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CLARENCE KING DIRECTOR

THE

COPPER-BEARING ROCKS

OF

LAKE SUPERIOR

By ROLAND DUER IRVING

WASHINGTON
GOVERNMENT PRINTING OFFICE
1883

NEWPORT, R. I., *October* 23, 1881.

SIR: I have the honor to transmit herewith the manuscript of the text and illustrations of Prof. Roland D. Irving's memoir on the Copper-Bearing Rocks of Lake Superior.

Very respectfully, your obedient servant,

RAPHAEL PUMPELLY,

In charge of Division of Mining Geology.

HON. CLARENCE KING,

Director of the United States Geological Survey.

UNIVERSITY OF WISCONSIN,
DEPARTMENT OF GEOLOGY AND MINERALOGY,
Madison, October 15, 1881.

SIR: I send you herewith the manuscript of my memoir on the Copper-Bearing or Keweenawan Rocks of Lake Superior.

I am, sir, with great respect, your very obedient servant,

ROLAND D. IRVING.

RAPHAEL PUMPELLY,
In charge Division Mining Geology,
United States Geological Survey, Newport, R. I.

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BY R. D. IRVING.

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This memoir aims at a general exposition of the nature, structure, and extent of the series of rocks in which occurs the well-known native copper of Lake Superior.

This is a work which has never been attempted before, nor could it have been accomplished sooner. A number of geologists have written on different portions of the Lake Superior basin during the past fifty years, but until very recently any attempt to compile a general account of the copper-bearing rocks would have met with some insuperable obstacles. Not to speak of the difficulties to be encountered in trying to reconcile the conflicting statements of different authors, any one making the attempt would have met the two serious obstacles of nearly complete ignorance as to the nature of the crystalline rocks which form so large a part of the series, and complete ignorance as to the distribution and structural relations of the formations of the western end of the Lake Superior Basin, both on the Minnesota and Wisconsin sides. The first of these obstacles was in part removed by the microscopic studies of Professor Pumpelly, whose conclusions as to the nature of the Keweenaw Point rocks were published in 1878.[1] The second was also in part removed by the investigations of the Wisconsin Geological Survey, whose results as to that portion of Wisconsin which borders on Lake Superior were first published in 1880.[2] There still remained unknown, however, a wide extent of the series in Minnesota, a most important omission, since in this region only is it possible to connect the rocks of the South and North Shores. The rocks of the southern range of Keweenaw Point were also still very vaguely known, and the structure of the Porcupine Mountains had never yet been made out.

It thus became necessary for any one attempting to present anything like a general account of the series to cover these gaps, and extend the microscopic investigations begun by Professor Pumpelly, so far as possible, over the whole extent of the series. It was also necessary that he should familiarize himself as much as possible with those districts which had already been more or less thoroughly worked up, by studying the descriptions of others on the ground. This work, including also the preparation of this memoir, I have undertaken to accomplish during the months between July, 1880, and March, 1882—short enough a time, especially when a large share of it has been given to other work. I was, however, already quite familiar with the series as developed in Wisconsin, with the microscopic characters of its rocks, so far as previously known, and with the literature of the subject; so that, with the aid of several assistants, I have been enabled to accomplish the main objects aimed at. My chief regret in connection with the field work, which was of necessity confined to the season of 1880, has been my inability, on account of lack of time, to visit Isle Royale, the region about Lake Nipigon, and Michipicoten Island. The full descriptions of these places, given respectively by Foster and Whitney, Bell and Macfarlane, together with a type suite of specimens collected by the latter gentleman at

[1] "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior." Proc. Am. Acad., 1878, XIII, 253–309.

[2] R. D. Irving, R. Pumpelly, E. T. Sweet, T. C. Chamberlin, and M. Strong, in the Geology of Wisconsin, Vol. III.

Michipicoten, and kindly sent me by the Director of the Geological Survey of Canada, help to supply this deficiency in some measure.

My plan of field work, as carried out, included: (1) a study of the north shore of the lake from Duluth to Nipigon Bay, including excursions up the principal streams for distances of from five to twenty miles; (2) a trip from Grand Marais, on the North Shore, northward and westward to the headwaters of Cascade and Brulé Rivers, including an examination of the country about Brulé Lake and Eagle Mountain, a region never before visited by any geologist; (3) a very rapid examination of the east coast from the Sault to Mamainse; (4) a study of the well-known mining region of Keweenaw Point, including the little-known district in the vicinity of Mount Houghton; (5) a comparatively thorough examination of the Porcupine Mountains, a knowledge of whose hitherto unknown structure was necessary to the understanding of that of the entire lake basin; (6) an examination of Silver Mountain, southwest from L'Anse; (7) a rapid exploration of the "South Copper Range," eastward from Lake Agogebic; (8) an examination of the valleys of the Kettle and Snake rivers in Minnesota, with the view of determining the extent of the copper-bearing rocks in that direction, and the manner in which they terminate westward; (9) an examination of the valley of the Cloquet River to its junction with the Saint Louis, and of the latter stream from this junction to its mouth.

Such extended investigations could not be all carried out in person in one season. My own immediate attention was given to the north shore of the lake from Duluth to Nipigon Bay, to the region of Portage Lake and Mount Houghton, and to the region south of Ontonagon. In the other work I was aided by Messrs. W. M. Chauvenet, A. C. Campbell, R. McKinlay, L. G. Emerson, and B. N. White. Messrs. McKinlay and Campbell made the river trips between Duluth and Grand Marais; Messrs. Chauvenet and McKinlay together examined the country from Grand Marais to Brulé Lake, and the valleys of the Cloquet and Saint Louis Rivers; Mr. McKinlay alone examined the valleys of the Snake and Kettle Rivers; Mr. A. C. Campbell made the trip from the Sault to Mamainse; Messrs. Chauvenet and White together studied the eastern half of the Porcupine Mountains, while Messrs. Campbell and McKinlay took the western part.

Besides the aid received from those directly connected with the work, I have to thank for assistance also a number of others, and especially the following gentlemen: Professor T. C. Chamberlin, for notes of observations on Snake River, Minnesota; Professor A. H. Chester, of Hamilton College, Clinton, N. Y., for a series of notes, accompanied by specimens, on the rocks of the Vermillion Lake region, and of the north shore of Nipigon Bay; A. R. C. Selwyn, Director of the Geological Survey of Canada, for information and for a suite of specimens illustrating Macfarlane's reports on Michipicoten Island; Professor N. H. Winchell, State Geologist of Minnesota, for loan of township plats of the Minnesota coast, and for information with regard to the back country between Pigeon River and the lake shore; Frank Klapetko, of the Delaware Mine, Keweenaw Point, for measurements made in the vicinity of Lac La Belle; Messrs. John Chassells and J. R. Devereux, of Houghton, for sundry favors; B. C. Chynoweth, agent of the Mass mine, Ontonagon, for assistance in that region; and B. N. White, of Ontonagon, for information as to the course of the slate belt of the Porcupine Mountains to the eastward. Mr. White had traced out this belt to some distance east of the Ontonagon, and kindly gave to me all the results of his labor.

The combination of the results of previous work and of new original observations, by which this memoir must be made up, have compelled great irregularity in the amount of detail given in describing the different districts. So far as the statements are based upon older work, detail has been generally omitted, but whenever I have felt it necessary to differ from previous writers, and in all new descriptions, I have used detail freely.

The list of geologists who have during the last fifty years, from time to time, written on the group of rocks which forms the subject of this memoir is a long one. Omitting the names of those whose writings have not been based on personal examinations, or have been preceded only by very slight examination, or are obviously unworthy of notice from lack of geological knowledge on the part of the authors, I may mention the following geologists as having written more or less copiously upon this subject, the dates of the first and last publications being added in each case: Bigsby, 1824–1852; Bayfield, 1829; Houghton, 1831–1844; Jackson, 1845–1869; Hubbard, 1846–1850; Logan, 1846–1866; D. D. Owen, 1847–1852; Foster and Whitney, 1849–1861; Louis Agassiz, 1850–1859; Marcou, 1850–1859; Norwood, 1852; Whittlesey, 1852–1877; Rivot, 1855–1856; Hunt, 1861–1878; Macfarlane, 1866–1869; Alexander Agassiz, 1867; Bell, 1869–1875; Pumpelly, 1872–1880; Marvine, 1873; Brooks, 1873–1876; Rominger, 1873–1876; Irving, 1874–1880; Sweet, 1875–1880; Chamberlin and Strong, 1880; N. H. Winchell, 1879–1881; and Wadsworth, 1880. The preparation of anything like a satisfactory account of the explorations upon which the numerous writings of these geologists have been based, or of the writings themselves, would have taken away more time than I could afford to lose from the original studies necessary to my own work, and I therefore have not attempted it.

I have, of course, familiarized myself with these writings, but the proportion of them from which I have drawn facts for incorporation into this memoir is a small one. I name them here in order of time of publication: J. W. Foster's and J. D. Whitney's joint "Report on the Geology and Topography of a Portion of the Lake Superior Land District in the State of Michigan, Part I, Copper Lands," made to the Commissioner of the General Land Office, 1850; Sir W. E. Logan's "Geology of Canada," 1863; Thomas Macfarlane's, "Report on Lake Superior," in the Report of Progress of the Geological Survey of Canada for 1863–'66; the same gentleman's paper "On the Geology and Silver Ore of Wood's Location, Thunder Cape, Lake Superior," published in the Canadian Naturalist for 1869; Robert Bell's reports on the regions north and east of Lake Superior, published in the Report of Progress of the Geological Survey of Canada for the years 1866–'69, 1870–'71, and 1872–'73; the report of R. Pumpelly and A. R. Marvine on the copper-bearing rocks of Keweenaw Point, in the Geological Survey of Michigan, Vol. I, 1869–'73, Part II; R. Pumpelly's paper on the "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior," published in the Proceedings of the American Academy of Arts and Sciences, Vol. XIII, p. 268, 1878, and "Lithology of the Keweenawan System," published in Vol. III of the Geology of Wisconsin, 1880; my own reports on the "Geological Structure of Northern Wisconsin" and "Geology of the Eastern Lake Superior District" of Wisconsin, both in Vol. III, Geology of Wisconsin, 1880; E. T. Sweet's report on the "Geology of the Western Lake Superior District," in the same volume; T. C. Chamberlin's and M. Strong's joint report on the "Geology of the Upper St. Croix District," also in the same volume; and N. H. Winchell's "Ninth Annual Report of the Geological and Natural History Survey of Minnesota," 1880.

In every case where I have taken information from these works I have indicated it by direct reference. It will, perhaps, be well to give a general statement here as to the extent of my indebtedness to each of them. Foster and Whitney's work applies solely to that portion of the copper-bearing series which is included within the state of Michigan, *i. e.*, to the region lying between the eastern extremity of Keweenaw Point and the Montreal River, and to Isle Royale. For my statements as to Isle Royale I have had to depend almost exclusively upon this work, read in the light of my own experience. The former district I have myself examined, and have only used Foster and Whitney's statements, chiefly to aid in mapping, as supplementary to my own observations. Logan, in his geology of Canada, describes briefly all of the rocks of the north and east shores of Lake Superior from the Minnesota boundary to the Sault. I have only drawn from him, however, for the east coast, Michipicoten, and the islands south of Nipigon Bay. Macfarlane's "Report on Lake Superior" includes a further description of Michipicoten Island and the east coast, having been based on more detailed observation than that of Logan. I have drawn somewhat from this report, but especially have used it for locating the series of Michipicoten rocks sent me by Mr. A. R. C. Selwyn, and which I describe microscopically in Chapters III and VII. The same writer's account of the Geology of Wood's Location has aided me in reading rapidly the structure of the peninsula between Black and Thunder bays, though I differ from him in some of his most important conclusions. Dr. Bell's several reports on the geology of that portion of Canada north and east of Lake Superior, including a manuscript map based on them, have been drawn upon liberally for accounts of those regions I have not myself seen, more especially of the Nipigon Lake basin, and for data for mapping away from the lake shore, although I have here again departed from the author in some important points. The descriptions and maps of Messrs. Pumpelly and Marvine, in the first volume of the Geological Survey of Michigan, have furnished a large part of the material from which I have made up my account of the structure of Keweenaw Point. Pumpelly's microscopic descriptions of the "trap" and amygdaloid of Keweenaw Point have formed the basis for my own microscopic studies, whose results I give especially in Chapter III, in which I have occasion to quote freely from his memoirs above mentioned. The general reports on the geology of Northern Wisconsin included in the third volume of the Geology of Wisconsin, by Messrs. Chamberlin, Strong, Sweet, and myself, have supplied all of the material for the description of that region which I shall give in Chapter VI. Upon N. H. Winchell's reports I have depended for a few locations of rocks in the country back of the Minnesota coast and along the national boundary line.

It is desirable that I should give here a brief account of the different views that have been held as to the origin and relations of the copper-bearing rocks, although this will involve reference to a number of points whose explanation must be deferred to subsequent pages. This series of rocks is described by all writers as made up of reddish sandstones, conglomerates, "traps," and amygdaloids, while a few of the authorities recognize also the local development of reddish felsitic or "jasper"-like rocks. As to the origin of these several kinds of rocks, however, as to their mutual structural relations, and as to their position in the geological scale, there has been the widest divergence of views.

The sandstones of the series appear to have been taken by all as of the usual sedimentary origin, but the conglomerates into which they shade have been regarded both as eruptive and as sedimentary. Messrs. Foster and Whitney, whose work, having been for thirty years the most widely recognized authority upon Lake Superior geology, may appropriately be mentioned first, maintained the eruptive origin of the bowlder-conglomerates of Keweenaw Point in the following language:

The conglomerate of Keweenaw Point and Isle Royale consists of rounded pebbles of trap, almost invariably of the variety known as amygdaloid, derived probably from the contemporaneous lavas, and rounded fragments of a jaspery rock which may have been a metamorphosed sandstone, the whole cemented by a dark-red iron sand. This cement may be regarded as a mixture of volcanic ash and arenaceous particles, the latter having been derived from the sandstone then in the progress of accumulation. It is not unusual to meet with strata composed entirely of arenaceous particles associated with the conglomerate beds; and where these expand to a considerable thickness, the associated sandstone appears in alternating belts of white and red, and exhibits few traces of metamorphism; but where the belts of sedimentary rock are thin, and come in contact with the trappean rocks, the sandstone is converted into a jaspery rock, traversed by divisional planes, and breaking with a conchoidal fracture.

The trappean pebbles often attain a magnitude of eighteen inches in diameter. Their surfaces do not present that smooth, polished appearance which results from the attrition of water; in fact, a close observer can readily distinguish between those which have been recently detached from the rock and those which have for a time been exposed to the recent action of the surf.

The conglomerate appears to have been formed too rapidly to suppose that the masses were detached and rounded by the action of waves and currents, and deposited with silt and sand on the floor of the ancient ocean ; for, while the contemporaneous sandstone remote from the line of volcanic foci does not exceed three hundred or four hundred feet in thickness, the united thickness of the conglomerate bands in the vicinity of the trappean range on Keweenaw Point exceeds five thousand feet. As we recede for a few miles from the line of the volcanic fissure, these amygdaloid pebbles disappear, and are replaced by arenaceous and argillaceous particles. We are, therefore, disposed to adopt the theory, as to the origin of such masses, first suggested by Von Buch: "When basaltic islands and trachytic rocks rise on fissures, friction of the elevated rock against the walls of the fissures causes the elevated rock to be inclosed by conglomerates composed of its own matter. The granules composing the sandstones of many formations have been separated rather by friction against the erupted volcanic rock than destroyed by the erosive force of a neighboring sea. The existence of these friction conglomerates, which are met with in enormous masses in both hemispheres, testifies the intensity of the force with which the erupted rocks have been propelled from the interior through the earth's crust. The detritus has suddenly been taken up by the waters, which have then deposited it in the strata which it still covers."

Those pebbles having a highly vesicular structure may have been ejected through the fissures, in the form of scoriæ, while in a plastic state, and have received their rounded shape from having been projected through water—on the same principle as melted lead, when dropped from an elevation, assumes a globular form.

In the jaspery fragments included in the conglomerate, we often observe a structure analogous to the woody fibre of trees. These fragments are composed of laminæ, more or less contorted, and furrowed longitudinally, like the markings in the extinct plants of the genus *Sigillaria*. A series of striæ, as fine as the engraver's lines, run parallel with the larger ones. These can be traced on some of the specimens, and generally extend through the different folds; while others possess a structure like the cellular tissue of wood. We have no confidence in the vegetable origin of these markings, nor have we any theory to offer in explanation.[1]

The same views are as strenuously maintained in other publications by the same authors,[2] who were, however, preceded in them by Dr. Douglas Houghton. The latter speaks of the conglomerates under the name of "trap tuff," and states distinctly that they are made up almost exclusively of pebbles and bowlders of "greenstone and amygdaloidal trap."[3] Even those conglomerates in which there is evident more or less sandy material he speaks of as made up entirely of comminuted greenstone, while the sandstone and shale which with so great thickness form the upper part of the series on Keweenaw Point, he considers to be of sedimentary origin, the material having been worn from pre-existing granitic rocks.

So far as I have noticed, none of the other writers on Lake Superior geology have accepted these peculiar views as to the origin of these conglomerates—all regarding them as made up of water-worn pebbles detached from some pre-existing rock—and for the excellent reason that Dr. Houghton's and Messrs. Foster and Whitney's facts, as well as their theory, failed to stand closer study. The included pebbles are only in very subordinate quantity of "trap" or amygdaloid, being almost wholly of some sort of acid eruptive rock, *i. e.*, felsite, quartziferous porphyry, quartzless porphyry, granitic porphyry, augite-syenite, or granite. The fundamental difference between such pebbles and the associated basic massive rocks is alone enough to overthrow the theory, even were there not other sufficient arguments against it. Further, the pebbles are just as plainly water-worn as those of any other conglomerates, though they may have in some cases had the polish removed by surface alteration.

The "trap" and amygdaloid are by some writers considered as having had a common origin, but by others are separated. Under the generic term of "trap," Messrs. Foster and Whitney included "greenstone, granular and amygdaloidal trap, basalt, etc.," and held to their origin in part as lava flows, contemporaneous with the deposition by ordinary sedimentation of

[1] *Op. cit.*, pp. 99, 100.
[2] Am. Jour. Sci. (2), XVII, 1854, pp. 11–38, 181–194.
[3] Joint Documents, Mich., 1841, pp. 472–607.

the associated sandstones, and in part as protrusions "in vast irregular masses, forming conical or dome-shaped mountains," or "continuous lines of elevation."[1] While they class the amygdaloids and traps together, they do not appear to have distinctly recognized that the former are the vesicular upper portions of the lava flows.

Houghton regarded all the traps as intrusive, and the amygdaloids as semi-fused sedimentary matter or interfused eruptive and sedimentary matter,[2] in which view he was followed by Jackson.[3] Similar views as to the intrusive origin of the traps were held by a few others at an early date, but the only one of these holding these views who had made any extensive field explorations was Norwood,[4] who in his account of the Minnesota coast represents a large proportion of the bedded crystalline rocks of that coast as intrusive; but even he does not regard all of the traps as having had this origin. The amygdaloids he appears to look on, for the most part, as sediments altered by igneous action, his general term for them being "metamorphic shales." A few of these rocks he seems to regard as volcanic tufas, an origin which was somewhat doubtfully assigned by Hunt to all the amygdaloids.[5] N. H. Winchell has recently revived the peculiar views of Norwood as to the origin of the amygdaloids of the Minnesota coast.[6]

Of others who have written on Lake Superior geology the larger number have maintained the origin of the traps as lava flows. Among them may be mentioned Logan,[7] Hunt,[8] Macfarlane,[9] Bell,[10] Pumpelly,[11] Marvine,[12] Irving,[13] Chamberlin,[14] and Sweet.[15] Rivot[16] only has maintained

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[1] *Op. cit.*, p. 58.
[2] Joint Documents, Mich., p. 490.
[3] Am. J. Sci. (1) XLIX, pp. 62–72.
[4] "Geology of the Western and Northwestern Portions of the Valley of Lake Superior," in Owen's Geological Survey of Wisconsin, Iowa, and Minnesota, pp. 333–424.
[5] Geology of Canada, 1863, pp. 698, 699.
[6] Seventh and Ninth Annual Reports of the Geological and Natural History Survey of Minnesota.
[7] Geology of Canada, 1863, pp. 71, 72.
[8] Second Geol. Survey of Penn., Azoic Rocks, Part I, p. 256.
[9] Report of Progress of Geol. Survey of Canada, 1863–'66, pp. 115–164.
[10] Report of Progress of Geol. Survey of Canada, 1866–'69, pp. 313–364.
[11] Proc. Amer. Acad. 1878, XIII, pp. 253, 254.
[12] Geological Survey of Michigan, 1873, Part II, pp. 109–112.
[13] Geology of Wisconsin, Vol. III, p. 7.
[14] Geology of Wisconsin, Vol. III, p. 391.
[15] Geology of Wisconsin, Vol. III, p. 336.
[16] Annales des Mines (5), VIII, 173–328, and 364, 374.

a metamorphic origin for them. Pumpelly and Marvine first recognized definitely that the amygdaloids are but the upper portions of the beds of "trap," and the distinction between the true vesicular amygdaloids and the non-vesicular pseud-amygdaloids, which distinction the latter subsequently made still plainer by his microscopic investigations,[1] to which we are indebted for our first knowledge as to the nature of the so-called "traps." Marvine's conclusions from his examination of the beds of the Eagle River section of Keweenaw Point, made before the use of the microscope in the study of these rocks, deserve mention as containing the first plainly and thoroughly worked-out argument, from structural characters alone, in favor of the lava-flow origin of the "traps," and of the connection with the trap beds of the amygdaloids. The results of the work of the Wisconsin Survey, as given in the third volume of the Geology of Wisconsin, by Chamberlin, Sweet, Strong, and myself, fully sustained the conclusions of Pumpelly and Marvine.

The most recent writers on the copper rocks of Lake Superior have been N. H. Winchell and Wadsworth. Winchell's views as to the sedimentary and metamorphic origin of the amygdaloids of the Minnesota coast have already been mentioned. In the same category he appears to include a large part of the bedded traps, the more highly crystalline kinds only being regarded as of eruptive origin.[2] Wadsworth's paper maintains the lava-flow origin of the traps, although no points are advanced in favor of this conclusion that had not already been fully covered by Pumpelly and Marvine. It is worthy of note that while maintaining that Foster and Whitney are the only authors who have written correctly on Lake Superior geology, Wadsworth should yet depart from them in several very important points—such as the origin of the conglomerates—and this without a word of comment.

