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THE GEOLOGICAL

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NATURAL HISTORY SURVEY

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The Twenty-third Annual Report, for the Year 1894.

N. H. WINCHELL,
State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, STATE PRINTERS.
1895.

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ADDRESS.

MINNEAPOLIS, MINN., Dec. 20, 1894.

To the President of the Board of Regents:

DEAR SIR—I have the honor and the pleasure of tendering herewith the twenty-third annual report of the Geological and Natural History Survey, so far as pertains to the progress made in the geological department thereof, accompanied by some statements respecting the General Museum and the library accessions.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

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SPECIAL ASSISTANTS IN 1894.

E. O. Ulrich.................................. ......Paleontology
J. M. Clarke........... ....Paleontology
H. V. Winchell..................................Economic Geology
H. B. Ayres.......................... .... Mapping of Carlton Co.

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ILLUSTRATIONS.

ERRATA.

Page 32, tenth line from bottom, for "district terrane" read distinct terrane.

Page 79, sixteenth line from top, for "$1,958.85" read $1,058.85.

Page 79, seventeenth line from top, for "$5,535.33" read $4,635.33.

Page 195, fifth line from bottom, for "∞P, P∞" read ∞P∞, P.

I.

SUMMARY STATEMENT.

The work of the year has consisted chiefly in the study and arrangement of field-notes and collateral data and the preliminary examination of some of the specimens collected. Some of the final maps and manuscripts have also been prepared. Contour lines, based on the barometic and other levels obtained by the survey, have been placed on most of the township plats. The geological boundaries having been, in the main, determined with sufficient exactness by the field work of 1893, it remains only to draft the final sheets and compare and adjust all the data for the final report. This is progressing as fast as possible. Prior to the final description of the formations, all the field specimens must be examined more carefully than it has yet been possible to do. This is a tedious and technical process in which chemical and microscopical methods are followed.

During the year considerable labor has been put on a reconsideration of the general classification of the rocks of the lake Superior region, involving the study of some more remote collateral questions. This has been done preparatory to the correct grouping and naming of our oldest formations. This labor is not yet finished, and will not be till the final report is completed, as it is a continuous and progressive development, which has such wide scope that all geologists, who are, or have been, at work on the rocks, are contributors to the result.

The economic development of important interests in the northern part of the state has been constantly observed and noted. This repeated appearance of new and interesting geologic features incident to such development tends to delay the progress of the work toward the closing up of the investigation. It becomes necessary to re-examine the localities where these new developments spring up in order to embrace the facts in the general discussion. The recent discovery of considerable quantities of gold in the vicinity of Rainy lake led to one of these new developments. The survey, while it is in active progress, also incurs a certain obligation to examine and report upon such interests, in order to furnish to the public authentic information. Such information serves to correct the wild rumors that sometimes get started, and often prevents the waste of ill-guided exploration by directing would-be investors in the essentials of profitable enterprise. In the months of September and October an examination was made of this region by Dr. U. S. Grant and Mr. H. V. Winchell, and their joint report on the same is embraced in the following pages. The assays which have been made of specimens procured by them in the field warrant the statement that gold exists in the Rainy lake region, in some places in sufficient quantities for successful quartz mining. These localities are near the International boundary line, and mostly in Canadian territory. There are some encouraging locations within Minnesota territory. The interest that has been aroused on this subject has attracted many to the district, resulting in the creation of several townsites which have several hundred inhabitants, as well as drawing attention to the fine agricultural lands of the Rainy river valley, and to other natural resources.

Volume III of the final report is still in the printer's hands. It has been delayed in completion by several unavoidable causes, but principally by a change in plan as to the amount of paleontology it should contain. It was decided to embrace a report on the gasteropods and cephalopods of the Lower Silurian, with the necessary plates. This would so enlarge the volume that it was thought best to put it up in two "parts," and it will be so published. During the last year there have been published independently some of the chapters of this volume, viz.:

Chapter VII. The Lower Silurian Ostracoda of Minnesota. By *E. O. Ulrich*. Pp. 629-693, 4 plates; published July 24, 1894.

Chapter VIII. The Lower Silurian trilobites of Minnesota. By *John M. Clarke*. Pp. 694-759, with 82 figures in the text; published Sept. 27, 1894.

The twenty-second annual report has also been published. The collaborators on the survey have published elsewhere the following contributions, devoted mainly to the geology of the state and of the northwest.

The fishing banks between cape Cod and Newfoundland. *Warren Upham*. Amer. Jour. Sci., 3, vol. xlvii, pp. 123-129, Feb., 1894.

Diversity of the glacial drift along its boundary. *Warren Upham*. Ibid., 3, vol. xlvii. pp. 358-365, May, 1894.

British drift theories. *Warren Upham*. Amer. Geol., vol. xiii, pp. 275-279, April, 1894.

Tertiary and early Quaternary baseleveling in Minnesota, Manitoba and northwestward. *Warren Upham.* Ibid., vol. xiv, pp. 235-246, Oct., 1894.

Tertiary and Quaternary stream erosion in North America. (Abstract.) *Warren Upham.* Amer. Ass. Ad. Sci., vol. xlii, pp. 181-183, 1894.

Pleistocene climatic changes. *Warren Upham.* Geol. Mag., new ser., dec. 4, vol. i, pp. 340-349, Aug., 1894.

Wave-like progress of an epeirogenic uplift. *Warren Upham.* Journ. of Geol., vol. ii, pp. 383-395, May-June, 1894.

The epeirogenic theory of the causes of the ice age. *Warren Upham.* Glacialists' Mag., vol. i, pp. 211-217, May, 1894.

Quaternary time divisible in three periods, the Lafayette, the Glacial and Recent. *Warren Upham.* Amer. Nat., vol. xxviii, pp. 979-988, Dec., 1894.

Evidences of superglacial eskers in Illinois and northward. *Warren Upham.* Amer. Geol., vol. xiv, pp. 403-405, Dec., 1894.

Composite generic fundamenta. *John. M. Clarke.* Amer. Geol., vol. xiii, pp. 286-289, Apr., 1894.

American species of Autodetus, and some paramorphic shells from the Devonian. *John M. Clarke.* Amer. Geol., vol. xiii, pp. 327-335, May, 1894.

Early stages of Bactrites. *John M. Clarke.* Amer. Geol., vol. xiv, pp. 37-43, pl. 2, July, 1894.

Nanno, a new cephalopodan type. *John M. Clarke.* Amer Geol., vol. xiv, pp. 205-208, Oct., 1894.

Artesian water-supply for Minneapolis. *N. H. Winchell.* [A letter to the City Council]. In the official proceedings of the Council, and in the Evening Spectator, Minneapolis, Aug. 25, 1894.

The Columbian Exposition. Some special state exhibits of the crystal line rocks. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 108-113, Aug., 1894.

The origin of spheroidal basalt. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 321-326, Nov., 1894.

Sketch of Dr. John Locke. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 341-356, [portrait], Dec., 1894.

A new meteorite, Minnesota No. 1. *N. H. Winchell.* Amer. Geol., vol. xiv, p. 389, Dec., 1894.

A sketch of geological investigations in Minnesota. *N. H. Winchell.* Jour. of Geol., vol. ii, Nov., 1894.

The state of Minnesota. *U. S. Grant.* Compte Rendu de la 5me Session du Congres geologique international, pp. 302-311, Washington, 1893.

Although the years 1893 and 1894 have witnessed a general and severe financial depression, the development of the iron ores of the state has been unabated. The shipments during 1893 were 739,919 tons from the Mesabi range and 820,621 tons from the Vermilion range. For 1894 the Mesabi range pro- 1,790,000 tons and the Vermilion range about 1,000,000 tons. A more detailed statement is given on another page of this report.

II.

THE ORIGIN OF THE ARCHEAN GREENSTONES.

BY N. H. WINCHELL.

In the twentieth annual report the writer presented some "preliminary considerations as to the structures and origin of the crystalline rocks." In the progress of that discussion he had occasion to make reference (pp. 20-25) to the Archean greenstones. Attention was directed to their anomalous character, their stratigraphic position, and to the limited scope of the philosophy which assigns them to a changed condition of basic irruptives through the action of dynamic metamorphism.

In the further consideration of the same subject it became necessary to study more carefully the work of Dr. Geo. H. Williams, in his valuable contribution to the geology of the northwest, then lately published.*

The tendency of the conclusions reached by Dr. Williams is to refer the greenstones as a body to dynamic metamorphism of massive irruptive rocks. Some of the crucial issues of this investigation, as they appeared to the writer were brought out in that former discussion, which offered a preliminary dissent from this conclusion, and which presented the bearing of some important broad considerations which indicated in general a sedimentary origin for the mass of the greenstones. The writer has also briefly referred to this subject in a paper on the greenstone agglomerate at Ely, Minn.†

The following pages will be devoted to a critical examination of the published work of Dr. Williams, based mainly on the facts presented by himself, but partly on the writer's own acquaintance with the regions described by him.

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*_The greenstone schist areas of the Menominee and Marquette regions of Michigan; a contribution to the subject of dynamic metamorphism in eruptive rocks_, by GEORGE HUNTINGTON WILLIAMS, with an introduction by ROLAND DUER IRVING. (Bulletin 62 of the U. S. Geological Survey, Washington, 1890, pp. 241, and 16 plates). Received by the writer March 5, 1891.

†The Kawishiwin agglomerate at Ely, Minn., Amer. Geol. vol. ix, pp. 359-368, 1892.

It was in April, 1893, that this review was begun by the writer. He has devoted to it such hours as have been free from other duties, at irregular intervals, until it has assumed the proportions of a chapter far beyond the magnitude which was contemplated. The writer is conscious that the work is one of the *chefs d'œuvres* of the U. S. Geological Survey, and that it has already had a powerful influence in directing the sentiment of all geologists who have not specially interested themselves in this question. It is not expected that this criticism will counteract that tendency to any important degree. It will require another similar treatise, prepared with equal ability from a different point of view, to effect that result. In the meantime, however, as the writer in the course of his study of the crystalline rocks of the state, comes upon this question, he is forced to consider it before he can proceed with his further studies. Not being ready to accept some of the leading conclusions reached by the author respecting the greenstones of the regions discussed, it appears to be necessary to present in some detail the objections, and the reasons therefor, which he entertains.

The greenstones are the *bete noire* of the geologists of the crystalline rocks, and he who attacks them should consider well the hazard before he lets fly his first sling. The work of the writer on these ambiguous rocks has been largely in the field, but supplemented with laboratory and library studies, and he has experienced some fluctuations in his views as to their origin from time to time as he received new evidence. At first disposed to class them among clastic rocks, the derivation of whose sediments he considered problematical and did not venture to inquire into, he was induced later by the preponderating testimony and judgment of microscopical lithologists, to theoretically group them as eruptive in order to justify what he thought a necessary postulate respecting some of their attendants. After further and prolonged examination in the field, accompanied by some studies of their microscopical structures—his own and those of others—he was compelled to return, in a large measure, to his original opinion. His present belief is, therefore, that the great bulk of the "greenstones" as an Archean terrane, ought to be classed as *pyro-clastic*, i. e., that they originated from eruptive agencies, as tuff and all kinds of volcanic debris sometimes very coarse, and were distributed and somewhat stratified by the waters of the ocean into which the materials fell. That there would have been, and that there is evidence to show that there was, in conjunction with such volcanic outbursts, an occasional escape from the same vents, of liquid lava, he is quite ready to admit, but he considers these as subordinate features, and with great difficulty identifiable. He would reverse the main conclusion of Dr. Williams as to the comparative amounts of these two sorts.

With this brief statement of the point of view from which this review is written, and an acknowledgment of his indebtedness to Dr. Williams for many fruitful ideas, and of patriotic pride in the capacity which he has shown as an American geologist in the production of so thoughtful and learned research in this difficult field, the writer desires simply to call attention to some of the passages in the interpretation of facts and in the scope of the philosophy of the bulletin, which appear to be faulty, fundamentally, and therefore to impair materially, the validity of the author's conclusions.

As to the interpretation of facts, it will be convenient to divide them into (a) megascopic, and (b) microscopic.

As to the author's use of the theory of "dynamic metamorphism," we shall present some considerations under the following divisions, viz: (a) dynamic metamorphism as a theory, calling attention to an essential difference between reconstructive metamorphism and a retrogressive mineral change such as shown by the greenstones and the green schists. (b) The greenstones as a geological terrane.

(a) MEGASCOPIC FACTS NOT NOTED OR MISINTERPRETED

First and chiefest amongst the megascopic facts here to be mentioned is the wide and almost universal stratiform structure which can be seen in the greenstones of the lake Superior region. It is true that the author confines his discussion strictly to the Marquette and the Menominee regions, and is not presumably responsible for facts that are to be found in other parts of the region. It is reasonable, however, that an author who draws broad conclusions respecting a rock terrane which extends over many districts, should be held accountable to all the facts that may be found characteristic of that terrane throughout its extent. If the interpretation which he finds sufficient for the facts in the area which he examines be not sufficient to cover the essential facts pertaining to the same terrane in another part of the region, his conclusions are faulty and must be amended or abandoned. In this case shelter cannot be taken from this responsibility by suggesting that the greenstone schist belts of the Archean in Minnesota, or of Canada, or even of Europe, are possibly not in the same stratigraphic series, and may therefore not have a similar origin and history, for the stratigraphic place of the Archean greenstones here discussed is well ascertained, and has been avouched to be the same not only throughout the northwestern states, but in European countries wherever their taxonomic place has lately been determined. They constitute the uppermost of the three grand stratigraphic divisions of the Archean.* This was involved in the final conclusion of Prof. Irving respecting this (Marquette) region (p. 19), and had before been announced distinctly by N. H. Winchell for the greenstones of the Archean in Minnesota.† However, whatever their stratigraphic position, or their age, the scope of the investigation is stated by Prof. Williams to be such as "to discover if possible the origin of the greenstone schists of the lake Superior region." (P. 31). This he enters upon, however, with an evident pre-conceived determination to make the investigation a contribution to the metamorphism of eruptive masses. (P. 30).

Now the general stratiform structure which these greenstones present, and their evident megascopic fragmental character can be seen in many places about Marquette and also quite distinctly at the Lower Quinnesec falls on the Menominee river. Indeed, Prof. Williams himself, as noted by Prof. Irving in his introductory note (p. 23), ascribes the most of the greenstones of the Marquette area to a "surface origin," as contrasted with a deep-seated irruptive origin, their original condition having been that of a volcanic tuff, and Dr. Williams himself admits that the northern area of greenstone at Marquette is of sedimentary origin. In the Menominee area, where these rocks are described as exhibiting little or nothing that points to sedimentary, or surface, origin, is a large exposure of plainly fragmental rock. This fact was noted by Dr. M. E. Wadsworth in a recent report‡ in the following terms:

In this connection it may be well to correct a very striking error in Williams's work, in which he describes the transition of eruptive diabases into sericitic schists at the Lower Quinnesec falls. This error is apparently due to a failure to observe the well-marked conglomeratic structure of the rock on the Michigan side of the falls, which shows that the main

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* MICHEL LEVY: Sur l'origine des terrains cristallins primitifs. Int.Cong. Geol., London meeting, 1888 (1891). Pp. 117-118.

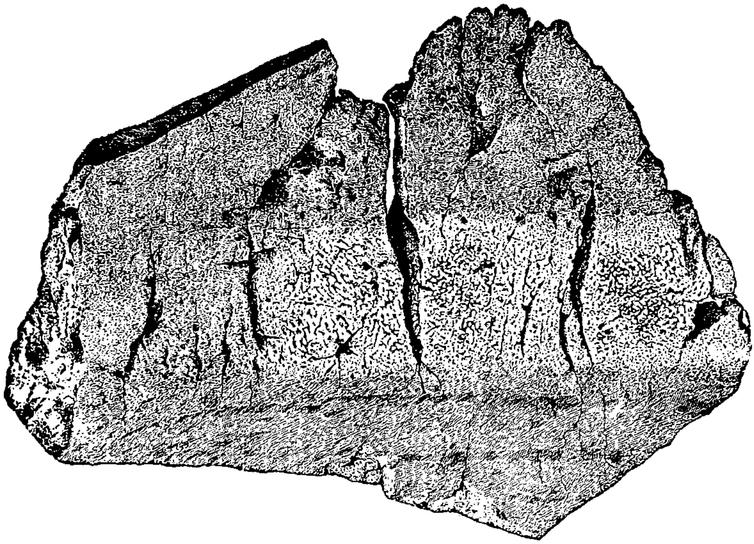
† Seventeenth Minnesota Report, pp. 43-44.

‡ Report of the State Board of Geological Survey of Michigan, 1893, p. 125.

rock at these falls is not a massive eruptive diabase or diorite, but a porodite (an old eruptive ash or conglomerate). * * * * Of the fragmental and conglomeratic nature of the rock no one can possibly doubt after studying it on the Michigan side, below the falls, and then tracing it back into the finer-grained and more compact part near the bridge. So good an observer as Williams could hardly have been led astray if he had examined the whole ground. A similar mistake seems to have occurred at the upper Quinnesec falls.

Under the guidance of Dr. Wadsworth a party of about twenty geologists, making an excursion from the late sessions of the Geological Society of America and of the American Association for the Advancement of Science, at Madison, 1893, visited and inspected the very place to which Dr. Wadsworth here refers. It is perhaps an eighth of a mile below the bridge (and the falls) on the left bank of the river. The trees have been removed and the rock is bare in many places. Scattered through the greenstone are numerous pebbles or small boulders, mainly of a nature similar to that of the rock embracing them, but sometimes much more siliceous. They are so numerous as to be in contact. Rudely stratified patches occur, and in one case a considerable outcrop of jaspilitic silica, with cloudings of color (red and purple), stands out to view. There seemed to be a general concord with the criticism made by Dr. Wadsworth. It was quite evident that here was a considerable area of plainly fragmental rock embraced in the greenstone of the Lower Quinnesec falls Indeed the general appearance, not only here but at most points at these falls, observed by the writer on the occasion of this visit, was not unlike many occurrences which might be referred to in Minnesota. It is simply a question of weight of evidence—as between the eruptive characters and the fragmental. Confessedly Dr. Williams did not find any characters, even microscopic, of undoubted nature, in this rock which would ally it with certainty to the eruptives. But all the indistinct microscopic evidence adduced can plausibly be explained on the supposition of a fragmental origin for the whole. On the other hand the rock presents, as stated above, certain unmistakable evidences of original fragmental nature. These unquestionable evidences carry great weight as against certain hypothetical microscopic structures, which can easily be accounted for on the supposition of an original fragmental origin. Hence the rock at the Lower Quinnesec falls, or the greater part of it, can be classed with the tufaceous greenstones of the Marquette region which Dr. Williams allows to have had a sedimentary origin.

In connection with the interpretation of the megascopic features of these greenstones, Dr. Williams fails to note important distinctions. There are, *a priori*, various kinds of lamination, of banding, of schistose structure and of foliation, and they have different causes, but Dr. Williams refers to them all with indifference, and assigns them all to dynamic pressure and shearing. The only exception to this is seen in the case of the "banded greenstones" north of Marquette. Here the stratification is so evident that the author admits it is a sedimentary structure, although it resembles in many respects, and in its intimate structure grades into, that banding and schistosity which characterize the greenstones in other parts of the Marquette area regarded by the author as of dynamic origin. Some of these structures are certainly due to pressure and shearing, even in the rocks at the Lower Quinnesec falls, but some of the others are not. This general confusion, and lack of appreciation of these different structures, may be illustrated by the use made of the rock specimen figured on page 81, reproduced below.



Great stress is laid on the open transverse fissures or gashes which appear as in the figure on the weathering out of some of the secondary minerals on the face of the rock wall of the "gabbro ridge" of Brooks (dioryte ridge of Williams), but no mention whatever is made of the light colored band which extends entirely across the specimen—as shown in the figure. To the eye of the writer these gashes may be due to glacial action or even to a later period of dynamic pressure. Similar gashes have been seen in the quartzytes of Minnesota,* and Dr. E. Andrews has seen somewhat similar markings in a similar rock on the northeastern shore of lake Huron.† In both cases they were unhesitatingly ascribed to the action of glaciers. However, whatever may be the cause of these "gashes," there seems to the writer but little doubt as to the cause of the light-colored band—it is plainly a sedimentary bed, and its existence can be referred to the action of the ocean which received presumably, and more or less distributed all its materials here, as well as the pebbles and other fragmental material seen in this rock a short distance below the falls.

This light colored band is certainly of the same nature and origin as other bands seen at the Lower Quinnesec falls, attributed by the author to dynamic shearing along certain parallel planes within the mass of the rock, and if he would be consistent he would be compelled to ascribe this band to the same cause. This explanation, however, would annul his argument for the dynamic origin of the gashes, since they stand at nearly right angles in the same rock mass.

Some other megascopic characters which evince a stratified sedimentary condition for the original rock are ascribed to frictional movement along certain planes and not along others. Indeed a plain banding which is quite like that seen in many of the fine graywackes and slates into which these greenstones gradually pass (in other places), and which is incontestably of sedimentary origin, is explained away as an effect of dynamic pressure and shearing There is plainly a greater fineness of grain, and a greater supply of quartz in some bands than in others, but this greater amount of quartz, and the coincident greater change in the associated minerals, are attributed to a greater activity of chemical change attendant on these planes of supposed greater slipping in the rock-mass. As an instance of the nature and the use made by the author of the microscopic phenomena to explain and annul what by most geologists would be taken as plain megascopic evidence of stratification by sedimentation, we give the following extract from page 87. The italics are the writer's:

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*Final Report on the Geology of Minnesota. Vol. 1, p. 548.

†American Jour. Sci. (3), xxvi, 101.

Nos. 11004 and 11010, taken from either side of the above described band, [*i. e.* a "band of much lighter colored rock"] represent somewhat schistose varieties of it, which have been *produced by the action of pressure. That this is actually the case is admirably shown by a microscopic examination.* The hornblende of the original rock seems to have passed completely into a very pale and colorless chlorite. Saussurite, on the other hand, is less abundantly developed than in the more massive rock above described, and it is disposed in narrow veins or in small, irregular spots. The ilmenite has given its place to a dark gray substance resembling leucoxene. This is drawn out in stringers following the direction of the schistosity, and in the centre of these a yellow grain of rutile may sometimes be observed. Calcite is also present. The structure of the rock is completely different from that from which it is supposed to have been derived. It is now composed largely of a fine-grained ground-mass. This is made up of a micrograniitic aggregate of minute grains of an unstriated substance resembling quartz but which, from its high specific gravity, is probably a feldspar.

We fail to see in these chemical and microscopic characters a proof of the application of pressure. If we were to attempt to explain them we do not see any difficulty in considering these schistose bands more siliceous and finer bands of tufaceous sedimentary materials. Being finer the mineral fragments were more changed from their originals prior to consolidation than were the minerals of the "more massive bands"; and again, being of finer grain, they took on the slaty schistosity under pressure more readily than the coarser and more massive strata. It is well known that a slaty cleavage, and hence a schistosity, which is a result of intersecting multiple cleavage, is frequently developed, in sedimentary graywackes, in the fine-grained strata, but does not appear in the coarser ones, although the coarser ones must have been subjected to the same pressure in the same directions and in equal amounts. The writer has seen this exemplified in a succession of layers made up of materials of differing fineness. It is a common fact exemplified in all roofing-slate quarries. We also cannot understand why a crushing or shearing pressure, presumed by the author in so many instances to account for a finer grain and for a degradational change in the concerned minerals, would not, with its predicated greater chemical activity, cause a chemical reconstruction of those minerals instead of a retrogression. Nor is it easy to see how, under dynamic action, such crushing and slipping could be made to pervade in some cases very thin layers or strata in the bulk of the rock, and in others should affect very large thicknesses (p. 105), and that these alternating coarse and fine kinds should be distinctly and persistently separable from each other in straight parallel planes extending for many feet or even many rods, and until the exposed surfaces become hid from view. This feature of Dr. Williams' philosophy, however, will be examined separately. We here only allude to it as it is involved in his attempt to account for some of the magoscopic features by hypotheses somewhat novel and ill-founded. We are aware that during the last ten years great progress has been made in deciphering these "parallel structures" of rocks, and in assigning them to their causes. In this progress it has been shown that in many instances "certain parrallel structures" have been mistaken for sedimentary structure. Some extreme statements have, however, been made, to the effect that a parallel banded structure of differing composition and varying fineness of grain *is no evidence whatever of an original sedimentary origin.* But such wild affirmations, in the face of a uniform, worldwide experience and testimony to the contrary, carry with themselves their own refutation. It would hardly be more absurd to affirm that there is no such thing as a sedimentary structure. It remains to be seen whether some of the "banding" which petrographers have ascribed to other causes may not still have been primarily of sedimentary origin.

It is a singular fact, and one which is responsible for numerous errors of observation and interpretation, that stratification and cleavage are frequently, and prevailingly, parallel in the same rock mass. When they cross each other, as they do in some important areas in northeastern Minnesota, they are seen to diverge also in the proper characters by which they are separately identifiable, and each can be fully described by itself. But the well-nigh universal fact that they agree in direction is a significant index of a certain common history, pointing to a participation in some common experiences. Now this direction is usually broadly parallel to the ancient shore-lines of the adjacent land areas. The increments of land to the continent were marked by pressure and upheaval, which would not only be felt most markedly along the previous lines of weakness in the crust coincident with the strike of the sedimentation, but would at the same time produce a parallel schistosity in the rocks so raised above the sea. The latest of the Archean formations is the Kawishiwin and, as it shows both of these structures, it must have shared in this common experience. In other words, it must have been amenable to the same influences as an oceanic terrane, and it must therefore have had the widespread distribution of an oceanic terrane rather than the erratic and restricted distribution of an irruptive one.

In the description of the greenstones seen at the Lower Quinnesec falls Dr. Williams calls attention to some patches of porphyritic rock, and he is impressed with what he considers an anomalous condition of these feldspar crystals, viz., they do not show the degradational change, to that degree which prevails in the rest of the rock. He strives to account for this in the following way:

I know of no way of interpreting this phenomenon, substantiated by so many instances, except by supposing that the pressure which acts powerfully in stimulating chemical action in the solid rock, is relieved in the harder grains of a crushed band, since these are able to change their positions by slipping among the softer materials. * * * The occurrence of the freshest feldspar in the most crushed rock must be regarded as the rule. (P. 88.)

In another instance, in discussing certain acid rocks at Marquette (p. 150), the author finds both quartz and feldspar grains in a rock which has undergone such dynamic action. The former is stretched and broken, but the latter is fresh, rigid and unchanged, and does not show evidence of great pressure. Here also the general principle which above is found to pervade the greenstones when porphyritic, is subjected to the anomalous hypothesis that feldspar is more enduring under pressure than quartz. But it is hard to believe that the feldspar endured the shearing and elongating action when the quartz was thus crushed. Under the supposition that the large grains were "able to change their position by slipping amongst the softer materials," the query naturally arises, why could not the quartz grains as easily slip from their places and avoid the pressure as the angular feldspar grains? It is perhaps more probable that the quartzes were original and that the feldspars were produced by the chemical action incident to the later dynamic forces.

This porphyritic structure at the Quinnesec falls is not common. The mass of the rock is destitute of it. Its fortuitous and limited occurrence suggests that it is not an original structure of the rock. A porphyritic magma would be likely to be wholly, or at least widely, porphyritic on cooling—at least if it moved in such quantity as to produce the greenstones of the region. It is hence reasonable to suppose that the chemical activities were sufficiently "stimulated" in this greenstone mass, by the shearing movements to which it has been incontestibly subjected, after consolidation, to produce the sporadic porphyritic areas which it now manifests. This would allow not only the local partial recrystallization, but would also give opportunity for any later disturbances to fracture to some extent the porphyritic feldspars, as described by the author, while still leaving them comparatively fresh or even building out their periphyries. It would also relieve the anomaly of supposing that feldspar, in some cases though not in all, substantially remains intact under such dynamic action as the author appeals to, and it would, further, account for the occurrence of these porphyritic feldspars, which in other places Dr. Williams seems to have determined to be albite (pp. 156, 157), prevailingly in those portions of the greenstone in which the greatest mechanical effect is observable, viz., in the fine and schistose areas. It is to be admitted that the author seems to have determined these crystals to be of labradorite. They would be expected to be of albite if of secondary origin, and outwardly they have a resemblance to albite. The physical characters which the author mentions are supposed to be diagnostic of labradorite (p. 88). The specific gravity agrees with labradorite, and the extinction angles on either side of the twinning line, being 12° to 20°, agree with those of labradorite, which, according to Rosenbusch, affords extinction angles of 5° to 27°. This anomalous preservation of feldspars in the midst of what is regarded by the author as the most crushed and "metamorphosed" of the greenstones, *i. e.*, in the fine banded schists below the falls, is mentioned at several places. (See pp. 92 and 93.)

The author describes (p. 92) ellipsoidal, or lenticular, masses of non-schistose rock about which the schists appear to wind, enclosing them entirely. Although he does not so state, we infer that the direction of the fibrous structure of the schists is constantly parallel to the outer surfaces of these ellipsoidal masses. The writer has observed this to be the fact in several instances. The author describes the outermost of these envelopes as a "typical chlorite schist" in which alternating and interlacing areas of pale green chlorite may be distinguished in a fine quartz-albite mosaic. He takes these minerals to be the product of the same mysterious agent (dynamic metamorphism) which is appealed to to explain a similar mosaic in the banded schists—the same also as is presumed to have caused the parallel banding which has widely been taken for sedimentary structure. It appears, however, that there is a curious anomaly in thus appealing to "pressure" to produce such a variety of effects. If pressure caused the parallel banding of the adjacent schists, as presumed by the author, (which we hope the reader will not confound with schistose structure), how can the same pressure produce at the same time a straight banding and a schistose structure which surrounds in parallel arrangement the periphyry of a lenticular mass and not only one, but many lenticular masses? Why should these ellipsoidal cores under the action of pressure be seggregated from the mass and surrounded by a finer rock arranged in schistose structure parallel to their periphyries, while they themselves show no such structure? They are largely decayed within, it is true, and have the grain of the surrounding rock mass in general. The mysterious agent then must have penetrated them thoroughly on the hypothesis of the author. It remains to account for this anomalous action of this agent. If, on the other hand, this be considered an agglomeratic portion of rapidly accumulating tufaceous sediment, received into an ocean heated perhaps by proximity to volcanic vents, and it be admitted that by the solvent action of its waters these sediments were changed mineralogically to about what they now appear to be, the finer and more siliceous parts of the residue, after oceanic levigation being allowed to lodge in the interstices between the coarser masses, surrounding them often in shells, as it were, of finer materials, and then the whole allowed to consolidate, and to experience the history which followed, what features, we may ask, would such a mass present after some pressure and stretching, which are not found in this rock by Prof. Williams?

The criticisms which have now been made of Prof. Williams' discussion of the megascopic features at the Lower Quinnesec falls, may in the main, be applied to his discussion of the same features at the Upper Quinnesec falls, as well as those at Sturgeon falls, for, as shown by him, the regions examined have a great similarity. The characters brought out at the latter place are particularly suggestive of fragmental origin (p. 71), viz: The structure of the rock is irregularly granular, none of the components being in any degree idiomorphic. Frequent and abrupt changes in the coarseness of the grain are observable. Colorless chlorite and zoisite are mixed indiscriminately, and often a mosaic of quartz and epidote, or of quartz and albite, composes the greater part of the finer-grained portion of the rock, or of the schists into which the coarser rock graduates, while the fragments of feldspar are seen to be broken and battered, and for the most part changed to sericite or calcite. These signs of fragmental origin we can perhaps attribute to the powerful solvent action of the Archean ocean. They are such as are ordinarily attributed to weathering, when they are found to characterize, under known mechanical and chemical exigencies, rocks of this character exposed to present atmospheric forces, and we have no reason to exempt Archean time from those effects of atmospheric action which we are familiar with at the present.*

Continuing the consideration of the magascopic characters which seem to have been omitted or misinterpreted by Dr. Williams, we may follow his course of investigation from the Menominee valley to the Marquette region. Here he divides the greenstone area into four parts; the eastern, western, northern and the Deer lake areas. The rocks of the northern part of the "eastern" area are so plainly banded by sedimentation that he concludes that they are derived from volcanic tuffs. The southern part, though widely characterized by a fine almost aphanitic grain and by what he designated, in the case of the Menominee greenstones, as "spheroidal parting," and though he gives no description indicating how they are related to the rocks of the northern part, he considers to be altered eruptive rocks. It might be stated here that the two grade into each other by imperceptible degrees, passing through a siliceous and hematitic phase, named *Eureka beds* by Dr. Romiger, in which some iron ore has been mined, all belonging to the same greenstone series, and that further west, on the pinching out of the siliceous, or jaspilyte band, the two parts become indistinguishable, blending into one, in the manner represented on the map of Dr. Romiger, and in the manner in which such jaspilyte lenses rise and disappear along the strike in the greenstones of Minnesota. Whatever origin may be assigned to the northern part of the Marquette area, it is difficult, if not impossible, to divorce it from the origin assignable to the southern.

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*Since the foregoing was written Prof. Williams has died. On resuming this study it is our first impulse to render to his memory some tribute expressive of the sense of loss which, in company with all American geologists, we experience in the sudden decease of one of our number when in the prime of his ability and activity. At 38 years of age Dr. Williams seemed to promise many years of active geological work. His brilliant career at Johns Hopkins University bespoke for the literature of American geology in the near future many and valuable contributions from his laboratory. Largely through his energy have the petrographical methods of Europe, and especially those of Germany, been introduced into America—greatly to the enrichment of our geological knowledge. He was not simply a petrographer, but a geologist of broad culture and grasp, who was as ready to apply his microscopic data to questions of greater scope as he was to discover the data. His occasional contributions to the geology of Maryland and of the Appalachians constitute some of the epochal steps of the geology of eastern America. Personally Dr. Willams was of courteous and engaging address, professionally obliging to all, socially making friends of all acquaintances, a ready and rapid speaker, a clear thinker and a beloved teacher. American geology has had but few his peer.

The "western" area of the greenstone is immediately in the line of strike of the southern part of the "eastern" area, and is continuously traceable from it. He also calls it the Negaunee area. He considers the greenstones of this area to resemble those of the southern part of the Marquette area. In the very center of this area, however, he found (p. 175) a remarkable fragmental rock, being a conglomerate resembling the "slate conglomerates" of the Canadian geologists and the Ogishke conglomerate of Minnesota. Impressed with the evidence of fragmental origin he frankly acknowledges that this rock, whose extension in no direction does he seem to have traced out, it is impossible to assign to any other than a fragmental origin and, although he here finds the same "spheroidal parting" as seen in the greenstones of the northern Marquette area, and the same kind of light-green aphanitic greenstone, he does not see any reason to assign the two rocks to the same cause. Nor does he attempt to explain in what way or at what place this fragmental greenstone can be separated from the other greenstones of the area. The acid masses embraced in this conglomerate are supposed by Dr. Williams to have been ejected by volcanic explosions in the midst of much basic ash, torn from the ducts through which the basic matter was discharged. It appears to the writer that the existence of this fragmental rock in this area of greenstone thus admitted by Dr. Williams, will be found fatal to the principal conclusion of the author touching the Negaunee area, for these conglomerates have been found to pervade the greenstones everywhere, and to fade out into them on all sides.

The greenstones of the "northern" area are "striped and banded" in the same manner as those of the northern part of the Marquette area, and are hence supposed to have been originally volcanic tuffs. In one of these, however, which he still seems inclined to have considered a massive rock originally, are porphyritic crystals of hornblende, recalling a green porphyrite schist found in northern Minnesota which has been classed with fragmental rocks after careful study by Dr. U. S. Grant.* Indeed, the general *tout ensemble* of these green schistose rocks closely compares with those about Kekequabic and Fall lakes in Minnesota, both of which have been pronounced fragmental on microscopic evidence.

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* Twenty-first Minnesota report, pp. 23-27.

Still further west, in the same general belt of greenstones as the Marquette and Negaunee areas, is the Deer lake area. Throughout this whole greenstone belt is a uniformity of topography, and a constancy of outward lithology which implies to the observant geologist a unity of geological origin and structure —a fact which could also be said to extend many miles further west. In the Deer lake area, to which the author's attention was directed by Dr. Irving, this greenstone contains many fragmental rounded forms, some of them being felsitic, but most of them of some form of greenstone. Here also, according to Irving, are indistinct traces of oceanic sedimentary structure. Dr. Williams styles these rocks "green schists and agglomerates," and welcomes the fragmental characters as confirmatory of the conclusions he reached respecting the banded greenstones of the northern part of the Marquette area, although here the banded structure is almost wanting. Here, also, the acid masses are thought by the author to be referable to some volcanic ejection by which fragments were torn from the walls of the ducts through which the more voluminous basic materials were discharged.

It appears then that the greenstone areas examined by Dr. Williams have prevailingly fragmental characters. This is apparent from the descriptions if not from the general conclusions he has given. The only exceptions are, (1) the Menominee area, and, (2) the southern part of the eastern area at Marquette. Still even in the Menominee area he allows certain portions to have had a fragmental origin, viz., at Four-Foot falls and at the Upper Twin falls, pp. 124, 132.

He puts the whole of the northern Marquette area, the northern part of the eastern area at Marquette, the Deer lake area and a part of the Negaunee area (which part cannot easily be separated from the rest of the Negaunee area), amongst the volcanic tuffs which bear unimpeachable proofs of sedimentation, and, as has already been stated, an important area of evidently fragmental rock occurs in the Menominee area at the Lower Quinnesec falls, and cannot there be distinguisbed geographically from the rest of the Menominee greenstone. Another is reported by the author at the Upper Twin falls (p. 133.)

To a geologist who has traveled over these greenstones for many miles, and for many days of many seasons, this result is not at all surprising, for one of their most frequently recurring phenomena is a fragmental and a conglomeratic composition, a feature which goes so far sometimes as to make the rock change to a siliceous porodyte with little or no trace of the ferromagnesian minerals remaining. It is such fluctuations, which occur both gradually and sporadically, that have caused the writer, when he has studied them in the field, to doubt the original massive character of any of them. It is hard to understand how such wide-spread fragmental characters could pervade a great formation, and yet that it could be properly classed broadly as an original massive rock changed to its present features by subsequent metamorphism. Instead of throwing the burden of proof, as to origin, upon the fragmental theory, when the megascopic characters become uncertain, with an assumption in favor of the irruptive theory, it seems to the writer that this burden lies upon the advocates of the irruptive hypothesis, and that the preponderance of evidence, from a megascopic point of view, is strongly in favor of a sedimentary origin of all such ambiguous greenstones.

In further discussion of the megascopic characters it is nec cessary to call attention to the confusion into which Dr. Williams seems to have fallen in the use of terms denoting megascopic structures. The writer has elsewhere* called attention to the variety of structures which are found in the crystalline massive rocks, and to the necessity of clear definitions for the terms applied to them. It is when clear ideas of these structures and their possible causes do not exist in the mind of the geologist that he is led to generalizations which embrace them all, or several of them, incorrectly. The point of view from which he approaches their discussion also inclines him favorably toward the abandonment of distinctions which ought to be carefully noticed. These truths are exemplified by some of the sentences of this bulletin. The following may be noted:

On p. 168 dykes are called "bands" of coarser materials.

On p. 192 the coarser layers of what some have considered sedimentary stratification are called "bands."

On p. 171 *et passim*, a schistose structure is called a "foliation."

On p. 179 a slaty cleavage is called a foliation. See also p. 202.

On p. 179 a quarzyte lying between two conglomerates and dipping steeply in conformity with them toward the south, is denied the structure of stratification and is said rather to be "foliated" by pressure.

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* Twentieth Report of the Minnesota Survey. "The crystalline rocks; some preliminary considerations as to their structures and origin." 1891 (1893).

On p. 110 a banded structure, consisting of gneiss alternating with green schist, is described, and a distinction is drawn between it and a schistose structure which is said to sometimes pervade the gneiss. But on p. 110 the banded structure and the schistose are confounded in one sentence as the same, and due to the same cause, viz., "The schistose or banded structure of these rocks, when such exists, is a secondary feature, produced by the same dynamic agencies which rendered the greenstones themselves schistose." The shifting of the name here, however, does not destroy the sense. It only shows a looseness of the use of these terms. Many such cases could be pointed out, viz , pp. 40, 44, 45, 82.

In many places the term "parallel arrangement" is employed. It seems to be applicable to various structures, and is made to cover several. On p. 149-50 it is used to express the arrangement of new crystallization products which give rise to a gneissic or "flaser" structure, produced by pressure. On p. 157 it indicates the disposition of microscopic hornblendes. On the other hand, it is applied to many macro-structures, and in some cases without definition. It is obvious that in many such cases the reader is wholly at a loss to comprehend the idea designed to be conveyed by the author when it is not defined in the context. This seems to indicate that all, or nearly all, the "parallel" arrangements are assignable, in the mind of the author, to the same cause, and that it matters little whether the specific structure under consideration be defined carefully or not. Nothing will illustrate this more completely than a single quotation. On p. 201 the author gives his idea of macro-structural metamorphism, and says:

> This embraces all modifications in the structure of the massive rocks produced by dynamic agencies and plainly visible to the unaided eye. Such changes consist, for the most part, in the production of a banding, foliation, or schistose structure which tend to make the eruptive rocks resemble stratified deposits. They are a secondary feature and must be correlated with the slaty cleavage, not with the original bedding of sediments.

The author lays great stress on the occasional divergence of the schistose bands, which appear in the greenstones at the Upper Twin falls (p. 132), from the normal and usual direction for the region, and argues from this divergence that the banding cannot be due to sedimentary structure. He infers therefore that it must have been due to crushing pressure acting locally in different directions and that no part of the banding seen there, however much it resembles that banding at Marquette which he acknowledges is caused by sedimentation, can be referred to sedimentary action. But this argument would prove too much, for it can be applied to all parts of the greenstone terrane. There is nothing more evident in the greenstones in the region of Tower, Minnesota, than the divergence of sedimentation banding from the normal direction there prevalent. This is so common that it involves not only the green schists but the sericitic schists and the graywackes and jaspilytes,—and even the argillitic slates into which the chloritic schists gradually pass. Some years ago the writer employed this common fact to disprove the eruptive origin of the jaspilytes at Tower.* Such sudden divergences of the jaspilyte beds from the prevailing direction had been presumed to prove the eruptive origin of the jaspilyte. On the contrary it was found that, along with all the sedimentary rocks of the vicinity the jaspilyte had been broken, and the several strata had been thrust amongst the neighboring beds and made to hold various angles with the direction of the prevalent strike. Such features were illustrated in the report referred to. They proved, on the argument appealed to for the jaspilyte, that the argillytes and the graywackes must also have had an eruptive origin, thus reducing the argument to an absurdity. This consideration taken with the discovery made by Dr. Williams and reported by him on p. 133, that one of these bands showing such contrast at the Upper Twin falls was made up of fragmental materials, certainly goes far toward putting a negative upon the general conclusion of the author as to the nature of these fine-grained bands.

Before closing the discussion of the megascopic evidence brought forward by the author, it may be profitable to present in a summary form the results that seem to be derivable from this part of the examination. Employing only the facts and interpretations which are presented in the bulletin, the two kinds of rocks described by the author, *i. e.*, those that he presumes to have been massive and those which he finds to have been fragmental, are found to exhibit the following features in common. This comparison is not intended to involve those intrusive rocks, of later date than the greenstone formation, which are found everywhere amongst the Archean terranes, and which the author also describes in this bulletin. Only one acquainted with the region can distinguish, sometimes, whether

*Fifteenth Report of the Minnesota Survey, pp. 231-243, 1886.

the author has in hand one of these later intrusives or one of the original greenstones, for the field evidence is frequently defective.

Common megascopic characters.

They both show a banded structure which constitutes an apparent stratification. Pp. 97, 125, 164; pp. 133, 154, 185.

They show the same direction of strike and of schistosity. Pp. 110, 129; p. 154.

In both the coarser bands grade imperceptibly into the finer. P. 75; p. 176.

They both have a parallel structure in all their parts, both macroscopic and microscopic, which runs uniformly in the same direction, on a broad scale, for any certain place, but occasionally bands of schistose finer material are seen in each to diverge somewhat from the normal direction. Pp. 129, 132, 203; pp. 156, 186 (Irving).

They both graduate into silvery hydrous schists. P. 105; pp. 177, 190.

They both appear in the form of massive aphanitic greenstones. P. 164; p. 176.

They both appear as massive granular greenstones. Pp. 77, 84, 126; p. 155.

In both the alternation of lighter and darker bands is due to the preponderance of calcite and chlorite, and sometimes of quartz and epidote, in the lighter bands. P. 75; p. 156.

In both the structure of the rock may be irregularly granular, none of the components being in any degree idiomorphic, with frequent and abrupt changes in the coarseness of the grain. Pp. 68, 71; pp. 176, 187.

In both there is an absence of amygdaloidal structure. The only amygdaloidal rock mentioned is 11746, occurring near Baldwin's kilns, in a "well marked dike." P. 174; p. 201.

They both show the peculiar "spheroidal parting." P. 168; p. 177.

They are sometimes entirely destitute of characters that point to an eruptive origin. Pp. 74, 156, 164; pp. 154, 158.

They sometimes manifest clearly certain proofs or signs of sedimentary origin. P. 133; pp. 176, 188.

In the field they cannot be separated geographically.

It may be questioned reasonably whether the rocks of such marked characters, showing such macroscopic resemblances and such close relations, stratigraphic as well as geographic, can be said to have separate origins. Certainly on the basis of magascopic characters, even when reported by a geologist who entered the field with an avowed leaning (p. 31) toward the eruptive hypothesis, and even reaches a contrary general result, the evidence of sedimentary, or at least a fragmental, origin greatly preponderates.

This bulletin was written under the guidance of the view of Prof. Irving that the iron ores at Marquette and at Menominee are all in one and the same formation, and that none of the ore at those places is embraced within the greenstones. Since then it has been admitted by the geologists of the U. S. Geol. survey that the distinctions made out in Minnesota are observable in Michigan, and hence one ore horizon is much lower than the other, and is, indeed, involved, as in Minnesota, with these greenstones. This misconception of the geologic relations of the Michigan ore bodies is responsible for some of the errors into which the author has fallen. For instance, he has supposed the Eureka iron ore near Marquette to belong to the later "iron-bearing" strata of the region of Negaunee, and excludes it from the greenstones, while actually it is a lens of jasper and impure hematite within the greenstones, shading into novaculytes, east and west, in a manner similar to hundreds that occur in Minnesota. Again, the fragmental chloritic slates which occur below the Four-Foot falls in the Menominee area are excluded from the greenstones on the hypothesis that they belong to the iron-bearing detrital rocks, although there is no structural evidence to show it, but rather everything indicates that they are a phase of the green schists that prevail in the region. The Wisconsin survey sheets xxviii and xxix indicate that these chlorite slates are in the same formation as the greenstones. Again, the greenstone knobs about Negaunee, which certainly are outliers of the main greenstone belt, rising in the midst of the later iron-bearing rocks which lie non-conformably upon their slopes, are thought by Dr. Williams to be of the nature of the later intrusives and comparable to the diabase dikes which cut Lighthouse point. The correction of these misconceptions obviously involves important changes in the conclusions reached by the author as to the derivation and geologic history of some of the rock masses he has discussed.

(b). MICROSCOPICAL FACTS.

In this examination of the microscopical facts reported by Dr. Williams we shall simply collate them as he has determined them, without calling in question their actuality. In case we find reason to ascribe to them different significance, and hence to give them different interpretation, we shall do it with great deference to the learning and skill of the author. The writer has elsewhere insisted on the subordination of microscopic evidence to field evidence, and on the necessity of finding some middle ground on which the opposite testimony of these two methods of research whenever they seem to be contradictory, can find free and consistent standing,* since one natural truth when correctly understood cannot clash with another.

One of the most important and remarkable of the microscopical facts reported by the author relates to the feldspars. Notwithstanding the advanced state of decay which the old greenstones uniformly exhibit, the feldspars are found, even in the most schistose and "crushed" parts of the rock, to be remarkably fresh. In numerous instances the author suggests that they look like fresh crystallizations; indeed, as has already been stated, he deduces a rule that the *freshest feldspars are found in the most crushed rock.* At the same time he finds in the same rock, or the same kind of rock taken at other places, that the feldspar grains have suffered remarkable distortion and destruction under the action of the same mysterious dynamic forces. Although he suggests in several instances that the former may be "new crystallizations," and even concludes that the albite feldspar of the saussurite masses is a new crystallization (p. 158), it appears that he does not adopt what seems to be the most reasonable explanation of this anomalous action of the feldspars of these rocks. He passes the fact as unexplainable, except on the hypothesis that the feldspars may have been able "by slipping" to adjust themselves to the pressure and thus to avoid crushing. Why the quartzes, which appear beside the feldspars, could not have slipped, and escaped the effects of the pressure equally as well as the feldspars he does not explain. They, on the contrary, have been distorted, and sometimes show a peripheral granulation. Why other feldspars, in some such cases, should have been crushed more than the quartzes, is another anomaly which is left unexplained.

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*Twentieth Report of the Minnesota Survey, pp. 18-22.

These curious freaks of the mysterious agent appealed to by the author (dynamic metamorphism) to account for the present condition of the minerals of these rocks on the hypothesis of their having been massive eruptive rocks, may be, perhaps, understood better if the hypothesis be abandoned, and they be examined from the same standpoint as that from which the banded greenstones of the Marquette area are studied, viz., that of fragmental basic tuff. In such an oceanic terrane there would be of course, primarily, all the elements of a diabase, including feldspars, fragmental and entire. These would graduate secondly, into true erosion sediments, at distant points, or under favorable conditions at near points, but would accumulate rapidly and be consolidated in great masses at those points favorably situated for their preservation. In all cases they would be likely to show the effect of oceanic levigation, and all their minerals would take on more or less of the effects of atmospheric degradation, such changes being effected mainly prior to consolidation. Subsequently, on the application of pressure and shearing, accompanied by heat and by the tilting which has brought all the Archean rocks to a a position of verticality, the original feldspars were crushed and stretched, and many new crystallizations were promoted. This changed the semi-decayed minerals of the original oceanic tuff into reconstructed forms. The feldspars were surrounded, under new environments, by fresh rims or enlargements, or entirely new crystals were generated, the hornblendes extended their limits, the chlorites and micas were strengthened in their chemical integrity and perhaps converted to biotite, and the leucoxene rim of the menaccanite gave off sphene and rutile needles. These reconstructional changes can be legitimately ascribed to dynamic metamorphism, and if so explained and if the decayed appearances exhibited be considered as the effects of oceanic weathering in Archean time, the argument of the author, or so much of it as would remain, would be relieved of all these anomalies. The feldspars which are crushed and faded so as to "lose their outlines in the surrounding matrix" are probably the products of the old volcanic outbursts, original parts of the basic tuffs. Those which are fresh, or have fresh rims surrounding a decayed interior, may be of later date, as shown by Van Hise for certain feldspars of the Keweenawan sandstones.* At any rate in the absence of a demonstration for either hy-

*Enlargements of feldspar fragments in certain Keweenawan sandstones. Bulletin No. 8, U. S. Geol. Sur., 1884, p. 44.

pothesis this would obviate some difficulties, and is more reasonable than to ascribe all these contrary changes to a single force. It would, moreover, allow the megascopic characters to maintain their legitimate significance, paramount to the microscopic, and there would be no conflict in their interpretation. The coarser tuffs, less reduced by levigation, would thus be given the semi-crystalline resemblance to original diabase which the author describes; for they doubtless took on, like some limestones of Paleozoic age, a crystalline texture which obliterates, through great thicknesses, their original sedimentary features.

As with the megascopic characters the microscopic features afford suggestions of massive structures, but the evidence is seldom or never clear and convincing. The evidence of fragmental origin, on the other hand, while in some cases defective, is sometimes undeniable and is acknowledged by Dr. Williams, even for specimens taken from the very midst of rock which he concludes from other specimens to have been a massive eruptive (p. 133). How a massive basic rock, which must have cooled at considerable depth below the surface, can be said to show in places immediately adjacent, evidence of fragmental origin, is one of the difficulties of the argument which Dr. Williams does not attempt to explain, except by the statement that the fragmental rock must be considered to be of the nature of diabase tuff—which is no explanation at all, since it requires a deep-seated rock to be cotemporaneously in contact with an effusive eruptive one. If it be presumed that the diabase was also a surface eruptive rock, it may be answered that it should show some evidence of it, such as amygdaloidal structure or a layering characteristic of surface flows. Such features, however, have not been reported, although it cannot be questioned that occasional liquid eruptions must have occurred as accompaniments of the ejection of volcanic ash. What effect may have been produced on them by contact with the abounding oceanic waters of the time, is not certain, nor apropos at this point. The consolidation of tuffs may be so perfect as to render the resultant rock indistinguishable from an originally massive rock.

It will be well to summarize as follows the statements of the bulletin bearing on the microscopic characters which are the same in the admittedly fragmental rocks and in those which the author supposes to have been originally massive but are now "schistose." This covers the crucial point of the argument, for, if the "schistose" rocks interbedded with the massive layers, can be shown to be either fragmental or modified massive formations, the coarser ones, whatever the testimony of the microscope, must be of the same origin. We collate, therefore, as with the magascopic characters, those microscopic features which the author ascribes to both, with page references to the bulletin.

Common microscopic characters.

The chemical and microscopic characters of these schists (the banded schists at Marquette) agree closely with those of the associated massive greenstones. Pp. 154, 158.

Mineralogically they are now identical. P. 158.

They both show occasionally lath-shaped feldspar crystals like those of the diabase feldspars. Pp. 98, 163; p. 155.

They both show the development of albite feldspars, both porphyritically and in a saussurite, quartz-albite mosaic. Pp. 68, 78, 209; pp. 155, 157, *et passim.*

Both show the "peculiar" action of feldspar, in that the freshest feldspar is found in the most pressed and stretched rock. Pp. 93, 103, 157; pp. 177, 187.

They both, when "schistose," have a matrix of quartz, chlorite and calcite, with leucoxene and feldspars. Pp. 131, 132; pp. 155, 176.

They both contain striated, often lath-shaped feldspars, round which chlorite scales are seen to shape themselves in sinuous adjustment to the forms of the feldspar. P. 75; p. 176.

In both the feldspars are sometimes so altered that they seem to grade imperceptibly into the matrix (original feldspars). Pp. 73, 74, 81, 98; pp. 177, 187.

In both the feldspars are sometimes fresher than the quartz, and suggest new crystallizations (secondary feldspars). Pp. 78, 88, 112; pp. 156, 187.

They both contain crystals of tonrmaline. P. 200; p. 124.

[*Note.* The only observed instances of tourmaline being noted by Dr. Williams in what he considers a modified basic eruptive rock are on pages 132 and 200. In the latter it is referred to rock No. 11064, which he styles hornfels. There is no description of this rock. It is not mentioned where the author describes the associated numbers, on pages 104 and 105. Nos. 11062 and 11063 are likewise omitted. It is evident, however, from the context that these omitted numbers were collected in the same place and from the same rock, in general, as Nos. 11061 and 11065, both of which are fully described and considered examples of sheared gabbro. The other instance is mentioned on page 132 (No. 11139) when a chlorite slate, said to be one of the "most altered" rocks of the Lower Twin falls, contains abundant sharply defined crystals of tourmaline].

They both show, in general terms, a degradational change rather than a reconstructional one; that is, they show one that is attributable to the entrance of atmospheric agents. Pp. 81, 91, 93; pp. 156, 184, 187.

In both, the essential composition is fibrous green hornblende, quartz, epidote, zoisite and chlorite. P. 154.

In both the hornblendes sometimes show tuffted ends, suggesting, according to Van Hise, new growths, or, according to the author, a fraying out by some mechanical force which has broken and separated the lamellæ. P. 107; p. 155.

Both contain quartz, both primary and secondary. Pp. 81, 210; p. 155.

Both consist essentially of the decayed and battered minerals of diabase. P. 68; p 155

There is certainly nothing in the microscopic evidence that indicates different origins for these rocks. That is admitted by the author. It is apparent, therefore, that the author relied on megascopic features, which, as has been shown, preponderates in favor of fragmental origin. If that origin be allowed for the "schistose" belts, which we prefer to call sedimentary beds of finer materials, it will involve all the coarser beds which are plainly interbedded with the schistose, and will leave for the undoubted eruptive portions of the greenstones but a very small moiety; these perhaps may yet be detected and fully distinguished.

The author sums up his views respecting the aphanitic greenstones of the southern Marquette area as follows, on p. 165:

> The history of the schistose greenstones must be deciphered with the conjoint evidence afforded by the microscope, and a study of their relations in the field. The occasional survival of the characteristic diabase structure, even in some of the more foliated forms, taken in connection with their evident identity with and gradual transition into the massive varieties, appears to be sufficient proof that, with the exception of certain unimportant tuff deposits, these green schists have been derived from basic eruptives through the agency of the intense mechanical and chemical action.

This might be paraphrased as follows, and still would not be in contravention of the evidence:

The history of these massive varieties of greenstone, especially the aphanitic ones, must be deciphered with the conjoint evidence afforded by the microscope and a study of their relations in the field. The occasional survival of unmistakable tuff-structure, and of "slaty bands traversing the massive greenstones," even though exhibiting unimportant acquired resemblances to an original diabase-structure, taken in connection with their evident identity with and gradual transition into less foliated forms, appears to be sufficient proof that, with the exception of certain unimportant and undoubted eruptive masses, some of which may have been of later date than the main body of schists, these greenstones have been derived from basic tuff deposits through the agency of intense pressure which developed sometimes a mechancal and, more rarely, a chemical effect.

GENERAL CONSIDERATIONS.

(a) *Dynamic metamorphism as a theory.*

The eruptive basic rocks, or their tuffs, with which this bulletin has to do, were produced in their original condition, by *dry fusion*, in the natural laboratories of the earth. Some of them have been reproduced artificially by Messrs. Fouqué and Michel-Lévy.* They must therefore have exhibited at first the most ultra crystalline condition which such elements can be supposed to be susceptible of. Any change which they might suffer could only be brought about by the action of some force which would loosen the high chemical tension in which their atoms may have been placed by the process of cooling from dry fusion. Such change could only be brought about by the access of atmospheric elements, consequent on some of the natural vicissitudes of eruption. At once on the access of atmospheric agents, or on the subjection of these mineral compounds to other physical surroundings, a degradational change must have been started. No other change would be possible. Whether this change began immediately after ejection as volcanic matter, or before ejection, but after the magma came within reach of surface influences, such as aqueous vapor or lessened pressure, it was still a descending process, one which, when continued and completed, would finally reduce the minerals to an oxidized powder fit for mingling with the ordinary sediments of erosion. This, however, cannot be called *metamorphism*, as that term is defined and used. It is essentially a weathering process, although "weathering" is not usually supposed to begin before the rock is solidified and exposed to the ordinary action of the atmosphere. All upheaval, all crushing, or shear-

*Synthèse des minéraux et des roches. Paris, 1879.

ing or simple pressure, in so far as they facilitate the approach of atmospheric agents to the rocks affected, serve as means of degradational change. In so far as they produce heat which is brought to bear upon the crushed minerals, especially if it be conveyed to them by the action of aqueous vapor, there is a tendency to reconstruction and a restoration of the former crystalline integrity. Since, therefore, it is a fundamental law of physics that all force which is expended in such great movements as upheaval, and such friction as crushing or shearing or folding, produce equivalents in heat, it is necessary to allow for the presence of large amounts of heat when these dynamical processes were carried out. Since, further, water in the form of aqueous vapor has been present in all volcanic ejections, and, as water, has permeated all the rocks of the earth's crust, it is equally necessary to admit the presence of both heat and moisture at all places where any dynamic changes such as those mentioned have taken place, throughout geological history. Such movements, therefore, in their ultimate results, when acting normally at any depths within the earth's crust would leave the concerned original massive strata with a lower stage of crystallization than they had prior to their action. They would tend to solidify and reconstruct the fragmental grains of sedimentary strata, and would reinforce the igneous rocks in case they had begun to suffer from atmospheric agents. At still greater depths, beyond the reach of air and water, such pressure may have been sufficient to re-fuse the crust, allowing the product to return to its native condition. Near the surface of the earth, only, and in exceptional cases, could the heat which such changes must have created be supposed to have been dissipated without causing the recrystallization here indicated.

Metamorphism, therefore, in the sense in which the word is commonly used, is not a degradational change. It is the "passage, under circumstances of high temperature or pressure, or both, of less crystalline into more crystalline compounds; or the change of minerals into others not less crystalline or insoluble than themselves" (p. 36). Such changes are promoted in all fragmental rocks by the great dynamical movements to which the author has appealed. The retrogressive changes described by the author are not metamorphism, properly so called, they are instead *katamorphism*.

