Province.—In this province a section of the coast parallel to the mean trend of the shore, or roughly coincident with it, would show in the western part a prevailing series of "dyke profiles," and in the more eastern part very pronounced "mesa profiles." The dykes are on a grand scale, and as they form the axes of several of the long points which condition the bays, they appear to advantage in a section across these bays, though cutting them obliquely. Many of these great dykes, though rising in precipitous ridges, some nearly a thousand feet in elevation, have considerable masses of the adjacent country rock adhering to their sides, while others have lost this and rise shear from the water. This prominent dyke topography is practically absent in the Keweenian, except at a few localities, of which the vicinity of the Saw-teeth is the most notable. The horizontal line of the mesa profiles differs from the same line in the strike profiles of the Keweenian in the greater vertical interval between it and the lake level, and also in the fact that this interval is practically constant, however remote inland the section may be taken. A marked characteristic of the coast of the Animikie province, also which appears in this profile, is the talus profile, subsidiary to that of the mesas. In none of the other provinces do these talus slopes appear.

The Archæan Province.—The characteristic parallel profile of the coast of the Archæan province is that of the hummock, and does not differ essentially from the transverse profile given in generalized form in Fig. 6, except, that in a section coinciding with the mean trend of the shore, it would be broken by intervening stretches of water.

The Potsdam Province.—In this province the parallel profile is that designated as the "flat profile," and is somewhat similar to the strike profile of the Keweenian. It would differ from the latter in being closer to the line representing the lake level and in being more nearly horizontal, or so lowly arched as to be sensibly horizontal, and would be free usually from the interruptions due to the stream trenches and sharp coves of the Minnesota coast.

THE TRANSVERSE PROFILE.

The Keweenian Province.—If one leaves out of consideration the hummocky gabbro hills of Duluth, which are of limited extent, the transverse profile of the Minnesota coast is characteristically the "dip profile" in combination with which at the water's edge is a "precipice profile," where the slope of the coast breaks away shear. There is a uniform and constant lakeward dip of the bedded volcanic flows and injected sheets of which the series is composed, and the slope of the coast is clearly conditioned by this dip. At a few places along the coast the underlying basement upon which the Keweenian rests emerges in the beautifully rounded hummocks so characteristic of the Archæan terraces, but these are so limited in extent that they do not affect the character of the profile except in one case. This is at Carlton peak, where, at a distance of something less than two miles from shore, a huge dome of the underlying basement rock projects through Keweenian strata and gives its character to a portion of the profile. To the southwest of Carlton peak, also, a heavy sheet of coarse gabbro, several hundred feet in thickness, probably the remnant of a great intruded sill, rests upon the Keweenian flows and has a dip conformable with them, giving the appearance of a tilted mesa with a great scarp facing the northwest, and a less pronounced mesa edge facing the lake. Other localities where the characteristic "dip profile" is notably deviated from are, in the vicinity of the Saw-teeth, where there are important irruptive masses, intersecting the Keweenian; at Farquhar's knob, a ridge whose structure has not been investigated; at Beaver bay, where there is some topography of the mesa type; and at Grand Marais where, to the west of the harbor there is also a mesa ridge and to the northeast a moranic accumulation. The precipitous termination of the coastal slope, near the shore varies somewhat in character. Where the rock is a single mass from the water's edge to the top of thecliff, it is usually almost or quite vertical, as at the Palisades where the cliffs have their maxium elevation of 210 feet. Where the cliff is composed of different strata it is frequently step-like in character.

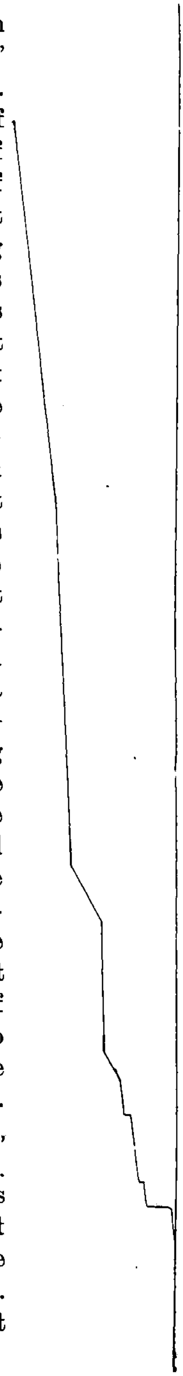

Fig. 4. Transverse profile of the Keweenian Province modified by the presence of two terraces.

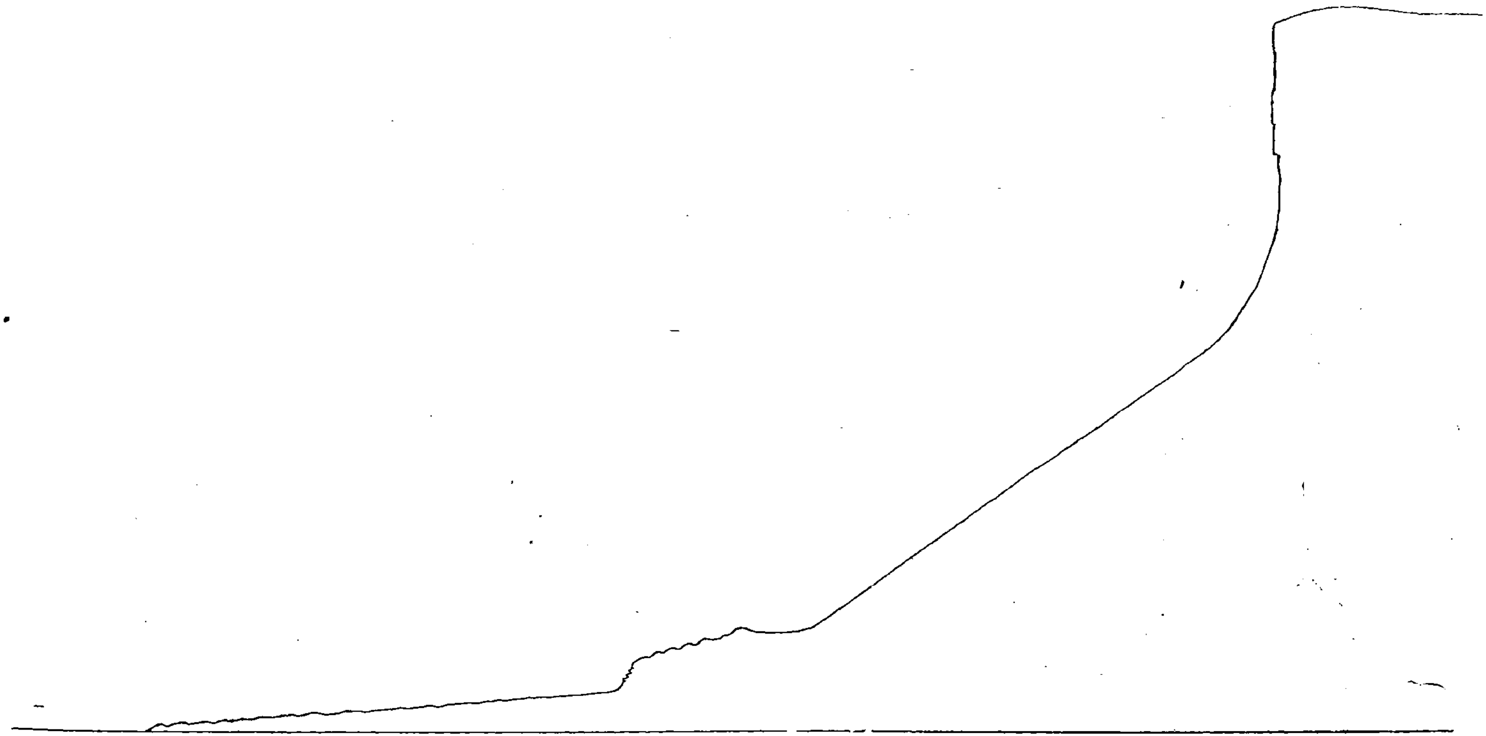

Fig. 5. Transverse profile of Animikie Province modified by a terrace and several beaches.

The transverse profile of the Minnesota coast is frequently modified by the presence of embankments and terraces of the ancient strands of the lake and it is probable that were the timber removed this modification would prove to be much more extensive and important than can at present be recognized.

The Animikie Province.—The transverse profile of the coast of the Animikie province is characteristically that of the mesa, usually with the subsidiary talus profile, but sometimes without it. The dyke profile is, however, not uncommon in the same part of the coast where it appears in the parallel profile. In the valley of the Kaministiquia the transverse profile is exceptional, as will be understood from what has been said of the development of the delta of that stream in a former part of this paper. At Port Arthur a trap sheet, such as usually forms the cap of the mesas, dips towards the lake and passes beneath it, and there is other evidence of local disturbance so that the profile here is abnormal. It is, however, more effectively modified here by the embankments of the former strands of the lake than is usually the case. Towards the head of Thunder bay the transverse profile crosses both the Animikie formations and the underlying Archæan, which emerges from beneath it, and the profile is correspondingly complex.

The Archœan Province.—Throughout the coast of the Archæan province the hummock profile prevails in sections transverse to the coast as in those parallel to it. The exceptions are few and are quite local. Where the coast is coincident with the strike of the schistose rocks, however, the hummock profile is combined sometimes with the precipice profile, and also at some few localities where sea-cliffs have been developed in massive rocks. Two of the exceptions to the general hummock profile are of special interest. In the profile of the coast to the east of Rossport there are places where a very distinct precipice appears with a shelf at its base, not immediately at the shore, but at some little distance from it. Resting at the base of the cliff are small outliers of the Keweenian lava flows, in place, showing clearly that the cliff is pre-Keweenian in date. Other portions of the hummocky slope of the north coast of the lake have small outliers of such volcanic rocks and also of Keweenian sedimentary rocks which locally modify the profile to a minor extent.

The second exception is also of exceptional occurrence. It occurs where the line of profile crosses some of the numerous trap dykes which intersect the Archæan of this coast. Very frequently these dykes have disintegrated much more rapidly than the adjoining country rock so that the spaces formerly occupied by them are now

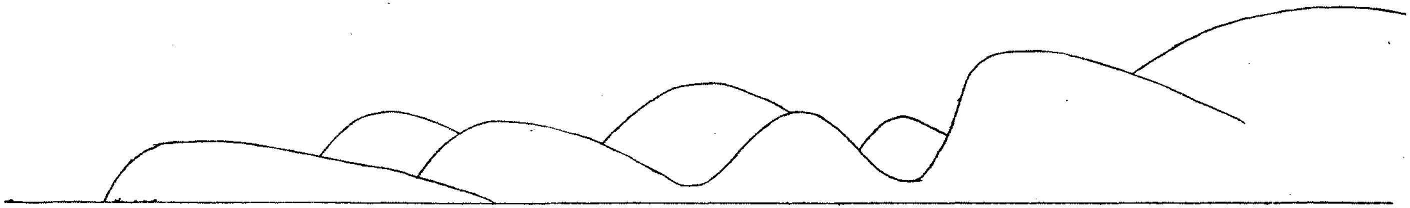

Fig. 6. Generalized transverse profile of Archæan Province.

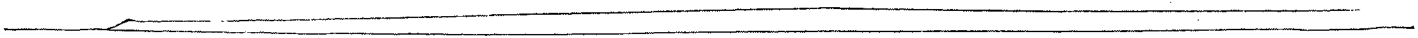

Fig. 7. Transverse profile of Potsdam Province.

sharp trenches of rectangular section. In short the hummock profile is modified by the presence of what may fairly be termed a *negative dyke profile.*

The Potsdam Province.—The transverse profile is here again the flat profile of low-lying undisturbed strata. Within the limits of what may fairly be termed the coast, however, we pass from the Potsdam to the Archæan and the two types of profile would commonly appear in combination.

THE ABANDONED STRANDS.

Considered as purely topographic features the abandoned strands of the north side of lake Superior appear most prominently in the transverse profile, as modifications of the primary coastal slope. This modification of the profile is only of local occurrence and therefore topographically not of great importance. Many extensive portions of the coast might be passed in review without a suspicion being raised in the mind of the observer of their having served as a succession of shore lines. The strictly topographic interest is therefore quite subordinate; and it is only when we begin to take cognizance of the various and wonderful physiographic changes which have conditioned the different stages of the lake that the real interest begins. The shore topography on the hill sides, even if it were far more continuous than it is, is but the registration of the former existence of conditions and activities other than those of the present, and it is the possibility of acquiring clear conceptions of these vanished conditions that gives zest to the inquiry. The nearness of this wonderfully different state of affairs to the present and its evident gradation into normal familiarities of our own day give the chase for the facts even a dash of excitement; so realistic is the picture of the geologic yesterday, conjured up by the contemplation of beautifully, perfect shingle beaches and terraces, one, two, three, four, five, and six hundred feet in the air.

But even this interest, strong as it is, has been made subordinate by the writer to another. The chief object in the inquiry has been to endeavor to ascertain by a careful series of measurements whether the old strand lines of the lake have maintained their original horizontality or have become warped and tilted as in the case of the shore lines of lake Agassiz and lake Iroquois. With this object in mind it was clearly recognized at the outset that it would be hopeless, owing to the merely local development of shore features, to settle the question by attempting to trace out continuously any single strand line or any set of such lines. It was, however, believed that the strands of different vertical series could be correlated, unless there had been rather complex movements, by carefully comparing the intervals between them. Whether the shore lines had been tilted or not, the interval between them would be constant, provided always that any tilting that might have occurred was subsequent to the abandonment of the lower of the set of strands considered.

In order to effect such a correlation the most accurate possible data were necessary, and steps were accordingly taken to ascertain the elevations of the various features indicative of shore lines by precise engineering methods. I was accompanied throughout the exploration by Mr. Louis A. Ogaard, who, assisted by Mr. Fred Kiehle as rodman, carried lines of levels from the shore to the various points designated by me in any series of beaches and terraces, using a Y level carefully adjusted from time to time. The figures given in descriptive notes which follow and in the table are the figures from his level book, and the writer vouches for the painstaking care with which this instrumental work was done. In these figures the decimals are not dropped for two ressons. (1) The figures do not represent always the actual level of the water. The crest of a beach is always above the level of the water line at which it is formed; the rear of a terrace may be sometimes above the actual water line and occasionally it may be below it, so that in nearly all cases a correction has to be made for the actual water level. The amount of this correction is never definitely known so it has been thought best not to apply it, but to give the figures for the actual observation. In this connection it is well to note that many of the apparent discrepancies in strand lines which are correlated in the table are doubtless due to the varying value of this correction. On the present shore the crests of living beaches facing the open lake were frequently measured at all elevations betwen 9 and 14 feet above calm water. In less exposed parts of the shore they usually did not exceed 6 feet in hight. Again, the base of a sea-cliff is commonly one or two feet above the calm water, though occasionally it coincides with the lake-level closely, and the rear of terraces forming at the mouths of streams is usually below the lake-level. (2) The second reason for giving the actual figures of the level book is that in a great many cases, particularly with reference to beaches, it was found to be entirely possible to determine the elevations accurately within a fraction of a foot, so sharply horizontal are these features, and there seems to be no good reason for giving figures less accurate than were obtainable. It will be understood then that the figures given do not represent precisely the actual water levels, but simply the elevation of shore features developed at the various stages from which the actual water levels may be inferred, within certain considerable limits of error.

Before discussing the data obtained by the inquiry or formulating any generalizations it will be well to first become familiar with our facts, and to this end a brief descriptive account is given of the various series of strand lines observed on the coast. The results of the levelling also are summarized in the table at the close of the descriptive notes. In these notes the word series and the number attached to it has the same significance as in the table. The Roman numerals also refer to the table. The table is expressive of a correlation which is discussed in the pages which follow it.

DESCRIPTIVE NOTES.

Series 1.—Duluth West.—On the hills of the city of Duluth a very clear and excellent registration of some of the higher stages of the lake may be observed. The city, as is well known, is being built upon the steep lakeward slope of a massive, rounded range of coarsely crystalline gabbro, which within the city limits rises to an elevation of probably 800 feet above the present level of the lake. On the upper portion of this slope the topography is such that it has been found a convenient and easy matter to construct, as part of the general embellishment of the city, a magnificent carriage drive around the brow of the hill. This carriage drive follows a contour line at an average elevation of perhaps 470 feet, and is known as the Lake View terrace.

It requires but a cursory inspection to see that the particular phase of the topography which has suggested and made easy the construction of this Lake View terrace is due to the imposing upon the steep and rocky hill-side of a feature which has been developed along a former shore line of the lake. This feature consists of a pronounced natural terrace or shelf facing the open lake. It varies considerably in width, being narrow where it rounds the shoulders of the hills and widening out very much in the bays and recesses. It has a gentle but constant slope lakeward, and ends rather abruptly on its outer edge, dropping away into the general steep slope of the hill. The back of the terrace is limited usually by the rounded glaciated forms which characterize the upper portion of the gabbro mass. These rounded forms at the back of the terrace are in places replaced, however, by vertical cliffs of gabbro with large blocks which have fallen from its face scattered about the rear of the terrace and partly imbedded in it. This vertical face of rock

FIG. 1. LAKE TERRACE WITH SEA-CLIFFS IN BACK GROUND, END OF NINTH AVE. W., DULUTH. PARTIALLY MASKED BY SUBSEQUENT WASH AT THE RIGHT. (P. 233.)

FIG. 2. BOULDER BEACHES, HORSESHOE BAY. (P. 247.)

with its talus of angular blocks represents undoubtedly a "sea-cliff" and is like the terrace a product of shore action. An example of such a sea-cliff may be seen near the upper end of Ninth Ave. West. [See Pl. VIII, Fig. 1.]

The material of which the terrace is built consists of surf-rolled boulders, pebbles, gravel and sand. The arrangement of this material is well seen in the cuts which have been made at a few points in the construction of the drive. In the cut at the upper end of Ninth Ave. W. about 150 feet in front of the sea-cliff just mentioned, the terrace has been sunk into so as to afford a vertical section of 9 feet. The lower 6 feet of this section show sharply bedded gravel and sand with occassional boulders up to one foot in diameter. [See Pl. X, Fig. 2.] The upper 3 feet of the section although composed of the same materials is not distinctly bedded, but this obscuration of the stratification may be due to the action of vegetation. The strata intersect the vertical plane of the section usually in quite horizontal lines. At the south end of the cut, however, oblique bedding of alternating wedges of gravel and sand is well seen, the dip of these beds being 25 degrees and less.

The relations of the various factors of the topography at the head of Ninth Ave. W. is illustrated in the diagrammatic section.

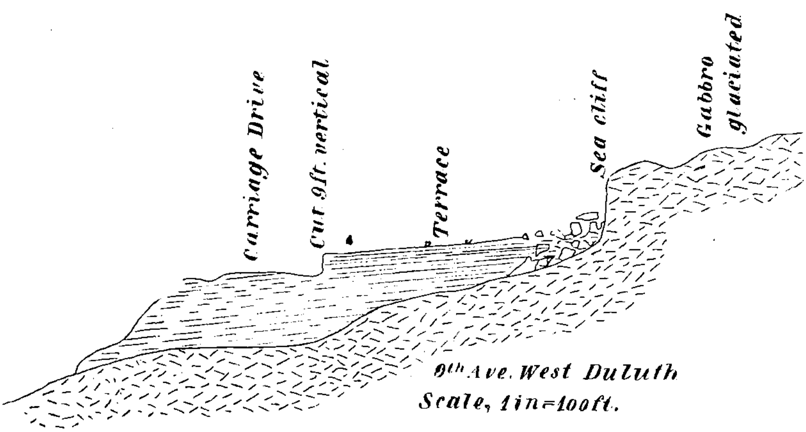

Fig. 8. Section at the head of Ninth Ave. W., Duluth. Elevation of terrace, 476 feet.

The rear of the terrace in front of the sea cliff was found to be 475.9 feet above the lake (XXIX). The structure of the terrace shows that while primarily it is a wave-cut feature, the cut shelf of rock and the slope below it is covered with current-sorted material which was probably brought down by minor drainage.

Evidence of shore lines at lower levels in the western part of Duluth were not satisfactorily observed, although they will probably be found if looked for on the slopes between Duluth and Fond du Lac.

At a higher level, however, there is a great beach which spans an embayment in the hill front and stretches continuously between the two shoulders of rock which are at the head of Sixth and Eighth Aves. W. respectively. The Seventh avenue inclined railway, which was under construction at the time the examination was made, terminates on this beach, the crest of which was found to have an elevation of 534 feet (XXXI). The presence of the beach is clearly revealed by the topography which it imposes upon the hillside. The contrast with the unaffected portions of the hill is striking. The horizontality of the beach crest is the feature which first attracts attention, the longitudinal profile of the beach with the rock on either side being not unlike that of the upper half of a dumb-bell, thus ⌒——⌒. The transverse profile shows the characteristic undulatory front slope of shingle beaches, the descent being by a succession of rounded steps. The same profile shows also a well marked lagoon hollow behind the beach. The ground plane shows that this lagoon hollow is entirely inclosed by the straight beach in front and by the rocky slopes of the hill on the sides and in the rear, so that the contour of its rim is roughly of the form of the letter D.

At the south end the beach has been quarried for road ballast and there the material which enters into its composition and the arrangement of the same is readily observable. The material consists chiefly of pebbles and boulders which range in size from two to six inches and have a prevailingly rounded form. There are a few large boulders up to two feet in diameter and a good deal of finer gravel. Stratification is not discernible in the mass of the beach and the pebbles and boulders are piled up in the irregular fashion so well exhibited by the living beaches of the lake. There was no longitudinal section which would permit of an observation as to the sorting of the material according to its relative coarseness. In the upper part of the beach there is some fine gravel and sand which shows a stratiform arrangement, but this is probably due to wash from the lagoon, since such drainage would doubtless have kept a way open for itself through the beach.

The undulatory front slope of the beach extends from its crest at an elevation of 534 feet down to the rear of the terrace already described at an elevation of 475.9 feet, and the relations seem to warrant the inference that the higher strand line is the older and that the water subsided by stages till it arrived at the one marked by the Lake View terrace, where it remained constant for a sufficient length of time to evolve the striking feature of the togography, the terrace being in fact cut into the slope of the older and higher beach.

Series 2.—Duluth, Tenth Ave. East.—Near the head of Tenth Ave. East, three distinctly marked strand lines are recognizable. The highest of these is a wave-built terrace of pebbles and boulders resting on a rocky slope and facing the open lake. Careful levelling established its elevation at 534.8 feet (XXXI) which agrees within a foot with the altitude established by an entirely independent line of levels for the beach at the head of Seventh Ave. West. From this elevation down to an altitude of 436.2 feet, or in round numbers a vertical distance of 100 feet, there is a continuous bank of beach material comprising boulders, gravel and coarse sand, lying upon the slope of the hill. On the front of this great embankment there is a level terrace, which, while not very broad, is persistent and on being traced southward is found to abut directly against the rocky slope at a place where the upper terrace is wanting. This second terrace was found to have at the rear an elevation of 473 feet (XXIX) which again agrees very closely with the figures obtained for the rear of the Lake View terrace in West Duluth. The structure of the upper terrace is not revealed by any section; but below the 473 foot terrace there have been a number of excavations for road ballast and in these it is seen that this lower part of the gravel bank is distinctly stratified with a dip in the direction of the slope of the hill, but at a much less angle. There is a small ravine to the left of the higher terrace and there is little doubt that the stream which flowed down this ravine supplied the material of which the whole of the 100 foot bank is constructed; and the development of the two terraces and the stratiform structure seen below the second one is probably explained by the following considerations:—

The bedrock of the ravine is much lower than the upper terrace (XXXI), and was so when the lake stood at the level at which the terrace was built. The ravine after becoming itself filled with detritus to the level of the lake would supply the material for the terrace, and besides this there would be much which would be carried down to the subaqueous slope and arranged by the varying currents into strata. As the level of the lake subsided the ravine would be cleaned out and its accumulations spread out on still lower slopes also in bedded fashion. In this way the 100 foot bank of gravel, etc., stratified in its lower part, would have been accumulated. The strand line XXIX represents a stage in the recession of the water, at which, as in West Duluth, a second terrace was imposed upon the slope of the growing bank, partially cutting into the flanks of the upper terrace.

At the foot of the rather steeply inclined 100 foot bank of beach material, the slope suddenly changes and flattens out into a broad, gently inclined terrace in which no rock in place is seen. The rear of the terrace was found to have an altitude of 436.2 feet (XXVII). Its surface is composed of a dark earth in which are embedded scattered boulders, and it is covered with grass or timber so that its substructure is not apparent. On following the rear of this terrace northward beyond the gravel pits, it is found to abut against the *roches moutonnees* of the hill-side without the intervention of the gravel. The age of this terrace relatively to the gravel terraces above it is doubtful. It is uncertain whether the gravel bank rests upon the rear of this terrace or whether the terrace is imposed upon the lower flanks of the gravel bank. Owing to the absence of natural sections no ready answer presented itself to this question, and time was not taken to investigate it. It is possibly an older terrace, but evidence of this supposition is lacking.

Series 3.—Hardy's Schoolhouse.—Near the eastern limits of Duluth, in the vicinity of Hardy's schoolhouse, there is a magnificent illustration of that phase of topography which is due to the development of a bar beach and delta deposit at the mouth of a valley, which has been the channel of a stream flowing into a lake at a level now abandoned. The altitude of the crest of the barrier beach was found to be 509.5 feet (XXX) above the lake. Northward from it there extends a forest-clad, rock-walled valley about a mile wide at the mouth where spanned by the barrier beach. About the mouth of the valley are several isolated rocky hills which evidently formed islands in the lake when it stood at this high level. They rise from out of the beach formation or from the flat-lying delta deposits farther out which represents the shoals of the old lake bottom. The crest of the beach has a curvilinear form and extends in a southwesterly direction from the rocky knob at the schoolhouse, which stands at its northeast extremity, to the rocky hills which rise at the back of the city. In a general way it seems concave towards the valley, but it is by no means a simple ridge. It has a very extensive aerial distribution, and while on the side it presents sections, as along the line of the electric tramway, which are simple lowly-arched ridges of beach material, towards the middle

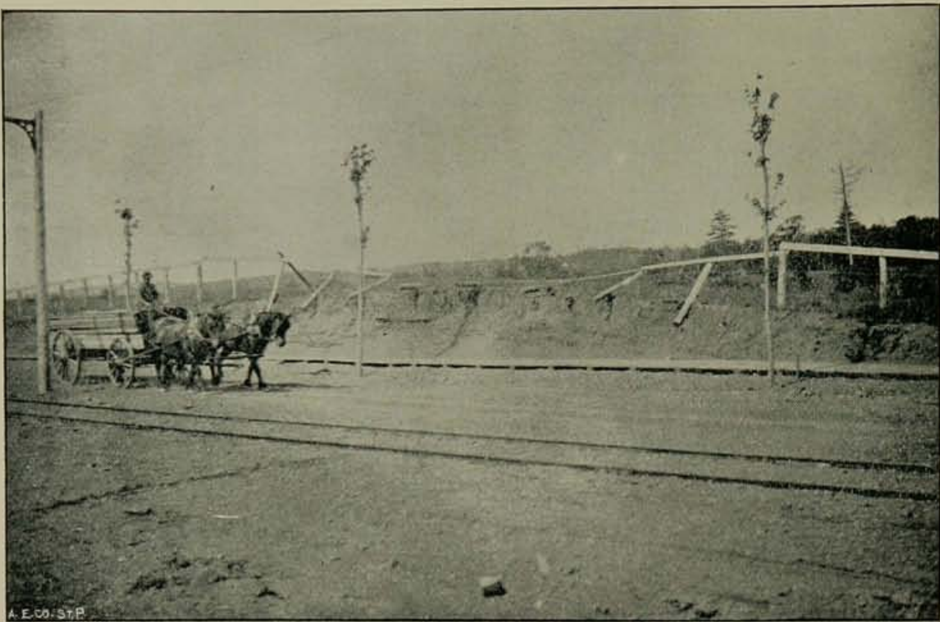

FIG. 1. GRAVEL CUT. SECTION ACROSS HARDY'S SCHOOL HOUSE BEACH, EAST DULUTH. (P. 237.)

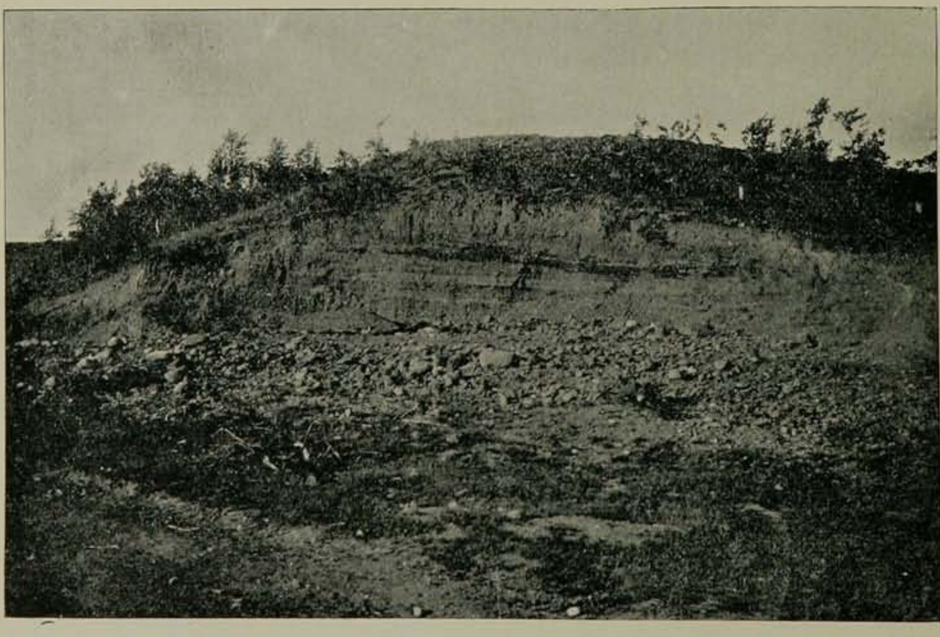

FIG. 2. CUT IN GRAVEL BANK, SHOWING STRATIFICATION OF OLD BEACH, DULUTH. (P. 233.)

of the valley it spreads out and grades into a broad delta. The crest of the beach is higher than the valley bottom to the north of it and also higher than the flat tract to the south. The section referred to on the line of the tramway near the schoolhouse is a cutting made in the construction of the road and displays a vertical section of about 6 feet of evenly bedded and obliquely bedded gravels with some sands. [See Pl. X, Fig. 1.]

On the lower slopes of the eastern part of the city of Duluth and for many miles northeastward along the coast, there are definite indications and suggestions of terraces when the land is viewed from a distance. There are two circumstances, however, which interfere with the recognition and location of these terraces at close quarters. The first of these is that the geological structure of this part of the coast is such that the strata dip lakeward at about the same angle as the slope of the terraces, so that the changes of inclination in the transverse profile are not sufficiently accentuated to permit of reliable determination of the line of the abutment of the terraces upon the hill-side. The second unfavorable circumstance is the prevalence of timber which obscures the surface but allows the general effect of a terrace to be sometimes dimly apparent at a distance. On account of these conditions, no time was spent in trying to locate shore lines between Duluth and Two Harbors.

Series 4.—Two Harbors (D. & I. R. Ry.).—On the line of the Duluth and Iron Range railway, northward from Two Harbors, one very strong suggestion of a strand line may be observed in the vicinity of mile post 32, in the abutment of a sloping plain against a series of morainic hills. This change of the character of the surface comes out most distinctly when viewed from a distance. From a hill top on the shore of the lake near Two Harbors, even although the country is wooded or only partially burnt, the effect of a plain abutting upon the hills is quite distinct. The corresponding change in the slope of the surface is recorded in the railway profile as published in Winchell's Iron Ores of Minnesota, plate No. XXXVII, where the rear of the terrace at the 32nd mile post is given at 475 feet (XXIX).

The railway yards and station, at the town of Two Harbors, are also on a terrace whose limitations to the northwestward could not be definitely recognized. The elevation of this plain at the railway junction is, according to the same authority, 35 feet above the lake.

Series 5.—Beaver Bay.—The mouth of Beaver river is well protected from south and southeast winds by a bold head, which, at its extremity, presents to the lake vertical cliffs over 100 feet high, but which is connected to the main land by a rocky ridge about 50 feet on an average above the lake. This ridge is partially mantled by old beach material and sand. The stream, after emerging from the gorge through which it discharges into the lake, hugs the northeast side of this protecting ridge for a couple of hundred yards, and on the other side of the stream there has been built up, by the joint action of the stream and easterly or northeasterly storms, a well defined spit. [See Pl. XII, Fig. 2.] This spit seems to be crowding the stream against the ridge, and in consequence it is cutting a terrace in the soft material which flanks it. This same condition of things seems to have obtained when the lake was 20 feet higher than at present; for, on the northeast side of the ridge, parallel to the present stream, and 20.1 feet (III) above it is a distinct terrace, which, while doubtless due to stream action, yet is in such a position that it must have, at the time of its formation, corresponded at its rear to the then level of the lake.

The next old strand line observed at Beaver bay is on the slopes above the base of the spit referred to, where a small but distinct terrace is found at an elevation of 79.9 feet (VII). The terrace looks out over the lake and lies to the northeast of the mouth of the gorge from which the stream emerges. The hill in which the terrace is cut is apparently moranic material resting in a rocky slope. There is doubtless also an admixture of stream detritus but the heavy sward prevents satisfactory determination of the structure of the hills.