The reddish, acid, eruptive rocks, which I describe in subsequent chapters as constituting so important a feature of the copper-bearing series, have been almost wholly overlooked heretofore. A number of writers have

[1] Metasomatic Development of the Copper-Bearing Rocks of Lake Superior. Proc. Am. Acad. Sci., 1878, XIII, pp. 253–309.

[2] Ninth Annual Report of the Natural History and Geological Survey of Minnesota, 1880. Preliminary list of rocks, pp. 10–114.

recognized such rocks among the pebbles of the conglomerates, but as massive rocks they have only been noticed by Foster and Whitney, Logan, N. H. Winchell, Macfarlane, and Bell. Foster and Whitney, who noticed them on Mount Houghton and in the Porcupine Mountains, looked on them as baked sandstones, the baking being regarded as due to the heat of the molten traps.[1] Winchell has noticed them on the Minnesota coast, but regards them again as altered sedimentary rocks.[2] Logan[3] and Macfarlane[4] have observed them only on Michipicoten Island, where Macfarlane seems to regard them as eruptive and Logan as fused sedimentary material. Bell merely mentions the existence of quartziferous porphyry on Lake Nipigon.[5] The failure to recognize the importance and eruptive origin of these rocks is peculiarly strange in the face of the almost universal association in volcanic regions of the two types of acid and basic eruptives.

Widely divergent views have been held with regard to the geological relations of the series as a whole, as well as with regard to the origin and structural relations of its constituent rocks. In the earlier days of the study of Lake Superior geology the general lithological similarity between these rocks and the Triassic sandstones and eruptives of the eastern states led to the view that they were of the same age. This view was held by Houghton,[6] and at one time by Jackson,[7] and latterly has been advocated by Bell.[8] Later, when the Cambrian age of the so-called "Eastern Sandstone", which forms the south shore of Lake Superior from the Sault westward to the east side of Keweenaw Point, came to be established, the copper-bearing rocks, being regarded as belonging to the same formation, were considered to be the equivalents of the Potsdam sandstone of New York. This is the position taken by Foster and Whitney,[9] Owen,[10] Ro-

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[1] *Op. cit.*, pp. 64–65.
[2] Eighth Annual Report of the Geological Survey of Minnesota, pp. 23–26. Ninth Annual Report, pp. 12, 17, 31, 32, etc.
[3] Geology of Canada, 1863, pp. 81–82.
[4] Geological Survey of Canada, Report of Progress, 1863–'66, p. 142.
[5] Report of Progress of the Geological Survey of Canada, 1866–'69, p. 348.
[6] Am. J. Sci., 1843 (1), XLV, 160.
[7] Am. J. Sci. (1), XLIX, pp. 81–93.
[8] Report of Progress Geological Survey of Canada, 1866–'69, p. 321.
[9] *Op. cit.*, p. 99.
[10] Geological Survey of Wisconsin, Iowa, and Minnesota, pp. 187–196.

minger,[1] Winchell,[2] and Wadsworth,[3] although these writers differ greatly among themselves as to the exact structural relations subsisting between the Eastern Sandstone and the trappean series.

As early as 1846 Logan regarded the copper-bearing rocks of Keweenaw Point as the equivalents of the Huronian of the north shore of Lake Huron,[4] and when, later, he abandoned this view, still regarding them as older than the Eastern Sandstone, he made them the equivalents of the so-called "Quebec Group" of Canada East.[5] In 1872 Pumpelly and Brooks advanced excellent reasons for placing the Keweenaw Point rocks below the Eastern Sandstone, and as, on the whole, nearer to conformity with the Huronian.[6] In 1876 Brooks changed his views so far as to abandon the conformity with the underlying Huronian, but he still maintained the unconformity with the Eastern Sandstone.[7] In 1880 the third volume of the Geology of Wisconsin presented new and weighty evidence of the pre-Cambrian age of the copper-bearing rocks, which are in Northern Wisconsin found to be separated from the basal fossiliferous Cambrian sandstones of the Mississippi Valley by a great intervening erosion, while from the underlying Huronian the separation did not appear to be so great. In that volume the copper-bearing rocks were described under the term of the Keweenaw or Keweenawan Series, following the previous suggestions of Hunt[8] and Brooks,[9] and the same term will be used in this memoir. A few months later appeared the volume of Mr. M. E. Wadsworth, in which the copper-bearing rocks are placed as the upper part of a series of which the Eastern Sandstone is regarded as the basal member—a view which can, I think, be easily shown to be untenable.

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[1] Geological Survey of Michigan, Vol. I, Part III, pp. 80-81.
[2] Eighth Annual Report Geological Survey of Minnesota, p. 25.
[3] *Op. cit.*, pp. 115-127.
[4] Am. J. Sci. (2), 1857, XXIII, 305-314.
[5] Geology of Canada, 1863, pp. 67-86.
[6] Am. J. Sci. (3), III, 428-432.
[7] Am. J. Sci. (3), XI, 206-311.
[8] Trans. Am. Inst. Min. Eng., I, 331-342.
[9] Am. J. Sci. (3), XI, 206-211. *Op cit.*, p. 66.

LITERATURE.

The following list of works includes all of any importance that embrace references to the Keweenawan rocks by geologists who have examined them in the field. The arrangement is a chronologic one, so that any one wishing to examine the history of the subject may do so conveniently.[1]

1824.

BIGSBY (JOHN J.). Notes on the Geography and Geology of Lake Superior. Quarterly Journal of Science and Arts, 1824–'25, xviii, 1–34, 228–269.

1829.

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[1] For the names of some of the foreign works I am directly indebted to Wadsworth's bibliography of Lake Superior geology, without which aid I might have overlooked them. *Op. cit.* pp. 133–157.

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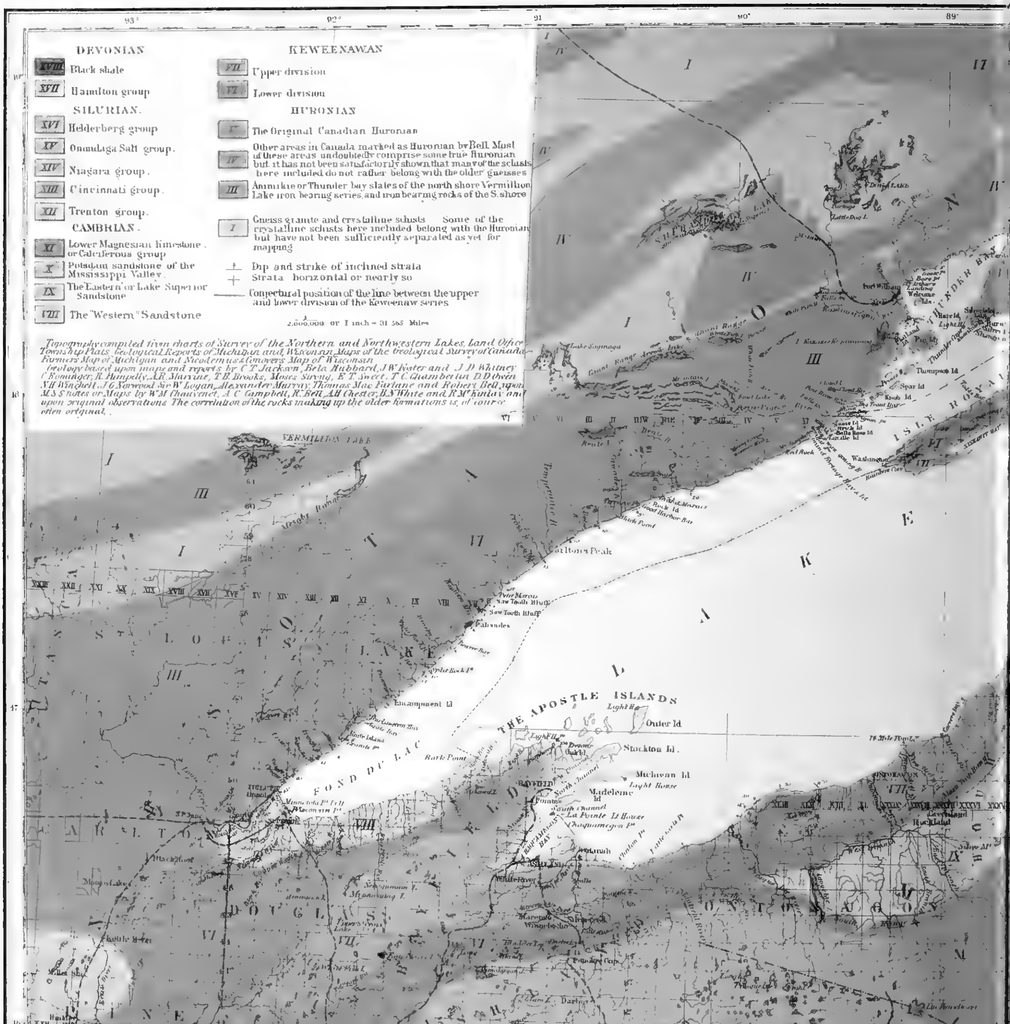
CHAPTER II.

EXTENT AND GENERAL NATURE OF THE KEWEENAW SERIES.

General statement as to the scope of the term Keweenawan.—General statement as to the geographical extent of the series.—More detailed description of its extent.—Extent of the series underneath the waters of Lake Superior.—Its entire geographical extent in square miles.—Constancy of its general characteristics.—Basic crystalline rocks.—Detrital rocks.—Porphyry-conglomerates.—Other conglomerates.—Sandstones.—Source of the pebbles of the porphyry-conglomerates now found in the original acid rocks of the series itself.—General characteristics of these original acid rocks.—Recapitulation.

That my statements as to the geographical extent of the Keweenawan rocks may be understood, it is necessary to say at the outset that I exclude from the Keweenaw Series the slaty rocks of the region of Thunder Bay and Pigeon River—the so-called "Lower Group" of Logan, and Animikie Group of Hunt. The nature and general relations of these slates are discussed on a subsequent page. It should also be stated that I include in the Keweenaw Series the white and red dolomitic sandstones with accompanying crystalline rocks, which are so largely developed in the peninsula between Black and Thunder bays, and stretch thence a long distance northward in the valleys of the Black-Sturgeon and Nipigon rivers, and occupy a large area about Lake Nipigon. Again, I exclude the horizontal sandstones which form the South Shore east of Bête Grise Bay, on Keweenaw Point, and westward from Clinton Point, in Wisconsin, to Fond du Lac, in Minnesota. The Keweenaw or copper-bearing series, then, as considered in the following pages, is made to include only the succession of interbedded "traps," amygdaloids, felsitic porphyries, porphyry-conglomerates, and sandstones, and the conformably overlying thick sandstone, as typically developed in the region of Keweenaw Point and Portage Lake on the south shore of Lake Superior.

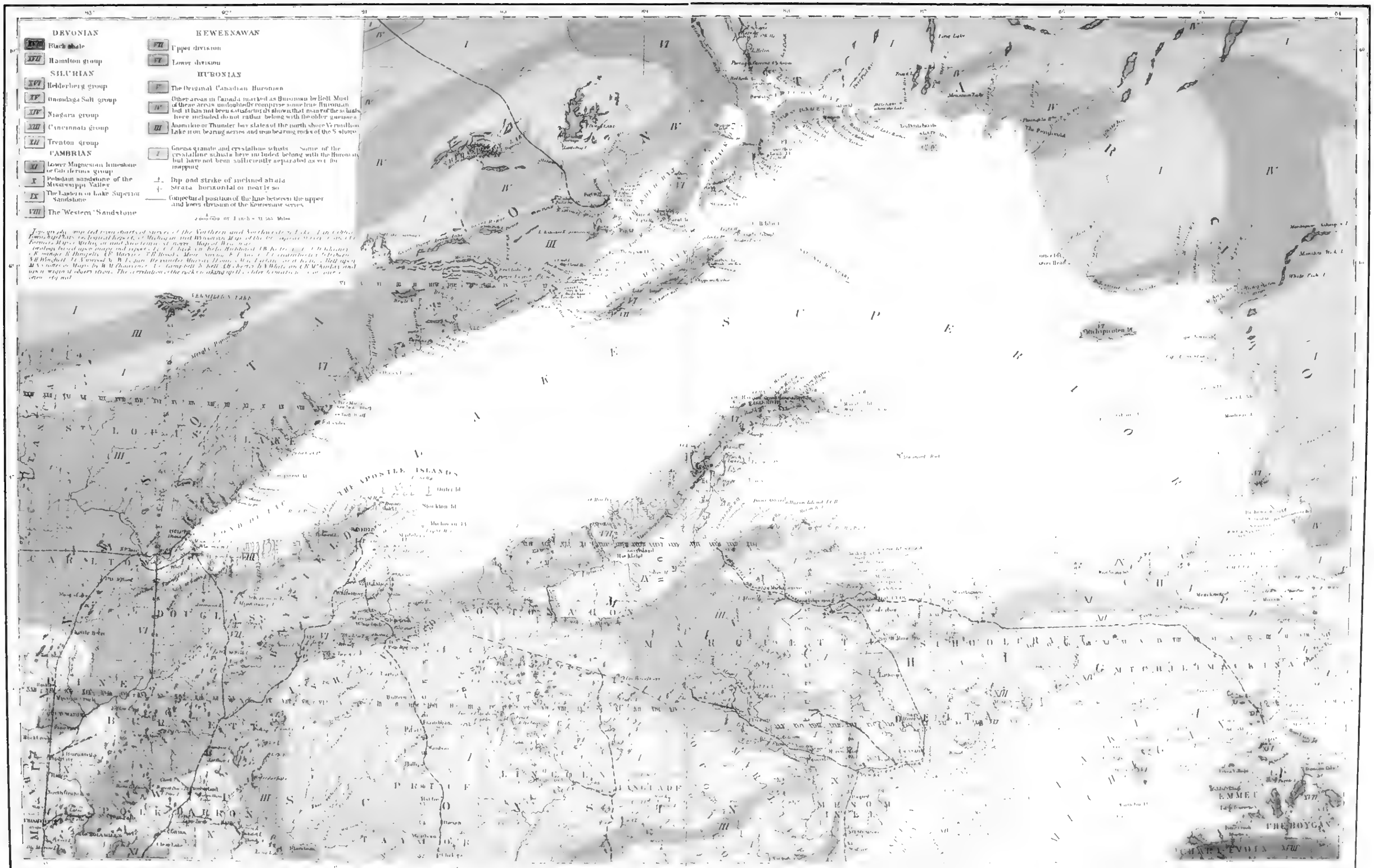
The series of rocks under consideration is almost entirely restricted to the Lake Superior basin, whose limits it passes only at the southwest, where



GEOLOGICAL MAP OF THE

A. Hoen & Co. Lith. Baltimore

LAKE SUPERIOR BASIN



GEOLOGICAL MAP OF THE LAKE SUPERIOR BASIN

there is an extension for a short distance into the west side of the valley of the Upper Mississippi. The bottom of the lake itself is, throughout most of its extent, composed of these rocks, as are also the immediate shores, for a great part of the lake's circumference. In much of its course around the lake basin this group does not reach many miles inland, in some places occupying only projecting headlands, the older rocks forming the intervening shores. Towards the west end of the lake, however, in the stretch across the state of Wisconsin, there is a very wide surface-spread, the area in Wisconsin alone being about five thousand square miles.

To convey a more definite idea of their distribution in the circuit about Lake Superior, it may be said that, besides underlying the greater part of the lake, the Keweenawan rocks form the larger part of Keweenaw Point, probably also underlying the horizontal sandstone of the remainder; constitute the Michigan shore from Keweenaw Point to the Montreal River, extending back into the country 8 to 20 miles; in all probability underlie the sandstone country still further away from the lake, since they appear again in a few places on its southern edge, which would carry them inland from the Michigan shore as much as 30 to 35 miles; underlie all of northern Wisconsin north of a line from the Montreal River at a point 15 miles from Lake Superior to Numakagon Lake, and thence to Saint Croix Falls, or the west boundary of the state; stretch in Minnesota over two-thirds of the triangular area included between the state boundary, the Saint Croix River, and the Saint Paul and Duluth Railway; constitute the entire Minnesota shore of the lake, from Duluth to Grand Portage Bay, running back into the interior about midway in the coast as much as 30 miles; make up the outer ones of the Lucille group of islands off Pigeon Point, and the whole of Isle Royale; form the entire peninsula between Black and Nipigon bays, with all outlying islands, and also the whole group of islands, large and small, south of Nipigon Bay; spread over a very wide area in the valleys of Black-Sturgeon and Nipigon rivers, north of Lake Superior; after a long interval, during which older rocks only appear on the coast, come up again in Michipicoten Island, which they entirely compose; appear again on the east coast of the lake at Cape Choyye, Cape Gargantua, Pointe aux Mines, Mamainse, Batchewanung Bay, and Gros Cap—at nearly all of which places they form mere edgings between the lake and the older rocks, the only exception being at Mamainse, where a great thickness is exposed; and, finally, constitute the isolated reef between Keweenaw Point and Marquette, known as Stannard's Rock. Between Gros Cap and Stannard's Rock the rocks of this series do not appear, but there can be little doubt that they are continuous underneath the lake and underneath the newer horizontal beds of the eastern part of the upper peninsula of Michigan.

The main dimensions of Lake Superior are as follows, in air-line distances:[1] from Fond du Lac to Sault Sainte Marie, 377 miles; from Duluth to Batchewanung Bay, the extreme straight-line length of the lake, 368.5 miles; extreme width from South Bay, near Grand Island, to the mouth of Nipigon River, 195.5 miles; width from Presq'isle River, on the Michigan coast, to Poplar River, on the Minnesota coast, 73.5 miles; from the eastern extremity of Keweenaw Point to Nipigon Point, 116 miles; from the same to Otter Head, 91.5 miles; from the same to Mamainse Point, 140.5 miles; from the same to Whitefish Point, 137.3 miles; from the same to Sault Sainte Marie, 170.5 miles; and from the same to Duluth, 212 miles. A measurement, first, on a line from Fond du Lac, N. 66½° E. to a point in the middle of the lake on the national boundary line, about 45 miles north of Keweenaw Point, and thence S. 55½° E. to Sault Sainte Marie, gave for the two distances, respectively, 229 miles and 191 miles, or, for the extreme length of the lake, measured along its middle line, 420 miles. The approximate length of the coast line of the lake, exclusive of the more minute irregularities, but including all the larger bays, is 1,700 miles. The coasts of the greater islands will increase this to 1,900 miles. The total area of the lake, exclusive of all the larger islands, but inclusive of all bays, is about 30,880 square miles. Deducting from the last figure 2,500 square miles for lake area underlaid by older rocks in the extreme northeast, in Thunder, Black, and Nipigon bays, and, again, between Keweenaw Bay and Marquette, we obtain 28,380 square miles as the approximate total extent of the group under the waters of Lake Superior.

To obtain its whole geographical extent we must add to the last figure

[1] All of these figures were obtained by careful measurements on the U. S. Lake Survey charts.

as follows: for Michigan, in the area between Keweenaw Point and the Montreal River (the "Main Trap Range," and Porcupine Mountains region) 1,744 square miles; for the area of horizontal sandstone south of the Main Range of Michigan, and west of the head of Keweenaw Bay, which area is undoubtedly underlaid by rocks of this group, 1,400 square miles; for Wisconsin, including the area in the immediate vicinity of Lake Superior, and again on the Saint Croix River, where the Keweenawan rocks are covered with horizontal sandstones, about 5,000 square miles; for Minnesota, south of the Saint Louis, including portions buried beneath horizontal sandstone, 1,000 square miles; for Minnesota, north of Lake Superior, about 3,200 square miles; for Isle Royale, 210 square miles; for Isle Saint Ignace and adjoining islands, 180 square miles; for Michipicoten Island, 75 square miles; and for small areas along the east shore between Cape Gargantua and the Sault, 90 square miles. These rocks are also undoubtedly buried beneath the horizontal formations of the south shore of the lake west of the Sault, but not to any very great extent. So that we may be safe in placing the entire geographical extent of the series at 41,000 square miles for the immediate basin of Lake Superior. This is exclusive of an extension northward of some of the lower beds into the basin of Lake Nipigon through the valleys of Black-Sturgeon and Nipigon rivers. The thickness of this extension, judging from Bell's descriptions,[1] is inconsiderable, the rocks lying often nearly horizontal. In the valleys of Black-Sturgeon and Nipigon rivers they appear to form strips between older rocks on either side, but in the Nipigon Lake basin to have a wider extent. Bell's map makes the total area in this basin as much as 5,000 square miles.

Throughout all of this wide extent, though local peculiarities are to be noted, the general characteristics of the group are wonderfully constant. The predominating rocks belong to the basic crystalline class. They are, as a rule, in distinct, but, for the most part, heavy layers, their bedded structure being due, as I believe, to their having been spread out as successive molten flows, and more rarely, perhaps, as injections between the previously formed layers. These basic rocks belong wholly to the augite-

[1] Report of Progress of Geological Survey of Canada, 1866–'69; 1872–'73.

plagioclase class, hornblende occurring only very rarely and then always as an alteration-product. Pumpelly has heretofore recognized the three types of diabase, melaphyr, and gabbro as characterizing the Keweenaw Point district, and after a study in the field of the entire North Shore, and the examination of large numbers of specimens from all portions of the Lake Superior basin, I am able, though having discovered a number of interesting new varieties, to add only two kinds deserving of distinct names, viz. diabase-porphyrite and anorthite-rock, and these are, after all, so closely allied to the others as to be hardly more than varieties. Indeed, the three kinds first named grade into each other in the field, and are themselves merely phases of an ancient class of rocks, for which the science has as yet established no common name, but which are the old equivalents of the post-Cretaceous basalts.

The diabase is a plagioclase-augite rock, with or without olivine, and without unindividualized base; the melaphyr carries more or less of this base with olivine, and is, throughout the Lake Superior region, everywhere characterized by the presence of relatively large individuals of augite, including numbers of minute plagioclases; while the gabbro has part or all of the augitic ingredient as diallage, is orthoclase-bearing or not, and is either olivine-bearing or not. The diabase-porphyrite is an olivine-free diabase, with a strong porphyritic development and a more or less thoroughly unindividualized base; and the anorthite-rock is merely a coarse gabbro, in which all ingredients but the feldspar are wanting. The nomenclature adopted for these rocks is Rosenbusch's. There are numbers of peculiar phases of the three kinds named, due to amygdaloidal and compact conditions, relative abundance of the several ingredients, coarseness of grain, the presence of unusual constituents, and, especially, internal molecular rearrangements. But the same types constantly recur in the circuit of the lake, and there are only one or two subordinate varieties that have not been seen again and again, and at points widely removed from each other. Some arrangement of the kinds as to horizon also is to be observed. One of the most interesting results of my work is the finding of gradation phases, not only between all the kinds named, but from the most basic kinds, with less than

46 per cent. silica, to the most acid of the acid kinds subsequently mentioned.