We do not desire to question the possibility, nor even the actuality of the mineral changes which are included under the term "dynamic metamorphism" by the author. Given a basic crystalline rock, and a fragmental one of the same chemical composition, like the tuffs at Marquette, and let them be subjected to equal pressure and shearing, with access of heat and moisture, and they would be made similar in mineral composition and perhaps in some of their structures, in the former by katamorphism and in the latter by ordinary metamorphism. They would both be changed to a crystalline schist, acid or basic according to the nature of the original rock. Such changes have passed over the rocks in vast areas of the earth's surface. Such changes are apparent in the basic tuffs wherever they are found to approach the region of the eruptive granites, whether in Michigan or in Minnesota. Toward the "eruptive" greenstones they show no such change, although they approximate the greenstones in all their characters. This fact indicates that the tuffs have not been subjected to any metamorphism worthy to enter into this discussion, and inferentially that the greenstones have also been exempt. The supposed dynamic changes described by the author in what he considers original diabases are precisely the same as those which he finds in the stratified tuffs. But, as already stated, we consider that a dynamic force which would have wrought such destructive changes in a diabase would have recrystallized the tuff which was associated with it. If they show the same characters now, as admitted by the author, they must have had a similar physical history since their deposition, and, as the tuffs are in an extremely decayed condition, the supposed diabase must have begun its history with a similarly decayed condition—in other words, it would not have been an original massive eruptive.

We are, therefore correct in assuming that the profound and ever-present retrogression in mineral crystallization which the greenstones exhibit cannot be attributed to dynamical movements, except in limited and irregular areas which cannot yet be defined, and that in general it must be referred to some cause whose natural effect looks toward the opposite direction, and which acted alike and simultaneously on the material of the greenstones and that of the fragmental tuffs.

We can find no cause adequate to the production of these changes except atmospheric action on volcanic ejectamenta. In case of lava flows contemporary with the tuff accumulation, such may have been largely or wholly destroyed by the solvent action of the ocean, or so permeated by the same changes that when consolidated they lost their identifiable features as igneous rocks. The saussuritization of feldspar with separate formation of zoizite and secondary silica is described by Prof. J. W. Judd* as the product of ordinary weathering of the gabbros of Mull, west coast of Scotland. "Every stage of this alteration (a kind of kaolinization) can be traced, from a slight clouding of the transparent feldspars to their passage into white and opaque pseudomorphs. Colorless augites acquire a brown or purplish tint on their exterior portions, which extends inward and finally embraces the whole crystal. They also change paramorphically to hornblende and to diallage, and in other cases to the structureless viridite which again becomes hornblende by uralitization. Enstatite and olivine produce serpentine, and ilmanite leucoxene. The whole rock may be still further decayed by atmospheric exposure "and reduced to a mass of dark colored clay, or wacke." He also remarks that this action results in a destructive change in the rock, whereas crushing movements in rock masses result in reconstructive changes. At any rate, so long as it cannot be affirmed that it is proven that dynamic movements were the only possible cause of these features, it is reasonable to allow that they may be referred to some other agent. The thesis of this bulletin would be proved had the author established the two following propositions. (1) Dynamic forces can produce the effects seen in the decayed conditton of the minerals of all the greenstones and the fragmental schists. (2). Dynamic action is the sole efficient cause that can have produced these effects. Lacking both of these, as it appears to the writer, the philosophy of the author is not sufficiently intact to warrant its unqualified acceptance.

(b) *The greenstones as a geologic terrane.*

It has already been shown that the greenstones of the Archean constitute a district terrane, forming the latest portion of the Keewatin, thus coming at the very top of those rocks which, in the lake Superior region, have been found to constitute the "fundamental complex." The Archean terminates abruptly, by the most profound plane of non-conformity that has yet been discovered in American geology. Its bedding, i. e., its sedimentary structure, stands vertical, or nearly so, at all places where it has been examined and reported. The basal beds of the Taconic pass transversely over them, indicat-

*Quart. Jour. Geol. Soc. xlii, p. 84. 1884.

ing a general subsidence beneath the ocean on the close of the volcanic age. Below the greenstones are found chlorite slates and schists, sericitic schists, clay slates, graywackes, conglomerates, quartzytes and jaspilytes. The greenstones pass gradually, by various alternations of "massive" and "schistose" greenstones, into chlorite slates, and then into clay slates. In other places these green schists verge off with an increase of very fine silica grains, into silky schists and to novaculytes, and with local increase of hematite into jaspilytes. These schists may all become so coarsely fragmental as to constitute conglomerates, "slate conglomerates," graywackes, siliceous porodytes and conglomerates made up of porphyritic felsyte pebbles. Whatever their composition, we have about come to the belief that they are all the result of oceanic action on volcanic ejectamenta. Their thickness in Minnesota seems to exceed that of any other of the Archean terranes. The Vermilion iron range is in this formation. We have discovered no general plane of discordance in the midst of this volcanic material. The conglomerates are local and irregular, and vary, not in accordance with the strata alongside of which they lie, as they would if they were of erosion origin, but wholly independently and irregularly. Generally, indeed, their pebbles cannot be referred to any rock in the region. They are like the pebbles described by Dr. Williams in the Deer lake agglomerate, quartz-porphyries and felsytes, ambiguous greenstones and red granites, with occasional angular pieces of jaspilyte. They seem to have all been thrown out from volcanic craters, and to have been spread out in comformable sheets by oceanic action, sometimes after long continued abrasion.

This series of fragmental materials has been locally and regionally affected by metamorphism, and has been converted into true crystalline schists. Restricted gneissic and granitic areas are surrounded by such schists, and the gradual transition from the fragmental Keewatin into the crystalline schists has been observed at many places. There is no general plane of non-conformity between them. In tracing the Keewatin schists downward, or at least in a direction toward the great areas of gneiss and eruptive granite which is often presumed to be in descending order, there is a gradual increase of crystallization until the rock is a fully crystalline mica, or hornblende-mica schist, which, in turn, becomes an acid gneiss by the continued increase of quartz and orthoclase. In general it may be said that throughout the series, from the top of the Kawishiwin to the gneiss of the Laurentian, there is no widespread plane of non-conformity, but a succession whose most marked characteristic is a gradual change, in descending order, from basic fragmental tuff-rock, with some which may have been originally massive, to acid schists and gneisses, the latter being wholly crystalline and fresh. This change in the schists is attributed to "regional metamorphism," but how it differs from local or contact, or even from dynamic metamorphism, it is not possible to discover, except that it is carried out on a much larger scale. The sedimentary structure is everywhere apparent and unquestionable. In the gneisses are sedimentary structures as apparent as in the schists; and at the same time the gneisses or, perhaps more properly, some granites which have acquired a foliated or sheeted structure, exhibit other "parallel structures" which have sometimes been mistaken for the sedimentary structure.

From this review it becomes apparent that the volcanic age was one whose action began feebly, its tuff constituting but a small part of the oceanic deposition. It increased throughout a vast lapse of time and culminated with a volcanic violence which seems to have everywhere terminated the Archean, and was followed by such a settling of the land areas that the following, or Taconic age, was introduced by a very general submergence, bringing the base of the Taconic nonconformably over the upturned beds of the Archean. It also becomes apparent from this review that the decayed greenstones and greenstone tuffs are much younger than the truly crystalline schists. They could not therefore have been metamorphosed nor subjected to any general dynamic force, such as pressure, folding and shearing, unless the same movements had involved the lower terranes. If the philosophy of dynamic metamorphism be correctly applied by the author it will be necessary that it shall answer the question—why do not the crystalline schists exhibit the same or similar semi-decayed crystallization as the greenstones and basic tuffs? and the question, why have not the eruptives (?) of the greenstones preserved their structures as intact as those of the older crystalline schists?

We look upon the greenstones in Minnesota as an oceanic terrane having a definite stratigraphic position, although probably involving some truly irruptive masses. Its materials, both basic and acid, are interbedded by sedimentation the one with the other, and are sometimes mingled. The decayed condition of these materials is due to the natural action of the Keewatin ocean prior to consolidation, and the crystalline condition of the lower beds is due to a later metamorphism which, having its active forces and seat at still greater depths, did not permeate the whole formation. It is not attributable so much to dynamic movements as to internal heat. Wherever such movements operated with great violence, the lower Keewatin sediments were fused, producing irruptive felsytes and granite. Such granite is bordered usually by belts of crystalline schist, evidently formed at the time of such fusion.

III.

PRELIMINARY REPORT ON THE RAINY LAKE* GOLD REGION.

BY H. V. WINCHELL AND U. S. GRANT.

CONTENTS.

*There is an idea more or less prevalent, and it has been stated in print, that the name of this lake is derived from a corruption of the French names Regnault or René, neither of which has the same meaning as the English *rainy*. There are no good grounds for this idea, which appears to be merely an assumption. The earliest map we have seen, on which this lake is represented, is that by Ochagach, an Assiniboine chief, who traced it for Verendrye in 1730. On this map Rainy lake is called "*Lac Tecamamisuen*." The next map on which Rainy lake is shown is that of Buache, entitled "Carte physique des terrains les plus élevés de le partie occidentale du Can-

INTRODUCTORY.

This report makes no pretension to be an exhaustive description of the Rainy Lake country and of the gold interests centered there. The time allowed for study in the field and in the laboratory has been entirely insufficient for the preparation of anything but a preliminary paper. The authors have, however, endeavored to present a report which will give some precise and reliable information concerning this region, the occurrence, richness and necessary treatment of the ores, the geological structure, and the other resources. It is hoped that this report will be of value as an easily accessible source of information to intelligent persons who desire to gain some knowledge of this district, as well as to those who are now in the region or who are contemplating visiting it.

The description of the geology and the general physical features of the Rainy Lake region applies especially to that part of the lake and its shores lying in Minnesota, but most of the statements will hold equally well for the territory on the other side of the International boundary. When certain features find better development in Canadian territory this fact will be mentioned. The geological observations of the authors have been supplementary to, and in a large degree confirmatory of, the reports on this region written by A. C. Lawson* and H. V. Winchell.† To these reports we are indebted for corroboration of many of the facts observed in the field, and in some cases for statements which are essential to this report, but which we are unable to make wholly on our own authority. This general acknowledgment will suffice to make it unnecessary to give references in cases where our observations agree with those of the above mentioned authors, but where we are entirely indebted for certain statements to the previously published reports reference will be made to the source of the information.

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ada" and published in 1754. On this map Rainy lake is designated as "*Lac Tecamamiouen ou de la Pluie.*" which is sufficient proof that at that early date, one hundred and forty years ago, the lake was known to the French explorers as *Lac de la Pluie* (Lake of the Rain). There are thus most excellent grounds for the belief that the name Rainy lake is a direct translation of the original French designation. Most likely also the French name was a translation of the Chippewa name.

*Report on the geology of the Rainy Lake region. Geol. and Nat. Hist. Survey of Canada, Ann. Rept. for 1887-'88, new series, vol. iii, pp. 1 F-182 F, pls. 12-19, 1889. Accompanied by a geological map.

†Report of observations made during the summer of 1887. Geol. and Nat. Hist. Survey of Minn., 16th (1887) Ann. Rept., pp. 395-478, 1888. Accompanied by a geological map.

GOLD, ITS OCCURRENCE AND ASSOCIATIONS.

Gold is found in rocks of every geological age. It occurs in the oldest and the most recent, both acid and basic, eruptive and sedimentary. In many districts it occurs in lodes composed of partially metamorphosed rocks, such as slates or schists, while its occurrence in holocrystalline metamorphic or igneous rocks is comparatively rare. Among sedimentary rocks its occurrence is almost confined to the sands of rivers which run for a part of their course through crystalline formations, or more particularly through districts in which gold occurs in quartz veins. Such river sands are rarely quite free from gold. The beds of ancient rivers no longer existent are also frequently auriferous.* The matrix in which the gold is contained is usually quartz, intersecting as veins or interlaminated with, subcrystalline, slaty or schistose rocks, especially hydromica and chloritic slates. Gold also occurs sparingly in similar veins in granite and gneiss, and has been detected in the trachytes of Colorado, and in Silurian and Carboniferous trachytes, as well as in some limestones.

The wide distribution of gold in minute quantities throughout the world was pointed out by W. E. Duboís in 1891** and is thus commented upon by W. P. Blake: † "There is a much greater dissemination of gold in a ragged granular condition, *in situ*, in fine particles in the midst of rock formations, and without any obvious connection with veins, than is generally supposed. Prominent examples are found in the belts or zones of layers of soft slate in Georgia, and in North Carolina. * * * * The Boly-Fields gold vein, Lumpkin county, Georgia, is an example of the occurrence of coarse, ragged gold in the midst of a mass of slate, without any defined quartz vein. The gold is closely associated with bornite, pyrites and dolomite." The dissemination of gold in the schistose rocks of North Carolina has also been noted by professor Kerr,†† and by Dr. Emmons, and similar occurrences have been noted in Texas, Nova Scotia, and in other parts of the world. At the Contention mine, Tombstone, Arizona, free metallic gold is found in the thin cracks and cleavage surfaces of partially decayed porphyry, and appears to have been deposited there from solution and not mechanically. It occurs in thin subcrystalline

*Rose. Metallurgy of Gold, 1894, p. 33.

***Jour. Am. Phil. Soc.*, June, 1861.

†Prod. Gold and Silver in the United States, 1884, p. 581.

††*A. I. M. E.*, X, 475.

flakes and scales, and may have been derived from the decomposition of the iron pyrites with which the adjoining sedimentary formations are charged. Gold also occurs in small quantities (1 part in 1,124,000) in the bed of clay on which the city of Philadelphia is built.*

According to Rose the most common mineral associates of auriferous quartz lodes or placer deposits are platinum, silver, iridosmine, magnetite, iron pyrites, galena, ilmenite or titaniferous iron ore, copper pyrites, zinc blende, tetradymite, zircon, garnets, rutile and heavy spar; wolfram, scheelite, brookite and diamonds being less common. Diamonds are associated with gold in Brazil, and also occasionally in the Urals and in this country. The sulphides present in auriferous quartz frequently contain gold, which is usually in part quite free, disseminated through the quartz, in visible grains, and in part locked up in the pyrites, whence but little can in general be extracted by mercury. It is, however, in all probability in the metallic state in pyrites, as was shown by F. D. Adams to be the case in ore from the Alaska Treadwell mine.† Calaverite is a telluride of gold, while sylvanite or "graphic tellurium," petzite and nagyagite are tellurides of gold and silver. Other gold tellurides and some native gold amalgams are occasionally seen, but none of these minerals are of much importance as ores, seldom occurring in any abundance. In Colorado, however, are a few mines in which the valuable ores are tellurides.

Placer gold is usually in the form of small scales, but pellets or rounded grains also occur, while larger masses or nuggets are usually of a rounded, mammillated form. The chief difference between the appearance of placer and vein gold lies in the fact that the former is always rounded, showing no sharp edges, even the crystals having their angles smoothed and rounded off. This has been pointed to by the advocates of the erosion theory of the origin of placer gold, as evidence in favor of their views, the roundness of the fragments being taken to prove that abrasion of the gold has been effected by attrition through moving water and grains of sand. The largest masses of gold yet discovered have been found in auriferous gravel,‡ but recent reports from the Coolgardie district, in western Australia, indicate that larger masses of gold may yet be found in quartz veins than have ever yet been taken from

*Rose, *loc. cit.*, p. 30.
†Am. Geol., IV, p. 92.
‡Rose, *loc. cit.*, p. 31.

placers. This will deprive the supporters of the chemica. theory of the origin of gold in placers of one of their most effective arguments.

Native gold usually contains silver in varying proportions, its color becoming paler with the increase of silver. Copper almost invariably contains gold, and even the Lake Superior copper, celebrated the world over for its purity, contains nearly one part of gold in a million of copper, The bronze and copper coins of all nations are usually found to contain greater quantities of gold than this. Similar evidence has been adduced, tending to show that all ores of silver, antimony and bismuth contain gold.*

Even the waters of the ocean contain gold, as demonstrated by Sonstadt in 1872.† Münster, in 1892, found an average of five milligrams of gold in a ton of sea water, or 26 tons of gold in a cubic mile of water. It has been estimated that the ocean has an average depth of 2,500 fathoms and contains 400 million cubic miles of water, thus holding in solution 10,250 millions of tons of gold, To appreciate to a slight extent the significance of this statement we have only to consider that the world's total output of gold during the past 400 years has been only about 5,300 tons and now amounts to about 200 tons per annum. If our gold were all taken from the ocean the "visible" supply would be sufficient to last 51 million years at the present rate of production.

The gold thus contained in the sea is held in solution as an iodide. But the gold which occurs in the rocks of the earth's crust is almost entirely native. For many years it was supposed that gold was not taken into solution by any but the most powerful reagents to form chemical compounds. It is now known, however, that gold is soluble in several of the most common acids and salts, and is transferred by them from place to place and redeposited.

I. VEINS AND THEIR ORIGIN.

It is quite probable that the original source of gold was in disseminated form in eruptive rocks. From these it has been segregated either directly into veins which cut these eruptives or into veins contained in sedimentary rocks which were formed from the decay and redeposition of the original eruptives. The minerals usually associated with gold in veins are quartz and pyrites. Other minerals such as galena, zinc blende, and other

*E. A. Smith, on Bismuth, etc., *Jour. Soc. Chem. Ind.*, XII, 1893, No. 4.
†Chem. News, XXVI, p. 159.

sulphides or carbonates are not uncommon, but quartz and pyrites are the companions of gold the world over. Upon the decay and erosion of the pyrites and quartz the gold is usually found in flakes or nuggets of greater purity and size than before the pyrites is oxidized. The portion of a gold bearing vein which has been thus affected by oxygen-bearing waters sometimes extends to the depth of two or three hundred feet and is frequently richer than the ore found at greater depths. When decay and erosion have progressed still further and the veins are broken down and washed away, the gold is found in the resulting gravel deposits, called placers, in the beds of streams and gullies. Such placers have produced a very large proportion (about two-thirds) of the world's store of gold, and at the present time placer gold amounts to about 40 per cent. of the total output.

Veins are differently defined by different writers. Phillips says they are "aggregations of mineral matter, differing in character from the enclosing rocks, in fissures formed in those rocks subsequently to their consolidation."* He says further that "true veins" traverse the enclosing rocks independently of their structure and not parallel to their foliation or stratification. Veins of this class are believed to have originated in fissures or faults produced by movements of portions of the earth's crust and to extend to an indefinite depth. It was formerly believed that unless a vein was of the variety called a "true" or fissure vein it had little value. This is not true, however, many large and profitable workings being in segregated or "bedded veins" which are in a general way parallel with the enclosing rocks, or even in mere impregnations of the rocks themselves.

It was at one time a common belief that veins and their contents were formed at the same time as the rocks which contain them. Then it was seen that they must be later than the rocks and of different relative ages, and it was popularly supposed that they were fissures filled by material which was forced into them in a molten and fluid condition from great depths. It is now generally thought that the contents of veins were deposited gradually from the various solutions which are continuously circulating through the rocks below the surface. Chemical analyses have revealed the presence in these solutions or ground waters of the various minerals that are now being deposited on the walls of the fissure from which they were

*Ore deposits, p. 50.

taken. The idea of sudden and volcanic or eruptive origin has given way completely to that of slow deposition through the agency of water.

Although silica, or quartz, is insoluble in the ordinary sense of the word, yet it is well known to geologists that it is held in solution in spring, river and sea waters. Thus Forchammer found in some samples three parts of silica in one million parts of water or 13,500 tons of silica in one cubic mile of sea water. Deville showed that the river Loire contained about four parts of silica in 100,000 parts of water. The waters found in mines also contain silica in solution. Daubrée proved experimentally that superheated steam has a solvent action on silicates and that upon lowering the temperature of the solution crystalline quartz of a character similar to that found in association with gold in quartz veins is precipitated. Silicified wood is another example of the fact that silica enters into solution, and is deposited by the reducing agency of organic and other matter. The quartz of auriferous lodes is then accounted for on the hypothesis of aqueous solution and precipitation.

Gold is also usually pronounced soluble only in chlorine, bromine, iodine and one or two other chemicals that are uncommon in nature; and if that were true there would be some difficulty in accounting for its presence in quartz veins formed by deposition from water. As a matter of fact, however, there are many solvents for gold, among them the following: (1) Sesqui-chloride and sesqui-sulphate of iron. Hence J. A. Phillips suggested that in the presence of a reducing agent sulphate of iron carrying gold in solution would be changed to pyrite or sulphide of iron, and the gold reduced to a metallic state. (2) Hyposulphite of soda. (3) Sulphuretted hydrogen at ordinary temperatures, producing a sulphide of gold which is soluble in alkaline sulphides, both of which reagents are generally present in underground waters. (4) As shown by Prof. Egleston, gold is soluble in the following:

Potassium bromide, heated to 150° to 200°C.

Potassium iodide, " 100° to 170°C.

Ammonium nitrate with ammonium chloride as impurity, at ordinary temperature and pressure.

Potassium sulphide at ordinary temperature and pressure.

Sodium " " " " " "

Potassium cyanide " " " " "

Ammonium sulphide heated to 145° to 180°C.

Free chlorine.

"He concludes from his experiment sthat gold is not only not insoluble, but that in nature it is constantly being dissolved out of the rocks and placers, the waters of filtration dissolving out of the rocks, in their passage through them, all the materials necessary for the solution of the gold, and carrying it in very dilute solutions until it meets some substance that precipitates it. * * * * The same conditions which cause the solution of gold in certain cases cause also the solution of silica. * * * No single agent is so powerful a solvent of gold as chlorine. Very few drainage waters are free from some compound of it, and no soil is without the nitrogenous materials necessary to set the chlorine free, and therefore capable of attacking the gold and rendering it soluble."*

Mr. Philip Argall speaks as follows regarding the origin of gold:†

1st. Australian geologists have long held that part of the gold held in the reefs was derived from the ocean, and was deposited with the strata now enclosing the veins.

2d. Gold was also derived from the eruptives, particularly the dioryte (greenstones).

3d. Gold, throughout the world, is of somewhat similar origin, and is in all probability mostly derived from igneous rocks.

4th. Gold readily enters into solution, and is so found in mine waters, and impregnating mine timbers, in association with the alkalies and alkaline earths combined with sulphur.

5th. These mine waters chiefly consist of the alkaline chlorides and sulphates.

6th. That waters holding these salts in solution are found in the inclusions of vein-quartz carrying the precious metals.

Experiments conducted by E. Cumenge tend to show that the alkaline auro-silicate, obtained in the wet way, may have played an important part in the formation of auriferous quartz.‡

HISTORICAL SKETCH OF GOLD DISCOVERIES IN THE LAKE SUPERIOR REGION.

There are reasons for believing that the first discovery of gold in the Lake Superior region was made by Dr. Douglass Houghton in 1845 not far from the present town of Negaunee. The story is told by Mr. S. W. Hill, and a voyageur named An-

*Trans. A. I. M. E., ix, 645, 646, 1881.

†Trans. A. I. M. E., xxii, 71, 193.

‡Rose, Metallurgy of Gold, London, 1894, p. 27.

toine du Noir. They agree in the statement that Dr. Houghton wandered away from camp one day, alone, as he was accustomed to do, and returned about dark with a bag full of specimens in which native gold was plainly visible. He told them that they were in a gold country, and that he should not be surprised to find quantities of it in the Huron hills. A piece of the quartz found at that time was worn as a pin for many years by Mr. Jacob Houghton, a brother of the doctor. The notes of this season's work were lost in the lake at the time of Dr. Houghton's death, but the accounts of the explorers are generally believed to be trustworthy and the discovery of the Ropes vein in this same vicinity at a later period is very strong corroborative proof of their verity.

Beyond the traces of gold found in assaying the silver and copper ores of Michipicoten island and other localities around lake Superior, there was no gold discovery or "boom" until 1865. In this year gold ore was reported from Vermilion lake, Minnesota, by state geologist Eames and others. A wagon road was laid out from Duluth to the new Eldorado, a distance of 75 miles through the forest. Prof. N. H. Winchell speaks as follows about this Vermilion lake development:* "At that time a flush of feverish excitement led to the expenditure of considerable money in sinking shafts and erecting works for mining. Three steam stamp mills were erected, another running by water power. One was owned by the New York Mining Company, whose location was near the "Mission" on the south shore, another by Nobles and Company, further northwest, and another by Seymour and Company. The water power mill was owned by the Wabasha Company, and was located about two miles from Vermilion lake, at Trout lake. Eight or ten mining companies were at work simultaneously in different parts, mainly on the southern shores, or on islands. A townsite was laid out at the southern extremity of the lake, several large buildings put up, and stated communication made with Duluth. The village was named Winston. Above the village, at Pickerel falls, a lumber mill was projected and the foundations laid." The very land subsequently found so valuable for iron ore, where the hard hematite and jasper stood out in bald knobs, a hundred feet high, was taken for gold claims. The veins, however, proved to contain more pyrite, marcasite and pyrrhotite than gold, and by 1867 the country was deserted, iron deposits and all.

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*Seventh Ann. Rep. Minn. Geol. Sur., p. 73, 1878.

The next gold discoveries were in Canada and were made in 1871 by Peter McKellar of Fort William, Ontario. The vein is said to be six or eight feet wide, composed of quartz and intercalated layers of green schist. The country rock is chloritic and dioritic schist, siliceous magnetite and massive dioryte, all having a northwesterly dip of 65° to 80°. The vein strikes and dips nearly conformably with the enclosing rocks. Intrusive syenite appears about a mile to the northeast. The mine developed here was called the "Huronian" and is situated on location "H 1" in Moss township near lake Shebandowan, about 70 miles northwest of Port Arthur. A 10-stamp mill was erected in 1883 and operated for a short time in 1884 and 1885. The gold occurs native and in combination as a telluride, associated with galena, pyrite, chalcopyrite and zinc blende. It is said that the mill "cleaned up" $21.00 per ton of ore stamped, and that much of the gold was lost. Owing to the expense of procuring supplies the mine has not been worked since 1885.

In 1872 gold was found on an island in Partridge lake, a short distance west of Lac-des-Mille-Lacs in a large quartz vein cutting "Huronian" schist. Samples from this vein which showed nuggets of gold were exhibited at Philadelphia in 1876.

In 1875 small nuggets of gold were found in a vein of quartz intersecting reddish granite at Victoria cape on the western side of Jackfish bay, on the north shore of lake Superior. Another vein of quartz 1½ to 3½ feet thick, holding iron pyrites, galena and blende and cutting the granite in close proximity to a slaty dioryte at this locality yielded on assay $27 worth of gold per ton.*

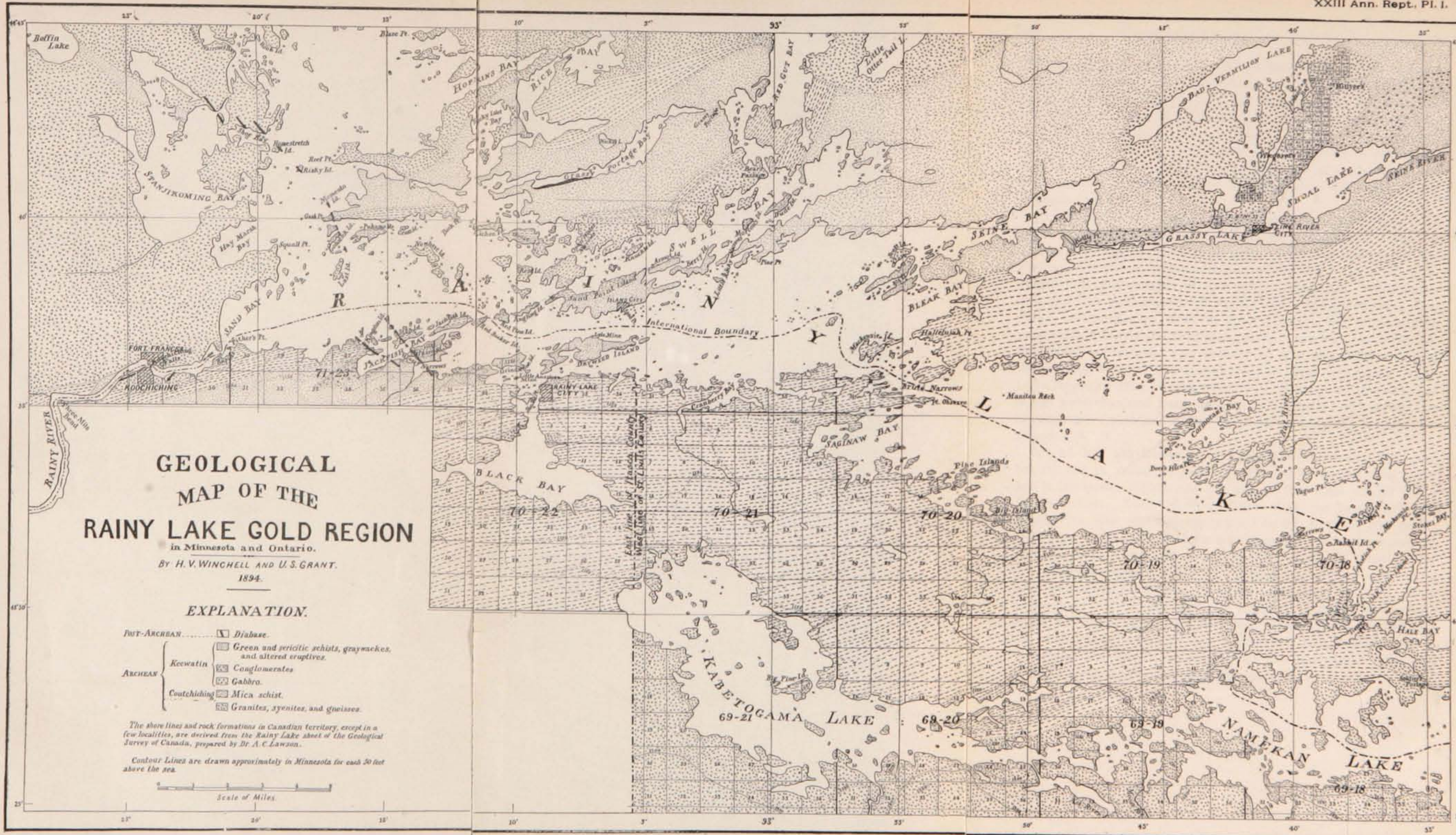
Gold has been known to exist at Lake of the Woods since 1878, and has been referred to in the Canadian geological reports and other literature. The title to lands in that vicinity being claimed by both the Ontario and Dominion governments, mining was not actively prosecuted until 1890 or thereabouts. It is difficult to learn what success has attended mining operations in this district. It is certain that many of them have been unprofitable, but whether this has been due to the poor quality, small quantity, or cost of mining and treating the ore, or to the lack of scientific mining and metallurgical methods could not be ascertained. The rocks of this region are quite similar to those around Rainy lake, and it might be supposed there would be some similarity between the veins of the two districts. If, then, there are profitable mines on Lake of the

*Report Royal Commission of Ontario, Mineral Resources, 1890, p. 26.

Woods, there is encouragement for Rainy lake. The Sultana mine is often referred to as having been operated profitably, notwithstanding the money wasted in apparatus for handling refractory ores of which the mine is said to contain less than five per cent. Indeed, it is doubtless because of the mistaken idea that the gold ore of the Lake of the Woods is refractory that more development work has not been accomplished, and more information gained as to the true character and richness of these veins.

In 1881 Mr. Julius Ropes noticed gold in a vein about six miles northwest of the city of Ishpeming, Michigan. Regular mining was begun here in October, 1882, and during the following summer a 5-stamp mill was erected. In 1884 a 25-stamp mill was completed and put in operation. This is the only genuine gold mine in Michigan, although there have been other discoveries of gold in quartz veins, and considerable prospecting in the shape of test pits and shafts. In 1885 considerable excitement was caused by the discovery of gold three miles west of the Ropes mine on land belonging to the Lake Superior Iron Mining company. Some beautiful samples of ore were obtained here, but the average did not warrant the expenditure necessary to develop a mine, and the project was abandoned.

All of the auriferous quartz lodes of the Lake Superior region are in rocks of Archean age. The majority of them are in the green schists and are not of the class called "true fissure" veins. None of them have thus far been markedly productive, and most of them have failed to yield any profit whatever. If there are any which promise to become paying mines it must be because of cheaper methods of treating the ore or the presence of better ore resulting from more favorable geological conditions in their immediate vicinity. For a description of the geology of the Rainy Lake region as well as the different "prospects" thus far discovered in that district the reader is, referred to the sections of this report entitled "General features and geology," (p. 47) and "Descriptions of veins in general and of individual properties" (p. 72).


GEOLOGICAL
MAP OF THE
RAINY LAKE GOLD REGION
in Minnesota and Ontario.
BY H. V. WINCHELL AND U. S. GRANT.
1894.
EXPLANATION.
POST-ARCHEAN .... Diabase.
ARCHEAN
Keewatin
Green and sericitic schists, graywackes, and altered eruptives.
Conglomerates
Gabbro.
Coutchiching
Mica schist.
Granites, syenites, and gneisses.
The shore lines and rock formations in Canadian territory, except in a few localities, are derived from the Rainy Lake sheet of the Geological Survey of Canada, prepared by Dr. A. C. Lawson.
Contour Lines are drawn approximately in Minnesota for each 50 feet above the sea.
Scale of Miles.
RAINY LAKE
RAINY RIVER
KABETOGAMA LAKE
NAMEKAN LAKE
SHOAL LAKE
BAD VERMILION LAKE
GRASSY LAKE
SEINE RIVER
International Boundary
FORT FRANCES
KOOCHICHING
RAINY LAKE CITY
BLACK BAY
SAGINAW BAY
SAND BAY
STANJIKOMING BAY
HOPKINS BAY
RICE BAY
SWELL BAY
BLEAK BAY
SEINE BAY
JACKFISH BAY
HALE BAY
DRYWEED ISLAND
Pine Islands
Manitou Rock
Brule Narrows
Big Island
Big Pine Id.
71-23
70-22
70-21
70-20
70-19
70-18
69-21
69-20
69-19
69-18

GENERAL FEATURES AND GEOLOGY

I. GENERAL FEATURES.

Location.

The area shown on the accompanying geological map (plate I) comprises the region here reported on. Roughly speaking it includes the northeastern corner of Itasca county, the northwestern corner of St. Louis county and a belt of country, eight to fifteen miles wide, immediately to the northward in Ontario. More accurately the region mapped and described extends from the east side of range 18 W., St. Louis county, (about longitude 92° 34′ west of Greenwich), west to the west line of range 24 W., Itasca county (about longitude 93° 29′), a distance of forty two miles; and from the south side of township 69 N., (about latitude 48° 25′) north to latitude 48° 45′, a distance of twenty-three miles. The map thus includes 966 square miles, which are about equally divided between Minnesota and Ontario.

Rainy lake comprises the larger part of the water surface in the area mapped. It extends along the International boundary from Kettle falls, in sec. 30, T. 70 N., range 18 W., westward to its outlet in sec. 25, T. 71-24, a distance of about forty-one miles. Less than one-fourth of the surface of the lake lies in Minnesota, and several bays extend north and northwest of the area shown on the geological map.

Rainy Lake City, which was the first town started in this district in Minnesota, is situated in section 34, T. 71-22, Itasca county, and is 135 miles in a straight line north-northwest of Duluth and 250 miles north of St. Paul and Minneapolis. Koochiching, Itasca county, and Fort Frances, Ontario, are on opposite sides of the Rainy river at Koochiching falls, twelve miles west of Rainy Lake City and two and a half miles west of the outlet of Rainy lake.

Topography.

Rainy lake is a very irregularly outlined body of water with many crooked bays and numerous islands, which vary in size from mere reefs to those several square miles in extent. The surface of the lake, inclusive of islands, has been computed to include 344 square miles. Its extreme length is from the east end of Hale bay, which is about four miles east of Kettle falls, northwestwardly to the extremity of Northwest bay, in all, fifty-five miles. The extent of the lake east and west is forty-six miles, and the extreme width (north and south) thirty-three miles, of which twenty-three miles are in Canadian territory. On account of the irregular shape of the lake and its numerous points and islands there is no very considerable stretch of open water, but in a few places the view is unobstructed for ten to fifteen miles in one direction. That part of the lake lying along the International boundary consists of an eastern arm extending from Kettle falls to Brulé narrows, and the southern side of the main part of the lake lying west of Brulé narrows. The eastern arm is twenty miles long (east and west) and from two to five miles wide. The main part of the lake has several large bays running north into Ontario; in fact, most all of this section of the lake lies north of the boundary line. The only extensive bay on the Minnesota side is a shallow body of water lying in the north half of T. 70-22, known as Black bay, or as Rat Root lake by the Indians.

The land surrounding Rainy lake, except on the west, slopes toward the lake, which thus receives the drainage of a considerable area The extent of the drainage basin of Rainy lake is some 16,440 square miles, of which 4,440 are in Minnesota and 12,000 in Ontario. The two most important sources of supply from Minnesota are the waters of the Vermilion river and those of the International boundary chain of lakes. This latter source brings water from both sides of the boundary line for a distance of 150 miles to the east-southeast of Kettle falls, i. e. from the divide between the lake Superior and the Hudson bay drainage in T. 65 N., R. 2 W., Cook county (between North and South lakes). Rainy lake, whose drainage basin is equal to nearly one-fifth of the area of the state of Minnesota, discharges its waters through the Rainy river. This begins at the outlet of the lake in sec. 25, T. 71-24, a locality known as Koochiching by the Indians. Here are two small rapids, with a fall of three feet, beyond which the river flows westward as a stream 600 to 1,200 feet in width to the Lake of the Woods, and from thence the waters find their way into Hudson bay. Two and a half miles west of the outlet are the Koochiching falls where the river plunges over a ledge of rock twenty-one to twenty-four and a half feet high at different stages of water in the river. (See plate II, figure 1.) It is estimated that there are 12,000 cubic feet of water flowing out of Rainy lake every second.

The altitude of Rainy lake has not been definitely determined, but the estimate of Mr. Warren Upham* of 1,115 to 1,120, or a mean of 1,117 feet above sea level, is probably nearly correct. The greatest known depth of the lake is at a place about six miles north-northwest of the Brulé narrows, where there is the lowest depression in the region, or a depth of water of 110 feet, while the average depth of the lake is probably not far from forty-seven feet.† The accompanying table gives the hights in feet above the sea level of some of the lakes in this vicinity and to the southward. Those marked by an asterisk are accurately determined.

TABLE OF ALTITUDES OF LAKES.

Rainy lake, 1115 to 1120; mean	1117
Kabetogama lake	1125
Namekan lake	1125
Sand Point lake	1126
Crane lake	1126
Little Vermilion lake	1127
Loon lake	1166
Lac la Croix (Nequaquon lake)	1186
Iron lake	1210
Crooked lake	1240
Basswood (Bassimenan) lake	*1300
Vermilion lake	*1357-1360
Lake Superior	*601.56

The Rainy Lake district is of the nature of a plateau with a very gentle slope from all directions, except the west, toward the lake. This plateau, while not having a perfectly even surface, still is not broken by any considerable elevations or depressions, and altogether has a decided flatness. The immediate shores of the lake usually do not rise more than fifty feet above the water, and land 100 feet higher than the lake surface is not common. The highest land in the Minnesota part of this district is just to the south of Kabetogama lake, and the highest elevation in the area mapped is between Open Water narrows and Bear's passage, where a ridge rises about 275 feet above the lake level, or somewhat less than 1,400 feet above the level of the sea. The lowest depression has already been mentioned, 110 feet below the surface of the lake, or 1,007 feet above the sea. The average elevation of the land is probably not more than sixty feet higher than the lake, or 1,175 feet above the sea. A number of soundings made by Dr. A. C.

*Altitudes between lake Superior and the Rocky mountains; U.S. Geol. Survey, Bul. No. 72, p. 188, 1891.

†A. C. Lawson; *op. cit.*, pp. 13 F, 16 F.

Lawson show that the general level of the lake bottom is about as much below the surface of the water as the adjacent land is above it; consequently if land and water areas were in equal amounts the general level of the plateau would be nearly that of the surface of the lake. But, as the land surface much exceeds the water, the average elevation is some feet above the lake level; and it is estimated that the average elevation of the plateau in the area shown on the geological map (plate I) is approximately 1,150 feet above the sea, or 548 feet higher than lake Superior.

The remarkable general flatness of the district is well shown by the large area penetrated by water that stands at nearly the same level. Rainy lake itself, with an extent of forty-six miles east and west and thirty-three miles north and south, may be said to extend through a rectangular area of these dimensions; thus its waters are spread out in various parts of a district including 1,500 square miles, and the general elevation of this rectangular district is not many feet above the lake surface. While just to the south and southeast is a series of lakes, including Kabetogama, Namekan, Sand Point, Crane and Little Vermilion lakes, which have an area probably half as large as Rainy lake and which stand at a level only eight or nine feet higher.

This plateau-like nature of the district will be again referred to in the outline of the geological history of the region, and a possible explanation of the present topography will be suggested.

In its general appearance this district is characteristic of much of northeastern Minnesota; it is a country of lakes, swamps, and timbered rocky knolls. The surface, especially in the district here reported on, is not truly hilly, but mammillated or hummocky. The small knolls that rise above the level of the lakes and swamps are glacially rounded and are covered with only a scant soil, which, however, supports quite a luxuriant growth of pines, spruces, balsam fir, white birch and poplar. The shores of Rainy lake are generally rocky, but toward the western end sand beaches are frequently seen, and the heads of the bays are usually marshy or swampy. Over large tracts there are practically no surface deposits of glacial or more recent origin, the rocks coming to the surface whenever the thin forest soil is pushed aside. The surface is dotted with numerous lakes and lakelets varying in size from an acre to bodies of water a hundred or more square miles in extent. The lakes are largely in completely rock-bound basins and most of them are elongated in a direction parallel to the trend of the country rocks. From one rocky basin a short, rapid stream carries the water of one lake down to the next lower basin, and in this way the greater part of the drainage is accomplished. Aside from these streams there are over large areas none of any importance and nothing that can be called a river, but wherever the rocks are covered with considerable quantities of drift the lakes become scarcer and the drainage is carried on by the ordinary rivers and smaller streams. The outlets of the lakes are so narrow that, after the melting of the snows and after the early spring rains, the waters are partially dammed back and held at a level four or five, or even ten feet higher than normally.

At the west end of Rainy lake this surface of lake and rock suddenly gives way to a plain of clays, through which the underlying rock rarely emerges. The change from the rocky lake country to this clay plain is abrupt and very striking, and is intensified by an equally sudden change in the flora; the lake shores and the country to the east have a forest largely of evergreens and boreal in its aspect, while to the west of the lake a forest largely deciduous and more southern in its character appears. The extremely flat surface of the plain is, as far as altitude is concerned, a continuation of the rocky plateau to the east; it has a gentle slope to the west and is unvaried by lakes or other features except the shallow, steep-sided trenches cut by the Rainy river and its tributaries.

II. GEOLOGY.

The rocks underlying this district are among the most ancient known. To a considerable extent they are completely crystalline, and, while many of them bear evidence of having been deposited in water as true sediments, still they offer no trace of any fossils and are regarded by some geologists as older than the earliest life on the globe. From the flat position, in which these strata were originally deposited, they have been elevated, folded and crumpled so that now they stand in abnormal attitudes; and, in addition to the mountain making forces to which these rocks have been subjected, they have been intruded by vast masses of granitic rock. Thus it is difficult to decipher the exact structure of the region. Another cause of this difficulty is the almost universal development, except in some of the granitic rocks, of parallel schistose structures, which are easily mistaken for sedimentary planes and which are not always parallel to these planes, although as a rule in this district the schistose structure coincides in direction with the bedding. The general strike of the rocks is from east and west to east-northeast and west-southwest, but outside of the area shown on the geological map the strike varies much, the rule being that it follows around the outlines of the great granite-gneiss masses of the region.

In age, all of these rocks, with possibly the exception of the diabase dikes whose exact age is unknown, are pre-Cambrian. They are readily separable into four distinct groups. Beginning with the lowest these are: 1. Laurentian, composed of granites and granitoid gneisses and allied rocks; 2. Coutchiching, composed of mica schists grading into fine grained gneisses; 3. Keewatin, composed of hornblendic, greenish and sericitic schists, conglomerates, graywackes, etc.; 4. Diabase dikes, more recent than and cutting all the others. The following table will show the position of these rocks at the base of the geological column, their equivalents in the country to the southeast of Rainy lake and their designations in the terms used by the Geological and Natural History Survey of Minnesota. In the nomenclature of the United States Geological Survey the Keewatin and Coutchiching belong to the Algonkian, and the Laurentian to the Archean or Basement Complex.* In the table the uppermost or more recent rocks are placed at the top.

Geological Names.			Rainy Lake District.	Equivalents to the Southeast.
PALEOZOIC	TACONIC	Keweenawan	Diabase dikes?	Copper-bearing rocks of lake Superior.
		Animikie	(Wanting)	Iron ores and other rocks of the Mesabi range.
ARCHEAN	ONTARIAN	Keewatin	Greenish and sericitic schist, conglomerate, graywackes, etc	Iron ores and other rocks of the Vermilion range.
		Coutchiching	Mica schists and fine grained micaceous gneiss.	Crystalline schists on both sides of the Vermilion range.
	Laurentian including eruptives.		Granites and gneisses.	Granite and gneisses of Vermilion and Basswood lakes.

*More information concerning the designations and relations of these ancient rocks in Minnesota and their equivalents in adjacent territory can be gained by consulting the table of the "Pre-Silurian Rocks of Minnesota," which faces page 4 of the 21st (1892) Ann. Rept. Geol. and Nat. Hist. Survey of Minn., 1893.

The Rainy Lake district has no rocks more recent than these ancient Archean ones, but scattered over the surface are small deposits of glacial drift, and just west of the lake, as has already been mentioned, is a considerable thickness of clays.

*The Laurentian.**

The Laurentian is composed entirely of completely crystalline rocks,—granites and syenites with gneisses of the same mineralogical composition. The extent of territory covered by such rocks in northern Minnesota and adjacent portions of Ontario is surprisingly great. Nearly a third of the region here reported on is underlain by the Laurentian, while all the shores of Rainy lake north of the area shown on the geological map are composed entirely of these same rocks. Contrary to expectation these hard granitic rocks do not always form pronounced hill ranges, as is the case with the Giant's range of granitic hills on the northern flank of the Mesabi iron range, but very frequently these areas of Laurentian rock give a comparatively level surface on which are extensive and extremely irregularly outlined bodies of water. Examples of these spider-like lakes stretching over considerable areas of granite can be seen in Saganaga, Basswood (Bassimenan) and Crooked lakes, and in Lac la Croix and a large portion of Rainy lake itself.

In color the Laurentian rocks are white, gray, pinkish and reddish, the prevailing color in any one place being largely due to the color of the most important mineral,—the feldspar. In grain these rocks vary from those in which the individual minerals can scarcely be recognized with the naked eye, to very coarse aggregates where some of the feldspar crystals are several inches across. Most of these rocks can be called granites, *i. e.*, they are granular aggregates of quartz and feldspar with a dark mineral, either black mica (biotite), hornblende or augite. Sometimes two of these are present, and in other places, especially in the coarse grained dikes or veins which occur in the mica schists, white mica (muscovite) is the only mineral present in addition to the quartz and feldspar. The quartz fre-

*In this report the term *Laurentian* is used to include all the gneissic and granitic rocks of the Archean in this region. That many of these rocks are of later date than and intrusive into, parts of the Coutchiching and Keewatin, is well known; but, as such rocks have generally been mapped and described as Laurentian in the previous reports of the Minnesota survey, and as they have been also described under this term by Lawson in his well known writings on the geology of that part of Ontario lying immediately to the north of Minnesota, and as such rocks are generally known as Laurentian, the writers have thought best to retain this term in the present report, even though this usuage is, in part at least, a violation of the idea of Laurentian used strictly as an age term.

quently diminishes in quantity and even completely disappears; such a rock with no quartz, or a very small amount of it, is known as syenite. In fact all the minerals vary greatly in amount in the different parts of one rock mass. For example, a rock in a certain place composed of quartz, feldspar and hornblende will vary by a gradual decrease of the hornblende until almost none is left, and we have a rock composed almost entirely of quartz and feldspar; or, as the hornblende decreases, mica or augite may increase and we have a change from a hornblende granite to a mica or an augite granite. The only mineral which is prevalent throughout the whole of the Laurentian is feldspar, and even this varies greatly in amount within small distances.

In structure, also, the Laurentian rocks differ considerably. The granites and syenites are sometimes massive in appearance, *i. e.*, they exhibit no schistose or laminated structures; the structure is granular, and every part of an exposure is like every other part, except perhaps as regards the relative proportions of the different minerals or the fineness of the grain. But this massive appearance is by no means prevalent throughout the whole region; it generally gives place to a somewhat schistose or foliated structure. Some of the minerals of the granite or syenite are often seen elongated or flattened in one direction; this is especially true of the mica. When this is the case the rock breaks more easily along the planes in which these crystals lie. Or the rocks may be crossed by narrow streaks which are composed largely of one mineral with the longer diameters of many of the crystals lying roughly parallel. At other times certain bands, one to three or more inches wide, will be seen running through the rock, each band being of a somewhat different composition or texture from the adjoining ones. These foliated and banded rocks are known as gneisses, and in this region they can be conveniently designated as granite gneiss or syenite gneiss, depending upon whether the mineralogical composition is similar to that of granite or syenite. These various features of the Laurentian rocks allow them to be separated into different classes or groups both mineralogically and structurally, but these groups are frequently seen grading into each other. The hornblende granite of one point will pass gradually into a hornblende syenite near by, and this again may change to a mica syenite. Again, a perfectly massive rock will become foliated within a short distance, the intervening steps between the massive and the foliated or gneissic rock being readily traceable. It thus is often impossible to draw a line between the various phases of these Laurentian rocks; consequently in the geological map no attempt has been made to separate the different varieties. It is unnecessary to describe all the outcrops of these rocks, or to indicate the areas occupied by each of the different groups, but a brief account of a few of the more interesting or typical occurrences will be given below.

At Koochiching falls the rock is a medium gray biotite syenite; the component minerals are white feldspar and biotite, with a little hornblende and epidote. This syenite is massive in some places, but usually shows a slight indication of a foliated or gneissic structure, thus approaching a biotite syenite gneiss. It contains many darker masses, sometimes a foot or more in diameter; they are composed of the same minerals as the main part of the rock, but the mica makes up a very large proportion of each dark mass. These darker masses can be referred to fragments of foreign rock included in the syenite, or to segregations of the basic minerals of the syenite itself. This medium grained gray biotite syenite is the usual phase of the rock at the falls. It is especially well shown in the rocks thrown out from an excavation for a canal at Fort Frances made by the Canadian government some years ago. Below the falls the rock becomes porphyritic with crystals of flesh colored feldspar which are often an inch in length. These crystals stand out all over the weathered surfaces of the rock. Two islands about three-fourths of a mile below the falls contain excellent exposures of this rock; the upper of these islands is composed of syenite alone, while the lower also shows a fine micaceous schist, which, in places, is seen in sharp contact with the syenite; and in other places there is apparently a transition from the syenite to the mica schist within a distance of a few feet.* Along the river above the falls on the Canadian side no outcrops were seen, but two exposures of the syenite occur on the Minnesota side; the first of these is in the town of Koochiching about where the north line of sec. 34, T. 71-24 cuts the shore, and the second is near the center of the N. ½ of N. W. ¼ sec. 35, T. 71-24. At the latter outcrop the rock is porphyritic with feldspar crystals, most of which are bright red in color, while a few are greenish.

In the N. E. ¼ of sec. 28, T. 71-23, in Rainy lake, is an island elongated in a north and south direction, while just a few

* 17th (1887) Ann. Rept. Geol. and Nat. Hist. Survey of Minn., pp. 410-412, 1888.

yards to the southwest is another and smaller island on which the usual relations of the Coutchiching mica schist and the Laurentian granite are clearly and unmistakably shown. The latter rock forms the northeast side of this little island and the former the southwest side; along the center of the island the two are in contact. The granite is a light gray rock of medium grain, composed of white feldspar, which is probably largely orthoclase, quartz and biotite. There is sometimes a sub-porphyritic aspect due to the existence of a few crystals of feldspar larger than the other crystals of the rock. There is also an indication of a foliated structure caused by an indistinct streaming of the biotite and an elongation of some of the feldspars in one direction. This is not pronounced enough to strictly allow the application of the term gneiss, and the rock may be called simply a granite, or a gneissic or gneissoid granite if it is desired to make the existence of an indistinct foliation prominent. This partial foliation agrees in strike and dip with the mica schist which stands nearly vertical and trends 50° to 60° east of north. At the contact line, which roughly follows the direction of the strike, the granite is not particularly finer grained, nor does it differ otherwise from its normal condition. A few angular fragments of mica schist are to be seen entirely surrounded by the granite, and in the mica schist are irregular vein-like forms or dikes running both across and along the beds of mica schist; some of these dikes can be traced directly into the main mass of granite. They are of all sizes from a fraction of an inch to several feet in width. A hand specimen collected to illustrate the contact shows a small stringer of granite, one-fourth of an inch wide, which starts out from the main mass of the granite, runs for two inches in the mica schist and then gradually thins out and disappears. The relations of these two rocks show conclusively that the granite here acts as an eruptive rock and that it has been forced, while in a plastic or fluid state, into cracks or fissures in the mica schist. At the contact the mica schist does not appear much different from the same rock a short distance away, but it is harder and less schistose, and microscopical examination would probably show some mineralogical changes due to the heat of the granite. Another interesting feature on this small island is the occurrence of small dikes of a finer grained rock which cuts the granite itself and is therefore of later date. This rock is a very fine grained white granite composed almost entirely of quartz and feldspar;

it cuts the main granite in numerous small dikes which are two feet or less in width. These dikes are not finer grained at the edges than at the centers, and they do not exhibit any foliation; there is nothing to show definitely how much later these dikes are than the main mass of the granite, but it is probable that the two rocks do not differ much in age. One dike of this fine grained white granite (or aplyte) was seen in the mica schist.

Three-fourths of a mile east of these islands, on the blunt point near the center of the north side of section 27, T. 71-23, the granite and mica schist are again seen in contact. Here the granite exists commonly in thick bed-like forms between the layers of mica schist, but in many places these "beds" are seen to be directly continuous with other masses of granite that cut directly across the beds of mica schist. The contact of these two rocks can also be seen on the island in the S. E. ¼ of sec. 22, T. 71-23.

It is not uncommon to find in the mica schists large veins or dikes of very coarse grained rock of a composition similar to the granites. In such places the individual crystals often reach a length of several inches. The minerals of these coarse grained rocks are feldspar, which is usually pinkish or reddish and is either orthoclase or microcline, quartz, and most commonly muscovite. The quartz and feldspar are often grown together in such a manner as to form graphic granite, *i. e.*, a certain large mass of feldspar, which is shown to be all one crystal by the extension of the same cleavage plane through it, is spotted all over by smaller grains of quartz; and each quartz grain, when studied under the microscope, is seen to have the same crystallographic axes as the other grains in the same feldspar crystal, showing that these grains are really all parts of the same quartz crystal. Perhaps a good illustration of this growing together or interpenetration of feldspar and quartz can be had by likening the feldspar crystal to a sponge full of cavities, which cavities have all been filled by a continuous mass of quartz. Rocks of this nature are quite common along the shores of Kabetogama lake, and to the south and east along the International boundary. The individual crystals of feldspar often reach surprising dimensions. For instance, in one place a crystal was seen which measured actually thirty-three inches in length, and many were found over a foot long. The locality where this large crystal occurs is on the point which is at the center of the W. ½ of S. E. ¼ sec. 19, T. 70-18, on the south shore of the eastern arm of Rainy lake. Here this coarse grained rock, which is often known as pegmatyte, forms large veins or dikes in the mica schist. Sometimes these pegmatyte forms occur in the granite itself.

A short distance northwest of Shoal lake are gold bearing veins in an area which has been mapped as granite. The rock in which the veins occur is somewhat different from that seen elsewhere, and, as it has been called by various names, we have endeavored to make a rather careful examination of the specimens we have of this rock in order to determine, if possible, just what the rock is. As just stated, this rock has been called granite, and there are areas in the midst of the rock which hold the veins that are true granite and which do not seem to be sharply separated from the vein-holding rock. A description of a specimen from one of these granitic areas on Wiegand's location, A L 75, is as follows:

Macroscopically this rock is a gray granite of medium grain, and quite fresh. The minerals are quartz, feldspar and biotite; the first two are in approximately equal amounts and compose three-fourths to five-sixths of the rock. The feldspar is whitish, varying to greenish and pinkish, the latter shade apparently due to iron staining.

Under the microscope the structure of the rock is seen to be truly granitic. In addition to the minerals mentioned above are small flakes of muscovite and a few greenish areas composed of chlorite. The quartz is ordinary granitic quartz containing bubbles and gas cavities. It shows undulatory extinction, and frequently a large grain has been fissured into many smaller ones which, however, have not been separated from each other and so extinguish at almost the same time. Undulatory extinction and this fracturing of the grains are the effects of pressure on the quartz, which mineral is one of the first to show the effects of having been subjected to pressure, especially when enclosed in a hard solid substance like granite. The feldspar is highly altered, largely to a mass of brightly polarizing flakes and fibres which seem to be muscovite. In some grains a trace of polysynthetic twinning still remains, and undulatory extinction is present. The feldspar was originally orthoclase and an acid plagioclase apparently of the albite-oligoclase series.

To sum up, this rock is a typical medium grained biotite granite, or granityte, with the feldspar considerably altered; the rock has been subjected to pressure, as shown by the fracturing of the quartz and the undulatory extinction of both quartz and feldspar, but no schistose structure can be seen either in the hand specimen or in the slide.

The rock in which the veins occur at Wiegand's location, A L 75, is a peculiar greenish gray rock composed of quartz grains imbedded in yellowish green groundmass. The quartz is in glassy grains of all sizes up to those one-fourth of an inch across; some of the grains are pinkish, due to iron staining. The groundmass is too fine grained to allow its constituents to be distinguished by the naked eye; it appears homogeneous, is soft, has a greasy feel, can be readily scratched with a knife and effervesces slightly with cold hydrochloric acid. A slight schistose structure can be distinguished in the ground mass. A few grains of pyrite occur, but fully a third of the rock is quartz.

The thin section shows a number of quartz grains of various shapes and sizes imbedded in a groundmass of minute fibers. The quartz shows undulatory extinction and fissuring to a better degree than in the granite just described. A few small flakes of muscovite are present, also a small amount of calcite and an opaque yellowish substance. The fibers of the groundmass are quite small and polarized in rather bright colors; they are muscovite or sericite. Mixed in with the fibers are very minute grains of quartz and perhaps also some of feldspar. At places in the groundmass are irregular areas and shreds of feldspar; often these have a few flakes of the mica in them and their edges are jagged, due to a penetration of the fibers into the feldspar substance. Frequently several areas of feldspar in the same vicinity extinguish together, showing that they are remnants of an originally larger grain which has passed almost completely into mica. The fibers of the groundmass are often elongated in one direction; this causes the schistose structure of the rock.

As to just what this rock was originally, it is hard to make a positive statement. That it has been subjected to pressure and shearing is evident from the condition of the quartz and the schistose structure of the rock. It is also evident that some parts, at least, of the groundmass are due to a breaking down of feldspar grains, the remnants of which are still present; it is not improbable that most of the groundmass has a like origin. While all the field relations of this rock are not known, still it occurs in an area of rock in which are parts that are certainly granite, as that just described, and it does not seem to be sharply separated from these certainly granitic areas. The quartz grains are very similar to those in the granite above described. Thus it seems possible, and indeed probable, that the rock under consideration was originally a granite, and that it has been subjected to pressure and shearing, which have induced the schistose structure, and which, with the aid of percolating waters and perhaps heat also, altered the original minerals (excepting the quartz) to the present fibrous ground-mass. The quartz shows fracturing and undulatory extinction, but is otherwise unaltered as it is almost indestructible when compared with the other minerals of the granite. That the rock might have been other than a granite it is impossible at present to deny; there are, however, no characters that necessarily indicate another origin. The original nature of the rock can be determined only by a careful investigation of the field relations supplemented by microscopic evidence. But from our present knowledge we would consider this rock as most probably an altered phase of granite.