Farther up on the slopes of this hill a broad terrace has been built up evidently in the form of an embankment of the stream detritus dumped into the lake at its higher stages. This terrace is best seen in the cultivated fields on the west side of the Beaver river. It abuts against the steeper hills as an old shore-line near the grave-yard at an elevation of 126 feet (XI). A few hundred feet down the slope of this broad and gently-sloping terrace is a low beach-like ridge of fine gravel which is probably of the character of barrier beach at 114.8 feet (X). On the east side of the river the hill rises somewhat uniformly in the form of a broad sloping well timbered terrace. A wagon road through the timber shows that while the slope is uniform in general it is uneven in detail, is strewn with boulders, and characterized by abundance of red mud. This broad terrace at about a mile back from Beaver bay encircles a rocky hill which rises from the rear of the gentle, nearly flat slope with steep sides which in places are absolutely vertical for over one hundred feet. The sides of the hill at these places present the character of a sea cliff and the abutment of the gentle boulder-strewn terrace against this rocky hill is taken to be the mark of an old strand line, at a time when the hill was an island of the lake. This abutment was found by our measurement to be at 313.9 feet above the lake (XXII). The hill thus encircled has a diameter of perhaps one-half mile and rises to about 700 feet above the lake. It was ascended to the summit, but no red mud and very few boulders were seen above the terrace plane. Nor were any indications of higher strand line observable either on this hill or on the surrounding hills as seen from its summit. The summit affords a good view of the surrounding country and the terrace in question appears to run in between the hills as a valley bottom which as far as could be judged in the timbered state of the country, rose on the flanks of the hills to a constant level. Between this hill and the lake on the general slope of the main terrace there is a subordinate terrace at an elevation of 173 feet (XV).

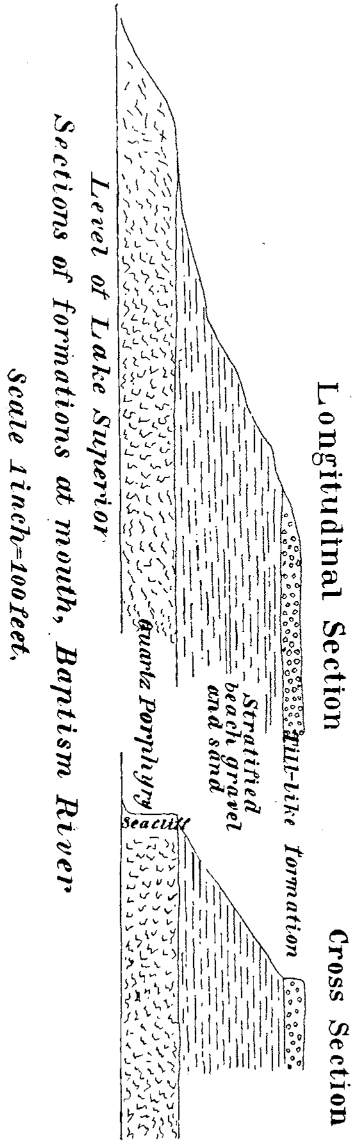

Fig. 9. Sections at mouth of Baptism river.

Series 6.—Baptism River—Just east of the mouth of the Baptism river below the Palisades, a clear-cut sea-cliff facing the open lake reveals a unique and interesting section. The cliff rises practically from the present level of the lake, but there is a low beach a few yards wide between its base and the edge of still water. The lower 30 feet of this sea-cliff is vertical and consists of one of the acid formations of the Keweenian volcanic series which are usually so intimately jointed and so susceptible of mechanical disintegration. Upon this rock rests a thickness of over 50 feet of stratified material which presents all the characters of a shore embankment.

It is made up chiefly of coarse sand, gravel and boulders entirely uncemented. Upon this stratified beach-like material rests about 11 feet of heterogeneous material which has all the characters of boulder till. The part of the sea-cliff above the lower vertical wall of rock, although made up of these incoherent materials, presents at numerous places a vertical escarpment in its upper part with a talus mantling its lower part down to the brink of the rocky cliff. The section parallel to the shore, as seen when approaching the shore from the lake, is shown in Fig. 9, as is also the cross section.

The upper incoherent portion of the sea-cliff although presenting a front which stands somewhat further back from shore than the lower rocky portion is not apparently receding at a faster rate, but is receding *pari passu* with the undermining of the rocky foundation on which it rests. The line of demarkation between the rocky lower portion of the sea-cliff and the stratified material which rests upon it is a roughly horizontal one and seems to be the trace of an old plain which is of the nature of a terrace. The dividing line between the stratified beach material and the third or till-like member of the section, is also a horizontal line and is sharply marked. There seems to be no good ground to doubt the beach character of the middle member of the section for the following reasons: (1). The character of the material is that which usually constitutes shore drift. (2). Its stratification is similar to that of embankments composed of material not too coarse. It is both horizontally and obliquely bedded, the planes of the false bedding being frequently discordant. (3). The apparent embankment extends out from the west side of a bold promontory which lies to the east of the Baptism river and the material is coarser near this rocky ridge than further from it. (4). It faces the open lake and extends across the front of a valley. In view of these facts the formation is interpreted to be an embankment of the character of a beach bar that once crossed or partially crossed the mouth of a bay into which the old river discharged. The material of which the embankment is built is partly foreign, doubtless brought by the stream from morainic accumulations inland, and partly local from the mechanical disintegration of the cliffs. The upper member of this section, as has been stated, presents the heterogeneous character of boulder till. In places it is a pure red plastic clay with only occasional pebbles in it, but quite devoid of structure; a few yards away this will merge into a clay mixed with sand and pebbles in the most irregular fashion, together with numerous boulders both rounded and angular up to two feet in diameter. Could the formation be shown to be boulder till of glacial origin, the section would be of great interest in connecting the old high leads of the lake with the presence of glacier ice at a time posterior to the primary glaciation of the region. The suggestion that this till-like formation is of glacial origin is sustained in a measure by the fact that it is found at the mouth of a short valley at the upper end of which are ranges of hills much higher than are usually seen on this coast, and which might have served as a gathering ground for local glaciers. In spite, however, of these suggestions of glacial causes, the origin of the formation must be for the present regarded as problematical, and the evidence inconclusive. In some of the western placer mining districts the heavy beds of stream detritus, consisting of boulders and pebbles of greatly varying sizes imbedded in clayey matrix, and devoid of definite arrangement within a given bed of great thickness, resemble closely much of the material which sometimes is called boulder till and referred to glacial origin.* In view of the insufficient examination of the surrounding conditions nothing beyond suggestion is offered as to the origin of the till-like stratum. It is assumed that the summit of the stratified gravel is the approximate crest of a barrier beach which by some means has been covered by the till. The summit is 83.8 feet above the level of the lake and it thus falls into place with strand line VII. On the upper or westerly side of the mouth of Baptism river, behind the club house, there is a distinct wave-cut terrace which has been carved out of a morainic accumulation, the rear of the terrace being 49.0 feet above the lake (V). The terrace has a very low angle of slope and is strewn with boulders which project above the surface, giving it the character of a boulder pavement, in the sense in which Prof. J. W. Spencer uses that term. The sea-cliff behind the terrace is low and has been rounded by atmospheric waste. The morainic material rests upon the same terrace-like platform rock as that observed on the east side of the river. The terrace and sea-cliff face the open lake.

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*Formations of the character commonly designated as boulder clay may, it seems to the writer, in some cases have an origin greatly different from that at present ascribed to them and proper criteria of a purely petrographical character, so to speak, for discriminating between the true glacial formations and those due to other agencies are not yet formulated. Other criteria are of course available, such as the form of the mass, its relation to adjacent formations and other conditions of occurrence. But there seems great room for error if we rely on the character of the formation petrographically considered as a means of recognizing its mode of development.

Series 7.—Saw-teeth.—About three miles east of the mouth of Baptism river in the vicinity of the Saw-teeth, a search was made for terraces at a place where the country had been burnt and the jungle appeared to be passable. None were seen from the shore, and the fact that the search proved successful warrants the belief that at many places along the Minnesota coast ancient terraces and beach lines will be revealed as the timber is cleared. At the locality in question, a great embankment of shore drift mantles the underlying rocks up to a level of 130 feet above the lake. The upper limit of this embankment forms a horizontal contour around the hill and marks the rear of the highest terrace. Above it the hill rises with an acclivity of about 25 degrees to a hight of about 300 feet above the lake. The terrace has a slope of perhaps 5 degrees and at the place examined is about 150 feet wide. There is no trace of water-worn material on the rocky slope above the rear of the embankment, only scattered angular blocks of local origin; and from the summit of the hill no suggestion of higher terraces was obtained from an inspection of the surrounding, thickly-wooded hills. The terrace (XXI) probably belongs to the "cut and built" type of Gilbert, but no well-defined cliff has been developed and the accumulation of shore drift has been proportionately more rapid than the cutting action, a fact due doubtless to the proximity of streams. About 150 feet from the rear of the embankment, the upper terrace is limited by the sea-cliff of the next lower terrace. The sea-cliff, having been cut in the incoherent material of the embankment, is well defined, although its slope is something less than the angle of repose. The terrace at the base of this sea-cliff is only 50 feet wide and has an altitude of 99.5 feet (IX). Below this is another low sea cliff, the base of which is 84.5 feet high (VII), at the rear of a broad, gently-sloping terrace which extends for nearly one-fourth of a mile to the brink of the cliffs above the present shore.

Series 8.—Carlton Peak—From the vicinity of the Saw-teeth to Carlton peak fairly definite suggestions of two, and in some cases more than two terraces are obtained by an inspection of the coast from the lake. The country is, however, heavily timbered, and experience proves it to be impracticable to locate them within a reasonable time by crawling through the jungle. On the slope from Carlton peak to the shore the timber has been burnt, and by hard scrambling through the windfall it was possible to reach the terraces and ascertain their elevations approximately by aneroid observations. The figures obtained by this means were 80 feet, (VII) and 125 feet (XI) respectively, above the lake for the rear parts of two very gently sloping terraces that have been cut in a broad embankment of soft material which must have accumulated at still higher stages of the lake. The precise registration of these higher stages was not observed, but the conditions of examination were unfavorable, and it is probable that higher terraces on the flanks of Carlton peak will be found.

Series 9 and 10.—Poplar River—The Poplar river cuts through a broad embankment of sand, gravel, etc., which mantles the rocky slope of this part of the coast for many miles. The front of the embankment overlooking the lake descends rapidly to the present shore by a succession of cliffs and cut-terraces which have been carved out of the main embankment at various successively lower stages of the water subsequent to that at which it was accumulated.

The brink of the main embankment is about 116 feet above the lake, and from this point its upper slope rises very gently landward for nearly two miles to an elevation of about 300 feet where it abuts sharply against a steep range of a gabbro. The general character of the topography and the underlying structure is analogous to that described at Beaver bay, where a broad gently-sloping terrace of incoherent material abuts on precipitous rocky hills at an elevation of about 314 feet. The rear of this broad terrace at Poplar river was only ascertained very approximately by an aneroid observation, so that the figures are not incorporated with the more precise data of the table. The wooded character of the country practically prevented precise observations at points distant from the shore without an expenditure of time, labor and money, which would have been inconsistent with the modest plan of our operations. Although the newer terraces carved in the front of this main embankment face the open lake, they are in the immediate vicinity of the mouth of the stream, and the stream currents have doubtless played an important part in the development of the terraces, supplying and removing detritus contemporaneously with the cutting action of the waves The terraces and cliffs are all remarkably sharp in cross profile. The terraces are narrow and vary but little from horizontal. The angle of slope of cliffs was carefully measured and three were found to have a declivity of 28°, two of 27°, and one (the lowest) of 32°.

The lowest terrace of the series is a wave-built terrace, and is only 6.9 feet (I) above the level of the lake at its rear, where the fishermen's boat-houses stand. Towards the lake it grades into the present shore. The higher terraces have none of the characters of wave-built structures so far as can be discerned. At the summit of this series of terraces and cliffs, just at the limit of the main embankment, is a beach-like ridge with somewhat lower ground behind it and a series of minor, succesively lower, parallel ridges on its gentle lakeward slope. This ridge is interpreted to be a barrier beach developed at a favorable stage of the emergence of the coast. The accompanying cross profile was plotted to scale in the field from precise measurements.

On the east side of the mouth of Poplar river only three distinct strand lines have been registered on the front of the main embankment. These are, a well-formed wave-cut terrace facing the lake at an elevation of 78.4 feet (VII); a less distinct terrace, which is seen in vertical section where the river gorge cuts it, to be composed of stratified gravels, the elevation of its summit being 99.6 feet; and again a beach-like ridge, the highest line on the front of the embankment, at 116 feet.

Series 11.—Coast east of Poplar River. — East of Poplar river two terraces are observed to follow the shore more or less continuously for some miles. Both are covered with timber, but as they are low and not usually distant from the shore, their topographic character is not obscured beyond recognition. Both are wave-cut terraces and have been carved out of a primary embankment which mantles the rocky slopes of the coast. These terraces were found to be susceptible of partial measurement at a fishermen's clearing about two miles from Poplar river. Here the brink of the lower terrace is 14.5 feet above

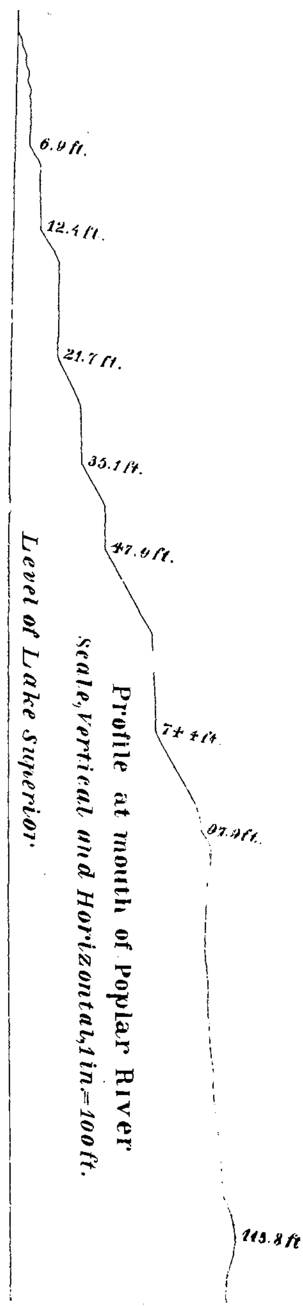


Fig. 10. Profile at mouth of Poplar river.

the lake, the front limit being a steep sea-cliff rising from the present shore. The terrace is 150 feet wide and at its rear has an elevation of 17.8 feet (III), thus exhibiting a slope of about 2 in 100. From the rear of this terrace an other sea cliff rises with a slope of 37 degrees and the brink of the second terrace is 37.5 feet above the lake. The terrace runs back under the beach apparently nearly flat. The elevation of its rear portion was estimated to be 6 feet higher than its brink, thus making the shore line about 43.5 feet (V) above the lake. The low sea-cliff which rises above the present shore and limits the lower terrace lakeward is rather a striking feature of this part of the shore, being a vertical scarp of the old embankment material resting upon rock varied in places by shorter stretches in which the cliff is wholly rock or wholly embankment gravel.

Series 12.—Good Harbor Bay.—The next locality along the coast where the ancient strand lines are sufficiently recognizable to be measured is at Good Harbor bay. The bay is open to the east and northeast and presents on the maps but a small jog in the generally uniform trend of the shore. The west side of the bay is overhung by a sea-cliff of very slightly inclined beds of red and brown shales and shaly sandstone which rises vertically to a hight of 15 feet. Between the base of the cliff and the shore line there is a narrow and low beach of shingle derived chiefly from the cliff. Above this sea-cliff there is a terrace about 100 feet wide and 20 feet high at its rear (III), which is thickly strewn with shingle. Immediately above this, with a low cliff between, is another terrace 25 feet wide and 27.2 feet high at its rear (IV), and also cut out of shingle and gravel. A third sea-cliff cut out of irregularly stratified gravels and sands of a primary embankment rises above this for about 50 feet. Above the summit of the cliff the ground rises gently in a rolling succession of beach-like ridges for several hundred feet horizontally and then grades into a distinct terrace abutting against the higher slopes of the hill at an elevation of 115.3 feet, (X).

Series 13.—Grand Marais.—The pinkish acid volcanic rocks of the vicinity of Grand Marais have by their mechanical disintegration along the sea-cliffs afforded an abundance of shingle and gravel with which the waves have banked up a fine series of beaches. These have been arranged in parallel ridges in the form of a beautifully distinct and typical wave-built terrace. As this terrace encroached upon the area of the lake the space between the shore and the rocky island upon which the lighthouse stands was spanned by a spit, and the construction of the terrace was limited to the northeast side of the resulting bar, since the latter closed in a bay, the only entrance to which is by a deep channel between rocky points through which no shore drift could enter. [See Pl. XII, Fig. 1.] Within the bay at Grand Marais the wave action has been restricted, for lack of supply of new material, to working over the old material brought there before the bar was established; and its effect has been doubtless to extend the size of the bay and render it shallow. Within the bay the crest of the living beach has an altitude of 5.5 feet and is 23 feet distant from the water. Parallel to this and 65 feet farther inland across an intervening hollow is an old beach, the crest of which is 6.1 feet above the lake (I). Behind this is again a hollow and beyond the ground rises in two low steps to culminate in a third distinct and bare beach-crest at a distance 105 feet from the second. The altitude of this third beach is 12.1 feet (II). This is again followed landward by a parallel hollow, and again the ground rises (all bare shingle and gravel) in two low steps, each about 25 feet broad, the higher of which is 17.5 feet at its edge. Neither of these steps is taken to mark a definite stage of the water. The upper of these steps grades into a gently sloping wave-cut terrace 260 feet wide and 29.1 feet high at its rear. Thus from the back of this terrace (IV) to the present shore there appears to have been no sudden drop in the level of the lake but a gradual recession of the water. At stage IV the waves were cutting a terrace out of a pre-existent embankment of shingle and gravel. As the water sank the supply of drift from neighboring cliffs seems to have increased so that terrace-cutting gave way to terrace-building. The particular section selected for measurement shows the wave-built terrace at its narrowest part. Farther east it is many times broader.

Along the line of examintion the cutting action which produced the terrace of strand IV had eaten back into an embankment of shingle to the line of a beach of a former higher stage of the lake. For at the rear of the terrace a low sea-cliff of shingle rises with a slope of 28 degrees and this slope is nearly coincident with the front slope of a very distinct shingle beach with a hollow behind it, the crest of which is 43.6 feet above the lake (V). Above the level of this beach, the slope of the hill rises gently with an undulating profile, and presents a surface of gravel obscured by forest loam and shrubbery. In this vaguely undulating profile which was plotted to a large scale with great care, in the field, only two shore lines are distinctly registered, viz: one at an elevation of 55.9 feet (VI), in the form of a terrace 26 feet wide, and another at 113.5 feet (X), where the last of the gravel was observed.

Less than half a mile farther west, however, two still higher strand lines were observed and their altitudes measured. The lower of these is a terrace 127.3 feet high (XI) which is well seen from a distance towards evening, but which is less apparent at close quarters. The higher is a distinct but not an extensive gravel terrace encircling low glaciated domes of rock at an elevation of 162.6 feet (XV). This upper terrace is nearly on a level with the lower part of the bold bluff which overlooks Grand Marais on its southwest side. This bluff presents vertical walls from 20 to 50 feet high and was a sea-cliff when the water stood at the 162.6 foot level. On the east side of Grand Marais village a trail goes up over the hill. This was followed to the summit of the pass, about 750 feet above the lake, in search of higher strand lines. But although the trail passes almost continuously over morainic accumulations, no trace of a shore line was observed at levels higher than that last recorded.

Series 14.—Kimball's Creek—From Grand Marais eastward a low terrace, corresponding to strand line IV or the 29.1 feet terrac at Grand Marais, may be observed for several miles along the coast as far as Cow-tongue point. Higher traces of shore lines are doubtless present, but they are utterly obscured by the jungle. At the bottom of the bay below Cow-tongue point three terraces are observable from the lake, but only two of these could be located. The third eluded our search although it must have been covered by us in our excursion in quest of it near Kimball's creek; and the second was difficult to locate with precision on account of the lack of contrast between its slope and that of a pre-existent slope of rock in which no cliff had been carved. This terrace has a measured minimum elevation of 80.1 feet (VII), and its maximum is within two or three feet of this figure. It is evidently neither a wave-cut nor a wave-built terrace, but might be classed as a current-built terrace. Below this is a flat clearing on which stands a half-breed's house. The flat is the first of the three terraces referred to. At its rear it is 28.5 feet high (IV), and above it rises a steeply inclined sea-cliff carved out of the primary embankment, whose upper surface constitutes the second terrace. Farther along the shore this terrace is again seen about a mile below Fish-hook point, and again below the mouth of Brulé river, where it is being cut into by the wave-action so as to present the scarp of a sea-cliff rising above the existing shore.

Series 15.—Horseshoe Bay.—At the bottom of Horseshoe bay there is a very remarkable and striking series of three beautifully developed beaches. The bay, as its name implies, is not long proportionate to its width, but its shores converge towards the upper end and the wave action has been exceedingly energetic in consequence of this rapid convergence. Vertical cliffs of massive gabbro in the vicinity of the bay, particularly on its west side, where they rise to an elevation of 50 feet, have supplied the material of which the beaches are constructed. There is also a sparing admixture of glacial erratics. The remarkable feature about the beaches is that there is no shingle or gravel or any fine material whatever in their composition. They are strictly boulder beaches resembling ridges of cannon balls, although there are as many sub-angular boulders as rounded ones. [See Pl. VIII, Fig. 2.] The crest of the lowest of these beaches is only 20 feet horizontally distant from the present shore line and its crest is 11.9 feet (I) above the lake. The crest is strikingly horizontal and curves parallel to the contour of the shore. It may be the storm beach of the present stage of the water, but the size of the boulders which range on an average from 6 inches to 12 inches in diameter, suggest that the crest was built up when the water was somewhat higher than now. Behind this beach there is a slight depression and behind this the second boulder beach rises to an elevation along its crest of 17.6 feet (II). The distance between the two beaches from crest to crest is about 100 feet. The boulders of which this beach is composed do not on the average vary much from 12 inches in diameter. This second beach is again followed by the usual parallel hollow and behind this rises the third and most imposing beach of the three. The crest of the latter is 200 feet distant from that of the second beach and is 38.6 feet high (IV). The front of this beach is not a simple slope as is the case with the two lower beaches, but its profile shows a distinct step-like feature in its lower part such as may be some times seen in clear water on the subaqueous slope of some of the living beaches of the lake. The component boulders of this beach are perceptibly larger than those of the lower beaches, the average diameter being over 12 inches. Many were measured which greatly exceeded this dimension. This beach was clearly developed as a bar across the bay when the water was at stage IV, for behind the beach there is a broad expanse of marshy ground much lower than the beach, which represents the lagoon formed by the establishment of the beach bar. At higher elevations of the surface of the water, Horseshoe bay would have been merged with the common expanse of the lake and the shore carried further inland than the range of our observations.

Series 16.—Double Bay—A fine display of terrace topography, visible through the burnt and still standing timber, meets the view on entering Double bay. The present shore line is backed by a steep sea-cliff which is being carved out of an embankment which is probably fundamentally morainic, although modified in form by shore action of former high stages of the lake. Numerous boulders are worked out of the embankment and are strewn along the present shore, but it is largely also composed of clayey material. Stretching back from the brink of this sea-cliff is a nearly flat terrace, which is about a quarter of a mile broad, and which spans the entire breadth of the embayment. The rear of this terrace is about 32 feet above the lake (IV). Above it rises a second sea-cliff followed by another broad terrace similar to the first, having an altitude at its rear which measured 85.8 feet (VII). This second sea-cliff is not continuously distinct. Above it spreads out a broad sloping plain which varies in width, according to the topography of the rocky slope which here begins to emerge through the superincumbent embankment. Along the line of section measured, this terrace is about a half mile wide and abuts upon a rocky slope; the line of abutment is horizontal, and although no well-marked sea-cliff has been developed, owing to the resistant character of the rock, it may with great probability be taken to mark approximately a shore line. Its elevation, as measured is 160.5 feet (XIV). On top of this rocky ridge at an elevation of 278.9 feet, and at a distance inland of about a tenth of a mile from the rear of the last mentioned terrace was found a distinct gravel bar surrounding low rocky knolls and spanning the gaps between them. To the northeastward this beach appears to merge into a terrace which abuts upon the precipitous flanks of a spur of Farquhar's Knob. The rear of this terrace would be a few feet higher than the figures given for the elevation of the gravel bar, but its precise elevation was not determined. It doubtless corresponds to strand XXI.

Series 17.—Grand Portage—It was hoped from a distant inspection of the topography of the pass through the hills at Grand Portage, from its being fairly free from timber, and from its gentle grade, which renders the country accessible for some miles from shore within moderate limits of elevation, that the registration of the ancient strand lines of lake Superior would at this place be fuller than usual. This hope was, however, not fulfilled, and only a few of the strand lines were satisfactorily located by carrying a line of levels along the portage trail. From the nature of the embayment in the hills it is evident at a glance that at the higher stages of the water Grand Portage bay must have extended several miles inland and have had a somewhat irregular shore contour with sharp indentations, particularly on its west side. From the precipitous character of the bluffs or promontories which limit the embayment on either side it is presumed that very little of the general shore drift found a lodgment in the bay, and whatever embankments may have accumulated would be of local derivation. The fact that the general shore drift did not find its way into the bay at the higher stages of the lake, either around Mt. Josephine on the east or the bold precipices which rise on the west of the embayment, is evidenced by the absence of such drift on the wave-cut terraces which contour these precipitous slopes on either hand, as will be noted later. In spite of this exclusion of the general shore drift, there is evidence that at probably all recorded stages of the water, the water was in the middle parts of the bay as it is now, always shallow, and that waves, although very effective on the neighboring steep slopes where the water was deep, left comparatively feeble traces of their action on the successive shores at the head of the bay. The conditions which have favored an excessive accumulation of local detritus in the bay and rendered it shallow from the highest stages of the lake down to the present are, (1) the presence of a massive morainic ridge crossing the valley about four miles north of the village, and, (2) a small stream cutting through it which has built up a succession of sloping delta plains, each of which has been cut through in turn as the level of the lake dropped. The higher and older delta plains appear to be much more extensive than the later, and it is a possible case that at the time of their building the stream flowed from beneath ice still lingering behind the moraine in the upper part of the valley. The highest delta forms a very distinct broad plain which has been terraced by the stream, but which cannot be clearly separated at its rear from the present front slope of the moraine. Half a mile or more in front of the moraine there projects through the plain a rocky glaciated dome a few hundred feet in diameter. The abutment of the plain upon the steep slopes of this island-like mass of bare rock is very sharp. An inspection of the surface of the rock, which is uneven in detail on top, warrants the belief that it was not submerged at the time of the formation of the plain which encircles it, and that it was, therefore, but little above the level of the water which conditioned the slope of the plain. The elevation of the plain at this point was measured at 339.7 feet, which altitude is placed in the table as representing approximately strand line XXVII.

A higher terrace was also observed abutting on a rocky slope at an elevation of 458 feet, but the brushy character of country obscured its relation to that just mentioned and it could not be determined to be distinct from it.

Further down the valley on a lower delta slope are two low beach-like ridges, one at 254.7 feet (XX), and another at 231.8 feet (XVIII), which appear to have been barriers thrown up by the breakers in a shallow bay at some distance from the shore and similar to the barrier which is now forming in Grand Portage bay. On a still lower delta plain and much nearer the lake is still another low barrier ridge which has an elevation of 103.5 feet (IX). The church of the village stands on a terrace which, at its rear, at the foot of a low and worn-down cliff carved out of delta material, is 74.7 feet high (VII). Immediately to the lakeward side of the church the ground drops steeply to the level of the terrace on which the village is built. This drop represents a sea-cliff which is one of the most striking shore features of Grand Portage. The terrace which extends out from its base is 37.9 feet above the lake (IV). There is still a lower terrace the rear of which is about 8.6 feet above the lake (I). The present bay is shallow out as far as Grand Portage island so that the waves break before reaching shore; and one of the results of this is the development of a subaqueous ridge or barrier parallel with the shore line. Boats drawing over a foot of water may ground on this barrier, but between it and the shore the water is deeper. The barrier as yet appears nowhere above the surface of the lake and probably it will never so develop into a barrier beach, but always remain subaqueous since heavy storm waves necessary for the throwing up of the initial subaerial ridge can not reach this line on account of the lakeward shoal.

Series 18.—Mount Josephine. The south side of Mt. Josephine presents a succession of strand lines most of which are exceptionally well defined. The mountain is a ridge about 800 feet high and consists of a great dyke of gabbro or diabase, to both of the steep flanks of which a selvage of southerly dipping slates and quartzite of the Animikie is still adhering up to varying elevations. The extremity of the ridge juts out into the lake as a sharp point which forms the eastern limit of Grand Portage bay and is known as Hat point. The most striking and most heavily scored of the strand lines is a wave cut terrace (XXX) which contours the side of the ridge at an elevation of 509.5 feet and sweeps around in a beautifully shaped curve where the ridge abuts upon the main mass of rock from which it is a spur. The timber has been burnt over a portion of the hillside so that the character of the terrace, as a heavily cut shelf, perfectly horizontal, projected against the side of the hill, attracts the eye from a long way off, and excites the curiosity of even the casual observer as a peculiar feature of the landscape. At close quarters the terrace was found to be about 100 feet wide, to have a gentle lakeward slope for this distance, and then to drop away into a steep declivity of the hillside. At its rear rises a steep cliff which is partly the side of the great dyke, partly the inducated slates adhering to the dyke, and partly a wall of the dyke rock, farther in than its original side wall, which has been established by the cutting action at the level of the terrace. The terrace is strewn with great blocks which have fallen from the vertical cliff, and at one place a considerable talus has accumulated in great part since the wave-action ceased. There is a considerable proportion of glacial drift over the lower flanks of the ridge and this seems to have extended up to the summit of the ridge since there are some northern erratics strewn over the surface of the terrace. It is possible that the terrace may in part, particularly at its northern end, be cut out of a morainic dump. The summit of Mt. Josephine is heavily glaciated. A small portion of beach shingle and gravel is strewn over the surface of the terrace. The possibility of the terrace being a feature of differential degradation was critically considered on the ground but all the evidence observed made clearly for its wave wrought origin. The facts that the strata dip southerly while the rear of the terrace is horizontal, that the slope of the terrace is outward and independent of the dip, and that the terrace character is maintained where it swings in the curve of the ——— away from the line of the dyke, indicate at once that its form and situation are not conditioned by the structure of the rocks. The terrace is further interesting as yielding to accurate measurement figures for its altitude which are identical with those obtained for the equally well-defined strand line (series 3) at Hardy's schoolhouse in East Duluth.

This terrace, although the most pronounced of the dents in the west side of Mt. Josephine, is not the highest. There are two higher and presumably older terraces, neither of which is so extensive along the hillside nor so wide. Both of these are much alike in their general character, and in the measure of their extent and they rise one above the other. They are continuous for only a few hundred yards and both vary from about 30 to 50 feet in width. Both are backed by a sea-cliff and both are strewn with blocks of rocks derived from it and from drift accumulations.

These terraces are respectively 587.2 feet (XXXII) and 607.3 feet (XXXIII) above the lake. One of them is a prominent feature of the hillside as a distinct horizontal shelf visible at long distance; the other is not so apparent, owing, doubtless, to the thickened shrubbery. It is suggested in explanation of their short extent, that they lie in a slight embayment on the side of this ridge and so somewhat protected; while their continuation on the more salient portions of the ridge has been undermined and cut away by the same wave action which resulted in the devlopment of the broader terrace at 509 feet. These two terraces at 587 feet and 607 feet are remarkable for being the highest strand lines which have thus far been observed on the coast of lake Superior.

Lower on the same slope of Mt. Josephine are two other sharply scored but narrow terraces which lie well within the unburnt timber and which are therefore not apparent at a distance. The first of them in descending order is at an elevation of 313.5 feet (XXII) and the second at 226.1 feet (XVIII). Both are readily observable on the trail which crosses Mt. Josephine from Grand Portage to Wauswaugoning bay, and both appear to be cut out of the accumulation of drift which here mantles the rocky base of the ridge. Still further down at the base of the hill is a boulder beach (V) the crest of which is 43 feet above the lake; and between this and the shore there is again a drop in the general slope to an even terrace which is 19.9 feet (III) high at its rear, and which extends for less than 100 yards to the brink of the sea-cliff of the present shore. This last sea-cliff has a hight of 13 feet.

Series 19.—Wauswaugoning Bay.—Wauswaugoning bay is limited on the southwest side by Hat point and on the northeast by the base of Pigeon point. The shore along the side of Hat point is a precipitous cliff without a beach or visible shelf at its base, and the water is deep. This line of high cliff, rising in places to a hight of 800 feet, is continuous around the embayment, but leaves the shore line about half way from the extremity of the point and sweeps round to the vicinity of Pigeon falls roughly parallel to the shore, but usually several hundred yards distant from it. At the base of Pigeon point the ground is low, and at higher stages of the water Pigeon point was either an island or was completely submerged so that portion of the sediment of Pigeon river then found its way into Wauswaugoning bay. But as Pigeon river is a new stream, being a succession of cataracts and stretches of still water, the sediment is small in quantity and very fine so that it supplied practically no material which would remain in the zone of shore drift on a wave-beaten shore. Its sediments have taken the form of a delta at the head of Pigeon bay where protected from wave action. The Pigeon river is clearly a very recent drainage and it seems probable that the ancient outlet was into Grand Portage bay. This dearth of stream detritus has characterized the shores of Wauswaugoning bay at all stages of lake Superior, there being no other stream cutting through or tumbling over the cliffs which rise around it. In this respect the bay presents a marked contrast to the neighboring bay at Grand Portage with its heavy deltas. The contrast between the two bays is perhaps best seen in the character of the strand line registrations. The higher stages of the lake were not strongly registered at the head of Grand Portage bay because of the lack of contrast between the subaerial and subaqueous slopes of the delta. At the head of Wauswaugoning bay the water line of the higher stage was not registered at all, because the shore was along the face of vertical cliffs of pre-lacustrine origin. As the lake subsided the water surface reached the talus of the cliffs and terrace lines were doubtless carved. But in the vicinity of the cliffs the growth of the talus since the water subsided has rendered them unrecognizable; and it is only when we come to comparitively low stages of the lake, where on the gentler slopes of the talus, conditions have been favorable for the carrying of a bar across the head of the bay, that permanent strand lines have been established. These bars form two magnificent beach embankments with lagoon hollow behind and undulatory slope in front. They are composed entirely of coarse shingle of quartzyte and hard siliceous slate which mostly weather red. The vegetation has been burnt off and the crests are remarkably sharp and continuously horizontal lines, which by their color and distinctness give a striking character to the landscape. The upper of these two beaches is 76.5 feet (VII) above the lake and the lower 43.7 feet (V).