Interstratified with these basic crystalline rocks, at many different horizons, but generally greatly more abundant above, are detrital beds, chiefly reddish conglomerate and sandstone. The conglomerates are for the most part made up of pebbles of one or more of three kinds of acid rocks, viz: (1) a red to brown or purple felsite, nearly or quite without either quartz or orthoclase as porphyritic ingredients; (2) a true quartziferous porphyry, usually brick-red in color; (3) a non-quartziferous porphyry, with bright-red striated feldspar crystals; and (4) fine-grained to coarse-grained granitic porphyry and augite-syenite, of which the several phases verge towards quartziferous porphyry or granite on the one hand, and quartzless porphyry or an orthoclase-bearing gabbro on the other. The first two kinds are commonly without structural lines, but occasionally show faint and wavy bandings. One or two of these kinds will be found to predominate greatly at any one place, the same conglomerate belt showing at different points along its course great differences in this respect.

Pebbles of the basic rocks also occur in the porphyry-conglomerates, but they are relatively very rare. Pebbles of altogether different rocks are occasionally seen; as, for instance, on the peninsula of Mamainse, on the east coast, where granitic and gneissic pebbles are abundant. The matrix of these conglomerates appears to be of the same material as the pebbles themselves, and in the coarser kinds can easily be seen to be so. It is frequently permeated by calcite, which at times has completely replaced the matrix, yielding a striking looking combination of red and brown pebbles with a background of pure white cleavable calcite.

An altogether different conglomerate from those just described, and one of much more restricted distribution, has a red shaly matrix, often finely laminated, in which the pebbles are wholly of the common diabase and diabase-amygdaloid. Of these conglomerates there seem to be again two kinds; one in which the pebbles are distinctly waterworn, and another in which there is no such distinct evidence of water action, and in which the vesicular exteriors of the balls suggest their possible origin as volcanic scoriæ that have become buried in the accumulating detritus. The first of these varieties has been noted on the North or Minnesota Shore only. The other has been observed on both the South and North Shores, and is often hard to distinguish from a kind in which the red shaly material is most confusedly mingled with the vesicular amygdaloidal diabase, which at times seems to grade into the detrital matrix, and again to be separated from it in more or less distinctly defined balls; an appearance suggesting the deposition of detrital material upon and within the extremely scoriaceous upper portion of a lava flow.

Sandstones make up much the greater portion of the detrital members of the series, reddish sandstones prevailing. These run from earthy and shaly to quite coarse granular, but are always aluminous from the presence of a more or less decomposed feldspathic constituent. They vary from brick-red to quite dark-red in color, and are made up in large measure of the detritus of the same acid rocks that have supplied the pebbles of the conglomerates, as was first shown by Pumpelly. In the darker kinds more or less basaltic detritus is included. Quartz is never an exclusive, nor often even a very prominent, ingredient in any of the sandstones belonging without dispute to this group. Certain sandstones forming the eastern side of Keweenaw Point, and again the Wisconsin shore as far west as Fond du Lac in Minnesota, are highly quartzose in their uppermost portion, but these do not belong to the Keweenaw Series. Many of the red sandstones are highly charged with secondary calcite. Those kinds of sandstone which are dark-gray to nearly black in color are made up of basic detritus, usually mingled with more or less of the common porphyry detritus, and cemented by secondary calcite. These sandstones often contain only a rare quartz grain, having then not over fifty per cent. of silica. They grade into finer varieties, which at times pass into an earthy black shale or slate. These gray sandstones and accompanying black shales, with a thickness of several hundred feet, have been recognized in a single belt, running from the neighborhood of the Gratiot River, on Keweenaw Point, to Bad River, in Wisconsin—a total distance of 150 miles.

The source of the materials which make up the porphyry conglomerates and red sandstones has been a matter of speculation to all writers on Lake Superior geology. Foster and Whitney supposed them to come from the friction of the ascending igneous rocks against the rocks penetrated,[1] but they ignored the totally different natures of the porphyry of the pebbles and of the diabases forming the greater part of the series. Besides, it has long been plain that the pebbles of these conglomerates are simply waterworn fragments of some massive acid rocks, which could never have been far removed from where the pebbles now are. It has been supposed by some that the original massive rocks were to be looked for in the older so-called Huronian, although wherever this Huronian is exposed in the Lake Superior country such acid rocks are noticeably wanting.

I find the source of the pebbles in the massive acid rocks of the series itself, and recognize now for the first time that these original acid rocks are one of its most prominent features, characterizing it, as they do, throughout its entire extent, although always subordinated in quantity to the basic kinds.[2] I find it even possible to trace some of the pebbles of the conglomerates to their immediate sources. Pumpelly has shown[3] that the same belt of conglomerate will vary in its predominant pebbles in different portions of its longitudinal extent, while several conglomerates in one section will often show the same characteristic pebbles, facts which are to be explained by the differences in the original rocks at different points along the trend of the formation, and the derivation of the pebbles of the several

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[1] *Op. cit.*, p. 99.

[2] Foster and Whitney (Report on the Lake Superior Land District, Vol. I, pp. 65 and 70) speak of "quartzose porphyry" and "jasper" as occurring at Mount Houghton, on Keweenaw Point, and in the Porcupine Mountains, but they do not seem to have appreciated the true nature of these rocks, which, moreover, they regarded as merely alterations of the red sandstones by the heat of the intrusive rocks. Macfarlane distinctly recognizes the existence of true quartzose porphyry and of "trachyte" and "phonolite," on Michipicoten Island (Report of the Geological Survey of Canada for 1866, pp. 137-143), but he does not appear to have realized the importance of his observation.

Hunt has recently spoken of a true quartzose porphyry as occurring on a small island near Saint Ignace Island, on the North Shore, but he appears to regard this as Huronian, though it is undoubtedly merely one of the numerous instances of the occurrence of this rock within the Keweenaw Series. (Second Geological Survey of Pennsylvania. Special Report on the Trap-Dykes and Azoic Rocks of S. E. Penna., § 372, p. 193, and § 446, p. 229.) In my work in the Bad River country of northern Wisconsin, in the years from 1873 to 1877, I myself had also recognized true granites cutting gabbro at the base of the Keweenaw Series, and also noted and mapped two or more belts of apparently massive quartzose porphyry and felsite; but these latter were so poorly exposed—the deceptively massive appearance of some of the conglomerates being well known to me—that I only provisionally announced the existence of massive acid rocks in my published results (Vol. III, Geology of Wisconsin, pp. 11 and 193-198.)

[3] Geological Survey of Michigan, Vol. I, Part II, p. 16.

conglomerates of one section from a common source. Thus the Portage Lake conglomerates all carry a great predominance of non-quartziferous porphyry pebbles, while further northeast a granitic porphyry or augite-syenite becomes very abundant, and still further, in the region of the Calumet mines, a true quartz-porphyry prevails. In the latter case the source was a quartz-porphyry mass to the southeast, of which small exposures are still to be seen. In the Eagle River conglomerate again a common pebble is a quartzless porphyry, much like the massive rock exposed at the old Suffolk location to the southeast. The same association is to be noted in the Ontonagon and Porcupine Mountains regions.

These original acid rocks embrace all of the kinds included as pebbles in the conglomerates, viz: true quartziferous porphyries, with large doubly terminated quartzes and orthoclases as porphyritic ingredients; a non-quartziferous porphyry; compact felsite; granitic porphyry and augite-syenite; and true granite. Most of these rocks are of some sort of reddish hue, running from a pale pink to a bright brick-red; whence in large measure the red colors of the conglomerates and sandstones derived from them.

In recapitulation, then, it is to be said that the Keweenaw Series consists of eruptive flows and beds of detrital rocks interstratified with one another, the eruptive rocks occurring also subordinately in dike form.

The eruptive rocks include basic, intermediate, and acid kinds, as is commonly the case with volcanic regions of more modern activity, but there is no such chronological relation between these three kinds, as is so often found to be the rule in Tertiary and post-Tertiary volcanic regions.

An extraordinary thing is the complete absence from the series of anything like volcanic ash; another point of difference between it and the rocks of regions of more recent volcanic activity, and one which helps to support the view that the eruptive rocks of this region have come through open fissures, and not after the manner of the volcanic flows of the present day, as the extreme uniformitarians would have us believe.

The detrital rocks of the series are all composed of water-derived fragments, broken for the most part from the acid rocks of the series itself.

Such viscous materials as these acid rocks must have been when molten would solidify into more or less bulky, erect masses of relatively small area; and their degradation into geologically contemporaneous conglomerates seems to have been chiefly rendered possible by this mode of occurrence. Strewn as they were around the rim of a basin whose middle portion was steadily depressing during the growth of the series and whose edges were at the same time rising, each of these bulky masses was able to supply the materials for a number of different horizons of sandstone and conglomerate.

CHAPTER III.

LITHOLOGY OF THE KEWEENAW SERIES.

SECTION I. BASIC ORIGINAL ROCKS.—Pumpelly's investigations on the basic rocks of Keweenaw Point; of Northern Wisconsin.—Status of the subject at the close of the Wisconsin Survey.—Nomenclature.—General statement of results.—Classification.

COARSE-GRAINED BASIC ROCKS.—*Orthoclase-free diabase and gabbro, and olivine-gabbro:* general macroscopic description of; olivine of; plagioclase of; magnetite of; augite or diallage of; accessory ingredients of; appearance in the field of; typical localities of; tabulation of microscopic observations on.—*Orthoclase-bearing gabbro:* distinctions from the non-orthoclastic gabbros; orthoclase of; plagioclase of; magnetite of; augite and diallage of; accessory ingredients of; occurrence in the field of; typical localities of; tabulation of microscopic observations on.—*Hornblende-gabbro:* distinctions of, from preceding kinds; tabulation of microscopic observations on.—*Anorthite-rock:* general description of; tabulation of microscopic observations on.

FINE-GRAINED BASIC ROCKS.—Quantitative relations.—*Olivine-free diabase, of the ordinary type:* Pumpelly's study of; occurrence in the field of; amygdaloids and pseudamygdaloids of; alterations of; microscopic characters of; typical localities of; tabulation of microscopic observations on.—*Olivinitic fine-grained diabase and melaphyr:* Pumpelly's descriptions of; occurrence in the field of; tabulation of observations on.—*Ashbed-diabase and diabase-porphyrite:* macroscopic characters of; microscopic description of: wide range in acidity of; typical localities of; tabulation of observations on.—*Amygdaloids:* relations to the other basic rocks of; microscopic characters of; macroscopic characters of; Pumpelly's study of; altered forms of; Pumpelly's conclusions.

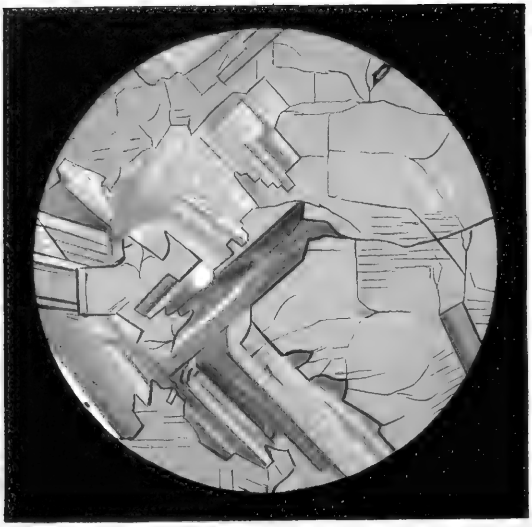
SECTION II. ACID ORIGINAL ROCKS: Quantitative relations of; classification of.—*Quartzless porphyry:* relations of, to the diabase-porphyrites and quartziferous porphyries; macroscopic characters of; microscopic characters of; porphyritic ingredients of; typical localities of; tabulation of microscopic observations on.—*Quartziferous porphyry and felsite:* quantitative relations and occurrence of; difficulties in the study of; Rosenbusch's nomenclature; macroscopic characters of matrix of; microscopic characters of matrix of; macroscopic and microscopic characters of porphyritic ingredients of; origin of; typical localities of; tabulation of observations on.—*Augite-syenite and granitell or granitic porphyry:* macroscopic characters of; microscopic characters of; gradation phases of, into other kinds; difficulty in finding a name for; relations of, to the modern trachytes; typical occurrences of; tabulation of microscopic observations on.—*Granite:* occurrence of, in the Bad River country of Wisconsin; macroscopic and microscopic characters of; absence of, in the rest of the extent of the formation.

SECTION III. SUMMARY VIEW OF THE ORIGINAL ROCKS OF THE KEWEENAW SERIES.

SECTION IV. DETRITAL ROCKS.—*Conglomerates.*—*Sandstones.*—Basic sandstones.—Quartzose sandstones.—Secondary minerals in sandstones.—Tabulation of microscopic observations.

The natural grouping of all of the rocks of the Keweenaw Series into the three classes of basic original, acid original, and detrital rocks has already been indicated.[1] In what follows, each prominent variety is taken up in some detail.

[1] See Chapter II.



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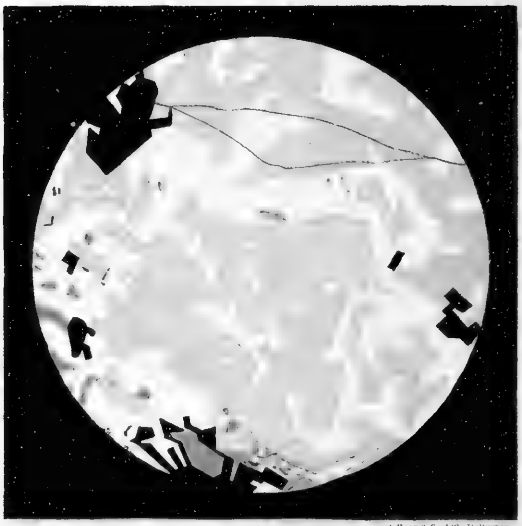

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OLIVINE-FREE GABBROS

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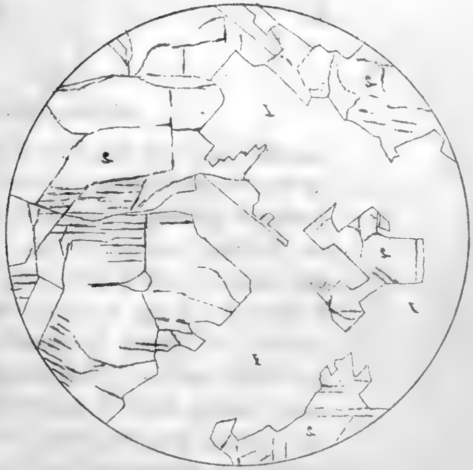

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Figs. 1 and 2. Diabase or gabbro from coast of Lake Superior near Beaver Bay, Minn. Fig. 1 ordinary light. Fig. 2 polarized light. Scale 21 diameters.
Anorthite(1); augite(2).

3

4

Figs. 3 and 4. Gabbro from coast of Lake Superior near Duluth, Minn. Fig. 3 ordinary light. Fig. 4 polarized light. Scale 30 diameters.
Anorthite(1); diallagic augite(2); titaniferous magnetite(3); iron oxide(4)

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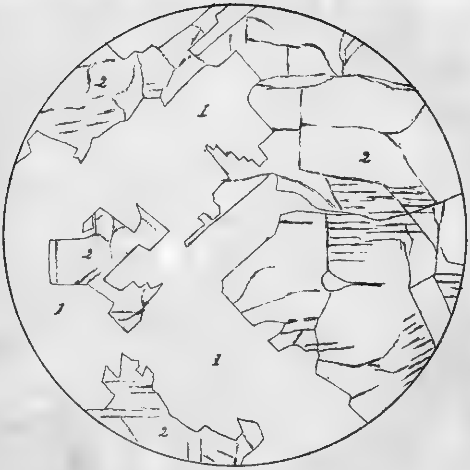

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Figs. 1 and 2. Diabase or gabbro from coast of Lake Superior, near Beaver Bay, Minn. Fig. 1. ordinary light. Fig. 2 polarized light. Scale 21 diameters

Anorthite (1); augite (2).

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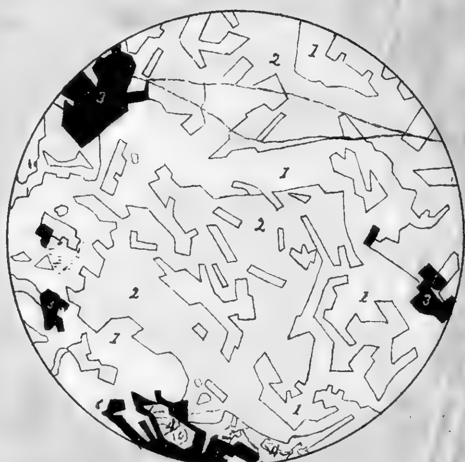

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Figs. 3 and 4. Gabbro from coast of Lake Superior, near Duluth, Minn. Fig. 3 ordinary light. Fig. 4 polarized light. Scale 30 diameters

Anorthite (1); diallagic augite (2); titaniferous magnetite (3); iron oxide (4)

SECTION I.—BASIC ORIGINAL ROCKS.

In his paper on "The Metasomatic Development of the Copper-bearing Rocks of Lake Superior," published in 1878,[1] Pumpelly first showed the true nature of the prevalent basic rocks of the copper region of Michigan. His work was chiefly on specimens from the section displayed on the lower Eagle River, Keweenaw Point. Subsequently (1880), the same geologist published[2] the results of an examination of a suite of specimens collected for the Wisconsin Geological Survey by Messrs. M. Strong, E. T. Sweet, and myself in the districts severally under our charge. These Wisconsin rocks he was able for the most part to throw into the same groups whose existence he had already determined in his Michigan work, the only important addition being one or two varieties of true gabbro, now first proved to exist in the Lake Superior country. These gabbros were further described in the same volume by Mr. A. A. Julien, and in some detail by myself.

At the close of the investigations of the Wisconsin Survey the list of the basic rocks of the Keweenaw Series stood as follows: *gabbro*, including gabbro proper, olivine-gabbro, uralitic gabbro, and an orthoclase-bearing gabbro; *diabase*, including the ordinary, prevalent, fine-grained type, one or two coarse-grained varieties, a type designated as "ashbed" diabase, a pseud-amygdaloidal diabase, and true diabase-amygdaloids; and *melaphyr*, including melaphyr proper, as also its pseud-amygdaloidal and true amygdaloidal phases. The names gabbro, diabase, and melaphyr were given in accordance with the usage of H. Rosenbusch, who has classed the pre-tertiary plagioclase-augite rocks as indicated in the following scheme:[3]

I. GRANULAR.
- *a.* Plagioclase-augite = *diabase.*
- *b.* Plagioclase-augite-olivine = *olivine-diabase.*

II. PORPHYRITIC, containing more less of an insoluble base.
- *a.* Plagioclase-augite = *diabase-porphyrite.*
- *b.* Plagioclase-augite-olivine = *melaphyr.*

[1] Proceedings of the American Academy of Arts and Sciences, Vol. XIII, pp. 253–309.
[2] Geology of Wisconsin, Vol. II, pp. 29–49.
[3] Microscopische Physiographie der Massigen Gesteine, von H. Rosenbusch. Stuttgart, 1877, pp. 317, 458.

III. GLASSY, known only as subordinate, vitreous modifications of diabase-porphyrite not deserving of a special name.

IV. GRANULAR PLAGIOCLASE-DIALLAGE ROCKS.

a. Plagioclase-diallage = *gabbro.*

b. Plagioclase-diallage-olivine = *olivine-gabbro.*

For the present work I have studied some eight hundred sections made from specimens collected from all parts of the entire extent of the Keweenaw Series, including the typical localities of Pumpelly's Michigan descriptions. I have also had in my hands the original sections made by Pumpelly for his study of the Wisconsin rocks. Although my microscopic work has been extended over so much wider a field than his—covering, as it has, not only the already partly studied districts of Keweenaw Point and northern Wisconsin, but also the hitherto wholly unstudied rocks of the north and east shores of the lake, of the Bohemian Range on Keweenaw Point, of the Ontonagon, Porcupine Mountain, and "South Range" districts of western Michigan, of the Snake and Kettle River region of Minnesota, and of Michipicoten Island—its chief result, so far as the basic rocks are concerned, has been to extend the application of Pumpelly's conclusions over the entire spread of the Keweenaw Series. I have been able to recognize a number of new varieties of his gabbro, melaphyr and diabase, and two new kinds—anorthite-rock and diabase-porphyrite—not to be included under any of these three, though closely related to them, and have found that there is a large class of rocks which are intermediate in point of acidity.

The classification given below of the basic original rocks of the Keweenaw Series is based not only on microscopic differences and resemblances, but also upon the characters and relations of the several kinds as seen in the mass, and on their prominence and persistence in the field. For instance, the first group given of the coarser grained rocks is made to include orthoclase-free gabbro and diabase, olivine-diabase, and olivine-gabbro,[1] because all of these in the hand specimens bear the closest resemblance to each other, and in the field are seen to constitute parts of the same continuous mass or bed, forming together one of the most prominently occurring types.

[1] The distinction between diallage and augite is a valueless one, since not only are both often found in the same section, but every gradation is found in the rocks of this class from augite to diallage.

It will be seen at once that all of the kinds named are very closely related. Except one extreme phase—the anorthite-rock—they are all plagioclase-augite rocks (the diallage being but a phase of ordinary augite) and all carry magnetic or titanic iron, while olivine is a common ingredient. The differences consist only in variations in coarseness of grain, relative amounts of the several ingredients, presence or absence of olivine, presence or absence of unresolvable base, presence or absence of orthoclase, variations produced by metasomatic changes, and variations in texture from granular to vesicular (amygdaloids). All of the kinds, though distinct enough in the field, are in fact, lithologically considered, but phases of one kind of rock, for which usage has not established any common name. The term "basalt," restricted by Rosenbusch to the younger equivalents of the pre-Tertiary olivine-diabase and melaphyr, has been much used with a more extended signification, and might, perhaps, be not improperly used as a general term for all plagioclase-augite rocks, young and old.

BASIC ORIGINAL ROCKS OF THE KEWEENAW SERIES.