The exact nature and origin of these Laurentian completely crystalline rocks in the Rainy Lake region and elsewhere are rather complicated questions and can not yet be settled to the satisfaction of all who have studied them. That these rocks in the region here considered are now totally lacking in characters that clearly show them to have once been clastic like ordinary sediments goes without saying. And there is no positive proof that the more pronounced gneisses,—those that show alterations of bands of different mineralogical or structural characters, which varieties of gneiss are not common,—were once sedimentary, although the presence of this banding and other less pronounced foliation is to some a strong argument for an originally sedimentary nature. That these granitic rocks are intrusive in numerous places into the Coutchiching mica schists, and often into the Keewatin rocks, is absolutely certain. Good proof of the metamorphism of the clastic rocks of the region to form gneisses has not yet been observed, although places that show this may be found in the future. Dr. A. C. Lawson, who is familiar with this region, thinks that these Laurentian rocks represent older rocks than the Coutchiching, but whether originally sedimentary or not is only to be guessed at; they have been softened and fused and while in this condition have been intruded into the rocks lying above them and there solidified. The following quotation from this author will help to explain his view:

This group of crystalline rocks, granites and syenites, foliated and non-foliated, forms the floor of the region upon which rest all other formations that are not in the condition of dykes or intrusive bosses. Regarded as a geological system of rocks it occupies an apparently paradoxical and anomalous place in any scheme of classification. As the floor or basis upon which the geological column of stratiform rocks rests, it must be regarded as the first or fundamental system of rocks of which we have any cognizance. If, however, we inquire as to the age of these rocks, we are forced, by the direct application of the simplest principles of geological science to look upon them as of later age than certain of the series which overlie them. We do not yet know their original condition prior to the fusion from which they solidified into granites, syenites and gneisses. They may have been sedimentary; they may have been the original crust of the earth. The abstract speculations that are so often indulged in on this and similar questions have not decided the facts of the matter. There is yet no sufficient ground for a just opinion upon it. But whatever may have been that original condition the evidence is clear on this point, viz: that the fusion and solidification, whereby they were brought into their present condition as firm crystalline rocks, took place at a period subsequent to the existence, in a hard, brittle condition, of the stratiform and often very distinctly clastic rocks which occupy a higher place in the column. Therefore, as rocks, the members of this fundamental system are of younger age than that of the nearest overlying formations. An analogous case with which every geologist is familiar is that of dykes. These are of younger age than the strata they cut, although the main mass, of which they are merely the apophyses, is far inferior to those strata and may form the base upon which they rest.*

Under this view, concerning the Laurentian, the floor on which the Coutchiching rocks, and in some places the Keewatin, were deposited is now entirely unrecognizable; it has been softened and moved so that its relation to the Coutchiching is now an eruptive one. On the other hand, it seem probable that parts of this old floor are still preserved; such places, however, have not yet been found in this locality, all the granite and gneiss areas examined apparently showing an eruptive relation to the Coutchiching; and the same can be said of the relations of the granite and gneiss to the Keewatin. However, to the north-east of Rainy lake, rocks apparently corresponding to the Keewatin have been found unconformable upon an older series of granites and gneisses† supposed to represent the Laurentian; and it is not impossible that the Keewatin conglomerate seen on the north of Shoal lake will be found to be unconformable on the granite to the north. Many problems concerning these ancient rocks,—Laurentian, Coutchiching and Keewatin,—especially as regards their relations to each other,—are still unsolved, and it will not be profitable to discuss them further here.

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* American Journal of Science, 3rd series, vol. 33, pp. 474-475, 1887.

† H. L Smyth; Structural geology of Steep Rock lake, Ontario; Amer. Jour. Sci., 3. vol. 42, pp. 317-331. pl. 11. 1891.

The Coutchiching.

This series of rocks, while occupying a large amount of territory, is of comparatively simple character and will need but a brief description. They extend along the south shore of Rainy lake from the outlet east to Jackfish bay, then for a distance of eight miles (to the line between Itasca and St. Louis counties) the Keewatin occupies the shore, but all the south shore east of this and all the shores of the eastern arm of the lake, with the exception of a few granite areas, lie entirely in rocks of this series. Other small areas are found to the north of the belt of Keewatin rocks that runs east-northeast from Jackfish bay.

Lithologically the Coutchiching is preëminently a mica schist formation; with the mica, which is mostly biotite, is either quartz or feldspar, and commonly both in the more coarsely crystallized facies. The rocks near the outlet of Rainy lake are mostly quite fine grained mica schists or even gray to brownish mica slates, but usually the Coutchiching rock is a well defined mica schist. In close proximity to some of the granite masses, as along the north shore of Kabetogama lake, the mica schist becomes quite coarsely crystallized and might properly be called a gneiss, but it is not easily confounded with the gneisses of the Laurentian. In addition to the usual minerals, others, such as garnet and staurolite, are sometimes found in the mica schists not far from their contact with masses of granite. The schistose structure, due to an arrangement of the mica scales in roughly parallel positions, is characteristic of this series. In many places there are rapid alterations of bands, from an inch to several feet in width, of slightly different mineralogical composition, structure or color; the position of these bands gives the strike and dip of the rock, and where they are lacking the schistose structure is taken to indicate the strike and dip, as this structure seems to be parallel with the banding wherever the two are seen together. There is a vast thickness of this monotonous mica schist formation along the eastern arm of Rainy lake and to the southward; several estimates by Dr. A. C. Lawson show an apparent thickness of about five miles.* These Coutchiching rocks in several particulars appear so much like ordinary sediments that it seems necessary to consider them as sedimentary beds which have been more or less recrystallized in situ by metamorphic processes. This change has been largely in the nature of regional

* Geol. and Nat. Hist. Survey of Canada, new series, vol. 3, pp. 101-102 F, 1889.

metamorphism, but the more coarsely crystalline condition of the beds in close proximity to intrusive masses of granite shows that contact metamorphism has also played an important part.

The relation of the Coutchiching to the Laurentian has already been mentioned. Its relation to the Keewatin is not definitely known. The Coutchiching, however, is lithologically quite distinct from the overlying Keewatin rocks, and in the field it is a comparatively easy task to separate these two series of rocks. Where they are in contact, however, they have the same strike and dip and thus appear strictly conformable. But the difference in lithology between the Coutchiching and Keewatin is marked; in the former we have no evidence of volcanic activity, while in the latter there are numerous proofs of great volcanic activity, in fact, the Keewatin can be said to be characterized as a period of intense and wide spread eruptions. Moreover, in the Keewatin are conglomerates, which, in places, seem to be basal beds resting on the Coutchiching. Lawson * has consequently inferred an unconformity between these two series, and while the existence of this is not undoubtedly proven, it still seems quite probable.

The Keewatin.

This series of rocks is more varied in lithology than either of the others just described, and it is of more interest on this account and also because in it are found most of the gold bearing veins thus far discovered. The rocks are conglomerates, slates, sericitic, chloritic and hornblendic schists, agglomerates, graywackes and more or less altered igneous rocks, both acid and basic. The presence of large amounts of hornblendic and other green schists, some of which are clearly of igneous origin, gives to this rock series a prevalent green color, and this abundance of "greenstones" and "green schists" is one of the most characteristic and distinctive features of the Keewatin series. That parts of these green rocks represent ancient igneous ejections, both lavas and ash beds, is absolutely certain; and, as before stated, they show that the Keewatin was a time of violent and extensive volcanic activity. But the Keewatin was also a time of deposition for ordinary sediments. Much of the fragmental volcanic material seems to have been deposited in water, which has given a stratiform character to the beds, and mixed with this fragmental igneous matter was more or less of

* *Op. cit.*

ordinary sediments; the two kinds of deposits evidently grade into each other, the igneous material predominating in close proximity to volcanic vents. These Keewatin rocks, like the other series, have participated in great earth movements, which have produced slaty and schistose structures. The effects of these movements seem to have been better registered in the Keewatin rocks than elsewhere by a more pronounced and almost universally present schistose cleavage.

The most important belt of Keewatin rocks is that which is first seen on the south shore of Rainy lake at Jackfish bay. West of here this belt has not been carefully traced out, but a few outcrops have been seen, some of which will be mentioned below. East of this bay the Keewatin forms the south shore of the line between Itasca and St. Louis counties; and a number of islands just to the north of the shore, the largest of which are Grassy, Grindstone, Dryweed and Sand Point, are mostly composed of the same rocks. This belt of Keewatin runs a little north of east, crosses the lake and extends past Seine bay and Shoal and Bad Vermilion lakes and eastward beyond the limits of the map.

To the west of Jackfish bay sections were made south from Rainy river in two places. The first was along the west line of sec. 35, T. 71-24, and southward for a mile and a half beyond the south line of this section. No outcrops were seen; the ground passed over is nearly level and forms a part of the clay plain which lies along the river. However, in the S. E. ¼ of S. W. ¼ of this same section there is an exposure of considerable extent which rises a few feet above the level of the plain. The rock is a fine grained gray sericitic schist or slate with no pronounced lines of sedimentation. The cleavage, as measured in three places, runs N. 50° E. (mag.) and stands about vertical. Parallel with the cleavage are fine laminæ which, in the absence of more definite indications, are assumed to represent the true sedimentary planes of the rock. The second section was made from the lake shore at the outlet, along the east line of range 24, to a point half a mile south of the southeast corner of T. 71-24. Several outcrops were crossed, all of which present a schistose cleavage that runs N. about 50° E. (mag.) and dips at a high angle toward the northwest. In some places a distinct alternation of beds of different composition was seen; these give the true strike of the rock which, as far as seen, coincides with the cleavage. The rock of these outcrops is largely a sericitic schist, but it frequently becomes darker colored and greenish and contains minute laminæ of white siliceous material.

On the south shore of Jackfish bay and on an island in this bay near the west line of sec. 26, T. 71–23, are excellent exposures of conglomerate. The conglomerate of this island, which is made entirely of this rock, has as a matrix a greenish to grayish fine grained schistose rock composed of silvery micaceous scales and other material which is too finely divided for recognition by the naked eye. In some places the matrix becomes coarser and is crowded with quartz grains the size of a pin's head and larger. The pebbles of the conglomerate are very numerous and are well distributed throughout the rock of the island; they vary in size from pieces the size of a pea to those that are ten inches across. Several kinds of rock are represented in these pebbles, but the most common is white or yellowish vein quartz; next in abundance are pebbles of a gray rock which seems to be a very fine grained granite. Pebbles more or less similiar to the matrix are also common; these are not easily recognized on fresh fractures, but on weathered surfaces they are quite readily distinguished. The pebbles are mostly well rounded; this is especially true of those composed of quartz, which are very sharply separated from the matrix and can be easily dislodged. The conglomerate has been subjected to shearing and stretching and as a result the pebbles are commonly seen flattened in one plane, which coincides in direction with the schistose cleavage of the matrix. The strike of this cleavage is N. 60–65° E. (mag.) and the dip is about vertical. In a few places there are some indications that the true strike of the conglomerate is almost at right angles to the strike of the cleavage; these indications, however, are not entirely satisfactory evidence of the position of the bedding, nor are there satisfactory evidences that the true strike is parallel with the cleavage. On the south shore of this bay are other outcrops of the conglomerate, the matrix at this place being a green schist. Small pebbles are not common here, most of those seen being over six inches in diameter; sometimes they reach a size of three feet in greatest diameter. These boulders are largely of one rock—a rather fine grained greenish to pinkish biotite granite. They are well rounded and lie with their long axes parallel with the strike, which is here plainly coincident with the schistose cleavage.

Other exposures of conglomerate occur to the east of Jackfish bay on the south shore in the N. ½ of sec. 31 and the S. ½ of sec. 30, T. 71-22. Here the matrix is a green hornblende schist, more or less siliceous. The pebbles are mostly of about the same nature as the matrix and are distinguishable only on weathered surfaces. They have been elongated in a direction parallel with the cleavage and on this account and also because they so closely resemble the matrix, it is hard to tell whether they originally possessed rounded outlines or not. However, a few boulders occur at this place, which are of rock similar to the granitic boulders in the exposures on Jackfish bay, and they are distinctly and smoothly rounded.

On the south shore of Dryweed island in sec. 25, T. 71-22, the rock of the island, which is a sericitic schist, becomes conglomeratic with granitic boulders similar to those just mentioned.

Another belt of conglomerate is seen along the north side of Grassy and Shoal lakes. The specimens we have of this show the matrix to be a rough green hornblendic schist, sometimes quite rich in large and small grains of quartz. The pebbles are of greenstone, black and red jasper, quartz and felsyte, many of them being well rounded. Just northwest of Shoal lake this conglomerate is found resting directly upon the granite mass of Bad Vermilion lake. The exact contact line is exposed for some distance, and small patches of the conglomerate, which are easily dislodged are found lying directly on the surface of the granite. Although a casual examination failed to find any pebbles in the conglomerate that could be certainly referred to the underlying granite, still the relations of the two rocks at this place seem to indicate that the conglomerate is unconformable on the granite.

Another typical rock of the Keewatin series is seen in the S. ½ of sec. 29, T. 71-22. The conglomerate to the west of this gradually loses its greenish character and becomes lighter colored and siliceous on going eastward; at the same time the boulders become less numerous and finally disappear altogether, and we have a rock that is fine-grained, hard, tough, siliceous, and silvery gray in color. This rock forms bare, rounded knobs in sec. 29 and is quite massive in appearance. It continues eastward to form Grindstone and Dryweed islands, but on these islands, especially the latter, it becomes softer and more schistose, forming a siliceous sericitic schist. It also in places shows evidences of bedding which is parallel with the schistose structure, and, as mentioned above, it becomes conglomeratic on the south shore of Dryweed island in sec. 25, T. 71-22.

Just to the south of this belt of siliceous sericitic schist lies a belt of greenish schists, which are of interest for the reason that in them are found the veins that have been most exploited for gold. This belt of rock comes to the shore in the N. E. ¼ of N. W. ¼ of sec. 32, T. 71-22, and continues eastward forming the islands in the N. ½ of N. W. ¼ of sec. 33, the most easterly of these islands being the one on which the Little American mine is located. The south shore of the lake eastward from Rainy Lake City to the line between Itasca and St. Louis counties is skirted by this belt of rock, and the islands in the S. E. ¼ of sec. 27, the S. E. ¼ of sec. 26, the S. ½ of sec. 35, T. 71-22, and some small reefs near the center of sec. 30, T. 71-21, are composed of the same. This belt of schists varies somewhat in lithology, being composed of sericitic, chloritic and hornblendic schists, which are quite fine grained and usually quite siliceous. The smaller and more eastern of the islands in the S. E. ¼ of sec. 26 has a small amount of more acid and lighter colored rock than is usual in this belt. This rock consists of scattered quartz grains imbedded in a siliceous and schistose matrix; it perhaps represents an ancient quartz porphyry.

Further mention and description of parts of the Keewatin will be found in the section entitled "Description of veins in general and of individual properties."

The diabase dikes.

These are not very numerous in the area here reported on, and the total amount of such rock is very insignificant when compared with the rocks of the three series already described. The dike rock is dark, tough and heavy; it varies much in grain in the larger dikes according to the distance from the dike walls, the interior being coarser than the exterior. The rock is usually an ordinary diabase, with the ophitic structure, and is composed essentially of augite and plagioclase feldspar. Several dikes were seen in the syenite a short distance below Koochiching falls, and a larger one occurs in the same rock in the N. W. ¼ of sec. 35, T. 71-24. The largest dikes seen are those near the mouth of Jackfish bay; while these two are not strictly parallel, they both have a general northwest-southeast direction. The more eastern of these cuts through rocks which belong to the three rock systems of the region. The exact age of these dikes is not known. They are, however, later than all the other rocks of the region which they cut, and they have not been subjected to the same forces which produced so pronounced cleavages in the older rocks. During the Keweenawan time there were great numbers of basic eruptions and injections in the Lake Superior basin, and the dikes of the Rainy Lake region may perhaps date from the same time.

Glacial deposits.

As has already been stated, the rocks around Rainy lake are usually not covered by glacial drift or later deposits. In some places, however, there are small areas where there are thin sheets of till concealing the bed rock, and glacial boulders are common throughout the whole region. The general direction of glacial movement across the Rainy Lake basin, as shown by scratches on the rocks, was from northeast to southwest. Below are given a few heretofore unpublished courses of glacial striæ in the Rainy Lake region referred to magnetic north.*

Center of W. side of S. E ¼ sec. 19, T. 70-18, S. shore of Rainy lake	S. 30-35 W.
N. E. ¼ N. W. ¼ sec. 30, T. 71-23, S. shore of Rainy lake	S. 30 W.
W. line of sec. 29, T. 71-23, S. shore of Rainy lake	S. 40 W.
S. W. ¼ S. W. ¼ sec 29, T. 71-22, S. shore of Rainy lake	S. 45 W.
N. W. ¼ S. E. ¼ sec. 28, T. 71-22, E. end of Grindstone island, Rainy lake	S. 33 W.
N. W. ¼ N. W. ¼ sec. 30, T. 71-21, small island at E. end of Dryweed island, Rainy lake	S. 42 W.

The level area devoid of rock which begins at the west end or the outlet of Rainy lake, is underlain by a considerable thickness of glacial deposits. These deposits consist of clays, which are often calcareous and sandy and are quite frequently bluish in color. Scattered throughout these clays are small pebbles of various kinds of rocks, the most common of which is a fine grained yellowish or pinkish limestone; sometimes fragments of this limestone are found which contain a few fossil remains. These clays are thought to have been deposited from melting ice and from streams flowing into the glacial lake Agassiz. This lake covered the Red river valley, the Lake of the Woods and Rainy lake areas, and a large amount of territory to the west and northwest at the close of the Glacial per-

*Other lists of glacial striæ in this region have been published by A. C. Lawson (Geol. Surv. Canada, vol 3, pp. 164F-169F, 1889); H. V. Winchell (Minn. Geol. Survey, 17th Ann. Rept., 1888); Warren Upham (Minn. Geol. Survey, 22d Ann. Rept., pp. 35-40, 1894.)

iod; the history and deposits of this great glacial lake have been carefully investigated by Mr. Warren Upham.* The thickness of the clay deposits along that part of the Rainy river shown on the geological map probably does not much exceed forty feet; in general, the hight of the river banks above its bed is a direct measure of the thickness of the clays.

There are no post glacial formations in the region except the usual soil, vegetable accumulations in swamps, and a few sand beaches, mostly derived from the clays by the washing and sorting action of the lake's waves.

Auriferous gravels forming placers are not known about about Rainy lake. Some search for placers has been made, but there seems to be no probability that any will be found.

Auriferous gravels may have existed in some of the old water courses just before the Glacial period, but if they did thus exist, which is improbable, they were entirely removed by glacial agencies. Since that time there has been no erosion violent enough to produce any gravel deposits. To be sure, gravels can be found in some of the depressions, but these are of glacial origin, and consequently are not necessarily derived from the auriferous rocks near at hand, but may have been and probably were transported many miles; moreover, in the glacial gravels there has been no assorting of the various constituents and concentration of the heavier portions, and so the gold, if it does exist in the gravels, is scattered through them indiscriminately and in such minute quantities as to preclude the possibility of profitable working.

Sketch of the geological history.

The oldest sedimentary rocks of which we have knowledge in the Rainy Lake region are the mica schists of the Coutchiching, but what composed the surface upon which these rocks were deposited is now unknown. An immense thickness of nearly uniform deposits was built up during Coutchiching time, and at the end of this period of deposition there was possibly a period of cessation of deposition accompanied by elevation of the land above the sea level and by erosion. But whatever the events at the close of the Coutchiching, we know that at the beginning of the Keewatin time there was a change from the deposition of uniform rather acid rocks to deposits of the most

* Geol. and Nat. Hist. Surv. of Minn., 11th (1882) Ann. Rept., pp., 137-153, 1884. Ibid., Final Rept., vol. 2, pp. 517-527, 1888. U. S. Geol. Survey. Bull. 39, 1887. Geol. Surv. of Canada, Ann. Rept., new series, vol. 4, pp. 1E-156E, 1890. Also in a forthcoming monograph of the U. S. Geol. Survey entitled "The Glacial Lake Agassiz."

varied nature, in which basic volcanic material played an important part. The Keewatin was a period of rapid deposition and wide spread volcanic activity. After the end of Keewatin deposition there was a period of elevation and intense folding, crumpling and shearing of the then existing strata, accompanied by the intrusion of enormous masses of granitic rock. The rocks were much altered or metamorphosed at this time by the dynamic forces to which they were subjected and also by the close proximity of large masses of intrusive rock; thus the strata underwent regional metamorphism, more or less pronounced throughout the district, and contact metamorphism where intruded by the granitic masses. We know that the folding and alteration took place in post-Keewatin time, and, from the relations of similar rocks to the Animikie southeast of Rainy lake, we suppose that it occurred in pre-Animikie time. This period of folding and alteration probably left the strata in approximately the same position and crystalline condition as we now find them. The accompanying cut (fig. 1) will show the general relations of the rocks of the Rainy lake region after this period and after the erosion to which they have been subjected up to the present time.*

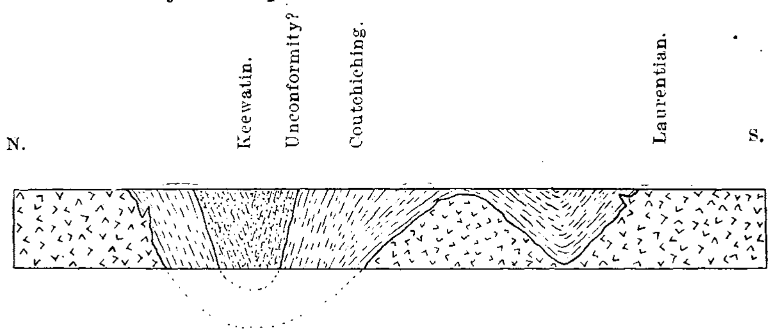

FIG. 1.—Generalized section north and south through the Rainy Lake region.

Some time after the events just spoken of, possibly in Keweenawan time, the rocks of the region were cut by the diabase dikes.

From the end of the Keewatin time to the present we have no proof that the land has ever been below sea level nor that it has ever been covered by post-Archean deposits, excepting, of

* It is quite probable that on future study, after carefully plotting the dips and strikes, the folding of this region will be found to be much more complex than this generalized cut indicates. For instance, what is represented as a single syncline in the Keewatin may really consist of several closely compressed synclines and anticlines. But as yet data are not at hand to show the existence of these numerous smaller folds.

course, the deposits of the Glacial epoch. It is possible that the Cretaceous ocean may have extended over this region, as strata of that age are found in northern Minnesota along the Big and Little Fork rivers and on the Mesabi iron range.* If such strata ever did exist in the Rainy Lake district, all traces of them have been removed by erosion.

From Keewatin time to the present, through all the immense period during which in other places were deposited the rocks of the Taconic, Cambrian, Silurian, Devonian, and other series up to the present period, or at least during a considerable portion of this time (for strata may have been deposited here during some of these periods and afterwards removed), we must assume that this region was above the sea level and was thus subjected to erosion. After the folding the surface was probably mountainous, and the amount of rock removed must have been enormously great; the number of hundreds of feet that the surface has thus been lowered can not be estimated. The effect of this long continued erosion was to gradually reduce the surface of the land to a lower level and finally when sufficient time had elapsed, an approximately flat surface not far above sea level would result. The probability of the production of such a flat or base-leveled area in Minnesota and Manitoba during Tertiary and early Quaternary times has been shown by Mr. Warren Upham,† and this cause will very conveniently explain the generally flat and plateau-like character of the Rainy Lake region. Since the production of this base level the hard Archean rocks have not been deeply eroded, and the surface consequently still retains approximately this base-leveled topography.

Glacial agencies have, since the base-leveling, removed any decayed rock or other material that may have remained on the rocky surface, and have produced the gently rounded and hummocky surface now existing. Since glacial time the Archean area has suffered practically no erosion, the lakes and streams following the depressions and irregularities which remained at the departure of the ice-sheet. The clayey plain to the west of Rainy lake also shows evidences of having been subjected to erosion for but a short period, and even during this time the erosion has not been extensive or violent.

* H. V. Winchell: Geol. and Nat. Hist. Surv. of Minn., 17th (1887) Ann. Rept., 1888. Amer. Geol., vol. 12, pp. 220-223, Oct., 1893.
J. E. Spurr: Geol. and Nat. Hist. Surv. of Minn., Bull. 10, pls. 10 and 11, 1894.

†Amer. Geol., vol. 14, pp. 235-246, Oct., 1894.

The surface is still monotonously flat except for the narrow, steep-sided, shallow trenches cut into it by the Rainy river and its tributaries; and only the largest of these streams have cut entirely through the blanket of clays down to the underlying rock, while none of them have excavated channels in the rock itself. This clay plain thus presents the peculiarities which are characteristic of a topographically young surface.

DESCRIPTION OF VEINS IN GENERAL AND OF INDIVIDUAL PROPERTIES.

At the time this examination was conducted but little more than a year had elapsed since the first shot was fired in a gold quartz vein on Rainy lake. Remote from railroads, with not even a wagon road at that time to connect it with the rest of Minnesota, this region must of necessity have a slower development than other new districts of equal natural resources but greater accessibility. Reached by a hundred or more miles of canoeing, Rainy lake had prior to 1894, been seen, aside from those who traveled the "Dawson route" in the "seventies," only by a few trappers, pine estimators, explorers and natives. The few farmers and traders who remained on Rainy river after this route across the country from Fort William to Fort Garry was abandoned—owing to the construction of the Canadian Pacific railway—rarely left their farms or trading posts to go to Rainy lake; and the few lumbermen engaged in their work around the lake were there only when the rocks were covered with snow. So it is little to be wondered at that the quartz veins remained undiscovered and undisturbed. Gold is usually found in placers and from them traced to the lodes whose rotting has produced the placers. But here there are no placers, and the veins are not rotted to any depth,—another reason why they might easily be overlooked or condemned as barren. But explorers for mineral deposits have sharp eyes. They examine everything that falls beneath their gaze. With pick and pan they pound up and wash every piece of rock that has a rusty stain, every fragment of quartz that comes into their hands. To them one species of rock is as good as another. In fact they frequently cannot tell the rocks apart or any of their names correctly. But an explorer's unaided eye can often detect at a glance a speck of gold that a mineralogist might pass over with a magnifying glass. His scent is keen and his zeal unflagging. Thus it happens that he sometimes stumbles upon discoveries in unexpected places.

The recentness of gold discoveries at Rainy lake, and its remoteness from railroads has delayed development. It can hardly be said that there are any mines as yet in the entire district. The depth of the deepest shaft did not exceed 45 feet at the time of examining it, and there are no underground levels. But one 5-stamp mill is thus far set up in the region—that of the Little American company, and not more than 500 tons of ore have been milled. The result of operations here, however, has been sufficiently encouraging to induce several other companies to order mills, and it is expected that there will be half a dozen mills in operation before the end of 1895.

Throughout the region quartz veins are common and even abundant, but most of them are small and insignificant and contain no minerals of economic importance. These small veins, known as gash veins, cut the rocks in various directions as narrow ribbons which gradually taper to a point and disappear; they are thus of limited length and are at most only a few inches wide, the majority being less than one inch across. They are found in all the rock series of the region and are especially noticeable in some of the gneisses and granites. These small gash veins are not known to be of any value, and exploitation of them is useless.

The prospecting for gold is now being conducted in three different classes of deposits, if we include those of the Canadian side as well as those in Minnesota. These three classes are (1) segregated veins, (2) fissure veins, (3) fahlbands; the first two being properly called veins, the last being rather belts of the country rock charged with an unusual amount of metalliferous material.

I. SEGREGATED VEINS.

The veins on the south side of Rainy lake and hence all those in that portion of the gold district which lies in this state, are of the variety known as "segregated veins." They are conformable with the bedding or foliation of the schists, but their gangue, being chiefly quartz, differs entirely in mineralogical composition from the enclosing rocks. This class of veins may extend with unbroken continuity for a considerable distance through the country rock, or may form lens-shaped bodies of limited extent, occupying a more or less distinctly defined belt of country. They vary in thickness from an inch to five or more feet, and may extend continuously for fifty or a hundred feet, or may pinch out in a shorter distance. When one of these quartz lenses is found, usually others exist close by in the direction of the strike; and, moreover, two or three of these lenses may be found side by side, or overlapping each other, being separated by only a few inches of the country rock. Thus there commonly exists a belt of rock, from one to ten or even more feet in width, in which quartz lenses are common; and in this belt the rock around the lenses is more or less completely impregnated with quartz. To this belt of quartzose rock, including the quartz lenses, the miners and explorers loosely apply the term *vein*. The "vein" may thus be several feet in width, but it is not composed wholly of vein material; in fact, it is seldom more than half quartz, and usually the quartz makes no more than one fourth of the total. The accompanying figure represents the surface exposure of one of these veins; it also represents fully as well a vertical cross section of the vein. The areas of undulatory lines indicate the country rock and the darker areas the quartz lenses, while the dotted area represents the belt of country rock which is more or less impregnated with quartz. The last two parts form the vein, using this term in its larger sense.

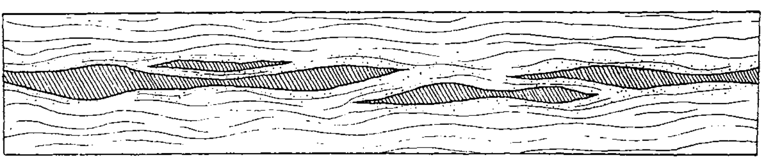

FIG. 2.—Generalized surface section of one of the segregated veins.

The minerals occurring in the veins are not many. The lenses are composed of pure white coarsely crystallized quartz; sometimes no other mineral is present. Usually, however, and always in the gold-bearing veins, there is some pyrite and a dark chloritic material which can generally be referred to fragments of the country rock. Pyrite is also frequently disseminated through the quartz-impregnated rock which surrounds the lenses. The gold occurs associated with the pyrite, but sometimes small flakes can be seen in the white quartz apparently entirely separated from the pyrite. Where the veins have weathered or decayed, particles of gold, the size of a pin's head or occasionally much larger, can be found on the surface of the vein in cavities left by the decay of the pyrite. Most commonly no gold is visible to the unaided eye. The gold is confined principally to the quartz lenses, but also occurs in small amounts in the quartzose rock around the lenses.

These veins vary considerably in width and in the amount of quartz and the number of quartz lenses in them. A vein that is ten feet wide and half to two-thirds quartz in one spot may vary in the distance of a few rods to half that width and may contain not more than a fifth part quartz; or on account of the absence of the quartz lenses it may be almost unrecognizable. Further on it may widen out and contain a large number of the lenses. Variation in the amount of gold seems to be as common and as pronounced as variation in width or number of quartz lenses.

On account of the water covered areas and those covered by swamps or soil, no vein has been traced any great distance, but in all probability they will frequently be found to extend more or less brokenly for several miles. The vein of the Little American mine appears again on the island just to the west of the one on which this mine is situated; while to the east and in the direction of the strike apparently the same vein appears at several places:--on the south shore of Rainy lake in the S. W.¼ of S. W. ¼ sec. 26, T. 71-22; in the S. E. ¼ of S. E. ¼ of the same section; and also on the island in the S. W. ¼ of S. W. ¼ sec. 25. Thus when a vein is known at one point it can confidently be searched for again in other exposuros along the strike, but nothing can be safely predicted as to its size and richness at other points. These facts can be determined only by exploitation and assays, but a vein which has a considerable width and richness at one point will more probably have the same characters at other points. In making these statements concerning the extent of certain veins over considerable distances reference is had only to the larger and more pronounced ones, *i. e.*, those which are several feet in width and which have a number of quartz lenses lying side by side or nearly so. Single lenses of quartz are not uncommonly found, but these are of only small size and others can not always be found by following along the strike of the first.

As has been already stated these veins run parallel to the strike of the cleavage of the country rock. They are thus narrow beds now standing in a nearly vertical position and extending indefinite distances. They occur in the rocks of both the Keewatin and Coutchiching. The veins found in the Coutchiching rocks are almost entirely of pure quartz, containing very little other mineral matter. They are very poor, or entirely lacking in gold. None of the veins in this series of rocks have as yet proved of value. The veins in the Keewatin rocks are richer and are the only ones in which paying amounts of gold have been found on the Minnesota side of the lake. The best veins occur in the greenish schists of the Keewatin. As far as known the most promising belt of this rock is that which comes to the shore at the head of the bay in the N ½ of sec. 32, T. 71-22, and extends eastward from there, including the Little American island and those just to the west of it, a narrow strip along the south shore of the lake eastward from Rainy Lake City to the west line of St. Louis county, and the small islands just to the north of this shore. Another belt of this rock just touches the north side of Dryweed island and in it is the Lyle mine, near the center of the S. E. ¼ of sec. 23, T. 71-22.

A consideration of the manner in which these veins were probably formed may throw some light on their exact nature. The cleavage planes of the country rock, parallel to which lie the veins, while trending on the whole in one general direction, still vary to a certain extent in their directions in distances of a few inches or feet, *i. e.*, they are undulating. An attempt was made to indicate this fact in the cut (figure 2, page 74) representing a section of one of these veins; here the undulating lines represent the cleavage planes of the rock. This cleavage is seen to be undulating or wave-like in form in a vertical as well as in a horizontal section. The surface of one layer of the rock may be very roughly likened to the surface of a lake with a "choppy" sea; just fitting into this surface is another complementary one of the rock layer next adjacent. Along the veins there has been some slipping (or faulting) of the different layers on each other; that this is the case is indicated by the sheared and crushed condition of the rock and by the frequent slickensided surfaces. When this faulting occurred, especially where there was no great pressure normal to the fault plane, there would be formed certain irregularly lens-shaped cavities where the surface of one layer did not fit the surface of the next adjacent one. These lens-shaped cavities are now represented by the lenses of quartz. This faulting would not be confined to slipping between two layers alone, but would occur between several adjacent layers, so that the faulted area is not strictly a plane but a bed of several inches or feet in thickness. How great this faulting has been we do not know, but that the area of weakness, in which were crushed rock and cavities, extends to a considerable depth seems quite certain. In this area of weakness solutions would easily travel and mineral matter would be deposited from them; thus would occur the impregnation of the crushed rock and the filling of the cavities. Under this view of the origin and nature of these veins it is seen that they lie along lines of faulting and that they could thus receive solutions emanating from great depths; thus these veins are in many features closely analogous to true fissure veins.

General considerations bearing upon the question of the source of the metalliferous constituents of these veins have already been given. In this connection, however, the views of Dr. A. C. Lawson upon this subject are pertinent and interesting, coming from one who has carefully studied the region under consideration. He says:*

The distribution of veins and metalliferous deposits in the Archæan has further an interesting bearing upon the question of the history of these rocks. The Laurentian rocks of the region are remarkably barren of metalliferous deposits. The Upper Archæan, particularly the Keewatin series which is largely composed of volcanic rocks, is rich in such deposits as native gold (with a little associated silver), iron ores, copper pyrites, iron pyrites, mispickel, galena and zinc blende. These minerals are abundant in the Keewatin series, though, of course, only occasionally found sufficiently concentrated to be of economic value.

There can be but little doubt that their occurrence in these rocks is intimately associated with the volcanic rocks, although the period of their formation is not necessarily that of the formation of the volcanic rocks themselves. Now, unless we regard the floor upon which the upper Archæan was deposited to have been the original crust of the earth, for which supposition we have no good evidence, we must assume that it was made up of ordinary strata, either volcanic or sedimentary, or composed of both. As such it is probable that it was traversed by veins, and that in the volcanic portions, if not elsewhere, these veins were metalliferous.

But in the Laurentian we do not find anything like the number of veins that are found in the Upper Archæan, and those that are occasionally observed are not metalliferous. The simplest explanation of this marked difference between the Upper and Lower Archæan, as regards veins and metalliferous deposits, appears to the writer to be precisely that which gives a satisfactory account of all the other features of the region, viz: that the Laurentian rocks have passed through a state of fusion, while the superincumbent Upper Archæan remained unfused. This fusion would cause the dissemination throughout the magma of whatever metalliferous deposits had been segregated in veins, so that they could not be detected by ordinary means. The veins which cut the Upper Archæan are probably, as before suggested, due to aqueous emanations from the Lower Archæan magma, the metals in the veins being probably derived from the

*Congrès géol. international. 4me Sess., 1888, p. 145.

volcanic rocks traversed by these emanations, so that the very causes which obliterated veins and metalliferous deposits in the lower portion of the Archæan may be said to have given rise to those in the Upper Archæan.

Little American mine.

This vein, the first to be discovered and developed, belongs to the class of segregated veins. Situated on a small island in the N. W. ¼ of sec. 33, T. 71-22, one hundred miles from any railroad, and developed in the face of all the obstacles to be met with in a new district, it has served to attract attention to this undeveloped portion of our state, and, whether it proves to be the most profitable mine in the region or not, it will in this way always be remembered as the most useful.

Geo. W. Davis discovered the vein while prospecting alone about the last of July, 1893. Reaching the island one evening about dark he had no opportunity to examine the quartz which he saw until the following morning when he "panned" it and obtained gold. Mr. Davis remained on the island and in the vicinity for nearly a month and then went only as far away as Fort Frances to renew his store of provisions. On his return, about the last of August, he brought back with him a man named Quirk and a blacksmith from the "Fort" and together they fired the first blast on the 29th day of August, 1893. Subsequently going to Duluth with samples of his ore and telling of his discovery, a company called the Bevier Mining and Milling Company was organized in January, 1894, with A. S. Chase, "Hutch" Bevier and "Jeff" Hildreth as incorporators. Having some trouble to secure title to the land it was purchased from the government by using the right of selection or "scrip" of the St. Paul, Minneapolis & Manitoba railway. Active operations were at once begun under the direction of Mr. Hildreth and a 5-stamp mill was set up on the mainland at Rainy Lake City, about one mile from the island, where the shaft was sunk. This mill began stamping on July 16, 1894, and continued with some interruption until Sept. 24 of the same year, when, having used all the ore in stock and finding the cost of the operation too great, it was shut down. Shortly afterwards the operation of the mine and mill passed into other hands and plans were laid for work on a more systematic basis. A casual inspection of the mine will reveal a woeful lack of business ability in the arrangement and execution of the operations of mining and milling. The expenses must have been at least double what they should have been, even with so many difficulties to overcome. The hole in the ground, called by courtesy

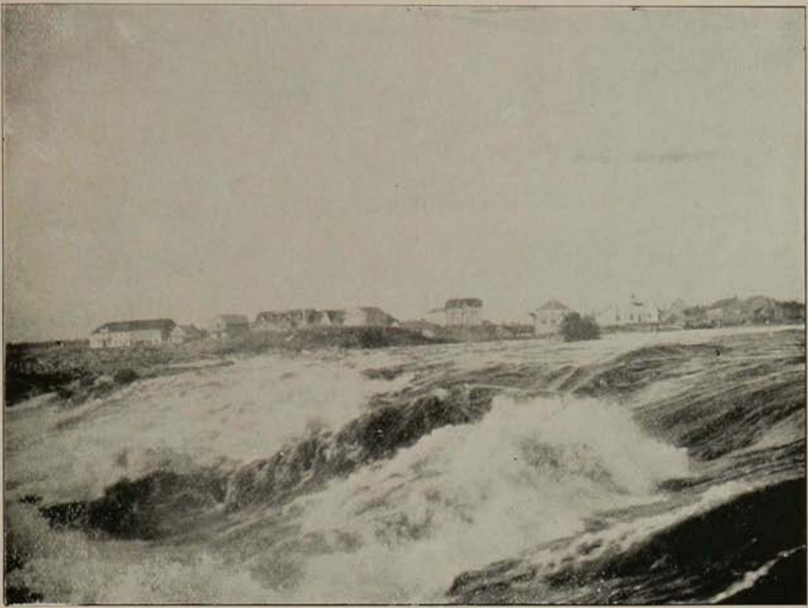

FIG. 1. KOOCHICHING FALLS; MIDDLE SHOOT, LOOKING FROM THE MINNESOTA SIDE TOWARD FT. FRANCES. JUNE, 1894.

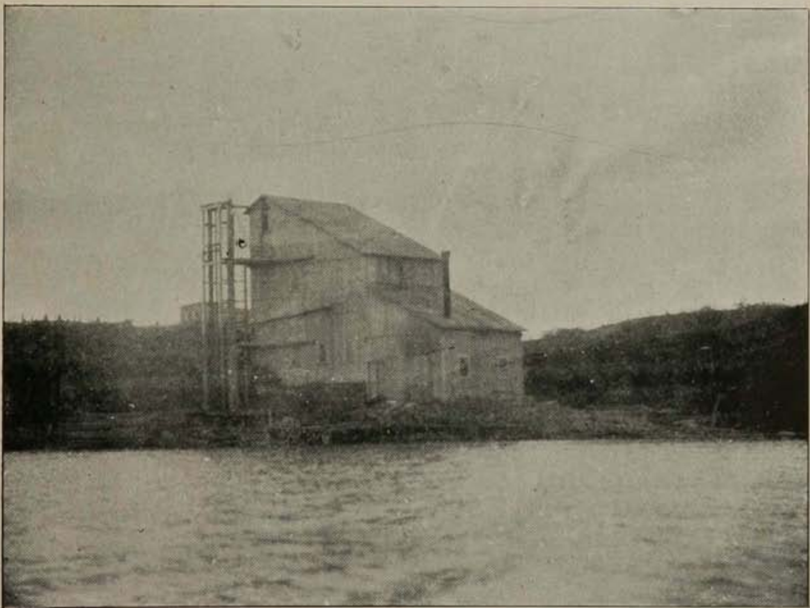

FIG. 2. THE FIRST STAMP MILL AT RAINY LAKE. ERECTED FOR THE LITTLE AMERICAN MINE.

a shaft, was about 10'x40'x44' and was as ragged a cavern as can be found in the state. With no timbering, no pumps, nothing but a hand windlass for hoisting ore, rock and water, and the mill a mile away, it is a good example of the folly of robbing a mine in order to provide ore for present purposes without proper development for future mining. Every item of expense must necessarily have been abnormally large by such poor management as is here displayed.

As to the operation of the mill the following quotation from a letter received from Mr. A. S. Chase, one of the directors of the Bevier Mining Company, contains considerable reliable information:

From the best information I have the mill ran in all fifty-two days. The nearest estimate as to quantity of ore crushed is 500 tons. We have no record of each clean up but the actual shipments of bullion were: August 10th, $362.30; August 20th, $1,958.85; September 18th, $2,481.76; October 18th, $732.42; total, $5,535.33. The cost as near as we can tell, was about $7.00 per ton for mining and milling. With proper management it can doubtless be mined and milled for $3.00 per ton. We have but five stamps and of course the cost of milling would necessarily be large, but there are other reasons for the great cost of producing this bullion which can be easily overcome. The mill produced all the way from 8 to 27 ounces of bullion per day, showing very clearly that quantities of rock were crushed which, with proper sorting, would not have been used, especially with this little mill. It is certain that there was no attempt at deception and I am fully convinced that gold in largely paying quantities exists in the Rainy Lake region.

The vein is about ten feet in width and dips south about 80°. Its strike is N. 80° E, and it is believed to run across the next island west of the Little American. The ore is gray quartz with streaks and masses of the schist which constitutes the country rock enclosed in it. It contains a rather small amount of pyrites and some visible gold. Less than five per cent., and perhaps less than three per cent., of the ore goes into the concentrates which have an assay value of about $12.50 per ton. Samples of the ore taken from the vein at the depth of ten feet and from the top of the stock pile where the ore from the bottom of the pit was supposed to lie, assayed $11.51 ($11.39 gold and $ .12 silver), and $3.37 ($3.31 gold and $ .06 silver) respectively.

Big American mine.

This is the homestead of George Davis, the discoverer of gold at Rainy lake. The property constitutes the southwest corner of Dryweed island. A pit five feet square and five feet deep has been dug in the usual siliceous sericitic schist of the island. In the pit are three quartz lenses, none of them more than a foot in width. The rock at the pit is more schistose and greener in color than the adjoining rock. The strike is N. 70° E. (mag.), and the dip is 90°. Exposures near by show other quartz lenses along the strike a few yards from the pit, but not enough work has been done here to show the width and probable extent of the vein.

Other prospects.

In the vicinity of Rainy Lake City are several places where some work has been done, but the veins are small or the exploitation has not gone far enough to show clearly their extent and value. Some of these prospects will be mentioned below.

On the eastern end of the island in the S. W. ¼ S. W. ¼ sec. 25, T. 71-22, a shaft has been sunk. It was reported to be down to a depth of twenty-eight feet, but in October the work had been abandoned and the shaft was partially filled with water; a short drift has been run out towards the south. The vein here, *i e.*, the belt of siliceous rock in which the quartz lenses occur, is about three feet wide as exposed at the surface.

The blunt point of land in the S. W. ¼ S. W. ¼ sec. 26, T. 71-22, is crossed by another vein, which has been uncovered at several places. In some places there is a width of nearly six feet of almost pure white quartz. This vein is probably a continuation of the one just mentioned on the island.

In the S. E. ¼ of S. E. ¼ sec. 23, T. 71-22, is a small island on which is what is known as the "Old Soldier mine". The island is made of mica schist in which are small veins of quartz and some beds or dikes of gneiss or foliated granite. This granitic rock varies in color, being light or dark according to the amount of biotite or hornblende it contains. A considerable amount of pyrite is disseminated through this rock.

The large island in the N. W. ¼ of sec. 26, T. 71-23, known as Kingston island, has a few small veins running across it. Some work is now being done upon these, but at the time of our visit it had not progressed far.

The vein of the Little American mine is seen again on the island nearest west of the Little American island, and the company has commenced operations here and are uncovering the vein and have started a drift along side of it.

It was formerly supposed that segregated veins are not so persistent as fissure veins, and that they are not so likely to be productive in depth. This view does not appear to have a basis in fact, however, since "recent mining operations have materially modified the received views respecting the value and persistency of the so-called segregated veins. Many of them are of great thickness and extent, and, after having been worked to very considerable depths, have been there found as productive as they were nearer the surface. The character of the veinstone of such deposits frequently appears to in no way vary from that of true fissure veins, from which they often differ in no respect except that their course is often parallel to that of the strata between which they lie." (Phillips, Ore Deposits, p. 91).

II. FISSURE VEINS.

True or fissure veins have already been briefly described, and the prevalent theory of their origin outlined, Their distinguishing feature is their entire independence of the strike or foliation of the enclosing rocks. Indeed, because of the wavy line of strike of the crystalline and semi-crystalline rocks, a fissure vein almost always cuts across the strike in some portion of its course. The walls of fissure veins have usually a more direct and even course than those of other veins, and are smoothed or "slickensided" in a similar manner.

The veins in the vicinity of Rainy lake which present the characteristics of fissure veins are those in the vicinity of Shoal and Bad Vermilion lakes, east of Seine bay at the east end of Rainy lake. Occurring for the most part in a granitic rock, they strike north and south or northwest and southeast,—almost at right angles with the series of segregated veins. The quartz is somewhat different in appearance, perhaps due largely to the fact that it is richly charged with the sulphides of iron, copper, lead, zinc and silver, and near the surface with the oxidized alteration products of these minerals. The first of these veins to be brought to public notice as containing gold is on location "A L 75" and is known as

Wiegand's location.

Thomas Wiegand and Alex Lockhart discovered auriferous quartz veins on this and adjoining locations in September, 1893. The veins strike north-south, or northwest-southeast, and vary in width on the surface from six inches to six feet. The ore is charged with zinc blende, galena, pyrite and free gold and is somewhat stained by iron rust near the surface. There is distinct evidence of crustification in some of the veins, while in others the ore is more homogeneous in texture and appearance. The walls are well defined and finely slickensided. The country rock immediately surrounding the veins is mentioned elsewhere (p. 58), and is not inaptly called "bastard granite" by some of the explorers of the region. This rock has often a foliation which corresponds in general with the strike of the schistose rocks which lie south of Shoal lake. The trend of the veins is across the prevalent foliation of the granite, and their length is sometimes seen to be at least half a mile, as revealed by the outcrops. In connection with Col. S. W. Ray of Port Arthur, Ont., Mr. Wiegand has done considerable exploring on these locations in the way of uncovering the veins and sinking test pits.

Pit No. 1 was 12 feet deep on the lode, showing the vein to increase in width from about 6 inches at the surface to 20 or 24 inches at the bottom, with a vertical dip. Near the top of the ground the vein is banded pink, red and white; but the quartz is all light colored at the depth of 12 feet, and appears to be nearly equally charged with "sulphurets" throughout. Where stringers of quartz join the vein from the walls considerable free gold is said to have been noticed. Just west of this pit, and about 75 feet from it, a parallel vein three feet in width is seen to outcrop. The latter has not been prospected.

Sample from the stockpile at No. 1 pit assayed $6.83 in gold and $ .15 silver, a total of $6.98 per ton.

Pit No. 2 is on location "A L 94." Its depth is 12 feet and it is sunk on two parallel veins separated quite sharply by a band of granite about two feet in thickness at the surface, and as far as shown in the test pit, the dip is about vertical and the strike north and south. Bunches of pyrites having a thickness of several inches are numerous in the eastern vein. Near the surface these were said to have been much rotted and held together by threads of gold. Considerable gold was obtained upon washing this pyrite in a pan, after crushing it finely in a mortar. A sample from the pile of quartz thrown out of the pit was assayed with the following result:*

Gold 2.32 oz. per ton, worth..................	$48.02
Silver .64 " "	.40
Total value per ton of ore.....................	$48.42

* The assays reported here were made by F. F. Sharpless in the laboratory of Sharpless & Winchell, Minneapolis.

Pit No. 3 is on location "A L 75," and at the time of examination was 19 feet deep. The vein is similar to those already described on these locations, striking north-south and having a width of one foot to three feet and a half, and growing wider as depth is attained. The dip is 80°. Samples taken from the stockpile and vein here gave the following assays:

Dump sample:

Gold, .35 oz. per ton, worth	$7.25
Silver, 2.46 oz. per ton, worth	1.55
Total value per ton	$8.80

Surface of vein:

Gold, 3.23 oz. per ton, worth	$66.86
Silver, .47 oz. per ton, worth	.30
Total value per ton	$67.16

The walls of these veins are smooth and sharply defined, being usually separated from the vein matter by a thin sheet of soft material, supposed to be the product of pressure, shearing and chemical alteration. Some of these veins can be traced for a mile across the country, maintaining their width and course quite persistently. The mineral content of the different veins varies considerably. Thus Vein No. 3 on Wiegand's location is more heavily charged with blende, pyrite, galena and chalcopyrite than Veins No. 1 and No. 2, but is no more richly "mineralized" than some veins seen elsewhere in this same immediate vicinity.

The Lucky Coon.

Hillyer's location, as it was first known, or The Lucky Coon, as it is now christened, is location "655 P" consisting of about 170 acres. It is situated, as shown on the map, north of the eastern end of Shoal lake, and east of Bad Vermilion. The country rock here is quite similiar to that at Wiegand's; but the granite is coarser and more massive, and has pink feldspar crystals developed in it at a short distance from the veins. At the time of examination two nearly parallel veins about 150 feet apart were being developed by shafts. This property is operated by Hugh Steele, of Duluth, W. G. Miller, of Minneapolis, Geo. Hillyer, of West Superior, and Carrol Carson, of Biwabik, Minn. The work was being done under the direction of Mr. Hillyer. Other parties who own an interest in it are Wm. Campbell and Messrs. Mosher and A. L. Robinson. The Seine River Mining company, of West Superior, Wis., is organized to work this mine, and a stamp mill is to be ordered at once. The strike of the veins is about E. 25° S. The more northerly one (No. 1) dips N. 25° E. 80°, while the more southerly one (No. 2) dips S 25° W, 80°, in other words the two veins are each within 10° degrees of verticality and dip away from each other so far as revealed by test-pitting. It is to be expected that the dip of one or the other vein will change so as to bring them both to a conformable dip in the same direction.

Pit No. 1, on Vein No. 1, at the time of our visit was about 10 feet deep, and its dimensions about 6x10. The vein has a width of about 6 feet and has good walls. It is banded or "crustified" and contains considerable pyrite, chalcopyrite, blende and a dark mineral resembling argentite. This vein has been traced for more than half a mile by surface outcroppings. The best ore is said to come from near the foot wall. A sample of ore taken from the bottom of the pit assayed $2.07 in gold, and showed no silver.

Pit No. 2 is on Vein No. 2, which has a width of 5 feet where exposed. It was very heavily mineralized from the surface to the bottom of the pit which was only 9 feet deep, and showed considerable gold in a decayed and oxidized state that was seen in the middle of the vein. The walls are smooth and slickensided and indicate a good depth to the vein. It contains the same sulphides noticed in Vein No. 1, with the addition of galena, and where these minerals have been removed by oxidation there is often a beautiful display of flecks and small nuggets of gold. Sample from all over the pile of ore thrown out of the pit gave just the same results as the sample from No. 1 pit. Ore taken from a heavily mineralized portion of the vein yielded an assay value of $43.26 gold per ton.

Other prospects near Shoal lake.

The Mosher properties are "A L 110," "A L 111" and "A L 112," and are in the same rock as Wiegand's and Hillyer's locations. Some prospecting has been done here on a vein that has a width of six feet and strikes northwest and southeast. Flecks of gold are visible in the vein matter, and the ore is quite similar in many respects to that of the Lucky Coon.

It is evident from a description of these veins that a larger percentage of the ore from those fissure veins near Shoal lake will be of the kind called refractory than is the case with the ore from the segregated veins contained in the Keewatin schists. What percentage this will be cannot yet be told. Some of the gold is contained in the quartz without association with the sulphurets, but much of it is so intimately mingled with them as to require treatment as refractory ores. It is also to be expected that the percentage of free-milling ore will decrease with depth. Certainly so far as the amount of free-milling ore is dependent upon oxidation of the sulphides there will be a rapid increase in the amount of refractory ore below the surface, for oxidation has extended but a few feet into the veins since the glacial period. It is quite possible, however, that a considerable proportion of the gold exists in the ore in a condition to be removed by milling and amalgamation, independently of any oxidation of the sulphurets. In that case there will not be so great a change in the ore as the mines grow deeper.

The veins in this vicinity being very numerous, nearly all of the land is already surveyed into mining locations and sold under the mining laws of Ontario. Lying a little outside of the district which properly comes under the jurisdiction of the Minnesota geological survey, the Seine river and Shoal lake region was only examined sufficiently to obtain an idea of its general worth, and many prospect holes and veins were not seen. Enough was seen, however, of individual properties, and of the geology of the district to create the impression that this is destined to be the richest area thus far prospected around Rainy lake. The reasons for this belief may be briefly stated. The veins are fissure veins and cross the strike of the rocks nearly at right angles. The ore is well charged with heavy sulphides, and the gangue is considerably stained and colored with them. The walls of the veins indicate that they will extend indefinitely downward, and explorations have shown their length to be considerable. The rock which contains the veins bears evidence of having undergone great pressure, shearing and chemical metasomatosis, and corresponds in age and mineralogical composition to the usual associates of auriferous veins.

But perhaps the most favorable feature of the veins of this particular portion of the Rainy Lake district is their intimate relation with the areas of eruptive rock called "gabbro" on the north and of greenstone on the south. This gabbro occupies an area of several square miles around Bad Vermilion lake, and there can be but little doubt that it has been of great importance in the formation and enriching of the veins in its neighborhood. It is not clearly proven that the veins date from the advent of the gabbro; but the fact that the gabbro seems to be later than the peculiar granite area lying between Shoal and Bad Vermilion lakes, and the further fact that the veins are quite different in strike from the other veins around Rainy lake, and appear to radiate from the gabbro area, as a center, is strongly indicative that the formation of the fissures was due to the irruption of the gabbro. As already stated, the proximity of eruptive rocks is almost universally believed to have exerted a beneficial influence on the richness of metalliferous veins, and it will be strange if it does not prove so in this instance.

III. FAHLBANDS.

Fahlbands are belts of rock, often of considerable width and extent, impregnated with sulphides of iron, copper and zinc, and sometimes, also, of lead, cobalt and silver. There are usually several of these belts having a considerable degree of parallelism with one another, and sometimes traceable upon their line of strike, for several miles. The amount of ore contained in such belts may be quite considerable, but it is only in a few localities found to be sufficiently concentrated to render its exploitation profitable. Fahlbands are usually found in regions of gneiss, mica and hornblende schists, talc schist or chlorite schist. Veins of quartz may be present in these fahlbands, running parallel with or intersecting them at various angles, but they are sometimes wanting entirely. There is usually a gradual transition from the metalliferous rock of the fahlband into the barren rock on either side, with which the fahlbands are usually conformable. When intersected by dikes of eruptive rock or veins of quartz there is frequently a considerable degree of enrichment at the planes of intersection. There are several points around Rainy lake where prospecting is in operation in fahlbands. Some of these are not worthy of mention. The best example of this class of deposit is the Lyle mine.

Lyle mine.

This is situated on a narrow point which runs out from Dryweed island near the center of the S. E. ¼ of sec. 23, T. 71-22, two and one-half miles northeast of Rainy Lake City. This property was located in the winter of 1893-'94 by William and Edwin Ward of Duluth. Work was begun on the shaft, which is eight feet square, on September 8th, 1894, and, at the time of our visit, a month later, it had reached a depth of twenty-two feet. The shaft is down in a peculiar kind of siliceous rock which consists of narrow bands of (1) finely divided quartz, (2) a dark greenish material, perhaps largely chlorite, and (3) bands of 1 and 2 combined. This rock constitutes a band about twelve feet wide. Throughout it are numerous quartz stringers or lenses of all sizes from those a fraction of an inch in thickness to one which, where exposed, is two and a half feet across. The quartz lenses and the belt of rock in which they occur contain a considerable amount of pyrite, more than is common in the veins about Rainy Lake City. Masses of coarsely crystallized siderite are found in some of the quartz lenses. This belt of siliceous rock, including the lenses, is probably two-thirds or more quartz, and it will be necessary to mine and stamp the whole rock as ore, as it is impracticable to separate the quartz lenses. Moreover, the siliceous rock, as stated above, contains considerable pyrite, and possibly some gold.

The country rock at this place is composed of chloritic and sericitic schists and a green schist in which are many small spots of siderite. The strike is N. 75° E. (mag.) and the dip 75° to 80° north of this line. Just to the south of the little point, on which the shaft is situated, on the main land of Dryweed island the rock is the usual sericitic schist which has been mentioned before (page 66) as forming grindstone and Dryweed islands. Here a few quartz lenses occur, but they have not yet been uncovered so as to show their true size and extent.

The surface of the vein at the shaft is rusted and more or less decayed, but this condition does not extend downward more than four to six inches, except along cracks.

TREATMENT OF RAINY LAKE ORES.

The development of the Rainy Lake region has not been sufficient to furnish data on which to base a statement as to the best method of treatment for its ores. Conservative and business-like methods and principles would lead investors to be absolutely certain that ore existed in quantity sufficient to supply a stamp mill for a few years, and that it was of such a characacter as to be best treated in a particular kind of stamp mill before risking their money in the purchase of one. And in order to gain such information it would be necessary to sink shafts numerous enough and deep enough to prove the quantity and quality of the ore. The mere fact that four or five stamp mills have been built for use in this region where there is not as yet a shaft or a drill-hole 75 feet deep, is in itself sufficient proof that the mines are being developed by parties of little or no experience in the mining business. There can be only one result of such hasty, ill-advised methods of procedure. Some, if not all of the companies will soon find themselves financially embarassed. The money which should have been spent in mine development will have been spent for machinery. When the stamp mills are on the ground and ready for operation there will be no ore to run them for any length of time, and not enough development in the mines to enable them to produce what the mills require. Thus the mill must be shut down and the public will say it was because there was no gold in the ore. The stockholders will be discouraged and the treasury of the company will be depleted without means of replenishing it. In other cases the free milling ore will so rapidly pass into refractory ore as the depth of the mine increases, that the mill which was built to treat the surface oxidized ores is unable to extract the gold from these more refractory ores, and must be discarded,—a dead loss to the company—and a new plant purchased. All of these things will exert a damaging influence on the reputation of the district as a whole, and should be avoided if possible. In a new district double precautions should be taken to insure against mistakes. Two or three shafts each 100 feet deep should be sunk and connected with levels on every property before a stamp mill or other plant is purchased. Then, with the mine opened up, and enough ore in stock to run the mill for six months, the mine will have a bona fide value. No difficulty will be experienced in raising money to buy the machinery needed. No hesitation will be felt as to what process to use. No trouble will be had in keeping the mill supplied with ore. The experience of the Lake of the Woods district should not be repeated at Rainy lake, but that is just what will happen if matters proceed as they are begun. Too great stress cannot be laid on this point. The old adage that "haste makes waste" is nowhere better exemplified than in matters of this sort. For the good of the pioneers, who deserve to succeed because of their confidence in the new region, and their efforts to develop it, no less than for the good of the district, we would urge upon the owners of prospects to "go slow" and develop their properties before ordering expensive concentrating and metallurgical plants.

As already stated, the ore which occurs within fifty feet of the surface of the ground at Rainy lake is free-milling, and the proportion of concentrates will not exceed 10 per cent. How much this percentage will be increased in depth is uncertain, but that there will be an increase is to be expected. With five or ten per cent. of the ore going into the concentrates there will be required facilities for treating these refractory sulphides on the spot. The expense of transportation to a smelter and the high smelter charges make shipping out of the question. Some method of treating the sulphurets cheaply at the mine or on the lake must be introduced.

In this connection the description of barrel-chlorination by the Thies process as conducted at the Haile mine, Lancester county, South Carolina, is of interest.* Working on a large scale, ore which assays $4.50 per ton on an average and contains 10 per cent of concentrates is treated at a profit by this process. The value of the roasted concentrates amounts to $30.00 per ton and the cost of roasting and chlorination is said to be $4.62 for 1⅓ tons raw pyrites. After thoroughly roasting the sulphurets the roasted material is placed in lead-lined iron cylinders 60''x42'' which rotate on their major axes 20 times per minute. Chlorine gas generated in these barrels dissolves the gold in from 4 to 8 hours, and it is then precipitated by ferrous sulphate. With an abundance of cheap fuel and water power this process might be practicably introduced in the Rainy Lake region, and operated in conjunction with stamp mills and amalgamation.

SOME OTHER GOLD MINES.

In reports of discoveries of gold ore in new regions we frequently read references to the wonderful results achieved in treating low grade ores elsewhere and the large dividends that some celebrated mines are regularly paying. Comparisons are drawn between the small yield of gold per ton in these large dividend-paying properties and the reported average of the ore in the newly discovered field, and it is usually the conclusion drawn from such comparison that if one mine can make a regular profit out of three or four dollar ore, any other mine ought to make proportionately greater profit out of eight or ten dollar ore. Such, however, is not the case, and it is for the sake of guarding against such misleading comparisons that the following brief description of some of these famous mines is introduced here. Among the mines thus most frequently referred to in this country are the Homestake, the Alaska-Treadwell and the Comstock.