Series 20.—Near Birch Island.—Outside of Wauswaugoning bay on the south side of Pigeon point and about half a mile east of Birch island there is a fine display of storm beaches. The material of which they are built is the detritus of the reddish Animikie quartzyte which is the prevalent rock on this part of the coast. The shore is well exposed to southerly winds. The beaches although well developed are here only found at comparatively low altitudes, there being no high slopes upon which embankments of higher stages of the lake could be lodged. Three distinct beach crests rise one above the other all having the same general character. The first of these is within reach of the waves of the present stage of the lake and is possibly the living storm beach in process of growth or having attained its maximum growth. Its crest is sharp and uniformily level at 13.6 feet above still water (I). About 150 feet from this crest rises the second beach equally sharp and distinct, with an elevation of 17.4 (II). On the front slope of this beach is a subordinate shelf-like feature. There is no perceptible depression in the 150 feet of space between the two beach lines. The third beach crest is about 100 feet behind the second and there is a slight depression between the two. There is a depression behind the third beach, *i.e.*, between it and the rocky slope upon which it has been banked up. The third beach has an elevation of 21 feet (III). All three beaches are, like those of series 19, absolutely devoid of soil or fine material of any kind. There is no blown sand to obscure their characters as perfect wave-built embankments of shingle and gravel spanning the bay between two rocky ridges.

Series 21.—Pigeon Point.—From the abandoned ranch at the mouth of Pigeon river a trail crosses Pigeon point to the shore on the south side. This trail is transverse to the trend of the rocks and between the two main ridges is an embayment which opens to the south-east on the south side of the point. The trail in crossing this embayment follows the crest of a shingle beach which spans it. The total length of the beach is something less than one-eighth of a mile, there is no breach in it and behind it is a well defined lagoon hollow. The crest of the beach was found to have an elevation of 75.6 feet (VII). On the front of the embankment which culminates in this beach a second beach has been developed at an altitude of 56.6 feet (VI). It is probable that several other beaches lie between this and the shore, but the interval is heavily timbered and definite results are scarcely obtainable.

Series 22.—Pigeon River.—At the mouth of Pigeon river, on the Canadian side, there are three fairly distinct traces of shore action. They are found on the south side of the point of land which separates the canon of the Pigeon from Pigeon bay. The highest is of the nature of a short gravel bar, connecting two projecting masses of rock. It is about one foot lower in its middle than at the sides where it abuts upon the rock. Its elevation at the latter place was found to be 134.3 feet (XII). The fine character of the gravel (mostly of slate), and the low curvature of the bar indicates development under sheltered conditions, such as the local topography would suggest. On the lower flanks of the hillside are two distinct terraces, one at 60.8 feet (VI) and another at 18.2 feet (III), both of which are probably rather to be strictly interpreted as stream terraces of the Pigeon, but being at its mouth and below rapid water, they represent very closely the stages of the lake at which they were developed.

Series 23—McKellar's Point.—The south side of McKellar's point near its extremity, has afforded conditions eminently favorable for the accumulation of a series of shingle beaches, viz: A cove between rocky bluffs, high sea-cliffs on either side shedding fragments of quartzyte, hard slate and trap through various successive stages of the lake, and exposure to the full sweep of the lake from the south. The fact that the beaches have accumulated on one side of a narrow ridge-like promontory has insured them from intersection by drainage lines and thus they are remarkably perfect in form. They have been protected also by forest growths but these have recently been removed by fire up to about 100 feet above the lake, leaving the bare red banks of shingle and boulders. It is quite noticeable in comparing the different beaches of the series that the material composing the higher ones is coarser than that of the lower. In the higher beaches, the embankment is made up essentially of boulders in which the flattened shingle character is comparatively rare. They are mostly subangular and have an average diameter of over six inches according to deliberate estimate made on the ground. There is in these higher beaches nothing which might be termed gravel. In the lower beaches the shingle-like character of the drift is pronounced. Some of the higher beach accumulations have been cut into by the wave action at lower stages, so that a part of the old material of the higher beaches has been worked over in successive zones of shore attrition. It is possible that the lower accumulations may be mostly composed of material derived from the older and higher accumulations, and if so, the contrast in form and size of the pebbles would be accounted for. The same contrast in the character of the beach material was observed on Wauswaugoning bay though to a less marked degree.

The series of strand lines on McKellar's point is divisible into three parts. The highest is a boulder beach that spans the embayment at an elevation of 137.6 feet (XII). Between this and the next beach there is an interval of perhaps two hundred yards in which no distinct shore lines were observed. This beach constitutes the first of the three divisons of the series and seems to be distinct from those which follow. At about 100 feet altitude we come well within the burnt timber and at the same time upon the second division of our series. This division consists of a continuous succession of beaches extending over a horizontal distance of about 300 feet. The actual figures obtained by levelling were for the highest of the succession 101.4 feet (IX) and for the lowest 82.2 feet (VII). Between the two beaches at these respective elevations, there are three distinct intermediate ridges, of which the middle one is perhaps the most pronounced and has an elevation of 89.7 feet (VIII). The succession seems to indicate, without question, a gradual recession of the lake between stages IX and VII. Whether this gradual recession continued below VII or not cannot be inferred from the record of this series. For, at a lower level the lake, whether arrived at by a gradual subsidence or by a sudden drop, conditions of shore action were so changed that instead of wave-building wave-cutting set in. This resulted in the development of a distinct wave-cut terrace and corresponding sea-cliff, both carved out of the pebble embankment. The terrace is about 100 feet wide and the sea-cliff is 25 feet high, and rises with as steep a slope as it is possible for the loose material of the embankment to lie. The rear of the terrace was found to be 48.4 feet above the lake and seems to represent stage V. This sea-cliff and the shore features below it constitute the third division of our series of strand lines. On the front part of this terrace there has been built up a distinct but low beach or barrier ridge which has an elevation of 36.3 feet (IV). The front limit of the terrace is again a cliff, almost vertical in places and carved out of shingle. At the base of the cliff is a beach accumulation which seems to be the beginning of a wave-built terrace. The terrace effect is somewhat marked, although the embankment is narrow. The maximum elevation of the embankment at the foot of the shingle cliff is 8.4 feet (I) and it is within easy range of storm waves of the present lake.

Series 24.—Thompson Island.—On Thompson island there are three strand lines recognizable. Two of them are shingle beaches and the third is a line of wave wrought caves on the south side of the island. The island is a long narrow ridge composed of a great trap dyke with some subordinate dykes running parallel to it and blocks of horizontal strata lying between the dykes or adhering to their sides. The upper of the two beaches lies on the summit of the main dyke at about the highest point of the east end of the island. The altitude of its crest is 97 feet (IX). The lower beach is at the extreme east end of the island. Its crest was found to be 28.7 feet above the lake (IV). Both beaches are composed of clean shingle and pebbles free of all fine material and unobscured by soil. The development of caves on the face of the nearly vertical side of the main dyke seems to have been primarily conditioned by weak spots in the rock due to the inclusion of masses of slate in the trap. The occurrence of a series of them at the same level and having the same general character as some smaller caves developed on the present shore can only be referred to shore action. The caves are widest at the mouth and at the bottom; and the sides converge rapidly inward and upward. Those examined were about 20 to 25 feet in length, and were about 12 to 15 feet high, at their entrance. The floors sloped outward. After comparing them with similiar cavities on the present shore line a point was selected in the floor of one of these caves as representing most probably the water level, and it was found by measurement to be 45.6 feet above the lake (V).

Series 25.—Shore opposite Flat Island.—The trap capped cliffs of hard slaty sandstones which are so characteristic of the topography of Thunder bay have at all stages of the lake afforded an abundant supply of durable shingle, and the fact that only a small number of beach accumulations have been observed on the talus slopes of these cliffs is due to the presence of the timber which obscures them from view. Wherever conditions are favorable on this part of the coast for observation, by reason of fire having removed the timber, or by reason of such talus slopes being within a short distance of the present shore, the beaches are observable. On the shore opposite Flat island there is a set of three beaches which are entirely analagous to those described on McKellar's point. They have been built up on the talus which encircles a sharp projecting angle in a line of vertical escarpment. At the summit of the series is a great beach ridge whose normal hight was found to be about 105 feet (IX), but which at one place is somewhat higher and is irregular in its form, as if the effect of the storms at this projecting point had been exceptionally great. This higher part has a maximum hight of 109.2 feet. From this great beach ridge a continuous succession of later beaches extends down to a beach crest which has an elevation of 86.4 feet (VII). The intervening beaches are sometimes distinct and sometimes run into one another. They seem clearly to indicate, just as the beaches at McKellar's point do, a gradual recession of the waters of the lake through this distance. Below this lower beach there is again as at McKellar's point, a precipitous, here nearly vertical, sea-cliff carved out of the shingle. At the base of the cliff a broad sloping terrace extends out to the present shore. The rear of this terrace at the base of the cliff is found to have an elevation of 45.3 feet (V). On the front part of this terrace at a distance of 150 feet from the present shore is a low barrier beach, the crest of which is 8.8 feet above the lake (I). The entire series is well bared and the beaches above the sea-cliff are destitute of all vegetation and soil. The sea-cliff is remarkable for its precipitous, wall-like character, while composed of loose shingle. There is no cementing material whatever and the broad flat character of the shingle alone enables the cliff to maintain its form.

Series 26.—Shore above Carp river.—In the embayment of the coast next above that into which Carp river flows, the country has been burnt over partially, revealing some fine shingle beaches at the head of the embayment. These cannot be seen from the shore but may be viewed to advantage from a boat some distance out on the lake. They are about half a mile inland from the present shore. The embayment within which they lie is bounded by vertical walls of columnar trap resting on flat Animikie slate, the two walls converging and meeting at the head of the embayment. On the sides of this embayment, at the immediate base of the cliffs, is the remnant of a terrace which appears to be nearly flat and which was found to have an elevation of 164.1 feet (XIV). The terrace is composed of shingle and gravel with cliff debris much less water worn. Below this and spanning the embayment from cliff to cliff is a great embankment of shingle the summit of which is a perfect beach. The distance between the canon walls along the line of the embankment is not more than a quarter of a mile. There is no breach whatever in the embankment. Behind the beach, *i. e.*, between it and the talus of the cliffs which encircle the head of the embayment is a very pronounced lagoon hollow, the bottom of which is about ten feet lower than the crest line of the beach. The crest of the beach is 138.2 feet above the lake (XII). Against the front slope of this great embankment another beach also of large dimensions has been built at a lower stage of the lake. Its crest has an elevation of 122.5 feet (XI). A little below this at an elevation of 116.8 feet is another, but feebly developed beach which probably also indicates a distinct though short-lived stage of the water. The conditions of the embayment are, it is perhaps needless, to say, peculiarly favorable for the development of such embankments. The continuous line of cliffs, of which the embayment is but an indentation, would, below the base of the trap cap, shed a large amount of fairly hard but slaty Animikie sandstone for the formation of the shingle, which, traveling along the shore, from either quarter, would be entrapped in the embayment. The latter is in ground-plan, funnel-shaped, opening upon the lake and exposed to northeasterly storms.

Series 27.—Carp river.—The sides of the canon through which the overflow of Loch Lomond finds way to lake Superior by the short succession of rapids known as Carp river, contains numerous registrations of old strands, which are for the most part clearly defined. The canon is funnel-shaped, and has been an embayment at all the known stages of the lake. A wagon road ascends the canon to the level of Loch Lomond, a distance of about two miles, which renders the inspection of the topography of the canon an easy matter. Rising immediately from the present shore line there is a rolling succession of small, ill-defined gravel beaches at low levels which were not regarded as altogether simple in their development, but probably as having been modified by the stream which emerges at this point. They seem, however, to indicate a gradual recession of the water without leaving an emphasis at any one stage to suggest its longer continuance than its associate stages. The first well-defined beach has an elevation along its crest of 33.8 feet. (IV). This is followed by another great beach of perfect form at an elevation of 52.1 feet. (V). Above this are two terraces flanking the south side of the canon, one at 82.1 feet (VII) above the lake, and the other at 106.3 feet.(IX). Both are evidently current-built terraces and may owe their origin to stream action: but as their situation is near the mouth of the canon, their level corresponds very closely to that of the lake at the stages when they were built, unless the stream had a delta extending far out into the lake, a feature of which there is no evidence and which is highly improbable at the mouth of so short a stream arising from the overflow of a clear water lake. Further up the road is another great gravel beach which has been built up on the gently sloping surface of a great accumulation of stratified gravel which has once filled the canon, but is now cut through by the stream to bedrock again. The crest of the beach at the point leveled was 139.8 feet (XII) above the lake. The section afforded by the sides of the stream trench shows gravels to a thickness of nearly one hundred feet and proves that the canon as a feature of stream erosion antedates the high levels of the lake. Above this, on the north side of the canon, there are three small terraces, doubtless again essentially stream built, but also as argued above, representing closely levels of lake Superior. They were found to have the following elevations by our measurements, viz.: 221.8 feet (XVIII), 256.4 feet (XX), 288.1 feet XXI.

Series 28—Pie Island—The "Pie" of Pie island is a magnificent example of the *mesa* topography which is so characteristic of Thunder bay scenery. A roughly circular area of columnar trap, the remnant of a once extensive sheet, lies horizontally upon the flat Animikie slates. The edge of the trap, together with that portion of the slate which intervenes between it and the summit of the talus, presents vertical walls several hundred feet high. The top of the "Pie" is about 850 feet above the lake. This mesa was surrounded by waters of the lake at its higher stages beyond the general upper limit of the talus, and it is doubtless encircled by corresponding beaches and terraces on the slopes beneath the timber. There are strong suggestions of such features which even the timber cannot obscure. On the west side of the island the ground has been cleared and cultivated, and here on Mr. Keefer's ranch some of the strand lines stand out clearly and attract the eye at a distance of many miles. There are three of them which were sufficiently distinct at close quarters to permit of precise location. The highest of these is a broad terrace abutting upon the talus of the "Pie." It has the form of a great spit, the rear of which is 221.5 feet (XVIII) above the lake. It seems to be essentially a current-built structure, and there is no wave-built beach at its highest part, the material of the terrace being mostly fine gravel and broken shale. The crest or axial line of the spit, however, slopes downward or lakeward and seems to have been a salient of the shore line at various lower stages, at which its construction was continued, and upon the sides of which true beaches were thrown up. The profile, both along the axial line and transverse to it, is undulatory while regularly descending. Among several somewhat vaguely defined beaches which contour this complexly built spit, there is one very fine shingle beach which leaves nothing to be desired in the perfection of its form, its linear continuity, and its state of preservation. The crest of this beach was found to be 136.5 feet (XII) above the lake by our levels.

The third strand line is a broad terrace which along the line of our measurement abuts against a talus of great angular blocks of trap. Here it has an elevation of 43.5 feet (V) and slopes away from this altitude, without any marked break, to the low cliff above the present shore, in the vicinity of Mr. Keefer's house. More patient examination of the talus slopes of Pie island where the timber is thin, would doubtless reveal many other strands.

*Series 29.—Brulé Point.**—There is but one strand in this series, the coast being comparatively low. It consists of a well defined shingle and pebble beach in a small bay on the west side of the point. The crest of the beach was found to be 34.7 feet (IV)

*By an error printed Brulé *river* in the table.

above the lake. This beach seems to be correlative with a broad terrace which extends far inland and which could not in the time given to the inquiry be discriminated from the plain of Kaministiquia delta. This delta has been developed at various successively lower stages of the lake and would require careful and very critical examination in order to win from it any record of definite and prolonged stages of its base level.

Series 30.–Kaministiquia.—At the higher stages of lake Superior a large stream swept down the valley of the present Kaministiquia. At Kaministiquia station on the Canadian Pacific, this valley is constricted by the approximation of rocky hills which rise nearly 500 feet above the level of the railway at this point. Immediately below the station the valley begins to open out and continues wide and open to lake Superior. This narrow place in the valley seems to have been the head of the delta plain of the ancient stream. There is a gravel pit close to the railway station which reveals gravel and sand in false bedded attitudes. The pit presents a section of a very extensive terrace which appears to be the remnant of the old delta plain. This terrace adheres to the east side of the valley, the river in cutting its way down through it in pursuit of its steadily lowering base level having clung to the west side of the valley. But with such an open valley it seems probable that the waters of the lake which conditioned the apex of the delta were not far distant and that the level of the terrace at its abutment against the rocky slopes of the cañon indicate approximately the maximum figures for an altitude of one stage of the lake. The level of the terrace was found to be 455.1 feet above lake Superior. It is placed in the table as indicating a distinct stage of the lake (XXVIII) with considerable hesitation. It is not improbable that it should more properly be correlated with strand line XXVII.

Series 31.—Port Arthur.—In this series are some of the most beautiful terraces which have been noted among the strand lines of the north side of lake Superior. The series is also unique in comprising a well developed "*hooked spit.*" The effect of the terraces is strongly accentuated by the culture which has been imposed upon them. They are seen to best advantage, perhaps, within the town limits of Port Arthur, which is not yet so thickly built up as to obscure their character. [See Pl. IX. Fig. 1.] The lowest terrace is that upon which the business portion of the town is built. Its rear ends sharply at the base of a sea-cliff and was found to have an elevation of 61.4 feet (VI). From this altitude it slopes gently though not quite uniformily to the present shore through a distance in the heart of the town of about a quarter of a mile or less.

FIG. 1. TERRACE IN TOWN OF PORT ARTHUR. STREET ABOUT SIXTY FEET ABOVE THE LAKE. (P. 262.)

FIG. 2. PROFILE OF TERRACES AT BACK OF THUNDER CAPE. FROM SAWYER'S BAY. (P. 199.)

The next terrace is that upon which stands several of the churches of the town, the court house, and many of the more prominent residences. It has a very sharp brink at the upper limit of the sea-cliff above referred to and is on an average less than half as wide as the terrace below it. Its rear is also remarkably sharp in its abutment upon its limiting sea-cliff. This sea-cliff is for the most part composed of the loose material of an earlier embankment, but in one place it is a precipitous wall of rock. The rear of this terrace was found by our levels to have an altitude of 89.8 feet (VIII). Above this are two remnants of higher terraces, one at 95.7 feet (IX) and the other at 118.4 feet (X), which, though narrow and not so sharply defined as the lower ones, appear as quite sharp and distinct lines when viewed from a distance. There is still another narrow terrace at 148.8 feet (XIII) which is rather illy defined and is not noticeable at a distance.

At the brink of the hill behind the town a little to the south of the Dawson road is a gravel pit which affords an admirable section of a beach. The beach crest runs out from a shoulder of the hill at the entrance to the valley of the Kaministiquia. The beach has been a spit which tended to continue its growth in the direction of the shore line from whence it received its material and so attempted to span the valley. Its extremity was, however, soon swung around so as to point up the valley, or bay as it was at the stage of the lake. In this way the characteristic form of a "hook" was developed and the form is perfectly preserved. The spit beach is somewhat remarkable for the number of large boulders which are strewn over its surface, while its section in the gravel pit shows it to be chiefly made up of comparatively fine gravel. The crest of the beach, at a point close to the base of the spit is 170.1 feet above the lake (XV). Its extent indicates a long continued stage of the lake.

Series 32—McKenzie—From McKenzie station, about 14 miles east of Port Arthur on the Canadian Pacific railway, a series of terraces can be seen scoring the hills to the north at a distance of probably a little more than a mile and a half to the farthest. An effort was made to locate these terraces by running a line of levels from the railway, but this only met with partial success. The terraces which appeared so sharp and unequivocal from the railway station lost their character when approached closely, and could only be recognized as terraces with considerable doubt. Some of these terraces, also, were of so remarkable a character that although figures for their elevations were obtained, they could not without more critical study be identified as strand lines of lake

Superior. Indeed only the broad sandy terraces immediately to the north of the railway, the lowest of the series, was found to possess sufficient of the character and definition of shore topography to warrant its being regarded as a strand. And even here the question had to be carefully considered whether it was not a flood-plain of the stream which traverses it, and the cliff at its rear a stream cliff. The material of which the terrace is composed, a stratified sand, seemed to indicate that it was not a flood-plain, but the bottom of a shallow bay of the lake, which the configuration of the hills suggests. Sections of the plain are well revealed in the cuttings and sand pits at McKenzie. This plain was found to be susceptible of very precise measurement. At McKenzie station it is 320.4 feet above the lake, and at its rear along the base of the cliff nearly a half a mile distant, it has an elevation of 326.8 feet (XXIII.) Above this are two shelf-like portions of the profile which suggest terraces, but the smallness of the one and the irregular surface of the other, render them doubtful as features due to shore action. The elevations of these are respectively 347 feet and 379 feet above the lake. Still higher is a much more distinct terrace at 420 feet above the lake, which would be interpreted as a wave-cut terrace were it not that, at its rear part, immediately in front of the cliff which rises above it, there are several very remarkable pits or kettle holes without apparent drainage outlet. The kettle holes have clearly originated after the development of the plain of the terrace. The pits were 15 feet to 20 feet deep, and irregularly funnel-shaped, and could apparently have been formed only by local subsidence of the ground. About 40 feet above this terrace, ascending the cliff at its rear, we come upon the brink of a much more extensive terrace-plain which is also backed by apparent sea-cliffs. The front of this terrace has an elevation of 460 feet, and its rear 497 feet with a slope of 37 feet in about a half a mile. When viewed on a level the plain presents a uniform, apparently flat surface. Immediately that the eye rises above it, however, it is discovered to be pitted over its entire extent by kettle holes which are similar to those noted on the plain below, but which are much larger and relatively to the area much more numerous. In many cases two pits are so close together that the narrow ridge separating them is quite wedge-like and has frequently broken down. The pits are so numerous that it is not practicable to traverse the plain in any direction in a straight line, but only to wind in and out on the narrow remnants of the original plain which are left between the pits. The sides of the pits are in many cases as steep as the material can lie. The material is morainic in character and contains numerous huge boulders. In some cases these large boulders were conspicuous features in the narrow bottoms of the pits. Here again the only suggestion that could be obtained after traversing the plain several times was that the pits were posterior in their origin to that of the plain. Above this remarkable pitted plain is another important terrace also composed of coarse morainic material, but not apparently pitted so far as observations could be made. This terrace is thickly wooded while the lower ground is burned off. On account of the brush it could not be examined easily, but it appeared to slope toward the rocky hillside of the valley, and although this appearance was not verified, it suggested, when taken into connection with the character of the material of which it was composed, the possibility that the feature was a true morainic terrace.*

A definite explanation of the mode of development of these interesting terraces is not possible from the scant study which the writer was able to give them. He can only commend them to students of topographic forms as an interesting field for study which is easily accessible. A tentative suggestion may, however, be not out of place. These terraces occupy the sides of a valley which was unquestionably filled with the continental ice sheet. As the front of the sheet receded this valley was very probably occupied by an ice current running out from the general body of the glacier, or it may possibly have been occupied still later by a local alpine glacier. The configuration of the hills would favor such a possibility. Students of the kettle moraine have come to the conclusion that the kettle-holes of that region have been formed by the burial of masses of ice within the moraine which afterward melted and caused the surface to collapse. There is an immense accumulation of morainic material in the valley we are considering. Is it possible that such accumulations contained numerous buried blocks of ice, which continued frozen until after the high stages of the lake had cut broad terraces out of the moraine? If the high stages of the lake followed closely upon the recession of the ice front, it seems not impossible, when we consider the low temperature which lake Superior maintaines even to this day.

Series 33.—East side of Thunder Bay.—The east side of Thunder bay from its upper end to Sawyer's bay presents a very bold and remarkably straight cliff several hundred feet high composed of Keweenian sandstone resting in Animikie slate, both flat bedded

*cf. Gilbert, Lake Bonneville, p. 81.

and in apparent conformity. The cliff is probably originally and genetically a fault scarp. In the face of the cliff there has been cut a distinct shelf or terrace, the rear of which, at the foot of a talus due largely to sub-aerial degradation, was found to be 57.5 feet (VI). The shelf is assumed to be, in part at least, a wave-cut terrace.

A similar terrace is being cut at the present level of the lake, causing the recession of the lower cliff, so that it is apparent that the shelf referred to must have been once wider than it now appears.

Series 34.—Back of Thunder Cape.—At the back of Thunder cape, on the south side of the entrance to Sawyer's bay, there has been preserved a series of wave-cut terraces and sea-cliffs which are of unusual interest for the perfection of their form and for the fact that being situated on a projecting portion of the coast they are revealed in sharp and distinct profile to certain points of view. The profile was photographed and is reproduced in plate IX, figure 2, the view selected being that obtained from the north side of Sawyer's bay. All of these terraces have been cut out of Animikie slates and present very sharp sea-cliffs particularly as regards the lower members of the series, where the cliffs are nearly vertical scarps which can only be scaled at certain favorable localities. The timber has been burnt so that their characters are unobscured. The first four of these terraces have a fairly uniform width which does not vary much from 100 feet, and all have the usual lakeward slope. The figures obtained for the elevations of these, at the base of their limiting sea-cliffs, are respectively 49.6 feet (V), 122 feet (XI), 170 feet (XV) and 261.2 feet (XX). The fifth terrace is smaller and has an elevation of 288.4 feet (XXI). The sixth terrace breaks down in its front part into a broad uneven plain when examined closely, but when viewed from a distance affords the simple profile of a continuous slope. Its altitude is 392.3 feet (XXV). Above this there is still another broad terrace, the rear of which was found to be at a point representing its sharpest features, 482.2 feet. This terrace slopes, however, rather rapidly, is more obscured by timber and could not be definitely recognized as of wave-wrought origin. It was therefore not placed in the table although there is a probability of its being a strand line. At its rear is a talus accumulation from cliffs of trap rock which rise high above it.

Series 35.—Silver Islet.—On the trail from the deserted village at Silver islet to lake Marie Louise an interesting series of beaches may be conveniently examined. The series is chiefly interesting for the great number of beaches which are found within a very limited vertical range. The crest of the present storm beach is 12 feet above the level of the lake. Between this and a beach the crest of which is 39.3 feet above the lake, there are no less than nine distinct well formed shingle beach ridges rising one above another on a gentle slope. The first two of these are somewhat larger and apparently of more importance than the others and are placed in the table at stages II and III, the elevation of their respective crests being 14.7 feet and 20.5 feet. The elevations obtained for the crests of the other shingle ridges are as follows: 21.4 feet, 23.2 feet, 25.9 feet, 26.7 feet, 31 feet, 33.7 feet, and 36.8 feet. If projected on a vertical plane these beaches, eleven in all, would appear closely crowded, but in reality, owing to the gentle slope upon which they have been built, they are spaced horizontally so as to be well individualized and spread over several hundred yards of ground in a direction transverse to their trend.

This portion of the series, only certain dominant members of which have been inserted in the table, clearly indicates a gradual recession of the lake, from the stage at which the 39.3 feet (IV) beach was built down to the present level.

At this level the beaches cease and the next indication of a strand line is a terrace at 59.2 feet (VI) with a low and rather ill-defined cliff at its rear. The next is an isolated beach resting on a rocky slope the crest of which is 89.2 feet (VIII) above the lake on the line of the trail. In ascending the trail we next come upon a beach at 136.7 feet (XII) which is the lowest of a continuous succession of beaches extending for a distance of about 600 feet. The highest has along its crest an elevation of 149.2 feet (XIII). This succession of beach ridges has practically the character of a wave-built terrace with this exception, that the stage of the water has not been constant but has been very slightly lower for each successive ridge of the terrace. From the upper beach of this nearly horizontal succession of beach ridges there is another succession which rises more rapidly and which is fewer in number. The upper member of this succession is a beach the crest of which is 168.2 feet (XV). Here then we have evidence of a gradual recession of the lake from stage XV to stage XII or from 168.2 feet to 136.7 feet. The beach which represents stage XV (168.2 feet) is also the highest point of the trail along that portion of it on which strand lines are observable. In other words, the beach is an old bar beach thrown across the mouth of a channel between two portions of the lake, so that after passing over it, we begin to descend over another succession of beaches. These present the same continuity as on the side first approached and our levels showed, that the rolling profile of beach ridges crowded together, continued from the crest at 168.2 feet to 140.8 feet. In this succession there is one prominent beach larger than the rest which has an altitude of 161.4 feet (XIV). Farther along the trail there is a distinct nearly flat terrace at the base of an escarpment of Keweenian rocks, of which two determinations of altitude at points ¼ mile apart, are 115.9 feet and 116 feet (X). Further along the face of the scarp a small terrace was found with an elevation of 127.4 feet (XI). The trail then passes over a remarkable sandy plain which appears to have been once shallow lake bottom. The plain was found to be about 132 feet above the lake but it is somewhat ridged in places and some sand dunes have been raised above its general surface.

Series 36.—Nipigon.—At some of the higher stages of lake Superior, lake Nipigon and the great lake into which it now drains by a succession of rapids must have had a common level. The present valley connecting the two bodies of water was always narrow and bounded by precipitate hills of rock, in which, however, there may have been notches affording other outlets than the present one. The channel was particularly narrow just where it would have emerged upon the open lake, being from ¼ to ½ mile wide according to the stage of the water. At one of these higher stages (which one is not definitely known but it was certainly over 200 feet higher than the present) a bar was thrown across the mouth of the channel partially or wholly shutting off the basin of lake Helen from that of lake Superior. This bar formed an immense beach which has been cut through by the Canadian Pacific railway just west of the bridge over the Nipigon river and is used as a gravel-pit so that its structure is well revealed. This great gravel beach is unfortunately covered by a dense jungle which renders its investigation extremely difficult. An attempt was made to ascertain its form and carry a line of levels to its crest. But it was soon realized that it was far from simple in its character and that no safe conclusions could be reached without giving the inquiry much more time than was at our disposal. An apparent crest was reached at an altitude of 198.3 feet, but the impression was obtained that probably the bar had been developed at successive stages of the water on the same general lines, and that the figures obtained afforded no reliable information as to any particular long-continued stage of the lake. But while the strand or strands to which the beach itself corresponds was not definitely ascertained, the slopes of the embankment afforded an excellent opportunity for the registration of lower stages of the water. Upon its slopes there are several very distinct wave or current-cut terraces. Some of these face the open lake and record unequivocally a stage of its waters; others face the channel of the Nipigon river and are due rather to current scouring and therefore strictly of the nature of stream terraces; but being in immediate vicinity of the lake with no drop in surface of the water in the short distance which intervened, they represent also stages of the lake, the figures being a little smaller than the corresponding wave-cut terraces would give.

The highest of these flanking terraces is a broad forest covered plain which in the vicinity of the beach embankment, but not at the rear of the terrace, has an elevation of 131.7 feet (XII). The great breadth of this terrace, its flatness, and the fine sandy material of which it is chiefly composed, indicate that it is not a common shore wave cut or wave built terrace. It is a plain of deposition probably of the character of a delta, and yet it probably represents very closely a level of the lake. A few hundred yards behind Nipigon railway station the front of this broad terrace drops abruptly in the form of a sea-cliff at the base of which a sharp but narrow wave-cut terrace having an elevation of 89.8 feet (VIII). This terrace is traceable around the face of the great bar-beach to the vicinity of the Nipigon bridge. Another determination of its elevation obtained at this place gave the figures 89.9 feet. This narrow terrace in turn drops in a low sea-cliff to the terrace flat on which the railway depot stands and over which the track is laid. At its rear it has an elevation of 82.2 feet (VII).

Crossing the railway track and descending the wagon road to the Hudson Bay Co's. port, we cross three cut terraces having respectively the elevations 61.3 feet (VI), 28.4 feet (IV), and 13 feet (II). In addition to these there is a well marked terrace cut out of the slope of the great bar-beach on the lake Helen side of the railway bridge. This has an elevation of 53.3 feet (V).

Series 37—Mazokamah—About half a mile southeast of the mouth of the Mazokamah a high bluff of the Archæan juts out into the lake. On the streamward flank of this bluff there has been revealed by a recent forest fire, a series of remarkably sharp, step-like terraces overlooking Nipigon bay. The terraces, like so many others on this coast, are not cut into the rock, but into an earlier-formed embankment which lies imposed upon the rocky slopes. At the summit of the embankment is a great shingle beach bar at an elevation of 360.6 feet (XXIV) with a lagoon hollow behind it. The origin of this primary embankment is suggested by its proximity to the canon from which Mazokamah river issues. It seems originally to have been an immense embankment which accumulated at the highest stage of the lake registered by the bar referred to. The conditions of coastal topography at this high stage of the water favored such a local accumulation. The stream supplied the boulders, shingle and gravel. The storms distributed them now on this side of the river's discharge and now on that. The portion which was cast to the eastward could not easily recross the mouth of the cañon. Its tendency to move as shore drift far from the point of discharge was effectually checked by the deep water off the jutting shoulder of the bluff. It was, therefore, confined within an open-mouthed bay of smaller extent, and as it accumulated, mantled the rocky slope down into hundreds of feet of water. It is out of this embankment that various later stages of the lake have wrought successive terraces, and at the same time added to its lower slopes. The terraces are generally uniform in character, the widest being about 120 feet and the narrowest about 25 feet, and all are equally sharp. The sea-cliff which rises from the rear of each terrace and extends to the brink of the next higher in the series is, with one exception, of the same character in all cases, and is a straight slope having a declivity somewhat less apparently than the ordinary angle of repose of such material, being probably about 24 degrees. The exception is the cliff between (XVI) 193.1 feet and (XVII) 214.5 feet, which is a rather uneven slope with a much gentler declivity The terraces have thus

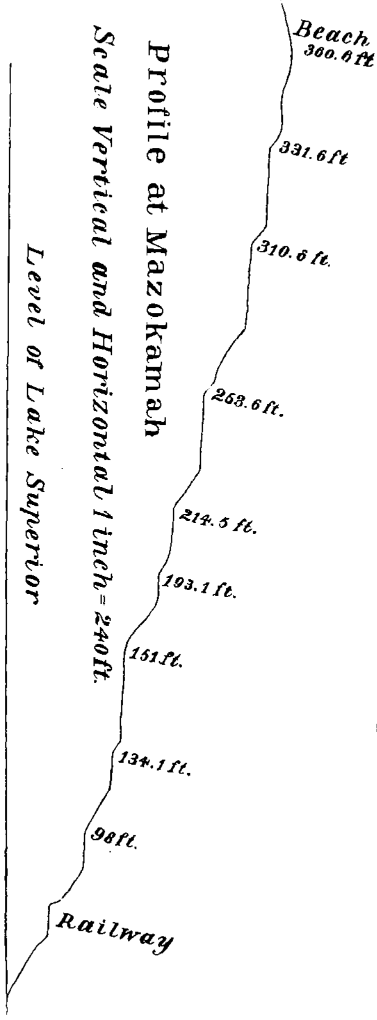


Fig. 11.

the character of the wave-cut type, but while this is their essential character it is very probable that at each stage of the water the Mazokamah river continued to add fresh supplies to the shore drift, so that they are in part also of the character of Gilbert's "cut and build" terrace. The new accessions at each stage being of the same character of material as the embankment in which the cut was being made, it is difficult to distinguish between the cut shelf and its added extension. The vertical distribution of the terrace at this locality is shown in the accompanying diagram. Fig. 11.