I. COARSE-GRAINED.
1. Gabbro and diabase; olivine-gabbro and olivine-diabase; all free from orthoclase.
2. Orthoclase-bearing gabbro.
3. Hornblende-gabbro.
4. Anorthite-rock.

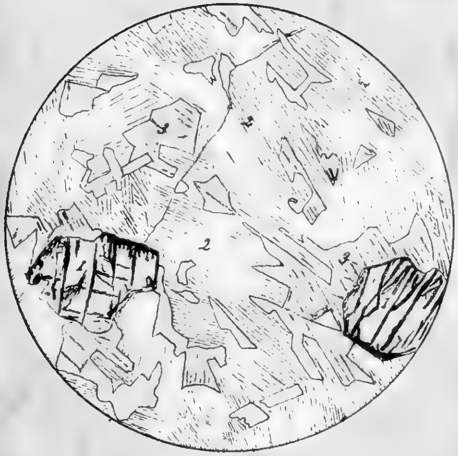
II. FINE-GRAINED.
5. Diabase of the "ordinary type."
6. Olivinitic fine-grained diabase and melaphyr.
7. "Ashbed"-diabase and diabase-porphyrite.
8. Amygdaloids (vesicular diabase and melaphyr).

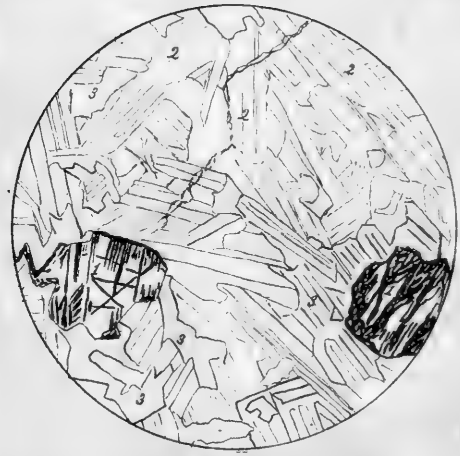
COARSE-GRAINED BASIC ROCKS.

Orthoclase-free diabase and gabbro, olivine-diabase and olivine-gabbro.—The rocks included here have a prevailing very dark-gray, often black, shade. More rarely they are light-gray, when the plagioclastic ingredient becomes greatly predominant, as is apt to be the case in the coarsest kinds. Not unfrequently a brownish film (ferrous oxide) over the shining black augite produces a resinous hue, and a somewhat similar effect is occasionally produced by a relatively large proportion of olivine. The texture is a very highly crystalline one, causing a rough-surfaced fracture. The several primary ingredients, except olivine, can nearly always be recognized with a lense, and in the coarser kinds with the naked eye. The specific gravity ranges from 2.8 to 3.1.

The olivine, which is a common, but not constant, ingredient of these rocks, is, when present, always the oldest of the chief ingredients, as is plainly enough shown by its relation to the others in the thin section. Occasionally in the fresher rocks it may be detected with the lens in characteristic glassy, green grains, and at times is even of so large a size as to attract the unaided eye; as, for instance, in a resinous-hued, rather coarse, and a good deal weathered rock, which forms a low cliff on the north shore of Lake Superior (Sec. 34, T. 57, R. 3 E., Minnesota), a short distance east of the mouth of the Brulé River. In this rock the olivine occurs in abundant, black, glassy particles, from one-sixteenth to one-third inch in diameter, with a scaly structure from commencing decomposition, and is evidently, from its high iron content, close to the variety *hyalosiderite.* In specimens from the vicinity of Bladder Lake, in Ashland County, Wisconsin, a light-green, glassy olivine is very noticeable to the unaided eye.

As seen under the microscope, the olivine occurs nearly always in irregularly-outlined, rounded particles, from a fraction of a millimeter to two or three millimeters in length. Only very rarely does it present crystalline outlines. Commonly, it is largely fresh, presenting a grayish or nearly colorless section, with the characteristic rough surface. It is, however, very rarely so fresh as to be without some traversing rifts, edged with a greenish-brown or brownish-yellow alteration-product. In less fresh kinds this brown alteration has affected the whole area, and in such cases the rock has macroscopically a pronounced resinous appearance. Less frequently, but still often, the iron oxide, instead of being deposited about and within the olivine, has been leached out, and then the mineral is more or less completely represented by a greenish material, supposed to be serpentine. In a number of sections in which this greenish alteration was observed magnetite was noticed in small particles, associated with the green in such a way as to suggest that it also was an alteration-result from the olivine. In some of the very coarse-grained gabbros of Bad River,





Figs 1 and 2 coarse olivine-diabase or olivine-gabbro from French River Minnesota Scale 25 diameters
Fig. 1 ordinary light Fig 2 polarized light. See pages XI. 281
Olivine (1); anorthite (2), diallagic augite (3)

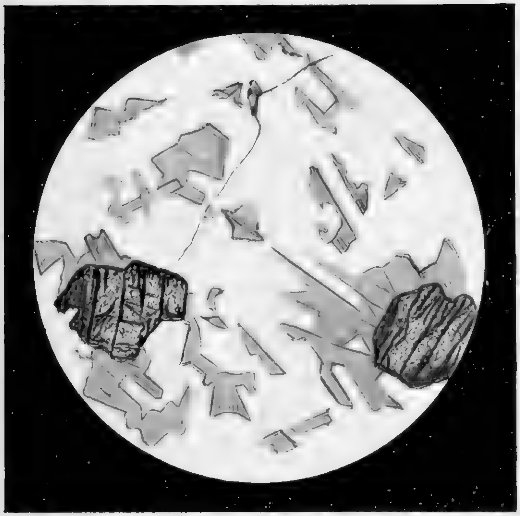
Fig. 3. coarse olivine-diabase or olivine-gabbro from north shore Lake Superior, near Sucker River, Minn. Scale 25 diameters. Ordinary light. See pp XI and 47
Olivine (1); anorthite (2); diallagic augite (3), titaniferous magnetite (4); green alteration product of olivine (5)

Fig 4. large olivines from same rock as shown in Figs 1 and 2 Scale 25 diameters. Ordinary light. See p. XI, 281
These olivines all appear as if eaten, or worn; only portions are entirely fresh (1); they are traversed by rifts (2); along which there is an alteration to serpentine (3); and oxide of iron (4), both of which alteration products also extend away from the cracks.

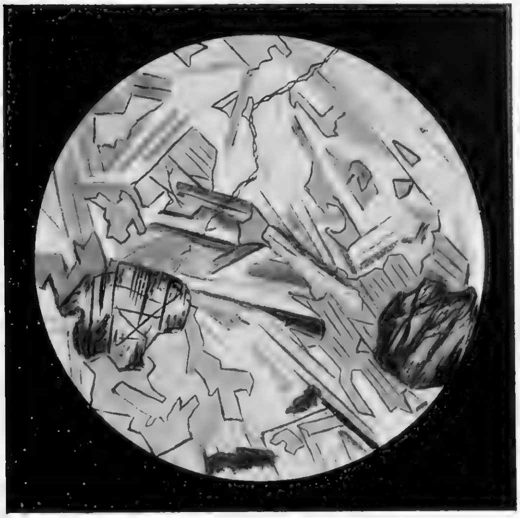
Figs 1 and 2. Coarse olivine diabase or olivine gabbro from French River Minnesota. Scale 25 diameters
Fig 1 ordinary light. Fig 2 polarized light. See pages 87, 251
Olivine(1), anorthite(2), diallage or augite(3)

Fig 4. Large olivines from same rock as shown in Figs 1 and 2. Scale 25 diameters. Ordinary light. See p. 87, 251
These olivines all appear as if eaten, or worn; only portions are entirely fresh(1); they are traversed by rifts(2); along which there is an alteration to serpentine(3), and oxide of iron(4), both of which alteration products also extend away from the cracks.

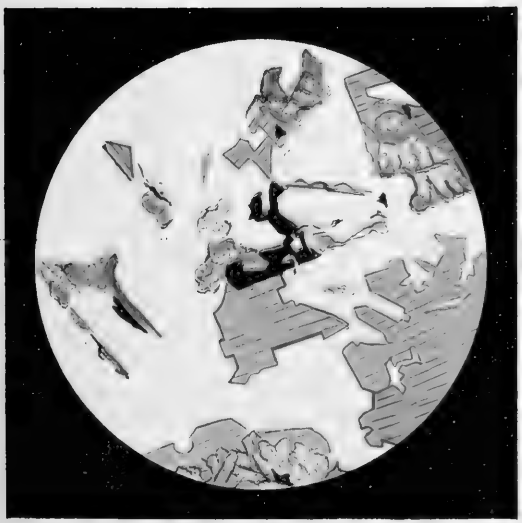
Fig 3. Coarse olivine-diabase or olivine-gabbro from north shore Lake Superior, near Sucker River, Minn. Scale 25 diameters. Ordinary light. See pp 81 and
Olivine(1); anorthite(2); diallage or augite(3); titaniferous magnetite(4); green alteration product of olivine(5)



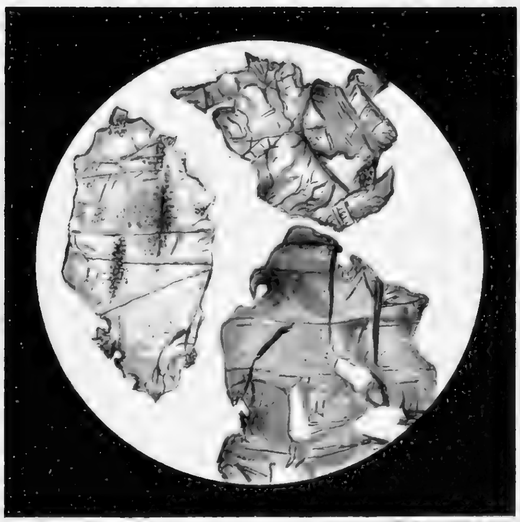
1



2



3



4

OLIVINE GABBROS

Wisconsin, as first shown by Julien,[1] the olivine shows a very interesting and unusual mode of change, namely, into biotite, viridite, and talc, the two former replacing the interior of the olivine grain, the latter forming a sort of shell of minute flakes around the outer part of the grain. Particles may be seen in all stages of this change.

Next to the olivine, in order of age, is the plagioclastic ingredient. Its crystals are usually in elongated forms, running from under a sixteenth of an inch in length to two or three inches in the coarsest kinds. The outlines of these crystals are commonly linear, or at least partly so, but in some sections the mutual interruptions have produced completely rounded contours. In composition—to judge from measurements of the angle contained between the maximum extinction positions of adjacent hemitropic bands, in sections cut at random in the zone $O: i \bar{\imath}$, as viewed between the crossed nicols—the plagioclase appears always to be near the basic end of the feldspar series. The sections measured were known to be in this zone by their giving equal, or nearly equal, angles between the position of coincidence of a nicol plane and the lines of junction of the hemitropic bands, and the maximum extinction position of the one set of hemitropic bands on the one side of this position of coincidence and that of the other set on the other side. The method is Pumpelly's modification of Des Cloizeaux's method of distinguishing between the plagioclase feldspars.[2] According to it, those feldspars from which the largest angles obtainable, after measuring a number of individuals, are below 36°, are classed as oligoclase; those whose largest angles lie between 36° and 62°, as labradorite; and those giving angles above 62°, as anorthite—the size of the angles increasing with the basicity.[3]

[1] Vol. III, Geology of Wisconsin, p. 235.

[2] Metasomatic Development of the Copper-bearing Rocks of Lake Superior; Proc. Am. Acad. Sci., Vol. XIII, pp. 30, 31. (1878.)

[3] The method is, of course, open to the objection that it determines the presence of only the high-angled or basic feldspars. In a rock of which a number of sections refused always to give any but low angles this would not be any objection, but in those giving high angles it leaves room for doubt. Nevertheless, in the present case I have little doubt that there is only one feldspar concerned. This is indicated by the exact similarity in all respects in any one thin section between the high-angled and low-angled particles, the latter of which are, indeed, but few in number. So far as the Lake Superior rocks are concerned, I have always found those feldspars which refuse, through a number of sections, to give high angles to have strongly-marked peculiarities, among which greater tendency to decomposition, and relatively very narrow lineations between the nicols are most prominent. It is also my experience that these low-angled feldspars are always associated with orthoclase, or, if they occur without orthoclase, that they are only large-sized porphyritic ingredients in an aphanitic base.

In the table given below the angular measurements always represent the largest angles that could be found. It will be noted at once that two-thirds of these measurements are high enough for anorthite—the most basic of the plagioclases—while in all the remaining sections entered as containing labradorite, angles were obtained not far below the upper limit for that mineral. In some of these cases there was difficulty in finding enough plagioclase sections in the right zone, and other slices might have given higher angles.

The plagioclastic ingredient of these rocks is commonly quite fresh, and always fresher than the olivine or augite. When alteration occurs, it is usually but a slight cloudiness. In the angular measurements made on over two hundred sections of the several kinds of basic rocks, it was observed that the freshness of the plagioclase bears a distinct relation to the size of the angle between the maximum-extinction positions of the adjacent hemitropic bands, the freshest feldspar always giving the largest angles, and *vice versa*. Pumpelly gives an instance (that of the rocks of bed 96 of the Eagle River section, Keweenaw Point) of a change of the plagioclase to prehnite in a rock of this class. This is an alteration commonly noted in the finer diabase, but in the rocks of the class now under description it is well-nigh unknown.

In sections of the very coarse-grained gabbro of Bad River, Wisconsin, large areas are often seen which polarize monochromatically, and are hence parallel to the brachy-pinacoid. These areas are thickly crowded with minute black needles, arranged in several directions. The needles, whose nature is in doubt, are characteristic[1] of the gabbros of many other regions. In the Bad River rock the set of the needles lying parallel to the vertical axis includes very much the larger number. Other needles, making an angle of 112° with the first, and evidently placed parallel to the strong basal cleavage, are fewer in number, but much longer. Still others, very numerous, lie oblique to the plane of the section, and are parallel to pyramidal planes.[2] The occurrence of the large monochromatically polarizing

[1] Geology of New Hampshire, Vol. III, Part IV, pp. 94.

[2] Compare Geology of New Hampshire, Vol. III, Part IV, Plate V, Fig. 5; also Fig. 3, Plate XV D, Geology of Wisconsin, Vol. III; also Fig. 58, Plate X, Rosenbusch's "Microscopische Physiographie der massigen Gesteine."

Coarse Olivine-Gabbro from Bladder Lake, Wis.; Ordinary light. Scale 10 diameters
Labradorite (1); augite (2); diallage (3); olivine (4); titaniferous magnetite (5), biotite (6), Secondary to olivine,— biotite (7); iron-oxide (8); talc 9; viridite (10).

Coarse Olivine-Gabbro from Bladder Lake, Wis.; Ordinary light. Scale 10 diameters

Labradorite (1); augite (2); diallage (3); olivine (4); titaniferous magnetite (5), biotite (6), Secondary to olivine,— biotite (7); iron-oxide (8); talc 9; viridite (10).

COARSE OLIVINE - GABBRO

areas which contain these needles, and the irregularity and frequent great breadth of the lineations, as a result of which crystals are found at times giving only two bands, have led to the idea that such rocks from other regions contain orthoclase,[1] and the same conclusion has been announced for the Bad River gabbro by Julien,[2] who also supports his decision by an appeal to the cross-barred twinning of the grains as seen in the polarized light. This appearance was for a long time supposed to be characteristic of orthoclase, but the supposed orthoclase has since been shown to be microcline, and a cross-barred twinning is now known to be common in labradorite as well. Moreover, a careful examination of the cleavage directions, so often emphasized by inclusions, makes it certain that we have to do with a triclinic feldspar. The plagioclase of these rocks is often the most plentiful ingredient, but in the darker colored varieties is dominated by the augite, which in some of the very black kinds constitutes nearly the whole section.

The iron-oxide constituent of these rocks appears commonly to stand between the plagioclase and the augitic constituent in point of time of crystallization. This is not always evident, even for the magnetite that is a primary constituent, while there is undoubtedly at times a magnetite resulting from the alteration of the augite. The distinction between magnetite and titanic iron, still more between magnetite and titaniferous magnetite, in rock sections, is a difficult one always, and often is well-nigh impossible without a quantitative analysis, when the characteristic crystalline outlines of magnetite and the equally characteristic white alteration-product of titanic iron and of highly titaniferous magnetite are both lacking. The powder of the finer grained of these rocks generally yields a considerable beard to the magnet, and in the coarser kinds the plainly visible metallic-lustered particles are always strongly magnetic. A number of qualitative tests made yielded, about half and half, negative results and feeble reactions for titanium. On the whole, I am inclined to consider that in these rocks the iron-oxide ingredient is always a titaniferous magnetite, although the titanium is at times in very minute quantity. In size this ingredient runs from mere dust to particles a quarter of an inch across, and usually is in as large

[1] H. Rosenbusch, *op. cit.*, p. 460.
[2] Geology of Wisconsin, Vol. III, p. 234.

particles as the olivine. It occurs commonly in very irregularly outlined forms, much more rarely in elongated parallel rods, in which no distinct crystalline outlines can be made out.

The augitic constituent, which varies from augite to highly fibrous diallage, is invariably of later formation than the olivine and plagioclase; and commonly, perhaps always, is later than the magnetite also. It often includes the olivine grains, and has always its outlines determined by those of the previously formed plagioclase. As seen with the naked eye, on a fresh fracture, it is of a lustrous black color, more rarely having a tendency to a metallic luster. On a weathered surface the diallage is at times of a brilliant, brassy, metallic luster. It is commonly the coarsest ingredient present, its particles at times reaching as much as one or two inches across, even when the rest of the rock is not unusually coarse. Very often one crystal will present in the thin section a number of wholly detached areas, which are proved to be parts of one individual by their common cleavage directions, and common behavior between the crossed nicol prisms.

In some cases, when the augitic constituent is diallage and reaches the extraordinarily large sizes above noted, it will include a large number of plagioclase crystals, and then the rock presents externally a peculiar appearance, analogous to the luster-mottling described by Pumpelly as characteristic of the Michigan and Wisconsin melaphyrs, only on a far grander scale. The body of the rock in these cases is no coarser than usual, nor does the hand specimen present any peculiar appearance until it is held in a certain position, when a brilliantly flashing, brassy surface is seen, from half an inch to two inches across, where before seemed to be only the usual mingled ingredients. The explanation of this peculiar appearance, as Pumpelly has shown for the melaphyrs, lies in the existence of the diallage in extraordinarily large areas enveloping many plagioclases. This appearance is presented in a most striking manner by the rock of the cliffs of the north shore of Lake Superior, ten miles northeast of the village of Beaver Bay, Minnesota, and again six miles northeast of the same place, between the Palisades and the mouth of Baptism River. The rock seen at these places is of a moderately coarse grain and black color. It is very fresh within, but without is weathered to a light brown, and on the wave-worn surfaces the eye catches in every direction the flashes of the brassy diallage faces, which are often as much as two inches across.

In the thin slice the augitic ingredient presents a wine-colored or violet section, varying considerably in depth of tint. It often shows the characteristic prismatic cleavage, but more commonly is traversed by irregular cracks, or is affected in very varying degree by the diallage cleavage, parallel to the clinodiagonal. It is often quite fresh, but often also has undergone alteration, generally to some sort of soft, greenish, chloritic substance, which is feebly dichroic, or non-dichroic, in the section. This change is at times complete, no augite cores remaining. The alteration-product is often stained brown from the peroxidation of the iron of the augite, but in other cases has a pale-green color. These light-green areas sometimes contain particles of magnetite in such a way as to suggest that they, too, are secondary products from the augitic alteration. The change of augite to uralite, so characteristic of the orthoclase-gabbros of the Keweenaw Series, is only very rarely seen in the rocks of this class, and then with an inconsiderable development.

In only two or three sections out of the forty studied of this class of rocks was any apatite found, and then only in rare and minute crystals, although search was made for it in every one of the sections. A few scales of biotite were occasionally found.

The existence in these rocks of serpentine, chlorite, viridite and the brown and red oxides of iron as secondary or alteration-products has been mentioned. These ingredients rarely exert any considerable influence on the outward appearance, the rocks of this kind being on the whole remarkably fresh. Prehnite as an alteration-product of the plagioclase is exceptional, as stated above.

The rocks of this class present in the field very massive exposures, often with very marked columnar structure. They occur in very heavy beds, and are never furnished with an upper amygdaloidal or vesicular portion.

As typical and easily accessible localities for these rocks may be mentioned the cliffs of the North Shore, between Sucker and Knife River Bays; again for some five miles southward and four miles northeast of the hamlet of Beaver Bay; and again for long distances between the mouth of Brulé

River and Grand Portage Bay—all on the Minnesota coast. Other places are the Lake shore at Duluth (small areas); Brewery Creek, Duluth; the north shore of Nipigon Bay, near the mouth of Nipigon River, Ontario, Canada; the west side of the mouth of Nipigon Straits; and the beds immediately over "The Greenstone," in the Eagle River section of Keweenaw Point, especially the beds numbered 107 and 96 by Marvine.[1] These rocks are also common in the country back of the Minnesota coast, where they form most of the steep-backed ridges so commonly encountered in traversing the woods of this region. The Duluth gabbro falls for the most part under the next head, *i. e.*, is orthoclase-gabbro; but in the western extension of the Duluth gabbro belt towards Fond du Lac, and again to the northward, on the Cloquet River, very coarse olivine-gabbros are abundant. There is again an immense development of these rocks, often with excessively coarse grain, in the Bad River country of Wisconsin, where they underlie the greater part of a belt of country forty miles in length and two to four in width.

The following tabulation presents in a compact way the observations made on a number of specimens of these rocks brought from different parts of the Lake Superior basin. The angular measurements by which the feldspars were determined are included. The numbers of the specimens, when unaccompanied by any letter, are the collection numbers of the specimens gathered especially for this work. Numbers with the letter "W" attached belong to a collection made by Col. Charles Whittlesey in the Bad River region of Wisconsin, and now, with the thin sections, in the cabinet of the Wisconsin State University. Those with the letters S, SW, and I attached were collected respectively by Messrs. Strong, E. T. Sweet, and myself, for the Wisconsin State Geological Survey, and are also now, with the thin sections, in the cabinet of the Wisconsin State University. For further statements as to the four last-named collections, with descriptions of many specimens, see the Geology of Wisconsin, Vol. III., pp. 27 to 49, 53 to 238, 305 to 362, and 365 to 428.

[1] Geological Survey of Michigan, Vol. I, 1869–1873, Chapter VIII., pp. 117–140.