* Trans. Am. Inst. Min. Eng., vol. xix, p. 607.

Homestake mine.

The Homestake mine is located in the Black Hills, near Deadwood, South Dakota. The ore is not in a vein, but rather in a "belt" or zone of slates or schists containing many lenses and shoots of ore, consisting of quartz impregnated with more or less pyrite. This "belt" is about 2,000 feet in thickness and is bounded on the east and west by quartzytes. The age of these rocks is Archean, corresponding to those in the Rainy Lake region; and the gold contained in them was partially introduced prior to the Potsdam epoch and partially at some subsequent period. The rock seems to have been enriched by the influence of certain intrusions of porphyry, and is more productive and of a less refractory nature near these intrusions. The ore is what is called "free-milling," but still contains several per cent. of pyrites which pass into the concentrates and are treated by some metallurgical process for the gold they contain.

At the several properties located along this "belt" there are various methods of mining in vogue. Surface ores were taken out in large open cuts, but at present most of the mining is underground and conducted on a scale of great magnitude. Immense quantities of ore are mined and put through the stamps, as may be seen by an inspection of the annual reports of the operating companies. Several hundred stamps are kept at work, pounding out from two to four tons per stamp per diem. The average yield of gold per ton varies from $2 to $4, averaging about $3.87 in the Homestake mine, and $2.42 in the Deadwood-Terra and other mines where porphyry intrusions do not occur. In 1888 the cost of mining at the Homestake was $1.68 per ton, and the cost of milling was $0.83, a total of $2.51. The yield for the same year was $3.71 per ton, leaving a net profit of $1.20. (A. I. M. E., xvii, 577.) As there were mined nearly a quarter of a million tons of ore, the total profit was a handsome one. The dividends paid by the Homestake company from 1884 to 1892, inclusive, amount to $4,943,750.

Alaska-Treadwell.

Although in operation but a few years the Alaska-Treadwell mine has paid its owners dividends amounting to $2,225,000 up to 1894. This mine is situated on the eastern side of Douglas island, on the coast of Alaska. The ore deposit consists of a mass of quartz and white feldspar of medium grain and pale gray color, containing a small amount of calcite and impregnated throughout with small crystals of iron pyrites. The thickness of the ore body is from 400 to 500 feet, and it is bounded on the northeast and southwest by dark colored argillytes supposedly of Triassic age. Mr. G. M. Dawson suggests* that "this ore body is the upper portion or feather edge of a granitic intrusion, probably contemporaneous and connected with the characteristic granites of the neighboring coast ranges, but which, owing to peculiar conditions has become decomposed and silicified by solfataric or hydrothermal action, to which the concentration of gold in it, and the deposition of pyrites are also due."

Since 1888 the mine has operated 240 stamps and 96 concentrators which have milled and concentrated 500–700 tons of ore each 24 hours. Although largely a free milling proposition, there are several per cent. of concentrates which are roasted and chlorinated.

The cost of chlorination in 1890 and 1891 amounted to 22 and 19 cents respectively per ton of ore milled. The cost per ton of concentrates treated for these years was $9.02 and $7.61 respectively.

The average total cost of mining, crushing, amalgamating, retorting, etc., in 1892 was about $1.50 per ton, on an average product of 16,000 tons of this ore per month The assay value of the ore is only about $3.75 per ton and yet it is mined and treated so economically as to have a net profit of nearly $2.00 per ton.

Comstock lode.

Differing materially in the character of ore deposit, enclosing rocks, situation and product, from the two mines just mentioned is the Comstock lode, the largest producer the world has yet seen. The contrast between it and the Homestake mine is illustrative of the very point which we seek to emphasize, viz., that location, nature of the ore and cost of treatment have more to do with the question of profit and loss than the assay value of the ore itself.

The Comstock lode consists of wide, gently dipping masses of crushed and decomposed country rock cemented together and filled up by saccharoidal granular quartz and some calcite in all of which the ore is very finely disseminated. Enclosed

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* Am. Geol. 1889. vol. 4, p. 84.

almost wholly in eruptive rocks, basalt, augite andesyte, quartz-porphyries, metamorphosed diorytes, phorphyritic diorytes and granites, it was not to be wondered at that hot waters were encountered at great depths in the mine, or that these hot solutions had effected the deposition of such a marvelous store of wealth. The foot-wall is dioryte from Gold Hill to Virginia City, metamorphic slates south of Gold Hill, and in one place for a short distance a diabase dike. The hanging-wall is usually hornblende andesyte in the upper region and diabase in the lower levels.

The ores are silver ores, stephanite, polybasite, argentite and some galena and zinc blende. The bullion contains about 43 per cent. of its value (6 to 7 per cent. of its weight) in gold, and 57 per cent. in silver.

The product of the mines located on the Comstock lode up to Jan. 1st, 1881, was, in round numbers, 7,000,000 tons of ore which yielded bullion valued at $306,000,000. The average value of the ore was $43.86 per ton inclusive of the amount lost in tailings. The dividends and profits up to the same date amounted to $118,000,000 which was reduced by assessments of $62,000,000 to a net profit of $56,000,000, showing that the cost of operation amounted to $35.71 per ton of ore produced.

These few facts show without any need of emphasis or comment, how widely different are the costs of mining operations under different conditions. Each mining district and each property in the district must be considered by itself and developed in the light of the conditions which surround it independently of what any other mine has accomplished or expects to accomplish. It is quite evident from the foregoing brief outline of facts that because the Homestake and Alaska-Treadwell mines pay dividends on four dollar ore is no reason why mines on Rainy lake can do the same; nor, on the other hand, that because it cost $35 a ton to mine and treat the ore of the Comstock lode it will cost the same in Minnesota. The fact to be emphasized is that under suitable conditions ore deposits can be profitably exploited even though the value of their contents varies from $35 down to $4 or less per ton. The next thing is to determine in each case whether the ore body is present or not, and under what conditions, and with what environments.

OTHER RESOURCES AND ROUTES OF TRAVEL TO RAINY LAKE.

I. OTHER RESOURCES.

This report is devoted primarily to a discussion of the gold-bearing rocks of the Rainy Lake region, but it will not be out of place to call attention to other natural resources as these must play an important part in the development of any mining district. Moreover, the presence in the vicinity of Rainy lake of an abundance of natural resources, other than the gold, is destined to aid very materially in the rapidity of settlement and development of the northern parts of Itasca and St. Louis counties.

Useful mineral substances.

In the large pegmatyte veins or dikes, which occur especially in the mica schists along the south shore of the eastern arm of Rainy lake and on the shores of Kabetogama lake, are plates of mica (muscovite) two or three inches in diameter. As yet no mica has been found in sufficient quantity or in large enough plates to be economically useful, but more careful exploration of these pegmatyte veins may be rewarded by the discovery of larger masses of this mineral.

Other minerals, such as iron pyrites, sphalerite (zinc blende) galena and copper pyrites, occur in the Rainy Lake region, especially in the quartz veins, but it is hardly probable that large amounts of any of these will be found.

The Keewatin rocks of this district are of the same geological age and of the same general character as the rocks in which are the rich iron deposits of the Vermilion range and some parts of the south shore of lake Superior. Deposits of iron ore have already been reported from the Seine River country, but as yet no careful exploration for iron ore has been attempted. We wish to call special attention to the probability of the existence of large masses of iron ore in the Rainy Lake region, and we feel that exploration in this line is more likely to result in the discovery of mineral wealth than exploration for any other mineral except gold. The rocks marked Keewatin on the map (plate I) are the ones in which exploration for iron ore should be carried on.

Many of the granites and syenites, and some of the other rocks, will make excellent building stones. Good material for grindstones, whetstones and hones, and probably also for roofing slates, exist in the Keewatin rocks. The numerous limestone fragments found in the clays along the banks of the Rainy river have sometimes been burned for lime by the settlers. The clays to the west of Rainy lake contain beds which will evidently make good bricks, and some of the beds will probably be found to possess the characteristics necessary for some kinds of pottery.

Coal has been reported a number of times from the banks of the Big Fork and Little Fork rivers, which are in Itasca county and southwest of Rainy lake. This coal occurs in the form of lignite in the Cretaceous shales, which are known to outcrop in places along these rivers, and it is probable that rocks of this age exist, although usually buried under a considerable thickness of glacial drift, in most of Itasca county and the counties to the west. On account of the discovery and recent development of lignite beds in the vicinity of Redwood Falls, it is thought best to call attention to the possibility of the existence of similar beds in the region to the southwest of Rainy lake. This lignite in Minnesota does not seem destined to be of any great value, but possibly some of it may prove of local importance. In this connection we quote the statements made in reference to coal in Minnesota by the senior author of this report some two years since:

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, occurring in Cretaceous shales, which were found in patches on the Little Fork river by the writer in 1887. 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 peculiar 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 the mass 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 water even though laid in water for some time. The 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 d posits cannot be overestimated, and if we have such in Minnesota the sooner we know it the better.*

Timber.

The usual white and Norway pines are found throughout this entire region, but not always of sufficient size to pay for cutting. Yet, there are many places along the shores of Rainy lake and the adjoining bodies of water where there are groves of good sized pines; and many scattered areas of timber exist in the vicinity of the Big Fork and Little Fork rivers. Some of the pine has already been cut and taken to Rat Portage, but much remains to be cut as soon as the demand for lumber in this district increases. A saw mill was in operation near Rainy Lake City during the last summer and two or three others on Rainy river.

In hardwood timber the white birch, which occurs throughout the region and which often reaches a size suitable for lumber, may be mentioned; oak and elm of good size occur in the flat clayey district just to the west of Rainy lake.

The numerous swampy tracts of this part of the state are often covered by a dense growth of excellent spruce timber. This is used in large amounts in the manufacture of pulp and paper, and, as the more southern regions are being rapidly devastated of their timber, the spruce of northern Minnesota will soon become exceedingly valuable; growing as it does in the lower and damper grounds it is not so subject to destruction by forest fires as the pine.

Agriculture.

The plain of clays which extends westward and southward from Rainy lake is destined to support a large farming population. As already mentioned these clays were deposited in the glacial lake Agassiz and are thus of similar origin to the subsoil of large parts of the Red River valley. Above this subsoil is a considerable thickness of black loam. This land naturally supports a luxuriant growth of vegetation, and, where it has been cleared and cultivated, as in many places along the Canadian shore of the Rainy river, it has been found to yield large crops. Most all of the usual produce, excepting yellow dent corn, have been successfully grown in this district; and especially large returns have been made in oats, wheat,

* Geol. and Nat. Hist. Survey of Minn., 20th Ann. Rept., pp. 179-180, 1893.

potatoes, cabbages, turnips and hay. There are large tracts of land south of the Rainy river, which are as yet unsettled and which are unexcelled for agricultural purposes by other land in the state. As is usual in a new mining country the farming interests are neglected at first, but in the Rainy Lake district there is no reason why this should continue so, as the conditions for making farming a profitable business are here so favorable.

The following quotation from Dr. A. C. Lawson's report on the geology of the Rainy Lake region* is strong testimony as to the adaptability of the soil and climate of the region for the support of a dense population:

Agriculture is perhaps the most promising of the economic prospects of the region. Rainy river from its source at Coutchiching to Hungry Hall, flows for eighty miles through a rich alluvial plain, which, so far as can be judged from the banks of the river, is eminently adapted to support a large agricultural population. Travelers and explorers vie with one another in praising the beauties of the river and its capabilities for settlement. Mr. S. J. Dawson in his "Report on the exploration of the country between lake Superior and the Red river settlement" says of it, "The distance from Rainy lake to the Lake of the Woods, following the windings of the stream, is about eighty miles, and throughout the whole of this extent the land fronting on the river is fit for settlement without, I may say, a single break; indeed, I have never seen anything to equal it in my experience, except at Swan river and on the Assiniboine." * * * * Prof. H. Y. Hind in his account of the country examined by the same expedition says: "No part of the country through which we have passed from lake Superior northwards can bear comparison with the rich banks of the Rainy river thus far. The river has preserved a very uniform breadth, varying only from about 200 to 300 yards. The soil is a sandy loam at the surface, much mixed with vegetable matter. Occasionally, where the bank has recently fallen away, the clay is seen stratified in layers of about two inches in thickness, following in all respects the contour of what seems to be unstratified drift clay below. Basswood is not uncommon, and sturdy oaks, whose trunks are from eighteen inches to two feet in diameter, are seen in open groves, with luxuriant grasses and climbing plants growing beneath them."

A more recent authority is Mr. J. O. Bolger, P. L. S., who explored the region in the summer of 1886 for the department of Crown Lands of Ontario, with the special object of ascertaining its fitness for settlement. His description and opinions are more valuable than the preceding and are even more optimistic. He says: "I first encountered good land at the point where the forty-ninth parallel or the first base strikes Lake of the Woods, and following up Little Grassy river, which empties into the lake a couple of miles south of this point, I found, from traveling in every direction, that the block of four townships composed of townships one and two south, ranges twenty-three and twenty-four east, contains a large percentage of the finest land I have ever seen, and the same descrip-

*Geol. Nat. Hist. Survey Canada. part F, 1887, p. 186F.

tion applies to the block of land lying westward between these townships and the Lake of the Woods. Little Grassy river is navigable for canoes for a distance of about eight miles from its mouth and the land on the shore is all good, being composed of a rich calcareous drift formation equal to any soil in the best agricultural districts of Ontario.

The timber along the river is chiefly large, thrifty poplar, mixed with some scattering oak and swamp elm, and some evergreens, such as balsam and spruce; inland, the timber changes in character somewhat from that along the river shore as large balm of Gilead, spruce, balsam and tamerac are met with more frequently and the nice open bush which prevails along the river banks is changed for a tangled, brushy undergrowth; but the character of the soil remains the same. Tamarac and spruce swamps occur frequently in this section of the country, as is the case all through this large level area of good land which lies along the banks of Rainy river. These swamps were all perfectly dry this summer, and are all capable of being made into excellent land by drainage, as they lie nearly as high as the surrounding dry lands, and only require proper ditching to take the surface water off in wet seasons. The extreme levelness of the country causes the presence of so much swamp land here, as the surface water has no means of escaping from the low-lying portions, and, consequently, the growth of moss and swamp timber is engendered. I noticed that in most cases the beds of the little streams are deep enough to form outlets for ditches and drains, and these creek beds are usually so numerous that to drain any swamp no very long ditches would be required; in nearly all the swamps through which I passed I observed the soil to be a black vegetable mould, varying in depth from one to three feet, and always underlaid by the same calcareous clay alluded to. I seldom met the muskeg proper, that is to say, the wet, shaky bog in which water is present at all seasons of the year, and which grows nothing but dwarf spruce and moss. I then paddled up Rainy river, and on both shores I found the same kind of country as I have described as being in the vicinity of Grassy river, and, as there, a good number of settlers along the river on the Canadian side, I had an opportunity to observe the soil while under cultivation, and to see the kind of crops it is capable of raising.

The soil I found to be most excellent in character, calcareous clay overlaid by a thin streak of whitish fine earth about six inches in thickness, and this again covered with a coating of vegetable mould; and these three mixed up together in the working of the land form a soil which cannot be excelled in any part of the Dominion. I saw along the river crops of potatoes, turnips, hay, oats, wheat, corn, tomatoes and cabbage, all grown to perfection this season, which shows that the climate, as well as the soil, is suitable to successful farming, especially when tomatoes ripen, as they certainly did this year, as well as I ever saw them ripen in the vicinity of Lake Ontario. * * * *

"The timber is chiefly poplar, which grows to a great size; I have seen trees over eighteen inches across the stump, and sixty feet long clear of the limbs. Balm of Gilead, too, prevails in some sections, while spruce, tamarac and balsam of thrifty growth are everywhere met with. In some places magnificent cedar abounds, large enough for telegraph poles, shingle bolts or any other use to which cedar is applied; there are some groves of pine through this section, but it cannot be called a pine country, that is on this drift formation."

Such testimony as to the character and value of the land through which Rainy River flows, leaves little for me to say beyond expressing my entire concurrence in the opinions quoted as to the great suitability of the country for settlement and agriculture. Settlers are going in gradually and there are some excellent farms along the river front. * * * * The river affords an easy means of access, and the levelness of the country renders roads easy to build.

This agricultural district is not confined to a narrow belt of land along the river, but has, in Minnesota, an approximate area of 5,000 square miles, between Rainy lake and the Red River of the North and south of Rainy river. Over this area the annual rainfall varies from 33 inches at Rainy lake to 17 inches at St. Vincent. The absence of hills, rock outcrops and even of boulders, is remarkable, and the land is nearly all timbered. In short all the qualifications necessary for a habitable region are found in this hitherto overlooked portion of our great state. It will not be surprising to see in the Rainy River valley as dense a population as is supported by any equal area in Minnesota.

Miscellaneous resources.

As has already been stated in the description of the physical features of the district, there are waterfalls at the outlets of many of the lakes. Some of these streams are of considerable size, and their accessible power would be eagerly sought after if located in the well settled eastern states. By far the largest water power in the district is that of the Koochiching falls. Here the Rainy river descends from twenty-one to twenty-four and a half feet, the amount of fall varying with the stage of the water. It has been estimated that there are 12,000 cubic feet of water flowing over this fall every second, and the power here generated averages 30,000 horse power, with a probable minimum of 20,000 horse power. This is thus seen to be by far the largest water power in the state, much exceeding that at the falls of St. Anthony. A dam of from five to ten feet at the head of these falls, would increase the height of the falls as many feet, and would also raise the level of Rainy lake from two to seven feet, thus furnishing an immense mill-pond with an enormous supply of water for use in times of low water in the river. The value of this water power as an aid in the development of this part of the state cannot be overestimated.

Considerable trapping is done in the winter in this section of the country, and the trade in furs has been an important business ever since the establishment of the Hudson Bay company, which still has a store at Fort Frances. Many of the inland lakes abound in white fish and lake trout and the catching and shipping of these will furnish livelihood for a considerable population as soon as there are better facilities for transporting the fish to market.

Summary.

It is only necessary here to emphasize the fact that in the Rainy Lake district there are many natural resources, aside from the gold-bearing veins, which have not yet been developed and which would make the district an important one even if it contained no gold. We wish especially to call attention to four of these natural resources which seem destined to make this district develop with rapidity: 1, the excellent farming lands; 2, the large bodies of standing timber suitable for manufacture into lumber and paper; 3, the large water power; and 4, the possibility of the existence of valuable deposits of iron ore.

II. ROUTES OF TRAVEL TO RAINY LAKE.

At present there is no railroad running into the Rainy Lake region, the nearest station being Tower, on the Duluth and Iron Range R. R., seventy miles in a direct line southeast of Rainy Lake City. It is understood that several roads are considering the advisability of extending branches into this region, and it seems probable that the summer of 1895 will witness the commencement of active preparations along these lines.

There are three principal routes by which Rainy lake may be reached, during the summer season, as follows:

1. A regular passenger train on the Duluth and Iron Range R. R. leaves Duluth at about 3 P. M. and arrives at Tower the same evening. The next morning a steamboat may be taken from Tower to the outlet of Vermilion lake, and from here a stage ride of twenty-six miles brings one to Crane lake. A tug takes passengers from this point about twenty eight miles to Kettle falls, and from here other boats run to Rainy Lake City, Koochiching and Ft. Frances. From each of these towns all parts of Rainy lake may be reached by steamer or canoe. The trip can be made in two days, or less, from Tower. This route is the shortest and quickest for those who are in easy rail communication with Duluth, and it has been the route most frequented during the last summer.

2. The second route runs over the Great Northern R. R. to Winnipeg and from there via the Canadian Pacific R. R. to Rat Portage at the north end of Lake of the Woods. From this point steamboats may be taken through Lake of the Woods and up the Rainy river to Ft. Frances and Koochiching. This is the most comfortable route, as the boats running from Rat Portage are larger and better equipped than those on the Tower route; but it is more expensive and takes more time than the latter route.

3. The Canadian Pacific R. R. during the last summer sold tickets from Duluth to Port Arthur by steamer, and from the latter point to Rat Portage by rail. From Rat Portage the rest of trip was made as indicated above.

Persons visiting Rainy lake will frequently find it advisable to purchase a small camping outfit and a canoe and to engage a guide or woodsman, either a white man or an Indian. A person thus equipped can travel anywhere in the region; in fact it is only by means of canoes that large tracts of the Rainy Lake district and of northeastern Minnesota are visited at all.

During the winter Rainy lake can be easily reached from Tower, Mountain Iron, Hibbing or Grand Rapids by team.

To anyone contemplating a short outing we heartily recommend a trip to the Rainy Lake region and through the evergreen forests of northeastern Minnesota and its crystal lakes, teeming with white fish, pickerel, wall-eyed pike, bass and lake trout. The expenses of such a trip are comparatively small. Two persons, who are accustomed to canoeing, can start from Duluth, spend two weeks in going from Tower to Rainy lake and back again, largely or entirely by canoe, and can return to Duluth for an expense of twenty-five dollars each, including canoe, railroad fare and provisions for the entire trip. The most agreeable time of year to visit this region, either for purposes of exploration or pleasure, is during August, September and October. Usually after the first of August the insect pests of the region, mosquitoes, blackflies and sand flies, are sufficiently reduced in numbers to render life in the woods pleasant and even delightful. And in September and October the larder may be abundantly supplied with game.

Maps.

Only two maps of the Rainy Lake region, which are large enough for convenient use in exploration, have been published. The first of these is the "Rainy Lake Sheet" of the district of Rainy River, published by the Geological and Natural History Survey of Canada; it accompanies the report on this region by A. C. Lawson,* and can be obtained from the Geological Survey, Ottawa, Ontario. This map is on a scale of four miles to one inch, and on it the various rock formations are designated by different colors. It shows the Minnesota shores of Rainy lake and considerable territory to the north and west of the lake; the outlines of the bodies of water in Canadian territory are much more accurately represented than on any other map.

The second map is entitled "Map of the Rainy Lake gold district from Ft. Francis to Kettle falls," is published by Patton & Frank, Duluth, and is sold at fifty cents a copy. This is on a scale of one mile to one inch. It shows the shores of Kabetogama lake, the Minnesota shores of Rainy lake, and the subdivisions of the sections, as accurately as do the government township plats; but the Canadian shores of Rainy lake are necessarily less accurately shown.

It is hoped that the map (plate I) which accompanies this report will prove useful. The scale is three miles to one inch. It shows the different rock formations, the positions of the villages which have recently sprung up in this region, and also the more important mining locations.

OTHER REPORTS OF GOLD IN MINNESOTA.

Very few months pass in which there is not some report in the newspapers of gold discoveries somewhere in Minnesota. From one end of the state to the other, in all kinds of situations and under various possible and impossible conditions these discoveries have from time to time been reported. Most of them fail to arouse any general interest and are soon forgotten. But in some instances the fact of some real basis for the reports, or the persistence and deceptive misrepresentations of mining swindlers keep the rumors alive until the public is actually deceived and led to "take some stock" in them.

It is a fact that gold is widely disseminated in nature, and that it may be found in small quantities in the sand and gravel deposits of the river beds and lake basins of the state. But

* Report on the geology of the Rainy Lake region; Geol. and Nat. Hist. Surv. Canada. new ser., vol. 3. pp. 1F-182F, 1889.

this is in such minute quantities and in such a fine state of division that it is seldom noticed and is rarely the cause of any of these unfounded rumors. Rusty mica, either in the sand of creek beds or in rotten granite boulders, is most frequently mistaken for gold by the uninformed. Almost every week samples of this stuff are sent in for examination, and the senders are usually very loth to believe that the shiny particles have no value whatever. When unprincipled individuals make such discoveries, or find quartz veins, no matter how barren, particularly in a farming community, they sometimes make a pretense of starting mining operations, and succeed in selling considerable amounts of stock or land at inflated and fictitious valuations.

I. REDWOOD FALLS "GOLD MINE."

A good illustration of this class of mining operations is furnished by those of the Minnesota Gold Mining and Refining company. For several months this corporation furnished reports to the daily papers of the wonderful gold quartz found in the Minnesota River valley near Redwood Falls, or more properly speaking, near Delhi, about eight miles from Redwood Falls. These news items recorded the progress of explorations at the "mine" owned by this company. Shafts were being sunk; ore was being taken out, and sent away to be assayed and even in car lots to be treated; stamp mills were ordered, an electric light plant was to be erected; a village was projected; and an electric road was talked of, to accommodate the miners who would wish to go to and fro between the "mine" and Redwood Falls.

The corporation was organized with a capital stock of $500,000 in shares of $10 each, and stock was offered for sale at $6 per share, a valuation of $300,000 for the property. The officers of the company were active in disposing of this stock, and represented their ore to have a value of $40 to $95 per ton; saying also that single assays had given results as high as $2,960 per ton. Finding that many citizens of the state, who could ill afford to throw away any money, were likely to invest in this stock, one of the writers made a visit to the "mine" and took samples of the rock for assay.

The developments were rather disappointing to one who had read the newspaper stories. Situated in the Minnesota River valley, but a few feet above the water, was a test pit less than 20 feet deep. This was the "mine." The "plant" consisted of a board shanty, a windlass and two buckets. The large force of men for whose convenience an electric road was to be built eight miles, consisted of five laborers. The vein was barren quartz in a ledge of granitoid gneiss, altogether of most unpromising appearance. Upon assaying the samples procured,* no gold or silver was found. These facts were at once given to a Minneapolis newspaper and published, together with other items of a confirmatory nature, resulting in a suspension of operations at the "mine" and a rapid decline of the market price of this worthless stock. Similar swindles may again be inaugurated, and more successfully carried out. It would appear wise to have so meprecaution taken by the State against them. If it were made the duty of some state officer to inspect all reported discoveries of valuable mineral deposits and publish his opinion of them, those who were unlearned in such matters might be saved many losses, and the reputation of the community would not be so often stained by such transactions.†

II. GOLD NEAR ELY.

Of an entirely different character from the foregoing is the reported discovery of gold on lot 6, section 30, T. 63–12, near Ely, Minnesota. Indeed it has been known for some years that gold occurs in quartz veins, between Tower and Ely. Mention was made of the fact in the geological report for 1889 and assays were reported of samples, taken by members of the geological survey corps, showing gold to the amount of a dollar per ton.‡

On Oct. 14, 1894, the first blast was fired in the above mentioned property and assays of the ore thrown out from the exploring shafts have been made by many different chemists, nearly all of whom found some gold and silver. The vein has a width of five or six feet, strikes about northeast and south-

*This assay was made by Sharpless and Winchell.

†It should also be stated that the foisting of such mining schemes upon the public for the purpose of stock-selling is not always due to the ignorance or the fraudulent designs of the owners. It not infrequently happens in Minnesota, as in Arkansas and Georgia, that assayers are more guilty than the active promoters. The writer has knowledge of several such criminal acts on the part of assayers in Minnesota. There is a strong temptation to magnify the favorable results of assays. The cupidity of the owner once aroused, he easily enlists several of his friends. The assayer's business is increased by the spreading reports and he may keep the craze going for several months or years by a judicious distribution of his false returns. The State of Minnesota to-day is cursed by the practices of a few such assayers—against whom there should be some law as rigorous as against quack doctors.

N. H. WINCHELL.

‡18th Ann. Report, Minn. Geol. Sur., pp. 19, 21, 1890.

west, and has a vertical dip. It is said to be a contact vein between syenite on the northwest and greenstone on the southeast. This vein has not been seen by us, but samples from it which we have examined show a quartz fairly well mineralized with pyrite and galena, and somewhat mixed with wall rock. Situated close to the Duluth and Iron Range railway and in other respects well located for economical development and operation, a low grade ore could be profitably worked here provided it occurs in sufficient quantity. This can be determined by further exploration. The owners of this property are C C. Prindle, A. W. Dutton, B. E. Wells and Ed. McIntosh, of Duluth.

Work of exploration is being prosecuted on the same vein in sec. 25, T. 63-13, under the direction of Morris Thomas, of Duluth.

CONCLUSION.

Concisely stated, the facts described in the foregoing pages lead to the following conclusions: There is gold in quartz veins in the vicinity of Rainy lake. As yet the development is insufficient to warrant the positive assertion that profitable gold mining operations can be conducted there; but in certain localities the prospects are full of encouragement and promise to the conservative operator.

The best portion of the district for gold, so far as at present developed, and as indicated by the appearance and nature of the veins and the geological conditions surrounding them, is not within the limits of our state. Some gold is found south of the boundary line, and its discovery was the starting point for the explorations so vigorously prosecuted during the past year. But, as in all other mining districts, the majority of the veins are not worth working, and, indeed, many of them, chiefly belonging to the class of segregated veins, contain no gold whatever. There are excellent opportunities for the investment of capital in the gold mining industry of Rainy lake; but unless selected and developed with discrimination and scientific judgment the chances are that the property chosen may not develop into a permanent and productive mine. It is our confident belief, however that the proper forces have been in operation at several points around Rainy lake to produce auriferous quartz lodes of a richness that will compare favorably with those of many other prosperous mining districts.

If the development of operations now in progress shall demonstrate the existence of extensive deposits, as we believe will be the case, the future of the district for gold mining is assured. It is even now accessible at moderate cost; fuel, water and water power are abundant, and labor cheap. Modern methods have made the cost of exploitation, even of refractory ores, much less than it was only a few years ago. With the large bodies of low grade ore which are destined to furnish the greater part of the world's output of precious metals in the future, the costs of mines and mills as advantageously situated with reference to wood and water as those at Rainy lake, have been estimated at $2.00 a ton for mining and $3.00 a ton for barrel chlorination or for treatment by the cyanide process of ores adapted to it, and from which 90 per cent. of the metal can be saved. Where practically all the gold can be extracted by amalgamation, as at present at Rainy lake, there should be a good profit on five dollar ore in permanent veins which have an average width of five feet or more.

The surprising adaptability of the soil and climate of the the Rainy River valley for agriculture, together with its stores of timber for lumber and paper manufacture and its large water power, instill in us the conviction that northern Minnesota is an empire by itself, destined in the near future to become the home of a large and prosperous community engaged in the occupations of farming and manufacturing.

IV.

THE TOPOGRAPHICAL SURVEY OF MINNESOTA*.

BY W. R. HOAG.

The needs of the people, which are thought to fall to the government or to the State for supply, are, as a rule, slow in receiving just recognition. Wherever this tardiness becomes sufficiently pronounced to warrant it, private capital steps in and frequently supplies the need much more quickly and fully than public sentiment would have justified congress or legislatures in doing. Tradition is strong, and we are slow to delegate to the Nation or State the control of those institutions which are now serving the people acceptably. Especially true is this with those having their birth and doubtful beginnings since the establishment of our government. The railroad, the telegraph and telephone, the express also, might be named as examples in point.

It is believed that the present great activity in the world of thought and letters is directly incident to the maintenance of a domestic system which imposes upon those embraced in it a tax so small as to be insufficient to pay for the actual service of such enterprises as those named, to say nothing of a good profit which, if continued long as a private enterprise, they must afford their owners.

While the question of imposing upon those who employ a public agency little or none, burdens disproportionate with the accommodation received, in order to lighten the load of others who use it much, is a legitimate topic of discussion for the political economist, yet all are agreed that such a tax must greatly stimulate and strengthen whatever it thus unquestionably facilitates.

Who shall say what we have lost as a nation in activity and consequent development by permitting our telegraph systems to remain under private control with rates and conditions cal-

*Read before the Engineer's club of Minneapolis, Dec. 19, 1894, by W. R. Hoag, professor of Civil Engineering, University of Minnesota, and state topographer, in charge of the topographical survey.

culated in no way to encourage its wider use by the citizen, and as a rule prohibitory of such extension except where cost counts for naught or the time element is a ruling consideration. The great question of transportation incident to serving man's needs in the material world comes up with equal force. Not that we ask the question, shall the government now acquire control of the rail and waterways, but rather would not our territory have been developed much more rapidly and would not all of the strengthening and enriching effects of an efficient and economical system of transportation be present in a much larger measure than they are to-day had the government from the first developed railroad transportation the same as it has the postal system.

There is another class of needs which a civilized community soon comes to feel, but, being of a more general nature than those already noted, they have been receiving tardy recognition; and especially true is this in this country, where the national government has taken up the work only after urgent specific needs have demanded their consideration. I refer to surveys of the public domain, whether conducted with a spirit to discover the resources of the country as a purely geological and natural history survey, or as a topographical survey to meet the multiple necessities of our modern civilization.

Even the need of some scientifically consistent plan for purposes of description and partition of the land thrown open to settlement did not move congress till a large amount of such lands had been disposed of and in a manner giving the most absurd and expensive plan for farm boundaries, and unduly increasing the cost and uncertainty of all subsequent land surveys and descriptions. When, finally, the rectangular system of our public land surveys was devised and adopted about 1810, the standard of desirable accuracy was placed so low, and the execution of it by inexperienced contractors was so lamentably poor and the government inspection of it in many cases so farcical, that it has been estimated that the additional cost to the people from litigation, resulting alone from such poorly defined land boundaries directly incident to such cheap survey, has already far exceeded what would have been necessary to make an absolute topographical survey of the same, in which every important subdivision line would be given exact position by a system of triangulation and traverse, all having ultimate control in a rigid system of geodetic triangulation. In 17— it was seen that there was need of exact knowledge of our coast line, both for developing and protecting the shipping interests and for purposes of public defense, to meet which the U. S. Coast Survey was organized, and began this great work in 1807. In 1841 the Lake Survey was organized for the definite purpose of making a geodetic survey of our shore line of the great lakes. In 1878 the Geological Survey was given the special work of conducting geological researches in the western territories and has since extended its field to the whole country, and more recently has been confining itself largely to topographical surveys, in the absence of which it found itself unable to conduct with satisfaction its geological studies. The coast lines having been about completed in 1870, except those of Alaska, the work of the Coast Survey was enlarged by act of congress in 1871 to include hydrographic and topographic work on the great rivers of the country except the Mississippi and Missouri rivers, which had been assigned to special commissions in charge of the army and navy.

The Coast Survey, with the broadened title of Coast and Geodetic Survey, was also instructed to conduct a grand system of transcontinental triangulation and precise levels for the purpose, aside from those purely scientific in character, of coördinating not only all of its own work but that of any other agency. This latter function was calculated to aid especially in fixing international and interstate boundaries, and thereby to encourage state work of somewhat like character. To still further aid each State in prosecuting its topographical survey the U. S. Coast and Geodetic Survey was authorized to conduct a separate triangulation as a basis for such surveys, in those states having in vigorous operation their own state geological surveys.

To the U. S. Coast and Geodetic Survey was also entrusted the work of conducting a magnetic survey of the country.

Congress has not seen fit to create an institution whose prime function shall be to make a complete and accurate topographical map of the territory of the United States. Nor is it likely to, since there are already a number of district surveys one of whose functions is to make such a survey of its immediate locality; moreover, the avowed purpose of one of the lines of work of its oldest survey—the Coast and Geodetic—is to assist the different States in carrying on their own topographical surveys.

A further reason that the plan of individual state surveys is likely to prevail consists in the pride each State has in discovering and developing its own resources; in fact each independent State desires to supply all the needs of its citizens, so far as they can be supplied within the state, and as far as possible from its own resources.

Another difficulty, attending a general plan covering the whole country, appears when we consider that some sections of the country, on account of local difficulties, coupled with the desirability of great accuracy and full detail, might cost from two to five times as much to be adequately represented on the topographical sheet as other sections.

Again, some States from a keen sense of appreciation of the economic worth of a reliable topographical map, will need to have much more detailed work done, costing much more, than could be be carried out in other states on any general plan of equity to all. Just this thing has already happened in the state of Massachusetts when the national Geological Survey proposed to conduct for it its topographical survey if the State would meet half the expense. In arranging the details of the contract it appeared that the Geological Survey desired to do the work according to its usual plan followed elsewhere under like topographic conditions. The commission objected to this plan, claiming that the State could not afford to meet even half the expense of such a survey, as it would give them a map little better than the one they already had.

In other states, by reason of general inactivity in all matters relating to public improvement, even a map of average cost would meet no present need, and all money so expended would be lost to the country, until the State should awake to an appreciation of its true worth. On the other hand, not to carry the work along about equally in the different states would be a manifest injustice.

Another evil which must attend such general plan is the following:

Any such national survey must have at its head a director or superintendent with power to direct the details of the work—the general policy alone could be fixed by congress. That survey, dependent upon the continued favorable action of congress for maintenance will, if it be loyal to its own cause, endeavor to merit and gain the support of a majority in congress. But each congressman is, as a rule, keen to see that his State is receiving its full share of the benefits from such legislation, not receiving which he withdraws his support. A system of political trading results and friendly relations are maintained by work in some states and promises in others sufficient to control a safe majority in congress—which must result in a shifting policy of the survey and a consequent discontinuation of the work in some states in order to resume operations in others —which changes must follow closely and actively every change in the political color of congress. In that manner a great agency, created to subserve the best interests of the people impartially in a specific work, must soon degenerate into a vast political machine, an incidental feature of it being to do topographical work, the main function being to serve congress. While this picture may seem overdrawn to some, I firmly believe that in view of the difficulties present, some of which I have specified above, no such survey could survive a sufficient length of time to even become efficiently operative without coming substantially to this condition.

Indeed, this country has already furnished proof of this inevitable tendency, and its development has been such that one familiar with the modus operandi of our national surveys can not fail to see it. All this can be easily avoided by allowing each State to take up its own work at the time and in the manner which seems to it wise—conserving all the interests of the State and receiving whatever aid from the general government it may without sacrificing its control.

Though many States are at present engaged in conducting topographical surveys, according to one plan or another, but three, Massachusetts, Connecticut and New Jersey, have completed such surveys. In fact, considering the wide gap we have nearly closed with other nations of the world in the past half century in education and science, in transportation and invention and indeed in much that contributes to the wealth and greatness of a nation, we are far behind them in appreciation of the economic worth of an accurate topographical map. As a natural result we find that few States have taken advantage of the valuable cooperation offered by the U. S. Coast and Geodetic Survey in furnishing free to the State a preliminary triangulation, which must precede as a foundation all topographical work proper, Minnesota being ninth (?) in the list to thus coöperate.

The mining engineer fully realizes the value of a reliable topographical map of that section which is to be the field of his professional labor.

The municipal engineer knows that by the aid of an accurate topographical map only can he with certainty discuss questions relating to sources of water supply, location of reservoirs and standpipes or trace outlines of natural drainage for use in designing the most efficient and economical system of sewerage disposal.

To the sanitary engineer it becomes a valuable aid in searching out sources of contamination in wells or surface supply.

The geologist requires the aid of the topographical map for the fullest exposition of his results, especially in problems touching physical, stratigraphical and glacial geology.

The hydraulic engineer would need little else to determine the site and value of mill privileges or to study the matter of overflow of land relating thereto.

The survey is of great value in prosecuting studies in natural history and meteorology. To the civil engineer an adequate topographical map is the foundation upon which nearly all his problems must rest to insure economic solution.

It has been estimated that Massachusetts alone has paid $20,000,000 since 1836 in railway expenditures over what would have been necessary had it possessed at that time accurate topographical maps of its territory.

The army engineer can increase by one quarter the efficiency of the army by supplying it with topographical maps, enabling it to take advantage of every important feature of the land. Our late civil war was undoubtedly prolonged not a little by reason of the superior knowledge of their own territory possessed by the southern generals, gained mostly by hastily prepared maps made immediately before and during the war.

To the agricultural districts the topographical map proves of greatest value. It aids in the establishment and maintenance of a scientific system of highways, which to-day is the severest tax the farmer pays. It would give a uniform and absolute means of determining land lines and corners and also data for settling all questions of land drainage or irrigation.

If more proof is desired showing the need of better maps of our territory than furnished by the original land surveys, made half a century ago, it appears in the fact that private concerns have prepared such maps and have found sale for them among the people, sufficient to justify the undertaking. The more settled portions of our state have thus been twice surveyed and mapped already and some sections many more times.

These are among the leading benefits to be derived from a reliable topographical map, and are named only as a part of the ways in which the survey would soon come to furnish economic returns.

Some of the European States have covered their territory with repeated surveys, the earlier ones being of no present value, except to have served the very useful purpose of furnishing a field in which to develop what a topographical map must be to meet the demands of our modern civilization.

Shall we, as a State, acquire an adequate topographical map by this costly method? Or shall we, by adopting the most modern practice of the science, prove that we do not need these costly trial lessons? This question received its first answer in the State legislature of 1872, which committed us to the policy of conducting our own survey and the making of such measurements as may be necessary for an accurate map of the state.

This was the provision made in sec. 5 of the act creating the Geological and Natural History Survey, which was drafted by W. W. Folwell, introduced in the legislature by senator J. S. Pillsbury, a regent of the University, and received governor Horace Austin's approval March 1, 1872.

A second answer to this question was given in 1887, at which time, upon recommendation of N. H. Winchell, state geologist, the writer was appointed, by the superintendent of the Coast and Geodetic Survey, acting assistant and given immediate charge of their operations in this state.

The purpose of having these acting assistants appointed by the superintendent of the U. S. Coast and Geodetic Survey was to bring that part of the work requiring the most expensive instruments, rigid field methods and office reductions, under the direct supervision of one central highly professional authority. This alone insures that uniformity necessary where each state survey is an integral part of the one continental survey. It saves each State the expense of providing costly instruments needed only during the progress of the survey, as well as all instruments for conducting the primary triangulation, vertical measures, leveling and magnetics. The general direction and care of the field-work being in the hands of officers of life long experience, and the reduction of the notes made by professional computers at Washington assure that degree of accuracy which is essential to securing all of the objects of the survey; at the same time local interests are conserved by the fact that the actual field work is executed by citizens of the state, all the expenses of the work being borne by the National Survey.

Early in June, 1887, work was begun and has continued almost uninterruptedly during the summer months. During this time astronomical latitude and telegraphic longitude have been established at a station in the University grounds to serve as the absolute starting point of the survey. A primary base-line 5½ miles in length has been prepared and measured, located along Snelling avenue, St. Paul, which furnishes the element of distance to all lines. A line of precise levels has been run from the nearest sea-elevation bench-mark to this base-line, thus giving it sea elevation. From this base-line with its latitude, longitude and sea elevation accurately known, a complete system of triangulation has been extended over the greater part of Hennepin, Ramsey, Washington, Dakota, Goodhue, Wabasha and Winona counties, fully preparing this territory, amounting to about 2,500 square miles, for final topographical mapping. Besides this, other work, of the character of a reconnoissance, looking to a plan of triangulation, has been done in Chisago, Anoka, Wright, Carver, Scott, Rice, Dodge and Olmsted counties. For the past two years observations have been made, at all stations occupied for magnetic declination, with the view to making at an early date a complete magnetic map of the state for the use of all county surveyors. During the past season, employing instruments loaned by the Coast and Geodetic Survey, the Civil Engineering Department of the University has been conducting systematic observations at a magnetic station located at the experimental farm. The past season has been spent in work upon a topographical sheet covering the twin city district—including about 225 square miles, the first part of the season being devoted to the plane-table triangulation—the latter part to filling in the topography. The topographical work proper has been mostly confined to the interurban district west of Snelling avenue, and along the Mississippi river and lake and park regions of the cities where the city records would not furnish adequate details.

During the progress of the triangulation, in addition to locating the primary stations, which are 15 to 25 miles apart, the superintendent has ruled that the acting assistants will be allowed to make observations upon any other objects, such as church spires, tall chimneys, towers, etc., with the view to giving them position for use as secondary stations necessary to the state topographical survey when such objects can be subserved without extra cost to the national survey.

Since economy, as well as accuracy, demands that the primary stations be located as far distant from each other as possible, in most cases, it is of the greatest importance that these secondary points—in sufficient number and in favorable positions—be chosen and located during the progress of the primary work. Especially is this true when tall observing towers must be erected at the primary stations to overcome surrounding woods or intervening ridges, since such towers are not likely to remain in position until needed by the State in its topographical survey. If they be destroyed, the secondary and tertiary stations could not be located except by a rebuilding of tne original towers, incurring additional expense and delay. During the progress of the work in Hennepin, Ramsey, Washington and Dakota counties but three towers were required, and sufficient church spires, wind mill towers, etc., could be observed for secondary points.

Quite the opposite conditions are met in Goodhue, Wabasha and Winona counties, and towers are required at nearly all stations, ranging in height from 24 to 64 feet, and but few secondary points, except windmill towers, could be established owing to the small number of objects sighted. These, from their great number and similarity, proved of very little value, since all attempts at identification proved futile. The appearance of this latter difficulty, which threatened to seriously impair the usefulness of the main triangulation led the regents of the University of Minnesota, in the spring of 1892, to appoint the writer as state topographer, with instruction to establish such secondary stations as would render the broader triangulation of value to the state topographical survey.

A state topographical survey, such as is contemplated, is based upon absolute geodetic points and conducted by actual measurements and observations, the methods and degree of accuracy throughout being sufficient to enable a map to be made capable of showing accurately all topographical features as to *distance, direction* and *elevation, i. e.*, to show accurately the position, shape, direction, character, elevation, etc., of all lakes, rivers, hills, ridges, valleys; woodland, prairie or cultivated lands; government lines and corners; all highways, railroads and canals; all buildings in the country and in villages and cities; with contour lines which would show natural drainage, the grade or pitch of all roads, the descent of all rivers, etc. Besides these, together with many other details which would be represented on the map, the survey comprehends a published report, issued at convenient intervals during the progress of the work, which shall contain, besides the usual report on general progress of the work, expenditures and estimates, etc., a full account of all methods and description of instruments employed, and methods and results of the official reduction and computation. The principal purpose of the report is to show more accurately than can be platted on a map, the exact data gained by the field work, which accuracy is necessary for its proper continuance, and for various uses, practical and scientific. The value of such a survey to the State need not be argued, for the history of the progress of topographical surveys in all civilized countries is sufficient proof of their economic worth, the facts being that the older and more advanced nations, as England, France, Germany and Spain have been the leaders in the science of topography and geodesy, each devoting large sums of money to gain sufficiently accurate and reliable maps of its territory. The need of such maps increases with the increase in land values, and the density of population, and with the multiplied needs of an advancing civilization.

V.

HISTORICAL SKETCH OF THE DISCOVERY OF MINERAL DEPOSITS IN THE LAKE SUPERIOR REGION.*

By Horace V. Winchell.

The development of mining industry in the territory about us is so recent that its very beginning lies within the recollection of many. The earliest statistics of production commence but half a century ago, and yet how wonderful the growth and how fabulous its story! It might appear at first sight unnecessary to detail the early history of so young an industry in so new a region. But most of us are newcomers here and have taken things as we found them, without a careful investigation into the beginning of it all. We are well aware of the fact that we are in the midst of a district of marvelous natural resources. We know full well that in addition to our natural advantages American inventive skill and indomitable enterprise have pushed developments until our iron and copper mines are the wonder of the civilized world, and knowing these things we may have overlooked the day of small beginnings, and forgotten to inquire to whom we owe our present fame and wealth. It therefore seems appropriate that a brief summary of the order and date of early events should be presented before this Institute. Some of our traditions may not have a basis of fact, and others may have become more or less intermingled with fiction. It shall be our endeavor to collect the scattered data and present a narrative which shall render honor to whom honor is due for the discovery of our mineral wealth.

*From the proceedings of the Lake Superior Mining Institute, second annual meeting. Read March 7, 1894.

PREHISTORIC MINING.

Although the exploitation of our mines on a commercial scale has been in progress less than two generations, we cannot pride ourselves on being the original discovers and users of the metals they produce. I shall make quotations from the several writers on the subject, during the reading of this paper, without giving exact reference in each case. The bibliographical list appended hereto will furnish information as to the place where the reports quoted appeared. As to the use of metals by the Indians, Jackson remarks:

Long anterior to the settlement of this country by white men the children of the forest were familiar with the use of native metals, such as gold, silver, copper, and perhaps meteoric iron. Their wandering mode of life prevented the cultivation of the metallurgic art, and it is not supposed that they knew how to reduce metals from their ores by the forge or furnace. There is reason to believe that the aborigines in some parts of the country understood the art of obtaining metallic lead from the sulphuret, for the metal is so easily reduced from that ore by roasting it on an ordinary log fire, that it seems impossible for them to have failed to obtain lead if they even threw pieces of the ore into a fire. In the western states, where the lead ores occur loose in the soil and in decayed seams of the rocks, the Indians would have been most likely to have discovered the art of smelting lead. That metal is probably the only one they knew how to extract from its ores. But they understood the art of annealing the native metals by means of fire, and we find proofs in the ancient workings on Lake Superior, as well as in the accounts recorded by the ancient French Jesuits, who were the first Europeans that visited the lake, that the Indians built fires on and around the masses of native copper which were too large to be removed, and after softening the metal, cut off portions with their hatchets. They understood how to fashion the malleable native metals into all the various weapons, ornaments or tools employed by them, and manifested considerable ingenuity and skill in this handicraft, but no proofs have ever been discovered that they ever made any castings of metals fusible at a high temperature. Throughout the continent, wherever gold, silver or copper is found native in the soil, or in the decayed rocks, the aboriginal inhabitants were accustomed to work these metals into various articles, by hammering them with smooth stones, affixed to a withe bound round in a groove cut in the middle of the stone. (Op. cit., p. 373.)

But these "first families of America" went farther than the use of metals found in the glacial drift. They engaged in the operations of mining, in a manner similar to that revealed in the earliest mines of Great Britain, and with equally crude implements. Of some of these prehistoric mines Whittlesey speaks as follows:

The evidences of ancient mining operations within the mineral region of Lake Superior were first brought to public notice in the winter of

1847-8. Although the Jesuit fathers frequently mention the existence of copper, and even use the term *mines*, it is clear, from the general tenor of their narratives, that they neither saw nor knew of any actual *mining* in the technical sense of that word. They announced as early as the year 1636 the presence of native copper, and refer to it as having been taken from the "mines." This was prior to the time when they had themselves visited the Great Lake, and their information was derived from Indians. At the same time they speak with equal certainty of mines of gold, *rubies and steel*; but it must be borne in remembrance that the French word is not equivalent to our English *mines*, but may be more correctly rendered veins or deposits of metals or ores.

In the "Relations" for 1859-60 after missions had been established on lake Superior, the region is reported to be "enriched in all its borders by mines of lead almost pure, and of copper all refined in pieces as large as the fist, and of great rocks which have whole veins of turquoise!" It is probable that these accounts are second-hand, and such as the Chippewas gave when they exhibited to the fathers specimens of native metal in the shape of water-worn pieces and small boulders.

Boucher, in the "Histoire veritable," etc., in 1640, asserts that "there are in this region, mines of copper, tin, antimony and lead." He speaks of a great island fifty leagues in circumference, which is doubtless the one now called Michipicoten, where "there is a very beautiful mine of copper." Copper was also found in other places in large masses "all refined"; in one instance an ingot of copper was discovered which weighed more than 800 pounds, and from which the Indians cut off pieces with their axes after having softened it by fire. All this information Boucher obtained from some French traders, and not from his own observation.

The discovery of the first ancient mine is credited to Mr. Samuel O. Knapp, agent of the Minnesota Mining company. It was in the winter of 1847-48, at the Minnesota Copper mine, and the discovery is thus related by Foster and Whitney:

In passing over a portion of the location now (1850) occupied by the Minnesota Mining Co., he observed a continuous depression in the soil, which he rightly conjectured was caused by the disintegration of a vein. There was a bed of snow on the ground three feet in depth, but it had been so little disturbed by the wind that it conformed to the inequalities of the surface. Following up these indications along the southern escarpment of the hill, where the company's works are now erected, he came to a longitudinal cavern, into which he crept, after having dispossessed several porcupines which had selected it as a place of hibernation. He saw numerous evidences to convince him that this was an artificial excavation, and, at a subsequent day, with the assistance of two or three men, proceeded to explore it. In clearing out the rubbish they found numerous stone hammers, showing plainly that they were the mining implements of a rude race. At the bottom of the excavation they found a vein with ragged projections of copper, which the ancient miners had not detached. This point is east of the present works.

The following spring he explored some of the excavations to the west, where one of the shafts of the mine is now sunk. The depression was twenty-six feet deep, filled with clay and a matted mass of mouldering vegetable matter. When he had penetrated to the depth of eighteen feet, he came to a mass of native copper ten feet long, three feet wide, and nearly two feet thick, and weighing over six tons. On digging around it the mass was found to rest on billets of oak supported by sleepers of the same material. This wood, specimens of which we have preserved, by its long exposure to moisture, is dark-colored and has lost all its consistency. A knife-blade may be thrust into it as easily as into a peat-bog. The earth was so packed around the copper as to give it a firm support. The ancient miners had evidently raised it about five feet and then abandoned the work as too laborous. They had taken off every projecting point which was accessible, so that the exposed surface was smooth. Below this the vein was subsequently found filled with a sheet of copper five feet thick and of an undetermined extent vertically and longitudinally.

No less than ten cart loads of stone hammers, both with and without grooves, were found in this vicinity, besides a variety of other mining tools, among which may be mentioned cedar gutters or troughs to drain off the water, which was baled up in wooden bowls, cedar shovels, copper wedges or gads, copper chisels and spear heads, ladders formed of oak trees with the branches left projecting, wooden levers, copper mauls, etc.

There were three principal groups of these ancient diggings on Keweenaw point, viz: One a little below the forks of the Ontonagon river, another at Portage lake and a third on the waters of Eagle river. Although the old works were not always situated on good veins, yet they were regarded by practical miners as good guides to the valuable lodes. There were other veins on isle Royale and near the north shore, opposite Keweenaw point, which were extensively wrought in olden times. Whittlesey also states that in the other direction, "sixty and eighty miles to the southeast, in the iron region near Marquette are remains that are also ancient."

The date when these mines were worked and the races that wrought them are unknown. It is generally believed that the tools and implements found there are relics of the Mound Builders, and the opinion is gaining ground that the Mound Builders were ancestors of our present Indians. The discovery of two hemlock trees on which were counted 290 and 395 rings respectively, growing on the rubbish heaps of these old workings, and the further observations made by Whittlesey, showing that there were decayed trunks of trees of the same species but of a still earlier generation lying in these troughs, are evidence that the works must have been abandoned 200 or 300 years before Columbus started on his voyage of discovery. The further fact that their existence was unknown to the Indians at the earliest time of which we have any record, is another proof of their great antiquity.*

It does not appear that the natives mined silver or gold as they did copper. It is not unlikely that they were familiar with the metals, and were aware of their occurrence in the drift, mingled with the copper, or in the rocks of Thunder bay. But since they do not occur in large masses like copper, and the Indians had no idea of fusing or smelting them into ingots, but little use was probably made of them.

EARLIEST DISCOVERIES BY WHITE PEOPLE.

The first white man to visit lake Superior was Jean Nicollet†, who was sent from Quebec by Champlain, with seven Huron Indians as his only companions, on July 1, 1634. He did not come so far west as the copper district, however, but went back through the straits of Mackinaw down to lake Michigan, after staying some time for rest at the place since called Sault Sainte Marie. It was not until 1666-67, about the time that Marquette established the Mission at Sault Sainte Marie, that we have more detailed accounts than those furnished by Lagarde in 1636 and the relation already mentioned. (1859-'60)

In the relation of Claude Allouez (1666-67), there is a chapter entitled, "Mines of copper which are found on lake Superior," from which is taken the following (Jackson's Lake Superior, p. 378):

> Up to the present time it was believed that these mines were found on only one or two of the islands; but since we have made a more careful inquiry, we have learned from the savages some secrets which they were unwilling to reveal. It was necessary to use much address in order to draw out of them this knowledge, and to discriminate between the truth and falsehood. We will not warrant, however, all we learned from their simple statements, since we shall be able to speak with more certainty when we have visited the places themselves, which we count on during this summer, when we shall go to find the "wandering sheep" in all quarters of this great lake. The first place where copper occurs in

*There is some evidence, still, that the Indians who were met by Cartier on the lower St. Lawrence were familiar with the processes of extracting metallic copper from the rock. Champlain gives a statement of their description in "Voyage du Sieur de Champlain", Paris, 1613, as quoted by Slafter. N. H. W.

†H. V. Winchell, *American Geologist*, Feb., 1894, p. 126.

abundance, after going above the Sault, is on an island about forty or fifty leagues therefrom, near the north shore, opposite a place called Missipiconatong.

The savages say it is a floating island, which is sometimes far off and sometimes near, according as the winds move it, driving it sometimes one way and sometimes another. They add that, a long time ago, four Indians accidentally went there, being lost in a fog, with which this island is almost always surrounded. It was long before they had any trade with the French, and they had no kettles or hatchets. Wishing to cook some food, they made use of their usual method, taking stones which they picked up on the shore, heating them in the fire, and throwing them into a bark trough full of water. in order to make it boil, and by this operation cook their meat. As they took up the stones they found they were nearly all of them pure copper. * * * Before leaving they collected a quantity of these stones, both large and small ones, and even some sheets of copper; but they had not gone far from the shore before a loud voice was heard, saying in anger, "Who are these robbers who have stolen the cradles and playthings of my children?" The sheets of copper were the cradles, for the Indians make them of one or two pieces of wood (a flat piece of bark with a hoop over one end), the child being swathed and bound upon the flat piece. The little pieces of copper which they took were the playthings, such pebbles being used by Indian children for a like purpose. This voice greatly alarmed them, not knowing what it could be. One said to the others it is thunder, because there are frequent storms there; others said, it is a certain genie whom they call Missibizi [Mesabi], who is reputed among these people to be the god of the waters, as Neptune was among the pagans; others said that it came from Memogovisiousis—that is to say, sea-men, similar to the fabulous Tritons, or to the Sirens, which always live in the water, with their long hair reaching to their waists. One of our savages said he had seen one in the water; nevertheless, he must have merely imagined that he did. However, this voice so terrified them that one of these four *voyageurs* died before they reached land. Shortly after, a second one of them expired; then a third; so that only one of them remained, who, returning home, told all that had taken place and died shortly afterwards. The timid and superstitious savages have never since dared to go there for fear of losing their lives. * * *

Advancing to the place called the Grand Anse (Great bay), we meet with an island three leagues from land, which is celebrated for the metal which is found there and for the thunder which takes place, because they say it always thunders there (Thunder cape). But further towards the west, on the same north shore, is the island most famous for copper, called Minong (the good place), Isle Royale. This island is twenty-five leagues in length; it is seven leagues from the main land and sixty from the head of the lake. Nearly all around the island, on the water's edge, pieces of copper are found, mixed with pebbles, but especially on the side which is opposite the south, and principally in a certain bay which is near the northeast exposure to the great lake. There are shores "tous escarpéz de terre glaize," and there are seen several layers or beds of copper, one over the other, separated or divided by other beds of earth or rocks. In the water is seen copper sand, and one can take up in spoons grains of the metal big as an acorn, and others fine as sand. (This description probably refers to Rock harbor). * * * Advancing to the head of the lake and returning one day's journey by the south coast, there is seen in the edge of the water a rock of copper which weighs 700 or 800 pounds, and is so hard that steel can hardly cut it; but when it is heated it cuts as easily as lead. Near Point Chagaouamigon, where a mission was established, rocks of copper and plates of the same metal were found on the shores of the islands.

Last spring we bought of the savages a sheet of pure copper, two feet square, which weighed more than 100 pounds. We do not believe, however, that the mines are found on these islands, but that the copper was probably brought from Minong (Isle Royale), or from other islands, by floating ice, or over the bottom of the lake by the impetuous winds, which are very violent, particularly when they come from the northeast.

Returning still towards the mouth of the lake, following the coast on the south, at twenty leagues from the place last mentioned, we enter the river called Nantounagan (Ontonagon), on which is seen an eminence where stones and copper fall into the water, or upon the earth; they are readily found. * *

Proceeding still further, we come to the long point of land which we have compared to the arrow of the bow (Keweenaw point); at the extremity of this there is said to be a small island which is said to be only six feet square, and all copper! * * We are assured that copper is found in various places along the southern shore of the lake.

In the "Relations" for 1670-71, Pere d' Ablon remarks that "The great rock of copper of 700 or 800 pounds, and which all the travelers saw near the head of the lake, besides a quantity of pieces which are found near the shores in various places, seem not to permit us to doubt that there are somewhere the parent mines, which have not been discovered."

Baron la Hontan refers to mines of pure copper on lake Superior in his "Voyages dans l'Amérique septentrionale," published in 1688.

In the "Histoire de la Nouvelle France," by Peter Francois Xavier Charlevoix (Tome IV, p. 415) is another account of native copper. This Jesuit made a "tour of the great lakes" in 1721, but does not appear to have visited lake Superior.

Peter Kalm, a Professor of "Oeconomie" in the University of Abo, in Swedish Finland, traveled in the provinces in 1748 and 1749. He also mentions having seen masses of copper which came from the "Upper Lake," and were brought down by the Indians. He speaks of them as being found in the ground near the mouths of rivers and supposes that ice or water carried them down the sides of mountains. (London Ed., vol. 3, p. 278.)