Series 38.—Simpson Island.—The terraces of the north side of Simpson island are like those at Mazokamah of the wave-cut type. They have about the same lakeward slope and have similar but steeper cliffs rising from their rears. They present a decided contrast, however, to those on the opposite side of the bay at Mazokamah in the paucity of loose material which they exhibit. The terraces being formed on the side of an island there was no contribution of stream and gravel and the shore drift arising from the waste of cliffs was small in amount. The terraces are essentially cut out of the rock of the island and the vigor with which the cutting proceeded is shown in the steep and in some cases nearly vertical declivity of the sea-cliffs behind them. The rock is a sandstone, rather friable in places, with a distinct bedding and southerly dip at low angles. It is protected above by a heavy trap cap. These characters have favored the cutting of the terraces and the cliffs remain much as the shore action left them, having shed but a small amount of talus since the cutting ceased. The fact that the strata dip south while the cliffs face the north precludes the possibility of an unmodified shelf of rock having been mistaken for a

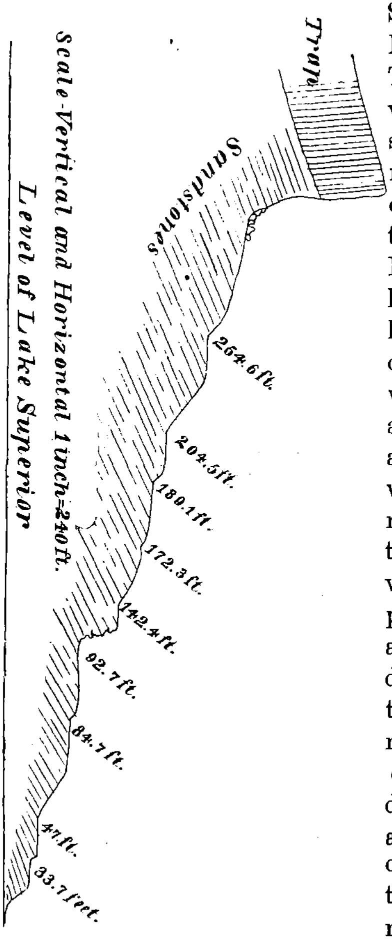


Fig. 12. Profile of north side of Simpson Island.

terrace. The ground has been well burnt of its timber and the terrace slopes are well defined. There is some sandstone and shale-shingle and trap pebbles of local derivation, but these are more abundant on the lower than on the upper terraces so far as the vegetation will permit of observation. The width of the terraces varies from about 25 to 300 feet. The highest terrrace is 254.6 feet above the lake, and at its rear rises a precipice upon which the higher levels have not been registered, or if so, such registration has been obliterated by the undermining action of the Grand Portage stage (XX) of the lake.

Series 39.—Winston's—At Winston's siding half way between Rossport and Schreiber is a heavy but quite local accumulation of coarse delta material which has been opened as a gravel pit. The material has been supplied by a small stream which has probably traversed a moraine, as the material is very heterogeneous. The embankment appears to be essentially of the character of delta, spreading out fan-shaped from the mouth of a little canon, but much modified by wave action. Its upper surface in the vicinity of the pit was found to have an elevation of 210 feet (XVII?) The surface is here gently sloping and the maximum hight was not obtained. The general nature of the embankment was not realized when first examined and its altitude measured, and it was only later when viewed at a distance from the lake that its delta character became apparent.

Series 40.—Schreiber—The railway shops at Schreiber, a divisional point of the Canadian Pacific railway, and the small town which is growing up around them, occupy a perfectly level piece of land less than a square mile in extent in a region where such level tracts are exceedingly "few and far between." This flat is rudely triangular in shape, one side facing lake Superior, the shore of which is two miles distant. On the other two sides it is bounded by bare or scantily wooded rocky hills which rise irregularly to elevations of a few hundred feet within sight of the railway station. On the northwest side of the flat where it abuts upon the rocky slopes, a small rapid stream from the north has cut a deep sharp gorge down to bedrock showing a thickness of detritus which varies according to the uneven character of the rocky floor, but which probably averages over 100 feet. The rocky ridges which bound the two sides of the flat continue lakeward as bold promontories so that the flat occupies an embayment in the hills. The lakeward boundary of the flat is a beautifully defined beach bar which extends across the embayment from ridge to ridge save where it has been cut through by the stream. The ground has

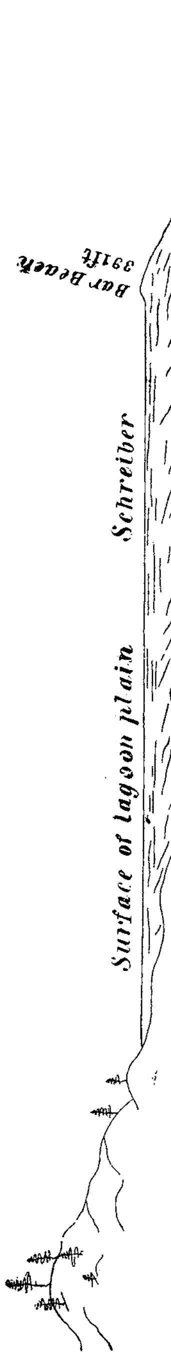


Fig. 13.

Profile at Schreiber Scale, Vertical and Horizontal, 1in.=500ft.

been cleared of the heavy jungle by fire and the characters of the beach bar are not disguised by the thin veil of new growth. The crest of this bar has an altitude of 391 feet above the lake, and on its front it descends rapidly lakeward till it reaches the uneven rocky slope upon which it is imposed. The flat behind it is a filled-in lagoon having a uniform elevation of about three or four feet below the crest of the beach bar. The history of the development of the topographical features thus described cannot be stated in detail from the brief study given to it, but broadly it appears to be as follows: At the higher stages of the lake the stream coming from the hills at the apex of the old embayment dumped its sediment and gravel into the then bay. All but the gravel of the sediment was retained within the bay owing to the deep water off its limiting promontories, and formed a heavy embankment at the bottom of the bay. As this embankment extended lakeward the point of discharge of the stream was apparently carried sufficiently far lakeward to come within the influence of the waves and currents of westerly and southwesterly storms, so that a spit was developed running easterly, which eventually spanned the bay and became a bar. The choking of the first channel of the stream and the filling in to a uniform level of the inclosed lagoon would naturally follow.

Other lower beaches or terraces may possibly be found between this beach bar and the present shore line, but on the trail followed by the writer none were clearly recognized, the country being rough and difficult of inspection.

Series 41.—Terrace bay.—Terrace bay has long been noted for its terraces and their character, as ancient strands of lake Superior were recognized as early as 1847.*

The embayment occupied by Terrace bay is rudely horseshoe-shaped and the hills rise steeply above the bay in a succession of great terrace steps, like a magnificent amphitheatre. These terraces are ideal in their perfection of form, free of timber for the most part, and as sharp in their profile as if they had been constructed of masonry. The embayment seems to have been originally occupied by an immense embankment which spanned the valley, the abundance of the material being due doubtless to the proximity of the early representative of the Black river, which now enters lake Superior a little to the east of Terrace bay. The top of this embankment is a broad well-rounded beach, the crest of which is 392.2 feet (XXV) above the lake. It evidently was a bar beach which separated a deep lagoon from the open lake. It is on the front of this embankment that the terraces have been constructed.

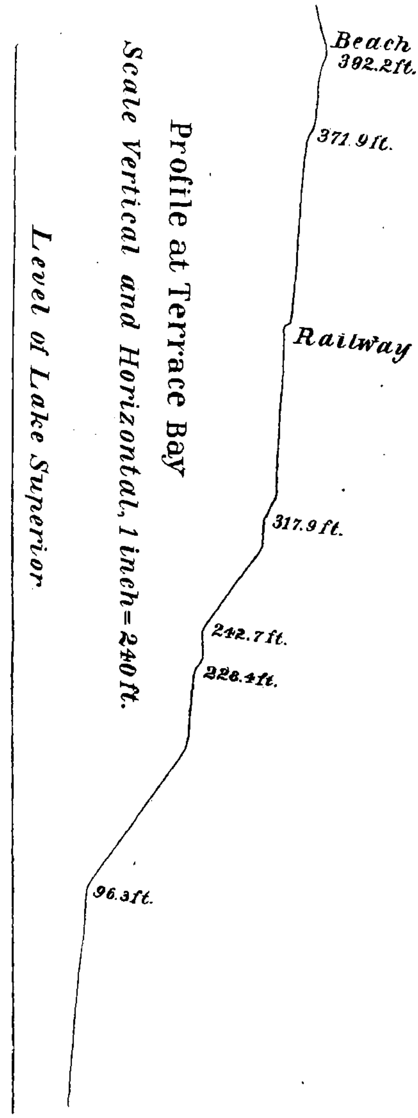


Fig. 14.

The material of the embankment is unconsolidated gravel andpebbles, and the cliffs at the rear of each terrace have the angle of repose of such material, viz., uniformly 34° by measurement. The width of the terrace varies from 1,000 feet to 50 feet. The series

*Logan—Report of Progress, Geological Survey of Canada.

is so simple in its general character that no farther description is necessary. A profile plotted from measurements is given, which it is hoped, will afford some idea of the distinctness of the terraces. The elevations obtained for the rear part of the different terraces are as follows: 96.3 feet (IX), 228.4 feet (XVIII), 242.7 feet (XIX), 317.9 feet (XXII), 371.5 feet (XXIV). The impression which an inspection of the series gives is that, having been developed at different and distinct stages of the water, the subsidence of the lake must have been by great leaps from the level of one terrace to that of the next below. This notion is, however, at once corrected, when it is remembered that the development of one terrace may involve the destruction of many or all of the earlier formed terraces or benches. The number of the terraces is, therefore, no indication whatever of the number of distinct and long-continued stages of the lake. These terraces are essentially wave-cut terraces, but as the supply of material for construction doubtless continued at all stages, to some extent at least, they may in part be current-built terraces. And as the material from the cliffs in process of recession would be the same as the shore drift supplied by neighboring streams, there would be no observable difference between the portion of the terrace which is cut and that which is added to it, and there would be no break in the profile.

Series 42.—Jackfish Bay.—On the east side of Jackfish bay, just south of Jackfish station on the Canadian Pacific railway, there is an embayment in the hills which is now spanned by a railway embankment, which, at its highest part, is about 85 feet above the lake. The upper part of this embayment was, at the highest stage of the lake of which there is here a record, the seat of the accumulation of an immense embankment. The surface of the embankment is apparently flat and no rise could be detected with the spirit level for a distance of an eighth of a mile. It passes under the timber and its full extent was not determined. It appears to be a delta plain of a drainage system which found other outlets as the waters of the lake fell to lower stages. The elevation of this delta plain was found to be 418.3 feet. (XXVI) On the front steep slope of the delta there have been carved two very distinct terraces, both with well-defined steeply sloping sea-cliffs remarkably uniform and intact. The first of these in descending order is about 100 feet wide and at the base of its sea-cliff has an altitude of 391.3 feet (XXV). The second terrace is smaller but no less distinct. Its elevation is 367.2 feet (XXIV). Below the front of this terrace the profile of the surface changes from the step-like character given to it by the terraces to a gentle slope extending to the present shore about a mile distant. On this slope, on which the underlying rock may in places be seen protruding, a great many shingle and gravel beaches have been thrown up at different stages of the lake; and we have here perhaps the fullest representation of the ancient strand lines of the lake that is to be found anywhere on this coast.

The first five of these beaches are distinct from one another being well spaced both vertically and horizontally. Their individuality is no less marked than their general perfection of form, size, and continuity. They are concave lakeward and usually have a distinct depression behind them. The country has been burnt and they are easy of access for purposes of examination.

The figures obtained by our leveling for the crests of these five beaches is as follows: 317.2 feet (XXII), 259.2 feet (XX), 237.9 feet (XIX), 228.5 feet (XVIII), and 175.6 feet (XV). About 6 feet above the last (XV) there is a beach-like ridge which may also be indicative of a distinct stage of the water, but was thought to be a feature of practically the same shore as that at which beach XV was developed. On the lower slope of beach XV there is a narrow terrace which appears to be cut into the higher embankment at an elevation of 157.9 feet (XIII). The ground is somewhat obscure at this place and the fact that it was really a cut terrace and not the incipient form of a wave-built terrace was not clearly established. Continuing down the slope there are well defined and distinctly spaced beaches at elevations for which we obtained the following figures, viz: 135.9 feet (XII.), 127.7 feet (XI an exceptionally large beach), and 119.5 feet (X).

These are followed by a continuous succession of rolling beaches, the highest of which has an elevation of 110.1 feet and the lowest 84.9 feet; of this succession the most prominent are the last mentioned and one at 102.9 feet which are placed in the table as strand lines (VII) and (IX); between these two for a distance of 1200 yards one beach follows another closely. An inspection of the ground leaves little doubt in the mind of the observer but that there was a gradual and comparatively regular recession of the waters of the lake from the stage corresponding to the 110.1 foot beach to that at which the 84.9 foot beach was formed. On the lakeward side of the railway embankment we find another rolling succession of beaches, the figures for the crests of which are as follows: 57.1 feet (VI), 53.8 feet, 51 feet and 46.2 feet (V). These follow one another closely and again indicate a lowering of the water by easy stages. Separated from these by an interval are two lower beaches quite distinct from each other. The first is an embankment of great size at 33.5 feet (IV); and the second is less prominent and has an elevation of 19.2 feet (III). The lowest record is that of a small wave-built terrace 9.8 feet high, the product of the waves of the present stage of the lake and which is an abandoned terrace only as regards its rear portion. Its front is still growing. It is a significant fact that the only horrizontal wave-built terrace in this very full record of shore lines is that of the present strand and suggests that the present stage has been perhaps the most enduring of the many through which the lake has passed. Where conditions for the development of shingle and gravel beaches have been so favorable, it is remarkable that no single stage of the lake should have lasted long enough for the construction of the characteristically rigid wave-built terraces which are seen at some places along the present shore.

Series 43—Three miles east of Jackfish.—Just around the rocky point which defines the limit of Jackfish bay and about three miles or less from Jackfish station may be seen another fine series of strand lines which present a strong contrast to those last described. We have seen that in series 42 the conditions of the embayment favored the growth of beaches and that with the exception of two terraces near the top of the series there are practically no well defined wave-cut terraces. In series 43 just around a jutting ridge of rock which separates the two embayments, we have a fairly full series of strand lines in which there is not a single beach, the whole series being composed of terraces. The embankment in which they are cut is an extensive one in which a large gravel pit has been opened for the railway. Its upper surface is quite flat, so far as could be observed and its entire extent was not investigated. It appears in places to abut sharply against projecting portions of the rocky ridge. It appears to be analogous to the embankment at the head of the Jackfish embayment of series 42. Its elevation is 212.9 feet (XVII). The front of this terrace is limited by the sea-cliff of a lower terrace which has an elevation of 174.5 feet (XV). This terrace is very narrow owing to the recession of the sea-cliff of the next lower terrace which is that upon which the railway track lies. This has a maximum elevation of 111 feet, but the precise rear of the terrace is not susceptible of exact determination, and this figure (111 feet) was considered in the field several feet too high for what is probably the true rear of the terrace. Below this are four well defined cut terraces having the following altitudes, viz: 59.2 feet (VI), 47.3 feet (V), 40 feet (IV) and 16 feet (III). Below this is a great beach which appears to be yet within reach of exceptional storms although its crest is 13.3 feet high. By an error it appears in the table as strand line II.

Series 44.—Dog River.—To the east of the Dog river we have a set of conditions somewhat analogous to those at Terrace bay. At a very early date Dog river was a source of supply for a great mass of shore drift. The prevailing storms have thrown it all to the east side of the river, where at a high level of the lake it accumulated in a great embankment. On the summit of this embankment at a point about three miles east of the mouth of Dog river, a beach was thrown up which separated a shallow lagoon from the open lake. Below this beach on the front of the embankment there have been cut numerous terraces which are well preserved and perfect in form. The crest of the summit beach is 323.4 feet (XXIII). The following elevations were obtained for the rear part of the various terraces in descending order: 314.7 feet (XXII), 255.4 feet (XX), 215.6 feet (XVII), 100.7 feet (IX), 39.7 feet (IV), 16.5 feet (III). A very interesting feature of this series is that the actual process of their development may be observed in progress at the present shore. The cliffs are there actively receding and have a declivity which is the angle of repose of the gravel and sand of which the primary embankment is composed. The recession has gone so far that for a considerable distance the 16.5 foot terrace has been entirely obliterated save at points where it is protected from undermining by a projecting basement of hard rock. A broad sub-aqueous terrace of very gentle slope is being formed and the waves which traverse this shallow shelf being feeble at the shore line, the rear of the terrace where it abuts upon its sea cliff is precisely the level of the lake.

Series 45.—Sand River.—On the south side of the Sand river about a quarter of a mile from its mouth are two terraces the lower of which is very distinct while the upper is somewhat indefinite and hard to recognize on account of large numbers of huge boulders which cumber it. The terraces are composed mostly of boulders and large pebbles brought down by the stream. They flank the rocky walls of the canon in which the stream flows, but their position is clearly conditioned by a former level of the lake, the stream having cut through them as the lake subsided. The levels obtained for these terraces are 75.2 feet (VII) and 118 feet (X).

Series 46.—Montreal River—The Montreal river in its lower stretch is a torrent rushing through a very narrow, high-walled canon whose form is due to structural planes in the granite of the country. This torrent has brought down to the lake a large

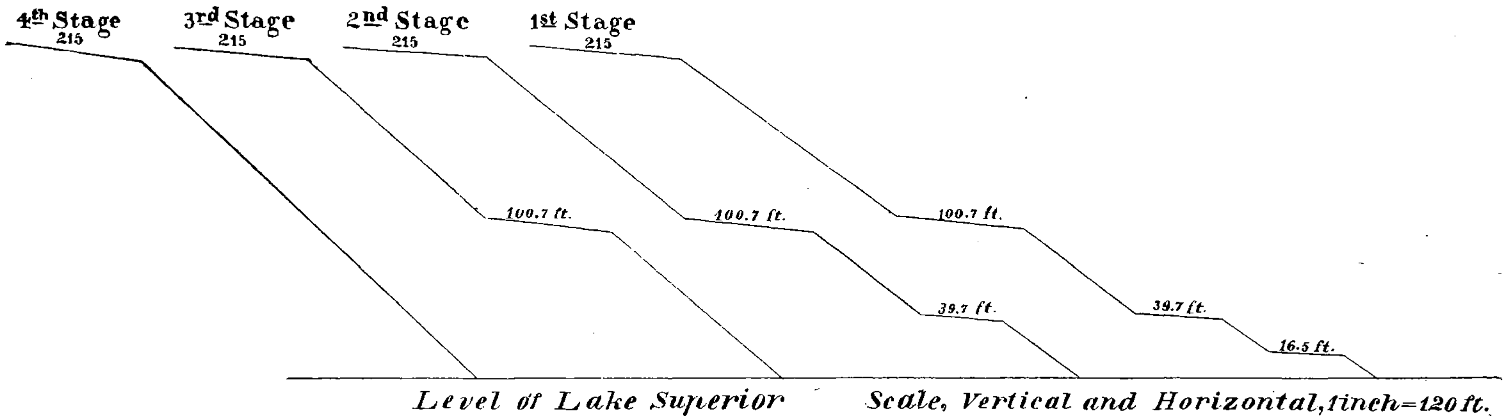


Diagram illustrating obliteration of Terraces east of Dog River

1st Stage shows four actual Terraces.
In the 2nd stage the sea cliff of the present shore has receded till it coincides with the sea cliff of the 16.5 ft. terrace.
In the 3rd stage the same sea cliff has receded till it coincides with that of the 39.7 ft. terrace. In the 4th stage 3 of the four terraces have been obliterated.

Fig. 15.

amount of very coarse material which has been dumped at the mouth of the canon and spread out in the form of a delta. The surface material of the delta consists chiefly of large boulders and angular blocks whose average diameter is perhaps three feet at the mouth of the canon, with masses of less size down to cobble stones farther lakeward. The finer gravel has been carried to the outer edge of the delta and there thrown up into a magnificent beach through which the stream maintains a narrow passage to the lake. This fine bar has its counterpart for an older phase of the stream at an elevation of 211.3 feet (XVII) less than half a mile up the canon and above the edge of its more precipitous part. The bar has the form of a great beach extending across the valley and although covered with timber is easily recognized by its form and by the material of which it is built. This bar beach forms the crest of a great embankment probably much the same in character as that accumulating at the mouth of the present stream. On the front slope of this embankment there have been developed four sharply marked terraces. The upper two of these have elevations of 134.8 feet (XII) and 78.7 feet (VII), respectively, the first being over 100 feet wide and the second not more than 25 feet. Both appear to be essentially wave-cut terraces and have sea-cliffs as steep as the material of which the primary embankment is composed will lie. The lower two terraces have elevations of 61.9 feet (VI) and 45.2 feet (V) and are the surfaces of former deltas which have been cut through by the lowering of the base level. Their proximity to the open lake and their position below the precipitous narrow part of the canon make it clear that their elevation is approximately that of the lake at the stage at which their rear part was built. They have no true sea-cliffs, and they lie below the level of rocky surface upon which the higher embankment with its secondary terraces rests.

Series 47.—Mamainse.—At the deserted mining village of Mamainse three of the ancient shore lines of the lake may be recognized by the usual characteristic features. The lowest of these is a gravel and shingle beach which skirts the back of the old stamp mill. Its crest, where crossed by our levels, is 122.1 feet (XI). The second is a distinct terrace which at its rear was found to be 156.8 feet (XIII). The third is also a terrace, but a somewhat extensive one, the rear of which was not observed. It is an apparently flat gravel plain, thickly timbered, the surface of which, near its brink, is 191 feet above the lake (XVI).

TABLE

Showing the Observed Distribution of Abandoned Terraces and Beaches, on the North Side of Lake Superior between Duluth and Sault Ste Marie.

ELEVATIONS IN FEET ABOVE THE LEVEL OF LAKE SUPERIOR IN 1891.

	1 Duluth West.	2 Duluth, 10th av. E.	3 Hardy's School House.	4 Two Harbors, D. & I. R. Ry.	5 Beaver Bay.	6 Baptism River.	7 Saw-teeth.	8 Carlton Peak.	9 Poplar River, W. side.	10 Poplar River, E. side.	11 Two miles E. of Poplar R.	12 Good Harbor Bay.
I									6.9			
II									12.4			
III					20.1				21.7		17.8	20.0
IV									35.7			27.2
V						49.0			47.9		43.5	
VI												
VII					79.9	83.8	84.5	80.0	74.4	78.4		
VIII												
IX							99.5		97.9	99.6		
X					114.8				113.8	116.		115.3
XI					126.0		129.2	125.0				
XII												
XIII												
XIV												
XV					173.0							
XVI												
XVII												
XVIII												
XIX												
XX												
XXI												
XXII					313.9							
XXIII												
XXIV												
XXV												
XXVI												
XXVII		436.2										
XXVIII												
XXIX	475.9	473.0		475.0								
XXX			509.5									
XXXI	534.0	534.8										
XXXII												
XXXIII												

	13 Grand Marais.	14 Kimbal's Creek.	15 Horse Shoe Bay.	16 Double Bay.	17 Grand Portage.	18 Mt. Josephine.	19 Wauswaugoning Bay.	20 Near Birch Island.	21 Pigeon Point.	22 Pigeon River.	23 McKellar's Point.	24 Thompson Island.
I	6.1		11.9					13.6				
II	12.1		17.6		8.6			17.4			8.4	
III						19.9		21.0		18.2		
IV	29.1	28.5	38.6	31.9	37.9						36.3	28.7
V	43.6					43.0	43.7				48.4	45.6
VI	55.9								56.6	60.8		
VII		80.1		85.8	74.7		76.5		75.6		82.2	
VIII											89.7	
IX					103.5						101.4	97.0
X	113.5											
XI	127.3											
XII										134.3	137.6	
XIII												
XIV	162.6			160.5								
XV												
XVI												
XVII												
XVIII					231.8	226.1						
XIX												
XX					254.7							
XXI				278.9								
XXII						313.5						
XXIII												
XXIV												
XXV												
XXVI												
XXVII					439.7							
XXVIII												
XXIX												
XXX						509.5						
XXXI												
XXXII						587.2						
XXXIII						607.3						

	25 Shore opposite Flat Is.	26 Shore above Carp River.	27 Carp River.	28 Pie Island.	29 Brulé River.	30 Kaministiquia.	31 Port Arthur.	32 McKenzie.	33 East Side of Thunder Bay.	34 Back of Thunder Cape.	35 Silver Islet.	36 Nipigon.
I												
II	8.8										14.7	13.0
III											20.5	
IV			33.8		34.7						39.3	28.4
V	45.3		52.1	43.5						49.6		53.3
VI							61.4		57.6		59.2	61.3
VII	86.4		82.1									82.2
VIII							89.8				89.2	89.9
IX	104.9		106.3				95.7					
X							118.4				116.0	
XI		122.5								122.0	127.4	
XII		138.2	139.8	136.5							136.7	131.7
XIII							148.8				149.2	
XIV		164.1									161.4	
XV							170.1			170.0	168.2	
XVI												
XVII												
XVIII			221.8	221.5								
XIX												
XX			256.4							261.2		
XXI			288.1							288.4		
XXII												
XXIII								326.8				
XXIV												
XXV										392.3		
XXVI												
XXVII												
XXVIII						455.1						
XXIX												
XXX												
XXXI												
XXXII												
XXXIII												

	37 Mazokamah.	38 Simson Island.	39 Winston's.	40 Schreiber.	41 Terrace Bay.	42 Jack-fish Bay.	43 Three miles below Jack-fish	44 Dog River.	45 Sand River.	46 Montreal River.	47 Mamainse.	48 Sault Ste Marie.
I												
II						9.8	13.3					
III						19.2	16.0	16.5				
IV		33.7				33.5	40.0	39.7				
V		47.0				46.2	47.3			45.2		49.0
VI						57.1	59.2			61.9		
VII		84.7				84.9			75.2	78.7		
VIII		92.7										
IX	98.0				96.3	102.9		100.7				
X						119.5			118.0			
XI						127.7					122.1	
XII	134.1	142.4				135.9				134.8		
XIII	151.0					157.9					156.8	150.0
XIV												
XV		172.3				175.6	174.5					174.4
XVI	193.1	189.1									191.0	
XVII	214.5	204.5	210.0				212.9	215.6		211.3		207.6
XVIII					228.4	228.5						223.9
XIX					242.7	237.9						
XX	253.6	254.6				259.2		255.4				
XXI												
XXII	310.6				317.9	317.2		314.7				311.2
XXIII	331.6							323.4				
XXIV	360.6				371.5	367.2						365.3
XXV				391.0	392.2	391.3						
XXVI						418.3						413.9
XXVII												
XXVIII												
XXIX												
XXX												
XXXI												
XXXII												
XXXIII												

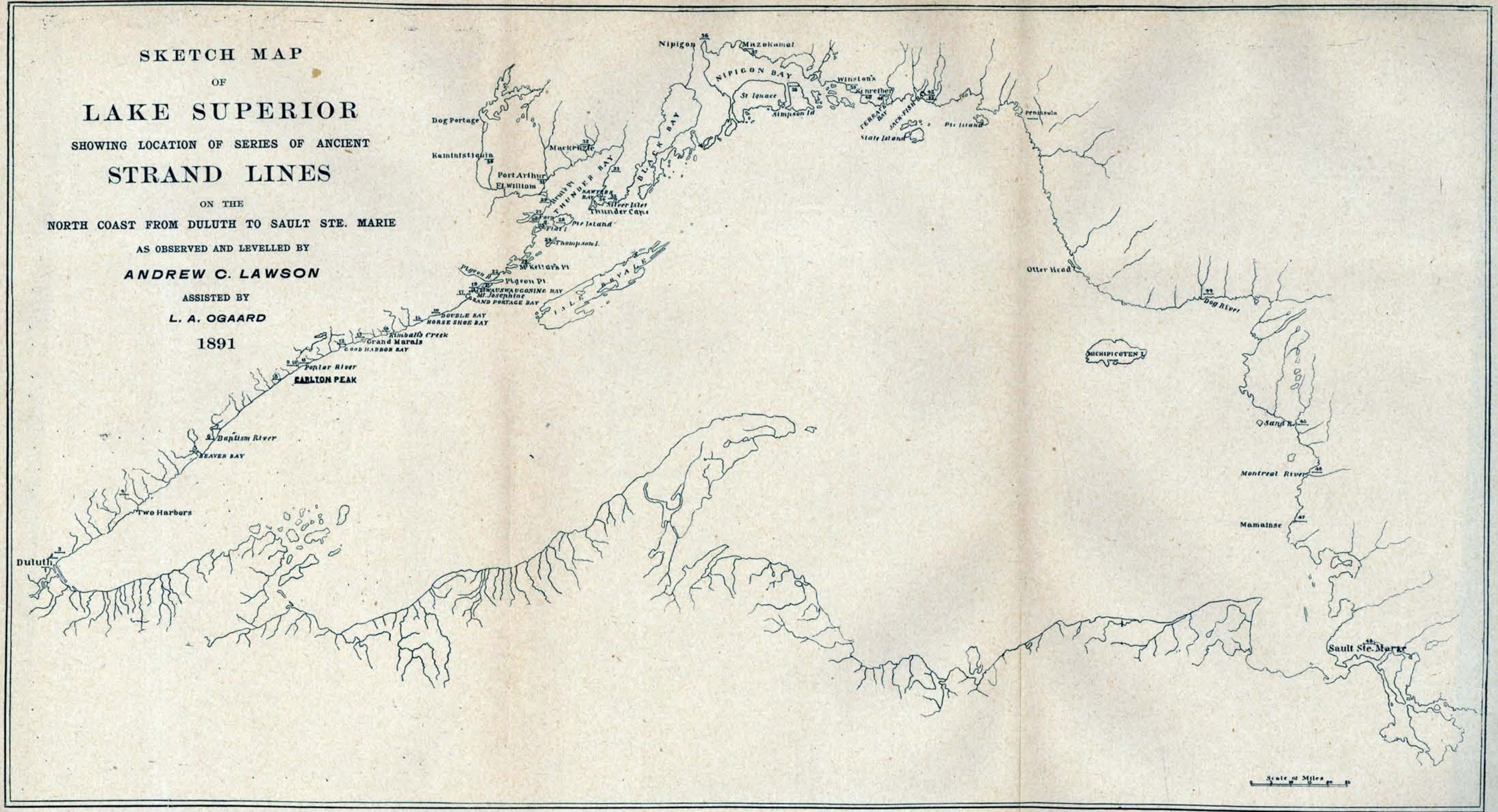
Series 48.—Sault Ste. Marie.—The last of our series of the ancient strand lines of lake Superior is in the vicinity of the present outlet of the lake, and is interesting for its geographical position between lakes Superior and Huron; for the high levels at which the strand lines are observable and for their well-preserved and unequivocal character. The terracing of the hills on the north side of the St. Mary's river is a conspicuous figure of the topography and may be readily examined at many points. The town of Sault Ste. Marie, in Ontario, is, like Port Arthur, built upon terraces. Of those within the town, two are very prominent, and there are suggestions of others. Only the lower of these two terraces has its sea-cliff (possibly stream cliff) within the town limits. The base of the cliff is just north of the line of the Canadian Pacific railway track, and on Pim street, where our levels were run, the rear of the terrace was found to be 49 feet above lake Superior (V). The cliff rises steeply and is composed chiefly of clayey material. The second terrace which extends back from the upper edge of the cliff, is a broad plain, at least a mile in width, and does not appear to have a well-defined cliff at its rear, but to have a sinuous abutment upon a series of low tumultuous hills composed of morainic drift. The altitude of this broad terrace at its rear was not precisely determined although our levels crossed it, but it is probably about 150 feet. These two terraces are distinct from the remaining members of the series which are grouped together farther back on the front part of the hills. They are probably best seen on the Tarentorus road, about four miles from the town of Sault Ste. Marie. Here an immense embankment has been accumulated along the front of the hills in the embayment now occupied by the Root river, which has since cut a deep canon through it. This embankment culminates in a great gravel and shingle beach, the crest of which is 413.9 feet above the lake (XXVI). Immediately below this there is a rolling succession of three benches for which the following elevations were obtained: 403.3 feet, 404.8 feet, and 400.4 feet, the succession indicating a stage of the water somewhat lower than XXVI at which there was a tendency to form a wave-built terrace with a gradually subsiding lake. A few hundred feet down the road we come upon a good terrace, the rear of which is 365.3 feet above the lake (XXIV). On the front part of the terrace is a distinct but low beach, two feet lower than the rear of the terrace. The road then drops to the level of another terrace which is several hundred yards wide and which has an altitude at its rear, where it encircles an island-like mass of rock that projects through it, of 311.2 feet

(XXII). The front of this terrace is the front of the primary embankment of shore drift and there are cut into its steep slope four wave-cut terraces ranging from ten to fifty feet in width, all well defined. The elevations obtained for these, in descending order are, 223.9 feet, (XVIII), 207.6 feet (XVII), 174.4 feet (XV), and 150 feet (XIII).