Tabulation of observations on coarse orthoclase-free gabbro and diabase.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O*: *ii*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
	Bed 107, Eagle River section, Keweenaw Point.	......	....	....	......	Medium-grained; black-and-white-mottled.	*Anorthite; magnetite,* or *titanic iron; augite.* (Pumpelly.)[1]	......	......	49 60 70 75
93 W .	Near Potato River, Ashland County, Wisconsin.	SE.	6	45	1 E.	Medium-grained; dark-gray; rough-textured. Sp. gr., 2.95.	*Anorthite; augite* tending to diallage; a little *altered magma.* (Pumpelly.)[2]	28 33 32	31 35 29	59 68 61
166 I ..	Ashland County, Wisconsin.	NW.	15	45	1 W.	Coarse-grained; very light-colored, gray, mottled with much white; rough-textured. Sp. gr., 2.80.	*Olivine,* in large areas reaching 2^{mm} in length, largely quite fresh, but also in part altered to ochre, biotite and talc; *anorthite,* greatly predominating; *diallage.*	26 23 18	23 34 21	49 67 39
3166 I .	Ashland County, Wisconsin.	NE.	34	45	2 W.	Fine-grained; dark-gray.	*Olivine,* largely quite fresh; *anorthite* abundant; *titaniferous magnetite; augite,* only slightly diallagic.	31 31	30 32	61 63
2028 S.	Bad River, Ashland County, Wisconsin.	NW.	31	45	2 W.	Very coarse-grained; light-gray; mostly made up of very coarse plagioclase, in which are embedded very numerous large olivines. Sp. gr., 2.82.	*Olivine,* very abundant and coarse, making up over one-third of the section, the particles elongated, reaching one-fourth inch in length, wholly altered to viridite, with some biotite in the interior and a shell of talc scales; *anorthite; magnetite,* sparse; *augite; diallage,* sparse.	34 25 37	30 28 38	64 53 75
12 I ...	Bad River, Ashland County, Wisconsin.	NE.	31	45	2 W.	Coarse-grained; dark-gray, somewhat stained with brown; rough-textured. Sp. gr., 2.81.	*Olivine,* partly fresh, partly altered, reaching 1.3^{mm} in length; *labradorite* greatly predominating; *augite; biotite* in minute scales between the plagioclase grains; *viridite, biotite* and *talc* secondary to *olivine; viridite* and *magnetite* secondary to augite; *ochre.*[3]	28 19 18	30 18 19	58 37 37
70 I ...	Ashland County, Wisconsin.	NW.	6	44	3 W.	Very coarse-grained; light-gray; shows much olivine to naked eye.	*Olivine,* very abundant, and coarse, partly fresh, partly altered to biotite and talc; *labradorite* or *anorthite* crowded with black needles, constituting most of the section; *magnetite,* sparse; *augite,* only slightly diallagic.	32 28 18	33 28 21	65 56 39

[1] Metasomatic Development of the Copper-bearing Rocks of Lake Superior, Proc. Am. Acad. Sci., Vol. XIII., pp. 256, 259.
[2] Geology of Wisconsin, Vol. III, p. 38.
[3] See also A. A. Julien, Vol. III, Geology of Wisconsin, pp. 235 to 237.

Tabulation of observations on coarse orthoclase-free gabbro and diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i\bar{i}$.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
84 S...	Brunschweiler's River, Ashland County, Wisconsin.	NW.	11	44	4 W.	Coarse-grained; dark-gray, mottled with white. Sp. gr., 2.92.	*Olivine*, partly altered; *labradorite; titaniferous magnetite; diallagic augite;* secondary *biotite, viridite, ochre.*	22 28 18	25 29 18	47 57 36
158 W.	Ashland County, Wisconsin.	NE.	15	45	4 W.	Coarse-grained; light-gray. Sp. gr., 2.81.	*Labradorite; titaniferous magnetite; diallage* sparse, partly changed to *uralite.*			
164 W[1]	Brunschweiler's River, Ashland County, Wisconsin.		22	45	4 W.	Fine-grained; dark-gray; lustrous.	*Anorthite; magnetite; diallage;* a little *biotite.*	30 33 36	37 36 32	67 69 68
86 I[2]...	Ashland County, Wisconsin.	SE.	14	44	5 W.	Very coarse-grained; light-gray.	*Labradorite; titaniferous magnetite: diallagic augite, uralite.*			
1132...	King's Creek, near Duluth, Minn.	NE.	12	49	15 W.	....	*Apatite; olivine* more altered than in the last section; *anorthite; titaniferous magnetite; diallage; biotite* in a few flakes; *ferrite.*	32 34 29 31	27 38 35 33	59 72 64 64
12.....	Brewery Creek, near Duluth, Minn.	SE.	22	50	14 W.	Medium-grained; dark-gray to nearly black; rough-textured. Sp. gr., 2.91.	*Olivine*, highly altered; *anorthite; titaniferous magnetite; augite* in part diallagic; *alteration-product of augite.*	29 30 18 33 30 23	32 37 27 37 27 21	61 67 45 70 57 44
1103...	Falls of Cloquet River, Minnesota. 400 N., 200 W.[3]	SE.	34	53	14 W.	Coarse-grained; very light-gray.	*Apatite; olivine*, mostly fresh, partly altered to green substances, and red and brown iron oxides; *anorthite; titaniferous magnetite; diallage; biotite* in a few small flakes; *ferrite.*	26 35 24 33	25 33 26 34	49 68 50 67
521....	Duluth, Minn., near center of		27	50	14 W.	Medium-grained; nearly black; rough-textured.	*Anorthite; titaniferous magnetite*, in elongated parallel rods; *augite*, in part diallagic; light green *alteration-product of augite.*	34 33 38	38 31 40	72 64 78
523....	North shore Lake Superior.	NW.	24	50	14 W.	Medium-grained ..	*Olivine; anorthite; titaniferous magnetite; augite*, in part diallagic, in large crystals, enclosing many feldspars.	23 21 20 39 17 28	24 19 21 32 16 25	47 40 41 71 33 53

[1] Vol. III, Geology of Wisconsin, p. 39. [2] Vol. III, Geology of Wisconsin, p. 40.
[3] 400 paces north and 200 paces west of the southeast corner of the section; 2,000 paces to the mile.

Tabulation of observations on coarse orthoclase-free gabbro and diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i\bar{i}$. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
579....	North shore Lake Superior; east point of Sucker River Bay, Minnesota.	SE.	2	51	12 W.	Medium-grained; light-gray; rough-textured.	*Olivine*, mostly very fresh, in part altered to a green substance; *anorthite; titaniferous magnetite; diallage*, in large areas, including many feldspars. A very fresh rock.	20 26 36 18	21 32 36 24	41 58 72 42
580....	......do	SE.	2	51	12 W.	Medium-grained; light-gray; rough-textured; close to 579.	*Olivine*, mostly very fresh, in part altered to a green substance; *anorthite; titaniferous magnetite; diallage*, in large arpas, including many feldspars.	42 32 33 33	30 47 31 35	72 79 64 68
582....	North shore Lake Superior, near east point of Sucker River Bay, Minnesota.	SE.	2	51	12 W.	Medium-grained; dark-gray; rough-textured; altered.	*Olivine*, very large and abundant, wholly altered to a green substance and magnetite; *anorthite; titaniferous magnetite; augite; diallage.*	31 34 35 37	30 39 40 35	61 73 75 72
583....	......do	SE.	2	51	12 W.	Medium-grained; light-gray; rough-textured; near 579. SiO_2 46.44 per cent.	*Olivine*, mostly very fresh; *anorthite; titaniferous magnetite; diallage* in large areas. A very fresh rock.	33 32	37 39	70 71
587....	North shore Lake Superior, between Knife and Sucker Rivers, Minnesota.	NE.	1	51	12 W.	Medium-grained; light-gray; rough-textured; near 579.	*Olivine*, very large, abundant and fresh; *anorthite; titaniferous magnetite; diallage; green alteration-products* of olivine and diallage.	37 31 33	43 40 38	80 71 71
588....	North shore Lake Superior, between mouths of Knife and Sucker Rivers, Minnesota.	SE.	36	52	12 W.	Medium-grained; dark-gray; rough-textured; near 579.	*Olivine*, very large and abundant; *anorthite; titaniferous magnetite; augite*, in part diallagic; *green alteration-products* of olivine and augite; brown iron oxide.	30 27 32 24	30 33 33 26	60 60 65 50
658....	Encampment Bluff, north shore Lake Superior, Minnesota.	NW.	22	53	10 W.	Medium-grained; dark-gray; rough-textured.	*Olivine; labradorite; titaniferous magnetite; augite*, in part diallagic, very coarse; *serpentine* as alteration-product of olivine; *a green alteration-product of augite.*	26 25 26 24	28 27 24 23	54 52 50 47
63.....	Encampment River, Minnesota.	NE.	10	53	10 W.	Medium to coarse-grained; black; rough-textured. Sp. gr., 2.89.	*Olivine*, partly altered; *anorthite; titaniferous magnetite; augite* non-diallagic; *alteration-products* of olivine and augite.	37 27 23 37	42 37 44 33	79 64 67 70

Tabulation of observations on coarse orthoclase-free gabbro and diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.*		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
67	do	NE.	10	53	10 W.	Medium-grained; brownish, with diallage; much altered; seamed by laumontite.	*Olivine*, wholly altered to green substance; *labradorite; titaniferous magnetite* in large areas; *diallage*, mostly altered to a green substance.	21 25 29	24 25 20	45 50 49
69	do	NE.	10	53	10 W.	Medium-grained; black; rough-textured.	*Olivine*, wholly altered to green substance; *anorthite; titaniferous magnetite; augite*, non-diallagic, greatly predominating.	33 32	39 31	72 63
682	North shore Lake Superior, below Split Rock River, Minnesota.	SW.	5	54	8 W.	Medium-grained; black; heavy; rough-textured. SiO_2 46.17 p. cent.	*Labradorite; titaniferous magnetite; augite; diallage; alteration-product* of augite and diallage.	33 30 25	27 26 27	60 56 52
779	North shore Lake Superior, one-quarter mile southwest of south point of Beaver Bay, Minnesota.	NW.	3	55	8 W.	Coarse-grained; black, stained with brown; rough-textured. Sp. gr., 2.87.	*Anorthite; titaniferous magnetite*, sparse; *augite*, in very large crystals, rarely diallagic, very fresh, and greatly predominating.	32 35 34	33 36 28	65 71 62
785	North shore Lake Superior; south side of Beaver Bay Point, Minnesota.	SW.	12	55	8 W.	Coarse-grained; black; rough-textured.	*Olivine*, represented by greenish-yellow alteration-product; *anorthite; titaniferous magnetite*, sparse and small; *diallage*.	40 31 28 31	33 30 31 36	73 61 59 67
789	do	SE.	12	55	8 W.	Coarse-grained; dark-gray; rough-textured.	*Labradorite; titaniferous magnetite*; diallagic *augite*, highly altered.	20 24 20 27	20 29 26 20	40 53 46 47
793	Falls of Beaver River, Minnesota.	SW.	12	55	8 W.	Coarse-grained; nearly black; rough-textured. Sp. gr., 2.93.	*Olivine*, in large areas, largely altered to brown ochreous substance; *anorthite; titaniferous magnetite*; diallagic *augite* in very large areas.	32 29 25 31	32 29 26 31	64 58 51 62
794	Beaver River, Minnesota.	SW.	12	55	8 W.	Coarse-grained; black; rough-textured.	*Olivine*, in large areas, much altered; *anorthite; titaniferous magnetite*; non-diallagic *augite*.	33 33 38	40 31 35	73 64 73
782	Falls of Beaver River, Minnesota.	SW.	12	55	8 W.	Coarse-grained; black; rough-textured.	*Labradorite; titaniferous magnetite*, not abundant; *diallage; viridite* as alteration-product.	18 17 24 29	24 17 23 28	42 34 47 57

Tabulation of observations on coarse orthoclase-free gabbro and diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O : ii*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
95.....	Beaver River, Minnesota, 875 N., 1,600 W.	SW.	12	55	8 W.	Medium-grained; red-and-black-mottled; very large diallage luster-mottlings.	*Anorthite*, greatly predominating; *titaniferous magnetite; diallage.*	28 29 30 28 33	27 25 30 24 35	55 54 60 52 68
1007...	Four miles north of Beaver Bay, Minnesota.	NW.	25	56	8 W.	Medium-grained to coarse-grained; gray; rough-textured.	*Olivine*, large, abundant and very fresh; *anorthite; titaniferous magnetite; augite* in part diallagic.	30 23 35 37	27 25 39 37	57 48 74 74
1012...	Six miles north of Beaver Bay, Minnesota.	NE.	13	56	8 W.	Medium-grained to coarse-grained; black; rough-textured.	*Anorthite; titaniferous magnetite; augite*, very much altered; *diallage;* much *ochre* and *ferrite.*	32 31 25	38 32 30	70 63 55
1021...	Eight miles north of north line of Beaver Bay, Minnesota.	NE.	2	56	8 W.	White-and-green-mottled; rough-textured.	*Labradorite*, much clouded; *titaniferous magnetic*, very abundant and coarse; *diallage*, largely altered to greenish dichroic uralite.[1]	24	25	49
819....	North shore Lake Superior; north point of Beaver Bay, Minnesota.	NW.	7	55	7 W.	Medium-grained to coarse-grained; black; rough-textured.	*Olivine*, very abundant and large, largely altered to the characteristic brown substance; *labradorite; titaniferous magnetite;* non-diallagic *augite* largely altered to greenish material.	24 23 31 31	24 30 25 29	48 53 56 60
821....	Island northeast of Beaver Bay, Minnesota.	NW.	5	55	7 W.	Medium-grained; black; rough-textured.	*Anorthite; titaniferous magnetite; augite* in very large areas; *diallage; viridite* as alteration-product of augite.	33 32 32 36	35 44 37 35	68 76 69 71
1515...	North shore Lake Superior; near mouth of Brulé River, Minnesota.	NE.	34	62	3 E.	Coarse-grained; nearly black; rough-textured; shows brassy diallage on weathered surface.	....	20 36 38 36	22 31 35 33	42 67 73 69
1528...	North shore Lake Superior; about 1½ miles east of Mawskequawcamaw River, Minnesota.	(abou (un	t) 5 sur	62 vey	5 E. ed).	Medium-grained to fine-grained; very dark-gray; rough-textured.	*Labradorite; titaniferous magnetite; augite*, non-diallagic, much altered to viridite material.	25 15 20	29 14 18	54 29 38

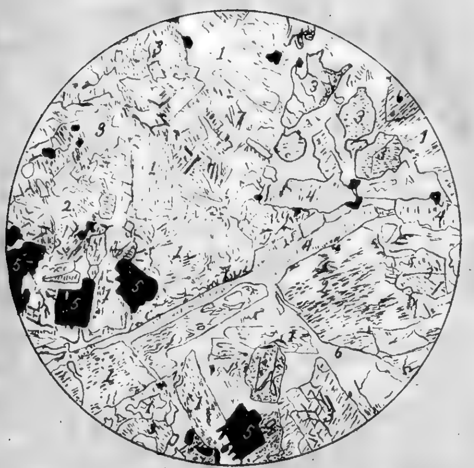
[1] The green appearance of the rock to the naked eye is evidently connected with this uralitic change.

Tabulation of observations on coarse orthoclase-free gabbro and diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ĭi*. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
1752	Northwest shore Nipigon Bay, near mouth of Nipigon River, Ontario, Canada.	......	....	....	......	Medium-grained; very light, gray, mottled with white; rough-textured. Sp. gr., 3.10.	*Olivine*, very fresh, abundant, and large; *apatite; labradorite; titaniferous magnetite; augite*, only slightly diallagic. A very fresh rock.	19 16 25	22 17 23	41 33 48

Orthoclase-bearing gabbro.—The rocks of this class are less common than those of the class last described, but are, nevertheless, often met with in all of the different districts crossed by the Keweenaw Series in its course around Lake Superior. They are distinguished from the ordinary gabbros and coarse-grained diabases by the presence of more or less orthoclase feldspar, and of a plagioclase near oligoclase; by the abundance of coarse-grained apatite, often large enough to be readily seen with a lens, or even with the naked eye; by the invariable absence of olivine; by the comparatively greater tendency to decomposition of the feldspars, the results of which are a clouding and reddening of the constituents, and the introduction of a greater or less amount of secondary quartz; by the greater richness of the magnetite in titanic acid; and by the common presence of a uralitic alteration of the augitic ingredient. So constant is the association in the Keweenawan basic rocks of orthoclase, oligoclase, coarse apatite, secondary quartz and uralitic alteration of augite or diallage, that only in rare cases is one of these characters found without most of the others.

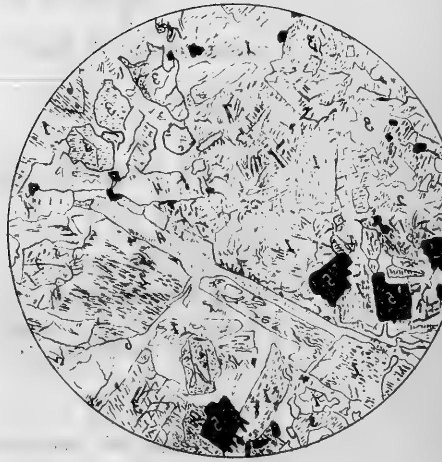
In grain these rocks cover about the same range as those of the last class, running from a medium-grain to an exceedingly coarse one, when the feldspar crystals reach some inches in length. The specific gravity is lower—2.7 to 2.8—than with the more common orthoclase-free gabbros,



Figs. 1 and 2 from near Lester River, Minnesota: Fig. 1 ordinary light. Fig. 2 polarized light.
Scales, Fig. 1, 20 diameters; Fig. 2, 37 diameters.
Labradorite (1), orthoclase (2); twinned augite (3); diallage (4); titaniferous magnetite (5); ferruginous alteration product of augite (6); secondary quartz network (7), saturating the feldspars.

Fig. 3. from Lac La Belle, Keweenaw Point. Ordinary light.
Scale, 20 diameters.
Oligoclase (1); orthoclase (2); diallage (3), much altered to uralite (4); titaniferous magnetite (5); grey substance (6) altered from titaniferous magnetite; apatite (7), Epidote (8)

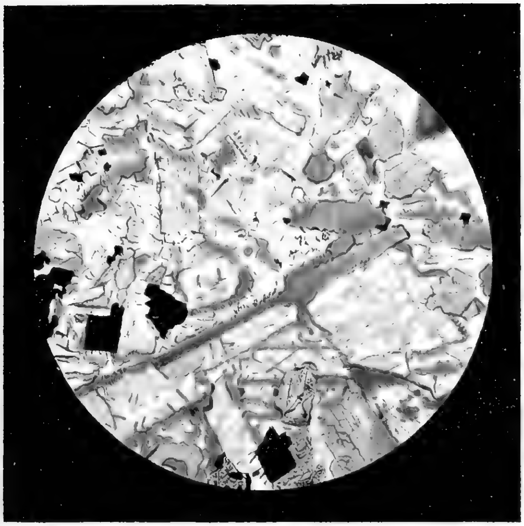
Fig 4. from Brunschweiler River, Wis. Polarized light.
Scale 35 diameters.
Labradorite (1); orthoclase (2); titaniferous magnetite (3), augite (4); secondary quartz (5); apatite (6).



Figs. 1 and 2 from near Lester River, Minnesota. Fig. 1 ordinary light, Fig. 2 polarized light.
Scales, Fig. 1, 20 diameters; Fig. 2, 35 diameters.
Labradorite(1); orthoclase(2); twinned augite(3); diallage(4); titaniferous magnetite(5); ferruginous alteration product of augite(6); Secondary quartz network(7), saturating the feldspars.

Fig. 3, from Lac La Belle, Keweenaw Point. Ordinary light.
Scale, 20 diameters.
Oligoclase(1); orthoclase(2), diallage(3), much altered to uralite(4); titaniferous magnetite(5); grey substance(6) altered from titaniferous magnetite; apatite(7), Epidote(8).

Fig. 4, from Brunschweiler River, Wis. Polarized light.
Scale 35 diameters.
Labradorite(1); orthoclase(2); titaniferous magnetite(3), augite(4), Secondary quartz(5), apatite(6).



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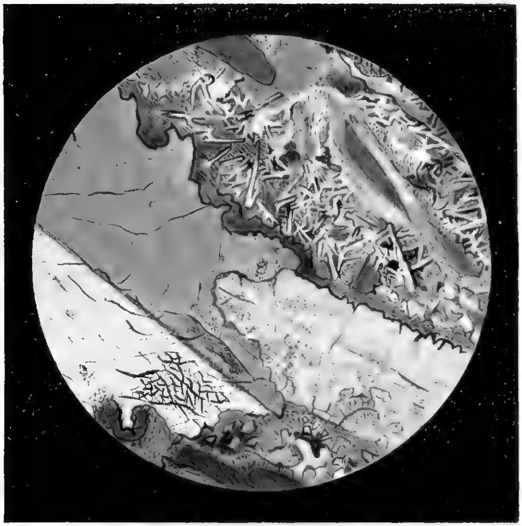

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ORTHOCLASE-GABBROS

not only because of secondary quartz, but also because of the nature of the feldspar and of the comparatively small amount of the augitic ingredient.

The orthoclase of these rocks is always more or less clouded, and is often reddened and charged with secondary quartz. The two latter results of alteration, however, vary greatly in the amount present, and are at times nearly or quite wanting, or at least the reddening is diminished so as to be hardly perceptible in the thin section, while the quartz may be wholly absent. The orthoclase appears always to be later in origin than the plagioclase, since its contours are always molded around those of the latter mineral.

The plagioclastic ingredient of these rocks gives in some sections angles higher than the limit set down for oligoclase, but it never reaches very high upon the labradorite range. It is always much less fresh than in the rocks of the previous class, in which extreme freshness of the feldspars is the rule, and is often reddened as much as the accompanying orthoclase. In some cases both it and the orthoclase show an alteration to a greenish chlorite. The lineation in the polarized light is at times very faintly seen, owing to decomposition, but is usually sufficiently distinct for measurement.

The magnetite of these rocks appears always to be much more highly titaniferous than that of the ordinary gabbros. It is generally in relatively large fragments, which have at times a marked pinkish tint, and then the attraction by the magnet is very feeble. In the thin section it is often accompanied by the peculiar white alteration-product indicative of the presence of titanic acid. It appears, however, always to be rather a very highly titaniferous magnetite than a true titanic iron. In the sections of the coarse orthoclase-gabbro of Duluth, the large, irregular areas of this ingredient are commonly surrounded by a brownish film, which appears usually to be merely ocherous, but is at times certainly made up in part of scales of biotite.[1] In some of these rocks the titaniferous magnetite forms bunches of such size as to have attracted attention as an iron ore, as, for instance, at Duluth, and again at several points in the interior back of Grand Marais and Beaver Bay. From some of this ore obtained some

[1] Compare G. W. Hawes, in Geology of New Hampshire, Vol. II, Part IV, Plate XI, Fig. 6.

miles back of Grand Marais, I obtained, some years since, over ten per cent. of titanic acid.