The first attempt at modern mining appears to have been made by Alexander Henry, an Englishman, who came to North America soon after the conquest of Canada by the British. He is said to have been attracted by the accounts given by Carver in 1765; but this does not appear to be the case, since he was here about the same time. He was saved at the massacre of Fort Mackinaw by an Indian, who adopted him and concealed him in a cave on Mackinaw island. During the years 1765-1770 he was occupied in coasting around the shores of lake Superior looking for mineral treasure. In his "Travels," published in New York in 1809, he mentions the mass of copper near the mouth of the Ontonagon river (which was afterwards removed to Washington), and states that he cut off from it with his axe a portion weighing a hundred pounds. He passed the winter of 1767 at Michipicoten on the north shore, near which point he discovered numerous pieces of "virgin copper" and a vein of lead ore. In 1770 he associated himself with Messrs. Baxter and Bostwick in a "company of adventurers for working the mines of lake Superior." They built a barge at Point aux Pins, and laid the keel of a sloop of forty tons. Early in May, 1771, they sailed for the island of yellow sand, where they expected to find gold, and make their fortunes; but they found nothing of value. The miners examined the coast of Nanibojou, and found several veins of copper and lead, after which they returned to Point aux Pins, and erected an air furnace. "The assayer reported on the ores which they had collected, stating that the lead ore contained silver in the proportion of forty ounces to the ton; but the copper ore only a very small proportion indeed."

From Point aux Pins they crossed over to Point aux Iroquois, where Mr. Norberg, a Russian gentleman, acquainted with metals, and holding a commission in the 60th regiment, and then in garrison at Michilimackinac, accompanied them on this latter expedition. Mr. Norberg found a loose stone weighing eight pounds, of a blue color and semi-transparent. This he carried to England, where it produced in the proportion of 60 pounds of silver to a hundred weight of ore. It was deposited in the British Museum. Henry now revisited the Ontonagon river, where, besides the detached masses of copper formerly mentioned, he saw "much of the same metal bedded in the stone." They built a house and sent to the Sault for provisions. He pitched upon a spot at the commencement of mining operations, and remarks that there was a "green-colored water which tinged iron of a copper color." In digging they frequently found masses of copper, some of which were three pounds in weight.

On the 20th of June, 1772, the miners returned, after having passed the winter at the Ontonagon. Their drift had caved in during a thaw, just as they supposed they were about to come upon a solid vein of copper, but in reality just on the solid red sandstone. Henry claims that it was not for copper, but for silver, that their company was formed, and that they expected to find it mixed with either the copper or the lead. In the summer of 1773 Henry and his crew worked in solid rock on the north shore, drifting into a vein which carried some copper, but which contracted from a width of four feet to as many inches in the distance of thirty feet. What ore they had was sent to England, but the English partners had had enough, and refused to contribute further to the expenses of the enterprise. Mr. Henry thus describes the termination of affairs: "This year, therefore (1774), Mr. Baxter disposed of the sloop and other effects of the company, and paid its debts. The partners in England were, his royal highness, the Duke of Gloucester, Mr. Secretary Townshend, Sir Samuel Tuchet, Mr. Baxter, Consul of the Empress of Russia, and Mr. Cruickshank. In America, Sir William Johnson, Mr. Bostwick, Mr. Baxter, and myself. A charter had been petitioned for and obtained, but owing to our ill success it was never taken from the seal office."

COPPER MINES.

There does not appear to have been any mining in progress for nearly 70 years after the efforts made by Alexander Henry. Indeed, the occurrence of copper seems to have been almost forgotten, and was only casually mentioned. There were no explorations made of any sort, looking toward the development of mines, until Douglass Houghton was appointed state geologist of Michigan in March, 1838. Even then, and although he must have been familiar with the facts concerning the distribution of drift copper, from his former explorations made in 1831 and 1832, yet nothing appears to have been done toward investigating the copper range until 1840. In his fourth annual report, submitted February 1, 1841, we find a discussion of the general prospects for profitable mining, including a description of the veins, and a comparison of them with those of Cornwall in which the statement is made (p. 58) that "After as minute an examination of the subject as circumstances will permit, I am led to the conclusion that the only ores of the metallic minerals, occurring in those portions of the veins, which traverse the rocks last alluded to, which can be reasonably hoped to be turned to practical account, are those of copper." He acknowledges that he was inclined to regard the occurrence of native copper as an unfavorable indication for permanence in mining until he had discovered that "that feature was more or less universal with respect to all the veins." He expresses himself in conclusion in the following conservative manner:

While I am fully satisfied that the mineral district of our state will prove a source of eventual and steadily increasing wealth to our people, I cannot fail to have before me the fear that it may prove the ruin of hundreds of adventurers, who will visit it with expectations never to be realized. The true resources have as yet been but little examined or developed, and even under the most favorable circumstances we cannot expect to see this done, but by the most judicious and economical expenditure of capital, at those points where the prospects of success are the most favorable. * * * I would by no means desire to throw obstacles in the way of those who might wish to engage in the business of mining this ore, at such time as our government may see fit to permit it, but I would simply caution those persons who would engage in this business in the hope of accumulating wealth suddenly and without patient industry and capital, to look closely before the step is taken, which will most certainly end in disappointment and ruin.

In a letter written by Dr. Houghton to Hon. Augustus Porter, member of congress from Detroit, replying to an inquiry in the "National Intelligencer," and dated December 26, 1840, we find substantial proof that he was not only acquainted with the location of some of the copper veins, but that he had actually gone into them and obtained native copper. His own statements are as follows (Bradish's "Memoir of Douglass Houghton," pp. 114-116):

Ores of zinc, lead, iron and maganese occur in the vicinity of the south shore of Lake Superior, but I doubt whether these, unless it be zinc and iron, are in sufficient abundance to prove of much importance. Ores of copper are much more abundant than either of those before mentioned, and a sufficient examination of them has been made to satisfy me that they may be made to yield an abundant supply of the metals. I do not mean by this that the copper is to be found in that region, as is the popular opinion, pure and without labor, but that capital may be safely invested in raising and smelting of these ores with profit to the capitalist. * * * The veins of ore traversing the mineral district of Lake Superior, in those portions I have examined closely, are of very frequent occurrence, and range from a few inches to fourteen feet in width. I do not now recollect (I write without a reference to field notes) that I traced any of those veins over a mile in length, and most of them less. * * * I brought from Lake Superior, on my return to Detroit this fall, from four to five tons of copper ores and am now busily engaged in making an analysis of them. Thus far they have proved equal to any ores I have ever seen, and their value for purposes of reduction cannot be doubted.

The average per cent. of metal is considerably above that of the ores of Cornwall. While speaking of the ores I am reminded of the beautiful specimens of native copper which came out with the ores in opening some of these veins. They are not very abundant, but some of them are very fine. In opening a vein, with a single blast I threw out nearly two tons of ore, and with this were many masses of native copper, from the most minute specks to about forty pounds in weight, which was the largest mass I obtained from that vein. Ores of silver occasionally occur with the copper, and in opening one vein small specks of native silver were observed. There are as yet, however, no evidences of the existence of this metal in sufficient abundance to be of practical value. * * * I hope to see the day when instead of importing the whole of the immense amount of copper and brass used in our country we may become exporters of both.

Dr. Houghton did not mention in his annual reports the location of any of the veins which he discovered, with one exception, viz., that of the green silicate of copper at Copper Harbor. The land had not at that time been thrown open for settlement or even for exploration, and he was undoubtedly reserving the details for publication in his final report, which he did not live to complete, owing to his untimely death by drowning in lake Superior, during a snow storm and gale near Eagle river, on October 13, 1845.

His official report, however, called attention to the possibilities of the region; and the cession of the land to the United States by the Chippewas, which was ratified March 12, 1843, was the signal for the commencement of a speculative craze which lasted for three years, and completely justified the fears expressed by Dr. Houghton in anticipation.

Credit for first calling attention to the copper range in a general way and for recommending its development must thus be given to Douglass Houghton. To Charles T. Jackson, however, undoubtedly belongs further credit for personally examining at a very early date and approving or condemnig many of the veins which were afterwards worked. We all know that the first mines were not in the conglomerate as at present, but in true fissure veins which crossed the conglomerate and interleaved amygdaloidal trap sheets in several systems. In these veins the copper (with a little silver) usually occurs native in masses of all sizes up to a thousand tons. The copper itself is 90 to 95 per cent. pure, and is believed to owe its origin to electro-chemical action which replaced portions of both the amygdaloid and conglomerate. In his report for 1849 Jackson distinctly states his claims for priority of discovery of the value of these veins. His first explorations were made in the summer of 1844, while in the employ of Hon. David Henshaw, who accompanied him to Keweenaw point "for the purpose of examining the country for copper." The linear survey had not at that time reached any portion of the so-called mineral lands, and Keweenaw point presented an unbroken wilderness. There was, however, already a crew of miners at work for the Lake Superior Mining company (which thus seems to have been the first incorporated organization in the field) and an encampment of United States soldiers.

These facts are mentioned by Jackson (loc. cit., p. 386), who further states that, although up to that time no such phenomena as veins of native copper had been known to exist and it would even have been "hazardous to the reputation of any geologist, who was not prepared to demonstrate the fact, to declare his belief in the practicability of mining for *native copper*;" yet in his first surveys on lake Superior (1844) he took "care to collect ample proofs of the existence not only of true veins of native copper, but also to prove the extent of the veins (as far as possible by surface observations) and that they became richer as they descended into the rocks."

He then proceeds to give the history of the first operations as follows (pp. 386-387):

The only houses which had been erected were the office of government mineral agency of General Walter Cunningham, at Porter's Island, Copper Harbor, and a rude log hut, built by Charles Gratiot, Esq., at Eagle Harbor, for the accommodation of his party of explorers. Not a road or trail existed anywhere on the point, and the tangled growth of spruce and white cedar obstructed the banks of the streams and the coast, giving a most unpromising appearance to the country, and offering great difficulties in the exploration of those regions which were considered most likely to expose the metalliferous veins. Numerous pits had been sunk at random, in the soil and rocks at Eagle Harbor, by the miners under the direction of Mr. Gratiot; but nothing considered worthy the attention of capitalists had been discovered, and the miners were about to leave the country. Mr. De Garmo Jones, of Detroit, had sent up Mr. C. C. Douglass to aid Mr. Gratiot in exploring the country, and he was associated with me in my labors, proving a very efficient assistant. Mr. Frederick W. Davis and Mr. Joseph S. Kendall accompanied me, and assisted in exploring the country for minerals.

It is well known that the results of my examination of the mineral lands on Keweenaw Point were the establishment of the fact that *native copper and native silver* existed there *in regular veins, which could be advantageously wrought by mining operations;* and that in consequence, the capitalists of the eastern States began the enterprises which have resulted in the demonstration of the practicability of mining profitably for copper and silver on Keweenaw Point. I selected the best veins for the establishment of permanent works, collected and analyzed the ores, discovered the nature of all the minerals accompanying the copper and silver veins, and published a brief report of my researches.

In 1845 I was again sent to lake Superior, and then explored other veins, and pointed out the superiority of the *metallic lodes* over those of the *ores of copper*—a result quite contrary to the general opinion of miners and geologists, but which has been most fully sustained by subsequent experience. As was anticipated by me, the green silicate and black oxide of copper at Copper Harbor soon gave out and was abandoned. The Boston and Pittsburg Mining Company transferred their miners from that place to the metallic copper lode, which I had surveyed in company with Mr. Whitney, at the cliff, on the southwestern branch of Eagle river. This mine is well known as one of the wonders of the world, affording the largest masses of copper which have ever been seen, and yielding a considerable amount of native silver. I again surveyed those veins I had explored in 1844, and advised the opening of a mine at a place which I named Copper Falls. Operations were forthwith commenced at this place, and a new company was formed by the division of the Lake Superior Mining Company. This mine is still in operation and has given promising results. The Lake Superior Mining Company sold out their rights to the veins at Eagle Harbor, opened mines on the borders of Eagle river in 1844 and continued their operations for some years at that place.

The foregoing rather copious quotations have been made for the purpose of showing the grounds for the claim that more credit belongs to Jackson than has usually been accorded to him in the literature of the copper regions. Further accounts of his explorations may be found in the report mentioned.

There were several other explorers in the district, at this early date, whose names are on record. The vein afterwards known as the Copper Falls mine was discovered by Joseph Hempstead and C. C. Douglass in 1844 and immediately visited by Jackson. It was on lands held under lease by the Lake Superior Copper company.

Whitney speaks as follows of the discovery of the Cliff mine, belonging to the Pittsburg and Boston Mining company. (Metal Wealth, p. 275).

The discovery and opening of this mine formed an era in the history of lake Superior and are also of high interest to the country, as it was the first mine in the United States, those of coal and iron excepted, systematically and extensively wrought, and at the same time with profit. Besides this, it has a peculiar importance as being opened on a vein bearing copper exclusively in the native state, a feature entirely unknown in the history of mining previous to the discoveries on lake Superior. * * *

During the summer of 1843 a Mr. Raymond made certain locations in the lake Superior region, for which he obtained leases, three of which he disposed of to parties in Pittsburg and Boston, who commenced mining in the summer of 1844. The first location was made at Copper Harbor, where the outcrop of a cupriferous vein on what is now called Hays's

Point, was a conspicuous object, known to the "*voyageurs*" as "the green rock," and had given a name to that beautiful harbor long before it became the center of the copper excitement. A little work was done here in the autumn of 1844, but on clearing away the ground on the opposite side of the harbor, where Fort Wilkins now stands, numerous boulders of black oxide of copper were found, evidently belonging to a vein near at hand, which was discovered in December, and proved to be a continuation of the one before worked on Hays's Point.

Mining was commenced here immediately; two shafts were sunk, about a hundred feet apart, and considerable black oxide of copper taken out, mixed with the silicate. This was very remarkable, as it is thus far the only known instance of a vein containing this as the principal ore, or in any other form than as an impure mass, mixed with the sulphuret of copper and oxides of iron and manganese, and resulting from the decomposition of the common ore, copper pyrites. This proved, however, unfortunately to be only a rich bunch in the vein of limited extent, and which gave out at the depth of a few feet, although the fissure continued. The workings were entirely confined to the conglomerate, which at that time was supposed to be as favorable to the development of the vein as any other rock. The gangue associated with the black oxide was principally calc spar, and some argillaceous and quartzose matter intermixed. Fine crystals of analcime were found connected with it. Crystallized red oxide and native copper were also obtained in fine specimens. About thirty or forty tons of black oxide were obtained in all, and sold for $4,500. The main shaft was continued down 120 feet, and levels driven each way for some distance without striking another bunch of ore, so that in 1845 the attention of the company began to be turned to exploring their extensive property, and, in Augnst of that year, the Cliff Vein was discovered by a party of explorers under the direction of a Mr. Cheny.

The vein was first observed on the summit and face of a bluff of crystalline trap, rising with a mural front to a height of nearly 200 feet above the valley of the Eagle river at its base. The break or depression made by it in the back of the ridge was quite distinct, and has since been traced to the lake and found marked by ancient excavations. At the summit of the bluff, as I saw it a few days after its discovery, it appeared to be a few inches wide, and contained native copper and specks of silver beautifully incrusted with capillary red oxide, with a gangue of prehnite. Half way down the cliff, it had expanded out to a width of over two feet, and consisted of numerous branches of laumonite, with a small percentage of metallic copper finely disseminated through it. Of course, at this time, nothing whatever was known of the varying character of the lode in different beds of rock, nor had the trap been supposed by the miners to be the principal metalliferous rock. It is now known that the vein could not be worked with profit in the rock in which it was discovered, namely, the crystalline trap or greenstone, as no vein has yet proved sufficiently metalliferous in that belt of rock to be profitably mined.

Without knowing anything of the entire change in the character of the rock which takes place at the base of the cliff, where there was a heavy accumulation of fragments of rock dislodged from above, and suspecting as little as any one else the unprecedented discoveries about to be made in the metalliferous bed beneath, I advised the clearing away and opening of the vein at as low a point as possible, because it appeared to widen out and improve in depth. A shaft was sunk a few feet, a little below the edge of the bluff, and a level driven into the greenstone a short distance, but nothing was done of importance until the talus at the base of the cliff was cleared away and the vein traced into the amygdaloid. A level was then driven in upon it, and, at a depth of 70 feet, the first mass of copper was struck, a discovery of the greatest interest, since it revealed the presence of a metalliferous belt whose existence had not before been suspected, and showed the extension of the lodes of lake Superior into belts of rock of different lithological character and the variations in richness attendant on such transitions.

It may be mentioned in passing that this mine paid dividends of about a quarter of a million of dollars between 1849 and 1856.

The following account is given by Whitney of the Phœnix Mining company:

This company, as originally constituted February 22, 1844, was possessed of seven three-mile-square leases on Keweenaw Point. It was the first organized company of the Lake Superior region, and was called the "Lake Superior Copper Company." Its stock was divided into 1200 shares of which the proprietors of the leases received 400 unassessable for their interest. The first superintendent was C. H. Gratiot, who had previously engaged in digging lead in Wisconsin. The seven locations, embracing over 40 square miles, were nearly all situated in the very richest portion of the mineral region.

During the summer of 1844, Dr. C. T. Jackson examined several veins which had been discovered on the property by C. C. Douglass and others, and under his direction work was commenced October 22, 1844, on Eagle river, near the place now known as the "Old Phœnix Mine", and carried on through the year 1845, and a stamping mill and crushing-wheels, of a kind suitable for grinding drugs, were erected, but soon proved to be entirely unserviceable. Up to March 31, 1849, when the Phœnix Company was organized and took possession of the Lake Superior Company's property, the latter company had expended $105,833.40, of which about half was probably for actual mining work, but they had done little or nothing towards developing the value of the property. The principal shaft was sunk on a "pocket" of copper and silver, without any signs of a regular vein, which soon gave out entirely.

The news of these discoveries attracted people from all parts of the land. The excitement increased rapidly, and soon the craze was in full blast. It is thus described by Whitney in his Metallic Wealth of the United States (p. 249):

In 1845 many hundred "permits" or rights to select and locate on tracts of land for mining purposes, were issued by the government, and 377 leases were granted. Most of the tracts covered by these were taken at random, and without any explorations whatever; indeed a large portion of them were on rocks which do not contain any metalliferous veins at all, or in which the veins, when they do occur, are not found to be productive.

In 1846 the excitement reached its climax; the speculations in stocks were continued as long as it was possible to find a purchaser, and a serious injury was inflicted on the mining interests of the country by the unprincipled attempts to palm off worthless property as containing valuable veins. But in 1847 the bubble had burst, and the country was almost deserted. Only half a dozen companies, out of all that had been formed, were actually engaged in mining.

The issue of permits and leases having been suspended in 1846 as illegal, Congress passed, in 1847, an Act authorizing the sale of the mineral lands and a geological survey of the district. In the meantime, while this survey was going on, the companies which had continued their operation made considerable progress, new ones were formed, and lands were purchased by them after bona fide explorations and discoveries of veins; the position and character of the really metalliferous rocks began to be known, and confidence was gradually restored. At the time of the completion of the geological survey, in 1850, and the publication in the following year, of maps of the whole region, on which the range and extent of the geological formations were laid down, copper mining in the Lake Superior district had become established on a firm basis and was rapidly developing.

The discovery of the metalliferous character of the conglomerate was made by E. J. Hulbert, John Hulbert and Amos H. Scott about the first of September, 1864. The pit was located by Mr. E. J. Hulbert, who claims to have been fully convinced that the exploration would result as it did. This was a most important discovery and one which altered the entire character of mining on Keweenaw point. It was the beginning of the present regime as contrasted with that in which the veins were wrought for mass copper.

IRON ORE.

Iron ore was discovered in Nova Scotia in 1604, even before the earliest reports of copper from the Lake Superior country. The discovery was reported by the Sieur de Monts, Lieutenant General of Acadia, appointed by Henry IV of France. In the province of Quebec iron ore was found in 1667; and in Ontario about 1800. The first iron furnace in Canada was established at Three Rivers, near Quebec, about 1630, and is the one mentioned by Kalm, in the work already quoted.

The reports of Dr. Houghton and his assistants C. C. Douglass and Bela Hubbard, for the years 1839 and 1840, and the reports of David Dale Owen for the same years, contain references to iron ores of recent geological age in the southern part of Michigan and Wisconsin. Houghton must even have had some knowledge of iron ores in the metamorphic rocks of the Upper Peninsula, for in his report for 1841 he says: "Although hematite ore is abundantly disseminated through all the rocks of the metamorphic group, it does not appear in sufficient quantity at any one point that has been examined to be of practical importance." On this quotation Brooks remarks (Geol. Sur. Mich., 1869-73, Vol. 1, p. 11):

At this date Dr. Houghton had traversed the south shore of lake Superior five times, in a small boat or canoe, on geological investigations. It is therefore probable that up to 1841 no Indian traditions worthy of credence in regard to large deposits of iron ore, had come to his knowledge. As there are, so far as known, no considerable outcrops or iron ore, which come nearer than seven miles to the shore of the lake, it is plain that investigations, based on observations taken along the shore only, could have determined no more than its probable existence, which is plainly indicated in the extracts given. Dr. Houghton was not aware of the existence of iron ore in quantity until the return of Mr. Burt's party of surveyors to Detroit in the fall of 1844, his examinations in the interior of the country having been confined to the copper region. Attention at that early period was entirely directed to searching for ores of more value than iron, and it is worthy of remark, that the Jackson and Cleveland Iron Companies, which were the first two organized, were formed to mine copper, silver and gold.

MARQUETTE RANGE.

The actual discovery of iron ore was made by Wm. A. Burt, United States deputy surveyor under the direction of Dr. Houghton, who had taken the contract to finish the linear survey and unite with it geological observations of the country traversed. In 1845 Mr. Burt's party, consisting of Wm. Ives, compass-man; Jacob Houghton, barometer man; H. Mellen, R. S. Mellen, James King and two Indians, John Taylor and Michael Doner, was engaged in establishing township lines and making geological observations in the manner described.

On the 19th of September, while running the east line of township 47 N., range 27 W., using the solar compass invented by Mr. Burt, remarkable variations in the direction of the needle were noticed. In this connection Mr. Jacob Houghton, one of the party, says:

At length the compass-man called for 'all to come and see a variation that will beat them all.' As we looked at the instrument, to our astonishment the north end of the needle was traversing a few degrees to the south of west. Mr. Burt called out, 'Boys, look around and see what you can find!' We all left the line, some going to the east and some to the west, and all of us returning with specimens of iron ore, mostly gathered from outcrops. This was along the first mile from Teal lake. We carried out all the specimens we could conveniently.

A year later Mr. Burt made the following statement (Jackson's Report, 1849, Part III, p. 852):

The fourteen beds of iron ore above described are the most important ores of iron, for quantity and quality, discovered within the boundaries of this survey. * * * It may be reasonably inferred that not more than one-seventh of the number of iron ore beds were seen during the survey of the township lines; and if this district of townships be subdivided with care in reference to mines and minerals, six times as many more will probably be found. If this view of the iron region of the Northern Peninsular of Michigan be correct, it far excels any other portion of the United States in the abundance and good qualities of its iron ores.

Mr. Bela Hubbard made a report "upon the geology and topography of the district south of lake Superior, subdivided in 1845 under the direction of Douglass Houghton, deputy surveyor" (Jackson's Report, *supra cit.*, p. 833). He makes the following statements:

The largest extent of ore noticed is in township 47, range 26, near the the corner of sections 29, 30, 31 and 32. There are here two large beds or hills of ore, made up almost entirely of granulated, magnetic or specular iron, with small quantities of spathose and micaceous iron. The more northerly of these hills extends in a direction nearly east and west for at least one-fourth of a mile, and has a breadth of little less than 1,000 feet; the whole of which forms a single mass of ore, with occasional thin strata of imperfect *chert* and jasper, and dips N. 10° E. about 30°. At its southerly outcrop, the ore is exposed in a low cliff, above which the hill rises to the height of twenty or thirty feet above the country on the south. * * * This bed of iron will compare favorably, both for extent and quality, with any known in our country.

As to the discovery of the Jackson deposit, which was the first to be mined in the Lake Superior region, we may quote from the letter from P. M. Everett to Capt. G. D. Johnson, dated Jackson, Mich., 1845, and contained in Brooks' report:

I left here on the 23d of July last and was gone until the 24th of October. * * * I had considerable difficulty in getting any one to join me in the enterprise, but I at last succeeded in forming a company of thirteen. I was appointed treasurer and agent to explore and make locations, for which last purpose we had secured seven permits from the Secretary of War. I took four men with me from Jackson and hired a guide at the Sault, where I bought a boat and coasted up the lake to Copper Harbor, which is over 300 miles from the Sault Ste. Marie. * * * We made several locations, one of which we called Iron at the time. It is a mountain of solid iron ore, 150 feet high. The ore looks as bright as a bar of iron just broken. Since coming home we have had some of it smelted, and find that it produces iron and something resembling gold—some say it is gold and copper. Our location is one mile square, and we shall send a company of men up in the spring to begin operations; our company is called the Jackson Mining Company. The actual discovery of the Jackson location was made by S. T. Carr and E. S. Rockwell, members of Everett's party, who were guided to the locality by an Indian chief named Manjekijik. The superstition of the savage not allowing him to approach the spot, Mr. Carr continued the search alone, resulting in the discovery of the outcrop, which he describes as indicated in Mr. Everett's letter. Previous to the discovery he was led to suppose from the Indian's description, that he would find silver, lead, copper or some other metal more precious than iron, as it was represented to be "bright and shiny."

July 23, 1845, articles of association of the Jackson Mining Company were executed at Jackson, Mich., and by these articles Abram V. Berry was appointed the first *President*, Frederick W. Kirtland *Secretary*, Philo M. Everett *Treasurer*, and George W. Carr and Wm. A. Ernst *Trustees*. * * * The location was secured by the permit issued to James Ganson and was described by metes and bounds, commencing at a certain large pine tree, the position of which was fixed by its course and distance from the corner of Teal lake. When the land was surveyed it was bought at $2.50 per acre.

The Cleveland Mining company was organized in the following year, the location having been discovered by Mr. Abram V. Berry, and obtained by Dr. Dassels of Cleveland. In 1846 Fairchild Ferrand explored the Jackson location and mined some ore. The Jackson company erected a forge in 1847 on the Carp river, three miles east of the mine, under the superintendency of Wm. McNair, and the first iron was made February 10, 1848, by A. N. Barney. In 1850, Mr. A L. Crawford, proprietor of iron works at Newcastle, Pa., took about five tons of Jackson ore to Pennsylvania, and worked it up. Two years later a larger amount was taken to Sharon, Pa., by general Curtis, who visited lake Superior for the purpose of securing better ore for his furnaces. In 1872 about 70 tons were sent to Sharon; and in 1856 was made the first regular shipment, amounting to 5,000 tons.

The deposit of iron ore at Republic appears to have been first discovered by J. W. Foster and S. W. Hill in the fall of 1848. In the report, presented by C. T. Jackson, of an exploration of the country lying between lake Superior and Green bay is found the following statement by Mr. Foster (loc. cit., p. 775):

After leaving the lake we saw no exposure of the rocks until we arrived at the north part of township 46, ranges 29 and 30. The river here forms a lake-like expansion, and is bounded on the northeast by a range of hills which rise abruptly to the height of nearly two hundred feet above the water.

We explored this ridge on section 1, township 46, range 30, and found that it was composed, for the most part, of nearly pure specular oxide of iron (fer oligiste). It shoots up in a perpendicular cliff, one hundred and thirteen feet in height, so pure that it is difficult to determine its mineral associations.

We passed along the base of this cliff for more than a quarter of a mile, seeking for some gap through which we might pass and gain the summit. At length, after much toil and by clambering from one point to another, we succeeded. Passing along the brow of the cliff, forty feet, the mass was comparatively pure; then succeeded a bed of quartz composed of rounded grains, with small specks of iron disseminated, and large rounded masses of the same material enclosed, constituting a conglomerate. This bed was fifteen feet in thickness, and was succeeded again by specular iron, exposed in places to the width of one hundred feet, but the soil and trees prevented our determining its entire width. This one cliff contains iron sufficient to supply the world for ages, yet we saw neither its length nor its width, but only an outline of the mass. Its bearing could not be accurately determined, but was inferred to be north of west and south of east, with a northerly dip of 85°.

The same deposit is described in similar terms in Foster and Whitney's Lake Superior (Part II, p. 22). In his first annual report Mr. Wright states that this property was originally "explored" by S. C. Smith, and entered by James St. Clair in 1854. The Republic Iron company was not organized until October 20, 1870, and the first ore was shipped in 1872.

The great demand for iron occasioned by the Civil war caused the iron interests which were in operation at that time to assume a very successful aspect. Development progressed rapidly and, although expenses were large, the demand for ore was constant, and the prices high, so that permanent and prosperous cities like Negaunee and Ishpeming were started and sustained by the iron or mining industry of Marquette county.

MENOMINEE RANGE.

The earliest reports of iron ore on this range are furnished by those same early geologists and explorers, J. W. Foster and S. W. Hill, whose trip across the country from lake Superior to Green bay in the fall of 1848 has already been mentioned. It seems almost incredible that their observations should have lain for so long a period unverified and forgotten, while the search for iron was prosecuted in other parts of the same region. But it was actually more than twenty years before these deposits were rediscovered and thoroughly explored. Foster's first account reads as follows (Jackson, loc. cit., p. 777):

About two miles southeast of the lower falls (of the "Twin Falls" on the Menominee), near S. 30, T. 40, R. 30, there is a large bed of specular iron ore associated with the talcose and argillaceous slates. It makes its appearance on the north side of a lake, and can be traced a mile and a half in length, and in places is exposed one hundred feet in width. It bears nearly east and west, and in external characters resembles that of the iron mountain before described. This bed was first discovered by John Jacobs, from whom I derived the information, and may be regarded as the southern limit of the iron. The distance from this point to the most northerly point where iron was discovered (on the Marquette range) is more than 50 miles in a direct line. Below the falls there are heavy accumulations of drift, so that the subjacent rocks are rarely seen; and this bed of iron ore, if it cross the river, is effectually concealed.

The limestone was also observed, and a bed of marble indicated on the map which accompanied the report. The iron ore was compared with that of Elba, New York, and Missouri, and said to excel them all in value and favorable location. It was pointed out that the natural outlet would be by way of Bay de Noquet on lake Michigan, the place where Escanaba is now situated, and that it was entirely practicable to construct a road to that point. In the "Report of the Commissioners of the Geological Survey" of Wisconsin for 1858, are the following remarks by Col. Chas. Whittlesey:

In 1850 I passed up the Menominee as far as Irwin Falls, and examined the rocks to the east of the river in Michigan. Here the magnetic and specular ores were found, and beautifully veined marbles. The system of Magnesian slates extending from Carp river, on lake Superior, westward and southwestward, which embraces the metamorphic limestones and the iron, was then traced to the state line of Wisconsin.

During the explorations of the present year, in tracing that system within this state across the Menominee river, I had the satisfaction to find that it produces here both iron and marble, in quantities that are inexhaustible.

I cannot in this note, nor until the analyses are completed, give an idea of the value of the ores, but I am satisfied that whenever a cheap mode of transportation is provided they will attract notice. Both the iron ores and the marbles exist on both sides of the river convenient to water power that is unlimited. A considerable part of the deposits of iron have hard wood near at hand suitable for coal.

Further mention of the "iron ridge" southwest of lake Antoine and near lake Fumée may be found in Foster and Whitney's Lake Superior, Vol. II, pp. 30, 31, 1851. On page 28 there is given a section taken from the manuscript of Col. Whittlesey, showing specular iron interstratified with saccharoidal limestone near a branch of Cedar river and near Little Bekuenesec falls on the Menominee river. It is also stated, in this connection, that Mr. W. A. Burt crossed a low ridge of iron ore in 1846, not far from the corner of townships 41 and 42, between ranges 29 and 30. This was not subsequently met with in running the township lines. This ore is, however, shown on the geological map of 1873.

In 1866 Thomas and Bartley Breen, of the town of Menominee, discovered the deposit which afterwards became known as the Breen mine, on sec. 22, T. 39-28. No further explorations were made until 1870, when the "fee" of the property had passed into the hands of the discoverers and Judge Ingalls and S. P. Saxton. Mr. Saxton then commenced the first active mining operations recorded in the region by sinking several test pits, and cutting two long trenches across the formation.

In 1867 the region was visited and examined geologically by Dr. Herman Credner, of Germany. His description, in German, was published in 1869, and contained frequent references to the iron ores.

The first systematic exploration was begun in 1872 under the immediate supervision of our distinguished president, Dr. Nelson P. Hulst, at that time the agent of the Milwaukee Iron company, the chief promoters of which were Mr. J. J. Hagerman and Mr. J. H. Van Dyke of Milwaukee. That the company had made a good choice in their selection of an explorer was soon proven by the discovery of the Vulcan and West Vulcan mines. Mr. Lewis Whitehead, who was Dr. Hulst's chief woodsman, was no less energetic than his superintendent, and soon had a road cut from the Breen to the Vulcan and camps erected at the latter place. In 1873 Mr. John L. Buell explored the Quinnesec property and carted the first ore (fifty-three tons) to Menominee, where it was smelted by the Menominee Furnace company.

The panic of 1873 put a damper on operations for a time But in 1877 the Menominee Mining company, of which Dr. Hulst was a member, purchased the leases of the Milwaukee Iron company, and again started the Doctor on the search for ore. He was again successful, this time discovering the celebrated Chapin mine. This was in 1878; and in 1880 the first shipments were made, amounting to 34,556 tons. The discovery of the Norway mine soon followed (in August, 1878), and thereafter the new range was entered fully in the list of ore producers from lake Superior.

PENOKEE-GOGEBIC RANGE.*

The magnetic iron ore belt of northern Wisconsin was first noted in 1848 by Dr. Randall, assistant geologist to Dr. David Dale Owen, while following the Fourth principal meridian northward.

In Owen's "Report of a Geological Survey of Wisconsin, Iowa and Minnesota" there is a "Geological report of that portion of Wisconsin bordering on the south shore of lake Superior, surveyed in the year 1849," by Charles Whittlesey. On pages 444-447 of this report (published in 1852) is a description of the "Magnetic Iron-beds of the Penokie Range." Analyses of iron ore found there are quoted which show from 56.3 per cent. to 66 per cent. of metallic iron, and the following statements are made:

> The bed of magnetic ore south of Lac des Anglais is of extraordinary thickness,—twenty-five to sixty feet. * * * In the wild and deep ravines where the Bad river breaks through the range, there is a cliff of slaty ore, most of which comes out in thin, oblique prisms, with well-de-

*H. V. Winchell, "A Bit of Iron Range History," *American Geologist*, March, 1894.

fined angles and straight edges, probably three hundred feet thick, including what is covered by the talus or fallen portions. I estimate more than one-half of this face to be ore; and in places the beds are from ten to twelve feet in thickness, with very little intermixture of quartz. There are portions of it not slaty, but thick-bedded.

The geological occurrence is fully figured and described, and the similiarity of this ore to "the extensive mines or rather mountains of iron ore in Michigan, described by Houghton, Burt, Jackson, Foster and Whitney" is also mentioned. The idea of exploitation on a large scale is conveyed in the last paragraph:

The position of the best exposures of ore which I saw is such as to require from eighteen to twenty-eight miles of transportation to reach the lake. The nearest natural harbor is in Chegwomigon bay, about twenty-five miles from the central part of the Penokie range.

The interesting origin of the name "Penokie" was given as follows by Col. Whittlesey in an article on "The Penokee Mineral Range" read before the Boston Society of Natural History in July, 1863:

In the Chippewa language the name for iron is *pewabik*; and I thought it proper to designate the mountains, where this metal exists in quantities that surprise all observers, as the "Pewabik Range." The compositor, however, transformed it to *Penokie*, a work which belongs to no language, but which is now too well fastened upon the range by usage to be changed.

Soon after the publication of Dr. Owen's report, the excitement of 1845-6 in reference to copper was repeated in reference to iron. Pre-emptors followed the surveyors, erecting their rude cabins on each quarter-section between the meridian and Lac des Anglais, a distance of eighteen or twenty miles. The iron belt is generally less than one-fourth of a mile in width, regularly stratified, dipping to the northwest, conformable to the formations, and having its outcrop along the summit of the second or southerly range.

So much iron was found there that he intended to call it the "Pewabik" range in 1850, even before the government survey of the region.

This paper was accompanied by a geological map of the range prepared by Whittlesey in 1860, on which the crest of the range and the outcrops of iron ore are marked with wonderful accuracy.

But Whittlesey was not the only geologist who observed and described the mineral wealth of this region. In 1858 Edward Daniels, one of the State Geological Commission, and prior to that time state geologist, visited the Penokee-Gogebic range and mentions it as follows in the Commissioner's report for 1858, pp. 10, 11:

The mineral resources also promise richly. The most important of these are the great deposits of iron ore found in the Penokie Mountains, about thirty miles inland from the head of Chegwomigon Bay. These iron beds follow the mountain ridge through several townships, having a direction a little north of east. * * * * The ore is principally the magnetic and brown oxide, with traces of specular iron, and occurs in seams parallel with the stratification, varying from a mere line to fifty feet in thickness; it is of good quality, well located for quarrying, and practically inexhaustible.

Another well-known scientist who saw and appreciated the ore deposits of this range was Dr. I. A. Lapham, afterward state geologist of Wisconsin. He visited the Penokee district with Daniels in 1858. His account of the trip may be seen in the Trans. Wisconsin State Agricultural Society, Vol. V, 1858-59. He there gives what is perhaps the first published map of the range, and speaks highly of the iron ore he saw there. In a report made by Dr. Lapham to the Wisconsin and Lake Superior Mining and Smelting company, dated November, 1858, and published in pamphlet form in 1860, we find the following:

It will be seen that we have already discovered good ore in such quantities as to be practically inexhaustible, situated at points accessible to water power and having bold fronts, rendering it comparatively easy to be quarried. For many years to come only the richest and most accessible ores can be brought into use, rejecting—at least for the present—all such as have too large a proportion of silica, and such as are not in a condition to be easily and cheaply removed from the natural bed.

Further full accounts of the Penokee-Gogebic range are to be found in Volume III of the Wisconsin geological reports for 1873-79, pages 100-166.

A brief description of this range by R. Pumpelly and T. B. Brooks, published in the report of the Michigan geological survey for 1872, seems to have attracted considerable attention. This report was accompanied by a map on which the belt of iron-bearing rocks is delineated in a general way.

In 1879 F. H. Brotherton directed explorations which very closely located the ore formation for the Canal company. Subsequent work of development has borne testimony to the accuracy of his field locations, all the mines since found in the district examined by him being on or very near the line at that time determined.

The first discovery of soft ore in situ and in large quantity is said to have been made by Capt. Nat. D. Moore, during the season of 1880. This was on section 15, T. 47-46, Michigan. Capt. C. P. Pease commenced explorations on the adjoining section [16] in June, 1881, for the Cambria Iron and Steel Co., and partially developed the Colby mine. Actual mining was begun here in October, 1884, by Capt. Moore, and the first ore was shipped on six flat cars over the Milwaukee, Lake Shore and Western railway to Milwaukee, and thence to Erie, Pa. Under the management of Mr. Joseph Sellwood this mine surpassed all predecessors in the amount of ore shipped during the first three years after it was opened.

The Sunday Lake mines were found by Geo. A. Fay, who conducted explorations in 1881 and 1882 for D. H. Merritt and others of Marquette, Mich.

During the fall of 1882 test pitting was started by Capt. Jas. A. Wood for Mr. A. L. Norrie, on the S. ½ of S. E. ¼, sec. 22, T. 47, R. 47. Ore was found almost immediately, and the great Norrie mine is the result of subsequent explorations on the same ore body.

The wave of mining stock speculation which fairly inundated the northern states during the two years following the discovery of these iron mines is of too recent date to require description. Suffice it to say that the production from the new range was simply phenomenal, doubling and trebling with unparalleled rapidity, and constituting one of the most remarkable chapters in the mining history of this remarkable country.

VERMILION RANGE.

The first account of iron ore on the Vermilion range appears in the report of state geologist H. H. Eames, published in 1866. On page 11 is this account:

The Iron Range of Lake Vermilion

is on the east end, on the stream known as Two River, which is about sixty feet wide. * * * This range is about one mile in length; it then ceases, and after passing through a swamp, another uplift is reached, from two hundred and fifty to three hundred feet high. The iron is exposed at two or three points between fifty and sixty feet in thickness; at these points it presents quite a mural face, but below it is covered with detritus of the over-capping rock. On this account its exact thickness could not be correctly ascertained. The ore is of the variety known as hematite and white steely iron, and is associated with quartzose, jasperoids and serpentine rocks. It generally has a cap rock of from three to twenty feet thick. A little to the north of this is an exposure of magnetic iron of very good quality, forming a hill parallel with the one described.

The hematitic iron has a reddish appearance from exposure to atmospheric influence; its fracture is massive and granular, color a dark steel gray. The magnetic iron ore is strongly attracted by the magnet and has polarity, is granularly massive, color iron black.

At the request of the legislature of Minnesota Col. Charles Whittlesey made a "Report of Explorations in the Mineral Regions of Minnesota during the years 1848, 1859 and 1864," published in Cleveland in 1866. In this report is a map of Vermilion lake and the Mesabi iron range. It also contains, on page 10, an announcement of the discovery of iron ore at the former locality by Eames. Here Col. Whittlesey gives it as his opinion that workable iron ore exists near enough to lake Superior to render it of practical value.

The first "shot" was put in the ore at Vermilion lake by Geo. R. Stuntz and John Mallmann in 1875, on the "south ridge." In 1884 the Duluth and Iron Range railroad was constructed from lake Superior to the mines at Tower, and mining was begun under the direction of Capt. Elisha Morcom. Afterwards, with a change of ownership, in 1886, the management passed to Mr. D. H. Bacon, under whose supervision subsequent discoveries were made and the mines developed into one of the finest plants in the country.

The mines at Ely were first opened by Mr. Jas. Sheridan and his associates in 1886, but were soon turned over to the present owners, under the superintendence of Mr. Jos. Sellwood and his mining captain, John Pengilly. The record of the Chandler has been a most creditable one. Further detailed accounts of the Vermilion range may be found in "The Iron Ores of Minnesota," Bulletin No. 6 of the geological survey of Minnesota, which was written in 1890 and published in 1891.

MESABI RANGE.*

In 1850 J. G. Norwood mentioned iron ore as occurring at Gunflint lake (D. D. Owen's report of Wisconsin, Iowa and Minnesota, p. 417), and stated that it appeared to be in the eastward continuation of the hills known farther west as the Mesabi, and which extended to Pokegama falls on the Mississippi river. He did not notice ore in sufficient quantities to impress him with its value as a merchantable ore deposit, but simply noted its occurrence near the west end of the lake.

H. H. Eames, the geologist mentioned above, was the first to note iron ore on the Mesabi range and consider it of any value. In his report of 1866, published the following year, is an account of the ore on the western end of the range, at Prairie river, together with several analyses, showing it to be

*This spelling of the name "Mesabi" is adopted because it conforms with the usage of the state and national geological surveys for many years, and is in accord with the decision of the National Board of Geographic Names.

of good quality. Mr. Eames took steps to secure title to this property and develop it; but the time had not yet come for such an enterprise to be successful.

Favorable mention is made of the Mesabi in various other geological reports, between that time and 1891. N. H. Winchell and A. H. Chester described it at some length in the seventh, ninth, tenth and eleventh reports, and the State was urged to take steps to have it developed. In the volume on the iron ores of Minnesota, however, may be found the most elaborate discussion of the rocks of this range. The views held at this time, before the actual discovery of any of the numerous deposits since opened up, are well expressed in the following quotations (op. cit., pp. 112, 160):

They [the ores of the Mesabi] are destined to play a very important part in the future development of the iron industry of the state. They occupy fourfold the area that is occupied by the Keewatin ores [Vermilion range], and they are nearer the ore-shipping points as well as the iron-using markets. It is on account of this high promise of future productiveness that they are fully described in this bulletin. * * *

There can be no reasonable doubt that in Minnesota, about the western and northwestern confines of the Lake Superior basin and extending westward to the Mississippi river, there will yet be mined in the Mesabi range even greater quantities of hematite than have been taken from that marvel of mining districts, the Penokee-Gogebic range, which blazed out with such a brilliant record only a few years ago.

The first persistent exploration of the Mesabi range for iron ore was made by the Merritt brothers, Lon and Alf., of Duluth, Minn., and to them in largest measure must be credited its unprecedently rapid development, and to a certain extent the disastrous consequences to the iron ore interests of the entire Lake Superior region during 1893. The Mountain Iron mine was found on the 16th day of November, 1890, by a crew of workmen under Capt. J. A. Nichols. In August, 1891, the next large deposit was discovered by John McCaskill, Capt. Nichols and Wilbur Merritt; this has since developed into the Biwabik group of mines. In 1892 two railroads were built to the range, and in 1893 the shipments amounted to 620,000 gross tons, a record for the first full year's shipments that has never been equalled.

CANADIAN IRON ORE.

Deposits of iron ore are known to exist in Ontario, north of lake Superior. The McKellar brothers of Fort William, have done more than any others to discover the iron ores of that vicinity. Although not yet thoroughly explored by shafting or drilling, it is probable that there is a considerable amount of merchantable ore in the Thunder Bay district which will be of value when the country is more thickly populated. It is not likely that it will ever enter into serious competition with the ore of those portions of the Lake Superior region situated in the United States, owing to its poorer quality and greater cost of production. So far as these deposits are at present developed they do not compare favorably with those on this side of the boundary line.

SILVER.

Having devoted considerable space to a description of our two most prosperous snd profitable mining industries, it remains for us to mention more briefly the discovery of silver and gold.

The occurrence of native silver mixed with the copper of Keweenaw point and the north shore of the lake was noticed at an early date, and has already been referred to under the head of copper. The only mines around lake Superior that have been wrought for any length of time for silver alone are on the north shore, around Thunder bay. The discovery of silver grew out of explorations for copper. In 1846 Mr. William Logan spent the summer in an examination of the Canadian shore of the lake. During the same season Mr. Forrest Sheppard conducted the first explorations for the Montreal Mining company, starting on May 2 from Montreal with a small party, which was soon increased to the number of eighty or more. The coast was examined from Sault Ste. Marie to Pigeon river, a distance of about 500 miles, and eighteen locations were selected. Each location was five miles in length and two in width, thus containing ten square miles of territory. One of these locations included Silver islet, on which the silver was not discovered, however, until 21 years later. Prince's location, west of the Kaministiquia, on Thunday bay, seems to have been the scene of the first discovery of silver in what was at that time a large quantity. The vein had a width of 14 feet, composed of calcite, barite and amethystine quartz, with a metalliferous streak in the middle. Two shafts and an adit level were opened, and masses of silver several pounds in weight were taken out. It is reported that the silver carried an appreciable amount of gold. This work was abandoned about the year 1850.

In 1856-1857 the Montreal Mining company, on the advice of their superintendent, Mr. E. B. Borron, attempted to develop a mine on their location at point Mamainse. There were several veins which made a good surface showing of native copper, chalcopyrite and galena, with silver both native and in the lead sulphide. Five shafts were sunk to depths varying from 14 to 60 feet on the most promising leads. But the veins did not hold out in depth, and operations were suspended in 1857.

The Prince and Mamainse mines, however, seem to have been more highly valued for copper than for silver, and the first discovery of silver of any consequence was made by Mr. Peter McKellar in the autumn of 1866, at what afterwards became the Thunder Bay mine. About a year later the Shuniah (later called Duncan) vein was found to be silver-bearing by Mr. John McKellar and Mr. Geo. A. McVicar. This was in May, 1867. Work was prosecuted on these veins in 1869 and 1870, the expenditures at the latter mine having amounted to about half a million dollars for a total yield of $20,000, before the final suspension in 1882.

The events leading to the discovery of silver on Silver islet and the account of the "find" are given as follows by Mr. Thomas Macfarlane (Trans. Am. Inst. Min. Eng., vol. VIII, 1880, pp. 227, 228):

It was, in all likelihood, the McKellar discoveries, together with the imposition by the Ontario government of a tax of two cents per acre on Lake Superior mining lands, which prompted the Montreal Mining Company to begin a systematic exploration of their northwestern locations. For twenty-two years these had been allowed to lie almost entirely neglected. Several of them were indeed visited and explored by Mr. Pilgrim of Sault Ste. Marie and the late Mr. Harrick, P. L. S., but the results were not such as to encourage the company to proceed to active mining operations. Indeed, during the greater part of this time, the company's resources wêre taxed to the utmost in developing and working the Bruce copper mines. It may safely be asserted that in doing this they experienced a dead loss of $400,000, a fact which is abundantly sufficient to account for the unwillingness of the board and shareholders to risk further capital in mining operations. The causes above given were, however, enough to induce them to incur a moderate outlay for exploring their lands, and early in 1868 I was employed by the company to take charge of a party for this purpose. * * * * On the 16th of May our exploring party, consisting of six men besides myself, arrived in Thunder Bay, on board the steamer Algoma, which was heavily freighted with men and materials for working the Thunder Bay Company's mine. After visiting the latter and the Shuniah (now the Duncan) mine, and calling the attention of the men of our party to the appearance and characters of the native silver and silver glance produced by them, we started in our Mackinaw boat on the 19th southwestward for Jarvis's location. * * *

On Jarvis's Island five different veins were found, and in one of them native silver and silver glance were discovered (the former by Mr., now Dr., C. O. Brown, and the latter by Mr. Patrick Hogan), specimens of which were forwarded to Montreal. * * * On the 1st of June we left Jarvis's for Stewart's location at Pigeon river, where we remained until the 21st, making a very close exploration for a distance of three miles inland. * * * On the 21st of June we returned to Fort William, and on the 23d reached Thunder Cape and Wood's location. * * * I * * * determined to make a complete geological map of Wood's location, and arranged with my assistant, Mr. Gerald C. Brown, to have the shore line accurately surveyed. It was while engaged planting his pickets on the many islands fronting the location that Mr. Brown first landed on the rock shortly afterwards named by me "Silver Islet," and observed the vein and the galena occurring in it. I then visited the island to obtain specimens of the galena and the enclosing rock, and three men were set to work to blast out some of the galena. It was while engaged working on the islet that one of these men, Mr. John Morgan, found the first nuggets of metallic silver, close to the water's edge. A single blast was sufficient to detach all the vein rock carrying ore above the surface of the water. * * * The silver was discovered on the 10th of July [1868], and on the 15th three packages of the best specimens were shipped from Fort William to Montreal.

During the next two years Mr. Macfarlane worked on this rock in the lake, exposed to storms which sometimes swept completely over the island and tore away all their buildings and bulwarks. The Montreal company could not be induced to incur the expense necessary to mine in earnest, although the rock taken out under the water in the winter of 1869-70 yielded $16,000 when it was smelted. The property was sold in 1870 to the Silver Islet Mining company, composed of capitalists from New York and Detroit, Michigan, with Capt. W. B. Frue as superintendent.

The discovery of silver-bearing veins in the Rabbit and Silver Mountain districts was made in 1882 and 1884 respectively, by Mr. Oliver Daunais, who learned of them through an Indian named Tchiatong, who formerly worked for the geological survey and had developed quite a fondness for exploring. Mr. Daunais, having married this Indian's daughter, was enabled to overcome his reluctance to reveal his discoveries, and was conducted nearly to the spot and then told to find the veins himself, which was not a difficult matter.

There have been occasional discoveries of silver in other parts of this district; and companies have been formed to operate mines on surface showings of greater or less attractiveness. One of the most persistent attempts to mine silver ore was made in the vicinity of Ontonagon, Michigan. Mr. Austin

Corser, of that place, is said to have discovered silver ore in situ in 1856. When the land was surveyed, in 1870, he procured a preëmption on the S. W. ¼, sec. 14, 51–42, on Little Iron river, about a mile from lake Superior. In 1872 a mining craze of the regulation style set in. It reached its greatest intensity in 1874, and subsided in the following year. A stamp mill with amalgamators was erected near this place in 1875 by the Ontonagon and Superior Mining companies, under the direction of Mr. F. W. Crosby, but only about 50 tons of ore were milled. The boom collapsed, and the mines shut down, the Cleveland being the last to quit, in 1876.

GOLD.

Although mines of the yellow metal are neither numerous nor large producers individually in this section of the county, they are found on both shores of the lake, and it is not improbable that they will increase in number and productiveness during the next decade.

There are reasons for believing that the first discovery of gold was made by Dr. Douglass Houghton in 1845, not far from the present town of Negaunee. The story is told by Mr. S. W. Hill, and a voyageur named Antoine Du Noir. They agree in the statement that Dr. Houghton wandered away from camp one day and returned about dark with a bag full of specimens, in which native gold was plainly visible. He told them that they were in a gold country, and that he should not be surprised to find quantities of it in the Huron hills. A piece of the quartz found at that time was worn as a pin for many years by Mr. Jacob Houghton, a brother of the doctor. The notes of this season's work were lost in the lake at the time of Dr. Houghton's death, but the accounts of these explorers are considered trustworthy, and the discovery of the Ropes vein in this same vicinity at a later period is strong corroborative proof of their truthfulness.

In 1865 a gold boom was started in Minnesota. The ore was reported by state geologist Eames and others to have been discovered in paying quantity at Vermilion lake, 75 miles north of Duluth. A wagon road was laid out to the new Eldorado; new towns were started, shafts were sunk, and a stamp mill was taken up there and set up on Trout river. The very land subsequently found so valuable for iron ore, where the hard hematite and jasper stood out in bald knobs, a hundred feet high, was taken for gold claims. The veins, however, proved to contain more pyrite and pyrrhotite than gold; and by 1867 the country was deserted, iron deposits and all.

In 1871 gold ore was found by Mr. Peter McKellar at Jackfish lake, near lake Shebandowan, about 70 miles northwest of Port Arthur. It was developed into the mine called the "Huronian," and worked during part of 1884 and 1885. In 1883 a 10-stamp mill was erected, but was operated only a short time, owing to the expense of getting supplies in so remote a region.

Another gold-bearing quartz vein was found by Mr. Archibald McKellar, on an island in Partridge lake, west of Lac des Mille Lacs, in 1872; and in 1875 nuggets of gold were discovered by Mr. Donald McKellar in a quartz vein at Victoria cape, on the western side of Jackfish bay, north shore of lake Superior. Nothing of importance was done to develop either of these mines.

Gold was found on Lake of the Woods in 1878 or earlier, and there has been more or less mining for the precious metal in that region ever since.

In 1881 Mr. Julius Ropes noticed gold in a vein about six miles northwest of the city of Ishpeming. Regular mining was begun here in October, 1882, and during the following summer a 5-stamp mill was erected. In 1884 a 25-stamp mill was completed and put in operation. This is the only genuine gold mine in Michigan, and *its* history has not been an enviable one.

In 1885 considerable excitement was caused by the discovery of gold three miles west of the Ropes mine on land belonging to the Lake Superior Iron Mining company. Some beautiful samples of ore were obtained, but the average did not warrant the expenditure necessary to develop a mine.

CONCLUSION.

In closing this brief history attention should be called to the fact that the majority of our metalliferous belts were discovered by official geologists in the performance of their assigned duties. In many instances the very ore deposit was found, examined, accurately located and described with a thorough appreciation of its value, a quarter of a century or more before any advantage was derived from the information thus early given to the public.

Especial mention should also be made of the distinguished services rendered to the sciences of mining and economic geology by the wonderful man from whom this beautiful city takes its name. Dr. Douglass Houghton may be justly styled the father of mining on lake Superior. To his indomitable enterprise and courage no less than to his versatile and colossal intellect is due the credit for the right start which was made; and in many ways his broad-gauged generous spirit is still discernible in the conduct of affairs around us.

We have attempted merely to mention the discovery of our mineral deposits, and not to sketch their subsequent development. But it were not becoming in me to close without calling attention to three other classes of creditors to whom our obligation is large. Our present condition of prosperity has been rendered possible first, by our brethren from Cornwall, Austria and other parts of Europe who, leaving their home surroundings, have journeyed to our shores and devoted years of hardest manual labor in delving for Nature's hidden treasures. Their lives have been passed underground, in dark and often dangerous galleries, while the fruits of their labors have been largely reaped by others.

We are greatly indebted in the second place, to the liberal policy of our State and National Government regarding technical education. Such institutions for scientific training as the one located in this city exert an incalculable influence for good on the material conditions surrounding us as well as on the lives and characters of our inhabitants.

Third and finally, our obligation is great to the mining engineers and superintendents who have planned and directed the development of these natural resources. In a new country, confronted with new problems, with unforeseen difficulties constantly arising, they have met each obstacle as it arose, and with industrial genius reaching almost to the sublime, have snatched victory at times from the very jaws of defeat, until our mining industry stands as it does to-day—in many respects without a parallel on the face of the globe.

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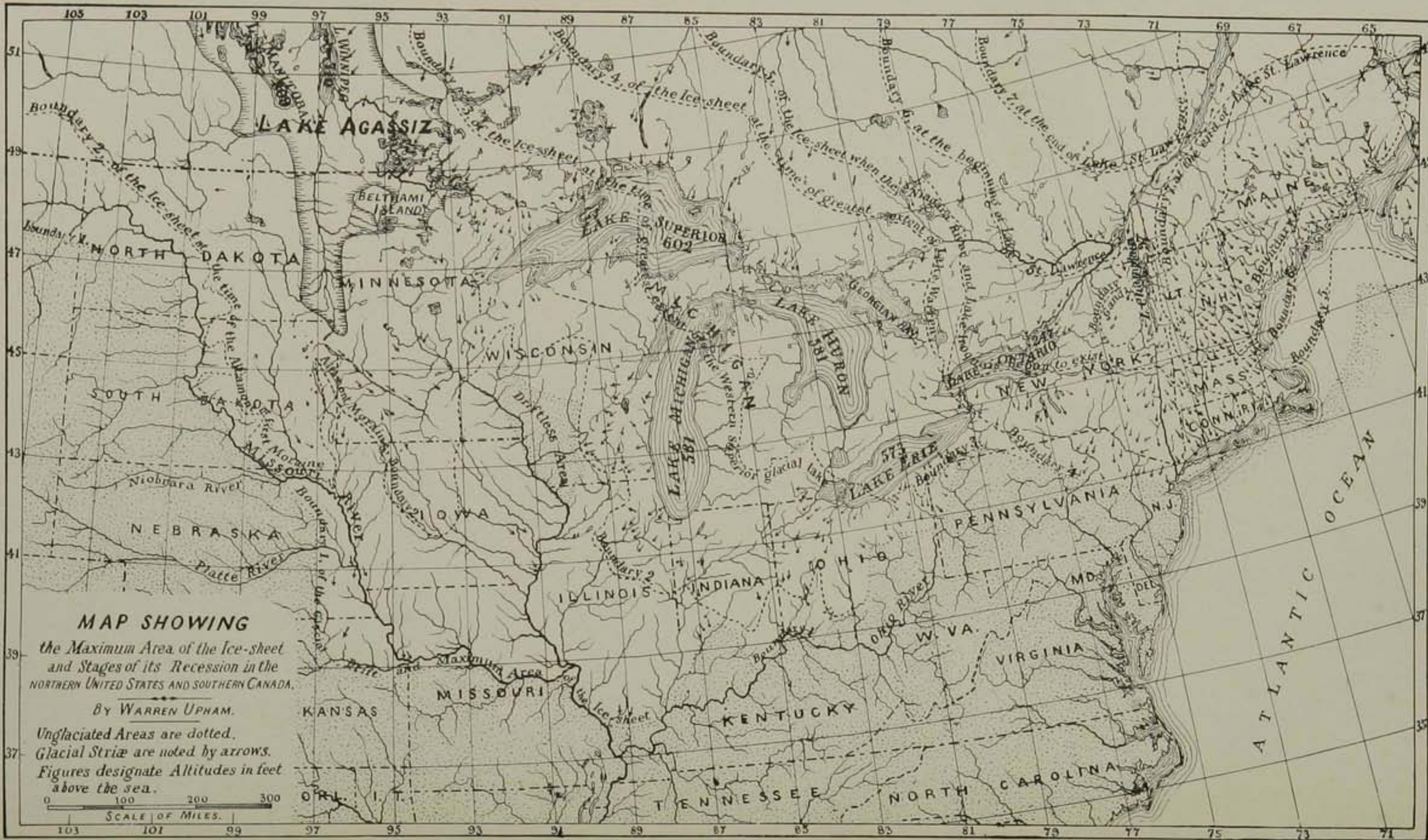
VI.

LATE GLACIAL OR CHAMPLAIN SUBSIDENCE AND RE-ELEVATION OF THE ST. LAWRENCE RIVER BASIN.*

By Warren Upham.

CONTENTS.

*This paper has been written as a continuation of the investigation which was published in pages 54 to 66 of the Twenty-second Annual Report of this survey, relating to the glacial lakes which are now succeeded by the present great Laurentian lakes. It has been partially presented elsewhere in the Bulletin of the Geological Society of America, vol. vi, pp. 21-27, Nov., 1894, and in the American Journal of Science, III, vol. xlix, pp. 1-18, with map, Jan., 1895. It was also given as an address before the Western Reserve Historical Society, Cleveland, Ohio, Dec. 22, 1894.



STAGES OF RECESSION OF THE NORTH AMERICAN ICE-SHEET.

INTRODUCTION.