DISCUSSION OF RESULTS.

The facts set forth in the preceding pages, regarding the hypsometric and geographic distribution of the observed abandoned strands on the coast of lake Superior, suggest many interesting problems which cannot be here entered upon. The information which has been won is but a contribution to an inquiry into a very important chapter in the recent physiographic development of North America. The full inquiry will require the labor of many investigators through many years before entirely satisfactory and invulnerable conclusions are attained. A few preliminary inferences and suggestions, arising from a consideration of the data which has been presented, may here, however, be discussed briefly.

Up to the present point the abandoned strands with which we are concerned in this inquiry have been discussed as topographic features of the *coast* of lake Superior, and they have been alluded to as having been developed at the higher stages of that lake. But a little reflection will make it clear that all but the very lowest of these strands represent stages of a sheet of water which was very different in its general physiography from the present lake Superior. It was many times more extensive than lake Superior, and covered the entire region of the great lakes Huron and Michigan with several hundred feet of water. The extent of this vast lake was probably at least twice as great as the combined areas of the present lakes Superior, Michigan and Huron, or about 150,000 square miles; and these lakes are but the remnants of its waters gathered together in the subordinate depressions of the once greater basin. The Algonquin beach which skirts the coast of lake Huron marks but an episode in the later stages of subsidence of this remarkable sheet of fresh water. For such a lake it would be manifestly incongruous to retain the name lake Superior, and confusion would constantly arise by such a usuage. It is, in fact, scarcely possible to discuss the problems presented without some distinctive name for the immense lake which played so important a röle in the post-glacial physiography of the continent, and of


SKETCH MAP
OF
LAKE SUPERIOR
SHOWING LOCATION OF SERIES OF ANCIENT
STRAND LINES
ON THE
NORTH COAST FROM DULUTH TO SAULT STE. MARIE
AS OBSERVED AND LEVELLED BY
ANDREW C. LAWSON
ASSISTED BY
L. A. OGAARD
1891
Duluth
Two Harbors
Beaver Bay
Baptism River
Carlton Peak
Poplar River
Good Harbor Bay
Grand Marais
Kimball's Creek
Horse Shoe Bay
Double Bay
Grand Portage Bay
Mt. Josephine
Pigeon Pt.
Pigeon R.
Isle Royale
Thompson I.
Pie Island
Thunder Bay
Thunder Cape
Silver Islet
Sawyers Bay
Ft. William
Port Arthur
Kaministiquia
Dog Portage
Mackenzie
Black Bay
Nipigon
Nipigon Bay
St. Ignace
Simpson Id.
Winston's
Terrace Bay
Jack Fish Bay
Slate Island
Pie Island
Peninsula
Otter Head
Dog River
Michipicoten I.
Sand R.
Montreal River
Mamainse
Sault Ste. Marie
Scale of Miles

which the present great lakes are but residual parts. The necessity for such a convenient designation has been anticipated by Spencer, who has suggested for this great lake the name LAKE WARREN.*

By lake Warren, then, will be understood the great sheet of water along whose successive shores were developed the terraces and beaches now apparent on the north coast of lake Superior; and the name will be applicable to this lake from its highest stages down to that stage when its waters became definitely segregated into the different subordinate depressions, and assumed the characters of the present great lakes. The different shore lines of lake Warren may, of course, receive special designations without in any way interfering with the name of the lake itself.

A glance at the table shows that in different parts of the coast of lake Superior the number of observable strand lines varies from one to nineteen; while along very considerable portions of the coast none can be detected. This great discrepancy in the records of the different distinct stages at which the waters of the lake Warren have stood is to be accounted for in different ways. Of course a very large proportion of the discrepancy is only apparent, and is due to the fact that the coast is a timbered country. Were the coastal slope stripped of its timber many of the local series of strand lines would have a much fuller representation than is shown in the table. And in this respect forest fires are coming rapidly to the assistance of the inquiring geologist. If fire continues its destructive work in the future as vigorously as in the past few decades, the record of ancient beaches and terraces will in many places be much fuller than is here given. But apart from gaps in the series due to obscuration of the topography by timber, there are many localities where the topography is well exposed, and all the beaches and terraces present may be accurately determined; and on comparing these with one another very serious differences are at once apparent, even when the localities are not widely separated. These may be due to one or another of two causes. (1) The coastal slope is not equally susceptible of receiving the registration of shore lines at different levels. One portion of the slope may be admirably adapted to the formation of sea-cliffs and embankments, while another portion either above or below may not lend itself to the development of such features. This difference in susceptibility of receiving shore line impressions is due partly to the varying character of the rocks and partly to the general steepness of the coastal slope. (2) A second cause of the lack of con-

*Trans. Roy. Soc. Can., Sec. IV, 1889, p. 122.

cordance between the different series of shore features is that many of them, particularly those which take the form of terraces in preexisting embankments, have been obliterated by wave action operating at lower levels than that at which they were formed, by the process described as now in operation near Dog river.

There is, however, still another important possibility to be considered. There may have been differential movements within the limits of the present lake Superior basin when its outlet was relatively higher than at present. There are two general cases under such a supposition: (1) the differential movement may have been of such a character that a portion of the coast did not change its altitude relatively to the outlet, while another portion did so change; or (2) the entire coast, within the limits named, may have changed its altitude relatively to the outlet, or become inclined. In the first case one shore line in one part of the coast would correspond to more than one shore line in another part, *i. e.*, there would not be in all parts of the coast the same number of abandoned strand lines even if the record were quite complete. But the supposition is a violent one, involving post-glacial faulting or flexure of which there is no evidence whatever. In the second case there would be an equal number of strand lines in all parts of the coast (supposing none were re-submerged) but all would converge upon the outlet if projected on a vertical plane.

In both cases the vertical interval between the same pairs of strand lines in all different parts of the coast would not be constant Moreover, it would be by the merest chance that in the second case the same figures would be obtained for the vertical interval between strand lines in different parts of the coast. If it can be shown that, notwithstanding the actual discrepancies in the different local series, there is a prevailing constancy of interval between strand lines in different localities, we shall not be warranted in assuming that the discrepancies apparent in the table are due to local move mentsat a time when the basin was fuller than now. To be convinced that there is a prevailing constancy of interval one has only to study the table of elevations, bearing in mind the fact, that the elevations given of the ancient shore features of lake Warren may differ a varying number of feet (ordinarily up to ten feet) from the actual water level at which they were formed. In the table will be found many striking coincidences of vertical interval; and the nature of the problem is such, that positive evidence of this character is important, while negative evidence is practically valueless, owing to the fact many conditions may cause apparent discrepancies, while only one set of conditions would favor a constancy of vertical interval between the abandoned strands, viz., *a uniform subsidence of the water along the entire extent of the coast.* Not only is there a prevailing constancy of interval between the abandoned strands, suggesting the correlation implied in the table, but when we compare the intervals between the strands of the various local series and the present level of the lake there is a far more imposing array of coincidences. This becomes apparent in the following table, in the consideration of which it must be again remembered that, if the same features were to be subjected to the same kind of measurement, there would be a maximum discrepancy for the present level of the lake of 15 feet. In addition to this there are possible errors of observation and instrumental errors to be taken into account; so that the maximum discrepancies in the following table are very moderate in extent.

TABLE

Showing the extent of coincidence of the vertical intervals between the level of lake Superior and some of the abandoned strands of lake Warren at various well distributed localities on the coast.

Number of localities.	Maximum and minimum values of the interval in feet.	Maximum discrepancy in feet.
7	17.6- 12.1	5.5
11	21.7- 16.0	5.7
17	40 0- 27.2	12.8
18	53.3- 43.0	10.3
10	61.9- 55.9	6.0
18	86.8- 74.4	12.2
5	92.7- 89.2	3.5
12	106.3- 97.0	9.3
9	119.5-113.5	6.0
9	129.2-122.0	7.2
10	142.4-134.1	8.3
6	157.9-148.8	9.1
4	162.6-160.5	2.1
8	175.6-170.0	5.6
3	193.1-189.1	4.0
7	215.6-204.5	11.1
7	231 8-221.8	10.0
2	142.7-237.9	4.8
7	261.2-253 6	7.6
3	288.4-278.9	9.5
7	313.9-310.6	3.3
3	331.6-323.4	8.2
4	371.5-360.6	10.9
4	392 3-391.0	1.3
2	418.3-413.9	3.4
2	439.7-436.2	3.5
3	475 9-473.0	2.9
2	509.5-509.5	0.0
2	534.8-534.0	0.8

This remarkable coincidence of vertical interval could not be a matter of accident, and it seems to the writer to warrant the correlation of the abandoned strands of the lake as expressed in the table. But if this be granted it also demonstrates another important fact: viz., The lack of local deformation in the strand lines since their abandonment by the subsiding waters of the lake. For it is clear, that if the strands are to be correlated as indicated in the table, they are as perfectly horizontal as when they were functional shores. And in this statement we have a satisfactory, even if unexpected, answer to the question proposed at the outset of the investigation.

It follows from this conclusion, that every distinct altitude occupied anywhere on the coast by a strand line represents a stage of lake Warren. In other words, the total number of observed strands marks the minimum number of distinct stages. There are recorded in the table 33 strands having distinct altitudes. With reference to one of these (XXVIII) there is some doubt as to its representing a stage distinct from one recorded at a lower level. Thus there have been in the history of the recession of the lake at least 32 definite stages. The maximum number recognized in any one locality is 19, so that the minimum defect in the record in the most favored locality is 13, i. e. in the most complete series only 60 per cent. of the minimum complement of shore lines is represented.

So far as can be inferred from a consideration of the observed strand lines, the subsidence of the lake may have been effected by a gradual lowering of the waters, with a definite halt at each of the stages represented by a strand line in the topography of the coast; or the waters may have dropped rapidly from one stage to another. The latter assumption for so large a sheet of water involves so much violence that it is naturally repugnant to the geological mind. The only probable condition which would give rise to a rapid drop in the water of the lake would be the rupture of an ice dam. But, as will be urged in the sequel, ice barriers appear to be ruled out of the problem. Conditions favoring the rapid trenching of soft material, such as morainic dèbris, producing effects similar to the rapid lowering of lake Bonneville, are possible; but in the utter absence of evidence of such action this possibility can scarcely be entertained at present. It seems probable, then, that the lowering of the water has been gradual. But while this is so it does not imply that the subsidence was uniformly gradual; the occurrence of successions of beaches following one another closely on certain of the lower portions of the coastal slope (as has been indicated in earlier pages of this paper) seems to mark a much more gradual subsidence within certain limits of elevation than that which usually obtained. On the other hand, the wide vertical gaps between the strand lines in the higher parts of the coast may indicate a more rapid lowering of the water, or at least less frequent stoppages of the process of subsidence. But owing to the imperfection of the record the evidence is at best only suggestive on this point.

There can be little question but that every one of the many stages of lake Warren had its level determined by a definite outlet, just as the level of lake Superior is conditioned by the overflow at Sault Ste. Marie. The existence of post-glacial beaches and terraces at high levels in the vicinity of Sault Ste. Marie, demonstrates clearly that no ice barrier, spanning the interval between the high ground on the north side of the lake and that on the south side, can be invoked to explain the high level strand lines of the north coast as those of a body of water dammed back by a glacier lobe, and corresponding in geographical extent approximately with the present lake Superior. It was a sheet of water of much vaster proportions; and for such it is entirely reasonable to suppose that epeirogenic movements may have been in progress in one portion of its area and not in others; or that a movement of uniform elevation or depression in one part may have proceeded contemporaneously with local warping in another. Further, since the supposition of an ice barrier at Sault Ste. Marie is out of the question, and since there is no known single gorge of post-glacial age which, by being progressively trenched, would, without crustal warping, account for the lowering of the waters through a range of 600 feet, we seem, so far as our present knowledge serves us, to be forced to assume crustal deformation as the primary means of the lowering of the outlet of the lake. A consideration of the abandoned strand lines of the north coast of lake Superior warrants the conclusion that whatever deformation may have been in progress, the region examined was not locally warped, although it may have been uniformly uplifted or depressed. Thus it seems probable that local warping of the crust, in some region far removed from lake Superior, is accountable for the lowering of the land barrier which held back the waters of lake Warren. The region in which evidence of such changes should be looked for lies to the south and southeast of lakes Michigan and Huron; and the movements which here concern us are probably closely related to those revealed in the warping of the Iroquois and Algonquin shore lines, as described by Gilbert and Spencer. These warpings, however, must represent a late movement in the general process; since the scoring of the Algonquin beach of Spencer is probably only a recent episode in the subsidence of the great sheet of water which embraced all three of the upper lakes.

The general epeirogenic result of the movements which lowered the southern and southeastern barrier of the basin of lake Warren, and caused the registration of the great succession of strand lines now observable on the north coast of lake Superior, seems to have been an absolute and uniform elevation of a large portion of central Canada, including the region about lake Superior, of several hundred feet, and a relative, and probably also an absolute, depression of the region south of the present lakes, embracing the states of Ohio and Indiana. For on the north side of the divide between lake Superior and Hudson's bay, at a distance from lake Superior of from 150 to 200 miles, post-glacial marine deposits occur on Kenogami river at an elevation of 450 feet above the sea, extending thence continuously to the shore of James' bay; and similar post-glacial marine deposits occur on the Missinibi river at an elevation of 300 feet.* Since the occupancy by the sea of these egions north of the divide and the high stages of lake Warren are both clearly post-glacial, we would seem to be warranted in correlating the two events; and also in further correlating the gradual subsidence of lake Warren with the emergence of the Hudson's bay slope from beneath the sea.

If the general supposition be true, that the draining of lake Warren was due to the relative lowering of a land barrier far southeast of the present lake Superior, it seems probable farther that the outlet of this vast sheet of water shifted from time to time in consequence of the continental warping. It would be quite reasonable, also, to suppose that if a southerly land barrier conditioned the high levels of lake Warren, the same barrier may have been high enough at first to determime a northerly drainage of the lake to Hudson's bay. The suggestion that such was the case is strengthened by the following interesting circumstance.

The hight-of-land portage south of Long lake, *i. e.*, the divide between the St. Lawrence system of drainage and that of Hudson's bay, is only about 15 miles distant from the shore of lake Superior. The elevation of this pass is 1,102 feet above the sea,† *i. e.*, it is 500 feet above the present level of lake Superior. The description of the pass by Bell leaves little doubt but that it is the abandoned bed of a large river. Now one of the most heavily marked of the abandoned strand lines of the north coast of lake Superior has a precise altitude of 509 feet. The coincidence is a remarkable one, and it is difficult to resist the conclusion that stage XXX of the lake was determined by the altitude of this pass, the drainage be-

*Bell, Geol. Survey of Canada, Report of Progress, 1871-72, p. 112, and 1875-76, p. 340.
†Upham, Bull. Geol. Soc. Am., Vol. 2, p 263.

ing northward. Mr. Upham, if the writer understands him, regards this pass as an outlet for the southerly drainage of a hypothetical lake, dammed back to the north by a wall of ice; but the writer can find no warrant for Mr. Upham's supposition. It is not improbable that the continental ice sheet was still extensive towards the east at the time that lake Warren stood at stage XXX; and it is possible that a lobe of its southern margin may have reached nearly as far south as Sault Ste. Marie. But it had certainly disappeared from the present coast of the northwestern part of the lake and probably had been sufficiently removed from the region northward to permit of the northerly drainage here suggested.

About 50 miles northeast of Michipicoten harbor is another pass, somewhat lower, at an altitude of 440 feet above lake Superior,* at thedivide south of Missinaibi lake. It is possible that this pass may have been blocked with the ice sheet when the Long lake outlet was open, or it may have been blocked with morainic débris which has been since trenched by stream action. If this pass ever served as an outlet of lake Warren it is doubtless to be correlated with stage XXVI which has so strongly marked a strand line at Sault Ste. Marie.

There are other possible outlets concerning which, for lack of information, it is impossible for the writer to speak definitely. It seems not improbable, for instance, that the valley of the St. Croix river served as an outlet for the overflow of some of the high stages of lake Warren, conveying its waters to the Mississippi. The bed of an old channel at the lowest point of the divide between Bois Brulé and St. Croix rivers is described by Upham, who gives the elevation as 468 feet above lake Superior.† This seems to correspond well with strand XXIX of lake Warren, which, at Duluth, has an elevation of about 475 feet. There are possibilities of another outlet to the same general drainage by way of the Illinois river. The Fort Wayne channel doubtless offered another outlet at a different attitude of the surface and a greater absolute elevation than it now has. The Nipissing depression may possibly have been available at some of the higher stages.

Prof. N. H. Winchell, also, has suggested that there is a former outlet by way of Whitefish valley through Little Bay de Noc.‡

*Upham, op. cit., p. 264.
†Op. cit. p. 258.
‡Am. Jour. Sci., Vol. II. 1871, p. 19.

VI.

DIATOMACEÆ

OF MINNESOTA INTER-GLACIAL PEAT.

BY BENJAMIN W. THOMAS, F. R. M. S.

WITH A LIST OF SPECIES AND SOME NOTES UPON THEM, BY PROF. HAMILTON L. SMITH, M. A., L. L. D. ALSO DIRECTIONS FOR THE PREPARATION AND MOUNTING OF DIATOMACEÆ. BY DR. CHRISTOPHER JOHNSTON AND PROF. H. L. SMITH.

Samples of inter-glacial peat from Blue Earth county, Minnesota, sent by Prof. N. H. Winchell, state geologist of Minnesota, were found to be well filled with the siliceous frustules of over 100 different species of fresh water "Diatomaceæ." The stratum of peat from which the specimens were taken was reported as being overlaid by some twenty-two feet of boulder clay, and as resting upon the same material, but I am not advised as to the extent or thickness of the peat in this interesting deposit. The clay both above and below the peat carried many boulders showing glacial striation and on microscopical examination yielded Foraminifera, Radiolaria, and other marine forms peculiar to Minnesota, and some other western boulder clays, but marine forms were not detected in the peat.

Diatomaceæ constitute a group of microscopic organisms of great interest to the student of natural history. They are a family of confervoid algæ of very peculiar character, and the living forms are found in great numbers in almost all waters that are exposed to the sun and air, forming a brown, or yellowish layer at the bottom of the water, adhering to submerged logs and rocks, or attached to the fronds of the larger algæ. Specimens which contain the living diatoms are of course the most valuable for the proper study of their life history, but the plants are so variable in character and habit that it is difficult to give directions that will in all cases give the best results for collecting and preserving them. Collections should be made of plants growing entirely beneath the water, attached to rocks, piers, logs, etc., or to the larger algæ. The slimier the plants appear, if in water free from sand and mud, the richer will be the harvest, as the brown, or yellowish coating upon the algæ and other submerged objects is frequently but a mass of living Diatomaceæ and the moss-like carpeting upon submerged rocks, is often largely made up of beautiful specimens of the filamentous species.

The growing algae, carefully taken from their attachments, can be thoroughly dried, and each collection carefully placed in separate paper boxes, or wrapped in strong, clean paper, and plainly labeled, giving locality, date of collection, etc., or they may be kept moist in phials or small bottles, with a little creosote added to prevent mould, as recommended by Prof. Smith. When prepared either dry or moist as above suggested they can be carefully laid away for future examination, and the dried material can safely be sent to correspondents by mail or otherwise.

But as many of the most carefully collected and promising specimens prove to be of little or no value it is not only desirable but also a most interesting and profitable study to examine them while fresh from the water.

For this purpose with a pipette take a small quantity of sediment from one of the collecting bottles as soon as possible after its collection, and before creosote or other preservative has been added, put a drop from the pipette onto a microscope slide, place a cover glass over it and with a blotter absorb the surplus water. If the collection is of good material the microscope with a one-fourth inch objective will show an abundance of living diatoms, with their rich and beautifully colored endochrome. Some of the frustules will be connected by *stipes* to the larger algæ, some in *tubes*, others in long ribbon-like *filaments*, while many will exhibit those independent and almost intelligent movements that so nearly resemble animal life, and which has caused and is yet causing much discussion among scientists.

The individual cells of the Diatomaceæ containing the protoplastic endochrome are called *frustules* and have an external coating of nearly pure silica, which consists of two portions or *valves*, which are connected at their margins by hoops or bands of variable widths forming a minute box. These siliceous shells or frustules occur in a great variety of beautiful and symmetrical forms, and the valves, or main surfaces of the frustules, are generally richly carved and sculptured, and under the microscope show striæ pinules, ribs, cells, knobs, bosses, etc., in almost innumerable variety and combinations, and some of the species when properly prepared and mounted are the best known tests of the resolving power of microscope objectives. The valves of one well known species that is quite abundant in most of our western waters, the Amphipleura pellucida, show at the rate of 90,000 to 100,000 lines or striæ to the inch.

DIATOMACEÆ are undoubtedly of comparatively recent geological age, and I find no reliable authority of their having been found below the TERTIARY, although unverified claims have recently been made of the finding of their siliceous remains in the coal formations.

The fossil remains of DIATOMACEÆ abound in the vast sub-plutonic and other strata on the Pacific coast of North America, which exhibit both fresh water and marine species, though rarely in a mixed state. In most of the deposits the predominating species present indicate the character of the water, and the climatic influences under which they were accumulated; different species or groups of species, usually appearing in fresh, brackish, or salt water, and in seas, lakes, rivers and marshes.

While a majority of the fossil diatomaceous deposits hitherto discovered are of fresh water origin, by far the most extensive are marine, and some of them spread over large areas. One of the most important stratums of this character in North America is considered as belonging to the Miocene-Tertiary, and is on or near the Atlantic coast, and is largely in the states of New Jersey, Maryland and Virginia. The principal deposits in Maryland commence at about sixteen feet above tide water, and are covered with four to twelve feet of earth. They then dip below tide water until at Fortress Monroe they are from 200 to 400 feet below the surface, and from an artesian well at Atlantic City, N. J., fossil diatomaceous material containing several new and beautiful species has recently been secured from depths respectively of 406, 510, 535, 550 and 628 feet below the surface.

The extent of some deposits of fossil Diatomaceæ and the vast number and variety of forms contained in them, seem almost incredible, and Dr. Buckland states that the remains of these minute forms have added more to the mass of the exterior crust of the globe than has the bones of animals. Ehrenberg estimated that one of the diatomaceous deposits in Bohemia, covering a large area to an average thickness of some fourteen feet, contained not less than 40,000,000,000 diatoms to the cubic inch, and Mr. Frederick Habershaw, several years ago, published a catalogue of over 4,000 species then known to diatomists.

While the samples of inter-glacial peat submitted for examination were all well filled throughout their entire substance with the siliceous remains of fresh water Diatomaceæ, it is not probable that preparations from the small number of specimens at our disposal, and the consequently small number of slides prepared and submitted to Prof. Smith for examination, will be exhaustive as to the diatomaceous contents of the peat. Accumulations of peat and diatoms, like deposits of more nearly pure diatomaceous material, are probably of very slow growth, and, as is well known to microscopists, the upper layers of a stratum often exhibit different species from those found in the lower, or other parts of the same deposit, which may have been accumulated thousands of years earlier, and under different climatic and other influences, and it is quite probable that a more thorough examination of this very interesting deposit will yield many species which were not on the slides submitted for examination, and consequently are not included in the following very valuable "list of species," and the interesting notes upon them, by that veteran diatomist, Prof. H. L. Smith.

Their value and appropriateness in this connection, fully justifies me in using the paper of Dr. Johnston, with the supplement by Prof. Smith, on the "Preparation and Mounting of Diatomaceæ," which originally appeared in "The Lens,' a journal published by "The State Microscopical Society of Illinois," and which is nearly out of print.

LIST OF SPECIES AND SOME NOTES UPON THEM.

BY PROF. HAMILTON L. SMITH.

The discovery of a peat deposit between two layers of boulder clay in Minnesota, is not only interesting but remarkable, inasmuch as the organisms found in the over and underlying clay are all of marine origin, while those of the deposit, lying between, are not only fresh water forms, similar to those found in the sub-peat deposits of the eastern states, but with one or two exceptions, are forms living at the present time in the great lakes or their tributaries; so that, geologically speaking, the deposit appears to be of very modern origin. While the difference between this and the sub-peat deposits of the eastern states is not very marked, yet a few distinctive species do occur, and will be mentioned in the notes appended to the list, which ally it to the fossil deposits of Oregon, Utah and California, and which, to a practiced eye, would serve to indicate the intermediate position, and to distinguish it from both. How such a deposit, which is certainly of much more recent origin than the boulder clay, came to be thus interposed, is an interesting question,—a question for the geologist to settle. The thickness of the overlying bedvaries from twenty to thirty feet; this, and the lower bed, like theother boulder clays of Minnesota, show, on careful examination, only marine fossils; whereas, as already mentioned, only fresh water and recent forms are found in the peat deposit. At the request of Mr. B. W. Thomas, I have examined a series of slides very carefully prepared by him, and the result will be found in the following list; these are all fresh water diatoms.

The larger diatoms were many of them broken, owing to the character of the deposit, which contained much sand, but the smaller forms were mainly perfect.

The number of species might have been considerably extended if I had followed the example of some of the European diatomists, and affixed *n. sp.* to each form with a slightly varying outline, striation or size. I have in the list, gone to the fullest extent in this direction which I thought allowable; indeed, the number might be somewhat lessened with advantage.

The almost total absence of Surirelleæ Nitzschieæ Pleurosigmæ and Synedreæ, which abound in many eastern deposits, is a characteristic feature, and also the presence in great abundance of spicules of Spongillidæ, and small, flask-shaped bodies; some of these latter are quite smooth and others reticulated or covered with short spines, and all are rigidly siliceous. Ehrenberg classed them with the Infusoria, and even placed them in different families, calling the smooth forms "Trachelomonas," and the hispid or armed ones "Chætotyphila." I have frequently found these in recent gatherings, and they occur quite abundantly in some sub-peat deposits. *e. g.* Wrentham, Mass., and Smithfield, R. I. I give in the list the average length or diameter of the frustules as they occur in this deposit, also references to where figures illustrating the different species may be found, and in the appended notes will be found remarks on most of the species.

HAMILTON L. SMITH.

DIATOMS FOUND IN INTER-GLACIAL PEAT. MINNESOTA.

*Length.	Ref. No.			Author.	Plate.	Fig.
10	1	Achnanthidium..	flexellum, Breb	Van H	XXVI	30
22	2	Amphiprora....	ornata, Bailey	Van H	XXII Bis	5
12	3	Amphora	ovalis, K..	Van H	I	1
40	4	Campylodiscus ..	clypeus, Ehr	Schmt.....	LV	3
9	5	Cocconeis	lineata, Ehr	Van H	XXX	32
5	6	Cyclotella	kutzingiana, Thwaites	Van H ...	XCIV	4-6
25	7	Cymatoplema	hibernica, W. S	S. B. D....	81	a
7	8	Cymbella	aequalis, W. S	Schmt	IX	69
7	9	Cymbella	affinis, K	Van H	II	19
16	10	Cymbella	cistula, Ehr	S. B. D	XXIII	221-a
17	11	Cymbella	cuspidata, K	S. B. D	II	22
17	12	Cymbella	cymbiformis, Ehr.	S. B. D ...	XXIII	220
24	13	Cymbella	ehrenbergii, K	S. B. D	II	21
23	14	Cymbella	gastroides, K	Van H.....	II	9
51	15	Cymbella	lanceolata, Ehr	S. B. D.....	XXIII	219
8	16	Cymbella	parva, W. S.	S. B. D. ...	XXIII	222
10	17	Cymbella	subaequalis, Green	Van H.....	III	2
7	18	Denticula	elegans, K	S. B. D	XLIX	14-15
6	19	Denticula	tenuis	S. B. D.....	XXXIV	293
5	20	Encyonema	caespitosum, K	S. B. D	LV	346-a
9	21	Encyonema	gracile, Ehr	Van H	III	20
22	22	Encyonema	prostratum, Berk	S B. D....	LIV	345-a
12	23	Encyonema	turgidum, Greg	Van H	III	12
7	24	Encyonema	ventricosum, K	Van H	III	16
9	25	Epithemia	alpestris W. S.	S. B. D....	I	7
32	26	Epithemia	gibba, K	Van H	XXXII	1, 2
30	27	Epithemia	granulata, K	S. B. D....	I	3
8	28	Epithemia	ocellata, K	S. B. D....	I	6 a b
14	29	Epithemia	proboscidea, K.-W. S	Van H	XXXI	10
23	30	Epithemia	turgida, Ehr	S. B. D....	I	2
9	31	Eunotia	arcus, Ehr	Van H	XXXIV	2
9	32	Eunotia	arcus var bidens, Gru	Van H	XXXIV	7
15	33	Eunotia	formica, Ehr	Van H	XXXIV	1
7	34	Eunotia	incisa, Greg	Van H	XXXIV	35 a
38	35	Eunotia	major, W. S.—Rab	S. B. D....	XXXIII	286 a
11	36	Eunotia	pectinalis, K	S. B. D.....	XXXII	280 a
3	37	Fragilaria	construens, Ehr	Van H	XLV	26-27
8	38	Fragilaria	virescens, Ralfs	Van H	XLIV	1
5	39	Gomphonema....	abbreviatum, K	Van H ...	XXV	16
14	40	Gomphonema....	acuminatum, Ehr. var. coronata	Van H ...	XXIII	15
20	41	Gomphonema....	brebissonii, K	Van H	XXIII	23
12	42	Gomphonema....	capitatum, Ehr..	Van H	XXIII	7
11	43	Gomphonema...	commutatum, Gru	Van H	XXIV	2
13	44	Gomphonema....	constrictum, Ehr	S. B. D....	XXVIII	236 a
11	45	Gomphonema....	cristatum, Ralfs	S. B. D....	XXVIII	239 a
12	46	Gomphonema....	intricatum, K	Van H	XXIV	28
13	47	Gomphonema....	subtile, Ehr. forma Augusta	Van H	XXIII	14
9	48	Gomphonema....	subtile, var. sagitta, Schuman..	Van H	XXIII	27
7	49	Mastogloia	grivillei, W.S	Van H	IV	20 a
9	50	Mastogloia	smithii, Thwaites	Van H	IV	13
3	51	Melosira	crenulata, K	Van H	LXXXVIII	19
13	52	Melosira	tympanum, Ehr	....	....	....
13	53	Navicula	acuta, W. S	S. B. D....	XVIII	171
13	54	Navicula	ambigua, Ehr	S. B. D....	XVI	149
12	55	Navicula	ambigua, forma craticularis	Van H	XII	6
15	56	Navicula	amphigomphus, Ehr	Van H	XIII	2
13	57	Navicula	amphirhynchus, Ehr	S. B. D....	XVI	142
12	58	Navicula	bacillum, Ehr	Van H	XIII	9
7	59	Navicula	borealis, Ehr.—K	Van H	VI	3
12	60	Navicula	braunii, Green	Van H	VI	21
24	61	Navicula	cuspidata, K	S. B. D....	XVI	131
32	62	Navicula	cuspidata forma craticularis	S. B. D....	IX	67
40	63	Navicula	dactylus forma maxima, Ehr	Van H	V	1
13	64	Navicula	dicephala, Ehr. (pinularia biceps, Greq	M. J., 1856.	I	28
8	65	Navicula	elginehsis, Greg	M. J., 1856.	I	33
20	66	Navicula	firma (Iridis var.), Ehr.—K	Van H.....	XIII	1
6	67	Navicula	frontinalis, Gru	Van H.....	XII	33 b

*Relative length or diameter 1=.0001 inch.

Abbreviations: Van H—Van Heurck's Atlas.
Schmt—A. Schmidt's Atlas.
S. B. D.—Smith's British Diatomaceæ.
M. J.—London Microscopical Journal.

*Length.	Ref. No.			Author.	Plate.	Fig.
18	68	Navicula.........	gastrum, Ehr. (var. styriacea, Gru.)	†D. F. J. L.	A	35
15	69	Navicula.........	hemiptera, Ehr.—K..............	Schmt.....	XLIII	27
15	70	Navicula.........	hitchcockii, Ehr..................	Schmt.....	XLIX	35
13	71	Navicula.........	interrupta, W. S................	S. B. D....	XIX	284
9	72	Navicula.........	laevissima, K. (Staawoneis rectangularis, Greg.)...............	M. J., 1854.	IV	17
14	73	Navicula.......	lata, Breb...	Van H	VI	1
23	74	Navicula.	legumen, Ehr....................	Van H..	VI	16
22	75	Navicula....	limosa, K................	Van H.....	XII	8
15	76	Navicula.........	limosa, var. gibberula, K.	Van H.....	XII	19
12	77	Navicula.........	limosa, var. ventricosa, Ehr.—Donk.........................	....	XII	24
30	78	Navicula....	ludloviana, A. S	Schmt	XLVI	15
37	79	Navicula.........	major, K...	Van H.....	V	3
12	80	Navicula.........	mesolepta, Ehr..................	S. B. D....	XIX	182
12	81	Navicula.........	mesolepta, var. stauroneiformis, Ehr.	Schmt	XLV	53
50	82	Navicula.........	nobilis, Ehr.—K.	Van H.....	V	2
8	83	Navicula.........	slesvicensis. Gru................	Van H.....	VII	29
11	84	Navicula.........	trinodis. Lewis...................	‡	2	6 a
28	85	Navicula.........	viridis. K......................	Van H.....	V	5
10	86	Navicula....... .	viridula, K........................	Van H.....	VII	25
21	87	Navicula.........	vulpina. K.	Van H.....	VII	18
5	88	Navicula.........	winchellina, N. Sp. (nav inflata, Donk.)	§D. B. D,..	III	9
32	89	Nitzschia.........	amphioxys. K.—W. S..............	S. B. D....	XIII	105 c
11	90	Nitzschia.........	thermalis. K...........	Van H.....	LIX	22
31	91	Stauroneis........	acuta, W. S.........	S B. D....	XIX	187
9	92	Stauroneis	anceps, Ehr.....................	S. B D ...	XIX	190
23	93	Stauroneis..	gracilis, Ehr......	S. B. D....	XIX	186
61	94	Stauroneis........	phoenicenteron. Ehr.............	S. B. D....	XIX	185
12	95	Stauroneis........	punctata, K—Ehr...............	S. B. D....	XIX	189
40	96	Surirella.........	crenulata, Ehr..........	.....	....	
56	97	Surirella.........	splendida. Ehr..................	S. B. D....	VIII	62
80	98	Synedra..........	capitata, Ehr.....................	S. B. D....	XII	93
100	99	Synedra	longissima, W. S. ?...............	S. B. D....	XII	95
12	100	Tabellaria.	fenestrata, K	S. B. D....	XLIII	317 a

*Relative length or diameter 1=.000 1 inch.
Abbreviations: Van H—Van Heurck's Atlas.
Schmt—A. Schmidt's Atlas.
S. B. D.—Smith's British Diatomaceæ.
M. J.—London Microscopical Journal.
†—Diatomees de Frans Joseph Land.
‡—Notes on new and rare species, 1861.
§—London British Diatomaceæ.