The augitic ingredient of the orthoclase-gabbros, like that of the more ordinary orthoclase-free gabbros, runs from augite to diallage, and in some sections the two, quite distinct from each other, are present. In one peculiar class of the orthoclase-gabbros met with at a number of points in the country back from the Minnesota coast, and especially in what I have called the "Duluth" and "Lester River" Groups, the augite is in long radiating blades, which are very pronounced macroscopically, and which in the thin section are seen to be twinned. By far the most of the sections, however, show a true diallage, much more highly fibrous than in the orthoclase-free gabbros, and nearly always more or less extensively changed to uralite. This uralitic alteration, which, in cross section, shows the true hornblende cleavage, is finely displayed in the very coarse gabbro of Duluth.

Among the accessory ingredients apatite is always very prominent, in crystals which at times reach an eighth of an inch in length. Chlorite, as an alteration of augite, or more commonly of uralite, and biotite are often present, and iron and copper sulphides are often to be met with in small particles.

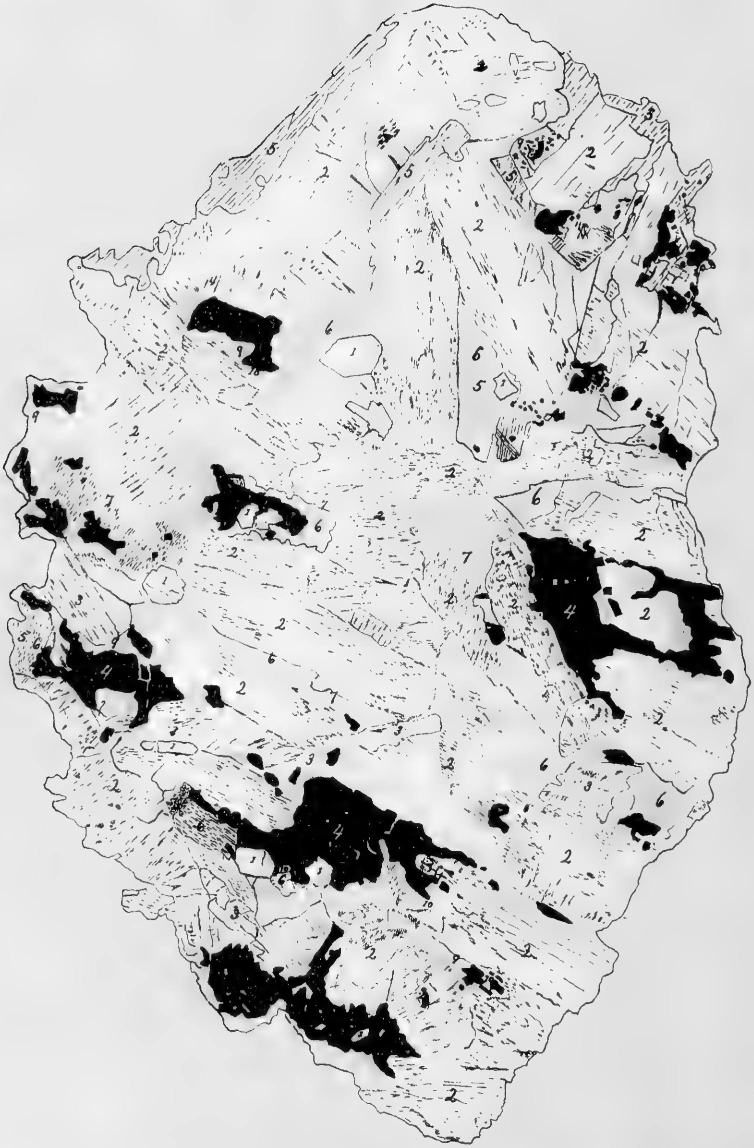
In the mass the orthoclase-gabbros do not present any features different from those of the orthoclase-free kinds, like which they occur chiefly in heavy flows, without amygdaloids. They may also occur as intersecting masses, but this needs proof; that is to say, it is not always possible to be certain as to the structural relations of rocks met with in isolated exposures in the woods.

As instances of the occurrence of orthoclase-bearing gabbros may be mentioned the coarse syenite-like rock of the Bohemian Mountain, on the north shore of Lac la Belle, Keweenaw Point; the bed numbered 94 by Marvine in his description of the Eagle River section of Keweenaw Point;[1] the rocks of a belt or belts running for many miles through the Bad River region of Wisconsin;[2] and the rocks exposed on the Aminicon River, in

[1] Geological Survey of Michigan, Vol. I, Part II, p. 134.
[2] Geology of Wisconsin, Vol. III, p. 170.

A. Hoen & Co. Lith. Baltimore

ORTHOCLASE - GABBRO



Very coarse orthoclase-gabbro from near Duluth, Minnesota.
Scale 10 diameters. Ordinary light.
See pages xliii, 51, 55, 269.
Apatite (1); oligoclase (2); orthoclase (3); titaniferous magnetite (4); diallage (5), often altered to uralitic hornblende (6), and to viridite (7); pyrite (8); ocher (9), surrounding the magnetite and pyrite and containing biotite scales of a secondary nature (10).

the S. E. ¼, Sec. 32, T. 48, R. 12 W., Douglas County, Wisconsin. Other instances are the coarse gray rock of the Saint Louis River bluffs at and near Duluth, Minn.; the exposures in the woods west of Lester River, Minnesota, in Sec. 29, T. 51, R. 13 W.; the rock exposed in the bed of Cascade River, in the southern half of Sec. 10, T. 62, R. 2 W.; the rock of the south side of Eagle Mountain, about four miles north of the last-named place; and the rock forming the west wall of the gorge through which the trail passes from Eagle Mountain to Brulé Lake.

Tabulation of observations on orthoclase-bearing gabbros.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.*		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
1902	Bohemian Mountain, north side Lac la Belle, Keweenaw Point, Michigan.	NE.	32	58	29 W.	Medium-grained to coarse-grained; mixture of red feldspars and shining dark greenish-black mineral.	*Apatite*, abundant, often quite large crystals; *oligoclase* and *orthoclase*, both reddened and dulled; *titaniferous magnetite; augite; diallage*, mostly altered to uralite; *amorphous green substance*, secondary to augite; *gray substance* secondary to titaniferous magnetite; a little *secondary quartz.*	14 11 4 2 20 4 15	17 13 7 4 18 5 12	31 24 11 6 38 9 27
Bed 94[1]	Eaglo River section, Keweenaw Point, Michigan.	SE.	30	58	31 W.	Medium-grained to coarse; black, thickly studded with long red feldspars. Sp. gr., 2.94.	*Apatite; oligoclase; orthoclase; titaniferous magnetite; augite;* a little *altered magma;* secondary *ferrite, chlorite, quartz*, from the feldspars; secondary *yellowish-green mineral* and *magnetite*, from the augite.			22 23 31 33 33 33 36
6 W.	Old Ironton trail, Ashland County, Wisconsin.	N. ½	34	46	1 W.	Coarse-grained, red, black, and gray mottled; shows much highly-magnetite. Sp. gr., 2.89.	*Plagioclase; orthoclase*, highly altered, much stained with ferrite; *titaniferous magnetite*, coarse and abundant; *diallage* largely altered to *uralite; chlorite* secondary to the feldspars; *magnetite*, secondary to diallage; a little *secondary quartz.*			

[1] Metasomatic Development of the Copper-bearing Rocks of Lake Superior, Proc. Am. Acad. Sci., Vol. XII, pp. 253-309.

Tabulation of observations on orthoclase-bearing gabbros—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
6 I.	Cut on Wisconsin Central Railroad, Bad River, Ashland County, Wisconsin.	SE.	30	45	2 W.	Coarse-grained; red-and-black mottled; rough-textured.	*Oligoclase*, predominating in large crystals, much clouded, but still showing the banding distinctly; *orthoclase;* very coarse *titanic magnetite;* greenish *hornblende* or *uralite*, showing strong dichroism, and in a marked degree the characteristic prismatic cleavage, but evidently an alteration from diallage and augite, as proved by the existence of a few cores of the original substance. This hornblendic mineral fills in the spaces between the oligoclases in the manner characteristic of the gabbros.	14 9 14	16 10 14	30 19 28
64 I.	Brunschweiler's River, Ashland County, Wisconsin.	SE.	16	45	4 W.	Coarse-grained, dark greenish-gray, mottled with dull red and white.	*Apatite*, in very large crystals; *labradorite; orthoclase; titaniferous magnetite*, very abundant and coarse; *uralite*; *quartz, ferrite, secondary feldspars; chlorite*, secondary to uralite.	21 16	23 22	44 38
112 I.	Bayfield County, Wisconsin.	NE.	12	44	6 W.	Coarse-grained; dark greenish-gray, sparsely mottled with red; dull.	*Oligoclase; orthoclase;* highly altered *titaniferous magnetite*, very coarse and abundant; *diallage*, almost wholly altered to *uralite; chlorite* secondary to feldspars; *ferrite*.	10	14	24
202 I.	Douglas County, Wisconsin.	SE.	32	48	12 W.	Medium-grained; red-and-gray-mottled. Sp. gr., 2.76.	*Apatite* in long crystals; *oligoclase*, stained red; *orthoclase; diallage*, sparse, mostly altered to a dark-green substance; *ferrite, chlorite, quartz*, secondary to feldspars.	10 17 10	11 15 11	21 32 21
205 I.	Aminicon River, Douglas County, Wisconsin.	SE.	32	48	12 W.	Coarse-grained. red-and black-mottled.	*Labradorite* (in sections cut at random in the zone *O: ii*, the angle ranged from 37° to 50°; a section cut independently and carefully parallel to *O* gave 12° to 14°); *orthoclase; augite; diallage* in twinned plates. (Pumpelly, Geology of Wisconsin, Vol. III., p. 41.)			

Tabulation of observations on orthoclase-bearing gabbros—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i$.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
10.....	Near Duluth, Minn., 1,980 north, 0 west.	NE.	33	50	14 W.	Very coarse-grained; light-gray; much pinkish titanic iron; very rough-textured.	*Apatite; labradorite; orthoclase; titaniferous magnetite; diallage* mostly changed to *uralite*.	23 9	22 10	45 19
3......	Near Duluth, Minn., 1,970 north, 680 west.	N. ½	28	50	14 W.	Coarse-grained; light-gray; very rough-textured.	*Apatite* in a few large crystals; *labradorite; titanic iron*, abundant; *diallage*, highly fibrous and largely altered to *uralite*.	22 27 27	21 20 23	43 47 50
4......	Near Duluth, Minn., 2,000 north, 1,300 west.	NW.	28	50	14 W.	Very coarse-grained; light-gray; very rough-textured.	*Oligoclase; orthoclase;* little *titaniferous magnetite; diallage* mostly altered to *uralite*.	12 8	11 13	23 21
5......	Near Duluth, Minn., 1,800 north, 2,000 west.	NW.	28	50	14 W.	Very coarse-grained; light-gray; very rough-textured.	*Apatite*, in quite large crystals; *oligoclase; orthoclase; titaniferous magnetite; diallage*, partly fresh, partly altered to *uralite; ochre; biotite*.	13 11 12	16 13 13	29 24 25
509....	Top of bluff, Duluth, Minn.	SW.	27	50	14 W.	Very coarse-grained; dark-gray.	*Labradorite; titaniferous magnetite; diallage*, partly fresh, partly altered to *uralite* and *chlorite*.	20 25 21	24 24 25	44 49 46
511....	.....do	SW.	27	50	14 W.	Very coarse-grained; light-gray; rough-textured.	*Apatite* in large crystals; *labradorite*, much altered; *titaniferous magnetite; diallage*, much altered; *chlorite*.	20 26 23	19 24 23	39 50 46
508....	Near quarry, Duluth, Minn.	SW.	27	50	14 W.	Very coarse-grained, the plagioclases running from a half inch to an inch in length.	*Labradorite* or *anorthite*, much clouded; *titaniferous magnetite; diallage*, mostly altered to *uralite*.	31 19	31 21	62 40
31.....	Lester River, Minnesota, near northwest corner.	NW.	4	50	13 W.	Medium-grained; red-black-and-green-mottled; much weathered.	*Apatite* abundant; *oligoclase* much clouded; *orthoclase; titaniferous magnetite;* non-diallagic *augite; alteration-product of augite*.	14 8 13	15 10 13	29 18 26
41.....	Near Lester River, Minnesota.	NE.	29	51	13 W.	Close to 39, less weathered.	*Labradorite, orthoclase*, in the characteristic twins; *titaniferous magnetite; augite* in long, twinned blades; *diallage;* a green alteration-product of augite; *secondary quartz*.	19 29 16 18	21 30 14 15	40 59 30 33

Tabulation of observations on orthoclase-bearing gabbros—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii*. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
39.....	.....do	SE.	29	51	13 W.	Medium-grained to coarse-grained; resinous; brownish; augite in long radiating blades. Sp. gr., 2.82.	*Apatite*, large and abundant; *labradorite; orthoclase; titaniferous magnetite; augite* in long, twinned blades; *diallage; ochre;* much *secondnry quartz.*	20 16 12 17	25 21 13 17	45 37 25 34
1057...	Bed of Cascade River, Minnesota; 12 miles from mouth.	S. ½	10	62	2 W.	Medium-grained; black-and-gray-mottled; rough-textured. Sp. gr., 2.82.	*Apatite; labradorite; orthoclase; titaniferous magnetite; diallagic augite*, much altered; secondary *quartz.*	21 30 22	18 28 18	39 58 40
1062...	South side Eagle Mountain.	(about)26 (Not surveyed.)		63	2 W.	Medium-grained to coarse; nearly black; rough.	*Apatite; labradorite; orthoclase; augite*, sparse, highly altered, and filled with dusty *magnetite* (alteration-product?); *secondary quartz.*	16 22 26	14 26 28	30 48 54

Hornblende-gabbro.—Along a belt of country, some fourteen to twenty miles in length, running westward from Bad River, Wisconsin, through parts of townships 44 and 45, ranges 3, 4, 5, and 6 west, at a horizon not far above the Huronian slates, exposures of a peculiar hornblende-gabbro have been noticed. This rock differs from the uralitic gabbros previously described in containing, instead of the fibrous, greenish, comparatively weakly dichroic uralite, a deep-brown, intensely absorptive, so-called basaltic hornblende. Some of these rocks have been described briefly by Pumpelly in the third volume of the Geology of Wisconsin,[1] under the name of "augite-diorite." He regarded the hornblende as primary, and the rocks as intermediate between diabase and diorite, whence the name.[2] In the same volume I suggested that the hornblende was secondary, and that the rocks were merely altered gabbros.[3] This opinion I find sustained by a re-examination of Pumpelly's sections, and a study of a number of

[1]Page 36. [2]Page 170. [3]Page 170.

1

Fig. 1. Hornblende-gabbro from Ashland County, Wis. Ordinary light. Scale 36 diameters

Labradorite(1); orthoclase(2); augite(3) largely altered to viridite and uralite; brown hornblende(4); titaniferous magnetite(5); apatite(6).

2

Fig. 2. Hornblende-gabbro from Ashland County, Wis. Ordinary light Scale 26 diameters

Oligoclase(1); orthoclase(2), brown hornblende(3); uralite (4), altered from diallage; titaniferous magnetite(5); quartz(6); apatite(7).

3

Fig. 3 Hornblende-gabbro from English Lake, Wis. Ordinary light. Scale 23 diameters

Hornblende(1) with cores of augite(2); labradorite(3) magnetite(4).

4

Fig. 4 Anorthite rock from north shore of Lake Superior, Sec. 5, T. 54, R. 8 W. Minn. Polarized light. Scale 17 diameters

Made up wholly of anorthite individuals

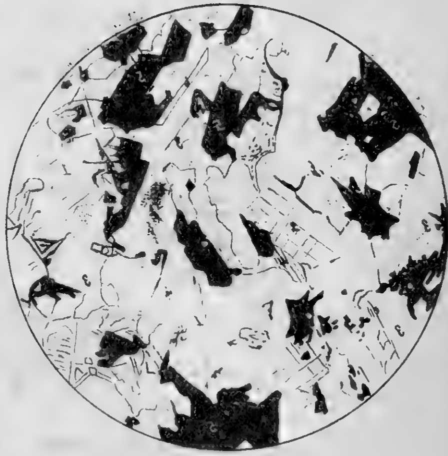
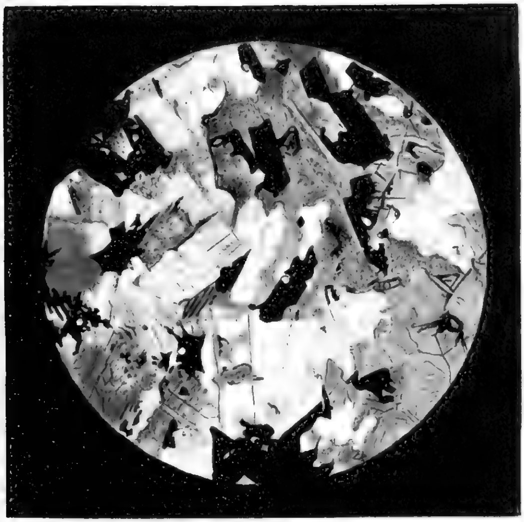


Fig. 1 Hornblende-gabbro from Ashland County, Wis.
Ordinary light. Scale 36 diameters
Labradorite(1); orthoclase(2); augite(3) largely altered to viridite and uralite; brown hornblende(4); titaniferous magnetite(5); apatite(6).

Fig. 2 Hornblende gabbro from Ashland County, Wis.
Ordinary light. Scale 26 diameters
Oligoclase(1); orthoclase(2), brown hornblende(3), uralite(4), altered from diallage, titaniferous magnetite(5); quartz(6); apatite(7).

Fig. 3 Hornblende-gabbro from English Lake, Wis.
Ordinary light. Scale 23 diameters
Hornblende(1) with cores of augite(2); labradorite(3); magnetite(4).

Fig. 4 Anorthite rock from north shore of Lake Superior, Sec. 5, T. 54, R. 8 W. Minn. Polarized light.
Scale 17 diameters
Made up wholly of anorthite individuals



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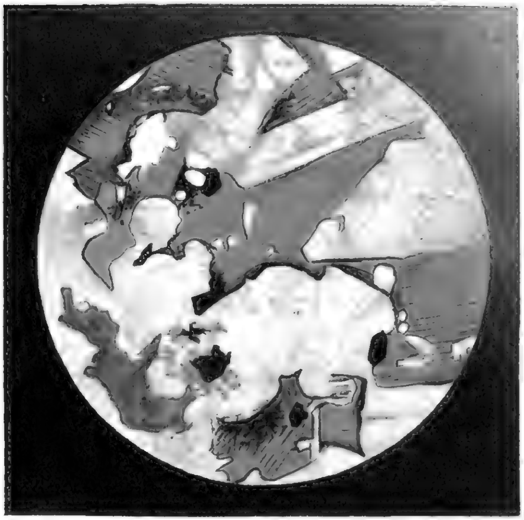

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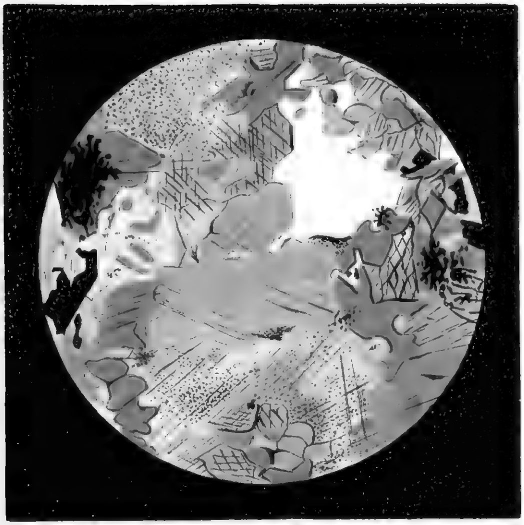

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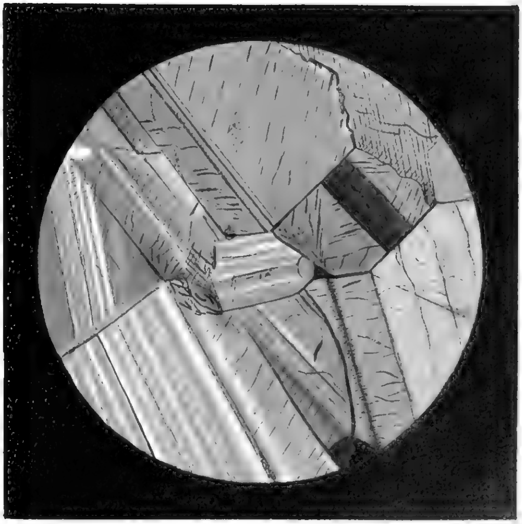

4

HORNBLENDE-GABBROS AND ANORTHITE-ROCK

new sections from other outcrops. The rocks described in the table have been selected to illustrate the different phases of this hornblende-bearing rock. The first one is a rock in which the basaltic hornblende is in small quantity only. The next three contain more hornblende, and are peculiar macroscopically, being mottled black, white and pinkish. They also carry a good deal of original quartz. The last two are black rocks, in which the hornblende makes up most of the section. Abundance of coarse apatite, presence of a low-angled plagioclase, of orthoclase, and of original quartz seem to be prevailing characteristics.