Before the Ice age the northern part of the North American continent, northwestern Europe, and Patagonia, were uplifted to altitudes far above their present hight, as shown by fjords and submarine continuations of river valleys. The cool and snowy climate attending the culmination of the elevation of these areas is thought to have amassed the ice-sheets by which their glacial and modified drift were formed. Other areas in warm temperate, tropical, and equatorial latitudes, as portions of southwestern Europe and western Africa, bordering on the Bay of Biscay, the strait of Gibraltar, and the Gulf of Guinea, extending south to the Congo river, were also differentially uplifted to a known maximum vertical extent of 6,000 feet, at the mouth of the Congo, higher than now; but the geographical position of these areas forbade their envelopment by land ice like the far northern and far southern regions of these great preglacial epeirogenic uplifts.*

Under the weight of the ice-sheets each of the three great drift-bearing areas, in North America, Europe, and Patagonia, sank from their preglacial altitude, until at the time of departure of the ice and deposition of its drift they stood several hundred feet lower than now, so that their coasts were partially submerged by the sea. From the basin of lake Champlain, where marine fossiliferous beds of modified drift overlying the till were early studied by E. and C. H. Hitchcock, the time of this recession of the ice and rapid formation of its moraines, eskers and kames, valley drift plains, and deltas, forming the closing stage of the Glacial period, has been named by Dana the Champlain epoch.

Accompanying the retreat of the ice, while its burden was being removed by the gradual melting from south to north in the northern United States and southern Canada, there ensued a re-elevation by which the land was raised to its present altitude or in part somewhat higher. The inclinations then given to the originally level shore lines of the glacial lakes in the basins of the Red river of the North and lake Winnipeg and

*The dynamic causes of epeirogenic movements, and their relations to the Glacial period as the probable causes of both its beginning and end, are more fully considered in an appendix of Wright's Ice Age in North America, 1889, pp. 573-595; Am. Jour. of Science, III, vol. xlvi, pp. 114-121, Aug., 1893; Geol. Magazine, IV, vol. i, pp. 340-349, Aug., 1894.

of the river St. Lawrence show that a wave of permanent epeirogenic uplift advanced from south to north and northeast, closely following the withdrawal of the ice. In the upper Mississippi basin, on the area of the glacial lake Agassiz, and about Hudson bay, this differential uplift has varied from probably 100 feet or less near the southern boundary of the drift to 500 feet or more upon the greater part of that region.*

The Quaternary era has thus been distinguished by three general epeirogenic movements of large portions of the earth's continental areas, first, upward to great altitudes; second, downward lower than now; and third, again upward, with minor oscillations of depression, giving the present relations of land and sea. The sequence and wide extent of these movements, and their significance as probable causes of the accumulation and departure of the ice-sheets, were first pointed out by Dana. Later, the ice weight and its removal were shown by Jamieson to have been important factors, respectively, in producing the Late Glacial or Champlain downward movement and the ensuing re-elevation. With the more recent discoveries of the great depths of many submerged river channels on both the Atlantic and Pacific coasts of North America and on the west side of the eastern continent, the sufficiency of the preglacial uplifts and resulting climatic changes to account for the Pleistocence ice-sheets has been established. These strangely unique conditions, namely, great altitude of the land and accumulation of the ice-sheets, seem to have been contemporaneous, the epeirogenic uplifts having been the cause of the glaciation.

The purpose of the present paper is to review the Late Glacial downward movement which brought the Ice age to an end, and the closely ensuing moderate uplift which attended the recession of the ice-sheet, as these movements affected the basin of the St. Lawrence river. The accompanying map (Plate III) shows the maximum area covered by the ice in this region and approximate outlines of the glacial boundary at successive stages of its retreat, with the formation of glacial lakes, as somewhat fully studied in this paper. We will first note briefly the means of measuring and estimating the preglacial altitude. A measure of the greater part of the Champlain subsidence is thus obtained, to which must be added the extent of that depression of the land below its present hight. The progress

*Journal of Geology, vol. ii, pp. 383-395, May-June, 1894.

of the re-elevation will be traced by the differential uplifting of the old shore lines of the successive glacial lakes which were the precursors of the present great Laurentian lakes, and by the limits of the Champlain marine submergence. Through these studies we come to an estimate of the duration of the Postglacial period, derived from the rate of erosion of the gorge of the Niagara river below its falls. Furthermore, a comparison of the Champlain and Postglacial wave erosion and resulting beach deposits of lake Michigan with those of lake Agassiz during its portion of the Champlain epoch gives an important clue concerning the time relationship of this epoch to the later and earlier parts of Quaternary time.

Preglacial Elevation of North America.

The submerged channel and fjord of the Hudson river, continuing to a distance of 105 miles off the coast southeastward from Sandy Hook, and having a maximum sounding of 2,844 feet where the ocean bed at each side on the margin of the submarine border of the continental plateau has a depth of only 600 feet, show an uplift of the eastern side of North America at the southern limit of the ice-sheet and glacial drift to the extent of more than half a mile. Northward, the submerged fjord outlets of the Gulf of Maine, the Gulf of St. Lawrence, and Hudson bay, are reported by Spencer, from his examination of the United States Coast Survey and British Admiralty charts, to have depths, respectively, of 2,664 feet, 3,666 feet, and 2,040 feet. On the coast of California Prof. George Davidson, of the U. S. Coast Survey, has found numerous submerged valleys, sinking to depths of 2,000 to 3,120 feet where they cross the 100-fathom line of the marginal plateau. In the interior of the continent the elevation of the northern part of the Mississippi basin is thought by Prof. E. W. Hilgard, from the fluvial transportation of Archæan pebbles and cobbles to the shores of the Gulf of Mexico, to have been 4,000 to 5,000 feet higher than now. These observations, and the fjords of all our northern shores, indicate a preglacial uplift of the northern three-fourths of North America, excepting probably Alaska, which has been glaciated only in the St. Elias region and southeastward, to a vertical extent ranging from 2,000 to 5,000 feet or more above the present hight.

During the Jura-Cretaceous and Tertiary cycles of baseleveling, the St. Lawrence, Mississippi, Hudson bay, and Mackenzie drainage areas had been sculptured by stream erosion to nearly their present general surface features of plains, pla teaus, and the Appalachian-Laurentide mountain belt. At the end of the Tertiary and during early Quaternary time, the greater part of the continent appears to have been bodily elevated, with gentle marginal flexure and tilting, so that the general contour remained unchanged, while slopes of 10 to 20 feet or more per mile were given to the borders, largely now submerged, of the uplifted area. The hollows which now contain the Laurentian lakes were parts of the Tertiary river valleys and plains, with free descent to the sea. On the south this ancient Laurentian river system included some of the head streams of the Ohio river, as shown by Carll and later writers up to the recent studies of Chamberlin and Leverett.* The preglacial uplift of the country, gradually raising Canada and the northern border of the United States to a greater altitude than the Ohio and Susquehanna basins, seems to have turned some of the previously northwardly flowing streams back toward the south. Tributaries of the Tertiary river in the basin of lake Erie became affluents of the Ohio; and probably several streams in the valleys of the Finger lakes, in central New York, were reversed from their former course which had been north to the river of the lake Ontario area, being turned south into the Susquehanna for a considerable time before the maximum ice accumulation and advance.

LATE GLACIAL SUBSIDENCE.

From the high continental elevation whose culmination was attended with the envelopment of an area of 4,000,000 square miles, or half of North America, beneath an ice-sheet averaging probably a half or three-fourths of a mile thick, there ensued a depression of this area to its present hight and chiefly lower. Throughout the areas of lake Agassiz and the St. Lawrence basin, the land is found to have sunk several hundred feet lower than now. In Maine and New Brunswick, along the St. Lawrence and Ottawa valleys, in the basin of lake Champlain, and about Hudson bay, the extent of the subsidence is known, by the marine submergence and its fossiliferous beds, to have ranged mostly from 200 to 500 feet below the present sea level; and in northern Labrador and Grinnell land, with parts of western Greenland, from 1,000 to nearly 2,000 feet.

The preglacial uplifting forces had been due probably to the gradual cooling and shrinking of the earth while mountain-

*Am. Jour. Sci., III, vol. xlvii, pp. 247-283, with four maps and eight profiles, April, 1894.

building by folds and faulting took place too slowly to permit the crust to accommodate itself, without this deformation, to the diminishing inner mass. Large tracts of the continents therefore were elevated, in comparison with other land areas and the ocean beds, since only by these changes, tending to a perpetuation of the continents, could a less volume be enclosed by the earth's crust without subtraction from its area through the formation of mountain ranges. General permanence of the continents and ocean basins, as taught by Dana, seems thus a necessary result of the epeirogenic movements required by the secular cooling and condensation of the globe. The growing tangential stress, however, aided by the weight of the ice-sheets, finally gained relief in extensive orogenic crumpling, faults, and overthrusts, along great mountain belts, as in the Himalayas, the Sierra Nevada, and the St. Elias range, all of which have been much disturbed and increased in hight during the Pleistocene period. The previously elevated lands, both of drift-bearing regions and within the tropics, then sank to approximately an isostatic condition, the ice-laden regions being carried mainly somewhat below their present levels.

On the high surface of the ice-sheets there still reigned an arctic severity of cold. For some time, as shown by Le Conte, the snow and ice accummulation went on faster than the subsidence, causing the maxima of the land depression and of the thickness and extension of the ice to be nearly contemporaneous. While the central parts of the ice-covered areas had fallen probably four or five thousand feet from their preglacial altitude, the borders of the ice were lowered apparently in general about half as much, thereby sinking closely to their present level; and this sufficed to turn the balance from glacial growth to a beginning of the final retreat. The summer heat and rains on the glacial boundary, when reduced to its present hight, melted away the ice margin faster than it could be replenished. This process gradually extended inward, giving steep gradients of the ice-front, which formed moraines whenever a series of exceptionally cool years and abundant snowfall allowed any pause or re-advance. The whole ice-sheet, through the continuance of the peripheral melting, disappeared; and meanwhile the land on which it had lain, being unburdened, was moderately re-elevated, in obedience to its law of isostasy, proportionally with the glacial melting and retreat.

The Champlain epoch was begun and ended, respectively, by the downward and upward epeirogenic movements. It comprised the time of departure of the ice-sheets, with many small and large glacial lakes temporarily formed by its receding barrier, and with marine submergence to hundreds of feet above the present shore lines. The Late Glacial subsidence appears to have been principally completed before the time of the glacial recession and accompanying deposition of the lacustrine and marine beds; but the following uplift was in progress, advancing as fast as the ice receded, from the beginning to the end of Champlain time. Indeed, considerable parts of the glaciated areas of North America and Scandinavia are still undergoing small and slow oscillatory movements, not having yet, during the short Postglacial period, fully reached isostatic repose.

Re-elevation by a Wave-like Epeirogenic Uplift.

Both the glacial retreat and the accompanying re-elevation of the land took place somewhat intermittently, or by successive steps. Many stages in the departure of the ice-sheet are shown by its series of partly parallel but often interlocking and sometimes overlapping retreatal moraines, which I have mapped, to the number of twelve, through Minnesota, North Dakota, and Manitoba, and of which a larger number have been explored and mapped by Leverett in Illinois, Indiana, and Ohio. On Long Island, Martha's Vineyard, Nantucket, and Cape Cod, I traced in 1878 the two most southern moraines of our Atlantic seaboard; and four or five others in New England have since been recognized through the observations of Profs. R. S. Tarr and C. H. Hitchcock, and of the present writer, crossing Massachusetts, Vermont, and New Hampshire. These moraines occur on the southern part of the drift-bearing area. Others farther to the north in Canada are described by Bell, Tyrrell, and Low. It is thus learned that the ice-sheet in the United States and southern Canada gradually withdrew from south to north and northeast, with occasional interruptions when it paused or for a short time re-advanced. Courses of glacial striæ and transportation of boulders (which show the direction of ice currents and the opposite direction of recession of the ice boundary at the end of the Glacial period), reported by G. M. Dawson, McConnell, and the other Canadian observers before named, in the northern part of British America, as in the Mackenzie basin, on the Telzoa river, and about Hudson bay and strait, indicate that similarly from the north side of the continental ice-sheet its recessional melting advanced inward, which there was southward, to the central parts of the drift-bearing region.

While the vast weight of the ice was being thus removed, the lake Agassiz area was being uplifted, as shown by its much inclined highest and earliest beaches, whereas the latest and lowest beaches are nearly horizontal. This uplift is found to have advanced like a wave from Minnesota and North Dakota northward through Manitoba and northeast to Hudson bay, permanently elevating the country as now, mostly about 500 feet above the hight which it held when first uncovered by the glacial melting. Soon after the ice receded, and while it yet continued to be the northern barrier of the decreasing glacial lake, the uplift along the whole extent of lake Agassiz, more than 600 miles from south to north, was practically completed. The southern half of that lacustrine area was first raised nearly to its present hight; later, its northern half was elevated, while the southern part received only a slight increase of hight; and lastly, the basin of Hudson bay, in the center of the glaciated area of North America, has been raised from its Champlain marine submergence of 300 to 500 feet.* Part of this elevation on the shores of Hudson bay is shown by Dr. Robert Bell to have been very recent, and it is even probably still in progress.

In like manner the Champlain history of the Laurentian lakes, and the marine submergence and emergence of the St. Lawrence, Ottawa and Champlain valleys, attest a wave-like advance of the re-elevating earth-movement from south to north and northeast, and probably in Maine and the eastern Canadian provinces from the coast northwesterly, following the recession of the border of the ice-sheet.

EVIDENCE FROM THE BEACHES OF THE GLACIAL LAKES IN THE ST. LAWRENCE BASIN.

Well marked old channels of outflow are found extending southward, at the levels of the deserted beaches, from lake Agassiz and from the glacial lakes which are now represented by the diminished, but still large, modern lakes Superior, Michigan,

*Article in the Journal of Geology, before cited. Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for 1879, pp. 84-90; Eleventh An. Rep., for 1892, pp. 137-153, with map; Final Report. vols. i and ii. U. S. Geological Survey, Bulletin 39 (1887), pp. 84, with map. Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv, for 1888-89, Part E, 156 pages, with two maps and several sections.

Huron, Erie, Ontario, and Champlain. The outlets prove that the great Pleistocene water bodies which occupied these basins were lakes, not gulfs or arms of the sea; and the differential uplifts of the basins, increasing toward the central part of the area of the continental ice-sheet, show that no land barriers, but the ice itself in its retreat, held in these lakes on their northward sides.

The basin of the St. Lawrence during the glacial recession held successively, and in part contemporaneously, no less than eight important glacial lakes, distinguished by their different areas, hights, and places of outlet. They are named the Western Superior and Western Erie glacial lakes; lake Warren, the most extensive, into which the two foregoing were merged; lake Algonquin, the successor of lake Warren in the basins of lakes Huron, Michigan, and Superior; lake Lundy, the glacial representative of lake Erie; lake Iroquois, in the basin of lake Ontario; lake Hudson-Champlain; and lake St. Lawrence, into which the two last named became merged. The glacial lake St. Lawrence, which is the only one of the series hitherto unnamed, extended over the Ottawa, Champlain, and St. Lawrence valleys previous to the melting away of the ice barrier, remaining latest in the vicinity of Quebec, by which event the sea, at a lower level than the former lake, was admitted to these valleys.

*The Western Superior glacial lake.**—In the west part of the basin of lake Superior the receding ice-sheet held a lake which outflowed southward through northwestern Wisconsin, across the present watershed between the Bois Brulé and St. Croix rivers. The highest shore line of this lake at Duluth is 535 feet above lake Superior (which has a mean level 602 feet above the sea); on Mt. Josephine, about 130 miles northeast from Duluth, its hight, according to leveling by Dr. A. C. Lawson,† is 607 feet; and at L'Anse and Marquette, Mich., 175 and 225 miles east of Duluth, it is found by Mr. F. B. Taylor‡ about 590 feet above the lake. The northeastward uplift averages seven inches per mile; and the eastward ascent is approximately three inches per mile. The latest and lowest of the Western Superior lake beaches observed at Duluth, occupied

*Proc. A. A. A. S., vol. xxxii, for 1883, p. 230. Geol. and Nat. Hist. Survey of Minnesota, Final Report, vol. ii, 1888, p. 642; Twenty-second Ann. Rep., for 1893, pp. 54-66 (first use of this name). Bulletin Geol. Soc. Am., vol. ii, 1891, p. 258. Am. Geologist, vol. xi, p. 357, May, 1893; and vol. xiv, p. 63, July, 1894.

†Minnesota Geol. Survey, Twentieth Ann. Rep., for 1891, pp. 181-289, with map and profiles.

‡Am. Geologist, vol. xiii, pp. 316-327 and 365-383, with maps, May and June, 1894.

by the "boulevard" or pleasure driveway, 475 feet above the lake, on the bluffs back of the city, appears to have an ascent of only about 35 feet in the distance to Mt. Josephine, showing that the uplift of the land was quite rapidly in progress while the ice-front still maintained the lake at the St. Croix outlet. Not long after the glacial retreat passed eastward beyond Mt. Josephine and Marquette, this lake was lowered and merged with lake Warren across the lowlands of the northern peninsula of Michigan. The vertical interval between the final stage of the Western Superior lake and the level of lake Warren shown by its earliest beach at Duluth was about 60 feet. Thenceforward the outlet of lake Warren past Chicago carried away the drainage from the glacial melting and rainfall of the Superior basin.

*The Western Erie glacial lake.**—Outflowing from the southwestern end of the lake Erie basin by a large abandoned watercourse, which reaches from Ft. Wayne, Ind., where the St. Joseph's and St. Mary's rivers unite to form the Maumee, across the present watershed to the Wabash river, this glacial lake formed two distinct beaches, named by N. H. Winchell the Van Wert and Leipsic ridges, separated by a vertical interval of 15 to 20 or 25 feet. The upper or Van Wert beach, with its crest varying in altitude from 200 to 220 feet above lake Erie (whose mean hight is 573 feet above the sea), extends about 75 miles east to Findlay, Ohio, and nearly an equal distance northeast past Bryan, Ohio, to the vicinity of Adrian, Mich., if not farther. At Findlay the lake while forming this beach, as Winchell and Leverett have shown, was bounded on the north by the ice-sheet then forming the Blanchard moraine. The second or Leipsic beach of the Western Erie lake, ranging in hight from 190 to 210 feet, runs from Ft. Wayne eastward 175 miles to its termination, as described by Leverett, at the line of a later moraine close southwest of Cleveland. Northeast and north from the old outlet the Leipsic beach reaches

* G. K. Gilbert, Am. Jour. Sci., III, vol. i, pp. 339-345, with map, May, 1871; Geology of Ohio, vol. i, 1873, pp. 540-556, with two maps. N. H. Winchell, Proc. A. A. A. S., vol. xxi, for 1872, pp. 171-179; Geology of Ohio, vol. ii, 1874, pp. 56, 431-433, etc. J. S. Newberry, Geology of Ohio, vol. ii, pp. 46-65, with three maps and numerous sections. E. W. Claypole, "The Lake Age in Ohio," Trans. Geol. Soc. Edinburgh, 1887, pp. 42, with four maps. G. F. Wright, "The Ice Age in North America." 1889, chapter xv (with reproduction of Prof. Claypole's maps, that of lake Erie-Ontario being on p. 355). J. W. Spencer, Am. Jour. Sci., III, vol. xli, p. 208, with map, March, 1891; Bulletin, Geol. Soc. Am., vol. ii, 1891, pp. 465-476, with map. Frank Leverett, Am. Jour. Sci., III, vol. xliii, pp. 281-297, with map, April, 1892. Warren Upham, Bulletin, Geol. Soc. Am., vol. ii, p. 259; Minnesota Geol. Survey, Twenty-second Ann. Rep., for 1893, p. 62 (first use of the name *Western Erie glacial lake*).

about 165 miles, past Adrian and Ypsilanti to Imlay, Mich., being nearly level to Ypsilanti, but thence in the 60 miles onward to Imlay having a rise of about 65 feet, to an altitude 849 feet above the sea. With the recession of the ice-sheet and the extension of this lake to Imlay, a lower outlet was opened over the watershed between the Shiawassee and Grand rivers in Michigan, 729 feet above the sea or 148 feet above lakes Huron and Michigan, where the Western Erie glacial lake became confluent with lake Warren and was thus reduced about 30 feet, falling from the Leipsic or lower Western Erie beach to the Belmore or earliest beach of lake Warren in the Erie basin.

Upon a large area, extending from Ft. Wayne east to Cleveland and northward to Ypsilanti and Detroit, the attitude or general slopes and levels of the land have remained unchanged since the departure of the ice-sheet, for these earliest beaches and the lower beaches of lake Warren in the same area are still nearly horizontal. The whole country there, however, has been uplifted, without tilting, about 110 feet, after the end of the separate existence of the Western Erie lake, for this is the hight of the Belmore beach around the west end of lake Erie above the highest and earliest beach of lake Warren at Chicago. A greater and differential uplift, with rapid tilting of northward ascent, was taking place north and northeast of Detroit during the Belmore and lower stages of lake Warren, simultaneous with the uniform elevation of the Western Erie glacial lake area. Further we learn that about half of the uplift of 110 feet for this region has occurred before the beginning of lake Algonquin and the date of the Algonquin beach, since that beach has a hight of 602 feet near the south end of lake Huron, being 60 feet higher than the correlative sublacustrine terrace plane beneath the surface of lake Michigan near Chicago, which marks the old Algonquin shore there.

*Lake Warren.**—Like the Western Superior and Western Erie glacial lakes, the far more extensive lake Warren at the beginning of its existence occupied only the southern end of the

*J. W. Spencer, Science, vol. xi, p. 49, Jan. 27, 1888 (proposing this name in honor of Gen. G. K. Warren); Proc. A. A. A. S., vol. xxxvii, for 1888, pp. 197-199; Trans. Roy. Soc. of Canada, vol. vii, for 1889, sec. iv, p. 122; Am. Jour. Sci., III, vol. xli, pp. 201-211, with map, March, 1891; Bulletin, Geol. Soc. Am., vol. ii, pp. 465-476, with map, April, 1891; "A Review of the History of the Great Lakes," Am. Geologist, vol. xiv, pp. 289-301, Nov., 1894 (containing citations of many additional papers by Prof. Spencer and others). G. K. Gilbert, "Changes of Level of the Great Lakes," in The Forum, vol. v, pp. 417-428, June, 1888; "History of the Niagara River," in Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for 1889, pp. 61-84, with eight plates (also in the Smithsonian An. Rep. for 1890, pp. 231-257); Geology of Ohio, vols. i basin of lake Michigan. It grew northward as the ice-sheet retired, and in due time it received these two lakes to itself, expanding thus into the basin sof lakes Superior, Huron, and Erie. The m aximum development of lake Warren stretched from Thomson, Minn., above and west of Duluth, eastward to lake Nipissing, a distance of nearly 600 miles; and from Chicago, where it outflowed to the Des Plaines, Illinois, and Mississippi rivers, it extended eastward in its highest stages across the southern peninsula of Michigan, and later by way of the strait of Mackinaw and over lakes Huron, St. Clair, and Erie, to the west end of the lake Ontario basin and to Crittenden in southwestern New York. This area exceeded 100,000 square miles, being nearly equal to the glacial lake Agassiz. The Belmore and Nelson beaches, the two highest formed by lake Warren in the basins of lakes Erie, Huron, and Superior, called by Spencer the Ridgeway beach (a later name than N. H. Winchell's "Belmore ridge") in their united course about the west half of lake Erie, show that, since the fullest expansion of this great glacial lake, the whole basin of lake Superior and the country eastward to lake Nipissing have been uplifted 400 to 550 or 600 feet, in comparison with Chicago and the southern part of the lake Michigan basin, while the uplift at Cleveland has been about 115 feet, and at Crittenden, N. Y., not less than 260 feet (more probably about 300 feet).

In the vicinity of Chicago, lake Warren formed three beaches, belonging to lake levels successively about 45 to 50 feet, 15 feet, and 30 feet above lake Michigan. That the beach

and ii. Frank Leverett, paper before cited; "Raised Beaches of Lake Michigan," Trans. Wisconsin Academy of Sciences, Arts, and Letters, vol. vii, pp. 177-192 (read Dec. 30, 1887). A. C. Lawson, "Sketch of the Coastal Topograpy of the North Side of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren," Minnesota Geol. Survey, Twentieth An. Rep., for 1891, pp. 181-289, with map, profiles, and figures from photographs. F. B. Taylor, Am. Jour. Sci., III, vol. xliii, pp. 210-218, March, 1892 (Mackinac island); Bulletin Geol. Soc. Am., vol. v, pp. 620-626, with maps, April, 1894 (lake Nipissing); Am. Geologist, vol. xiii, pp. 316-327 (Green bay) and 365-383 (south coast of lake Superior), with maps, May and June, 1893; id., vol. xiv, pp. 273-289 (east of Georgian bay), with map, Nov., 1894. The highest beach on Mackinac island, which Mr. Taylor calls the "Algonquin beach," seems to be correlative with his Nelson and higher beaches in the vicinity of lake Nipissing, regarded in this paper as marking the early high stages of lake Warren. C. Whittlesey, Smithsonian Contributions, vol. xv, 1864, pp. 17-22. E. Andrews, "The North American Lakes considered as Chronometers of Postglacial Time," Trans. Chicago Academy of Sciences, vol. ii. Nearly all the edition of this important paper was consumed in the Chicago fire of 1871. It is quite fully reproduced by James C. Southall in "The Recent Origin of Man," 1875, chapter xxxiii (pp. 495-503, with sections); and in "The Epoch of the Mammoth and the Apparition of Man upon the Earth," 1878, chapter xxii (pp. 348-367, with sections). N. H. Winchell, J. S. Newberry, E. W. Claypole, and G. F. Wright, as before cited. Geol. Survey of Canada, Report of Progress to 1863, pp. 912, 913. Warren Upham, Bulletin Geol. Soc. Am., vol. ii, pp. 258-265; vol. iii, pp. 484-487; Geology of Minnesota, Twenty-second An. Rep., for 1893, as before cited; Am. Geologist, vol. xiv, pp. 62-65, July, 1894.

at 30 feet was formed after that at 15 feet is shown by the occurrence in some places of a peat deposit, described by Andrews and Leverett, which passes underneath the 30 feet beach and is continuous from its upper side down to the lower beach. The peat marks a land surface over which the lake rose to form the middle or third beach, after having stood at the lower or second beach for some time. Still later, however, it probably again stood at the lower level, corresponding to the present watershed in the abandoned outlet. This old channel of outflow, at its summit, as I am informed by Mr. Ossian Guthrie from the canal survey, is now 11 feet above the mean level of lake Michigan, but the surface there is post-glacial silt; at another point, where the channel bed consists of till, and at a third place where the bed is rock, its hight in each case is only eight feet above the present lake, or 590 feet above the sea. The mouth of lake Warren appears to have been at first near Lemont, on the Des Plaines river, about 25 miles from the lake, where the river valley was obstructed by drift which suffered erosion, allowing the mouth of the lake to be transferred gradually upstream, at the same time being lowered to its final position ten miles from the lake shore in Chicago. Epeirogenic movements, between the times of formation of the second and third beaches, slightly lifted the outlet and adjacent portion of the course of the Des Plaines river, as compared with the southern and southwestern part of the lake Michigan basin, causing the old lake to extend a little farther on that side than before. Toward the north and east, however, this change was doubtless more than counteracted by the rapid differential rise of the land.

Fresh-water shells are found abundant in the 15 feet beach at Evanston and elsewhere southward through Chicago. All the species obtained, representing ten or more genera, are still living in this region. Wood of oak and cedar, and the thigh bone of a deer, have been also found in the same beach at Evanston.*

For the distance of about 185 miles from Chicago north to the south end of Green bay, the highest shore of lake Warren appears to be now nearly level, for Mr. Taylor finds evidence of submergence only to a hight of some 20 feet above that part of Green bay and the neighboring lake shore. Thence northward, however, the beach rises about 1.4 feet per mile for 110

*H. M. Bannister, Geology of Illinois, vol. iii, 1868, pp. 241, 242. F. Leverett, "Raised Beaches of Lake Michigan," before cited, p. 189.

miles to Cook's Mill, near the north end of this bay; in 60 miles from that latitude north to Houghton, it has an ascent of 260 feet, or 4⅓ feet per mile; but in about 90 miles onward, across lake Superior to Kaministiquia, where the shore is 455 feet above that lake, the rate of northward ascent is reduced to only a half of a foot per mile,

Along a west to east course, the Nelson beach (named by Taylor in the vicinity of North Bay, lake Nipissing, probably not distinct from the Belmore beach in Ohio and northward to Mackinac island) is 385 feet above lake Superior at Duluth; 410 feet at Houghton, having an eastward ascent of 25 feet in 150 miles; 414 feet at the Sault Ste. Marie, running level for 200 miles east from Houghton; and about 538 feet at the north side of lake Nipissing, or 497 feet above that lake, and 1,140 feet above the sea. In the distance of 220 miles from Sault Ste. Marie to lake Nipissing this beach now shows an ascent of 124 feet, or about seven inches per mile. These figures, with the preceding from Houghton to the north side of lake Superior, justify to a remarkable degree Dr. Lawson's opinion that the ancient shore lines of lake Warren in the Superior basin remain parallel with the water level of to-day. As compared with Chicago, the country enclosing lake Superior has been uplifted 400 to 450 feet; and the greater part of the differential elevation, expressed by tilting, took place upon the west to east belt of the northern peninsula of Michigan.

Three beaches of lake Warren are mapped by Spencer and named the Ridgeway, Arkona, and Forest beaches in Ohio, southeastern Michigan, and the province of Ontario north of lake Erie. These probably represent the three noted at Chicago and about the south part of lake Michigan. Farther north the number of distinct shore lines is much increased. In and near Duluth I find eight beaches referable to lake Warren, the lowest being 50 feet above lake Superior. On northern portions of the lake Superior coast several of these seem, as shown by Lawson's observations with leveling, to be each represented by two or more shores, separated by vertical intervals of 10 feet or more. Most of the northern beaches, it should be remarked, are very feebly developed, even in the most favorable situations for their formation, and are not discernible along the far greater part of the lake borders. During all the time of differential uplifting of the lake Warren basin and sinking of the water surface, whenever the diminishing lacustrine area was nearly unchanged for a few years or longer, the erosion and deposition effected by the great waves of storms, and the tribute of streams forming deltas, recorded these short lines.*

Lake Algonquin.†—When the glacial melting and retreat at length permitted an outflow from the St. Lawrence basin over a lower pass, which was through central New York to the Mohawk and Hudson, the water surface of the basins of lakes Michigan, Huron, and Superior, fell only some 50 or 75 feet, from the latest and lowest stage of lake Warren to its short-lived successor, lake Algonquin. This lake appears to have been ice-dammed only at low places on its east end, as at or near the heads of the Trent and Mattawa rivers, lying respectively east of lakes Simcoe and Nipissing, where otherwise its waters must have been somewhat further lowered to outflow by these passes. Careful study and comparison of the work of Spencer in tracing the Algonquin beach about the southern part of lake Huron and Georgian bay, and of Taylor in exploration of his "Nipissing beach" from Duluth east along the south coast of lake Superior and the north side of lake Huron and Georgian bay to lake Nipissing, convince me that these beaches were of contemporaneous formation, marking respectively the southern and northern shores of lake Algonquin, and therefore both to be known by the name Algonquin beach of Spencer, according to the law of priority. The earliest and principal stage of lake Algonquin is shown by these beaches to have coincided closely in area with lakes Michigan and Superior, but to have been considerably more extensive eastward than the present lake Huron and Georgian bay. It held a level which now by subsequent differential epeirogenic movements is left probably wholly below the level of lake Michigan by a vertical amount ranging from almost nothing to about 40 feet. Its shores were nearly coincident with the western shore of lake Huron, but eastward they are now elevated mostly 150

*Prof. Spencer, in his latest paper ("A Review of the History of the Great Lakes," Am. Geologist, vol. xiv, pp. 298, 301. Nov., 1894), supposes that an outflow from lakes Superior, Huron, Michigan, and Erie, passed by the way of Chicago to the Des Plaines and Mississippi rivers so lately as about 1,500 years ago, when the Niagara river had cut back its gorge to the Johnson ridge, about a mile north of the present site of the falls. This would have formed a beach 10 to 15 feet above lakes Michigan and Huron, and about 20 to 25 feet above lake Erie, around all their shores; and the absence of such a modern and still horizontal shore line, slightly higher than the present lake levels upon all this large area, forbids an acceptance of this hypothesis.

†J. W. Spencer, "Deformation of the Algonquin Beach, and Birth of Lake Huron," Am. Jour. Sci., III, vol. xli, pp. 12-21, with map, Jan., 1891; and other papers before cited. G. K. Gilbert, F. B. Taylor, and Warren Upham, as before cited for lake Warren. G. F. Wright, Bulletin Geol. Soc. Am., vol. iv, pp. 423-5; with ensuing discussion by Dr. Robert Bell, pp. 425-7.

to 200 feet above that lake and Georgian bay; and in the lake Superior basin they vary from about 50 feet above lake Superior at its mouth, and along its northeastern and northern shores, to 25 feet at Houghton, and to a few feet or none at Duluth.

The Algonquin beach at the south end of lake Huron coincides very closely with the land surface there and with the present St. Clair and Detroit rivers, by which the earliest outflow of the old glacial lake probably passed southward and thence ran east as a glacial River Erie, at first tributary to lake Lundy. As soon as that very briefly existing glacial lake was drained away, the river followed the lowest part of the shallow bed of the present lake Erie along all its extent, which then had an eastward descent of probably 200 feet, allowing no lake or only a very small one to exist in the deepest depression of the basin; and north of Buffalo it coincided with the course of the Niagara river.

Gilbert, Wright, and Spencer, have thought that for a long time the outflow of the three great lakes above lake Erie passed by the way of lake Nipissing to the Mattawa and Ottawa rivers It seems to me far more probable, however, that the epeirogenic uplift of the Nipissing region, which had elevated it already about 400 feet during the existence of lake Warren, continued so fast that both the Trent and Nipissing-Mattawa passes were raised the additional 50 feet needed to place them above the level of lake Algonquin before the glacial retreat uncovered the country east of them so that outlets could be obtained there.

With the continuance of the uplift of the lake Superior basin after the formation of the Algonquin beach, the mouth of lake Superior and the Sault Ste. Marie came into existence; and this movement allowed the lake level at Duluth to fall probably 40 or 50 feet beneath the Algonquin and present shore line. Subsequent differential elevation of the eastern and northern parts of the basin, as compared with Duluth, has again brought the west end of the lake up to the Algonquin shore, but not until the St. Louis river, while the water surface stood considerably lower than now, had deeply eroded its broad channel through the very gently sloping expanse of till from Fond du Lac to the harbor of Duluth and Superior.

The differential uplift of the Algonquin beach, as compared with Chicago and the previous mouth of lake Warren, has been about 60 feet near the mouth of lake Huron and at Duluth;

110 feet at the mouth of lake Superior; 200 feet at lake Nipissing; and 240 to 290 feet at Barrie, Lorneville, and Orillia, on lake Simcoe. A broad lobe of the waning ice-sheet, terminating on the highland area between the south end of Georgian bay and the west end of lake Ontario, appears to have delayed the elevation of that district, so that subsequent to the formation of the Algonquin beach more uplifting took place there than at the north side of Georgian bay and about lake Nipissing. The ascent of the Algonquin beach in nearly 200 miles from the mouth of lake Huron northeasterly to lake Simcoe averages about a foot per mile; and thence in about 135 miles north to lake Nipissing it descends at an average rate of about eight inches per mile.

While the eastern part of the lake Algonquin area was being much uplifted, with the formation of other beaches below the first, probably the southern part of the lake Michigan basin remained with a very slight change of attitude or none, having previously risen to approximately its present hight, which it has since held with little or no change. But the northeastward elevation, raising the country where lake Algonquin and now lake Huron have outflowed, gradually caused the water level at Chicago to rise some 40 feet above its old Algonquin level, which is shown by a sublacustrine terrace formed by the Algonquin erosion and beach accumulation.

On the Saugeen river, Ontario, and near the south end of Georgian bay, fresh-water shells are found in beds belonging to stages of lake Algonquin respectively about 40 and 100 feet below the main and earliest Algonquin beach, or 90 and 78 feet above the present lake and bay.

*Lake Lundy.**—From the Forest beach at Crittenden, Erie county, N. Y., marking the latest level of lake Warren, there is a descent of 125 feet between 860 and 735 feet above the sea to the earliest strand of the glacial lake Lundy, which for a time occupied the northeastern three-fourths of the lake Erie basin. A more conspicuous principal Lundy beach, 30 feet lower, on which is the "ridge road" named Lundy lane, near Niagara Falls, has an eastward ascent of 30 feet in about 40 miles from Font-hill, Ont., to Akron, N. Y., five miles north of Crittenden. Lake Lundy opened through a strait about 30 miles wide into the lake Ontario basin. Its outflow passed eastward, across the country close north of the Finger lakes, to the Mohawk and

* J. W. Spencer, "Deformation of the Lundy Beach and Birth of Lake Erie," Am. Jour. Sci., III, vol. xlvii, pp. 207-211, with map, March, 1894.

Hudson valleys, still partly filled by the receding ice-sheet and permitting a series of mouths of lake Lundy to be found at successively lower levels, until as the ice-border withdrew the water soon sank to the lowest point of the Ontario-Mohawk watershed at Rome, N. Y., where its level long remained, forming the Iroquois beach. One of the stages of the sinking lake Lundy or incipient lake Iroquois, probably nearly midway in altitude between the Lundy and Iroquois beaches, I find to be indicated by my studies of eskers in Rochester and Pittsford, N. Y.*

Lake Iroquois.†—This glacial lake, overflowing at Rome to the Mohawk and Hudson, occupied less area in the west part of the lake Ontario basin during its earliest stage than during the later and probably longer enduring lake stage by which the high Iroquois beach in that region was formed. Previous to the date of the western development of the Iroquois beach, the early water level stood at one time only a little higher than the present lake Ontario at Toronto and Scarboro Hights, 6 to 15 miles east of Toronto, as compared with the altitude, doubtless absolutely lower than now with regard to the sea, which the land then held in that part of the lake basin. This is shown by the occurrence of fossil fresh-water mollusks of fourteen species, and wood of ash, oak, and American yew, in beds at Toronto, described by Coleman, which now are 33 to 51 feet above lake Ontario, or 280 to 298 feet above the sea. All the mollusk species are now living; but four are restricted, so far as known, to waters tributary to the Mississippi. A boulder-bearing surface deposit above these beds proves that the front of the ice-sheet was not far distant; but the climatic conditions of that time, clearly indicated by the fauna and flora, were as mild as now. There next ensued, probably, a gradual rise of the lake, due to an uplifting of the country about its outlet at Rome, until it stood at the level of the well

*Proceedings of the Rochester Academy of Science, vol. ii, pp. 196-198, Jan., 1893.

†J. W. Spencer, "The Deformation of the Iroquois Beach and Birth of Lake Ontario," Am. Jour. Sci., III, vol. xl, pp. 443-451, with map, Dec., 1890; and papers previously cited. Thomas Roy (in paper by Sir Charles Lyell), Proceedings Geol. Soc., London, vol. ii, 1837, pp. 537, 538. Sir Charles Lyell, Travels in N. A., in 1841-42, vol. ii, chapter xx. E. J. Chapman, Canadian Journal, new series, vol. vi, 1861, pp. 221-229, and 497, 498. Sandford Fleming, Can. Jour., same vol. vi, pp. 247-253. George J. Hinde, Can. Jour., vol. xv, 1877, pp. 388-413. A. P. Coleman, Am. Geologist, vol. xiii, pp. 85-95, Feb., 1894. Geol. Survey of Canada, Report of Progress to 1863, pp. 912, 913. James Hall, Geology of New York, Part iv, 1843, pp. 348-351. Baron Gerard de Geer, "On Pleistocene Changes of Level in eastern North America," Proc. Boston Soc. Nat. Hist., vol. xxv, 1892, pp. 454-477, with map; also (excepting the map) in Am. Geologist, vol. xi, pp. 22-44, Jan., 1893. G. K. Gilbert, F. B. Taylor, E. W. Claypole, G. F. Wright, and Warren Upham, as cited for lakes Warren and Algonquin.

defined Iroquois beach, which has a hight at Toronto of about 200 feet above lake Ontario. Thick fossiliferous delta deposits had been, meanwhile, brought into the north edge of the lake at Toronto and several miles eastward along the lake-cliff section of Scarboro Hights, described by Hinde; and repeated re-advances of the ice-front, one during, and another after, the delta accumulation, formed, at the locality last noted, two deposits of till or boulder-clay.

In a limited sense the Toronto and Scarboro fossils may be called Interglacial, since they lie between deposits of glacial drift; but they seem better referred to moderate oscillations of the ice boundary than to the distinct glacial epochs which Coleman and Hinde infer from them. Both these beds and the richly fossiliferous Leda clays, which last overlie the latest glacial drift in the St. Lawrence, Ottawa, and Champlain valleys, may be referred to the closing stage or Champlain epoch of the Ice age; and they both testify, like the partially forest-covered Malaspina ice-sheet in Alaska, of the close sequence of a warm climate, with luxuriant plant and animal life, during and immediately after the recession of the ice-sheet. The transition from the Glacial to the Champlain climate seems readily explained by the epeirogenic depression which ended the Glacial period.*

The hight of lake Ontario is 247 feet; and that of the old Iroquois outlet crossing the water-shed at Rome is 440 feet, above the sea level. Thence the Iroquois beach in its course northward adjacent to the eastern end of lake Ontario has a gradual ascent, determined from leveling by Mr. G. K. Gilbert and the present writer, of about five feet per mile along a distance of 55 miles to the latitude of Watertown, where the highest beach is 730 feet above the sea, showing that a differential uplift of about 290 feet has taken place, in comparison with the Rome outlet. From Rome westward to Rochester, the beach has nearly the same hight with the outlet; but farther westward it descends to 385 feet above the sea at Lewiston and 363 feet at Hamilton, at the western end of lake Ontario. Continuing along the beach north of the lake, the same elevation as the Rome outlet is reached near Toronto, and thence east-northeastward an uplift is found, according to Spencer's leveling, similar to that before described east of the

*J. D. Dana, Trans. Conn. Acad. of Arts and Sciences, vol. ii, 1870, p. 67; Am. Jour. Sci., III, vol. x, pp. 168-183, Sept., 1875. Warren Upham, Glacialists' Magazine, vol. i, pp 236-240, June, 1894.

lake, its amount near Trenton and Belleville above Rome being about 240 feet. It is to be added that northward from Rome the Iroquois beach becomes divided into a series of distinct beaches, marking stages in the northeastward rise of the land and having near Watertown a vertical range of 80 feet below the highest and oldest, which was before noted; and that westward a similar series of strand lines also lies below the highest, likewise before noted, which there, however, contrary to the order northeastward, was the newest. The highest beach near Watertown was probably contemporaneous with the fossiliferous beds of Toronto; some of the intermediate northeastern beaches corresponded to the delta deposits of Scarboro; and the lowest northeastward lake level was continuous with the highest at Toronto, Hamilton, Lewiston, and east to Rome.

Between lakes Warren and Lundy the old water level near the west end of lake Ontario fell 125 feet, minus some amount to be subtracted for the progressing northeastward elevation of the land. The two Lundy shores are 30 feet apart vertically. From the lower and main Lundy beach the water fell about 480 feet to the earliest stage of lake Iroquois when the Toronto fossil shells lived in the edge of that lake, excepting that here again some undetermined amount must be subtracted to compensate the concurrent rise of the land. Adding these vertical intervals together, we have 635 feet, which probably may be reduced 100 feet, more or less, for the effects of the accompanying epeirogenic uplift. We have left some 500 or 550 feet, to be subtracted from the altitude of the old Chicago outlet of lake Warren, believed to have been then approximately as now, 590 feet above the sea, to give the earliest altitude of the Rome outlet. It thus appears, as I concluded from a similar computation four years ago, that the Rome outlet was at first only 50 or 100 feet above the sea level.* It was gradually uplifted, participating in the differential rise of the whole Ontario basin, to about 300 feet above the sea while the outflow continued here, and to probably 350 feet or more, lacking less than 100 feet of its present hight, by the time when the much farther retreat of the ice permitted the extension of the sea to Ogdensburgh and Brockville, on the St. Lawrence river near the mouth of lake Ontario. Intermediate between lake Iroquois and the Champlain incursion of the sea, the glacial lake St. Lawrence, into which lake Iroquois was merged by the retreat

* Bulletin Geol. Soc. Am., vol. ii, pp. 260-262.

of the ice-sheet from the northern side of the Adirondacks, filled the lake Ontario basin for a considerable time at levels below the Iroquois beaches.

As the area of lake Warren was being differentially much elevated during the earlier existence of that lake, and as the area of lake Algonquin was similarly uplifted in part or wholly contemporaneously with the Iroquois basin, so this region was being rapidly raised and tilted upward to the north and east while the lake level, held constantly without important downward cutting at the Rome outlet, inscribed many shore lines on the slowly moving land. All the movement throughout the whole region probably was upward; but the position of Rome, and its greater rise than western parts of the basin during the existence of lake Iroquois, caused the old beaches westward to have now declining gradients.

*Lake Hudson-Champlain.**—The absence of marine fossils in beds overlying the glacial drift on the shores of southern New England, Long Island, and New Jersey, and the water-courses which extend from the terminal moraine on Long Island southward across the adjacent modified drift plain and continue beneath the sea level of the Great South bay and other bays between the shore and its bordering long beaches, prove that this coast stood higher than now when the ice-sheet extended to its farthest limit. A measure of this elevation of the seaboard in the vicinity of New York during the Champlain epoch is supplied, as I believe, by the shallow submarine channel of the Hudson, which has been traced by the soundings of the U. S. Coast Survey from about 12 miles off Sandy Hook to a distance of about 90 miles southeastward. This submerged channel, lying between the present mouth of the Hudson and the very deep submarine fjord of this river, ranges from 10 to 15 fathoms in depth, with an average width of $1\frac{1}{4}$ miles, along its extent of 80 miles, the depth being measured from the top of its banks, which, with the adjacent sea-bed, are covered by 15 to 40 fathoms of water, increasing southeastward with the slope of this margin of the continenal plateau. During the whole or a considerable part of the time of the glacial lake Iroquois, this area stretching 100 miles southeastward from New York

* Warren Upham, Bulletin Geol. Soc. Am., vol. i, p. 566; vol. ii, p. 265; vol. iii, pp. 484-487 (first using this name). C. H. Hitchcock, Geology of Vermont, 1861, vol. i, pp. 93-167, with map. J. S. Newberry, Pop. Sci. Monthly, vol. xiii, 1879, pp. 641-660. F. J. H. Merrill, Am. Jour. Sci., III, vol. xli, pp. 460-466, June, 1891. W. M. Davis, Proc. Boston Soc. Nat. Hist., vol. xxv, 1891, pp. 318-334. S. Prentiss Baldwin, "Pleistocene History of the Champlain Valley," Am. Geologist, vol. xiii, pp. 170-184, with map. March, 1894. Baron de Geer, as cited for lake Iroquois.

was probably a land surface, across which the Hudson flowed with a slight descent to the sea. But northward from the present mouth of the Hudson the land at that time stood lower than now; and the amount of its depression, beginning near the city of New York and increasing from south to north, as shown by terraces and deltas of the glacial lake Hudson-Champlain, which were formed before this long and narrow lake became merged in the glacial lake St. Lawrence, was nearly 180 feet at West Point, 275 feet at Catskill, and 340 feet at Albany and Schenectady. From these figures, however, we must subtract the amount of descent of the Hudson river, which in its channel outside the present harbor of New York may probably have been once 50 or 60 feet in its length of about 100 miles.

Before the time of disappearance of the ice-barrier from the St. Lawrence valley at Quebec, the descent of the Hudson river beyond New York city may have diminished, or the seaboard at New York may have sunk so as to bring the shore line nearly to its present position; but the Hudson valley meanwhile had been uplifted, so that the outflow from the lake St. Lawrence crossed the low divide, now about 150 feet above the sea, between lake Champlain and the Hudson. This is known by the extension of fossiliferous marine deposits along the lake Champlain basin nearly to its southern end, while they are wholly wanting along all the Hudson valley. Indeed, the outflowing river from lakes Iroquois, Hudson-Champlain, and St. Lawrence, or the Hudson during the Postglacial period, channeled the lower part of this valley to a depth of about 100 feet below the present sea level, proving that the land there, as Merrill points out, stood so much higher than now at some time after the ice retreated.

According to the observations of Davis, Baldwin, and Baron de Geer, the highest shore line of the lake Hudson-Champlain is now elevated to about 275 feet above the sea at Catskill, N. Y.; 550 feet in Chesterfield, N. Y., on the west side of lake Champlain opposite to Burlington; and 658 feet at St. Albans, Vt. Assuming that the mouth of the lake, near New York City, was 50 feet above the sea, the differential northward uplift of the originally level shore has been at the rate of about two feet per mile for the 100 miles from the present mouth of the Hudson to Catskill; 1.7 feet per mile for the next 160 miles north to Chesterfield; and about three and a half feet per mile in the next 30 miles north-northeastward to St. Albans. Perhaps a higher beach may exist in Chesterfield, which would bring these gradients nearer to uniformity. The series noted there by Baldwin comprises eight beaches referable to the successive water levels of lake Hudson-Champlain, lake St. Lawrence, and the sea in the Champlain basin, their hights above the sea level of to-day being 550 feet, 530, 470, 423, 386, 365, 335, and 290 feet. The mean level of lake Champlain is 97 feet above the sea, and its maximum depth 402 feet. The lower four of these beaches belonged to the Champlain arm of the enlarged Gulf of St. Lawrence, as shown by the hight of its sand deltas and associated fossiliferous clays; but the higher four represent stages of the lakes Hudson-Champlain and St. Lawrence. These shore lines, like those of the glacial lakes farther west to lake Agassiz, were probably formed during times of rest or slackening in the somewhat intermittent epeirogenic elevation of the land.

*Lake St. Lawrence.**—The records of the Glacial and Champlain epochs in the St. Lawrence valley have been most fully studied during many years by Sir William Dawson, to whose work chiefly we are indebted for detailed descriptions of the evidences of the marine submergence of that region to a maximum hight at Montreal somewhat exceeding 500 feet above the present sea level. Earlier than that time of occupation of the depressed broad valley by the sea, it was filled from lake Ontario to near Quebec, by a great glacial lake, held on its northeast side by the receding continental ice-sheet. The directions of the glacial striæ and transportation of the drift in the St. Lawrence valley, running southwestward at Montreal and onward to the great lakes, but eastward from Quebec down the shores of the Gulf of St. Lawrence, and southeast across Nova Scotia and New Brunswick, show that the latest remnant of the ice barrier blockading this valley was melted away in the neighborhood of Quebec, then admitting the sea to a large, low region westward. Until this barrier was removed, a glacial lake, which here for convenience of description and citation is designated as the lake St. Lawrence, dating from the con-

*Sir J. William Dawson, the Canadian Ice Age (Montreal, 1893), pp. 301, with maps and sections, views of scenery, and nine plates of Pleistocene fossils. This volume sums up the author's work since 1855 on the glacial drift and associated lacustrine and Champlain marine formations of the St. Lawrence valley, embodying the studies which had been published in many papers in the "Canadian Naturalist and Geologist" and elsewhere. He had given a similar summary in a pamphlet of 112 pages, "Notes on the Post-pliocene of Canada," in 1872. J. W. Spencer, G. K. Gilbert, Baron de Geer, S. Prentiss Baldwin, and Warren Upham, as before cited for lakes Warren, Algonquin, Iroquois, and Hudson-Champlain.

fluence of lakes Iroquois and Hudson-Champlain and growing northward and eastward, spread over the Ottawa valley probably to the mouth of the Mattawa, and down the St. Lawrence, as fast as the ice-front was melted back.

When lake Iroquois ceased to outflow at Rome and, after intervening stages of outlets existing for a short time at successively lower levels north of the Adirondacks, began to occupy the Champlain basin and the St. Lawrence valley northward, changing thus to the lake St. Lawrence, its surface fell by these stages about 250 feet to the glacial lake Hudson-Champlain, which had doubtless reached northward nearly to the St. Lawrence. After this reduction of the water body in the Ontario basin, it still had a depth of about 150 feet over the present mouth of lake Ontario, as shown by a beach traced by Gilbert, which thence rises northeastward but declines toward the south and southwest. Its plane, which is nearly parallel with the higher Iroquois beaches, sinks to the present lake level near Oswego, N. Y. Farther southwestward the shore of the glacial lake at this lower stage has been since submerged by lake Ontario. The Niagara river was then longer than now, and the lower part of its extent has become covered by the present lake. From the time of the union of lakes Iroquois and Hudson-Champlain, a strait, at first about 150 feet deep, but later probably diminished on account of the rise of the land to the depth of about 50 feet, joined the broad expanse of water in the Ontario basin with the larger expanse in the St. Lawrence and Ottawa valleys and the basin of lake Champlain. At the subsequent time of ingress of the sea past Quebec the level of lake St. Lawrence fell probably 50 feet or less to the ocean level. The place of the glacial lake so far westward as the Thousand Islands was then taken by the sea, with the marine fauna which is preserved in the Leda clays and Saxicava sands.

The Champlain Marine Submergence.

That the land northward from Boston was lower than now while the ice-sheet was being melted away, is proved by the occurrence of fossil mollusks of far northern range, including *Yoldia (Leda) arctica* Gray, which is now found living only in the Arctic seas, preferring localities which receive muddy streams from existing glaciers and from the Greenland ice-sheet. This species is plentiful in the stratified clays resting on the till in the St. Lawrence valley and in New Brunswick and Maine, extending southward to Portsmouth, N. H. But it is known that the land was elevated from this depression to about its present hight before the sea here became warm and the southern mollusks, which exist as colonies in the Gulf of St. Lawrence, migrated thither, for these southern species are not included in the extensive lists of the fossil fauna found in the beds overlying the till.

In the St. Lawrence basin these marine deposits reach to the southern end of lake Champlain, to Ogdensburgh and Brockville, and at least to Pembroke and Allumette island, in the Ottawa river, about 75 miles above the city of Ottawa. The isthmus of Chiegnecto, connecting Nova Scotia with New Brunswick, was submerged, and the sea extended 50 to 100 miles up the valleys of the chief rivers of Maine and New Brunswick. The uplift of this region from the Champlain sea level was 10 to 25 feet in the vicinity of Boston and northeastward to Cape Ann; about 150 feet near Portsmouth, N. H.; from 150 to about 300 feet along the coast of Maine and southern New Brunswick; about 40 feet on the northwestern shore of Nova Scotia; thence increasing westward to 200 feet in the Bay of Chaleurs, 375 feet in the St. Lawrence valley opposite the Saguenay, and about 560 feet at Montreal; 150 to 400 or 500 feet, increasing from south to north, along the basin of lake Champlain; about 275 feet at Ogdensburgh, and 450 feet near the city of Ottawa. The differential elevation was practically completed, as we have seen from the boreal character of the Champlain marine molluscan fauna, shortly after the departure of the ice-sheet. With the areas of the glacial lakes Agassiz, Warren, and Iroquois, in the interior of the continent, this coastal region gives testimony of a wave-like epeirogenic elevation of the formerly ice-laden portion of the earth's crust, proportionate with the glacial melting and closely following the retreat of the ice from its boundaries of greatest extent inward to the areas on which its waning remnants lingered the latest.

On the Green Mountains of Vermont, the White Mountains region, and indeed probably over a large part of New England, a tract of the departing ice-sheet remained after the access of the sea to the St. Lawrence basin left the New England ice as an isolated mass. This is known by the large tribute of stratified drift quickly brought by streams from the melting ice of the Green Mountains area and deposited as gravel and sand deltas and offshore clays of the Winooski, La Moille, and Missisquoi rivers, described by Hitchcock and Baldwin, in the east border of the Champlain arm of the sea. On the west, too, a considerable remnant of the ice-sheet seems to have remained unmelted until this time on the Adirondacks, and to have likewise supplied the deltas and marine clays of the Au Sable, Saranac, and Chazy rivers in New York. Deflections of glacial striation down the valleys, with corresponding drift transportation and formation of local moraines across some of the mountain valleys, have been recorded by Hitchcock, Stone, and others, in Vermont and New Hampshire; but the time allowed for such glacial action, under the warm Champlain climate, was very short. The earlier melting of the ice along the St. Lawrence valley than on these mountain tracts was due on one side to the laving action of the waves of lakes Iroquois and St. Lawrence, and on the other side to the washing of the ice-cliffs by the fast encroaching sea in the Gulf of St. Lawrence, until at last near Quebec the barrier was severed.

From the Champlain submergence our Atlantic coast was raised somewhat higher than now; and its latest movement from New Jersey to southern Greenland has been a moderate depression. The vertical amount of this postglacial elevation above the present hight, and of the recent subsidence, on all the coast of New Jersey, New England, and the eastern provinces of Canada, is known to have ranged from 10 feet to a maximum of at least 80 feet at the head of the Bay of Fundy, as is attested in many places by stumps of forests, rooted where they grew, and by peat beds now submerged by the sea. As in Scandinavia, the restoration of isostatic equilibrium is attended by minor oscillations, the conditions requisite for repose having been overpassed by the early re-elevation of outer portions of each of these great glaciated areas. The close of the Ice age was not long ago, geologically speaking, for equilibrium of the disturbed areas has not yet been restored.

MEASUREMENT OF THE POSTGLACIAL PERIOD BY THE RECESSION OF NIAGARA FALLS.

Gilbert has recently expressed his doubt that the past rate of erosion of the gorge below the receding falls of Niagara can be so compared with the present rate as to afford any approximate measure of the time which has elapsed since the Ice age.* His first study of this question† gave about 7,000 years for the erosion of the Niagara gorge, if it had proceeded

*Nature, vol. 50, p. 53, May 17, 1894.
†Proc. Am. Assoc. for Adv. of Science, vol. xxxv, for 1886, pp. 222, 223.

with an average rate like the present. As this erosion began at the time of retreat of the ice-sheet from that area and has been in progress during all the subsequent time, it has been regarded as a geologic chronometer, like the similar erosion of the gorge below the falls of St. Anthony, from which Prof. N. H. Winchell had previously computed the length of the Post-glacial period in Minnesota to be about 7,800 years. On the other hand, Spencer gives the results of his computation of the duration of the Niagara falls and gorge as about 32,000 years.*

The largest element of uncertainty (as hitherto supposed) in the estimate drawn from the rate of recession of Niagara falls is shown by Gilbert's second and more full discussion,† to consist in the probability or possibility that for some considerable time, next following the melting away of the ice upon the area crossed by the Niagara river, the outlet of lakes Superior, Michigan, and Huron, may have passed to the St. Lawrence by a more northern course, flowing across the present watershed east of lake Nipissing to the Mattawa and Ottawa rivers. The Niagara would then have been a small river, being left with only a small area of drainage and consequently capable of only slow erosion of its gorge. This condition Spencer supposes to have lasted no less than 24,000 years, or three-fourths of the time which he allows for the whole of the gorge erosion. Against this hypothesis, the investigation here presented seems to bring important and decisive objections.

First we must note that the views held by Spencer and Taylor, that the high shore lines around the great Laurentian lakes are of marine formation, is inconsistent with the total absence of marine fossiliferous beds overlying the glacial drift throughout the basins of these lakes. Instead, fresh-water molluscan shells are found in the beaches and offshore deposits of lakes Warren, Algonquin, and Iroquois, as noticed in these pages. ‡ So far as the sea did extend, after the farther recession of the ice-sheets permitted it to come into the St. Lawrence and Ottawa valleys and into the basin of lake Champlain, marine fossils abound; but none are found above the Thousand Islands, which lie in the St. Lawrence at the mouth of lake Ontario. We may, therefore, confidently accept the Niagara

* Am. Geologist, vol. xiv, pp. 298-301, with longitudinal section of the Niagara gorge, Nov., 1894; Am. Jour. Sci., III, vol. xlviii, pp. 455-472, with maps and sections, Dec., 1894.

† "History of the Niagara River," before cited with reference to lake Warren.

‡ Fresh-water shells are also found in the beaches of lake Agassiz (Geol. and Nat. Hist. Survey of Canada, Ann. Rep., new series, vol. iv, for 1888-89, p. 49 E).

gorge as a measure of all the time since that area was uncovered from the ice-sheet.

The foregoing review of the departure of the ice-sheet from the St. Lawrence basin, and of the accompanying wave-like uplift, shows clearly that New York and New England were the last portions of the United States, at least eastward from the Rocky mountains, to be uncovered from the fast waning continental glacier. When lake Warren attained its greatest extent, the ice-sheet had melted off from all the northern United States west of lake Nipissing and Buffalo, N. Y.; but yet, to hold this glacial lake on the east, it remained unmelted upon the Niagara and lake Ontario or Iroquois area. Thus we see that all the moraines within the limits of the United States west of the great angle of the drift boundary near Salamanca, in southwestern New York,* are somewhat older than the moraines east of that angle, in New York, Pennsylvania, New Jersey, Long Island, and New England. The difference in age, however, between the western and eastern moraines and drift was, perhaps, no more than 500 to 1,000 years, as we may infer from the rate of retreat of the portion of the ice-front forming the northern barrier of lake Agassiz.