NOTES ON THE SPECIES.

No. 1. Achnanthidium flexellum Breb.=Cocconeis thwaitsii W. Smith. This diatom I found living at Copper Harbor, Lake Superior, and it occurs frequently in fresh water gatherings in the Eastern states. It is flexed in front view (f. v.), has dissimilar valves and a sigmord median line; outline of valve oval, aspect hyaline; not common in the deposit.

No. 2. Amphiprora ornata Bailey. First detected by him in the Croton water, and not uncommon in fresh water streams in the Eastern and Middle states. I have found it in filterings from lakes Erie and Michigan; one gathering from New Jersey has frustules nearly double the normal length. Bailey's figure, from Withlacooche river, Florida, is a rough outline; Mic obs. Smith Cont. 1850, Pl. 2, f. 15. In the list of Croton diatoms he considers it a Paludosa. I have never found it except contorted. The general aspect is hyaline,and the endochrome very delicately colored, and resembling in its arrangement that of a Nitzschia. Not common in the deposit and only broken frustules.

No. 3. Amphora ovalis K. Occurs abundantly in the living form and is cosmopolitan and not uncommon in sub-peat deposits. Ehrenberg describes and figures it as A. gigas in Abb. der Königl. Akad. 1870, from a deposit near Salt lake, Utah, where it is found associated with Surirella crenulata E, our No. 96. Not rare in the deposit.

No. 4. Campylodiscus clypeus E. I found only a few fragments of this diatom in the deposit. It occurs living at Petalume, Cal., and probably may be found in other western localities. I have not observed it in any gatherings from the great lakes.

No. 5. Cocconeis lineata E. Probably a variety of C. placentula, which is found in nearly all fresh water streams and ponds, densely incrusting stems of algæ, leaves of Potamogeton, etc. It is very variable in size; the larger forms are probably sporangial. The valves are generally broadly oval, and unlike: one, the lower, has median line and nodule. Common.

No. 6. Cyclotella kutzingiana. Exceedingly abundant in this deposit and of very variable size. C. meneghiniana is a more undulated form of this, and C. rectangulata is doubtfully distinct. The frustule is undulate in front view, and the valve, in s. v., shows this, especially the larger specimens, by a shaded band across a diameter, or a little one side of a diameter, and it is more or less apparent on all the valves. It is found everywhere living, and is common in almost all sub-peat deposits. Great confusion exists in the species of this genus.

No. 7. Cymatopleura hibernica W. S. This diatom is not very common, though I have found it living in gatherings from lake Erie, and also in fresh water deposits in the Eastern states. It is rare in the Minnesota deposit, and I found no whole frustules.

No. 8. Cymbella aequalis W. S. This pretty little diatom, which resembles a Navicula, is fairly abundant in the deposit. It has somewhat sharper ends than Greville's figure, Ann. & Mag. Nat. Hist. April 1885. Pl. ix, fig. 4. He describes it as having the striæ fine, but not close, and shows them in the figure rather too strongly marked. He found it in a peat deposit. It does not occur very frequently in the U. S., nor do I recollect ever meeting with it in gatherings from the great lakes. It occurs, however, fairly abundant near Richmond, Va.

No. 9. Cymbella affinis K. A small form, common, but not abundant in this deposit. The Cymbelleæ are generally present in all our sub-peat deposits, and occur extensively in the living condition in almost all fresh water gatherings. The distinction formerly made into Cocconema and Cymbella, based on the presence of a stalk or stipe for the former, is now properly abandoned; though Encyonema, generally found in the living condition in tubes, and which otherwise would fall into this genius, is yet retained. There is much confusion among these smaller forms of Cymbelleæ. Thus, I have specimens marked by Brebisson as C. affinis, which are C. ventricosa K.=Encyonema ventricosum, which is also C. ventricosa of Ag. Rut. Diat. Ex. No. 24, and given by Rabenhorst as a brackish species. C. affinis has a curved median line, extending to the extremities of the valve, while that of the Encyonemeæ is straight, or very nearly so.

No. 10. Cymbella cistula E.=Cocconema W. S. This diatom occurs plentifully in the deposit. It is distinguished from C. cymbiformis by being more bent or curved on the ventral margin of the valve, and also distinctly inflated. How far these can be accepted as specific characters is questionable. It is not difficult to find many intermediate specimens.

No 11. Cymbella cuspidata K. Common in this deposit, and varying considerably in size and distinctness of the produced ends. It is allied to No. 13, from which, however, it differs in its smaller size and finer striation. Both these forms are common in fossil deposits and in recent gatherings.

No. 12. Cymbella cymbiformis E. Common, and doubtfully distinct from No. 10, from which it differs only in wanting nearly or quite the inflation on the ventral margin of the valve, and in being much less curved. The striation is about the same.

No. 13. Cymbella ehrenbergii K. A large and fine species, distinguished from No. 11 by its much coarser striation and larger size, as well as sharper ends. It is not rare in this deposit.

No. 14. Cymbella gastroides K. This, and probably numerous other species, constituted by Grunow, Kutzing and Ehrenberg, on slight differences of form or size, is probably but a variety of No. 15. It is not common in this deposit and is distinguished mainly by its blunt ends. C. stomatophora Grun., which is a variety of this diatom, occurs living in the great lakes, and numerous varieties of this and the other Cymbellæ occur in nearly all our sub-peat deposits.

No. 15. Cymbella lanceolata=Cocconema W. S. This form, well figured in S. B. D. Pl. 23, fig. 219, is the same as the typical slide of C. gastroides, Eulensteins series No. 93. It is the largest of the Cymbelleæ found in this gathering, and is pretty abundant, though the frustules are mostly broken. It differs in size and coarser (moniliform) striation, from Nos. 10, 12 and 14, and may be a sporangial form.

No. 16. C., parva I have found conjugating, and the sporangial frustules were C. cymbiformis, and as in the case of Nav. amphigomphus, I have actually found the sporangial forms, (and in the same gathering) conjugating and producing the largest frustules, N. iridis. It is quite possible that these larger forms now designated C. lanceolata, and C. gastroides, may be sporangial forms of C. cymbiformis or C. cistula, and that Nos. 10, 12, 13, 14, 15 and 16 are but one species. C. parva is common in this deposit.

No. 17. Cymbella subaequalis Grun. Not common in the deposit, nor have I observed it in any other of the sub-peat deposits, or recent gatherings. Its occurrence therefore though rare in this particular deposit, is interesting. The figure given by Van Heurcks, atlas Pl. III fig. 2 is a good representation from specimens found at Brussels. The valve is naviculoid with blunt ends, and distinctly striated.

No. 18. Denticula elegans K.=D. ocellata W. S.; rather rare in this deposit. It is distinguished by the rounded ends of the valves; and the strong pervious transverse costae or ribs, give it the ocellated appearance, which distinguishes it from other species. This form, and the next, with many of the Epithemiae, abounds in the thermal waters of the National Park.

No. 19. Denticula tenuis K. More abundant than the preceding, but not common. It is frequently found in ordinary fresh water gatherings; striation quite conspicuous.

No. 20. Encyonema cæspitosum K. A marked character of this genus, which after all, is but Cymbella living in tubes, while the Cocconemeae slip out and the contracted tube forms a stipe, is this, viz, the median line in the other forms, terminates in the ends of the valves, while in Encyonema, it is nearly straight and terminates within the convex margin of the valves. This is a very conspicuous feature in the larger form, but may be noted also even in the smaller forms like the present one, which is tolerably abundant in the deposit. It is a common recent form.

No. 21. Encyonema gracile E. This is probably the Cymbella scotica W. S. It is a slender and somewhat longer form than the preceding, and more delicately striate and with sharper ends; it is pretty abundant in the deposit.

No. 22. Encyonema prostratum Berk. This is the largest and most robust form, coarsely moniliform striate, and exhibiting in a marked manner the peculiar features of the median line already alluded to. It is not abundant in this deposit, nor indeed in any of our sub-peat deposits. It is not uncommon in recent gatherings.

No. 23. Encyonema turgidum Gregory. This diatom is common in the deposit; it has sharp ends, and is coarsely moniliform striate.

No. 24. Encyonema ventricosum K. Smaller than the preceding; the ends are slightly produced; it is C. affinis of Bret., and C. ventricosa Ag. It is very variable in size; some frustules are smaller than those of No 20, but unlike these latter, they are almost straight on the vertical margin—abundant.

No. 25. Epithemia alpestris, W. S. This is, no doubt, a variety of No. 28, and also E. argus, as already suggested by Dr. Walker-Arnott, Microscopical Journal, Vol. VII, 1859, fig. 174. They are all distinguished in front view by a series of inter-margined ocelli, or foramina, as they are termed by W. S., though they are not openings at all, but siliceous nodules, and from these "eyes" comes the specific name argus. E. alpestris was separated as having produced somewhat recurved extremities, and nearly straight sides in f. v. Not rare in this deposit.

No. 26. Epithemia gibba K. This diatom is not as abundant as the preceding, and the valves are mostly broken. It is quite distinct from the other Epithemiae, for while these latter are adherent by the concave margin of the frustule, to the stems of confervæ, in the living condition; Epithemia gibba adheres by one end. It is further distinguished by the absence of granules on the valves, as in the other species.

No. 27. Epithemia granulata K. This form is perhaps the most abundant of the Epithemiae in the deposit, and is characterized by its long arched valves and slightly produced ends; and it appears to be somewhat more finely striated and granulated than No. 30, of which, however, it may be a variety.

No. 28. Epithemia ocellata K. The inflated frustules and blunt, not produced ends, served to separate this from No. 25. As already remarked these are features of doubtful specific value. This diatom is much less common in the deposit than No. 25.

No. 29? Epithemia proboscidea K. There appears to be some doubt about the E. proboscidea of W. S. being this form, as the latter is more coarsely marked and the valves are much more arched, and the ends more produced and recurved. The examination of W. Smith's original specimens shows that it is quite distinct from our present form.

No. 30. Epithemia turgida. This is doubtfully distinct from No. 27. Valves somewhat more arched, and apparently, not really, more coarsely granulated, and the ends are somewhat more recurved. It is not as common in the deposit as No. 27.

No. 31. Eunotia arcus E. This is not the Eunotia arcus W. S. which is a very different diatom, but it is Himandidium arcus W. S., a name given to the species of the genus which cohered after self division, forming a a ribbon or filament of frustules, a character considered now of no specific value. E. arcus is very variable in size and outline, it is generally arched, somewhat more convex on the dorsal margin, and has produced ends; the ventral margin is nearly straight and the valve is transversely and conspicuously striated. It is very abundant in the deposit and occurs plentifully in the many sub-peat deposits.

No. 32. Eunotia arcus var. bidens Grun. This variety is common, and is also, like E. arcus, variable in size.

33. Eunotia formica E. differs from No. 31 in having the ventral or concave margin of the valve, sharply undulated at the middle. It is the Himandidium undulatum of W. S. and is not uncommon in the deposit. It is very variable in size.

No. 34. Eunotia incisa Greg. This is a small form, more delicately striated than the preceding, and is rather abundant in the deposit. It occurrs in gatherings and fossil deposits of high latitudes in great abundance. The valves have a decided little notch near the ends, on the concave or nearly straight margin. This notch is, in the other Eunotiæ, replaced by an inter-marginal nodule.

No. 35. Eunotia major W. S.=Himantidium W. S. It is doubtful whether this is anything more than a large variety of E. arcus. It is abundant in the deposit.

No. 36. Eunotia pectinalis K. This diatom is but a variety of E. arcus. It was called Himandidium pectinale by W. S., and the frustules do adhere very firmly; but it differs in no way from E. arcus except to have the dorsal margin of valve flat, or even slightly indented, and it is generally somewhat smaller. Common.

No. 37. Fragilaria construens=staurosira E.=Odontidium tabellaria W. S. Valves small, hyalin, and inflated, sometimes so small as to resemble a small cross, and not unlike small specimens of Tabellaria flocculosa with which it has been confounded; it occurs in filaments of 5 to 10 frustules in the prepared slides, and is not rare. An abnormal form of this, and found only in a single gathering at Ormsby, Eng., wanting one of the arms of the cross, was called by W. Smith Triceratium exiguum; along with it in the same gathering was an abundance of the normal form with both the inflated and the stauriniform valves. It is not rare in both forms in the Minnesota deposit. The inflated valves are Kutzing's Navicula inflata, K. B. Tab. 3 fig. 36. Odontidium parasiticum W. S.=Fragilaria binodis E. is probably this diatom.

No. 38. Fragilaria virescens. Not rare to the deposit, both the valves with constricted ends and filaments of a few frustules.

No. 39. Gomphonema abbreviatum E. This small form is not uncommon in the deposit, the striæ are marginal, and easily seen; it may be a very small form of No. 43. It is difficult to decide whether this is Kutzing's species.

No. 40. Gomphonema acuminatum E. The Gomphonemæ are quite abundant in this deposit; and intermediate forms, between species constituted by Ehrengberg and many of the continental observers, are not rare. The present form, however, is well marked, quite variable in size, and readily recognized. Nos. 47 and 48 are probably slender varieties of the present diatom.

No. 41. Gopmhonema brebisonii K. This, which is a large, well marked variety of the preceding, and is probably same as G. turris E., occurs in considerable abundance in this deposit. It is a marked variety, and possibly a distinct species. It occurs living in the great lakes and their tributaries, as also all the other forms in this list.

No. 42. Gomphonema capitatum E.=G. elevatum E. This diatom is very abundant in the deposit, and also living in the great lakes. A large variety has been called G. herculeanum by Ehrenberg, and G. oregonicum E. and G. giganteum E. are probably varieties, as also Grunow's G. robustum. It is very variable in size in the deposit.

No. 43. Gomphonema commutatum Grun., occurs abundantly in the deposit. I have not observed it living. It is more conspicuously striated than the smaller forms of the preceding; striæ marginal; it is allied to G. vibrio, and except in the somewhat greater breadth of the valve is not to be distinguished from No. 46.

No. 44. Gomphonema constrictum E. The passage from No. 42 into this form is very easy, the capitate head is more constricted and rounded, and intermediate forms are not rare. It occurs in the deposit about as frequently as G. capitatum and is a common form, living in nearly all fresh waters.

No. 45. Gomphonema cristatum Ralfs. This is an intermediate form between the last and No. 40. Not as frequent in the deposit as the latter and generally smaller.

No. 46. Gomphonema intricatum K. Grunow's G. commutatum is allied to this, and G. hebridense of Gregory is probably the same. The striæ are marginal and the central nodule is almost midway from the ends of the valve, in this respect differing from the normal G. commutatum; but intermediate forms are abundant in the deposit.

No. 47. Gomphonema subtile. This is a very slender form of G. constrictum, and so also is No. 48, and both should be considered as varieties.

No. 49. Mastogloia grevillei W. S. This diatom is somewhat rare in the deposit and, so far as I am aware, has not been found in any other of our fossil deposits, or indeed in any gatherings from the western lakes. It is a small, coarsely-marked form, valves with cuneate ends, and the peculiar inflation figured in the British Diatomaceæ, Supp. pl. LXII, fig. 389*a*, on the under surface of the valves near the ends, is quite apparent. The frustules found in the deposit are all smaller than the original, found at Portland hills by Dr. Greville, but otherwise agreeing completely.

No. 50. Mastogloia smithii W. S. This diatom is rarer than the last in the Minnesota deposit. It is, however, a much more common form in fresh water gatherings. As found in the deposit the valves are somewhat narrower and with sharper ends than the normal form. The loculi are conspicuous and the striation much finer than that of M. grevillei.

No. 51. Melosira crenulata K. The absence of Melosireae from the Minnesota deposit is a marked feature, inasmuch as they constitute the larger portion of many of the Oregon, California and other fossil deposits of the Pacific coast, and they occur abundantly, living in all our fresh waters; but few frustules were found of this diatom. It is probably but a variety of M. nichalcea (orthosira) W. S.

No. 52. Melosira tympanum E.? It is somewhat doubtful whether this is the form described by Ehrenberg as occurring in the fossil deposit, Truckee river, California, but the few valves which I have found agree well with his figures.

No. 53. Navicula acuta W. S. Not very abundant in this deposit though not rare.

No. 54. Navicula ambigua E., rather rare in the deposit; the craticulate form is somewhat more abundant; perhaps this may be owing to the striking character of the latter, which makes it so much more conspicuous. These craticulate forms, arise from the persistence of the sporangial sheath which envelops the frustule. The striation on the valves, can be detected in under this. The ribs on the sheath, are much more pronounced in this form, and in No. 61 to which it is closely allied, than in any other of the Naviculeæ. N. brebissonii perhaps comes nearest, and a new genus Perizonium, was constituted to receive the craticulate variety of this diatom, which was called P. braunii. I have observed these rib-like markings in the sporangial sheaths of N. viridis, but none are so conspicuous as these of N. antiqua and N. cuspidata. The genus Stictodesmis of Greville, appears to be founded upon this character, and I have observed it in a small marine form, no ways differing from antiqua. The resemblance of these craticulate markings to those of Surirella, induced W. Smith, in the Birtish Diatomeceae, to figure and describe our No. 62, as Surirella craticularis.

No. 56. N. amphigomphus E. This is a variety of N. iridis E. with wedge shaped ends. The typical N. iridis is precisely like N. firma, No. 66, but larger. It is not rare in the deposit, and, like all the varieties of N. iridis is finely striate, and shows apparently a few intra-marginal lines parallel with the sides of the valve. All the varieties are common in our sub-peat deposits.

No. 57. Navicula amphirhynchus E. This variety of N. iridis, which scarcely differs from N. producta, is characterised by the produced ends. It is not rare in the deposit. The ends of the valve are blunt and there is a blank space around the central nodule.

No. 58. Navicula bacillum E. This small and somewhat hyaline diatom is not rare in the deposit. The valve has round ends and straight sides, and a distinct median line, with a blank space around the central nodule; striation fine. It occurs in many of the eastern sub-peat deposits. I have not observed it living in any gatherings from the great lakes, but it is abundant in some of the fresh water ponds of the New England states, and in fossil deposits from Sweden and Norway. N. bacillaris, Grey is smaller and more finely marked, and is without the central blank space.

No. 59. Navicula borealis E. K. This small and coarsely marked diatom, N. latestriata of Greg., is usually found among damp mosses on trees; it is not rare in the Minnesota deposit.

No. 60. Navicula braunii Grev. A small form, allied to N. gibba, and tolerably abundant in the deposit; the valve is inflated and has constricted and rounded ends; striæ marginal.

No. 61. Navicula cuspidata K. This fine diatom, which occurs plentifully in recent gatherings and in many sub-peat deposits; is not very common in the Minnesota deposit. The craticutale form appears to be somewhat more plentiful, and is a very striking object, and generally a little larger than the diatom as usually met with. As already remarked under No. 54 this form, our No. 62, was called Surirella craticula by W. Smith. The valves are finely but distinctly striate.

No. 63. Navicula dactylus E. Distinguished from N. iridis by its size and coarser pinnæ, and from N. major and N. nobilis by its straight, not inflated sides. Whether these features warrant a new species is questionable. The distinction into Pinnulariæ and Naviculæ, the former having smooth (apparently) ribs, or pinnae, and the latter striæ made up of fine dots (moniliform), is now abandoned, and all are termed Naviculæ. The species mentioned above are very common in sub-peat deposits and in recent gatherings. The marine forms with smooth ribs are comparatively few.

No 64. Navicula dicephala E. This is the Pinnularia biceps of Gregory, who supposed it new, but this name "biceps" had already been given by Kutzing to a different diatom, and as Ehrenberg has, no doubt, given the name "dicephala" to several entirely different forms, one of which is the "dicephala" of W. Smith and our No. 65, perhaps it would be better to adopt Lagerstedt's name and call the present form N. bicapitata. It is a well marked, though not large form, with straight sides and constricted rounded ends, (not unlike a "rolling pin"), it is dictinctly striate, and is fairly abundant in the deposit.

No. 65. Navicula elginensis Greg. This is the N. dicephala of W. Smith; it is smaller than the preceding, and the valve not unlike it in outline; the sides are generally a little incurved, and there is a peculiarity in the appearance of the central nodule, which at once distinguishes it from No. 64, which has a blank space around the nodule, absent in this form. This striation is rather coarse. It is about as abundant in the deposit as No. 64.

No. 66. Navicula firma. This is a smaller form of N. iridis, and not rare in the deposit.

No. 67. Navicula fontinalis Grun. I am not quite certain that this small diatom, which is very rare in the deposit, is Grunow's species. About a third of the length of the valve, the middle portion is blank, giving the impression of a wide stauros.

No. 68. Navicula gastrum E. var. styriaca Grun. This fine diatom, which is not uncommon in the deposit, reminds one at first glance of Stauroneis punctata. It is, however, larger and much more coarsely marked. The ends are produced in this variety, rather more than in the normal N. gastrum, only one specimen of which I observed in the prepared slides. The striæ are absent from the center, much as in Stauroneis punctata. It is a characteristic form in the deposit, and I do not recollect observing it in any other of the sub-peat deposits, or even in any recent gatherings. The normal form of N. gastrum, as figured by Donkin, has been found by Thomas and Chase in the water supply of the city of Chicago, from lake Michigan.

No. 69. Navicula hemiptera E. Not rare in the deposit; it is a small form, striæ marginal, outline of valve like N. iridis, but somewhat narrow in proportion to length.

No. 70. Navicula hitchcockii E. Quite abundant, and rather larger than those which I have found in the eastern sub-peat deposits, or in recent gatherings. It has a hyaline aspect and is allied to the variety of N. limosa, called "gibberula" by Kutzing. The ends, however, and central inflation, sharper; but it must be confessed, that some small forms of N. gibberula, approximate very closely to it.

No. 71. Navicula interrupta W. S. This is not the N. interrupta of Kutzing, which is only a variety of N. didyma E.; we may, therefore, retain W. Smith's name. Really, this species is a staurineiform variety of our No. 64, and exactly like it in every respect, except the central blank space or stauros which characterizes the present form. It is not so abundant in the deposits as No. 64. Nos. 80 and 81 are similar examples.

No. 72. Navicula laevissima K, Stauroneis rectangularis Gregory. A smaller form than N. bacillum, to which it has a remote resemblance, but the margins of the valves are slightly undulate and the striation somewhat coarser, and instead of the circular central blank space there is an arangement of the central striae giving the impression of a sort of stauros. It is fairly abundant in the deposit.

No. 73. Navicula lata Breb. This diatom is somewhat rare in the deposit, and at once recognized by the very course and distant pinnae; N. borealis is probably a very small variety. I have not observed it in any recent gatherings, but it is found in some of the fossil sub-peat deposits of New England.

No. 74. Navicula legumen E. This fine diatom is also rare in the deposit. The valve has three distinct undulations and rounded ends; the striæ are radiate, not reaching the median line, and there is a large central blank space, or pseudo-stauros around the central nodule.

No. 75. Navicula limosa K. This, and its varieties are common in the deposit. It belongs to the N. iridis group, and is distinguished by the inflation at the middle of the valve.

No. 76. Is a variety of the preceding, with smaller and sharper ends and somewhat deeper constirctions.

No. 77. Navicula ventricosa E.—Donk. Smaller than N. limosa, and less inflated, the sides of the valves are nearly straight; it is characterized by having a transverse blank space around the central nodule, and is not as common as Nos. 75 and 76.

No. 78. Navicula ludloviana A. S. This fine diatom has a resemblance to N. peregrina, which, however, is a marine species; it is characteristic of the Minnesota deposit. It is about the size of N. peregrina, but has a larger blank space at the central nodule. It is found in fossil deposits at Shasta, California, and is figured in Schmidt's Atlas; striae radiate conspicuous and not reaching the medium line.

No. 79. Navicula major K. A large form pretty abundant in the deposit, and differing from N. iridis and N. dactylus by having the valve inflated at the middle.

No. 80. Navicula mesolepta E. This is fairly abundant in the deposit. It has three central inflations and is deeply constricted towards the obtuse extremities. It is N. nodosa, E., a form confounded sometimes with N. legumen, and the latter may possibly be a sporangial form of this diatom.

No. 81. Navicula mesolepta var stauriniformis E. Exactly like No. 80, with the exception that this variety has a distinct central blank (stauros). It is not quite as common in the deposit as No. 80.

No. 82. Navicula nobilis E. K. This is a very large form of N. major, and not rare in the deposit, though the frustules are generally broken.

No. 83. Navicula slesvicencis Grun. This diatom is probably a variety of N. viridula, and is pretty abundant in the deposit. The striation in our form is somewhat more radiate than in Grunow's species, and the ends are a little more produced; but in the main it agrees so closely with specimens from Grunow, that I have little hesitation in adopting his name. The valves are slightly inflated and striae distinct.

No. 84. Navicula trinodis Lewis. This is not the N. trinodis of W. Smith, which is very much smaller and has rounded ends, and was considered by Dr. Arnott as Achnanthidium. The present form was first figured by Lewis, in Notes on New and Rare Species of the United States Seaboard. Phil. 1861, Pl. II fig. 6. His figure shows the striæ too plainly, for it has a hyaline aspect, and is not very rare in many recent gatherings. The constrictions are very much deeper, and the ends sharper than in N. gibberula; it is more like N. hitchcockii, but smaller, and more deeply constricted. It is rare in this deposit, but is found in some of the eastern sub-peat deposits.

No. 85. Navicula viridis K. Abundant, and variable in length and breadth; ends of valve round, and sides scarcely inflated; striæ or pinnæ conspicuous.

No. 86. Navicula viridula K. Common in the deposit, and variable in size; valves inflated and with punctured ends. It is one of the commonest of our fresh water forms.

No. 87. Navicula vulpina K. This diatom, which is not rare in the deposit, resembles N. ludloviana, but is somewhat more finely striate and with sharper ends, and wants the central blank space.

No. 88. Navicula winchelliana, n. sp., H. L. S. This small, but well marked diatom, is not very rare in the Minnesota deposit. It has been figured by Donkin Brit. Diat., pl. III, fig. 9, as N. inflata of Kutzing. An examination of Kutzing's figure, on the Santa Fiore deposit in which he found it, would have shown that Kutzing's diatom was Staurosira construens. The N. inflata of W. Smith is still another form found in the Peterhead deposit, and quite distinct from the present one which Donkin quotes as found in the Lough Mourne deposit. The latter agrees in all respects with our form, and is well figured by Donkin. It is characterised by having the two or three central striæ somewhat stronger or farther apart so as to give the appearance of a pseudo-stauros. No. 253 Cleve and Moller, Nav. viridula, var. ampiceros as figured in Schmidt's Atlas, might probably be mistaken for this, but wants the peculiar pesudo-stauros and is much larger and quite distinct. As the specific name inflata must be retained for W. Smith's form, I name the present one after Prof. Winchell, who discovered the deposit.

No. 89. Nitzschia amphioxys K. W. S. Not rare in the deposit, but very variable in size. The larger ones are generally broken.

No, 90. Nitzschia thermalis. Less abundant than N. amphioxys, and distinguished by the valve having straight or slightly incurved sides and sharply constricted capitate ends. The paucity of Nitzschiæ in this deposit is marked.

No. 91. Stauroneis acuta W. S. Not uncommon in the deposit. The valve has straight or somewhat incurved sides with sharp ends, and presents a rhomboidal aspect; striae distinct. It is found in recent gatherings with the valves adhering somewhat tenaciously into a filament of six or nine frustules, and is not uncommon in sub-peat deposits.

No. 92. Stauroneis anceps E. This is a small form with produced capitate ends, and finely striate, and is sparingly abundant in the deposit. There are intermediate forms between this and the next No , so that it is doubtful whither this is not a variety. The stauros barely extends to the margin of the valve.

No. 93. Stauroneis gracilis E. Much like the preceding but more distinctly striate and longer, ends of valves slightly produced; not capitate. This is really the parent frustule of S. phoenicenteron.

No. 96. Surirella crenulata E. Only a few fragments of this were found. It is quite common in the fossil deposits from Utah, and is figured by Ehrenberg, Abh. der Königh Akad, 1870, T. II, and fig. 6.

No. 97. Surirella splendida E. Fragments only were found of this diatom, but more abundant than the last. It is a very common form in recent gatherings and in sub-peat deposits. No other species of the genus Surirella were observed in the deposit.

No. 98. Synedra capitata E. Broken frustules of this were not rare, and also of the next species.

No. 99. Synedra longissima and possibly of S. radians. They were too fragmentary to decide.

No. 100. Tabellaria fenestrata K. Abundant.

*THE PREPARATION OF DIATOMACEÆ.

BY DR. CHRISTOPHER JOHNSTON.

In all the range of microscopic research there is confessedly nothing which offers more seductive attraction than that department of botany which comprises the *Diatomaceæ.* Apart from the exclusiveness with which the microscopist makes his observations and pushes his inquiries, there are charms which attach to the life, the modes and the extent of the reproduction, and to the vast results which follow the multiplication of these organisms. There is also a pleasing bewilderment in their large variety of form and dimension, from the grosser discoids to the almost infinitely little living chambers; and a perpetual delight afforded by their architectural beauty, and by the marvelous and matchless delicacy of the designs sculptured upon the siliceous skeletons of their frustules. The man of science pauses in his work to pore over the tracery of detail, and the philosophic student exhausts resource to effect combinations in objectives and in oculars which shall serve to bring the "markings" into view and to perpetuate the picture by photography.

However great the interest which life, habits, and reproduction inspire, the structure and configuration of the siliceous part especially command attention; for this flinty framework, resisting time and decay, alone endures, and is a recognizable integral in vast strata of the earth's surface, while the softer organic portion, leaving the character of the diatom to the skeleton, is caught up and utilized in obedience to the law which compels organic matter to incessant action, whether it mount successively higher or fall within the scope of the humblest organism. This animated matter loses its identity, and its relations to particular forms, but the silicified cachet of *Triceratium* and of *Coscinodiscus* is as palpable in the pillared rock or the California stratum as in the recent condition, or in the softer "deposits" of Nottingham, Md., and of Moron, Spain, or in the guano accumulations of the Chincha and other islands.

"Preparation of the "Diatomaceæ" ought strictly to signify the preservation of individuals or groups of these organisms in a permanent way, and their arrangement in a condition suitable for study and future reference. We would begin with the deep sea-soundings and end with animated pool water. It is not our purpose, however, to discuss at present the various devices adapted to

*The Lens, vol. 1, page 197.

accomplish a task so extended; but we desire to point out those methods of isolating the siliceous parts of Diatoms to which experience has given reputation.

It may be worth while to premise by stating—what is, of course, familiar to the student—that the coveted forms are to be met with in a great variety of conditions, either swarming fresh and full of life in pools, ponds or estuaries, clothed in fibres of green, brown or yellow, or clustering together in springs, pullulating in lakes and rivers, or tossed by the waves of the great ocean itself. In some of these situations the Diatomaceæ become and are the pabulum of myriads of beings, in whose bodies, as the *Acalephs*, the *Salpidæ*, the *Molluscs* and the *Holothuridæ*, their siliceous remains are constantly found by the microscopists, who use these and other creatures for their dredgers. They live with and upon other *Algæ*, and are met with in the green ooze of *Confervoids*, and even among the *Muscidæ*.

As ancient or recently fossilized, however, forming strata of considerable thickness, of widely different consistency and density, and not unfrequently of wide-spread geographical distribution, the Diatomaceæ astonish even the workers in science by the extent of their proliferation, and by the uneventful quiet of their living and dying, apparently undisturbed for whole ages in the conditions of their existence. Examples of these tedious and slowly cumulative formations may be instanced in Cassel, in California, in Jutland and in Maryland and Virginia, the latter furnishing so many varieties of configuration and such rare beauty in design and ornamentation. One of these diatoms, the *Heliopelta*, so much admired, has been selected by a distinguished author to grace the front page of his admirable work on the microscope.

It must be apparent that no one procrustean method of securing the prize can be made applicable in the business of "preparation." The extreme delicacy of *Amphipleura* forbids the rough boiling which *Coscinodiscus* invites; the free recent forms of any kind in "pure gatherings" obviously require nothing more than the destruction of the organic part, else the fairy-like embossing, as shown in lines or dots, is blurred, or disappears; while the so-called Diatomaceous "earths" or clays often tenaciously resist the deliverance of the imbedded gems, made adherent by a filmy, glassy cement, the product of time, an alkali, and a portion of the seeming lithophytes of other epochs. A lacustrine deposit may be washed out clean with water, but rock must be softened and sulphate of lime removed by boiling chlorhydric acid.

In general, the business of preparation involves two distinct processes: *first*, the liberation of the diatoms (as we shall henceforth, for convenience, call the siliceous skeletons of the *Diatomaceæ*) from all extraneous matters, with the exception of amorphous silex or some silicates; and, *secondly*, the complete isolation of the diatoms themselves. The former is, at times, toilsome and disagreeable, by reason of acid fumes which arise in its course; the latter is tedious and, like the other, time-consuming. But both call for a clear knowledge of method and precise executive manipulation, and both demand of the operator an intelligent adaptation of means to an end, and the *patience* with which the attainment of the end is made possible.

The simplest methods of cleaning are not always the most easy,—for example, the rescuing of diatoms from among the *Polycystinæ* of Barbadoes,—nor the most complicated always the most difficult, as, for instance, the treatment required by a sulphate of lime guano known here as the "Algoa Bay." Let us, however, attempt to make the several methods distinctly comprehensible, although in so doing we run the risk of emulating the tediousness of "neighbor Verges."