Tabulation of observations on hornblende-gabbro.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.*		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
137 W.	Ashland County, Wisconsin.	N.W. cor.	35	45	4 W.	Medium-grained; dark greenish-gray.	*Apatite*, in large crystals, very abundant; *labradorite*, in crystals often much rounded, quite fresh; *orthoclase (?)*; *magnetite* or *titanic iron*, very large and abundant; *augite*, very abundant, in very large, rounded particles between the feldspar grains, only rarely showing the diallage cleavage, partly fresh, partly altered by spots and streaks of a greenish feebly dichroic or non-dichroic substance; brown, intensely absorptive, and dichroic *hornblende*, not very abundant, occurring partly away from the augite—but like it between the feldspar grains—and partly in patches within the areas of the altered augite, in such a manner as to suggest its secondary origin; *uralite*, in little streaks within the altered augite.	12 19 24	17 21 21	29 40 45

Tabulation of observations on hornblende-gabbro—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O:\breve{i}$. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
2022 I.	Ashland County, Wisconsin.	S. W.	53	45	3 W.	Medium-grained; mottled black and white; rough. Sp. gr., 2.83.	*Apatite*, very abundant, in small crystals; *labradorite* and *orthoclase*, in much rounded particles; *diallage*, often partly altered to *uralite*; non-diallagic *augite*; basaltic *hornblende*; a few large scales of *biotite*; *quartz*, filling corners and apparently primary, abundant.	20	19	39
2020 I.	....do	......	2	44	3 W.	Medium-grained; nearly black; rough-textured.	*Apatite*; *oligoclase* and *orthoclase* in much-rounded grains; *magnetite*, or *titanic iron*; *augite*, very abundant, in large, rounded grains, at times diallagic; basaltic *hornblende*, not very abundant, secondary, and grading into *augite*; *quartz*, filling corners, not abundant.	7 5 1	5 3 4	12 8 5
106 I..	Ashland County, Wisconsin, north line of	N. W.	17	44	5 W.	Medium-grained; mottled black, white, and yellowish-pink; rough-textured.	*Apatite*, very large and abundant, just as in No. 1 of this group—often in hexagonal sections which reach .01^{mm} in diameter; *oligoclase*; *orthoclase*; *magnetite*, or *titanic iron*; *diallage* almost wholly changed to *uralite*; *basaltic hornblende*, occurring just as in 137 W., but very much more abundant; *biotite*, in a few flakes; *quartz*, in a few spots, filling corners, apparently original; *chlorite* and *ferrite*, secondary.	7 11	4 12	11 23
187 W.	English Lake, at outlet, Ashland county, Wisconsin.	S. ½	5	44	3 W.	Medium-grained; black; lustrous.	*Apatite*, in a few large crystals; *labradorite*; *magnetite*, small and sparse; *augite*, mostly quite fresh; *basaltic hornblende*, making up most of the section, in a few cases appearing to shade into the augite; *biotite*.	15 24 13	13 23 14	28 47 27
96 W..	Ashland County, Wisconsin.	S. ½	15	45	1 W.	Medium-grained to fine-grained; nearly black. Sp. gr., 3.08.	*Oligoclase*; *orthoclase*; *magnetite*; *augite*; *basaltic hornblende*; *biotite*. Resembles No. 5, but much finer grained.	14 13 11	17 16 13	31 29 24

Anorthite-rock.—At several points on the north or Minnesota shore of Lake Superior, between the mouth of Split Rock River and the Great Palisades, and again in the high point near the mouth of Temperance River, known as Carlton's Peak, are to be seen exposures of a very coarse light-gray to colorless or white rock, occasionally with a faint greenish tinge. This is seen in the thin section to be composed exclusively, or nearly so, of anorthite feldspar. Often there is no other mineral present except in exceedingly minute inclusions, and these are very sparse. In one section a few grains of altered olivine were noticed within the anorthite, and in two or three a little augite between the feldspar grains. The feldspar appears in every case to be anorthite. In no section did it show the peculiar arrangement of needle-like inclusions met with in European gabbros, and so common in the coarse gabbros of Lake Superior, to which this rock is very nearly related.

This anorthite-rock presents very interesting occurrences, as described in a subsequent chapter. It appears both as masses cutting black gabbro, and as included angular masses in the same rock.

Tabulation of observations on anorthite-rock.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O : ii.* Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
729....	North shore Lake Superior; 1½ miles below mouth of Split Rock River, Minnesota, near center of	SW.	5	54	8 W.	Very coarse-grained; the crystals reaching an inch in length and breadth; colorless to white; occasionally with a greenish tinge.	Pure *anorthite*, without accessory.	28 37 35	30 41 41	58 78 76
746....	North shore Lake Superior; 1½ miles below mouth of Split Rock River, Minnesota.	SW.	5	54	8 W.	Very coarse-grained; the single crystals often reaching ½ inch across; light-gray.	Pure *anorthite*, without accessory.	34 22 29	40 25 24	74 47 53

Tabulation of observations on anorthite-rock—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ĭĭ*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
750....	North shore Lake Superior; 1¼ miles below mouth of Split Rock River.	SW.	5	54	8 W.	Coarse-grained; nearly white, with faint greenish tinge.	Pure *anorthite*	39	34	73
								42	40	82
								35	33	68
759....	North shore Lake Superior; 2 miles below mouth of Split Rock River.	NE.	5	55	8 W.	Very coarse-grained; nearly colorless, with faint greenish tinge.	*Anorthite*, in large crystals, makes up most of the section. The large crystals are often crushed into fragments at their extremities. Among the fragments are smaller anorthite crystals, and numerous small rounded grains of *augite*.			
792....	Falls of Beaver River, Minnesota.	SW.	12	55	8 W.	Very coarse-grained; translucent; nearly colorless, but with faint greenish tinge.	Pure *anorthite*, in very large, unbroken crystals.			
795....	Beaver River, Minnesota.	SW.	12	55	8 W.	Coarse-grained.	*Anorthite*, in large crystals, makes up most of the section. A few small grains of *olivine*, altered to a brown ocherous substance, occur in the feldspars. A little *augite* lies between the feldspar grains. Bands of *viridite* cross the feldspars. The anorthite carries long rows of minute, rounded inclusions, readily seen with a low power (70 to 80 diameters). These rows run for short distances parallel to the cleavage, but are mostly in rows crossing the cleavages. A higher power shows numerous bubbles in these inclusions. The bubbles will not disappear or move at a temperature of 112° C. Black microliths also occur in the particles.			

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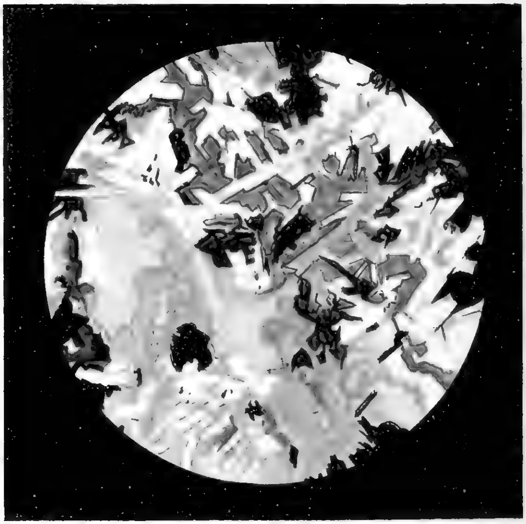

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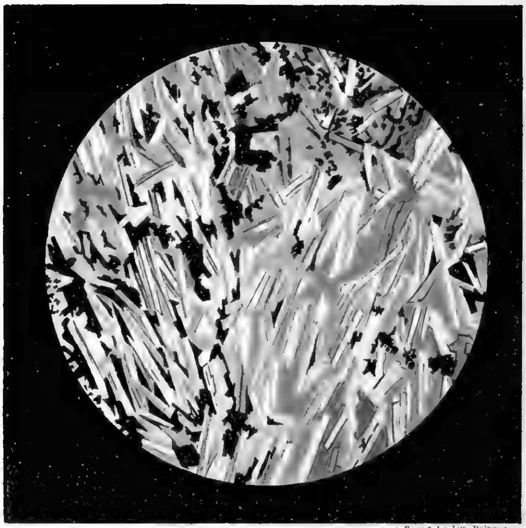

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A. Hoen & Co. Lith. Baltimore

DIABASE AND DIABASE-PSEUDAMYGDALOIDS.

Fig 1 Pseudamygdaloid from "Union Vein", Porcupine Mts. Mich. Ordinary light. Scale 21 diameters.
Plagioclase(1), green and brown pseudomorphs(2) of augite; pseudamygdules of calcite(3) and chlorite(4).

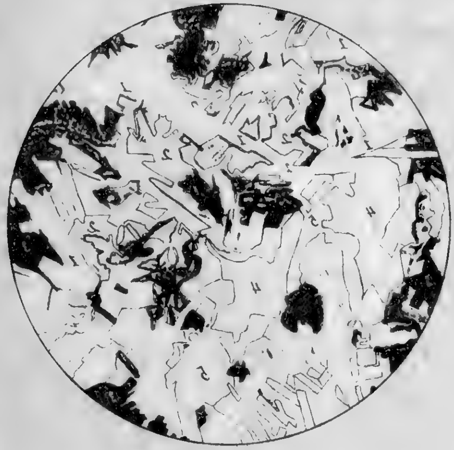

Fig 2 Pseudamygdaloid from Fond du Lac mine, Douglas Co. Wis. Ordinary light. Scale 21 diameters.
Oligoclase(1); brown alteration product of augite(2); titaniferous magnetite(3); pseudamygdules of chlorite(4) and epidote(5).

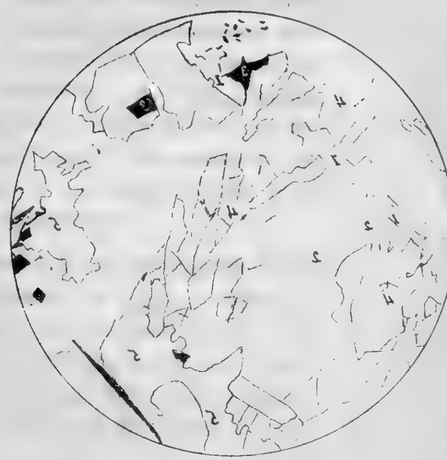

Fig 3 Pseudamygdaloid from Gogogashugun River, Wis. Ordinary light. Scale 56 diameters.
Oligoclase(1), largely altered to chlorite(2); magnetite(3); augite(4); chlorite pseudamygdules(5).

Fig 4 Diabase from north shore of Lake Superior, near Split Rock River, Minn. Polarized light. Scale 42 diameters.
Labradorite(1) in small tabular crystals arranged in a common direction, augite(2) in large areas each including many plagioclases; magnetite(3) in the interspaces of the augites.

Fig. 1 Pseudamygdaloid from Union "Vein", Porcupine Mts. Mich. Ordinary light Scale 26 diameters
Plagioclase (1), green and brown pseudomorphs (2) of augite; pseudamygdules of calcite (3) and chlorite (4).

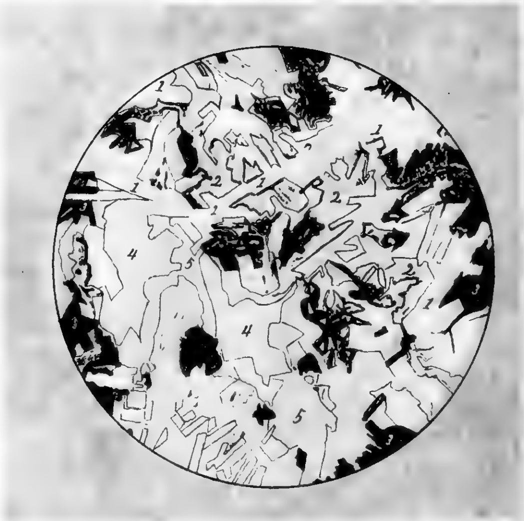

Fig. 2 Pseudamygdaloid from Fond du Lac mine, Douglas Co. Wis. Ordinary light. Scale 28 diameters
Oligoclase (1); brown alteration product of augite (2); titaniferous magnetite (3); pseudamygdules of chlorite (4) and epidote (5)

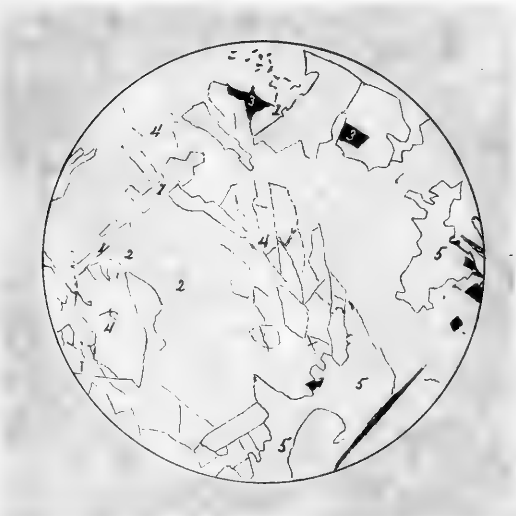

Fig. 3. Pseudamygdaloid from Gogogashugun River, Wis. Ordinary light. Scale 36 diameters
Oligoclase (1), largely altered to chlorite (2); magnetite (3); augite (4); chlorite pseudamygdules (5).

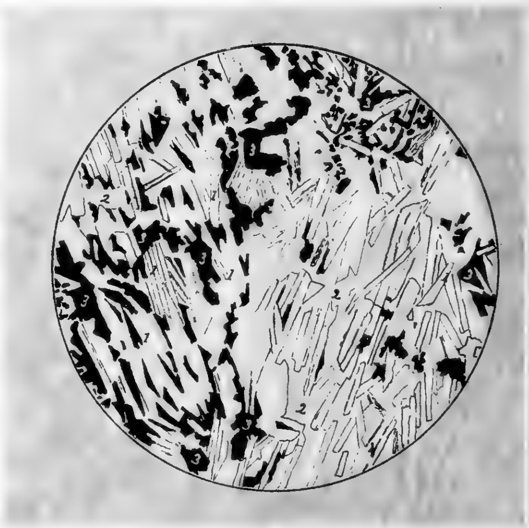

Fig. 4. Diabase from north shore of Lake Superior, near Split Rock River, Minn. Polarized light. Scale 42 diameters
Labradorite (1) in small tabular crystals arranged in a common direction; augite (2) in large areas each including many plagioclases; magnetite (3) in the interspaces of the augites

Tabulation of observations on anorthite-rock—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O:\bar{i}\bar{i}$.		
								Angle on opposite sides of cross-hair.		Whole angle.
								°	°	°
803....	North shore Lake Superior; Beaver Bay, Minnesota.	NE.	12	55	8 W.	Rather coarse; nearly colorless; translucent.	*Anorthite* makes almost the entire section; rare and small *augite* particles lie between the grains of feldspar.	22 27 24 32	26 31 28 33	48 58 52 65
811....	Island off south Beaver Bay Point, Minnesota.	SE.	12	55	8 W.	Coarse-grained; dark-gray.	*Anorthite*, with numerous minute cavities and particles like those of No. 795, but much smaller, makes most of the section. A few small *augite* particles, often altered to a greenish substance, lie between the feldspars.	34 31 30	46 42 37	80 73 67
822....	North shore Lake Superior; 2 miles below Beaver Bay, Minnesota.	NE.	6	55	7 W.	Coarse-grained; colorless to white.	Pure *anorthite*................	31 30	33 43	64 73

FINE-GRAINED BASIC ROCKS.

Looking over the Keweenaw Series as a whole, the fine-grained basic rocks are found to prevail in extent of surface spread and total thickness over the coarser kinds above described, though these latter are very frequently met with, and constitute great thicknesses, especially in the lower portions of the series. Coarse-grained layers continue to quite high horizons, as, for instance, some of the beds of the Greenstone Group of Keweenaw Point, but they are here much less frequent than in the lower portions, from which, however, the finer-grained kinds are never absent.

Olivine-free diabase of the "ordinary type."—In his descriptions of the Keweenaw Point diabases, Pumpelly recognized two types, to which he gave the names, respectively, of "ordinary" and "ashbed" types. The former name applies to the fact that, so far as his acquaintance with the Keweenaw Series went, that type was the most common and characteristic of all its crystalline rocks. The latter name was given because the type to which it was applied makes up the lower portion of the bed whose upper or vesicular portion is the extraordinarily scoriaceous amygdaloid so well known on Keweenaw Point as the "ashbed." The "ordinary type" is alone considered under the present heading, the "ashbed type," according to my observations, being more closely related to the diabase-porphyrites. While the ordinary type diabases, with their amygdaloids, are the most common kinds on Keweenaw Point, they do not appear to me, when we look the whole ground over, to be any more common than the fine-grained olivinitic kinds, and not much more so than those of the ashbed type.

The ordinary type diabases make up relatively thin flows, which are almost invariably furnished with vesicular or amygdaloidal upper portions. These vesicular upper portions have always undergone great internal changes, both in connection with the deposition of minerals in vesicles, and in the formation of pseud-amygdules, or minerals replacing primary constituents in such a way as to present macroscopically very much the appearance of the true vesicular fillings. The latter change, with others, has usually affected also the lower non-vesicular portions of the beds in greater or less degree. So general are these alterations that an account of these rocks has to be taken up with the internal changes that they have undergone more than with the nature and arrangement of the original constituents. Professor Pumpelly's studies have been so exhaustive that I can do no better than quote largely from him in this connection. His microscopic studies were chiefly made on specimens from the Eagle River section of Keweenaw Point (that is, on beds lying between the Great Conglomerate and the base of the Greenstone Group), and on specimens from the lower horizons at Portage Lake. I have examined, in addition, a large number of specimens from still higher and lower horizons on Keweenaw Point, and from all other parts of the extent of the formation. For the most part, my work has merely served to extend the geographical range to which most of his conclusions are applicable.

"Externally", according to Pumpelly, "the different varieties of these diabases are dark in shade, varying from almost black in unaltered specimens to dark-green or dark-brown, or varying, minutely subdivided mixtures of these colors, according to the relative proportions of chlorite and ferric oxide among the decomposition products. They vary in texture from medium fine-grained to crypto-crystalline, and the fracture from uneven and hackly to conchoidal."[1] To this I have only to add that a purplish shade, varying from a brownish-purple to a bright reddish-purple, is a very common one, and that a true conchoidal fracture is characteristic only of the kinds here set apart as a separate group under the name of ashbed-diabase.

The pseud-amygdaloidal alteration of these rocks, while it has taken place largely in the true amygdaloid, and has commonly affected the entire thickness of a bed in some degree, is especially characteristic of the middle portions of the bed. The common pseud-amygdules are chlorite, quartz, prehnite and calcite. They vary greatly in size, running from a quarter of an inch or more—rarely several inches—in diameter, down to minute particles. In the former case the rock is coarsely blotched with the colors of the pseud-amygdules, looking, as said, like a true amygdaloid, while in the latter case the only effect on the external appearance is a variation of the general shade.

Under the microscope, when not too profoundly altered, this diabase "is seen to have for primary constituents plagioclase, augite and an opaque black mineral, which may be either magnetite or titaniferous iron ore."[2] The last-named ingredient never shows any distinct crystalline outlines. It appears generally to be strongly attracted by the magnet, while, judging from the results of the analyses cited by Pumpelly[3] of the rocks of several beds of the Eagle River section of Keweenaw Point, titanic acid is often present. In these rocks, then, as in the coarser kinds previously described, the iron-oxide constituent appears to be a titaniferous magnetite.

The plagioclase appears, from optical measurements, to belong near oligoclase in the feldspar series. It appears in tabular polysynthetic crystals, whose long, narrow sections are scattered confusedly through the section, while the spaces between the crystals are occupied by augite, the augite in each space generally giving the integral polarization which indicates a single individual. In ordinary light the augite is distinguishable from the plagioclase by its very faint, delicate, violet-gray color, and by its anastomosing cracks. The sharpness with which it fills the interstices between the feldspar crystals shows that it crystallized after them. The magnetite occurs in small grains, rarely with an appearance of crystal outlines.[4]

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[1] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 31.
[2] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 32.
[3] R. Pumpelly, Metasomatic Development, pp. 285–293, etc.
[4] R. Pumpelly, Metasomatic Development, p. 270.

Almost always, however, the rock has undergone changes to a greater or less degree. The commonly resulting alteration-products are, as Pumpelly has shown, from the augite a green and greenish-brown chloritic substance, often with red-stained cracks; and from the feldspar a true chlorite, antecedent to which has been in many cases a change to prehnite. The following quotations are from Pumpelly's account of these changes.[1] The augite has changed first, unless there has been a little residuary base present.

Generally, in any thin section of the lower portion of a bed, a considerable proportion of the pyroxene is fresh, either throughout whole individuals or in parts of these.

In thin sections, by ordinary transmitted light, the pseudomorphous product is translucent, faintly light-green, with a tinge of brown. Between crossed nicols, in its most characteristic form, it shows irregular lamellar aggregate polarization. It is very soft under the needle, and is traversed by red-stained cracks, corresponding to the irregular fissures in the parent pyroxene, and it is by these, together with the structure as seen in polarized light, that it is generally best distinguished from the product after residuary magma-base.

The mineral forming these pseudomorphs is very probably the result of a process which has removed lime and some iron, magnesia, and silica from the pyroxene and brought in water, and it is, probably, poor in alumina.

The plagioclase is generally the last constituent that has been altered to any great extent. The usual product is chloritic. It is very usual to observe very minute particles of a green, apparently structureless substance, suspended in the interior of the feldspar in such a manner as to render the supposition quite possible that they are due to an alteration of inclosed particles of hyaline base. But an actual pseudomorphism of a chlorite after plagioclase is observable on a large scale. In the first stages small, tuft-shaped particles, consisting of laminæ, or fibers, radiating from a point, occur scattered through the interior of the feldspars, and these may wholly occupy a considerable portion of a crystal, while the rest still shows twin striation in polarized light. In the finished state no trace of the feldspar is visible except the outlines. The pseudomorph then shows an aggregate polarization, due to a confusedly-felted mass of minute chlorite tufts. The substance is poorly characterized. * * * *

There is another occurrence of chlorite in which the progress of growth is from within outward. Throughout the pseudo-amygdaloid occur grains of chloritic substance, which, in places, reach a diameter of one-fourth to two-thirds inch, with often more or less irregular outlines, often nearly round or oval. These consist of a dark-green mineral, with $H=2.5$, which fuses B. B. at 3—3.5 to a black magnetic slag. In different beds its texture under the hand-glass varies from amorphous to finely scaly. In thin sections, in polarized light, the substance often resembles closely that in the pseudomorphs after plagioclase, except that it shows evident growth from within outward. There is no defined wall, as of a pre-existing cavity, but the chlorite often

[1] R. Pumpelly, Metasomatic Development, pp. 270-272.

sends out long arms, which surround or penetrate the adjoining primary constituents. In this manner the chlorite-like pseudomorphs after plagioclase and pyroxene, etc., are sometimes incorporated into these pseudo-amygdules. Very often one of these bodies has a large central area filled with closely-packed radiating spheres, surrounded by fragments of a once continuous band with cross-fibrous structure, which evidently once formed the outer limit; outside of these fragments is an outer chlorite area, resembling that in the center, and generally bordered on its outer limits by a narrow cross-fibrous band which adapts itself closely to the primary constituents. The greater number of these bodies seem to have resulted from a gradual change of the primary minerals into chlorite by progress from molecule to molecule. At the first glance the structure does not seem to confirm this view; for the narrow outer band inclosing a large central filling seems to suggest either, 1st, a pre-existing cavity, on the walls of which the thin outer layer was deposited, as the older member, and within this the central filling as the younger; or, 2d, the replacement by chlorite of a former secondary mineral, which was attacked at the same time around its circumference, producing the outer band (shell), and throughout the interior.