This view of the order of going of the ice-sheet finds meteorological explanation as follows: Doubtless the prevailing course of storms during the Glacial and Champlain epochs, as at the present time, was from west to east and northeast. With the restoration of a temperate climate by the subsidence of the land to its present hight or lower, the sunshine and rains began to melt the ice away. Its border in general retreated and became steeper, but with interruptions, ranging in length from decades to centuries, when the snow accumulation and ice outflow caused important extensions of the glaciation. The warm air currents, bringing rain storms and therefore rapidly melting the front of the ice where they first swept over it at the west, would, however, be chilled as they passed onward, giving principally snowfall on more eastern parts of the ice margin. The western ice-melting also contributed much to the supply of moisture for this snowfall from the eastwardly moving storms. Hence, the eastern great ice-lobe, from Salamanca to Long Island, Cape Cod, and the Gulf of Maine, would be fed and fattened to be thick and spread in some places

* Consult Prof. Chamberlin's maps of the glaciated areas of the United States, U. S. Geol. Survey, Third Annual Report, Plates xxviii and xxxiii; Seventh An. Rep., Plate viii.

even beyond its previous limits, while all of the ice-sheet farther west in the United States was being melted away. *

Another unexpected conclusion, relative to the volume of the Niagara river while the ice-sheet was departing, is brought by our consideration of the uplift of the northern side of the glacial lake Warren, which along its extent of 600 miles from west to east was rapidly raised in general about 350 to 400 feet, as compared with the Chicago outlet, before the date of the Algonquin beach. In the vicinity of lake Nipissing this beach is 100 feet above that lake, or 743 feet above the sea, being so high, 50 feet upon a width of more than a mile, above the watershed east of the lake leading to the Mattawa and Ottawa rivers, that I cannot believe a river of such depth and width to have there outflowed. Instead, I think that the ice-sheet then still remained as a barrier upon the Mattawa and Ottawa areas; and that the earliest outflow from lake Algonquin went southward by way of the present St. Clair and Detroit rivers and thence east along the bed of lake Erie, as soon as the glacial lake Lundy was drained away, to the incipient Niagara and lake Iroquois. Eight-ninths of all the uplifting of the Nipissing area which carried its watershed above the hight at which it could be an outlet of lake Algonquin had taken place before the Niagara river and lake Iroquois began to exist. Later, while yet the ice was a barrier on the Mattawa area, I believe that the continuation of that uplift fully raised the Nipissing-Mattawa divide above lake Algonquin, for meanwhile the lake Iroquois area was undergoing a large differential uplift of increasing amount from south to north and from west to east. Further evidence that the ice border remained upon the high area between lake Ontario and Georgian bay, turning the waters of lake Algonquin southward and eastward to the Niagara river, until lake Iroquois began to exist with a level in its western part nearly like that of the present lake Ontario, is afforded, as previously shown, by the alternating fossiliferous beds and till deposits of Toronto and Scarboro. The Niagara river and falls thus appear to have had a volume equal to the present during their entire history. If there was any time of diversion of the waters of the upper Laurentian lakes to the Mattawa valley, it was of very brief duration, oc-

* On a smaller scale, during the melting of the ice-sheet in Minnesota, important snow accumulation on the east side of the Minnesota ice-lobe caused its extension while its western side was retreating, as noted, with explanation partly as here given, in Proc. Am. Assoc. for Adv. Science, vol. xxxii, for 1883, pp. 231-234, and Geology of Minnesota, Final Report, vol. ii, pp. 254-256, 409-413.

curring after some longer time of southward flow through the lake Erie basin, and would require only an insignificant addition to the estimate of 7,000 years, as given by Gilbert in 1886, for the duration of the Niagara river and of the Postglacial period.*

The great depth of the Niagara river (having a maximum sounding of 185 feet) at the foot of the falls, and for nearly two miles to the head of the Whirlpool rapids, has been regarded by Gilbert as a corroboration of the hypothesis that the volume of the river was for a long time greatly diminished by a Mattawa outlet from the upper lakes.† The deep excavation below the river level in the more recently eroded part of the Niagara gorge near the falls, analogous to pot-hole erosion, he attributes to a probably larger volume of the river than that which previously formed the shallower and longer portion of the gorge, excepting only at the Whirlpool, where the postglacial gorge coincides with one of preglacial age.‡ The greater thickness of the Niagara limestone, however, may probably account chiefly, as I think, for the deeper excavation by the cataract now than during the early part of its recession. Large blocks of this limestone doubtless act as pestles performing the very deep erosion under the impact of the falling water (an explanation suggested by McGee and published by Gilbert); and the much jointed superficial portion of the limestone may be less serviceable for this work than the deeper beds which were reached along this upper part of the gorge.

Relation of the Champlain Epoch to the Quaternary Era.

The duration of lake Agassiz, probably about 1,000 years, as estimated from the total wave erosion and resulting accumulation of beach gravel and sand on its shores, in comparison with those of lake Michigan during all the time since the recession of the ice-sheet,§ well confirms the earlier conclusion by Dana, from his studies of the valley drift along the river courses of

*Andrew M. Hansen (in the Journal of Geology, vol. ii, p. 142, Feb.-March, 1894) notes the approximate concurrence of about thirty independent measurements and estimates of the length of the Postglacial period which have been made in North America and Europe, all coming within the limits of 5,000 and 12,000 years.

†International Congress of Geologists, Report of the Fifth Session, Washington, 1891 (published 1893), pp. 455-458, with map.

‡Julius Pohlman has written on the preglacial erosion along the course of the Niagara, in Proc. A. A. A. S, vol. xxxv, for 1886, pp. 221, 222.

§Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv. for 1888-89, pp. 50, 51 E.

southern New England, that the retreat of the ice and deposition of its drift were very rapid. On the intervening area of the great Laurentian lakes all the observations here brought into correlation and historic sequence give similar testimony of the geologic brevity of the Champlain epoch. The moderate re-elevation from the Champlain depression was mostly accomplished by an epeirogenic movement advancing like a wave closely in company with the glacial melting and retreat; and both appear to have occupied no more than 4,000 or 5,000 years.

Accepting the estimate that the dates of the retreat of the ice-border past the falls of St. Anthony and Niagara falls were respectively about 8,000 and 7,000 years ago, we may well refer all the final melting of the ice-sheet upon the northern United States and British America, except the existing glaciers of the Cordilleran mountain belt and St. Elias region, to a Champlain epoch from 10,000 to 5,000 years ago. This includes the retreat of the ice from its late southern limits to the Altamont or outermost moraine, with the deposition of the loess and the subsequent uplifting of the Wisconsin driftless area and of the greater part of the upper Mississippi and Missouri region, probably occupying 2,000 years, more or less; the further recession during the existence of lake Agassiz and the glacial lakes of the St. Lawrence basin, with the formation of the many moraines traced across the northern states and some southern parts of Canada, probably 1,500 or 2,000 years; and the melting away of the lingering remnants of the ice-sheet upon Labrador and the country northwest of Hudson bay, perhaps 1,000 or 1,500 years. The northward differential uplifting of the area of lakes Agassiz, Warren, Iroquois, and St. Lawrence, took place very rapidly, the maximum epeirogenic movement upward being apparently from a half of a foot to one foot or more each year during several centuries, first on the southern and southwestern portion of the uplifted region, and thence proceeding to the north and northeast. The uplift was nearly proportional with the removal of the ice weight, and was doubtless due to inflow of the plastic or molten interior of the earth beneath the buoyant crust.

How long a time was needed for the great subsidence introducing the Champlain epoch, it will be more difficult to estimate. Perhaps it may have taken as long as the departure of the ice-sheet and the re-elevation, or it may have required twice that time, being thus some 5,000 to 10,000 years. This was a Late Glacial movement, leading to the end of the Ice age.

The earlier and probably longer part of the Glacial period, while the land had its great altitude causing the snow and ice accumulation on the drift-bearing areas, but with considerable secular climatic fluctuations and therefore retreats and re-advances of the ice-front, may well have included the formation of the early till in Illinois, Indiana, and Ohio, on which Leverett finds a soil and leached subsoil, comparable in thickness with those of the present surface, yet buried under thick deposits of later drift.* To the same time we may also refer the deposition of the flood-plain of glacial gravel and sand whose remnants form the surface of the highest terraces along the upper part of the Ohio river.† Again, in northwestern Illinois, the rock gorges studied by Hershey‡ suggest, like the oxidation, leaching, and soil formation of the early till, and like the great amounts of fluvial sedimentation and subsequent erosion in the Ohio valley, that the Glacial period in the United States was long as measured by years, though short in comparison with all other geologic periods, excepting the Post-glacial. Even with the high altitude favoring powerful stream erosion of the gorges and of the valley drift, the work done indicates probably a duration of the ice-sheet through 30,000 years, more or less, before the subsidence of the land began.

For the early Quaternary time of great elevation, preceding and bringing on the Ice age, we have an estimate of 60,000 to 120,000 years, drawn from the probable rate of deposition of the Lafayette formation in the lower Mississippi valley, and from the ensuing deep erosion of the Lafayette and underlying strata, immediately preceding the ice accumulation and doubtless in part contemporaneous with it.§

These estimates give for the whole Quaternary era some 100,000 or 150,000 years, placing its beginning ten or fifteen times as long ago as that of the Champlain epoch. The Tertiary era appears by the changes of its marine molluscan faunas to have been vastly longer, having comprised perhaps between two and four million years, of which the Pliocene period would be a sixth or eighth part, thus exceeding the

*Proceedings of the Boston Society of Natural History, vol. xxiv, pp. 455-459, Jan. 1, 1890.

†Chamberlin and Leverett, Am. Jour. Sci., III, vol. xlvii, pp. 247-283, with maps and profiles, April, 1894.

‡Am. Geologist, vol. xii, pp. 314-323, Nov., 1893.

§Bulletin, Geol. Soc. Am., vol. v, for 1893, pp. 96-100.

whole of the ensuing era of great epeirogenic movements and resulting glaciation.

DIVISIONS OF QUATERNARY TIME.*

The following table of the several divisions, periods, and epochs of Quaternary time, showing their relationship with the Champlain epoch, which has been reviewed for the region of the Laurentian lakes and river St. Lawrence in this paper, is arranged in the descending stratigraphic order of their geologic formations:

Psychozoic division...	Recent period..........	Recent or Present epoch.
		Terrace epoch.
Pleistocene division...	Glacial period.	Champlain epoch.
		Glacial epoch.
	Lafayette period......	Epoch of great elevation and erosion.
		Lafayette epoch.

Seeking to subdivide the Glacial period or Ice age with reference to its dynamic causes and secular fluctuations in climatic conditions, we find, first, a long epoch of general snow and ice accumulation. In its early part the growth of the ice-sheet was interrupted, at least locally and temporarily, by moderate oscillations of its boundary, as shown by layers of lignite between deposits of till observed by Dr. Robert Bell on branches of the Moose and Albany rivers tributary to the southwest side of James bay.† Later, after the ice-sheet attained its maximum stage in the Mississippi basin, reaching south to northeastern Kansas, central Missouri, and southern Illinois, this epoch included a long interval of extensive retreat of that part of the ice-sheet, followed by renewal of its growth until it again reached far south toward its former limits. This part of the Ice age is well denominated, from its envelopment of the land by ice-sheets, the Glacial epoch. Its chief cause I think to have been uplifts of the glaciated regions thousands of feet above their present hight.

Forest beds and other fossiliferous deposits of the interglacial stage in this epoch are found frequently, and on some large tracts almost continuously, occurring between deposits of the till or glacial drift penetrated by wells, from southwestern Ohio, through Indiana and Illinois, to northeastern Iowa and

*More ample discussion of these time divisions is presented in the Am. Naturalist, vol. xxviii, pp. 979-988, Dec., 1894.

†Geol. Survey of Canada, Report of Progress for 1877-78, p. 4 C; and Annual Report, new series, vol. ii, 1886, p. 38 G.

to Mower county in southern Minnesota.* Less frequent, but still sometimes occupying considerable tracts as shown by several wells near together, these interglacial beds are recorded by my notes of wells in Lyon, Renville, and McLeod counties, Minn., 60 to 90 miles north from the south line of this state. More rare instances of their observation are noted as far north as in Mitchell township, Wilkin county, and Barnesville in the south edge of Clay county, Minn.; and these most northern localities are situated within the area of the glacial lake Agassiz, respectively about 100 feet and 75 feet below its highest and earliest or Herman beach. If the altitude and slopes of the land had been then the same as now, an interglacial lake held by the barrier of the receding ice-sheet must have forbidden the growth of forests or formation of swamp deposits there until the outlet was deeply eroded or much farther glacial recession permitted that lake to be drained away northward. Under those conditions the growth of an interglacial forest at Barnesville would imply probably three to six times more glacial melting and recession than otherwise would suffice to account for the most northern of these observed interglacial deposits. It therefore seems to me more likely that during this glacial retreat the present basin of the Red river of the North, which was later occupied by lake Agassiz, had a considerably greater altitude than now, retaining a part, probably a large part, of its preglacial elevation, and that it was thus a land surface with southward descent and free drainage along the Minnesota river valley to the Mississippi. The recession of the ice-sheet, before its renewed growth, may then have reached only to the southern part of the Red river valley, instead of the great farther distance to Hudson bay which I formerly supposed in writing of these interglacial beds in Minnesota.†

The erosion of numerous and large interglacial stream courses in the early drift sheet of southern Minnesota and northern Iowa, including the Minnesota river valley and its

*W J McGee, Eleventh Annual Report, U. S. Geol. Survey, for 1889-90, Part I, pp. 486-496. Summaries of observations of the interglacial forest beds throughout this region, with discussion of their significance, are given by C. Whittlesey, Smithsonian Contributions, No. 197, vol. xv, 1864, pp. 13-15; J. S. Newberry, Geology of Ohio, vol. ii, 1874, pp. 30-33; N. H. Winchell, Proc. A. A. A. S., vol. xxiv, for 1875, Part II, pp. 43-56; G. F. Wright, The Ice Ace in North America, 1889, pp. 475-496; Frank Leverett, Proc. Boston Soc. Nat. Hist., vol. xxiv, pp. 455-459, Jan. 1, 1890, and Journal of Geology, vol. i, pp. 129-146, with map, Feb.-March, 1893. N. H. Winchell, Geology of Minn., Final Report, vol. i, 1884, pp. 313, 363, 390.

†Geology of Minn., Final Report, vol. i, 1884, pp. 402, 406, 466, 479-485, 507, 511, 552, 580, 581, 585-6, 609, 625; vol. ii, 1888, pp. 138, 186, 187, 199, 466, 529, 555, 662, 668.

continuation past Brown's Valley and above the bed of lake Traverse, channeled then apparently about 50 feet (or more) below the general surface of the adjoining country to the level of the Herman beach of lake Agassiz,* finds full explanation in this retreat of the ice-sheet to the vicinity of Mitchell and Barnesville, 200 to 250 miles inward from its farthest limits in North Dakota and on the northern boundaries of the Wisconsin driftless area, but 500 miles north from its limits in Kansas and Missouri.

During the ensuing stage of its renewed accumulation and growth, the ice-sheet reached from Barnesville about 200 miles westward into North Dakota, an equal distance eastward into northwestern Wisconsin and southeastern Minnesota, and some 350 miles or more south-southeastward in Iowa. Not only were the interglacial forest beds thus covered, but a marginal moraine, which had been formed probably during a slight pause or re-advance interrupting the later part of the intermediate glacial retreat, was likewise buried and is now indicated by exceptionally abundant boulders in a stratum of the drift shown in the cliffs of the upper part of the Minnesota river valley and by its tributaries, overspread by 25 to 50 feet of the later deposits of till.†

The two stages of growth of the ice-sheet may have been due, aside from their principal dependence on the high elevation of the land, to the climatic effects of the last two passages in the precession of the equinoxes, with accompanying nutation, bringing the winters of the northern hemisphere in aphelion about 30,000 years ago and again about 10,000 years ago. The intermediate time of the earth's northern winters in perihelion would be the stage of great retreat of the ice margin in the upper Mississippi region; but eastward, from Ohio to the Atlantic coast, there appears to have been little glacial oscillation.‡ This explanation accords with Prof. N.H. Winchell's computations from the rate of recession of the falls of St. Anthony for the Postglacial or Recent period,§ and with his estimate of the duration of the interglacial stage from the now buried channel which appears to have been then eroded

*Proc. Am. Assoc. for Adv. of Science, vol. xxxii, for 1883, pp. 222-227. Geology of Minn., vol. i, pp. 479-485, 507, 580; vol. ii, pp. 134, 172, 216, 519-525.

†Geology of Minn., vol. i, p. 626.

‡J. D. Dana, Am. Jour. Sci., III, vol. xlvi, pp. 327-330, Nov., 1893.

§Geol. and Nat. Hist Survey of Minnesota, Fifth Ann. Rep., for 1876, pp. 175-189; Final Report, vol. ii, 1888, pp. 313-341, with fifteen plates (views showing recent changes of the falls of St. Anthony, and maps). Quart. Jour. Geol. Soc., London, vol. xxxiv, 1878, pp. 886-901.

by the Mississippi river a few miles west of the present gorge below these falls.*

The chief cause of the Ice age is here thought to have been a high epeirogenic uplift; but the very noteworthy subdivision of the Glacial epoch in the upper Mississippi basin is ascribed to climatic conditions resulting from the same astronomic cycle of 21,000 years which Croll supposed to have been efficient, during the remote time of maximum eccentricity of the earth's orbit, to produce alternating glacial and interglacial epochs. Wallace, in his discussion of this subject in "Island Life," thinks that great altitude of the glaciated countries coincided with the last stage of maximum eccentricity, from 240,000 to 80,000 years ago, to cause the Ice age, altitude and eccentricity being thought perhaps of nearly equal influence. The view here presented looks on the Glacial period as occurring in a much later time of low eccentricity, and for its causation regards altitude as far more efficient than any astronomic conditions. The effects of varying astronomic conditions have been recently reconsidered by Dr. George F. Becker,† who thinks, altogether differently from Croll, Geikie, and Ball, that the combination of minimum eccentricity of the earth's orbit and maximum obliquity of the ecliptic is most favorable for snow and ice accumulation; and he states that these conditions have existed within the past 40,000 years, until 8,000 years ago, but he apparently would attribute a larger share of the causes of glaciation to geographic conditions, as land elevation. In Europe a very remarkable parallelism of the history of the Ice age with that in America‡ indicates dependence on similar causes, chiefly geographic, as epeirogenic movements, with changes of ocean currents, and subordinately astronomic.

This view, and the following tabulation of the Pleistocene glacial and interglacial epochs and stages in America may show good ground for compromise and harmony between the lately opposing doctrines of unity and of duality or greater complexity of the Ice age. If this period extended through 30,000 or 50,000 years, depending principally on epeirogenic uplifts and in less degree on the cycles of precession of the equinoxes, it would agree well with Geikie's and Chamberlin's

*Am. Geologist, vol. x, pp. 69-80, with three plates (sections and a map), Aug., 1892.

†Am. Jour. Sci., III, vol. xlviii, pp. 95-113, Aug., 1894.

‡James Geikie, The Great Ice Age, three editions, 1873, 1877, and 1894, notably pp. 774, 775, in the third edition; Journal of Geology, vol. ii, p. 739, Oct.-Nov., 1894; Am. Geologist, vol. xv, p. 54, Jan., 1895.

complex history of wavering glaciation, and also with its essential geologic unity and brevity which have been insisted on by Dana, Wright, Hitchcock, Lamplugh, Kendall, Falsan, Holst, Nikitin, and other glacialists. To my mind the diversity and the unity of this period seem like the opposite gold and silver sides of the proverbial shield, concerning which two knights, each having seen only one side, valiantly contended.

Widely extended depression of the ice-burdened land, until mostly it had somewhat less altitude than now, initiated the comparatively short final epoch of the Glacial period. Temperate and warm climatic conditions on the ice border, nearly as now on the same latitudes, then melted away the ice rapidly; its chief stage of loess deposition attended the early part of this glacial retreat; the partially unburdened land began to rise by a moderate uplift, approximately proportional to the glacial melting and nearly keeping pace with it; and conspicuous belts of morainic drift were amassed whenever the steep waning ice-front slackened its departure, or halted, or for any short time re-advanced. The general but fluctuating retreat of the ice-sheet at length uncovered all the country and constituted the closing or Champlain epoch of the Ice age, so named from the marine beds of that time overlying the till in the basin of lake Champlain and along the St. Lawrence and Ottawa valleys, by which the vertical extent of the subsidence terminating the Glacial period and of the succeeding re-elevation is measured.

Adopting the helpful new nomenclature proposed by Chamberlin,* we may provisionally formulate the minor time divisions of the Glacial and Champlain epochs as follows. The order of this table, as of the former more comprehensive one, is stratigraphic, so that for the advancing sequence in time it should be read upward.

NOTE. If we seek to compare this table with the Glacial series in Europe, it should first be remarked that in the Alps there were three chief stages of growth of the glaciers far beyond their present limits, the second being the maximum advance, doubtless contemporaneous, as shown by Geikie, with the maximum extension of the ice-sheet upon northern Europe. The first glacial stage of the Alps, which also appears to have left traces in southern Sweden not wholly obliterated by the next and greater glaciation, may be represented in America by the till beneath

*In two chapters (pages 724-775, with maps forming plates xiv and xv) of J. Geikie's "The Great Ice Age," third edition, 1894, Prof. T. C. Chamberlin proposes a chronologic classification of the North American drift under three formations, named in the order of their age, beginning with the earliest, the Kansan, East Iowan, and East Wisconsin formations.

the interglacial lignite in the basin of James bay, and these may belong to the time of northern winters in aphelion some 50,000 years ago. The second, third, and fourth glacial stages of the European Ice age, as tabulated by Geikie, are then seen to be wholly analogous in characteristics of ice extension and drift deposition, and they were probably also time equivalents, respectively, with the Kansan, Iowan, and Wisconsin stages in the United States and Canada. In each continent the interglacial time between the Kansan and Iowan stages had great subaërial erosion because of the continuing high elevation of the land; and the latest or moraine-forming stage of the glaciation seems, alike in Europe and America, to have belonged to the mainly rapid but fluctuating final retreat of the ice, showing, as I think, that each ice-sheet had in its lower part much englacial drift.

Epochs and Stages of the Glacial Period.

CHAMPLAIN EPOCH. (Land depression; disappearance of the ice-sheet; partial re-elevation of the land.)	WISCONSIN STAGE.. (Progressing re-elevation.)	Moderate re-elevation of the land, advancing as a permanent wave from south to north and northeast; continued retreat of the ice along most of its extent, but its maximum advance in southern New England, with fluctuations and the formation of prominent marginal moraines; great glacial lakes on the northern borders of the United States; slight glacial oscillations, with temperate climate nearly as now, at Toronto and Scarboro'; the sea finally admitted to the St. Lawrence, Champlain, and Ottawa valleys; uplift to the present hight completed soon after the departure of the ice. (The great Baltic glacier, and European marginal moraines.)
	CHAMPLAIN SUBSIDENCE....	Depression of the ice-covered area from its high Glacial elevation; retreat of the ice from its former Iowan limits; abundant deposition of loess.
GLACIAL EPOCH... (Ice accumulation, due to the culmination of the Lafayette epeirogenic uplift.)	IOWAN STAGE......	Renewed ice accumulation, covering the forest beds and extending south nearly to its early boundary. (Third European glacial stage.)
	INTERGLACIAL STAGE...........	Extensive glacial recession in the upper part of the Mississippi basin; cool temperate climate and coniferous forests up to the waning ice border; much erosion of the early drift.
	KANSAN STAGE.....	Maximum extent of the ice-sheet in the interior of North America, and also eastward in northern New Jersey. (Maximum glaciation in Europe.)
	UNDETERMINED STAGES of fluctuation in the general growth of the ice-sheet.	Including an early glacial recession and re-advance, as shown by beds of interglacial lignite in the region of the Moose and Albany rivers, tributary to James bay. (First glacial stage in the Alps.)

VII.

NOTES ON MINNESOTA MINERALS.

BY CHAS. P. BERKEY.

CONTENTS.

Several minerals already well known in Minnesota and others not recognized in former reports as occurring in this state have been analyzed and reported to the Minnesota Academy of Natural Sciences from time to time. The investigations have been carried on in the laboratories of the University of Minnesota, and the materials furnishing the basis of these notes are among the specimens of the department of geology and mineralogy.

MINERALS FROM AMYGDALOIDAL DIABASE AT GRAND MARAIS.

Nos. 1541 to 1548 inclusive are all from Grand Marais, and together form a group of specimens which was originally a geode in the amygdaloidal diabase at that place. The rock in which the minerals was found is an altered phase of the diabase so well known in the Lake Superior region. The rock attached to the minerals and in immediate contact is of a dark brown color sometimes tinged with green; and the vesicles, filled and partly filled, are so abundant as to make up almost half of the bulk of the rock. All of them, however, are comparatively small, the average being about one-fourth of an inch in length. Most of them are well filled with one or more of the minerals, calcite, laumontite, strigovite, apophyllite and quartz. Among these, laumontite and strigovite fill the greater number of amygdules. Quartz is present in small quantities.

Thin sections of this rock show that the original augitic constituent has entirely disappeared and a greenish chloritic substance has in part taken its place. The feldspar constituent has altered so much that few places are sufficiently fresh to ground a determination upon. Tests indicate labradorite. Quartz is found sparingly, lining some of the cavities and filling some of the small fissures. It also sometimes forms a thin layer between the calcite and the rock.

Chlorite is found scattered throughout the section. It may be, however, that it is not identical with that filling the amygdules.

The calcite is at several places developed into imperfect crystals of dog tooth spar. The greater part, however, is found filling the cavities and spaces between the other minerals. It is almost pure $CaCO_3$, carrying only a trace of $MgCO_3$ and 0.15 per cent. of insoluble matter.

This rock gave the following chemical analysis:

ANALYSIS OF AMYGDALOIDAL DIABASE.

SiO_2	55.40	per cent.
Al_2O_3	22.55	" "
Fe_2O_3	14.67	" "
FeO	3.75	" "
MgO	.74	" "
CaO	1.41	" "
H_2O	.97	" "
Total	99.49	

Apophyllite.

This mineral partially filled the geode with numerous small well formed crystals. It is the first occurrence of the mineral noted in Minnesota. The crystals are partially imbedded in the laumontite and also in direct contact with both the calcite and the rock. All are colorless to white and are transparent to translucent. Few measurements have been made, but the forms are easily determined. The only forms noted are: ∞P, $P\infty$, $0P$, comprising the prism of the second order, pyramid of the first order, and basal pinacoid. Although there are so few forms, there is considerable variety in the degree to which one form in the combination predominates over the other. Some of the surfaces are so heavily striated as to seriously interfere with measurements by reflection. Some of the smallest crystals are very pure and clear. The specific gravity of the best material is 2.34. All the reactions and characters agree with apophyllite.

In obtaining material for analysis a good deal of difficulty was experienced from the laumontite, which penetrates all the crystals to such an extent that only very minute fragments of sufficient purity could be obtained. The centre of nearly every crystal is occupied by needles of pink laumontite, and in thin sections they can be traced even further into the clearest portion. One of the elements usually found in apophyllite, fluorine, was not found in sufficient quantity to estimate, although a trace of it is indicated by qualitative tests.

ANALYSIS OF APOPHYLLITE

SiO_2	52 61	per	cent.
Al_2O_3	.67	"	"
Fe_2O_3	trace.		
CaO	25.22	"	"
MgO	.17	"	"
K_2O	3.03	"	"
Na_2O	1.71	"	"
HFl	trace.		
H_2O	16.17	"	"
Total	99.58		

In this analysis both Al_2O_3 (.67 per cent.) and the trace of Fe_2O_3 are probably due to the minute needles of laumontite that could not be avoided in the selection of material.

Laumontite.

This mineral fills many of the amygdules. It is in fine needles and in places is partially broken down to a powder The needles pierce the calcite as well as the apophyllite. This is one of the most common of the minerals of the amygdaloidal rock at many other places.

ANALYSIS OF LAUMONTITE.

SiO_2	53.87	per	cent.
Al_2O_3	18.06	"	"
Fe_2O_3	.88	"	"
CaO	11.19	"	"
MgO	.45	"	"
K_2O	.29	"	"
Na_2O	.67	"	"
H_2O	13.18	"	"
Total	98.59		

Strigovite.

The chloritic mineral which is referred to strigovite fills many of the amygdules as closely fitting pellets of a soft green substance which does not cling to the walls and can be easily removed entire. The outer smooth surface of each pellet is usually covered with a light brown powdery coating. There is throughout a definite fibrous arrangement shown in thin section. Good sections across these amygdules are difficult to obtain, however, on account of the difference in hardness of the parts. But with the aid of such a section it is not entirely certain that the green alteration product, already referred to in speaking of the rock, scattered in small quantities through the section, is identical with the green mineral filling the amygdules. It resembles in all respects the "viridite", "delessite", "chloritic substance", etc. of writers on these rocks. It was with a good deal of satisfaction that finally a full chemical analysis was completed of this green mineral from the amygdules.

ANALYSIS OF STRIGOVITE.

SiO_2	33.14	per cent.
Al_2O_2	13.22	" "
Fe_2O_3	24.20	" "
FeO	12.19	" "
CaO	1.50	" "
MgO	3.49	" "
H_2O	12.34	" "
Total	100.08	

This chemical analysis agrees more closely with *strigovite* than with any other of the chlorites.

DATOLITE.

No. 1518 is datolite. Several specimens of this mineral have been found on the lake shore near Flood bay in sec. 29, T. 53 N., R. 10 W., by Mr. Brandt and Mr. A. H. Elftman.

The color of the mineral is almost pure white; shape, nodular; texture, compact and very finely crystalline. The specimens show a conchoidal fracture and have an opaque, somewhat earthly appearance. The microscope and thin section reveal a micro crystalline structure. The hardness is about 4.5 and the specific gravity 2.9. Small fragments are easily fusible with intumescence to a clear glass and give off water. All tests agree perfectly for *datolite*.

ANALYSIS OF DATOLITE.

SiO_2	36.90	per cent
Al_2O_3 and Fe_2O_3	1.51	" "
CaO	35.67	" "
B_2O_3 by diff.	20.32	" "
H_2O	5.60	" "
Total	100.00	

The Lake Superior region is the only locality reporting this variety of datolite. These specimens are similar in all physical characters to the mineral reported by Prof. J. D. Whitney* from the vein stuff of the Minnesota mine on the south shore of lake Superior. And the chemical analysis varies but little from that given by Chandler.†

Datolite is found chiefly as a secondary mineral in basic eruptives with such associated minerals as calcite prehnite and various zeolites. All these conditions are met at Flood bay, but so far no specimen of this mineral has been taken from the rock in place. From its occurrence among the pebbles where foreign debris is to some extent mingled with that of local derivation, it is evident that the mineral may have a drift origin. The direction of the later glacial movements would make it possible for these pebbles to be carried from the localities where this variety has long been known, and de posited as drift where they are now found. Therefore the only positive fact of its occurrence in Minnesota is, that datolite is found as nodules among the pebbles on the shore of lake Superior.

TRAVERTINE.

In connection with certain questions relating to the Magnesian series of rocks in Minnesota, the travertines from some of the limestone and dolomyte beds have been investigated. One specimen was selected from the compact travertine as it occurs at Minneapolis to represent a deposit from a limestone. The other is from a similar deposit, occurring near Osceola, Wis., representing the dolomytes. The Minneapolis material is not the product of a typical limestone, although the percentage of $MgCO_3$ is comparatively low. The Osceola material is deposited beside almost a typical dolomyte.

*Amer. Jour. Sci., II, vol. xxviii, pp. 12-13, 1859.
†Ibid., p. 13.

It is beyond my present purpose to discuss any bearing such analyses may have upon those questions which incited the investigation. It is sufficient to give the results of these analyses for the equal benefit of those following similar lines of research.

ANALYSES OF TRAVERTINE.

	Minneapolis.	Osceola.
$CaCO_3$	98.01	98.20
$MgCO_3$	1.44	1.75
Totals	99.45	99.95

MARL.

No. 1549.—Recently upon draining a slough at Fergus Falls, a bed of marl was found beneath about two feet of black mud. The marl bed is reported as having a thickness of from two to two and a half feet. It is a soft loose shell deposit in which many of the shells are still quite well preserved. In color it is light gray. It easily crumbles for the most part to a fine powder. An investigation of this material was desired in order to estimate its value as a fertilizer. And, because like deposits may be found in many other localities, it seems advisable to render some general opinion of their value.

ANALYSIS OF MARL.

Insoluble portion:—largely SiO_2	4.010	per cent.
Soluble portion:—$Al_2O_3+Fe_2O_3$	1.160	" "
CaO	50.402	" "
MgO	2.144	" "
CO_2	41.825	" "
P_2O_5	.126	" "
Loss and organic matter	.333	" "
Total	100.00	

Estimating the lime and magnesia as carbonates we should have the following percentages:

$CaCO_3$	89.744
$MgCO_3$	4.480
$Ca_3P_2O_8$	.275

It is safe to predict that other marl beds in our state will give essentially the same results. The variable constituents would most likely be an increased amount of the insoluble matter and a corresponding decrease of calcium carbonate. Under slightly different circumstances the organic matter is much increased as a natural consequence of the gradual shallowing of the lake or pond and the establishing of conditions favorable to the formation of peat. It is not probable that phosphoric acid is present in any of our marls in sufficient quantity to be of much economic importance. Two other samples of marl taken from other localities give the same reactions, and the different constituents would show little variation from the amounts given above.

In some of the states marl is extensively used as a fertilizer. The most valuable, however, have been the greensands which are much used in New Jersey, and the results of an extended series of investigations are given in the annual report for 1886 by the state geologist. Those points in his conclusions upon the relative value of marls, which bear directly upon the present case, may be briefly stated as follows:

1. The most valuable marls are those which contain the largest percentage of phosphoric acid. The value of this constituent is about 6 cents per pound. The percentage multiplied by 20 will give the number of pounds per ton.

2. The most durable marls are those containing large quantities of carbonate of lime. When a marl crumbles to a fine powder it is more valuable than the coarser material.

3. All forage crops are particularly improved by marls. The green marls are spread upon the surface in the field to the amount of from 100 to 400 bushels per acre. Other marls must be used in larger quantities, but will produce good results.

4. The beneficial effect of one application of green marl has been observed to last for from 12 to 15 years.

One of the best sources of imformation is the work entitled: "Agriculture in some of its Relations with Chemistry," by F. H. Storer. The points of direct importance are condensed into the following:

1. Carbonate of lime tends to prevent puddling of clayey soils. The stone-like clods found in certain qualities of clay are serious hindrances to plant growth and are often improved by marls. After rains clays becomes less sticky.

2. The improvement of the texture of clayey soils is a practical fact of the very first importance.

3. Generally speaking, unless appreciable quantities of phosphoric acid are present, it is only the carbonate of lime in a marl that gives it fertilizing power. Marls can rarely do any harm for there is nothing hurtful in them.

4. The physical condition of the marl has much to do with its value. Easily pulverizable varities are best. They must fall to powder under the action of the atmosphere.

5. Carbonate of lime is helpful for nitrification.

6. "Root crops" are more subject to disease and failure on soils lacking lime. On poor sandy soils the best fertilizers are never so beneficial and lasting in their effect as when marl or lime has been first applied.

The points noted above are sufficiently clear. There is, however, among writers on this subject a wide diversity of views as to the importance and true value of marls. The present tendency is certainly more favorable to them. It is a well-recognized fact among geologists that limestone areas are pre-eminently fertile. It seems reasonable that increasing such constituents in other soils would be invariable beneficial.

In concluding this part of the subject, we must note that calcium carbonate, which forms almost ninety per cent. of the marl, is the material most in question. Therefore marl would prove most beneficial:

1. On poor sandy soils with other fertilizers.
2. On heavy clay soils, chiefly to improve the texture.
3. On soils soured and too acid, in affording the alkaline condition essential to nitrification and the preparation of plant foods.
4. On soils lacking a lime constituent.

The physical condition of the marl is very favorable for easy application and complete crumbling. The ease with which similar marls may be obtained in many places, while other fertilizers are comparatively expensive, will no doubt make this subject more important as an economic question as the need of a fertilizer becomes more apparent.

A point not yet touched upon, and needing only to be mentioned is—that marls of so high a percentage of calcium carbonate will burn to a good lime for local use. In case the soil is not of such nature as to require the marl, this other use may prove of value. In some cases a very good quality of lime can certainly be produced.

Some of the shells in this marl were very well preserved, although all of them are frail. In order to make comparisons with the fauna of our present lakes it became necessary to have the species determined. Accordingly, a sample of the marl including some of the best shells was sent to Mr. H. A. Pilsbry, of Philadelphia, who has reported the following:

1. *Planorbis bicarinatus* Say.
2. " *campanulatus* Say.
3. " *parvus* Say.
4. " *deflectus* Say.
5. " *exacutus* Say.
6. *Limnæa galbana* Say.
7. *Physa elliptica* Lea.
8. *Valvata tricarinata* Say.
9. *Amnicola limosa* Say.
10. " *lustrica* Pilsbry.
11. *Pisidium abditum* Haldeman.
12. *Sphærium*. Fragments only. Species undetermined.

Mr. Pilsbry further remarks that No. 6, *Limnæa galbana* Say, was described from the bed of a small lake in New Jersey and is not known to occur living. It is, however, closely allied to a recent species. There is nothing in the shells to indicate any especially different climate from that of Minnesota or Michigan to-day, although a similar modern pond would be likely to produce certain large species of *Limnæa* in Minnesota, such as *L. stagnalis*, *reflexa*, *palustris*, etc.

All of these species except Nos. 6 and 10, *Limnæa galbana* Say, and *Amnicola lustrica* Pilsbry, have been reported from the lakes and rivers of our state. *L. stagnalis* and *L. palustris* are noted by both Dr. U. S. Grant and Prof. J. M. Holzinger in the 16th Ann. R. of the Minn. Geological and Nat. Hist. Survey. Several species of *Sphærium* have also been reported.

A further examination of this marl, when larger quantities can be obtained, will no doubt add to this list. Until this part of the subject can be more thoroughly investigated no conclusions or remarks can have any definite value.

I am indebted to C. A. Ballard, Supt. of the Fergus Falls schools, for the material with which all the work has been done; and to H. A. Pilsbry, conservator of the conchological section of the Acad. of Nat. Sci., Philadelphia, for his aid in this note.

VIII.

CHEMICAL ANALYSES.

Below are given the results of the chemical work done for the survey since the analyses last reported (19th Ann. Rept., pp. 121-127). These analyses were made by Prof. J. A. Dodge, Prof. C. F. Sidener, Mr. A. D. Meeds and Mr. A. J. Hammond, in the chemical laboratory of the University of Minnesota, and the following report of them was prepared under the direction of Prof. G. B. Frankforter.

Chemical Series No. 217.

Pyroxene. Analysis by C. F. Sidener.

Silica	SiO_2	53.19	per cent.
Alumina	Al_2O_3	2.38	" "
Ferric oxide	Fe_2O_3	9 25	" "
Ferrous oxide	FeO	5.15	" "
Lime	CaO	17.81	" "
Magnesia	MgO	9.43	" "
Potassa	K_2O	.38	" "
Soda	Na_2O	2.63	" "
Water	H_2O	.01	" "
Total		100 23	

Chemical Series No. 218.

"Soft" copper. Analysis by J A. Dodge.

Lead	Pb	slight trace.	
Antimony	Sb	trace.	
Iron	Fe	.06	per cent.
Sulphur	S	.03	" "
Copper (by diff.)	Cu	99.91	" "
Total		100.00	

The "soft" copper is well refined.

Chemical Series No. 219.

"Hardened" copper. Analysis by J. A. Dodge.

Lead	Pb	trace.	
Antimony	Sb	.36	per cent.
Iron	Fe	1.34	" "
Sulphur	S	.33	" "
Phosphorus	P	.01	" "
Copper (by diff.)	Cu	97.96	" "
Total		100.00	

The analysis seems to show that the "hardened" sample is nothing but unrefined or imperfectly refined copper, containing foreign substances derived from the ore.

CHEMICAL SERIES NO. 220.

Iron ore. Analysis by C. F. Sidener.

Silica	SiO_2	10.25	per cent.
Alumina	Al_2O_3	.98	" "
Ferric oxide (Fe=59.241)	Fe_2O_3	84.63	" "
Water	H_2O	4.01	" "
Phosphorus	P	.046	" "
Manganese	Mn	trace.	
Magnesium	Mg	trace.	
Calcium	Ca	none.	
Sulphur	S	none.	
Total		99.916	

CHEMICAL SERIES NO. 221.

Sample of rock. Analysis by C. F. Sidener.

Silica	SiO_2	52.94	per cent.
Alumina	Al_2O_3	14.70	" "
Ferric oxide	Fe_2O_3	2.52	" "
Ferrous oxide	FeO	7.80	" "
Lime	CaO	6.56	" "
Magnesia	MgO	4.49	" "
Potassa	K_2O	.04	" "
Soda	Na_2O	3.09	" "
Carbonic acid	CO_2	4.86	" "
Water	H_2O	2.04	" "
Total		99.04	

CHEMICAL SERIES NO. 222.

Sample of rock. Analysis by C. F. Sidener.

Silica	SiO_2	60.61	per cent.
Alumina	Al_2O_3	16.61	" "
Ferric oxide	Fe_2O_3	1.97	" "
Ferrous oxide	FeO	5.09	" "
Lime	CaO	4.46	" "
Magnesia	MgO	3.10	" "
Potassa	K_2O	.25	" "
Soda	Na_2O	3.11	" "
Carbonic acid	CO_2	1.57	" "
Water	H_2O	2.45	" "
Total		99.22	

CHEMICAL SERIES NO. 223.

Supposed bog manganese. Analysis by J. A. Dodge.

Found only a trace of manganese, the material being clay mixed with peaty matter.

CHEMICAL SERIES NO. 224.

Feldspar. Analysis by J. A. Dodge.

Silica	SiO_2	51.45 per cent.
Alumina	Al_2O_3	31.94 " "
Ferric oxide	Fe_2O_3	trace.
Lime	CaO	14.31 per cent.
Magnesia	MgO	.27 " "
Soda	Na_2O	.85 " "
Potassa	K_2O	.21 " "
Water	H_2O	.68 " "
Total		99.71

CHEMICAL SERIES NO. 225.

Supposed bog manganese. Analysis by J. A. Dodge.

Carbonaceous matter (by equation)		57.16 per cent.
Silica	SiO_2	28.55 " "
Alumina	Al_2O_3	5.19 " "
Ferric oxide	Fe_2O_3	.98 " "
Black oxide of manganese	MnO_2	.48 " "
Total		92.36

CaO, MgO, Na_2O. K_2O, CO_2, SO_3 and P_2O_5 present but not determined quantitatively.

ANALYSIS OF MINERAL WATER.

Sample of water from a deep well at St. James, Minn., at depth of about 500 feet. Analysis by J. A. Dodge.

Mineral matter in suspension	844.47 grains per U. S. gal.
" " " solution	130.88 " " " "
Total	975.35 grains per U. S. gal.

Composition of matter in suspension:

Oxide of iron	large quantity.
Carbonate of lime	small "
Clay	very large quantity.

Composition of matter in solution:

Sulphate of lime	103.19 grains per U. S. gal.
Carbonate of lime	moderate quantity.
" " magnesia	small "
Chloride of sodium	" "
Potash salts	" "

Reaction slightly alkaline.

The water was very turbid with red clay; it was easily clarified by filtration through paper.

CHEMICAL SERIES NO. 226.

Granite. Analysis by J. A. Dodge.

Silica	SiO_2	66.84	per cent.
Phosphoric oxide	P_2O_5	trace.	
Alumina	Al_2O_3	18.22	" "
Ferric oxide	Fe_2O_3	2.27	" "
Ferrous oxide	FeO	.20	" "
Lime	CaO	3.31	" "
Magnesia	MgO	.81	" "
Potassa	K_2O	2.80	" "
Soda	Na_2O	5.14	" "
Water	H_2O	.46	" "
Total		100.05	

CHEMICAL SERIES NO. 227.

Feldspar. Analysis by C. F. Sidener.

Silica	SiO_2	67.99	per cent.
Alumina	Al_2O_3	19.27	" "
Ferric oxide	Fe_2O_3	.82	" "
Lime	CaO	.75	" "
Magnesia	MgO	.02	" "
Potassa	K_2O	3.05	" "
Soda	Na_2O	6.23	" "
Water	H_2O	.90	" "
Total		99.03	

CHEMICAL SERIES NO. 228.

Hornblende porphyryte. Analysis by J. A. Dodge.

Silica	SiO_2	60.32	per cent.
Phosphoric oxide	P_2O_5	.12	" "
Alumina	Al_2O_3	15.80	" "
Ferric oxide	Fe_2O_3	5.42	" "
Ferrous oxide	FeO	.89	" "
Lime	CaO	4.65	" "
Magnesia	MgO	5.08	" "
Potassa	K_2O	1.82	" "
Soda	Na_2O	4.09	" "
Water	H_2O	1.67	" "
Total		99.86	

CHEMICAL SERIES No. 229.

Winnebago meteorite. Analysis by C. F. Sidener.

Silica	SiO_2	38.23	per cent.
Alumina	Al_2O_3	2.39	" "
Ferrous oxide	FeO	5 94	" "
Chromic oxide	Cr_2O_3	.42	" "
Lime	CaO	1.64	" "
Magnesia	MgO	23.20	" "
Potassa	K_2O	.14	" "
Soda	Na_2O	.81	" "
Iron	Fe	23.27	" "
Nickel	Ni	1.67	" "
Cobalt	Co	.07	" "
Manganese	Mn	trace	
Copper	Cu	trace	
Sulphur	S	2.08	" "
Phosphorus	P	0.14	" "
Graphite	C	trace	
Total		100.00	

CHEMICAL SERIES No. 230.

Metallic part of Winnebago meteorite. Analysis by C. F. Sidener.

Iron	Fe	87.05	per cent.
Nickel	Ni	12.28	" "
Cobalt	Co	.217	" "
Copper	Cu	trace	
Phosphorus	P	.028	per cent.
Total		99.575	

CHEMICAL SERIES No. 231.

Pellets from the Winnebago meteorite. Analysis by C. F. Sidener.

Silica	SiO_2	47.71	per cent.
Alumina	Al_2O_3	5.00	" "
Ferric oxide	Fe_2O_3	2.70	" "
Ferrous oxide	FeO	12.07	" "
Lime	CaO	4.86	" "
Magnesia	MgO	27.29	" "
Total		99.63	

Chemical Series No. 232.

Quartz porphyry. Analysis by A. D. Meeds.

Silica	SiO_2	69.70 per cent.
Alumina	Al_2O_2	18.72 " "
Ferric oxide	Fe_2O_3	.65 " "
Ferrous oxide	FeO	.79 " "
Lime	CaO	2.25 " "
Magnesia	MgO	.45 " "
Soda	Na_2O	5.01 " "
Potassa	K_2O	1.68 " "
Water	H_2O	.71 " "
Total		99.96

Chemical Series No. 233.

Granite. Analysis by A. D. Meeds.

Silica	SiO_2	69.34 per cent.
Alumina	Al_2O_3	17.25 " "
Ferric oxide (including FeO)	Fe_2O_3	2.46 " "
Lime	CaO	3.43 " "
Magnesia	MgO	1.18 " "
Soda	Na_2O	4.33 " "
Potassa	K_2O	·71 " "
Water	H_2O	1.17 " "
Total		99.87

Chemical Series No. 234.

"Muscovado." Analysis by A. D. Meeds.

Silica	SiO_2	49.07 per cent.
Alumina	Al_2O_3	17.21 " "
Ferric oxide	Fe_2O_3	.46 " "
Ferrous oxide	FeO	12.68 " "
Lime	CaO	9.66 " "
Magnesia	MgO	3.60 " "
Soda	Na_2O	2.96 " "
Potassa	K_2O	trace.
Carbonic acid	CO_2	2.70 per cent.
Manganese	MnO	trace.
Water	H_2O	1.55 per cent.
Total		99.89

CHEMICAL SERIES NO. 235.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	86.35	per cent.
Alumina	Al_2O_3	.78	" "
Ferric oxide	Fe_2O_3	7.41	" "
Ferrous oxide	FeO	3.46	" "
Lime	CaO	.01	" "
Magnesia	MgO	.05	" "
Potassa	K_2O	.01	" "
Soda	Na_2O	.12	" "
Carbonic acid	CO_2	1.22	" "
Water	H_2O	.01	" "
Total		99.42	

CHEMICAL SERIES NO. 236.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	41.73	per cent.
Alumina	Al_2O_3	4.07	" "
Ferric oxide	Fe_2O_3	14.43	" "
Ferrous oxide	FeO	19.85	" "
Lime	CaO	.02	" "
Magnesia	MgO	4.41	" "
Potassa	K_2O	.02	" "
Soda	Na_2O	.18	" "
Carbonic acid	CO_2	5.76	" "
Water	H_2O	5.65	" "
Organic matter		3.50	" "
Total		99.62	

Also a trace of graphite.

CHEMICAL SERIES NO. 237.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	85.97	per cent.
Alumina	Al_2O_3	.67	" "
Ferric oxide	Fe_2O_3	11.40	" "
Ferrous oxide	FeO	.90	" "
Lime	CaO	.01	" "
Magnesia	MgO	.02	" "
Potassa	K_2O	.01	" "
Soda	Na_2O	.01	" "
Water	H_2O	.30	" "
Total		99.29	

Chemical Series No. 238.

Silica-kaolin. Analysis by C. F. Sidener.

Silica	SiO_2	77.89	per cent.
Alumina	Al_2O_3	13.55	" "
Ferric oxide	Fe_2O_3	1.83	" "
Lime	CaO	trace	
Magnesia	MgO	.36	" "
Potassa	K_2O	.84	" "
Soda	Na_2O	.58	" "
Water	H_2O	4.45	" "
Total		99.50	

Chemical Series No. 239.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	61.57	per cent.
Alumina	Al_2O_3	16.83	" "
Ferric oxide	Fe_2O_3	5.27	" "
Ferrous oxide	FeO	6.41	" "
Lime	CaO	.01	" "
Magnesia	MgO	3.44	" "
Potassa	K_2O	1.59	" "
Soda	Na_2O	.12	" "
Water	H_2O	4.70	" "
Total		99.94	

Chemical Series No. 240.

Taconyte. Analysis by A. D. Meeds.

Silica	SiO_2	23.80	per cent.
Alumina	Al_2O_3	7.95	" "
Ferric oxide	Fe_2O_3	5.97	" "
Ferrous oxide	FeO	32.21	" "
Lime	CaO	4.67	" "
Magnesia	MgO	5.89	" "
Soda	Na_2O	.29	" "
Potassa	K_2O	.18	" "
Manganese	MnO	trace.	
Carbonic acid	CO_2	11.84	per cent.
Water	H_2O	4.28	" "
Organic matter		3.35	" "
Total		100.43	

CHEMICAL SERIES NO. 241.

Taconyte. Analysis by A. D. Meeds.

Silica	SiO_2	56.28	per cent.
Alumina	Al_2O_3	3.29	" "
Ferric oxide	Fe_2O_3	15.25	" "
Ferrous oxide	FeO	18.28	" "
Lime	CaO	.93	" "
Magnesia	MgO	.72	" "
Soda	Na_2O	.25	" "
Loss on ignition		4.75	
Total		99.75	

CHEMICAL SERIES NO. 242.

Silica powder. Analysis by A. D. Meeds.

Silica	SiO_2	98.17	per cent.
Alumina	Al_2O_3	.50	" "
Ferric oxide	Fe_2O_3	1.03	" "
Lime	CaO	trace	
Magnesia	MgO	trace	
Soda	Na_2O	.25	
Potassa	K_2O	trace	
Loss on ignition		.19	" "
Total		100.14	

CHEMICAL SERIES NO. 243.

Taconyte. Analysis by A. J. Hammond.

Silica	SiO_2	57.00	per cent.
Alumina	Al_2O_3	1.43	" "
Ferric oxide	Fe_2O_3	27.05	" "
Ferrous oxide	FeO	11.08	" "
Lime	CaO	.40	" "
Magnesia	MgO	2.02	" "
Potassa	K_2O	.113	" "
Soda	Na_2O	.397	" "
Loss on ignition		.91	
Total		100 400	

CHEMICAL SERIES No. 244.

Taconyte. Analyses by A. D. Meeds.

Silica	SiO_2	64.04	per cent.
Alumina	Al_2O_3	2.11	" "
Ferric oxide	Fe_2O_3	2.81	" "
Ferrous oxide	FeO	22.14	" "
Lime	CaO	.60	" "
Magnesia	MgO	4.04	" "
Soda	Na_2O	.30	" "
Potassa	K_2O	.11	" "
Water	H_2O	3.73	" "
Loss on ignition		.67	" "
Total		100.55	

Another analysis of the same rock, which varies a great deal, gave:

Silica	SiO_2	58.94	per cent.
Alumina	Al_2O_3	2.72	" "
Ferric oxide	Fe_2O_3	3.01	" "
Ferrous oxide	FeO	22.94	" "
Lime	CaO	.71	" "
Magnesia	MgO	4.74	" "
Potassa	K_2O	.09	" "
Soda	Na_2O	.24	" "
Water	H_2O	3.35	" "
Carbonic acid	CO_2	3.72	" "
Total		100.46	

CHEMICAL SERIES No. 245.

"Muscovado." Tested by A. D. Meeds.

Gave a strong qualitative test for titanium.

CHEMICAL SERIES No. 246.

Glauconite. Analysis by A. D. Meeds.

Ferric oxide	Fe_2O_3	9.43	per cent.
Ferrous oxide	FeO	3.54	" "

CHEMICAL SERIES No. 247.

Rock containing glauconite, siderite and silica. Analysis by A. D. Meeds.

Insoluble in HCl, as follows:

Silica	SiO_2	74.53	per cent.
Ferric oxide	Fe_2O_3	.34	" "
Alumina	Al_2O_3	.22	" "
		75.09	" "

Soluble in HCl, as follows:

Alumina	Al_2O_3	1.35	per cent.
Ferric oxide	Fe_2O_3	1.96	" "
Ferrous oxide	FeO	14.84	" "
Lime	CaO	.63	" "
Magnesia	MgO	.92	" "
Soda	Na_2O	.11	" "
Potassa	K_2O	.10	" "
Carbonic acid	CO_2	5.10	" "
Water	H_2O	.62	" "
		25.63	

Of the FeO 8.35 per cent. is combined as $FeCO_3$, making 13.45 per cent. $FeCO_3$. The remaining 6.49 per cent. of FeO is combined as glauconite.

CHEMICAL SERIES NO. 248.

Glauconite. Analysis by A. D. Meeds.

Silica	SiO_2	47.12	per cent.
Alumina	Al_2O_3	2.60	" "
Ferric oxide	Fe_2O_3	3.51	" "
Ferrous oxide	FeO	28.48	" "
Lime	CaO	.61	" "
Magnesia	MgO	1 94	" "
Potassa	K_2O	.11	" "
Soda	Na_2O	trace.	
Water	H_2O	2.70	per cent.
Carbonic acid	CO_2	13.49	" "
Total		100.46	

DERIVATION OF THE FOREGOING SUBSTANCES.

Chem. Series 217.—Pyroxene from porphyritic augite soda granite; rock 86 Grant; N. W. corner of sec. 32, T. 65-6 W.; north shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 387, June, 1893; and 21st Ann. Rept., p. 48.

Chem. Series 218.—Metallic copper, nearly or quite pure, from Mr. Peter Johnson, Dassel, Minn.

Chem. Series 219.—"Hardened" metallic copper, nearly or quite pure, from Mr. Peter Johnson, Dassel, Minn.

Chem. Series 220.—Iron ore from pit No. 1, Cincinnati mine, Mesabi range. Representative sample of the Mesabi ore. See 20th Ann. Rept. p. 149.

Chem. Series 221.—Greenish felsyte (?), country rock at Ely; rock 1002.

Chem. Series 222.—Rock similar to the last, but from the interior of one of the rounded masses in the agglomerate at the railway cut at Ely; rock 1626. See Amer. Geol., vol. 9, pp. 359-368, June, 1892.

Chem. Series 223.—Supposed bog manganese (but really clay and peat), three miles N. W. of Monticello. See 19th Ann. Rept., pp. 80-81; and 20th Ann. Rept., pp. 321-322.

Chem. Series 224.—Anorthite, from cave at east of Split-rock point, north shore of lake Superior; rock 5 B Lawson. See Bull. No. VIII, p. 6.

Chem. Series 225.—Supposed bog manganese (really a peaty substance), Monticello. From Mr. J. N. Stacy. See 19th Ann. Rept., pp. 80-81; and 20th Ann. Rept., pp. 321-322.

Chem. Series 226.—Augite soda granite; rock 551 Grant; S. W. ¼ S. W. ¼ sec. 3, T. 64-7 W.; south shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 385, June, 1893; and 21st Ann. Rept., pp. 41-42.

Chem. Series 227. Anorthoclase from augite soda granite; rock 551 Grant; S. W. ¼ S. W. ¼ sec. 3, T. 64-7 W.; south shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 386, June, 1893; and 21st Ann. Rept., p. 44.

Chem. Series 228.—Hornblende porphyryte; rock 797 Grant; N. E. ¼ S. E. ¼ N. W. ¼ sec. 29, T. 65-6 W.; south end of Epsilon lake, Lake county. See 21st Ann. Rept., p. 58.

Chem. Series 229.—Winnebago meteorite, taken as a whole. Museum No. 7239.

Chem. Series 230.—The iron of the Winnebago meteorite. Museum No. 7239.

Chem. Series 231.—The rounded pellets of the Winnebago meteorite. Museum No. 7239.

Chem. Series 232.—Quartz porphyry, from a dike in the "greenstone" of the Kawishiwi river; rock 417 Grant; N. ½ N. E. ¼ sec. 21, T. 63-10 W., Lake county. See 21st Ann. Rept., p. 43.

Chem Series 233.—Characteristic specimen of the Saganaga granite, a coarse grained hornblende granite; rock 686 Grant; S. W. ¼ N. E. ¼ sec. 22, T. 66-5 W.; Saganaga lake, Cook county. See 21st Ann. Rept., p. 43.

Chem. Series 234.—Fine grained gabbro ("granulitic gabbro") or "muscovado;" rock 857 Grant; near N. line of sec. 2, T. 64-5 W., Bashitanakueb lake, Cook county. See 21st Ann. Rept., pp. 150-151.

Chem. Series 235.—Sideritic chert banded with siliceous and chloritic slates; rock 27 Spurr; N. E. ¼ S. E. ¼ sec. 33, T. 58-17 W., St. Louis county. See Bull. No. X, p. 54.

Chem. Series 236.—Dark green spotted-granular taconyte (green-sandstone?); rock 53 Spurr; S. E. ¼ sec. 4, T. 58-16 W., St. Louis county. See Bull. No. X, p. 70.

Chem. Series 237.—Red siliceous jointed taconyte, somewhat decomposed; rock 65 Spurr; S. W. ¼ S. W. ¼ sec. 2, T. 58-18 W., St. Louis county. See Bull. No. X, p. 116.

Chem. Series 238.—Banded silica-kaolin; rock 70 Spurr; S. E. ¼ N. E. ¼ sec. 6, T. 58-17 W., St. Louis county. See Bull. No. X, p. 81.

Chem. Series 239.—Taconyte (?) shale; rock 101 Spurr; S. E. ¼ N. W. ¼ sec. 18, T. 58-18 W., St. Louis county. See Bull. No. X, p. 148.

Chem. Series 240.—Sideritic and cherty slate; rock 112 Spurr; N. W. ¼ N. E. ¼ sec. 17, T. 58-19 W., St. Louis county. See Bull. No. X, pp. 10-11.

Chem. Series 241.—Glauconite taconyte, with magnetite; rock 217 Spurr; N. W. ¼ N. W. ¼ sec. 22, T. 58-20 W., St. Louis county. See Bull. No. X, p. 87.

Chem. Series 242.—Silica powder; rock 230 Spurr; S. E. ¼ N. W. ¼ sec. 23, T. 57-22 W., Itasca county. See Bull. No. X, p. 214.

Chem. Series 243.—Gray siliceous taconyte; rock 107 Spurr; S. W. ¼ S. W. ¼ sec 2, T. 58-19 W., St. Louis county. See Bull. No. X, p. 134.

Chem. Series 244.—Hard green taconyte, banded with magnetite; rock 14 Spurr; S. E. ¼ N. E. ¼ sec. 30, T. 58-17 W., St. Louis county. See Bull. No. X, pp. 103-104.

Chem. Series 245.—Fine grained noryte, or "muscovado"; rock 1784; north side of Muscovado lake, Cook county. See 21st Ann. Rept., p. 150.

Chem. Series 246.—Glauconite from St. Lawrence limestone; Museum No. 3292; Hebron, Nicollet county.

Chem. Series 247.—Glauconite and siderite from glauconitic taconyte; rock 125 Spurr; near N. E. ¼ S. W. ¼ sec. 17, T. 58-19 W., St. Louis county. See Bull. No. X, pp. 232-233.

Chem. Series 248.—Same as Chem. Series 247.

IX.

THE PROGRESS OF MINING.

BY N. H. WINCHELL.