Apparatus and Chemical Material.—Guided by our experience, the following-named articles are recommended as necessary for the work of cleaning and isolating Diatoms, which should be done in a chamber high above the ground, if possible, and not heated in winter by a flue. Hot-water pipes are far better, as affording immunity against dust. We enumerate:

German beaker glasses of different sizes, with a number of small china plates to serve as covers, several large watch-glasses, or shallow glass capsules of like shape; solid glass rods for stirring; small glass tubes or pipettes; a sand bath and an apparatus for heating; nitric acid, chlorhydric acid, sulphuric acid,—all the best "commercial," except the last, which should be "C. P."; carbonate of soda and carbonate of potassa, both C. P.; Atkinson's alcohol, freshly distilled water, and a copious supply of filtered soft water.

For displaying a cleaned sediment with the view of securing individual specimens, a number of glass slides one and a half inches by four inches should be provided; and for the preservation of finished work. or clean diatoms, a score of small bottles, with corks already fitted.

Finally a large camel's-hair pencil; a few slender cane (reed) strips, to serve eventually, when pointed very finely, to pick out single valves; a supply of litmus paper; a glass funnel, and Saxony filter paper, complete the category.

Method to be Employed.—As pure diatoms, guano findings, and diatomaceous earths or clays each require separate modes of treatment, let us first handle a guano specimen, because some of the steps to be trodden may be called fundamental, or we may say they are of very general application; still, they must in certain instances be preluded by others, may not be wholly needed in particular cases, and are of necessity to be followed by supplementary processes demanded by the peculiar nature of the products obtained.

A guano, such as the Chincha or that of Ichaboë, ought to be coarsely sifted to free it from pebbles, feathers, and masses of crystallized substances. The better part is still, however, very heterogeneous, consisting of diatoms in very small percentage, and of much extraneous matter, earthy, salty, and excrementitial. Boiling water dissolves a great part of all these, and should be repeatedly applied to the deposit, and as often suffered to stand after stirring, so as to leave behind the insoluble constituents, among which, of course, are the objects of our search.

The sediment will be materially lessened in bulk by a good boiling in a solution of carbonate of soda, one ounce to the pint, which dissolves much organic as well as some inorganic matter, and, besides, sets free adherent diatoms without injuring their structure. Carbonate of potash, however, is not so free from objection.

The residuum, being drained upon a filter, ought now to be boiled in an equal part dilution of nitric acid for about ten minutes in a beaker glass, the quantity of the fluid being a couple of inches in hight above a half-inch of the matter upon which it is destined to act. Lime not in the form of sulphate, and some other elements, are dissolved out as nitrates, and must be poured off in the solution when cold after standing. Hot water should now be added freely to the sediment and poured off after its subsidence until all acid shall have been removed, whereupon the residuum is to be once more drained upon a filter.

The matter remaining is now ready for pure nitric acid, in which it is to be boiled for five or even ten minutes; after which treatment, and before cooling, the whole must be deluged with hot water. After standing, the supernatant liquor is to be poured off, and the refractory deposit washed clean with cold filtered water, and drained as before stated.

The sediment now much reduced in quantity, is prepared for chlorhydric acid, in which it is to be boiled for the removal of sulphate of lime if in moderate quantity, perhaps of a small percentage of other matter, and of such metallic stains as have resisted the action of the aquafortis. Besides, the chlorine has bleached such vegetable organic debris as has escaped destruction, so that the sediment, now composed of diatoms, fine sand and siliceous dust, and extraneous vegetable remains, appears of a pale gray color.

When thoroughly washed in filtered or distilled water, and then rendered as free from moisture as possible, either by means of a filter or by gravitation, the deposit must be subjected to the action of sulphuric acid, C. P., which heated to the boiling point carbonizes the vegetable matters, which, in a charred state, blacken the fluids. The removal of this carbon is to be accomplished in the form of carbonic acid by the addition to the still boiling acid of oxygen, which at the very high boiling point of sulphuric acid combines with it, and the gas escapes in ebullition. Nitric acid (NO_5), may be slowly dropped in, one drop a time, (being very careful to protect the eyes, face and clothing from the miniature pyrotechnics that may result), until the black or dusky color gives place to the orange hue of nitrous acid (NO_3), being what is left of the nitric acid that has parted with two elements of oxygen; or else chlorate of potassa in fine powder, after the manner of Bailey, may be very gradually, and in small doses, dropped into the seething liquid. Upon each contact of the powder a vivid explosion takes place as the carbonaceous particles ignite and consume. Chlorine is evolved, to the great annoyance of the operator, and sulphate of potassa is added measurably to the sand and diatoms beneath. But soon all is of pearly whiteness, and the process is at an end.

The task of cleaning is near its accomplishment; for all that remains to be done is the abstraction of the acid and the washing out of the sulphate of potash.

Let the tyro be careful, and manipulate with deliberation; for the rapid admixture of sulphuric acid and water occasions a sudden and considerable rise of temperature. Instead of pouring or drawing off the hot or cooled fluid, we would recommend that a large beaker glass two-thirds full of hot filtered or distilled water be made ready, and that into the water, by very tardy pouring, or even dropping, the acid, and all it contains, be thrown. When cold, or nearly so, the supernatant fluid must be flowed away, which process is facilitated by holding a glass rod against the beaker's edge to guide the stream, and after repeated washings with distilled water in a fresh beaker (for the sulphuric acid clings to the pot-beaker), the diatoms, the sand, and the amorphous silica alone survive. All is now perfectly clean; but the constituents of the white powder must await separation, and this they can do only in *dilute alcohol*, because the particles mat or adhere irretrievably in water, in which, also, confervoids speedily arise. We *label* the vessel, and we choose our own time for isolating the precious forms, observing, however, that the whole sediment has shrunk within very small dimensions, as we set aside the result of so much labor.

Finally, in reviewing the work done, let us have in mind the intention of each of the acids employed, and remember that NO_5 boils at a moderately high temperature, which, as in other fluids, is increased by the presence of pebbles, bits of glass, or coarse sand; that HC_1 passes into ebullition at a comparatively low indication of the thermometer; and lastly, that the boiling point of SO_1 is very high indeed,—so elevated, in fact, as to jeopardize all inferior glass-ware.

The foregoing process is open to the charge of being time-consuming,—as are all other methods,—but we have invariably found the results to be excellent. The same success is claimed for a different procedure, practiced and recommended by F. G. Stokes,* and which may be here briefly set forth.

"Provide a beaker glass of six or eight ounces capacity, in which place about two teaspoonfuls of guano, and then fill to near the top with a saturated solution of carbonate of soda. Boil for half an hour, wash well with water, and, after standing, pour off the supernatant fluid very close.

Add now of chlorhydric acid two ounces, boil also for a half hour, wash well, and pour off very close once more.

Treat the sediment with one ounce of strong sulphuric acid. Let it act for ten minutes, and then add bicarbonate of soda cautiously, either in solution or suspension. Shake well during effervescence, wash well, and, with great caution, add two ounces of nitric acid. After effervescence, drop in two pinches of chlorate of potash, boil a half hour, or until the deposit becomes white, and, finally, wash the sediment thoroughly."

From what precedes, it must appear that the aim of the operator is the removal of all inorganic substances, either originally soluble or artificially made so, prominent among which is *lime*, and of all organic matters reduced by a destructive process to a soluble or gaseous form. And it is also evident that when certain of these strange elements are known to be absent, such parts of the processes as are applicable to them ought to be omitted, so that fewer steps are necessary to attain the end. Silex, or sand, of course, is not to be regarded in this connection, as it is as insoluble as the Diatoms themselves.

* F. G. Stokes, On Cleaning Diatoms, Quar. Jour. Micros. Science, vol. xv. p. 222.

Suppose we take a clay or earth, that of *Nottingham*, for example. Cretaceous matter forms but a small part of its substance, which consists, in fact, of Diatomaceous skeletons, more or less adherent through the agency of a mortar, probably a silicate of lime, and of fine siliceous particles, or even sand, less closely connected. To disintegrate a mass, let it first be slaked, as it were, by pouring over it a strong solution of carbonate of soda, and when, after a time, the whole falls to pieces in laminæ and in dust, let it be boiled for fifteen or twenty minutes in a quantity of the same solution, and the result will be the reduction of the cement, the formation of silicate of soda and carbonate of lime, and the almost perfect cleaning of the diatoms. The former is removable by hot water and frequent washings; the latter, by boiling in nitric acid; while chlorhydric acid dissolves out any sulphate of lime and, besides, bleaches by the abstraction of unattacked metallic stains. The fine siliceous dust, the torment of diatomists, can only be gotten rid of by elutriation, as will presently be shown, and refractory particles or lumps must be left behind in the washings.

If the reader have followed our *proces raisonne*, he will hardly be at a loss to answer the query, "What are we to do with such clay or rock as the *Monterey?*" some specimens of which we have found to be extremely hard or tenacious. In this instance, again, the difficulty presented is the disintegration of the rock without doing injury to the diatoms. We may make the mass very hot and then drop it into cold water, by which many diatoms will be sacrificed; or else we may slightly warm the specimen, drop it into a strong solution of carbonate of potash, and boil for a time, to be ascertained by the breaking down of the original lump. In the same way, carbonate of soda may be employed, with more safety to the forms in request, but with less general success; while the potash, which is more energetic in decomposing the cement, is very destructive, if not carefully watched, of the very objects we seek.

Once reduced to the state of powder, the rules just enunciated are to be followed.

Before leaving the difficult or troublesome, we feel obliged to notice such guanos as contain sulphate of lime in any quantity, but especially in large proportions. *Algoa Bay guano* (South Africa,) for instance, as furnished us by a reliable person, was found to consist almost wholly of this refractory substance, which required an especial treatment. Being soluble in boiling and hot dilute chlorhydric acid, it was found necessary to boil the Algoa guano in that dilution, and to pour the whole on a filter, whereby the sulphate of lime in solution ran off and deposited on cooling, while the guano residuum was caught by the filter, to be subjected again and again to the same process as long as it contained the salt of lime. The small portion of decalcified guano was next exposed to the action of NO_5 and HCI, in the usual way, with the result of securing some beautiful *Actinoptychi* and *Aulacodiscus petersii*.

Recent gatherings, unmixed with sand, mud, or other refractory extraneous substances, are not made to pass through the ordeal of an alkali and so many acids as in the case of a guano, but may be cleaned by the use of one of these agents with the aid of no long-continued heat. Chlorophyll will yield to carbonate of soda, and all possible lime here, to nitric acid; but when we have to deal with very delicate *Amphipleuras* or *Grammatophoras*, marked with almost ghostly lines, we should handle our reagents with gloves, and not boil out those exquisite markings which almost rival the art-ruled bands of Nobert. Maceration for a time may be sufficient; or, if the quantity be small, all phytic substance may be burned away by the heat of a spirit-lamp flame applied beneath a film of mica, on which the "once animated dust" reposes, and on which it may, without change, be mounted in balsam.

It is needless to remind the young operator of the necessity for delicacy in all manipulative procedures, and not least in the washings of pure gatherings, or of those containing the filmy forms. But care is especially to be exercised in the recovery of those most fragile diatoms which are met with in *Barbadoes earth.* Water alone, poured *gently* on this polycystinous deposit, will suffice to float away and waft them to slides ready for their reception. And this may be done in a beaker, so that the supernatant water, rendered milky by diatoms and siliceous dust, yields by elutriation the fairest of results.

Isolation of Diatoms:—We have already pointed out the advantage, nay, even the necessity, of preserving the fruits of all cleanings in dilute alcohol, in which they may rest in safety awaiting the separation of the morphous from the amorphous. And we may here add the advice to recommit the diatoms to alcohol finally before mounting, or incidentally, if interruption temporarily arrest the perfect course of the isolation. The methods of Mr. F. Okeden* by decantation, and by whirling in an evaporating capsule or large watch-glass, as suggested by Mr. J. A. Tulk,† we have found to answer every requirement if they be as dexterously managed as they are ingeniously devised. But we would call attention to a point

*Method of Washing Diatomaceous Earths and Clays; Quarterly Journal of Microscopical Science, vol. iii. p. 158.

†On the Cleaning and Preparing of Diatoms, vol. xi. No. 3, III.

not hitherto noticed, incidental to the decantation process, and which has reference chiefly to the discoid forms. It is this: When the diatoms were nearly or quite free from foreign matters, and beaker glasses were being used in the preparation, we observed that entire disks adhered to the flat bottoms of the vessels. We utilized this knowledge by emptying a beaker, by washing it out quite freely with distilled water, and, finally, by detaching and collecting the absolutely perfect diatoms by means of a soft camel's-hair pencil, well cleaned. In this way we have had excellent success with many gatherings, but with none better than the *Nottingham earth*, as was shown by some of our slides exhibited in Chicago at the reunion of the State Microscopical Society of Illinois.

We have now, by whatever process employed, attained the cleaning and separation of the diatoms, and have consigned them to the temporary guardianship of dilute alcohol; but there still remains for us the task of a final preparation of them for mounting. By the plan adopted and suggested by Mr. Okeden they have been "sorted" as to size; yet one washing more is necessary before we can transfer them to the expectant slides. If the diatoms were to be dipped out by a tube directly, and dropped either upon a cover or a slide, the rapid alcoholic evaporation would keep the whole field in agitation, and the objects would eventually group together in drying and materially mar the beauty of the preparation. This defect may be easily remedied by quickly washing out the alcohol; after which the even display of the diatomaceous forms is readily accomplished, especially if we give the end of the slide a fillip with the finger previous to putting it aside to dry spontaneously. At this point the microscopist has the election either of mounting in the *dry way*, or of embalming his tiny treasures in Canada balsam. He may add the balsam drop *au naturel* and gently heat over a spirit flame before applying the cover, or he may omit the evaporation and mount "soft," placing a small screw, for a weight, upon the cover, or he may use balsam thinned by chloroform, or dissolved in absolute alcohol, and filtered as recommended by Dr. Schaeffer, of the Army Medical Museum, and then apply the continuous pressure of a small weight. By the first method the slide will be immediately ready for use when labeled; by the others, a certain number of hours or days must elapse before the margins of the covers will have become securely attached. But the work is done, and the student may now gloat over the things of beauty which he views by the light of science. It is true that he may regret a few forms which have been floated off under the descending cover, but careful manipulation alone will in future prevent this mishap. But how can he imitate the exquisite groupings of the *Diatomaceen-Typn-Platte* of Möller? He may note qual› but he may, with much practice, approximate to the excellence of that wonderfully skillful preparer by arranging his diatoms dry upon a slide or cover previously coated with a thin film of gelatine, and then fixing them by exposure for a moment to the vapor of distilled water. In mounting with balsam the diatoms cannot change position, but the gelatine disappears, and is seen no more forever.

Before closing this paper, perhaps already too long, we deem it germane to the subject to refer to the plan which we have adopted with success in the selection or picking out of particular diatoms. It may not be altogether original, yet it is practical, and may aid the inexperienced.

Nothing is easier than to seize particular diatoms and transfer them to a bottle for future use, or to a slide, provided the field from which we select be rich and clean. Difficulty, however, occurs when forms in any gathering are few and far between. Let such prepared material be spread upon a large slide, covering a space of one inch by two, and let it be filliped as it is set away to dry spontaneously. With a two-third inch objective, search the white field for any diatoms whatever, and, upon finding, encircle each one with a line, made with the point of a match sharpened and moistened, adding near the circle a dot, or cross, or other sign, always appropriated to the same diatom, and of which a tallying record is kept on paper. At leisure one may, without trouble, single out any desired object, pick it off with a fine dampened point of cane (reed), not including the siliceous cuticle, and deposit it, free from injury, in a small drop of distilled water placed in the centre of the slide.

And here we leave our subject, with the remarks that none of the methods proposed can lead to success unless aided by patience, painstaking, the adaptation of means to an end, and by practiced manipulative skill; and that what appears to be present perfection is only to be regarded as one of the widening circles which tend towards, but which never reach, ultimathulan truth.

*ON THE PREPARATION OF DIATOMACEÆ.

BY PROF. HAMILTON L. SMITH.

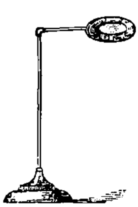
The following paper is intended as a supplement to the very excellent article by Christopher Johnston, M. D., in a former number of this journal, under the above heading, and I know of no better guide for the student. What I have to say relates to the rapid preparation, from crude material, where this has been at all carefully gathered, and to a mode of mounting, *invariably on the cover of the slide,* not mentioned by Dr. Johnston, but which has some great advantages. The gatherings should not be dried, but kept moist, in phials with a little creosote to prevent mould. I very much prefer to examine whole frustules, with both valves adherent, or if filamentous, still cohering. And I have many bottles of preparations for mounting which are nearly as clean as though they had been treated with acids. And many of the most interesting preparations which I have were never boiled in acids. Of course, very much depends upon the skill and carefulness of the gatherer, and a little patience and judgment will enable any one to obtain the crude material tolerably pure. Only a few days ago I made a gathering of *Nitzschiæ,* in which I have the frustules almost as free from foreign matter as though they had passed through the most elaborate acid and chlorate of potassa treatment.

Supposing, then, that one has before him a phial which will hold a considerable quantity of water compared with the sediment in it, the latter composed more or less of diatoms. We proceed thus, and if it has stood for some days perfectly undisturbed so much the better. The bottle is twirled rapidly, and the lighter material rising up in the axis will soon diffuse itself throughout the water. Allowing it to settle for two or three seconds, until to the eye the grosser portions have just been deposited, all that remains floating is now poured off into another phial, and it is from this stock that we are to separate the diatoms and sand from the clay and organic matter. The material poured into this second bottle is allowed to settle until the water simply appears milky or cloudy; the time will vary according to the minuteness of the diatoms, and can only be judged of from experience, say one minute, when all that remains floating must be poured off, and thrown away, unless there are very minute forms which it may be desirable to separate. The phial is again to be filled with rain, or distilled water, (hard or lime water should be strictly eschewed,) and again shaken up. As soon as the heaviest deposit touches bottom, the rest should be

*The Lens. Vol. 2, page 209.

poured off into a third phial, leaving say about one-fourth the amount behind in the second phial. The third phial will now consist mainly of sand and diatoms, with lighter organic matter and pure clay; the last two can be removed by elutriation; for this purpose, fill the phial No. 3 with water, and after well shaking allow it to settle two to five minutes, pour off and throw away the slightly milky water, and repeat the operation, allowing it to settle a somewhat longer time; the operation may be repeated a third time, when particles, suspended after an interval of eight or ten minutes may be poured off. Often, after the first settling of bottle No. 2, the diatoms will rise more pure in the mass by twirling the bottle than by shaking it up. A little practice and care will enable any one to separate certain diatoms, according to size. I had a gathering of *Pleusosigma spencerii* from Scioto river, O., sent to me, but although it had been chlorated, still when a mounting was made, not more than one or two frustules would be in the field of view, the great mass being either smaller forms, or fine fragments of silex; by careful watching and testing the time when the different sizes would remain suspended, I have made from this a preparation, which will show hundreds where before were scarcely any, and which would never be recognized as the same gathering. Supposing now a trial shows us the diatoms tolerably abundant, the trial being made by heating in the manner presently to be described; the phial is filled with alcohol and water, half and half. Some samples of alcohol leave behind a scum after evaporation, especially noticeable after burning in the mode presently to be described, and water which will leave crystals, or any scum, must be avoided; the beauty of the preparation will largely depend upon being particular in this matter.

For mounting diatoms I invariably place a drop of the fluid containing them upon the cover, *never on the slide.* The alcohol and water will spread out on the slide, but will remain heaped up on



the round cover,like a plain convex lens. I prepare a little stand, represented in the accompaning wood cut, of quite fine wire(so as not to conduct off too much heat) bent at right angles and inserted into a base; the free end is bent into a ring, and upon this ring is placed a square plate of very thin iron (such as is used for the so-called "tintypes" in photography, with the Japan burned off), held in place by bending the corners of the square over the ring, loosely, to allow expansion, without bending when heated; upon this plate the cleaned cover is placed, and then by means of a pipette, a drop of the alcoholic liquid with the diatoms is placed upon it, and the spirit lamp applied below. The alcohol takes fire and is allowed to burn out; the flame of the lamp is then placed beneath, and the rest gently boiled, the remaining alcohol escaping during this ebullition causes the diatoms, by this very act, to distribute themselves very evenly over the cover, and all matting is effectually prevented. It is better after one perceives that this even distribution has taken place, not to push the heat so as to make large bubbles again, but to slowly evaporate until dry, after which the full power of the flame must be applied until the iron plate and the glass cover is red hot; at first the mass of diatoms, &c., will become black, but as the organic contents and debris burn away there will finally remain only the silex nearly white. I invariably burn in this manner on the cover, even the specimens which have been prepared with acids, for the diatoms thus treated when mounted appear much sharper and cleaner. The amount of heat, if the diatoms are rigidly siliceous, as most of them are, may be the full power of an ordinary alcohol flame continued for some time, but if they are imperfectly siliceous, care must be exercised in the burning.

I invariably use old balsam for mounting, just as bought from the shops, especially if I wish to have a specimen which will bear immediate handling, or be ready to be sent off soon as mounted. Allowing then the cover to cool, while the slide is being cleaned to receive it, I place a drop of the balsam, which must not be fluid, only viscous, on the middle of the slide, and now *with this* pick up the cover from the little stand where it has been heated. The diatoms will be so fastened by the heating, that but few will flow out from under the cover, if any, in the subsequent treatment. I now hold the slide over the flame of the lamp (which should be much smaller than when used for the burning,) until not only all under the cover is a mass of small bubbles, but until very large bubbles, balsam steam, appear; the flame is removed soon as the bubbles are observed all running to one edge. I press down the cover at this place by a mounted pin and start them in the opposite direction. This may seem unnecessary, but long experience shows that this is the better way to get rid of them; during this the slide is held somewhat obliquely, the cover is kept from slipping by the pin, and if all the bubbles do not disappear, then with a very small flame heat is applied just beneath the obstinate ones, the slide being held slanting, and that part upwards where the bubbles are nearest the edge of the cover. The description is longer than the actual process, and the slide when cool is ready for immediate use. Perhaps I am wedded to old ways, but after trial of fluid balsams, without heat, I have always come back to the old way; still, for selected diatoms, some of these preparations of balsam are good. If the diatoms are to be mounted dry, always the best way, if for real study, I make a ring of the zinc white in balsam (sold by the opticians), and which in a moment or two is sufficiently hard to receive the cover, *and never runs in;* after standing an hour or two I give a finishing ring of the same, or the usual black varnish on the outside.

I think any one who will adopt the mode of mounting on the cover, and subsequent heating, as above described, whatever may be the rest of the procedure, will never consent to give up this part, since it effects so even a distribution, and such destruction of residual organic matter, and gives such increased brilliancy to the preparations; sometimes, if the acid has not been thoroughly washed out of acid treated specimens, snappy explosions will occur when the alcoholic mixture is heated; of course, the remedy is to pour off, and replace with pure water and alcohol.

VII.

OXIDE OF MANGANESE.

N. H. WINCHELL.

It was through the persevering efforts of Mr. J. N. Stacy that this ore has been discovered at and near Monticello, in Wright county. He first noticed a black substance along the bank of the Mississippi, overlying the gray boulder clay and underlying a thick stratum of gravel and sand. This black substance appeared to be brought to the surface and to be distributed more or less on the slope for a distance of several rods, through the action of spring water which constantly oozed from the bluff at about the same level. On having an analysis made Prof. Dodge reported the following May 26, 1891:

Sand and clay	4 98
Carb. lime	6.86
Carb. magnesia	.85
Oxide of iron	.51
Black oxide of manganese	79.83
Phosphorus	.09
Sulphur	.01
Water of hydration and organic matter	6.87
	100.00

Subsequently considerable examination was made in some of the bogs in the vicinity further west and north, so situated as to presumably constitute the main reservoir, notably for the water seen at the river bank, but also for the principal deposit of the manganese oxide, and, although several analyses were made of a ferruginous sub-peat deposit, no manganese oxide of sufficient purity was found at that time. Several shipments of a few tons each were made from the orignial locality, and the excellence of the product stimulated further exploration. The result has been to demonstrate that in several places a bog manganese exists in considerable quantity, more or less associated with bog iron ore, constituting an ore which is valuable for many uses in the arts. Analyses show manganese oxide ranging from almost nothing to ten per cent., and iron oxide to thirty and forty per cent., with the usual varying accompaniments of carbonate of lime, silica and organic matter. Such an ore is widely distributed through that part of the state, and it is very probable that, if exploration be continued, larger deposits of as great purity as that which is found in limited amount by the bank of the river, and analyzed as above, will be brought to light.

It has also been noticed that some of the iron ore deposits lately discovered on the Mesabi range are accompanied by a noteworthy percentage of manganese oxide, promising to be more valuable as manganese ores than as iron ores.

MUSEUM

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens
8101	Oct., 1892	Donation.	Proboscina tumulosa Ulrich	
8102	"	"	" frondosa Nicholson	
8103	"	"	Mitoclema (?) mundulum Ulrich	
8104	"	"	Rhinidictya neglecta Ulrich	
8105	"	"	" minima Ulrich	
8106	"	"	" " var. modesta Ulrich	
8107	"	"	Pachydictya pumila Ulrich	
8108	"	"	Arthropora bifurcata Ulrich	2
8109	"	"	" reversa Ulrich	3
8110	"	"	Stictoporella dumosa Ulrich	Num.
8111	"	"	Nematopora granosa Ulrich	
8112	"	"	Helopora mucronata Ulrich	
8113	"	"	" harrisi James	
8114	"	"	Arthroclema striatum Ulrich	1
8115	"	"	" cornutum Ulrich	1
8116	"	"	" armatum Ulrich	
8117	"	"	Callopora goodhuensis Ulrich	6
8118	"	"	" dumalis Ulrich	Num.
8119	"	"	" undulata Ulrich	4
8120	"	"	" pulchella Ulrich	3
8121	"	"	" pulchella var. persimilis Ulrich	2
8122	"	"	Homotrypa separata Ulrich	2
8123	"	"	" tuberculata Ulrich	4
8124	"	"	Homotrypella (?) ovata Ulrich	4
8125	"	"	" rustica Ulrich	
8126	"	"	Aspidopora elegantula Ulrich	1
8127	"	"	Mesotrypa (?) spinosa Ulrich	2
8128	July, 1891	Geol. Survey	" qubecensis Ulrich	5
8129	Oct., 1892	Donation	Eridotrypa exigna Ulrich	5
8130	"	"	Constellaria varia Ulrich	2
8131	"	"	Nicholsonella pulchra Ulrich	1
8132	"	"	Leptotrypa claviformis Ulrich	1
8133	"	"	Nematopora ovalis Ulrich	
8134	"	"	Batostoma montuosum Ulrich	3
8135	"	"	" varium Ulrich	1
8136	"	"	" fertile Ulrich	3
8137	"	"	" " var circulare Ulrich	
8138	July, 1891	Geol. Survey	Leptæna unicostata Meek & Worthen	1
8139	"	"	" "	3
8140	Aug., 1891	"	" "	10
8141	July, 1891	"	" "	3
8142	"	"	" charlottæ Winchell & Schuchert	1
8143	"	"	Rafinesquina minnesotensis Winchell	12
8144	"	"	" "	5
8145	"	"	" " var. inquassa, Sard.	Num.
8146	"	"	" "	5
8147	"	"	" "	Num.
8148	"	"	" "	6
8149	"	"	" " (?)	1
8150	"	"	" " (?)	5
8151	"	"	" alternata Emmons	11
8152	"	"	" "	1
8153	Aug., 1891	"	" "	5
8154	July, 1891	"	" "	3
8155	Aug., 1891	"	" " var. loxorhytis Meek	13
8156	July, 1891	"	" kingi Whitfield	2
8157	"	"	" deltoidea Conrad	20
8158	"	"	" "	3
8159	Aug., 1891	"	" "	4
8160	"	"	" "	4
8161	"	"	" "	5
8162	"	"	" "	5
8163	"	"	" "	6
8164	"	"	" "	3
8165	"	"	Plectambonites gibbosa Winch. & Schuch't	6
8166	"	"	" "	2
8167	July, 1891	"	Strophomena incurvata Sheppard	1
8168	"	"	" "	5
8169	"	"	" "	12
8170	"	"	" "	5
8171	"	"	" "	9
8172	"	"	" "	26
8173	"	"	" "	4
8174	"	"	" "	1

ADDITIONS.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Cannon Falls, Minn.	Tr'nt'n shales	E. O. Ulrich.
Cincinnati, Ohio	Hudson River	"
Cannon Falls, Minn	Trent. shales	"
Near Danville, Ky	Trenton	"
Cannon Falls, Minn	Galena shales	"
"	"	"
"	"	"
St. Paul, Minn	Trenton	"
"	Galena shales	"
"	Trenton	"
Near Cannon Falls, Minn	Galena shales	"
"	"	"
Waynesville, Ohio	Hudson River	"
Minneapolis, Minn	Trenton	"
"	"	"
Near Cannon Falls, Minn	Galena shales	"
"	"	"
St. Paul, Minn	Trenton	"
"	"	"
"	"	"
Near Cannon Falls, Minn	"	"
Minneapolis, Minn	"	"
Near Cannon Falls, Minn	"	"
"	Galena shales	"
Richmond, Ind	Hudson River	"
St. Paul, Minn	Galena shales	"
Minneapolis, Minn	Trenton	"
Decorah, Iowa	Galena shales	C. Schuchert.
Near Cannon Falls, Minn	"	E. O. Ulrich.
"	"	"
Murfreesboro, Tenn	Trenton	"
Minneapolis, Minn	"	"
Near Cannon Falls, Minn	Galena shales	"
"	Trenton	"
Minneapolis, Minn	"	"
St. Paul, Minn	"	"
"	"	"
Near Granger, Minn	Hudson River	Scofield & Schuchert.
Graf, Iowa	"	C. Schuchert.
Spring Valley, Minn	"	Scofield & Schuchert.
Iron Ridge, Wis	"	C. Schuchert.
West Side, St. Paul, Minn	Trent. shales	"
McGregor, Iowa	"	"
Decorah, Iowa	"	"
Mineral Point, Wis	Upper Buff	"
Rockton, Ill	L. blue beds	"
Janesville, Wis	"	"
4 miles north of Beloit, Wis	"	"
Preston, Minn	Trent. shales	Scofield & Schuchert.
12 m. S. of Cannon Falls, Minn	Galena shales	"
"	"	"
Preston, Minn	Trent. shales	"
6 mi. S. of Cannon Falls, Minn.	Galena shales	"
Mineral Point, Wis	Upper buff	C. Schuchert.
Spring Valley, Minn	Hudson River	Scofield & Schuchert.
Iron Ridge, Wis	"	C. Schuchert.
Oshkosh, Wis	Galena	"
Dubuque, Iowa	"	"
Weisebach's dam nr. Spring Val. [Minn	"	Scofield & Schuchert.
Near Hamilton, Minn	Top of Galena	"
Mantorville, Minn	Galena	"
Near Granger, Minn	Hudson River	"
Bellville, N. Y	Trenton	
3 mi. S. of Cannon Falls, Minn	Galena	Scofield & Schuchert. 50 ft. above base.
3 & 5 m. S. of Cannon Falls, Minn.	"	" "
Mantorville, Minn	"	"
Dodgeville, Wis	Trenton	C. Schuchert.
McGregor, Iowa	Trent. shales	"
Decorah, Iowa	"	"
Mineral Point, Wis	Trenton	"
4 mi. N. of Beloit, Wis	L. blue beds	"
Janesville, Wis	"	"
Mineral Point, Wis	"	"
Rockton, Ill	"	"

MUSEUM

SPECIMENS REGISTERED IN THE

Serial No	Obtained. When.	Obtained. Whence.	Name.	Number of specimens
8175	Aug., 1891.	Geol. survey...	Strophomena incurvata Sheppard	9
8176	"	"	" " "	11
8177	"	"	" " "	2
8178	"	"	" " "	6
8179	July, 1891.	"	" trentonensis Winchell & Schuchert	2
8180	"	"	" winchelli Hall	2
8181	Aug., 1891.	"	" trentonensis (?) Win. & Schuchert.	3
8182	"	"	" trentonensis Winchell & Schuchert	7
8183	"	"	" "	4
8184	July, 1891.	"	" rugosa Rafinesque.	12
8187	Aug., 1891.	"	" fluctuosa Billings	13
8188	"	"	" "	3
8189	"	"	" trilobata Owens	3
8190	"	"	" "	2
8191	July, 1891.	"	" planodorsata Winch'll & Schuchert	1
8192	Aug., 1891.	"	" billingsi Winchell & Schuchert	2
8193	"	"	" scofieldi Winchell & Schuchert	11
8194	"	"	" "	2
8195	July, 1891.	"	" "	1
8196	Aug., 1891.	"	Rhynchotrema capax Conrad	14
8197	July, 1891.	"	" "	10
8198	"	"	" "	22
8199	"	"	" "	8
8200	"	"	" perlamellosa Whitfield	2
8201	"	"	" anticostiensis Billings	16
8202	"	"	" "	10
8203	"	"	" "	4
8204	"	Donation	" ainsliei Winchell	3
8205	Aug., 1891.	Geol. survey...	" "	1
8206	"	"	" "	5
8207	July, 1891.	"	" "	1
8208	Oct., 1892..	Donation	Escharopora confluens Ulrich	
8209	Aug., 1891	Geol. survey...	Rhynchotrema inæquivalis Castelnau	4
8210	"	"	" "	18
8211	"	"	" "	12
8212	July, 1891.	"	" "	3
8213	"	"	" "	10
8214	"	"	" "	7
8215	"	"	" "	4
8216	"	"	" "	4
8217	"	"	" "	Num.
8218	Aug., 1891.	"	" "	"
8219	"	"	" "	5
8220	"	"	Zygospira recurvirostris Hall var. Minne-[sotensis W & S	Num.
8221	"	"	" "	10
8222	"	"	" "	34
8223	July, 1891.	"	" "	3
8224	Dec., 1891..	Donation	" "	Num.
8225	"	"	Raufella palmipes Ulrich	1
8226	July, 1891.	Geol. survey...	Strophomena winchelli Hall	1
8227	Aug., 1891.	"	Zygospira uphami Winchell & Schuchert..	10
8228	"	"	" modesta (Say) Hall	1
8230	"	"	Anastrophia (?) scofieldi Win. & Schuchert	28
8231	"	"	" hemiplacata var. rotunda W & S	1
8232	"	"	" hemiplicata Hall	5
8233	"	"	" "	2
8234	"	"	" "	2
8235	"	"	" "	2
8236	"	"	" "	3
8237	Jan., 1892..	Donation	Hallella saffordi Winchell & Schuchert	4
8238	Aug., 1891.	Geol. survey...	" nicolleti Winchell & Schuchert.	3
8239	"	"	" nicolleti Winchell & Schuchert.	Num.
8240	Feb., 1892	Donation	Aulopora trentonensis Win. & Schuchert..	1
8241	Sept., 1892.	Exchange	Pleurotomaria sphærulata	5
8242	"	"	tabulata	1
8243	"	"	Bellerophon montfortianus	7
8244	"	"	Polyphemopsis peracuta	3
8245	"	"	Nucula ventricosa	3
8246	"	"	Lophophyllum proliferum	5
8247	"	"	Spirifera camerata	1
8248	"	"	Athyris subtilita	5
8249	"	"	Diplodus compressus	1
8250	"	"	Head of Coelacanthus elegans	1
8251	"	"	Eurylepsis minimus	1

ADDITIONS—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Preston, Minn	Tr'nt'n shales	Scofield & Schuchert.
Fountain, Minn	"	"
St. Paul, Minn	"	C. Schuchert.
Minneapolis, Minn	"	J. C. Kassube.
4 miles N. of Beloit, Wis	L. blue beds	C. Schuchert.
Janesville, Wis	"	"
Kenyon, Minn	Galena shales	W. H. Scofield.
6 miles S. of Cannon Falls, Minn	Top Tr. shales	Scofield & Schuchert.
2 miles S. of Cannon Falls, Minn	Tr'nt'n shales	"
Iron Ridge, Wis	Hudson River	C. Schuchert.
Spring Valley, Minn	"	Scofield & Schuchert.
Near Granger, Minn	"	"
Mantorville, Minn	Galena	"
3 miles S. of Cannon Falls, Minn	"	" 50 ft. above base.
Iron Ridge, Wis	Hudson River	C. Schuchert.
Fountain, Minn	Galena shales	Scofield & Schuchert.
2 miles S. of Cannon Falls, Minn	"	"
St. Paul, Minn	Top Tr. shales	C. Schuchert.
4 miles N. of Beloit, Minn	L. blue beds.	"
Spring Valley, Minn	Hudson River	Scofield & Schuchert.
Graf, Iowa	"	C. Schuchert.
Iron Ridge, Wis	"	"
Near Clifton, Wis	"	"
Iron Ridge, Wis	"	"
Graf, Iowa	"	"
Iron Ridge, Wis	"	"
Near Clifton, Wis	"	"
Rochester, Minn	Tr'nt'n shales	N. Ainslee.
Preston, Minn	"	Scofield & Schuchert.
Chatfield, Minn	"	"
McGregor, Iowa	"	C. Schuchert.
Minneapolis, Minn	"	E. O. Ulrich.
10 mil's S. of Cannon Falls, Minn	Galena shales	Scofield & Schuchert, 50 feet above base.
Warsaw, Minn	"	W. H. Scofield.
Fountain, Minn	"	Scofield & Schuchert.
Neenah, Wis	Galena	C. Schuchert.
Oshkosh, Wis	"	"
Janesville, Wis	L. blue beds	"
Mineral Point, Wis	"	"
McGregor, Iowa	Tr'nt'n shales	"
Decorah, Iowa	"	"
6 miles S. of Cannon Falls, Minn	Galena shales	Scofield & Schuchert.
Warsaw, Minn	"	"
2 miles S. of Cannon Falls, Minn	"	"
6 miles S. of Cannon Falls, Minn	"	"
Near Fountain, Minn	Tr'nt'n shales	"
Oshkosh, Wis	Galena	C. Schuchert. [growth.
St. Paul, Minn	Tr'nt'n shales	" Specimens in all stages of
Minneapolis Minn	"	" Lake street bridge.
Oshkosh, Wis	Galena	
Weisebachs dam, n'r Spr'g Val'y	"	Scofield & Schuchert.
Spring Valley, Minn	Hudson River	"
6 miles S. of Cannon Falls, Minn	Galena	"
5 miles S. of Cannon Falls, Minn	"	"
12 miles S. of Cannon Falls, Minn	"	"
Weisbach's dam	"	" Near Spring Valley.
Near Fountain, Minn	"	"
Preston, Iowa	"	"
Decorah, Iowa	"	C. Schuchert.
Lebanon, Tenn	Glade l'm'st'n	"
Decorah, Iowa	Tr'nt'n l'mstn	"
Near Fountain, Minn	"	Scofield & Schuchert.
Near Cannon Falls, Minn	Tr'nt'n shales	C. Schuchert.
Richmond, Ohio	L. coal Meas.	Sam Huston.
"	"	"
"	"	"
"	"	"
"	"	"
"	"	"
"	L. b'r'en co'l M	"
"	"	"
Linton, Ohio	L. coal Meas.	"
"	"	"
"	"	"

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SPECIMENS REGISTERED IN THE

Serial No.	OBTAINED. When.	OBTAINED. Whence.	NAME.	Number of specimens
8252	Feb'y, 1892	Donation..	Scenidium halli Safford	2
8253	Dec., 1891	"	Strophodonta perplana Conrad	1
8254	"	"	Chonetes pusillus Hall	2
8255	"	"	Spirifer pennatus Owen	1
8256	"	"	Strophodonta nacrea Hall	1
8257	"	"	Orthis vanuxemi Hall	2
8258	"	"	Spirifer parryanus Hall	1
8259	"	"	Atrypa reticularis Linne	2
8260	"	"	Atrypa hystrix Hall	2
8261	"	"	Orthis suborbicularis Hall	3
8262	"	"	Strophodonta demissa Conrad	1
8263	"	"	Orthis iowensis Hall	2
8264	"	"	Cyrtina hamiltonensis Hall	1
8265	"	"	Heliophyllum halli	1
8266	"	"	Favosites alpenensis Winchell	1
8267	"	"	Cystiphyllum americanum Edwards and Haime	1
8268	"	"	Phyllipsastrea gigas ?	1
8269	"	"	Cyathophyllum davidsoni Rominger	1
8270	"	"	Stromatopora	1
8272	"	"	Streptelasma rectum Hall	2
8273	"	"	Mont culipora.	1
8276	July, 1891	Geol. Survey...	Orthoceras multicameratum emmons	1
8277	"	"	" "	2
8278	Aug., 1891	"	" "	1
8279	July, 1891	"	Actinoceras beloitense Whitfield	3
8280	"	"	Orthoceras junceum Hall	4
8281	Aug., 1891	"	" "	4
8282	"	"	" "	5
8283	July, 1891	"	" bilineatum Hall	1
8284	Aug., 1891	"	" "	2
8285	July, 1891	"	" amplicameratum Hall	3
8286	Aug., 1891	"	" " "	2
8287	"	"	" " "	1
8288	....	Donation.......	" planoconvexum "	1
8289	July, 1891	Geol. Snrvey...	Triptoceras	1
8290	"	"	Orthoceras anellus Conrad	1
8291	"	"	" olorus Hall	2
8292	"	"	" "	1
8293	Aug., 1891	"	Gonioceras (?) confertus Winchell and Schuchert	2
8294	"	"	Cyrtoceras mannitobense Whiteaves	6
8295	"	"	" "	1
8296	"	"	" "	1
8297	"	"	Orthoceras bilineatum Hall	1
8298	July, 1891	"	Gonioceras anceps Hall	1
8299	1891	Donation.......	Triptoceras planodorsatum Whitfield	1
8300	July, 1891	Geol. Survey...	Oncoceras pandion Hall	7
8301	Aug., 1891	"	" "	1
8302	"	"	" "	1
8303	July, 1891	"	" plebium ? Hall	1
8304	"	Donation	" "	1
8305	Aug., 1891	Geol. Survey...	Dekayella prænuntia Ulrich	3
8306	"	"	" " var. multipora Ulrich.	1
8307	Oct., 1892	"	" " var. simplex Ulrich...	....
8335	....	"	Cypricardites sardesoni Ulrich	1
8379	Sept., 1892	Donation.......	Monotrypa intabulata Ulrich	1
8380	"	"	Ceramoporella inclusa Ulrich	1
8381	"	"	Ceramophylla frondosa Ulrich	6
8382	1884	By purchase. ..	Trochonema beachi Whitfield	5
8383	1876-1879	Geol. Survey...	" "	12
8384	1880	Donation...	" "	2
8385	......	....	" "	2
8387	Aug., 1877	Geol. Survey...	" "	1
8388	....	....	" "	....
8389	....	....	" umbilicatum Hall	1
8390	....	....	Fusipira ventricosa Hall	....
8391	....	....	" subfusiformis Hall	....
8392	July, 1891	Geol. Survey...	Schizotreta minutula W. and S.	....

ADDITIONS.—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and remarks.
Lebanon, Ohio	Glade l'mst'n.	C. Schuchert.
Rock Island, Ill	Hamilton	J. A. Udden.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	Corniferous	"
" "	Hamilton	"
" "	Corniferous	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	Hamilton	"
Mineral Point, Wis	L. blue beds	C. Schuchert.
Rockton, Ill	U. buff beds	"
Rockdell. P. O., Minn	Galena.	Scofield and Schuchert.
Janesville, Wis	L. blue beds	C. Schuchert.
"	"	"
Near Fountain, Minn	Galena shales	Scofield and Schuchert.
" "	Trenton "	" "
Decorah, Iowa	" "	C. Schuchert.
Warsaw, Minn	Galena "	W. H. Scofield.
Mineral Point, Wis	L. blue beds	C. Schuchert.
Near Rochester, Minn	Galena	W. H. Schofield.
Preston, Minn	L Galena	Scofield and Schuchert.
Cannon Falls, Minn	Trenton limestone	W. H. Scofield.
Mineral Point, Wis	L. blue beds	C. Schuchert.
McGregor, Iowa	Trenton sh'l's	"
Janesville, Wis.	L. blue beds	"
Mineral Point, Wis	"	"
Stewartsville, Minn	Mid'le Galena	Scofield and Schuchert of Stewartsville. The largest specimen donated by F. L. Wood.
" "	"	
Mantorville, Minn	"	Scofield and Schuchert.
Pleasant Grove, Minn	"	" "
Near Fountain, Minn	Trenton sh'l's	"
Mineral Point, Wis	L. blue beds	C. Schuchert.
Minneapolis, Minn	Trenton limestone	H. V. Winchell.
Janesville, Wis	Lower bluff	C. Schuchert.
Preston, Wis	Trenton sh'l's	Scofield and Schuchert.
Minneapolis, Minn	Trenton limestone	
Janesville, Wis	L. blue beds	C. Schuchert.
Minneapolis, Minn	Trenton limestone	H. V Winchell.
Preston, Minn	Trenton sh'l's	Scofield and Schuchert.
"	"	" "
Minneapolis, Minn	"	E. O Ulrich.
"		
2 m. S. E. of Cannon Falls, Minn.	Galena shales	E. O. Ulrich.
Near Fountain, Minn	Trenton	"
St. Paul, Minn	"	"
Minneapolis, Minn		Wm. Howling. (5675).
		C. L Herrick. (5108).
		H. V. Winchell. (5063).
"		
"		C. L. Herrick. (773).
"		(6867).
Kenyon, Minn		N. H. Winchell.
Lime City, Minn		"
Decorah, Iowa		C. Schuchert.
Granger, Minn	L. Hudson R.	"

MUSEUM

SPECIMENS REGISTERED IN THE

Serial No.	Obtained.		Name.	Number of specimens
	When.	Whence.		
8393	....	....	Fusispira nobilis Ulrich and Scofield.......	....
8394	....	....	" vitata Hall..................	1
8395	....	....	" vaticina Ulrich and Scofield.....	1
8396	....	....	" convexa Ulrich and Scofield.....	....
8427	Sept., 1880	Geol. Survey...	Trochonema umbilicatum Hall..............	....
8428	1884	By purchase...	" beachi Whitfield...............	....
8429	Oct., 1892	Donation........	Pachydictya occidentalis Ulrich............	4
8430	Oct., 1892	Donation	Rhinidictya paupera Ulrich................	5
8431	"	"	Escharopora limitaris Ulrich	3
8432	"	"	Callopora ampla Ulrich	4
8433	"	"	Callopora crenulata Ulrich	2
8436	Aug., 1891	"	Asaphus gigas DeKay	1
8437	"	"	Asaphus megistus Locke	1
8438	"	"	" " "	1
8439	July, 1891	Geol. survey...	Lingula modesta Ulrich	3
8440	"	" ...	Maclurea cuneata Whitfield	22
8441	....	" ...	" " "	1

ADDITIONS.—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and remarks.
Decorah, Iowa....................	....	C. Schuchert.
Fountain, Minn....................	....	Scofield and Schuchert.
Petit's mill, Mantorville, Minn.	....	N. H. Winchell.
Decorah, Iowa....................	....	C. Schuchert.
Lime City, Minn..................	....	N. H. Winchell. (4104).
Minneapolis, Minn................	....	Wm. Howling. (5675).
St. Paul, Minn....................	Trenton	....
St. Paul, Minn....................	Trenton	E. O. Ulrich.
Minneapolis, Minn..........	"	"
Near Cannon Falls, Minn.......	Galena shales	"
St. Paul, Minn....................	Trenton	" [natural mould.
Granger, Minn.	Hudson river	R. H. Hesse, gutta-percha impression of
" "	"	" gutta-perc. imp. of nat.mould
" "	"	"
" "	L. Hudson R.	Scofield and Schuchert.
Lime City, Minn..................	....	N. H. Winchell.
" "	....	"

Additions to the Library Since the Report for 1890.

A

Albany. Geol. Survey of N. Y. Paleontology, vol. xiii. An. Rep. viii-x.
N. Y. State Museum, An. Reps. 43 and 44.

Austin. Geol. Survey of Texas. Second Report of Progress, Bulletins 2 and 3.
Geol. Survey of Texas. Bulletins 1-3; Second Report of Progress; Third Annual Report for 1891.

Avon. American Antiquarian, vol. xiv, No. 5, Sept. 1892.
American Antiquarian vol. xiv, No. 6, Nov. 1892.

B

Baltimore. Amer. Chem. Jour, xiii, 7, 8; xiv, 1-5; Johns Hopkins Univ. An. Rep. xvi; Biol. Lab. Studies v, i; Circulars ix, 80, 81; x 84, 87, 88; xi 92-99;
Johns Hopkins Univ. Circulars, vol. xi, No. 100. July 1892.
Johns Hopkins Univ. Circulars, vol. xii, No. 101, Nov. 1892.
Amer. Chem. Jour., vol. xiv, No. 6. Oct. 1892.
Amer. Chem. Jour., vol xiv, No. 7. Nov. 1892.
Amer. Chem. Jour., vol. xiv, No. 8. Dec. 1892.
Johns Hopkins Univ. Circulars, vol. xii, No. 102, 1893.

Basel. Naturforschenden Gesellschaft Verhandlungen ix, 2.

Berlin. Verhandl. Gesellschaft fur Erkunde, Band xix, Nos. 2, 3, 4, 5, 1892.
Gesellschaft fur Erkunde Zeitschrift xxvi, 4-6. Verhandlungen xviii, 7-10; xix, 1.
Zeitschrift Gesellschaft fur Erkunde, Band xxvii, Nos. 1, 2, 1892.

Bern. Mitt. Naturf. Gesellschaft, Nos. 1, 265-1268, 1891.

Bonn. Naturhistorischen Vereins der Rheinlande, Westfalens, und des Regbezuks osnabruck, Verhandlungen, viii, 5.

Boston. Proc. Amer Acad. Art and Science. 1890-91.
New England Magazine. N. S. iii, 6; iv, 2; old series ix, 6.

Bologna. Memorie della R. Accademia delle Scienze dell Instituto. Serie v, Tomo i. 1891.

Bridgeport. List of birds found in the vicinity of Bridgeport.

Brunn. Verhandl. Naturf. Vereines, band xxix. 1890.
Bericht Meteorology Commission Naturf. Vereines Beobachtung im Jahre 1889.

Bruxelles. Soc. Etomologique deBelgique, Compte-Reudu Series, iv, 15-25.

C

Cambridge. Peabody Museum of Amer. Archeology and Ethnology. An. Rep. xxii, 3, 4.
Harvard Coll. Mus. Com Zool. Bulletin xxiii, 4. 1892.
Mus. Com. Zool. Harvard Coll. An. Rep. of Curator, 1891. Bulletins xxii, 1-4; xxiii, 1, 2.

Champaign. Bulletin Ill. State Lab. Nat. Hist., vol. iii, Article xiii, 1892.
Biennial Rep. of Director of Ill. State Lab. Nat. Hist. for 1891–92.
Chapel Hill. Elisha Mitchell Sci. Soc. Jour. viii, 1, 2, v 2.
Chicago. The Brickmaker, ix, 5.
World's Columbian Exposition. Plan and Classification. 1892.
Christiania. Jahrbuch des Norwegeschen Meteorologischen Instituto fur 1890.
Norwegian North Atlantic Expedition. Zoology. Crinoida und Echinoida. 1892.
Chur. Jahresb. Naturf. Gesellschaft Granbundens fur 1890–91, xxxv Jahrgang.
Cincinnati. Soc. Nat. Hist. Jour., xiv, 3, 4; xv, 1.
Soc. Nat. Hist. Jour., xv, 2. July 1892.

D

Darmstadt. Vereins fur Erdkunde. Notizblatt, iv, 12.
Abhandl. Geol. Landesanstalt, Band ii, Heft 2. 1892.
Abhandl. ii, Geol. Landesanstalt.
Denver. State School of Mines. An. Rep. 1885, 1889. Biennial Rep. 1886, 1890. Building Stones of Colorado, 1884. Catalogue, 1890–91.
Colorado Scientific Society, Proceedings, iii, 3.
On the ore deposits of Newman Hill, near Rico, Col.
The Nature of the Chemical Elements.
Geology of Colorado Ore Deposits. 1888
Fuel Resources of Colorado. 1890.
The Post-Laramie Beds of Middle Park, Col., by Whitman Cross. Proc. Col. Sci. Soc. 1892.
Dublin. Royal Dublin Soc. Sci. Proc. vi, 6–10; vii, 1–2; Sci. Trans. iv, 6–8.
Royal Dublin Sci. Soc. Proc., vol. vii, pt. 4.
Sci. Trans. Roy. Dub. Soc., Vol. iv, Art. ix, xiii. July-Dec., 1891.
Sci. Proc. Roy. Dub. Soc., Vol. vii, Pt. iii. March, 1892.

E

Edinburgh. Trans. Edinburgh Geol. Soc., Vol. vi, Pt. iii. 1892.
Proc. Roy. Soc. of Edinbùrgh, Vol. xviii. Session 1890-91.
Erlangen. Sitzungsb. Physik-medicin Societat xxiv. Heft, 1892.

F.

Frankfort. Geol. Sur. of Ky. Rep. on Geol. of parts of Jackson and Rockcastle Co's. Rep. on Petroleum and Natural Gas in Western Ky.

G

Gera. Jahresb. Gesell. Freunden Naturw., 24th and 25th, 1889-1892.
Giessen. Bericht Oberhess Gesell. fur Natur-und. Heilkunde xxxiii 1892.
Glasglow. Philos. Soc. Proc., xxii, 1890-91.
Granville. Sci. Lab. of Denison Univ., Bul. vi, 2.
Denison Scien. Assoc., Bul. vii, 1892.
Greece. Library at Athens. Catalogue. Archeology, 1891. Report of Trustees for 1890-91.

H.

Halifax. Nova Scotian Institute of Nat. Sci. Pro. and Trans. Ser. 2, i, 1.
Hanover. Naturhistorischen. Gesell. Jahresbericht, xi, xli.

I

Iglo. Austria-Hungary. Ungarischen Karpathen-Vereins, Jahrbuch, vi, xviii.

Ungarischen Karpath-Vereines, Jarbuch xix, 1892.

Indianopolis. Stone, Vol. 5, No. 1, June, 1892.

Iowa City. Lab. of Nat. Hist. State Univ. Bulletin ii, 2,

K

Kiel. University. 114 Pamphlets, mostly inaugural dissertations.

Naturwissenschaftlichen Vereins fur Schleswig Holstein, Schriften, ix, 1891.

University. 67 Inaugural Dissertations; Die Entdeckungen auf dem Gebiete du Klassischen Philologie, 1891; Das Kaiserthune; Verzeichuiss der Varlesungen von Oct., 1891, zu March, 1892; und von April, 1892, zu August, 1892; Chronik for 1890-91; und für 1891-92; "Guilemi ii," 27th Jan., 1892; Portraits von 22 Professoren.

Schriften Naturw. Vereins fur Schleswig-Holstein. Band ix, Heft 2, 1892.

Konigsberg. Schriften der Physik-Okonom Gesell. 32nd year, 1891.

Physikalisch-Okonomischen Gesell. Hohenschichten Karte, Sec. Kronigsberg; Sec. Danzig; Sec. Bromberg-Marienwender.

L

Leeds. Geol. Assn. Transactions, vi. 1891.

Leipzig. Vereins fur Mittheilungen, 1888; Beitrage zur Geographic des Festen Wassen, 1897.

Mitt. Vereins for Erdkunde, 1891.

Lille. Soc. Geol. du Nord. Annales xix, 1891.

Lund. University Ars-skrift xxvii, 1890-91.

Luxemburg. Verein Luxemberger. Naturfreunde. "Fauna" No. 1: 1892.

M

Madison. State Hist. Soc. proc. xxxix. 1891.

Marburg. Gesell. zur Beforderung der gesamten Naturw. Jahrgang 1891.

Mecklenburg. Archiv Vereins Freunde Naturgesch 45th year, 1891.

Mendon. American Antiquarian xii (2-6), xiv (1, 3, 4).

Mexico. Memoires y Revista della Sociedad Cientifica "Antonio Alzate" Tomo vi. Nos. 1 and 2.

Sociedad Cientifica "Antonio Alzate" Memoires y Revista iv; 11, 12; v. 1, 2, 5, 6, 9, 10.

Boletin Mensual-Observatories Meteorologico. Tomo iii. No. 4, for April 1890. Printed 1892.

Memoires y Revista Sociedad Cientifica "Antonio Alzate" Tomo v. (1891-1892) Nos. 7, 8, 11, 12. 1892.

Minneapolis. American Geologist. viii. 4-6; ix. 1-2, 4-6; x. 1-2.

Mexico. Ministerio de Fomento, Anales ix. 1891; Observatories Meteorologico Magnetico Boletin Mensual iii, 2, 3.

Metz. Vereins fur Jahresbericht xiii.

Milwaukee. Wisconsin Academy of Science. Transactions i-vi, viii.

Minneapolis. Acad. Nat. Sci. Bulletin iii, 2. 1887-89.

American Geoligist. Vol. x. Nos. 3, 4. 1892.

American Geologist. Vol. x. No. 6. Dec. 1892.

Geol. and Nat. Hist. Survey of Minn. Bulletin 7, 1892.

Minnesota Hist. Soc. Collection vi. 2. 1891; i. 1850-56; ii. 1860-67; iii. 1870-80; v. 1885; vii. 1893; and Seventh Biennial Report 1893.
Montreal. Canadian Record of Science iv. 7, 8; v. 1, 2.
Moscow. Soc. Imp. Naturalists. Buls. 1, 2, 3; 1891, iv; 1892, i.

N

New Hampshire. Geol. and Minerolog. Sur. An. Rep. I, II. 1868-70.
New Haven. New Order of Extinct Eocene Mammals (Mesodoctyla).
New York. Am. Geog. Soc. Bul. xxii with Supplement xxiii, 3, 4, Part 1; Part 2; xxiv, 1.
Notice of New Reptiles from the Laramie Formation.
Academy of Science, Transactions, x, 2-6; Annales vi, 1-4.
Minerals i, 1, Jan. 1892.
Bulletin Amer. Geog. Soc. xxiv. 2, June 1892, Trans. Academy of Sciences xi, 3, 4, 5, 1891-92; Catalogue of Microscopes, Bausch & Lomb Optical Co.; Catalogue No. 8, the Ingersoll-Sergeant Drill Company.
Bulletin Amer. Geog. Soc. vol. xxiv, No. 3. Sept. 1892.
Nurmberg. Naturhistorischen Gesell. Jahresbericht viii, 8-13.
Abh. u Jahresb. Naturh. Gesell. Band ix. 1891.

O

Ottawa. Contributions to Can. Micro-paleontology iii. 1891.
Cambro-Silurian Rocks. 1883.
Contributions to Micro-Paleontology, Canadian Geol. Survey; Pt. iv, 1892.
Case of Maps for An. Rep. Vol. iv, of Geol. Sur. of Canada.

P

Paris. Soc. Zool. de France, Bulletin xvi, 7-10; xvii, 1-5; Memoires iv, 3-5, v. 1.
Bul. Soc. Sci. Nat. de l'Ouest de la France, Tome ii, No. 2. 1892.
Mem. Soc. Zool. de France. Tome v. Pt. 4, 1892; Bul. Soc. Zool. de France Tome xvii, No. 6, 1892; Bul. Soc. Zool. de France Tome xiv. No. 6, 1889.
Mem. Soc. Zool. de France, Tome v. Parts 2 and 3. 1892.
Peoria. Flora Peoriana. The Vegetation in the Climate of Middle Ill. 1887.
Philadelphia. Acad. of Nat. Sci. Proc. Vol. xxii. Part 1. 1892.
American Naturalist xxv. 298-308, 1892.
American Naturalist xxvi, No. 309-310-311, Sept., Oct., Nov., 1892.
Prag. Konigl. Bohn. Gesell: der Wissensch. Sitzungsb. Math-Natural class 1891., Jahresb. 1891.

R

Rio Janeiro. Museu. Nacional de Rio de Janeiro. Archivos i-vi. 1876-1882.
Rochester. Academy of Science Proc. i, 2.

S

Santiago. Actes Societe Scientifique. II. 2, 1892.
San Francisco. Cal. Academy of Science Proceedings, III. 1, 1891.
San Jose. Instituto Fisico-Geographico Nacionalde Costa Rica, Annales II. 2.

San Salvador. Observaciones Meterologicos, Aug.-Dec. 1891.
Observatories Astronomico y Meterologico, Resumen, June, 1892.
Observaciones Meterologicos hecas en el Observatories. Feb. 1892.

Salem. Bulletin of Essex Institute. Vol. xxiv, No. 3, Sept. 1892.

Scranton. Tabular Estimate of the Production of Coal in Northern Anthracite Coal Basin of Penn., 1892.

Springfield. Geological Survey of Illinois. Geol. and Paleon. VIII., 1890.

St. Louis. Missouri Botan. Garden. Annual Report, 1891.
Academy of Science, vol. vi, No 2, 1892.

St. Petersburg. Comite Geologique, Memoirs, xi. 2. Bul. 9, 10; x. 1, 5 with supplement.
Bul. de Comite Geologique, vol. x, Nos. 6–10; vol. xi. Nos. 1–5, 1892.
Verhandl Russ.-Kais-Mineral. Gessellschaft, 2d series, vol. xxviii, 1892.
Memoirs du Comite Geologique. Vol. xiii, No. 1.

St. Paul. Minnesota Historical Society. Minn. Hist. Collection, vi, 1, 1887.

Stockholm. Entomologiska Foreningen Tidskrift, xii, 1–4.
Geologiska Foreningen Forhandlinger, xiii, 1–5.

Sydney. Geol. Soc. of Australasia. Special Volume of Proceedings, 1885.
The Wealth and Progress of N. S. Wales, 1889–90.
Official Report of Nat. Aust. Convention. Debates, Mar. 2–Apr. 9, 1891.
The Year Book o f Australia for 1891. 10th year.

T

Toronto. Can. Institute. Trans. II, 1–4. Appeal to Can. Instit. on Rectification of Parliament.
Proc. Can. Inst., 3d Series, Vol. VII, No. 2, April, 1890.
Trans. Can. Inst. Vol. III, Part 1, No. 5, Dec. 1892.

Throndhjem. Det Kongelige Norske Videnskabers Selskabs. Skrifter, 1888–90.

U

Upsala. University. Aarsskrift. 1890.
Upsala Universitets Aarsskrift. 1891.

W

Washington. U. S. Geol. Sur. An. Rep. x, 1888–89; Bulletins 62, 65, 67–81.
Smithsonian Inst. An. Rep. 1890. Bul. Nat. Mus. 41, 42. Proc. xiv, 851, 857, 864, 865, 867–883, 858–860, 886; xv, 887, 888. Proc. for 1891, pp. 1–50.
Note on the Geuus Chonerlius or Xenopterus.
On the Genus Gnatyanacanthus of Bleeker.
Philosophical Soc. Bul. xi, 1888–91.
U. S. Nat. Museum. Spec. Bul. No. 1, 1892. Bul. 39, pts. F. and G, from Rep. U. S. N. M. 1890; pp. 253–383; 385–394; 395–409; 411–427; 429–591; 593–639; 641–680; from Proc. U. S. N. M. xv. pp. 889–894; 897–898; 900–904.
Chinese Relics in Alaska. U. S. N. M.
Description of a new species of star-gazer from Gulf of Mexico. U. S. N. M.

Description of two new forms of Basilenterus riflfrous from Mexico. U. S. N. M.

List of Foreign Correspondents of Smith. Inst. July 1885; Additions and Corrections July, 1888. Systematic arrangement of list July, 1888.

Mineral Resources of the U. S., Geol. Survey, 1889-90.

Smithsonian Inst. Excerpts Nos. 911-914 from Proc. U. S. Nat. Museum, vol. xv. 1892,

Bulletin Philo. Soc. vol. xi, 1888-91.

Proc. U. S. Nat. Mus. Title page and contents of vol. xiv, 1891.

Wien. K.K Zoologisch-Botanischen Gesellschaft, Verhandlungen xli,31-4.

Annalen K. K. Naturb. Hofmuseums. Band vii, Nos. 1, 2. 1892.

Verhandl. K. K. Zool.-Bot. Gesell. Band xlii, Nos. 1 and 2. 1892.

Z

Zurich. Naturforschenden Gesell. Vierteljahrschrift 1891, Neujahrsblatt xciv, 1892.

Vierteljahrschrift Naturf. Gesell. in Zurich, 37th year, 1st pt. 1892.

Vierteljahrschrift Naturf. Hofmuseums. Band vii, Nos. 1, 2. 1892.

Generalregister der Publikationen der Naturf. Gesell. 1892.

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PUBLICATIONS OF THE GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA.

I. ANNUAL REPORTS.

THE FIRST ANNUAL REPORT FOR 1872. 112 pp., 8vo with a colored map of the state. By *N. H. Winchell.* Published in the Regents' Report for 1872; contains a sketch of the geology of the state, as then known, and a list of earlier reports. Second edition (1884) identical.

THE SECOND ANNUAL REPORT FOR 1873. 145 pp., 8vo.; with illustrations. By *N. H. Winchell* and *S. F. Peckham.* Published in the Regents' Report for 1873. Out of print.

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THE TWELFTH ANNUAL REPORT, FOR 1883. Summary report, containing palæontological notes and a paper on the comparative strength of Minnesota and New England granites, twenty-six pages, by *N. H. Winchell;* final report on the Crustacea of Minnesota, included in the orders of Cladocera and Copepoda, 192 pages and 30 plates by *C. L. Herrick*, and a catalogue of the flora of Minnesota, 193 pages, with one map showing the forest distribution, by *Warren Upham.* Also in the Regents' Report for 1883 and 1884.

THE THIRTEENTH ANNUAL REPORT, FOR 1884. 196 pp. Geological reconnoisances. the Vermilion iron ores, the crystalline rocks of Minnesota and of the Northwest, the Humboldt salt-well in Kittson county, records of various deep wells in the state, fossils from the red quartzyte at Pipestone, reports on the New Orleans Exposition and on the General Museum, by *N. H. Winchell;* Geology of Minnehaha County, Dakota, by *Warren Upham;* Chemical report, by *Prof. Jas. A. Dodge;* Minnesota geographical names derived from the Dakota language. by *Prof. A. W. Williamson;* insects injurious to the cabbage, by *O. W. Oestlund;* Geological notes in Blue Earth county, by *Prof. A.*

F. Bechdolt; and on a fossil elephant from Stockton, by *Prof. John Holzinger;* papers on the Cretaceous fossils in the boulder clays in the Northwest, by *George M. Dawson* and by *Woodward* and *Thomas;* and notes on the Mammals of Big Stone lake and vicinity, by *C. L. Herrick*.

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THE EIGHTEENTH ANNUAL REPORT, FOR 1889. Report of further field observations in the regions of the crystalline rocks of the state and in the area of the original Huronian, by *N. H. Winchell*, and a review of American opinion on the older rocks, by *Alexander Winchell.* Octavo, pp. 234.

THE NINETEENTH ANNUAL REPORT, FOR 1890. 8vo. pp. 255, with illustrations. Translation of Boricky's elements of a new Chemico-microscopic method of analysis of rocks and minerals, and of Kloos' Geognostic and Geographical observations in Minnesota in 1877, by *N. H. Winchell*, chemical report by *Prof. Dodge*, the woods of Minnesota, by *H. B. Ayres*; museum and library additions, list of meteorites in the museum, petrography and geology of the Akeley lake region, *W. S. Bayley*, New Lower Silurian Lamellibranchiata, *E. O. Ulrich.*

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IV. BULLETINS.

No. 1. History of Geological Surveys in Minnesota. 1889. By *N. H. Winchell.*

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No. 7. The Mammals of Minnesota A Scientific and popular account of their features and habits, with 23 figures and eight plates. *C. L. Herrick.* 8vo. pp. 300. 1892.

No. 8. I. The Anorthosytes of the Minnesota coast of lake Superior. II. The Laccolitic sills of the Animikie rocks of lake Superior. —*A. C. Lawson.* In press.