The last statement in these reports concerning the product of the iron mines of the state was in the report for 1881, (20th report, pp. 152, 153.) Since that time the Legislature's "Blue Book" has contained such information, for 1892 and 1893. The years 1893 and 1894 exhibited, in the iron ore output from the state of Minnesota, a wonderful rate of increase as compared with the iron-producing states of the Lake Superior region. Financial revulsion visited the country in 1893, and continued through 1894, and the iron industry suffered great reverses. The output declined in the Marquette range in Michigan from 5,179,098 tons in 1891 and 1892, to 3,885,000 in 1893 and 1894. The decline on the Menominee range was from 4,086,118 tons, for the same time, to 2,604,146 tons. The Gogebic range fell off, for the same time, from 4,797,590 tons to 3,163,550 tons. In the Vermilion range the decline was slight, being from 2,064,165 tons to 1,774,320 tons. But the rapid development of the Mesabi range showed an increase from 4,245 tons in 1892 (first year of shipment) to 2,402,067 tons for 1893 and 1894. This so far overbalanced the loss on the Vermilion range that the state showed an increase from 2,064,933 tons in 1891 and 1892 to 4,176,387 tons for 1893 and 1894, which is about 100 per cent.

Accompanying the development of the iron industry have come many other industries, and other elements of financial and political growth. These, however, are not so important nor so numerous as they are destined to be in the near future. The whole region about the west end of lake Superior has felt the impulse of this development, and new improvements are projected on all hands, which when carried out will bring the northeastern part of the state into prominence as a manufacturing and commercial power.

The following figures show the actual production of iron ore from the mines of Minnesota by years, since 1884:

	Vermilion range.		Mesabi range.	
Product in 1884	62,124	tons.		
" 1885	225,484	"		
" 1886	307,948	"		
" 1887	394,910	"		
" 1888	511,935	"		
" 1889	844,638	"		
" 1890	880,290	"		
" 1891	896,515	"		
" 1892	1,167,650	"	4,245	tons.
" 1993	820,621	"	613,620	"
" 1894	953,699	"	1,788,447	"
Totals	7,065,832	tons.	2,406,312	tons.
Grand total for the state			9,472,144	tons.

Production of Iron Ore by Minnesota Mines to Dec. 31, 1894.

Note.—The following table agrees with other published statements of the Minnesota Survey in its reports and in the various Legislative Manuals, but it differs in some particulars from the figures given in the Marine Review, Cleveland, Ohio, Jan. 17, 1895. When such is the case the figures from this latter source are inserted in parentheses.

Name of Mine.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Totals.
Vermilion Range.												
Chandler	......	......	......	......	56,712 (54,612)	306,000 (306,220)	336,002	375,866 (373,969)	651,655	435,930	562,087 (558,050)	2,724,252 (2,716,438)
Minnesota	62,124	225,484	307,948 (304,396)	394,910 (394,252)	455,241 (457,341)	535,538 (535,318)	532,272 (532,000)	517,570	498,353	370,303	391,612 (390,463)	4,291,355 (4,287,604)
Pioneer	......	......	......	......	......	3,100 (3,144)	12,016 (12,012)	3,079	2,651	......	......	20,846 (20,886)
Zenith	......	......	......	......	......	......	......	......	14,991	14,388	......	29,379
Totals	62,124	225,484	307,948 (304,396)	394,910 (394,252)	511,953	844,638 (844,682)	880,290 (880,014)	896,515 (894,618)	1,167,650	820,621	953,699 (948,513)	7,065,832 (7,054,307)
Mesabi Range.												
Auburn	......	......	......	......	......	......	......	......	......	......	110,809 (108,210)	110,809 (108,210)
Biwabik	......	......	......	......	......	......	......	......	......	151,500	90,048	241,548
Canton	......	......	......	......	......	......	......	......	......	24,416	213,853	238,269
Cincinnati	......	......	......	......	......	......	......	......	......	26,372	......	26,372
Commodore	......	......	......	......	......	......	......	......	......	65,137	......	65,137
Duluth Iron Mining Co.	......	......	......	......	......	......	......	......	......	37,626	......	37,626
Franklin	......	......	......	......	......	......	......	......	......	46.617	223,399	270,016
Hale	......	......	......	......	......	......	......	......	......	3,616	24,167	27,783
Lowmore	......	......	......	......	......	......	......	......	......	1,645	......	1,645
Minnewas	......	......	......	......	......	......	......	......	......	13,858	2,140	15,998
Missabe Mountain	......	......	......	......	......	......	......	......	......	123,015	505.955	628,970
Mountain Iron	......	......	......	......	......	......	......	......	4,245	119,818	573,440	697,503
Norman	......	......	......	......	......	......	......	......	......	......	39,008 (38,999)	39,008 (38,999)
Vega	......	......	......	......	......	......	......	......	......	......	5,628	5,628
Totals	......	......	......	......	......	......	......	......	4,245	613,620	1,788,447 (1,785,839)	2,406,312 (2,403,704)
Grand Totals	62,124	225,484	307,948 (304,396)	394,910 (394,252)	511,953	844,638 (844,682)	880,290 (880,014)	896,515 (894,618)	1,171,895	1,434,241	2,742,146 (2,734,452)	9,472,144 (9,458,011)

X.

COMPRESSIVE STRENGTH OF SOME MINNESOTA BRICKS AND BUILDING STONES.

The following table shows the results of tests made at the request of the Minnesota State Commissioners of the Columbian Exposition, transmitted by Supt. L. P. Hunt. The data were kindly furnished by Col. C. McC. Reeve, Secretary. The tests were made at the Watertown Arsenal, Mass., May 21, 1894, under the direction of Maj. J. W. Reiley, Ordnance Department, U. S. A.

Test Number.	Description.	Marks.	Dimensions. Hight. Inches.	Dimensions. Compressed surface. Inches.	Dimensions. Compressed surface. Inches.	Sectional area. Sq. inches.	Weight, dry. Lbs.	Weight, dry. Oz.	Absorption of Water. Total. Lbs.	Absorption of Water. Total. Oz.	Absorption of Water. By Weight. Per cent.	Absorption of Water. By Volume. Per cent.	First crack. Lbs.	Ultimate Strength. Total. Lbs.	Ultimate Strength. Per sq. in. Lbs.	Remarks.
6595	John Lind & Co., Barnum, Red Brick.		2.28	7.98	3.67	29.25	4	4¾	...	9½	13.8	24.7	36,000	80,200	2,742	
6596	Red Brick.	"From F. X. Goulet's yd., Staples, Min."	2.24	7.86	3.87	30.41	4	9¼	......	10	13.6	25.3	102,000	176,100	5,791	
6597	" "		2.15	7.54	3.72	28.05	4	2¾	....	7	10.5	20.	54,000	192,000	6,845	
6598	Buff Brick (light).		2.53	8.26	3.76	31.06	3	15¼	1	3	30.	41.8	46,800	46,800	1,507	From Peter Becker
6599	Buff Brick (light).	"Lundgren Bros., Warren Brick, New Quaker."	2.35	7.66	3.60	27.58	3	14¼	......	10½	16.8	27.9	56,000	147,200	5,337	
6600	Pearl color Brick.	"F A. New Ulm"	2.35	8.62	4.26	36.72	6	¼	......	10½	10.9	21.0	92,000	154,100	4,196	Has an elliptical panel on one face .27" deep.
6601	Buff col'r Brick	"O. R. Mather Pelican Rapids, Minn."	2.27	8.17	3.92	32.03	3	13¼	1	½	26.7	39.2	106,000	111,300	3,475	
6602	Red Brick.		2.42	8.30	4.05	33.61	5	1¼	.....	13¾	16.9	29.2	66,000	92,000	2,737	

6603	Buff col'r Brick		2.40	8.08	3.88	31.35	4	6¼	...	13¾	19.6	31.5	109,000	214,200	6,833	From Fred Nat-heggen, Carlton.
6604	" " "		2.43	7.93	3.52	27.91	3	15	......	11½	17.9	28.6	38,000	117,400	4,206	From Dangs & Wiest, Blakeley.
6605	" " "		2.38	7.84	3.50	27.44	3	14¼	......	11	17.7	29.1	44,000	114,500	4,173	" "
6606	" " "	"Ness & Moog, St. Cloud."	2.25	8.23	3.86	31.77	3	9¾	1	¼	28.1	39.3	98,000	140,300	4,416	
6607	" " "	"Peter Beck'r, Belle Plane."	2.42	8.12	3.70	30.04	3	15¼	......	15½	24.5	36.8	74,000	77,600	2,583	
6608	" " "		2.30	8.26	4.05	33.45	3	13¼	1	3¼	31.4	43.2	75,800	75,800	2,266	From O. R. Mather, Pelican Rap's.
6609	Red Brick, hard burnt.		2.30	7.70	3.72	28.64	4	8¼	......	8	11.1	21.	63,000	212,000	7,402	From A. C. Ochs.
6610	Buff col'r Brick	"Ness & Moog, St. Cloud."	2.25	8.26	3.88	32.05	3	11¼	1	.....	27.	38.2	95,000	131,000	4,087	
6611	Red Brick.		2.15	7.94	3.83	30.41	3	12¾	.....	10¾	17.7	28.4	37,500	40,100	1,311	From J. A. McKay, Alexandria.
6612	" "		2.26	8.05	3.80	30.59	4	14¼	......	10¼	15.	25.6	87,000	90,050	2,944	From M. Mueller, Stillwater.
6613	Dry slate shale Brick, semi-dry.		2.29	8.45	4.07	34.39	5	13¾	......	8	8.5	17.5	238,000	249,200	7,246	From St. Louis River Slate Brick Co.
6614	Alexandria Bld'g. Brick		2.14	7.79	3.82	29.76	3	12½	......	8¾	14.5	23.7	51,000	62,700	2,107	
6615	Red Brick.		2.16	7.87	3.64	28.65	4	3¼	......	6¾	10.	18.8	158,000	202,100	7,054	From M. Mueller, Stillwater.
6616	Dry slate shale Brick, semi-dry.		2.34	8.49	4.10	34.81	6	¾	......	9	9.3	19.1	202,000	208,500	5,990	From St. Louis River Slate Brick Co.
6617	Red Brick.		2.32	8.09	3.74	30.26	4	8¾	.....	10½	14.4	25.8	45,000	73,900	2,442	From John Lind, Barnum.
6618	" (light)		2.20	7.88	3.83	30.18	4	5¾	.....	10¾	15.4	27.9	132,000	159,900	5,298	From F. X. Goulets, Staples.
6661	Kasota Pink Limestone.		4.82	4.88	4.92	24.01	.....	......	......	.....	....	....	174,000	261,300	10,833	From quarries of C. W. Babcock & Co., Mankato, Minn.
6662	Mankato Sandstone.		4.05	4.08	4.11	16.67	.....	......	......	.....	....	....	130,000	161,100	9,606	Tested on edge.
6663	Mantorville Sandstone.		3.96	3.99	4.03	16.08	.....	......	......	.....	....	....	141,100	141,100	8,775	
6664	Frontenac Sandstone.		3.96	4.00	3.96	15.84	.....	......	......	.....	....	....	148,000	160,200	10,114	
6665	Luverne Quartzyte		4.23	4.12	3.93	16.19	.....	......	......	.....	....	....	349,000	349,000	21,556	
6666	" "		4.22	3.97	4.03	16.00	.....	......	......	.....	....	....	299,000	318,000	19,875	
6667	Ortonville Granite.		4.03	3.90	4.02	15.68	.....	......	......	.....	....	....	300,200	320,100	20,415	
6668	Duluth Brownstone		3.98	3.96	4.02	15.92	.....	......	......	.....	....	....	69,300	69,300	4,353	
6669	Faribault Marble.		4.28	4.29	4.23	18.15	.....	......	......	.....	....	....	137,000	322,700	17,780	

XI.

LIST OF ROCK SAMPLES COLLECTED IN 1894.

By U. S. Grant.

The present list is a continuation of those found in: (1) the 17th Ann. Rept., pp. 201-215; (2) the 20th Ann. Rept., pp. 96-110; (3) the 21st Ann. Rept., pp. 59-67; (4) the 22nd Ann. Rept., pp. 78-86. Most of these rock samples have not been carefully studied in the laboratory, and so the names are to be regarded as often only approximately correct. The specimens in this series are numbered in green and can thus be distinguished from those of any other series of the survey or museum. Most of the specimens listed below are from the vicinity of Carlton or from the Rainy Lake region. Nos. 1058 to 1067 were collected by Mr. H. V. Winchell.

1017. Soft greenish shale, showing banding. North side of the St. Louis river at the mouth of the small creek in S. E. ¼ S. E. ¼ sec. 2, 48 16. This shale underlies unconformably a coarse conglomerate.

1017A. Quartzyte pebble from this conglomerate. Same place.

1017B. Dark flinty pebble. Same place.

1017C. Slate pebble. Same place.

1017D. Reddish melaphyre pebble from conglomerate. North side of the St. Louis river at the mouth of a stream, near center of sec. 1, 48 16.

1018. Gray slate, showing fine laminæ which are not parallel with the bedding. First rock cut on the Northern Pacific R. R. west of Wrenshall; N. W. ¼ N. W. ¼ sec. 8, 48-16.

1019. Fresh diabase from dike. Same place.

1020. Medium grained, pinkish, biotite granite. N. E. ¼ S. E. ¼ sec. 27, 67-13; west end of Bottle portage, Lac la Croix.

1021. Biotite gneiss. N. E. ¼ N. E. ¼ sec. 11, 67-14; southwest side of Roland island, Lac la Croix.

1022. Brownish, biotite schist. N. E. ¼ S. W. ¼ sec. 35, 68-14; end of point, Lac la Croix.

1023. Staurolite, biotite schist. N. E. ¼ N. E. ¼ sec. 34, 68-14; north side of small island, Lac la Croix. Rock not certainly *in situ*, but probably not far from the parent ledge.

1024. Biotite schist. S. E. ¼ S. E. ¼ sec. 33, 70-18; Kettle falls.

1025. Sericitic schist. S. E. ¼ S. W. ¼ sec. 35, 71-24.

1026. Fine grained, micaceous schist. S. W. ¼ S. W. ¼ sec. 33, 71–24; south shore of Rainy river.

1027. Biotite schist. Same place.

1028. Greenish schist. Near center of S. W. ¼ sec. 33, 71-24; reef near south shore of Rainy river.

1029 to 1029E. Series of specimens showing transition from biotite schist to biotite syenite. The more western of the two islands in the Rainy river, about three-fourths of a mile below Koochiching falls.

1030. Biotite hornblende syenite. Ft. Frances, Ontario; from the excavation for the canal.

1030A. Porphyritic facies of the same. S. E. ¼ S. W. ¼ sec. 27, 71-24; south shore of Rainy river.

1030B. Altered diabase from dike in the syenite. Same place.

1031. Diabase from center of dike in syenite. Near center of N. ½ N. W. sec. 35, 71-24; south shore of Rainy river.

1032. Brownish biotite schist. Near center of S. ½ S. W. ¼ sec. 25, 71-24; south shore of Rainy river.

1033. Brownish micaceous schist. 140 paces south of the east quarter post of sec. 25, 71-24.

1033A. Very fine grained, gray schist. Same place.

1033B. Gray siliceous rock. Same place.

1034. Greenish schist. Just south of the east quarter post of sec. 36, 71-24.

1035. Greenish siliceous schist. 550 paces south of the east quarter post of sec. 36, 71-24.

1036. Siliceous schist, rather coarse grained and massive in appearance. N. E. ¼ N. W. ¼ sec. 30, 71-23; south shore of Rainy lake.

1037. Mottled biotite schist. Near center of E. ½ N. W. ¼ sec. 29, 71-23; point on south shore of Rainy lake.

1038. Green schist. S. W. ¼ N. W. ¼ sec. 28, 71-23; south shore of Rainy lake.

1039. Dark, fine grained, micaceous schist. S. W. ¼ N. W. ¼ sec. 28, 71-23; south side of small point, south shore of Rainy lake.

1040. Biotite granite. The smaller of the two islands in the N. W. ¼ sec. 28, 71-2; Rainy lake.

1040A. Contact of mica schist and granite. Same place.

1041. Aplyte from dike. Same place.

1042. Greenish, micaceous schist. N. E. ¼ N. W. ¼ sec. 26, 71-23; Kingston island, Rainy lake.

1043. Greenish schist, matrix of conglomerate. Small island near center of W. ½ S. W. ¼ sec. 26; Jackfish bay, Rainy lake.

1043A. Conglomerate. Same place.

1043B. Gray pebble from the conglomerate. Same place.

1043C. Collection of pebbles from the conglomerate. Same place.

1043D. Fine grained biotite granite pebble in conglomerate. S. W. ¼ S. W. ¼ sec. 26, 71-23; south shore of Jackfish bay, Rainy lake.

1044. Volcanic tuff? South shore of Rainy lake at the west line of sec. 25, 71-23.

1045. Green conglomerate. West shore of small bay near the south line of sec. 30, 71-22; south shore of Rainy lake.

1046. Peculiar graywacke-like rock. S. W. ¼ S. E. ¼ sec. 30, 71-22; south shore of Rainy lake.

1047. Greenish schist. N. W. ¼ N. E. ¼ sec. 32, 71-22; south shore of Rainy lake.

1048. Brownish gray siliceous rock occurring in beds in the mica schist. South shore of Rainy lake, just west of the east line of sec. 32, 71-22.

1049. Green schist. N. E. ¼ N. W. ¼ sec. 33, 71-22; Little American island, Rainy lake.

1049A. Sericitic schist. Same place.

1049B. Darker phase of the same. Same place.

1050. Sericitic schist. S. E. ¼ N. W. ¼ sec. 28, 71-22; north side of Grindstone island, Rainy lake.

1051. Schistose quartz porphyry. Near center of E. ½ S. E. ¼ sec. 26, 71-22; small island in Rainy lake.

1052. Brownish biotite schist. S. E. ¼ N. E. ¼ sec. 36, 71-22; south shore of Rainy lake.

1052A. Micaceous schist. N. E. ¼ N. W. ¼ sec. 36, 71-22; south shore of Rainy lake.

1053. Gray muscovite biotite syenite. S. E. ¼ S. E. ¼ sec. 25, 71-22; south shore of Rainy lake.

1054. Greenish schist containing siderite. Lyle mine, near center of S. E. ¼ sec. 23, 71-22; north side of Dryweed island, Rainy lake.

1054A. Greenish rock laminated by siliceous bands. Same place.

1054B. Quartz and siderite from vein. Same place.

1055. Biotite gneiss, charged with pyrite. S. E. ¼ S. E. ¼ sec. 33, 71-22; Old Soldier mine; small island in mouth of Black bay, Rainy lake.

1055A. A darker phase of the same. Same place.

1056. Pinkish, biotite granite. Probably in N. ½ sec. 35, 65-17; east side of Vermilion river at north end of a long portage.

1057. Gold bearing quartz from vein. Lot 6, sec. 30, 63-12; near Ely.

1028. Greenish conglomerate. AL 76, north side of Shoal lake.

1059. Greenish conglomerate. Shoal lake.

1060. Conglomerate at contact with altered granite. North of Shoal lake.

1061. Greenstone. North shore of Shoal lake.

1062. Contact of saussurite gabbro and granite. Small lake south of Bad Vermilion lake.

1063. Saussurite gabbro. Island bay, Bad Vermilion lake.

1064. Biotite granite. A L 75, Wiegand's land, north of Shoal lake.

1065. Altered granite? Same place.

1066. Another phase of the same. Same place.

1067. Altered granite? Same place.

XII.

NOTES UPON THE BEDDED AND BANDED STRUCTURES OF THE GABBRO AND UPON AN AREA OF TROCTOLYTE.

By Arthur Hugo Elftman.

CONTENTS.

INTRODUCTION.

The following notes are based upon field observations made for the geological survey and subsequent laboratory study of the material collected. The writer has had the opportunity to examine the great gabbro mass of northeastern Minnesota through its entire width from the Duluth and Iron Range railroad to the vicinity of lakes Alice and Bellissima. From the former lake eastward through Little Saganaga lake to the region south of Gunflint lake, only the northern portion of the gabbro was examined by him. As the time, opportunity or necessity afforded, many localities were visited several times.

In the twenty-second annual report (p. 169) attention was called to several localities where interesting observations were made upon the gabbro. It is intended at present to give a short account of the following:

1. The bedded and banded phases of the gabbro.
2. The occurrence of the feldspar masses in the gabbro.
3. The description and relations of a dark, bedded olivine gabbro, or troctolyte.

MACROSCOPIC CHARACTERS AND FIELD RELATIONS.

Under this heading will be given some of the macroscopic characters of the rocks under consideration and their relations and appearance in the field. For a general description of the normal gabbro, the reader is referred to Dr. Bayley's discussion of the basic massive rocks of the Lake Superior region.*

The bedded and banded phases of the gabbro.

In the reports of the Minnesota geological survey frequent reference has been made to the "bedded" character of the normal gabbro in different localities. By this character invariably is meant a rude arrangement of the rock in parallel layers similar to the layers of sedimentary rocks. This is quite a common phenomenon along the northern limits of the great gabbro mass. The layers usually have a dip toward the south and in places this character may be quite extensive. The separation into layers does not depend upon a differentiation of the mineral components of the rocks, for it is usually best developed in a rock of medium texture and of a uniform distribution of the minerals. From this it seems that the peculiar bedded appearance is due to secondary causes acting upon the rock after it had solidified.

Under banded structure the writer includes the laminated appearance of the gabbro, which is due to the differentiation and arrangement in parallel bands of the mineral constituents of the rock. The bands have no regular arrangement. They appear and disappear in a manner not depending upon secondary causes. The gabbro, which usually presents a fairly uniform texture, along its central portion possesses the banded structure to a marked degree.

In considering the differentiation within the gabbro attention will be called to the various stages in which this has been noticed. South of Disappointment lake (T. 63 N., R. 8 W.) a short distance south of the contact with the older rocks the gabbro is medium grained and olivinitic. The "bedded" structure is well developed. In going south from here a distance of two or three miles one passes over ridges of this same gabbro. But away from the northern edge the rock has a tendency to become more varied in structure. The feldspathic and olivinitic portions occur in separate aggregates, giv-

*Journal of Geology, vol. i, Nos. 5, 6 and 7.

ing a peculiar spotted appearance to the rock. The diallage and olivine usually form clusters of crystals arranged radially around a common center. These areas vary in diameter from one to four inches. The plagioclase which makes up the greater part of the rock also fills up the spaces between the diallage and olivine. Although the olivine is altered on the surface to a brownish yellow product, thin sections of the rock show that it is quite fresh within the rock. Occasional boulders show the peculiar structure of the rock by their alteration. Apparently firm and fresh when struck with a hammer, these boulders readily crumple leaving the feldspathic portions in firm nodules and the olivinitic portions as a coarse sand. This disintegration is due to the alteration of the olivine.

The separation of the mineral constituents is quite common in the normal facies of the gabbro, and is mentioned by Dr. Bayley* as follows: "The varieties are merely local phases of the predominant rocks for on all sides they grade into one another by insensible transitions." It is the writer's intention to call attention to the separation into a sharply defined banded structure, which can be easily distinguished from the ordinary differentiation of the rock, which causes only a variation in the amount of the different minerals. This may occur in such proportions that areas of feldspar several yards in diameter may be separated. In the banded structure some of the bands have the composition of the normal gabbro; while others are composed almost wholly of feldspar on the one hand and the iron-bearing minerals on the other. The lines of division between the different bands are usually sharp and distinct, The bands vary in thickness from several inches to several feet and are generally quite irregular, varying considerably in thickness in different parts. There is no general direction in the bands. They are found in all portions and running in every direction. In this they differ from the bedded structure, which has nearly always a dip toward the south.

The banding is similar to that described and illustrated by Geikie and Teall in the Tertiary gabbro in the Isle of Skye.* The gneissic or banded structure is also referred to in Bulletin VI, of the Minnesota survey, p. 126. The hill east of Birch lake, mentioned in Bulletin VI, possesses more of the bedded than the banded structure, although the two are somewhat coincident in this case. The illustration shows the bedded and

*Jour. of Geol., vol. i, No. 7, p. 698.

*Quar. Jour. Geol. Soc., vol. iv, No. 200, p. 645.

not the banded structure. The importance of this banded structure is best considered in connection with the large feldspar masses within the gabbro.

The occurrence of the feldspar masses in the gabbro.

The large areas of feldspar rock south of Little Saganaga lake and westward along the central part of the gabbro area have been mentioned in the Minnesota reports.* These feldspar masses have been found in sizes varying from an aggregate of several crystals to mountain masses. The different areas have the same relation to the normal gabbro, and are of the same origin.

In the southeastern part of T. 61 N., R. 11 W. of the Fourth principal meridian, the gabbro possesses a marked banding. The feldspar bands often are ten to fifteen feet wide and occasionally widen out and form lenticular or oval areas of even greater width. The banding is continuous and the direction is parallel to the outlines of the feldspar masses. The composition of the bands was mentioned on a preceding page. That the smaller areas are due to the differentiation of the gabbro cannot be doubted, for their occurrence does not depend upon the banded structure of the gabbro. The line of division between the feldspar masses and the normal rock is sharp and distinct in the field and in hand specimens. This suggests that they may be inclusions of some older rock in the gabbro. Microscopical characters, however, show that this is not the case.

On account of their greater hardness the feldspar masses usually occur in knobs rising above the ordinary gabbro. Occasionally along the side of some perpendicular bluff the outlines of the rounded feldspar masses, surrounded on all sides by ordinary gabbro, can be made out. In section 36, T. 61 N., R. 11 W., a dome-shaped mass of feldspar, surrounded on all sides by the ordinary gabbro, rises fifty feet above the surrounding rock. On the southern flank of the mass and near the top are some patches of gabbro showing that the present and the original size of the mass are nearly the same.

In the large valley in the southeastern part of T. 61 N., R. 10 W., are extensive low outcrops of the feldspar rock. This rock is not found in contact with the ordinary gabbro, but a short distance south of the most southerly outcrop, a dome-shaped hill of ordinary gabbro rises several hundred feet

*Bulletin VI, p. 123. 22nd Ann. Rep., p. 169.

above the valley. Although it may appear that the two rocks in this locality are distinctly separate, there is no reason why their relations are not the same as at the last locality.

The high ridges south of Gabbro lake in T. 62 N., R. 10 W., also show various sized areas of feldspar in the predominating ordinary gabbro. The banded structure appears to some extent in connection with the feldspar.

An area of bedded and banded olivine gabbro.

In the southern part of T. 62 N., R. 10 W., the eastern part of T. 61 N., R. 11 W., the greater part of T. 61 N., R. 10 W., and extending into the townships south and east of the last named, is a considerable area of a dark, often reddish colored gabbro. On account of the small proportion of feldspar the color depends upon the character of the olivine. When fresh the rock has a dark waxy appearance, and when altered the color is usually dull black to brownish red or reddish yellow. A banded arrangement of the minerals is quite common, while the bedded structure prevails throughout the rock. The bedding does not depend upon the banding, for it has a comparatively uniform dip to the south and the bedding planes often are perpendicular to the banded structure.

The relation of this rock to the normal gabbro and the feldspar rock are somewhat difficult to determine. It has not been found in direct contact with them, since in every locality observed by the writer the contact was covered. The results of these observations may be stated as follows: Wherever the dark bedded olivine rock and the gabbro approach each other, even within a few feet, both preserve their characteristic structure and there are no signs of a transition of the one into the other. The olivine rock appears to be above the gabbro. It does not occur in a continuous area but there are several detached areas on the northeast shore of Bald Eagle lake, T. 62 N., R. 10 W., and in section 30, of the same township. At the last named locality the olivine rock is separated from the main mass by several ridges of ordinary gabbro.

MICROSCOPIC CHARACTERS.

The banded gabbro.

The mineral constituents are the same as those of the normal gabbro. The microscopical examination of the contact between the different bands will be of most interest. The texture of the different bands is the same and the minerals of one band are intimately united with those of the adjacent bands, showing that the bands were solidified at the same time and that the separation into layers is due to the differentiation of mineral constituents at the time of cooling.

The feldspar masses.

In thin sections these are seen to be composed of plagioclase feldspar, which, on the whole, probably possesses a higher extinction angle than is usually found in the feldspar of the normal gabbro. Occasional grains of olivine and diallage occur. The rock is quite fresh and the feldspar crystals are often perfectly clear and colorless. An examination of the contact with the normal gabbro shows the same results as given above, for the banded gabbros.

The dark banded olivine gabbro.

Just as this rock is distinctly separable from the normal gabbro in the field, so its microscopical characters are also different. The rock is composed of plagioclase and olivine with small grains of diallage and magnetite. The olivine makes up the greater part of the rock. It occurs in fairly regular crystal forms and is quite fresh. It is frequently altered to serpentine along numerous fractures through the grain. When alteration has gone on to a great extent, besides the serpentine, a brownish red product is formed staining the whole rock and giving it a brick red appearance. In nearly all cases the olivine is filled with numerous grains of magnetite, often making the mineral opaque.

The feldspar is a plagioclase, is quite fresh and is the same as that in the normal gabbro. It possesses, however, a shattering peculiar to this area in the Minnesota gabbro. Although fresh, the mineral is traversed by numerous fracture lines which are arranged radially around the olivine grains The degree of shattering does not depend upon the condition of the olivine, for it is just as prominent in the fresh rock as it is in the altered portions. In the altered specimens the alteration products of the olivine sometimes penetrate the fractures. The pyroxene when present is associated with the olivine.

The rock is properly a forellenstein or troctolyte. A section of troctolyte from Neurode in Silesia, which shows the same peculiar shattering of the feldspar, might easily be mistaken for a section of the rock representing the area described above. A section of this troctolyte from near Duluth was described by

Dr. Wadsworth.* The field relations of this rock are the same as those given for the area just described.† The hand specimens and thin sections of the rocks from these localities correspond in all their characters.

The troctolyte differs from the normal olivine gabbro in that in the former the pyroxene is present only in occasional grains, while in the latter, although it may be absent in a few sections, it is usually present in sufficient quantity to change the character of the rock. The olivine is the predominating component of the troctolyte and not of the olivine gabbro. The feldspar in the former is always thoroughly shattered and the fractures are arranged radially around the olivine. In the olivine gabbro, no matter how altered the olivine may be, the feldspar, beyond a few fractures, shows no shattering similar to that in the troctolyte. It may be of interest to notice that a large bowlder of this troctolyte has been found imbedded in the diabase at Beaver Bay and having the same relations to the matrix rock as the anothosyte.

SUMMARY.

In the preceding note the writer has attempted to emphasize the necessity of distinguishing between the bedded and banded structures of the Minnesota gabbro. As the term "bedded" implies a sedimentary origin of the rock, there is some objection in applying it to a structure in an eruptive rock. The terms bedded and banded are often used as synonyms, but it has been shown that in the Minnesota gabbro there exist two distinct structures which are different in origin. As a more appropriate term for what has been called "bedded" structure the writer proposes the term *sheeted*. This structure is very common in nearly all of the igneous rocks of Minnesota. Attention is called to the occurrence and formation of the large feldspar masses within the gabbro. These masses are regarded as parts of the gabbro itself and as due to a differentiation of that rock. The area of troctolyte is outlined, and some of the distinguishing features of the rock are given. Although this area may be a part of the great gabbro mass, it is necessary to note its relation to the gabbro as well as its peculiar microscopical characters.

*Bull. No. II, p. 95, No. 514, and plate V.

† 10th Ann. Rep't., 1881, p. 35, No. 514.

XIII.

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The present list consists of additions made from April 1, 1894, to Dec. 31, 1894.

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MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8034	1894	Donation	Asbestos and country rock	1
8035	Nov., 1894	Fell Apr. 9, 1894	Chondritic meteorite (Minnesota No. 1)	3
8036	Dec., 1894	Wm. H. Hobbs	Coarse ash	
8037	" "	" "	Fine ash	
8038	" "	" "	Fragment of olivine bomb	2
8039	" "	" "	Mellilite basalt	2
8040	" "	" "	Nepheline basalt and tachylyte	1
8041	" "	" "	Pseudobrookite in nephelinyte	1
8042	" "	" "	Diabase showing spheroidal weathering	1
8043	" "	" "	Trap dike in gneiss	1
8044	" "	" "	Enstatite rock	1
8045	" "	" "	Stretched dioryte, "cross gashed"	1
8046	" "	" "	Schistose porphyry	1
8047	" "	" "	Hornblende gneiss; sheared diabase	1
8048	" "	" "	Cortlandtyte (hornblende picryte)	1
8049	" "	" "	Spotted gabbro dioryte	1
8050	" "	" "	Schistose gabbro dioryte(hornblendegneiss)	1
8051	" "	" "	Allanite granite	1
8052	" "	" "	Hornblende noryte (dioryte)	1
8053	" "	" "	Hornblende noryte	1
8054	" "	" "	Mica dioryte	1
8055	" "	" "	Staurolite-cyanite mica schist	1
8056	" "	" "	Sillimanite garnet rock	1
8057	" "	" "	Staurolite-repidolite inclusion	1
8058	" "	" "	Staurolite-biotite schist	1
8059	" "	" "	Staurolite schist	1
8060	" "	" "	Mica schist	1
8061	" "	" "	Inclusion, containing emery, in dioryte	1
8062	" "	" "	" " spinel " "	1
8063	" "	Rev. J S Hanner	Clay concretions	8

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8629	May, 1894	By exchange	Chænocardium ? sp.?	6
8630	" "	" "	Orthis striatula, Schlotheim	9
8631	" "	" "	Atrypa reticularis, Linn	7
8632	" "	" "	" "	3
8633	" "	" "	" gregeri, Rowley	4
8634	" "	" "	Spirifera annæ, Swallow	8
8635	" "	" "	" euruteines, Owen	3
8636	" "	" "	Strophodonta callawayensis, Swallow	4
8637	" "	" "	" altidorsata, Swallow	8
8638	" "	" "	" navalis, Swallow	8
8639	" "	" "	" inflexa, Swallow	8
8640	" "	" "	Naticopsis ? sp.?	8
8641	" "	" "	Zaphrentis ? sp.?	8
8645	" "	" "	Coral	1
8646	1894	Presented	Illænus americanus, Billings	4
8647	"	"	Cast of Lamellibranch	1
8648	Aug., 1894	By exchange	Eridophyllum simcoense	1
8649	" "	" "	Spirifera parryana	4
8650	" "	" "	Favosites gothlandica	3

MINERALOGY AND LITHOLOGY.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Belleview, Redwood Co	Archean	[weight 9½ lbs.
Polk Co., Minn		Henry Sweet. Largest piece is entire,
Volcano, Lipari Islands		Eruption of 1888. By exchange
" " "		" " "
Alban Hills, Rome, Italy		"
Capo di Bove, " "		"
Rossberg, Hesse		"
Katzenbuchel, near Heidelberg, Ger		"
Brighton, Mass		N. side of Cambridge St. "
Monson, Mass		"
Pelham, Mass		"
Lower Quinnesec Falls, Mich		Figured in Bull. 62, U. S. G. S. "
Upper Quinnesec Falls, Wis		Credner's porphyroid. "
Lower Quinnesec Falls, Wis		See Bull. 62, U. S. G. S. "
Ilchester, Md		J. Hopkins Univ. Cir., No. 65. "
" "		"
" "		[intergrowth.
Ellicott City, Md		Envelope sphenes, allanite-epidote "
Butler's Station, N. Y.		Near Munger's Corners. "
Near King's Ferry, N. Y.		Railroad W. of King's Ferry. "
Stony Point, N. Y		Dike, on the R.R. near road bridge. "
		[On S. wall of clay pit.
Cruger's Station, N. Y		Sec. II, near No. 37 (of Pl. I, Fig. 4.) "
		[nite. Contact in Sec. I.
" "		Contains biotite, staurolite, cya- "
		[granite. Sec. III, at top of hill.
" "		Inclusion (Group III) in soda "
		[contact.
" "		Sec. II, midway from road at O to "
		[toward contact in Sec. II.
" "		Garnet & tourmaline, 100 from 250 "
" "		No. 25, Sec. II, loc. O. "
" "		Group I. "
" "		Margarite. Group IV. "
		[mi. w. of Willow River.
Willow River, Pine Co., Minn	Drift	Presented. Farm of John Thurnblad, 4

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Callaway Co., Mo	Snyder creek shales (Hamilton.)	D. K. Greger.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	" About ½ grown.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
Old Concord, Minn	Galena	A. D. Meeds.
" "	"	"
Cobbleskill, N. Y	Up. Held'b	W. E. Crane.
Belfast, N. Y	Chemung	"
Erie Co., N. Y	Hamilton	"

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8651	Aug., 1894.	By exchange...	Cystiphyllum corrugatum	3
8652	" "	" " ...	" varians	3
8653	" "	" " ...	Leiorhynchus limitaris	Several.
8654	" "	" " ...	Athyris spiriferoides	4
8655	" "	" " ...	Spirifera medialis	2
8656	" "	" " ...	Platistoma lineatum	2
8657	" "	" " ...	Nucleospira concinna	3
8658	" "	" " ...	Orthis vanuxemi	3
8659	" "	" " ...	Atrypa aspera	5
8660	" "	" " ...	Tropidoleptus carinatus	5
8661	" "	" " ...	Head of Phacops bufo	2
8662	" "	" " ...	Cystiphyllum conifollis	2
8663	" "	" " ...	Atrypa reticularis	5
8664	" "	" " ...	Spirifera ziczac	2
8665	" "	" " ...	Leiorhynchus mesacostale	4
8666	" "	" " ...	Zaphrentis ampla (= prolifica)	3
8667	" "	" " ...	Streptelasma rectum	4
8668	" "	" " ...	Striatopora limbata	5
8669	" "	" " ...	Favosites goodwyni	5
8670	" "	" " ...	Spirifera hungerfordi	5
8671	" "	" " ...	" mucronata	4
8672	" "	" " ...	" orestes	5
8673	" "	" " ...	Cyantophyllum juvenis	4
8674	" "	" " ...	Rhynchonella eximia	4
8675	" "	" " ...	Favosites digitatus	3
8676	" "	" " ...	Rhynchonella horsfordi	4
8677	" "	" " ...	Strophodonta nacrea	3
8678	" "	" " ...	" arcuata	3
8679	" "	" " ...	Orthis biforata var. lynx	3
8680	" "	" " ...	Rhynchonella capax	5
8681	" "	" " ...	Monticulipora ramosa	3
8682	" "	" " ...	Leptæna sericea	3
8683	" "	" " ...	Stellipora ahtheloidea	4
8684	" "	" " ...	Strophomena alternata	2
8685	" "	" " ...	Orthis testudinaria	2
8686	" "	" " ...	Rhynchonella capax var.?	5
8687	" "	" " ...	Orthis biforata	5
8688	" "	" " ...	" lynx	4
8689	" "	" " ...	" occidentalis	3
8690	" "	" " ...	Terebratula harlani	4
8691	" "	" " ...	Ostrea larva	4
8692	" "	" " ...	Rhynchonella neglecta	4
8693	" "	" " ...	Orthoceras undulatum	1
8694	" "	" " ...	Strophomena corrugata	4
8695	" "	" " ...	Leptocœlia hemispherica	Several
8696	" "	" " ...	Favosites niagarensis	1
8697	" "	" " ...	Orthis hybrida	3
8698	" "	" " ...	Dalmanites limulurus	6
8699	" "	" " ...	Spirifera crispa	2
8700	" "	" " ...	Cœlospira disparilis	4
8701	" "	" " ...	Strophomena depressa	2
8702	" "	" " ...	Leptæna transversalis	5
8703	" "	" " ...	Ceramopora imbricata	2
8704	" "	" " ...	Streptelasma calicula	6
8705	" "	" " ...	Favosites constrictum	6
8706	" "	" " ...	Orthis elegantula	5
8707	" "	" " ...	" hybrida	5
8708	" "	" " ...	Cyclonema cancellatum	4
8709	" "	" " ...	Stephanocrinus gemmiformis	2
8710	" "	" " ...	Strophomena striata	3
8711	" "	" " ...	Pentamerus oblongus	2
8712	" "	" " ...	Graptolithus clintonensis	Several
8713	" "	" " ...	Lingula cuneata	"
8714	" "	" " ...	Leptæna sericea	"
8715	" "	" " ...	Pentremites gordoni	3
8716	" "	" " ...	Chonetes illinoisensis	2
8717	" "	" " ...	Athyris subtilita	5
8718	" "	" " ...	Exogyra arietina	5
8719	" "	" " ...	Belemnites mucronata	4
8720	" "	" " ...	Favosites arbuscula	5
8721	" "	" " ...	Pleurotomaria subcomarginata	3
8722	" "	" " ...	Cyrtina hamiltonensis	4

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Erie Co., N. Y.	Hamilton	W. E. Crane.
York, N. Y.	"	"
N. Y.	Marcellus shale	"
Moscow, N. Y.	Hamilton	"
Moscow, N. Y.	"	"
York, N. Y.	"	"
" "	"	"
Moscow, N. Y.	"	"
" "	"	"
" "	"	"
" "	"	"
York, N. Y.	"	"
Moscow, N. Y.	"	"
" "	"	"
Belfast, N. Y.	Chemung	"
York, N. Y.	Hamilton	"
" "	"	"
Moscow, N. Y.	"	"
Charleston, Ind	Up. Held'b	"
Rockford, Ia	Hamilton	"
Thedford, Ont	"	"
Rockford, Ia	"	"
Charleston, Ind	"	"
Belfast, N. Y.	Chemung	"
Charleston, Ind	Up. Held'b	"
York, N. Y	Hamilton	"
Thedford, Ont	"	"
Rockford, Ia	"	"
Lebanon, Ky	Hudson R.	"
Chattanooga, Tenn	Trenton	"
Cincinnnti, O	Cincin.	"
" "	"	"
Dalafield, Wis	Trenton	"
Nashville, Tenn	Hudson R.	"
Curdyville, Ky	Cincin	"
Nashville, Tenn	"	"
Cincinnati, O	"	"
Nashville, Tenn	Hudson R.	"
Lebanon, Ky	"	"
New Egypt, N. J	Cretaceous	"
Marlboro, N. J.	"	"
Rochester, N. Y.	Niagara	"
" "	"	"
" "	Clinton	"
" "	"	"
Racine, Wis	Niagara	"
Rochester, N. Y	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	"	"
" "	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	"	"
" "	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	Clinton	"
" "	Niagara	"
" "	"	"
" "	"	"
" "	Clinton	"
Medina, N. Y	Medina	"
Rochester, N. Y	Clinton	"
Flag Pond, Va	Burlington	"
Youngstown, O	Waverly	"
La Salle, Ill	Coal M.	"
Helotes, Tex	Cretac	"
Marlboro, N. J	"	"
York, N. Y	Hamilton	"
Pratts Falls, N. Y	"	"
York, N. Y	"	"

XV.

LIST OF ROCK SAMPLES COLLECTED IN 1894 TO ILLUSTRATE THE FIELD NOTES OF N. H. WINCHELL.

1969. At Barnum, Carlton county, a low ridge west of the railroad station, showing a cut of 3 ft. by the R. R., is in Keewatin fine slate, becoming coarse and approaching fine graywacke. The dip is about 10 deg. toward the south, but the face of the cut shows many minor undulations. The specimen exhibits the finer-grained portions, with many diverse markings and wrinklings in the shining surface.

1970. Coarser and siliceous gray portions of the same outcrop at Barnum. There are in this rock siliceous masses and some white quartz in cavities.

1971. Micaceous fine graywacke. Moose Lake, Carlton Co.

1792. Center of sec. 16, 46-20, on Kettle river, Carlton Co. Samples of the supposed gold ore, for which mining operations were conducted at the mouth of Otter creek by Cunningham and Miner a few years since. The rock is a compact sericitic schist and the yellow ore is pyrite, disseminated through the cleavages of the rock itself in formless films and sheets, and occurring with quartz and siderite in cavities.

1973. Sample of red Keweenawan conglomerate furnished by Mr. S. J. Basye, Moose Lake, Carlton county. This is said by him to occur in a small outcrop, mainly under water, in a ravine, sec. 30, T. 46-18. He also states that in a low bluff it occurs further east. This place has not yet been seen by any party of the survey. If this report be authenticated, and the rock be found to be *in situ*, it will fix an important geographic datum for mapping the Keweenawan.

1974. S. E. ¼ S. E. ¼ sec. 2, 48-16. Sample of the soft green Keewatin rock, underlying the conglomerate at the river, from the point of contact. The Keewatin here has a plain low angle of sedimentary dip toward the south (say 20 deg.). If properly treated it would apparently make slate pencils.

1975. Sample of the finer sedimentary gritty material interstratified in the overlying quartzose conglomerate at the same place as the last.

1976. Pebbles from the crumbling red conglomerate which overlies the Keewatin and the quartzose conglomerate, at the mouth of the creek entering the St. Louis river on S. W. ¼ sec. 1, 48-16. These pebbles seem to show that this conglomerate is later in date than the traps, amygdaloids and porphyries of the Keweenawan—i. e. this part of it. But some of the pebbles are not from the Keweenawan; a very few are from the Keewatin, some may have come from the Animikie, and one is a piece of iron pyrite which embraces rounded grains of quartz, quite similar to the pyrite found in such abundance in the underlying quartzose conglomerate which itself contains no Keweenawan pebbles. Such a piece of pyrite has no known source except from the pyrite-bearing quartzose conglomerate which appears in the valley a short distance higher up the St. Louis. The strong contrast in the pebbles from these two conglomerates, and especially the occurrence of this pebble of pyrite in the upper one, points to the existence of two conglomerates in this valley, one of which would be in that case of the age of the Pewabic, at the base of the Animikie, and the other post-Keweenawan. There are, however, some large pebbles of coarse grit, with scattered kaolinic grains, in the lower conglomerate which may have come from the Pewabic, though not necessarily so. There are also a few large pebbles of hardened black slate which appear like the black slate of the Animikie hardened by the gabbro of Duluth. These latter facts seem to link the conglomerates together as of one date, post-Keweenawan. Yet this grit and this fine-grained black rock can be referred directly to their source in the Keewatin (see for instance Nos. 469, 458 and 468). No structural facts were observed indicating two dates for the accumulation of this conglomerate. In the 10th report (pp. 11, 32-34) are references to this conglomerate. The calcite vein, mentioned on p. 11, as well as the compact and hardened condition of this quartzose conglomerate, and its abundant pyrite, indicate an age greater than post-Keweenawan. The fact also, mentioned in the 10th report, p. 34, that the slaty structure of the underlying Keewatin produces a roughly similar slaty disintegration extending for some distance upward into the conglomerate, rather points to the production of the slatiness since the formation of the conglomerate. That would exclude it from being of post-Keweenawan age.

1977. Sample of fresh dike-rock, from the R. R. cut, N. W. ¼ S. W. ¼, sec. 8, 48-16, Carlton county. The dike cuts the slates of the region.

1978. Samples of slate, from the same R. R. cut, showing an incipient secondary cleavage.

1979. Sample of slate, from the same R. R. cut, showing a curiously crumpled fine banding, which seems not to be a sedimentary banding but a secondary structure due to the irregularity of the fiber, the latter perhaps caused by dynamic pressure. There is a fine opportunity presented in these rocks for the study of the structures produced in fragmental rocks by pressure. The ordinary slaty cleavage is but one of the results of such action.

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PUBLICATIONS OF THE GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA.

I. ANNUAL REPORTS.

(Distributed by the State Geologist.)

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. Second edition (1893) identical.

THE THIRD ANNUAL REPORT, FOR 1874. 42 pp., 8vo,; with two county maps. By *N. H. Winchell*. Published in the Regents' Report for 1874. Second edition (1894) identical.

THE FOURTH ANNUAL REPORT, FOR 1875. 162 pp., 8vo.; with four county maps and a number of other illustrations. By *N. H. Winchell*, assisted by *M. W. Harrington*. Also in the Regents' Report for 1875. Out of print.

THE FIFTH ANNUAL REPORT, FOR 1876. 248 pp., 8vo.; four colored maps and several other illustrations. By *N. H. Winchell;* with reports on Chemistry, by *S. F. Peckham;* Ornithology, by *P. L. Hatch;* Entomology, by *Allen Whitman;* and on Fungi, by *A. E. Johnson*. Also in the Regents' Report for 1876. Out of print.

THE SIXTH ANNUAL REPORT, FOR 1877. 226 pp., 8vo.; three geological maps and several other illustrations. By *N. H. Winchell;* with reports on Chemical analyses, by *S. F. Peckham*; on Ornithology, by *P. L. Hatch;* on Entomology, by *Allen Whitman;* and on Geology of Rice county, and *L. B. Sperry*. Also in the Regents' Report for 1877. Out of print.

THE SEVENTH ANNUAL REPORT, FOR 1878. 123 pp., 8vo.; with twenty-one plates. By *N. H. Winchell;* with a field report, by *C. W. Hall;* Chemical analyses, by *S. F. Peckham;* Ornithology, by *P. L. Hatch;* a list of the plants of the north shore of lake Superior, by *B. Juni;* and an Appendix by *C. L. Herrick* on the Microscopic Entomostraca of Minnesota; twenty-one plates. Also in the Regents' Report for 1878. Out of print.

THE EIGHTH ANNUAL REPORT, FOR 1879. 183 pp., 8vo.; one plate (Castoroides). By *N. H. Winchell*. Containing a statement of the Methods of Miscroscopic Lithology, a discussion of the Cupriferous Series in Minnesota, and descriptions of new species of Brachiopoda from the Trenton and Hudson River formation; with reports on the Geology of Central and Western Minnesota, by *Warren Upham;* on the Lake

Superior region, by *C. W. Hall;* lists of birds and of plants from Lake Superior, by *Thomas S. Roberts;* Chemical Analyses, by *S. F. Peckham;* Report by *P. L. Hatch;* and four Appendixes. Also in the Regents' Report for 1879 and 1880. Out of print.

THE NINTH ANNUAL REPORT, FOR 1880. 392 pp., 8vo., three appendixes, two wood cut illustrations and six plates. By *N. H. Winchell.* Containing field descriptions of 442 crystalline rock samples, and notes on their geological relations, from the northern part of the state, new Brachiopoda, the water supply of the Red River valley, and simple tests of the qualities of water; with reports: on the upper Mississippi region, by *O. E. Garrison;* on the Hydrology of Minnesota, by *C. M. Terry*; on the Glacial Drift and its terminal moraines, by *Warren Upham;* Chemical analysis, by *J. A. Dodge;* a list of the birds of Minnesota, by *P. L. Hatch;* and of the winter birds, by *Thomas S. Roberts.* Also in the Regents' Report for 1879 and 1880. Out of print.

THE TENTH ANNUAL REPORT, FOR 1881. 254 pp., 8vo., with ten wood cut illustrations and fifteen plates. By *N. H. Winchell.* Containing field descriptions of about four hundred rock samples, and notes on their geological relations, continued from the last report; the Potsdam sandstone; typical thin sections of the rocks of the Cupiferous series; and the deep well at the "C" Washburn mill, Minneapolis; with geological notes, by *J. H. Kloos;* Chemical analyses, by *J. A. Dodge;* and papers on the Crustacea of the fresh waters of Minnesota, eleven plates, by *C. L. Herrick.* Also in the Regents' Report for 1881 and 1882. Out of print.

THE ELEVENTH ANNUAL REPORT, FOR 1882. 219 pp., 8vo., with three wood cut illustrations and one plate. By *N. H. Winchell.* Containing a report on the Mineralogy of Minnesota, and a note on the age of the rocks of the Mesabi and Vermilion iron districts; with papers on the crystalline rocks of Minnesota, by *A. Streng* and *J. H. Kloos;* on rock outcrops in central Minnesota and on lake Agassiz, by *Warren Upham;* on the iron region of northern Minnesota, by *Albert H. Chester;* Chemical analyses, by *J. A. Dodge;* and an Appendix containing Minnesota laws relating to mines and mining, abstracted by *C. L. Herrick.* Also in the Regents' Report for 1881 and 1882.

THE TWELFTH ANNUAL REPORT, FOR 1883. Summary report, containing paleontological 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. Out of print.

THE THIRTEENTH ANNUAL REPORT, FOR 1884. 196 pp. Geological reconnoissances, 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. J. 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.* Out of print.

THE FOURTEENTH ANNUAL REPORT, FOR 1885. 354 pp.; two plates of fossils and two wood cuts. By *N. H. Winchell.* Containing summary report, notes on some deep wells in Minnesota, descriptions of four new species of fossils, a supposed natural alloy of copper and silver from the north shore of lake Superior, and revision of the stratigraphy of the Cambrian in Minnesota, with the following papers by assistants, viz: List of the Aphididæ of Minnesota with descriptions of some new species, by *O. W. Oestlund;* Report on the Lower Silurian Bryozoa, with preliminary descriptions of some new species, by *E. O. Ulrich;* Conchological notes, by *U. S. Grant*; Bibliography of the Foraminifera, recent and fossil, by *Anthony Woodward.*

THE FIFTEENTH ANNUAL REPORT, FOR 1886. 493 pp., 8vo.; 120 diagram illustrations and sketches in the text, and two colored maps; embracing reports on observations on the crystalline rocks in the northeastern part of the state, by *Alexander Winchell, N. H. Winchell* and *H. V. Winchell*; Chemical report by *Prof. J. A. Dodge;* additional railroad elevations by *N. H. Winchell*; list of Minnesota geographical names derived from the Chippewa language, by *Rev. J. A. Gilfillan*; and notes on Illæni, describing three new species, by *Aug. F. Foerste.* Also as supplement II of the Regents' Report for 1887–1888. Out of print.

THE SIXTEENTH ANNUAL REPORT, FOR 1887. 504 pp., 8vo.; two plates and 83 other illustrations. Contains reports on the original Huronian area, the Marquette iron region, on the Gogebic and Penokee iron-bearing rocks, on the formations of northeastern Minnesota (including the physical aspects, vegetation, quadrupeds and other vertebrates), the geology of the region northwest from Vermilion lake to Rainy lake and of the Little and Big Fork rivers; also notes on the Molluscan fauna of Minnesota.

THE SEVENTEENTH ANNUAL REPORT, FOR 1888. 280 pp., 8vo.; ten text illustrations. Contains: Report of *N. H. Winchell*, the crystalline rocks of Minnesota, a general report of progress made in the study of their field relations, with a bibliography of recent works on the crystalline rocks; report of *H. V. Winchell*, field observations in the iron regions; report of *U. S. Grant*, geological observations in northeastern Minnesota.

THE EIGHTEENTH ANNUAL REPORT, FOR 1889. 234 pp., 8vo. 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.*

THE NINETEENTH ANNUAL REPORT, FOR 1890. 255 pp., 8vo.; 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. Ayers;* 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.*

THE TWENTIETH ANNUAL REPORT, FOR 1891. 344 pp., 8vo.; 12 plates and 33 text illustrations. Summary statement; The crystalline rocks—some preliminary considerations as to their structures and origin, by *N. H. Winchell;* Field notes in 1890, by *N. H. Winchell;* Additional rock samples to illustrate notes, by *N. H. Winchell*; Field observations on certain granitic areas in northeastern Minnesota, by *U. S. Grant;* Catalogue of rock specimens, by *U. S. Grant;* The Mesabi iron range, by *H. V. Winchell*; 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 *A. C. Lawson;* Diatomaceæ of Minnesota inter-Glacial peat, by *B. W. Thomas*, (with list of species and some notes upon them, by *H. L. Smith*, and directions for the preparation and mounting of Diatomaceæ, by *C. Johnson* and *H. L. Smith*); Oxide of manganese, by *N. H. Winchell;* Museum additions; Additions to the library.

THE TWENTY-FIRST ANNUAL REPORT, FOR 1892. 171 pp., 8vo.; 2 plates and 21 text illustrations. Summary statement and comparative nomenclature, with a table of the Pre-Siluran rocks of Minnesota and their equivalents; The geology of Kekequabic lake in northeastern Minnesota, with special reference to an augite soda-granite, by *U. S. Grant;* Catalogue of rock specimens, by *U. S. Grant;* Field observations in 1892, by *N. H. Winchell;* Some problems of the Mesabi iron ore, by *N. H. Winchell;* Additional rock samples to illustrate report, by *N. H. Winchell;* Additions to the library.

THE TWENTY-SECOND ANNUAL REPORT, FOR 1893 210 pp., 8vo.; 7 plates and 3 text illustrations. Summary statement; Preliminary report of field work during 1893 in northeastern Minnesota, chiefly relating to the glacial drift, by *Warren Upham;* Preliminary report of field work during 1893 in northeastern Minnesota, by *U. S. Grant;* List of rock samples collected in 1893 by *U. S. Grant;* List of rock samples collected in 1893, by *A. D. Meeds*; Preliminary report of a reconnoissance in northwestern Minnesota during 1893, by *J. E. Todd;* Notes on the geology of Itasca county, Minnesota, by *G. E. Culver;* Preliminary report of field work done in 1893, by *J. E. Spurr*; List of rock samples collected in 1893, by *J. E. Spurr*; Preliminary report of levelling party, by *C. P. Berkey;* Preliminary report of field work during 1893 in northeastern Minnesota, by *A. H. Elftman;* List of rock samples collected in 1893, by *A. H. Elftman;* Museum additions; Additions to the library since the report for 1892; The exhibit of the survey at the Columbian Exposition, by *N. H. Winchell.*

II. FINAL REPORT.

(Distributed by the State Geologist.)

THE GEOLOGY OF MINNESOTA. VOL. I OF THE FINAL REPORT. 1872—1882. xiv and 697 pp., quarto; illustrated by forty-three plates and fifty-three figures. By *N. H. Winchell;* assisted by *Warren Upham.* Containing an historical sketch of explorations and surveys in Minnesota, the general physical features of the state, the building stones and the Geology of Houston, Winona, Fillmore, Mower, Freeborn, Pipestone, Rock and Rice counties, by *N. H. Winchell;* the Geology of Olmsted, Dodge and Steele counties, by *M. W. Harrington;* and the Geology of Waseca, Blue Earth, Faribault, Watonwan, Martin, Cottonwood, Jackson, Murray, Nobles, Brown, Redwood, Yellow Medicine, Lyon, Lincoln, Big Stone, Lac qui Parle and Le Sueur counties, by *Warren Upham.* Distributed gratuitously to all public libraries and county auditors' offices in the state, to other state libraries and state universities, and to leading geologists and scientific societies; the remainder are held for sale at the cost of publication, $3.50 per copy in cloth, or $5 in grained, half roan binding, upon application to Prof. N. H. Winchell, Minneapolis.

THE GEOLOGY OF MINNESOTA. VOL. II OF THE FINAL REPORT. 1882—1885, xxiv and 695 pp., quarto; illustrated by forty-two plates and thirty-two figures. By *N. H. Winchell*, assisted by *Warren Upham.* Containing chapters on the Geology of Wabasha, Goodhue, Dakota, Hennepin, Ramsey and Washington counties, by *N. H. Winchell;* and on Carver, Scott, Sibley, Nicollet, McLeod, Renville, Swift, Chippewa, Kandiyohi, Meeker, Wright, Chisago, Isanti, Anoka, Benton, Sherburne, Stearns, Douglas, Pope, Grant, Stevens, Wilkin, Traverse, Otter Tail, Wadena, Todd, Crow Wing, Morrison, Mille Lacs, Kanabec, Pine, Becker and Clay counties, by *Warren Upham.* Distributed according to law, in the same manner as Vol. I above.

THE PALEONTOLOGY OF MINNESOTA. VOL. III OF THE FINAL REPORT. In press.

III. MISCELLANEOUS PUBLICATIONS.

(Distributed by the State Geologist.)

1. CIRCULAR NO. 1. A copy of the law ordering the survey, and a note asking the co-operation of citizens and others. 1872.
2. PEAT FOR DOMESTIC FUEL. 1874. Edited by *S. F. Peckham.*
3. REPORT OF THE SALT SPRING LANDS DUE THE STATE OF MINNESOTA. A history of all official transactions relating to them, and a statement of their amount and location 1874. By *N. H. Winchell.*
4. A CATALOGUE OF THE PLANTS OF MINNESOTA. Prepared in 1865, by *I. A. Lapham*, contributed to the Geological and Natural History Survey of Minnesota, and published by the State Horticultural Society in 1875.
5. CIRCULAR NO. 2. Relating to botany, and giving general directions for collecting infomation on the flora of the state. 1876.
6. CIRCULAR NO. 3. The establishment and organization of the Museum. 1877.
7. CIRCULAR NO. 4. Relating to duplicates in the Museum and exchanges. 1878.
8. THE BUILDING STONES, CLAYS, LIMES, CEMENTS, ROOFING, FLAGGING AND PAVING STONES OF MINNESOTA. A special report by *N. H. Winchell.* 1880.
9. CIRCULAR NO. 5. To Builders and Quarrymen. Relating to the collection of two-inch cubes of building stones for physical tests of strength, and for chemical examination, and samples of clay and brick for the General Museum. 1880.
10. CIRCULAR NO. 6. To owners of mills and unimproved water-powers. Relating to the hydrology, and water-powers of Minnesota. 1880.

[The miscellaneous publications are mostly out of print.]

IV. BULLETINS.

(Distributed by the State Geologist, except No. 9, which is distributed by the State Botanist.)

No. 1. History of Geological Surveys in Minnesota. 8vo., pp. 37. 1889. by *N. H. Winchell.*

No. 2. Preliminary description of the Peridotytes, Gabbros. Diabases and Andesytes of Minnesota. 8vo., pp 158; 12 colored plates. 1887. By *M. E. Wadsworth.*

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