Amygdules resulting from both these processes are abundant in the amygdaloids proper; but they betray their origin in a marked manner, and differ essentially from these pseudo-amygdules.

Whatever the chemical nature of the process resulting in these pseudomorphs, the central area is the oldest member, while the outer band is the younger, and its cross-fibrous structure is only a transitional form destined to be changed to spheres with radiating structure. If we examine the structure of the outer band we find that its line of contact with the primary minerals, or its axial line, is usually more or less serpentine, and that the cross-fibers, instead of being parallel to each other, are more nearly perpendicular to the axial line of the band, and form closely-packed groups, in each of which the fibers radiate from a central point on the axial line, forming minute hemispheres, which bristle towards the interior of the body. The next stage of growth finished the other half of each sphere, and what was a cross-fibered band becomes now indistinguishable from the rest of the central filling, a new band having formed outside of the previous one. In places we find perfectly straight bands, with actually parallel cross-fibers, which can hardly be supposed to break up into spheres; and, indeed, we find that new parallel bands are formed outside of these until the line of attack becomes crooked, when the normal mode of growth is re-established. The remnants of these straight bands are then preserved in the interior of the body.

The fine-grained olivine-free diabases are typically developed in beds 22, 69 and 87 of Marvine's Eagle River section, Keweenaw Point;[1] at the old Union mine in the Porcupine Mountains; at the upper falls of the Montreal River, where the exposures are very large; and at numbers of other points on the South Shore. Similar rocks, apparently, are largely developed on Isle Royale, and again on Michipicoten, though this has not been proved by microscopic study. On the Minnesota coast, however, though occurring,

[1] Geological Survey of Michigan, Vol. I, part II., Chapter VII.

the olivine-free fine-grained diabases are greatly subordinate to the olivinitic diabases, ashbed-diabases and diabase-porphyrites among the fine-grained kinds, and to the non-orthoclastic and orthoclastic gabbros among the coarse-grained kinds.

Tabulation of observations upon fine-grained olivine-free diabases of the "ordinary type."

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ii.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
	Bed 22, Eagle River section, Keweenaw Point, Michigan; lower zone.[1]	SW.	19	58	31 W.	Rather fine-grained; indefinitely mottled dark green and purple. Sp. gr., 2.77.	*Labradorite; augite,* in part quite fresh, in part altered to a *green pseudomorph.*			34 34 36 51 60 62
	Bed 22, Eagle River section, Keweenaw Point, Michigan; pseud-amygdaloid zone.[2]	SW.	19	58	31 W.	Like preceding, with numerous prehnite pseud-amygdules, averaging 1/8 to 1 inch apart, and about 1/8 inch in diameter. The prehnite is usually of a flesh-pink color, with or without vitreous luster, and is radiated or not. Sp. gr., 2.72.	*Labradorite,* all more or less altered to *prehnite,* the change being at times complete; *augite* much altered; *prehnite* also forms countless pseud-amygdules from microscopic size up to ½ inch in diameter; also *chlorite* pseud-amygdules, and pseudomorphs after plagioclase.			
	Bed 87, Eagle River, Keweenaw Point, Michigan; lower zone.[3]	NE.	30	58	31 W.	Rather fine-grained; dirty gray-green; powder yields some magnetite. Sp. gr., 2.6 to 2.73. Composition: SiO_2 46.32; Al_2O_3 15.95; Fe_2O_3 .86; FeO 8.92; MnO .89; CuO 10.28; MgO 4.08; TiO_2 2.78; K_2O 1.23; Na_2O 3.56; H_2O 3.25 = 100.12.	*Residuary base* altered to dirty white substances; *apatite?; oligoclase* much altered to pseudomorphs and pseud-amygdules of *chlorite; magnetite; augite* highly fissured and more or less thoroughly changed to chloritic substance, with which are associated red and black iron stains, which are probably the source of some of the magnetite.			22 23 24 34 36

[1] Pumpelly, Metasomatic Development, p. 281. [2] *Ibid.*, p. 282. [3] *Ibid.*, p. 283.

Tabulation of observations upon fine-grained olivine-free diabases of the "ordinary type"—Continued.

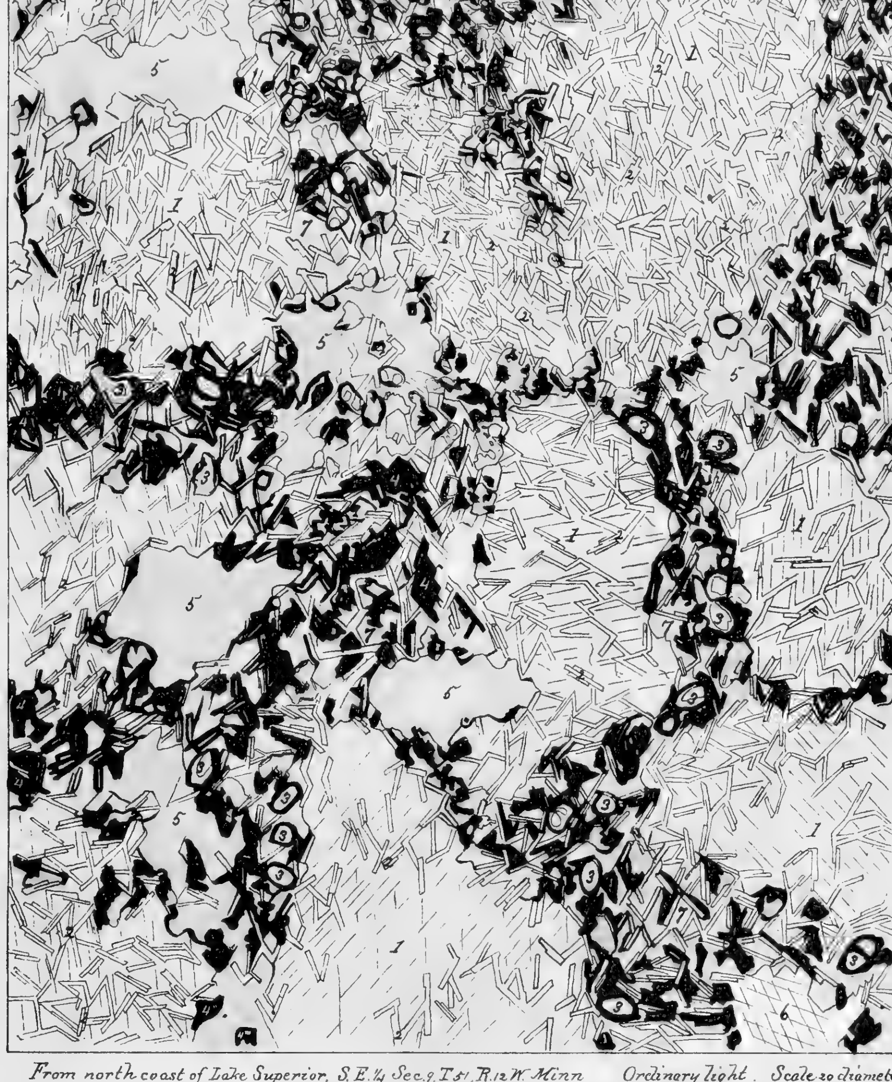
Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic character.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
	Bed 87, Eagle River section, Keweenaw Point, Michigan; middle zone.[1]	NE.	30	58	31 W.	Coarser grained than lower zone, with numerous pink feldspars and large bunches of chlorite. Sp. gr., 2.73 to 2.75.	*Oligoclase*, very much altered; *augite*, wholly changed to green pseudomorph with iron-stained cracks; large pseud-amygdules with dark-green *chlorite* (delessite).			26 29 34 35 36
	Bed 69, Eagle River section.[2]	NE.	30	58	31 W.	Fine-grained; dirty-green. Sp. gr., 2.87 to 2.95. Powder yields a little magnetite.	*Plagioclase*, largely altered to *chlorite; magnetite; augite*, in part fresh, in part changed to greenish substance.			
1966...	Bohemian Range, Keweenaw Point, Michigan.	......	9	56	31 W.	Fine-grained; dark brown mottled with green; abundant chlorite pseud-amygdules.	*Altered magma; oligoclase; magnetite; augite*, only rarely fresh, mostly altered to green substance, with red and black *chlorite* pseud-amygdules.	7 13	4 17	11 30
2526...	Union mine, Porcupine Mountains, Michigan; 1,950 north, 1,750 west.	NW.	27	51	42 W.	Fine-grained; dark purplish-brown; abundant large calcite pseud-amygdules.	*Altered magma; labradorite; augite* wholly altered to green and brown pseudomorphs; *calcite* and *chlorite* pseud-amygdules abundant.	19 18 19	16 21 20	35 39 39
2529...	Rock underlying Union mine amygdaloid, Porcupine Mountains, Michigan; 200 north, 1,750 west.	SW.	22	51	42 W.	....	*Altered magma; oligoclase; augite*, in part fresh, but mostly altered to green substance with red bands; abundant pseud-amygdaloidal *chlorite*.	3 5	8 7	11 12
22 W.	Ashland County, Wisconsin.	......	34	46	1 E.	Fine-grained; dark brown mottled with greenish black; highly weathered. Sp. gr., 2.85.	*Oligoclase; magnetite; augite*, wholly altered; pseud-amygdules of stellated *chlorite* and *calcite*; whole rock much charged with *ferric oxide*.			
26 W.	Montreal River, Wisconsin, at the crossing of the Flambeau trail.	......	21	47	1 E.	....	*Anorthite; augite; chlorite* and *calcite* pseud-amygdules.			

[1] R. Pumpelly, "Metasomatic Development," p. 284. [2] *Ibid.*, p. 288.

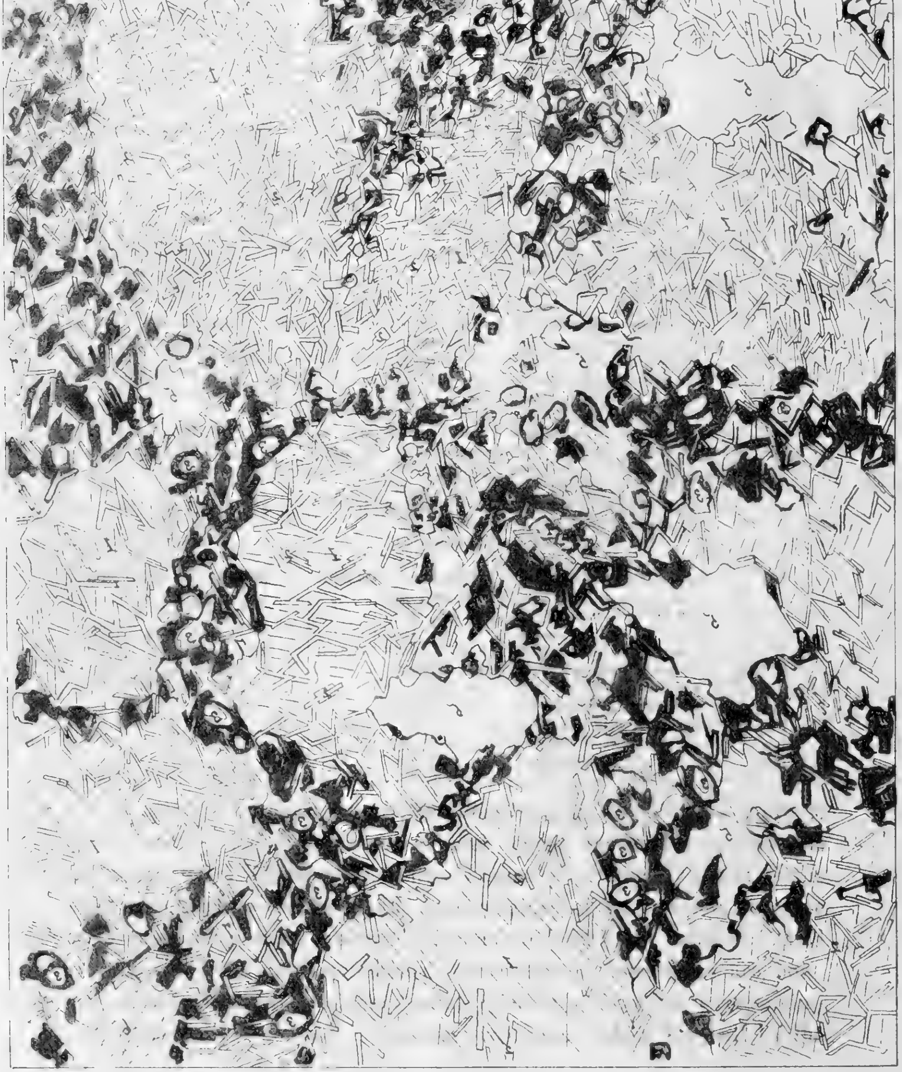
Tabulation of observations upon fine-grained olivine-free diabases of the "ordinary type"—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : ii$.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
40 W.	Montreal River, Wisconsin.	......	20	47	1 E.	Sp. gr., 2.81........	*Labradorite; augite* largely altered to green and brown substance; *chlorite* pseud-amygdules.			
63 W.	Ashland County, Wisconsin.	......	16	46	2 E.	Rather fine-grained; dark-greenish. Sp. gr., 2.90.	*Oligoclase* largely altered to chlorite; *magnetite* in rod-like forms, apparently filling cracks; *augite* abundant and fresh; *chlorite* pseud-amygdules.			
49 W.	Ashland County, Wisconsin, Flambeau trail.	......	19	46	2 E.	Rather fine-grained; greenish-gray to dark green.	*Oligoclase*, partly altered to chlorite; *magnetite*, as in 63 W.; *augite* quite fresh; *chlorite* pseud-amygdules.			
404 S..	Moose Creek, Douglas County, Wisconsin.	SE.	2	44	13 W.	Medium-grained; dark greenish-black. Sp. gr., 2.87.	*Oligoclase; magnetite; augite*, largely altered to green substance.			
8 SW.	Copper Creek mine, Douglas County, Wisconsin.	SE. cor.	15	47	14 W.	Fine-grained; dark brownish-gray. Sp. gr., 2.84.	*Plagioclase* in matrix and in porphyritic crystals; *augite*, wholly altered to green substance.			
12 SW	Fond du Lac mine, Douglas County, Wisconsin.	NE.	8	47	14 W.	Fine-grained; speckled brown, light and dark green.	*Oligoclase; magnetite* very abundant; *augite*, largely fresh, but partly altered to a reddish-brown transparent substance; pseud-amygdules of *epidote, chlorite* and *calcite; metallic copper.*			

Olivinitic fine-grained diabases, including Pumpelly's melaphyrs.—To these rocks, which grade through coarser and coarser kinds directly into the coarse-grained olivinitic gabbros already described, Pumpelly has given the name of melaphyr (following the nomenclature of Rosenbusch), because of the presence, in those examined by him from Keweenaw Point, of a small amount of altered residuary magma. Precisely the same rocks are, however, found without the residuary base, which is at best but a very unimportant ingredient, so that I have preferred to call them here all by the



From north coast of Lake Superior, S.E.¼ Sec. 9, T. 51, R. 12 W. Minn. Ordinary light. Scale 20 diameters
Augite(1) in large areas including many plagioclases (anorthite)(2); olivine(3) and magnetite(4), chiefly in the interstices of the augites, the olivine altered to ferrite and viridite; chlorite(5) and calcite(6) pseudamygdules; interstitial viriditic substance(7) which may in part be altered glass magma



From north coast of Lake Superior, S.E. ¼ Sec. 9, T. 51, R. 12 W. Minn. Ordinary light. Scale 20 diameters. Augite(1) in large areas including many plagioclases (anorthite)(2); olivine(3) and magnetite(4), chiefly in the interstices of the augites, the olivine altered to ferrite and viridite; chlorites and calcite(6) pseudamygdules; interstitial viriditic substance(7) which may in part be altered glass magma.

OLIVINE-DIABASE OR MELAPHYR

above general title. The term melaphyr is, however, used in the detailed descriptions of subsequent chapters whenever the residuary base appeared to be present.

Although grading through coarser kinds into the coarse olivine-gabbros, the fine-grained rocks here considered deserve a place by themselves. The gradation into the coarser kinds has never been observed in any one bed, and they are very strongly marked by their external characteristics both in the fresh and altered states. They have commonly undergone great alteration, the amount of change lessening rapidly as the rock becomes coarser. As a type of the fresh state of this rock Pumpelly has selected "The Greenstone" of Keweenaw Point, which is one of the transition phases toward the coarse gabbros. The following is his description of these rocks as developed on the South Shore.[1] It applies equally well to the olivinitic kinds of the North Shore, where "luster-mottled" fine-grained rocks are very abundant.

In its fresh state it is dark green, or greenish black, finely crystalline, very compact, hard and brittle, and breaks with an uneven to semi-conchoidal fracture. The powder of the rock yields to the magnet a beard of magnetite. The specific gravity is 2.90 to 2.95. It is an important characteristic of this rock that its freshly fractured surface is mainly occupied by spots one-sixteenth to three-fourths of an inch in diameter, each of which reflects the light with a satin-like sheen. The reflection is not carried to the eye from all the spots at once. It is generally necessary to change the position of the specimen many times to observe the different reflections. Aside from this sheen there is nothing, either in difference of color or texture, visible to the naked eye to betray the presence of these spots, which might be called luster-mottlings. To the naked eye, this phenomenon suggests, at once, interrupted cleavage of large individuals of one of the constituents, as the cause; but under a strong hand glass these reflecting surfaces show the same granular texture and character as the rest of the rock; and it is only when examined under the microscope, with an objective of low power and in polarized light, that the appearance to the unaided eye is corroborated. We here find the cause in the fact that each spot is the cross-fracture or cleavage of a crystal of pyroxene, which, in crystallizing, has inclosed hundreds of feldspar crystals. The weathered surface is rusty gray, scarcely one-fiftieth of an inch thick; but it is covered with knobs, which are due to the more rapid destruction of the materials between the pyroxene individuals. Examining thin sections under the microscope, we find the constituents to be plagioclase, pyroxene, olivine, and the alteration-product of the latter, as well as magnetite, and an unindividualized substance, both fresh and altered, occupying interstices. In thin sections the plagioclase is seen to exist in very sharply defined, and fresh, thin, tabular crystals, .001 to .002 inch thick, and .01

[1] Geology of Wisconsin, Vol. III, p. 33.

inch and less long. It contains scattering interpositions of an opaque black substance, and minute brown particles, which may be, or have been, glass. The crystals of plagioclase have predetermined the contours of all the other constituents, except the olivine, which crystallized first. The predominating feldspar is near anorthite, as determined by the angle between the principal sections. Occasional exceptionally large individuals, evidently cut in the plane *iĭ*, have their principal sections at an angle of 23°, with the edge *O: iĭ*, which would indicate albite or labradorite. The augite is very fresh and transparent, almost colorless in the thin section, but with a tendency to purple-gray. An imperfect cleavage is indicated by somewhat irregular parallel fractures. It fills the interstices between the closely-packed individuals of feldspar in such a manner that a single pyroxene crystal incloses many hundreds of these, while its crystalline integrity is shown by the uniform color in polarized light, and by the arrangement of the cleavage cracks throughout the area of the augite individual. It is a remarkable fact that, while these large individuals of pyroxene contain thousands of feldspar crystals, they inclose only very few of olivine or of magnetite. These minerals, together with the unindividualized substance, are crowded into the spaces between the pyroxenes. In this intermediate space, which surrounds the pyroxene individuals with a continuous net-work, we find, also, a few small pyroxenes, just as isolated grains of olivine occur in the pyroxene areas. A careful examination of this occurrence will, I think, convince the observer that, at the time the pyroxene crystallized, both the olivine and feldspar crystals, and apparently the magnetite, were already individualized; for where we find any of these in contact with the augite we find that the latter has adapted itself to the already defined contours of the others. While the augite inclosed the feldspar crystals with ease, it crowded the other constituents almost wholly into the surrounding spaces—a process which was facilitated by the presence of the then fluid unindividualized substance. The magnetite is in irregular-shaped bodies, which mold themselves sharply around the contours of the feldspar and olivine. The olivine is abundant in grains and roughly-outlined crystals, but, as a rule, however fresh the melaphyr may otherwise be, the olivine is partly or wholly altered.

The following is Pumpelly's more detailed account of the internal changes which these luster-mottled rocks have at times undergone.[1] The residuary base and the olivine are usually wholly altered, while the augite and plagioclase are much more commonly fresh than in the olivine-free kinds.

The first and ever-present stage of alteration is caused by the change of the residuary magma-base which fills the interstices between the crystalline constituents, and in places penetrates into or is inclosed in the interior of these. The physical and chemical character of this seems to have predisposed it to an easy change. It is now, as a rule, when seen in thin sections, a darker or lighter olive-green substance, and very soft under the needle (hardness not over 2.5). In polarized light it exhibits a

[1] "Metasomatic Development of the Copper-bearing Rocks of Lake Superior." Proc. Am. Acad. Sci., Vol. XIII, pp. 269–270.

fibrous aggregate polarization, and shows well its structure, which is short, fibrous, converging towards the center. The central portion shows sometimes little or no double refraction, but more generally it is filled with very minute polarizing spheres formed of radiating fibers. With one nicol this substance shows only absorption for intensity. The contours are generally sharply defined by the feldspar and pyroxene crystals, and the result is usually a more or less wedge-shaped form.

The next step has been the change of the chrysolite. In the so-called greenstone this has been only partial; but generally in the chrysolite-bearing beds it is complete. The result in thin sections is a faintly green substance, soft under the needle, and surrounded, within the original contours of the crystal, by a more or less opaque deposit of iron oxide, which also traversed it in fissures. The green substance shows by a well-defined cleavage in one direction that it is in thin laminæ. Between crossed nicols these laminæ have an appearance of twin structure, polarizing the light in alternate lines of brilliant red and green. The whole pseudomorph becomes dark when the cleavage is parallel to a nicol plane; and some individuals, probably cut parallel to the cleavage, remain dark through a revolution of the stage. The substance is, therefore, very probably uniaxial. It has very appreciable absorption for intensity and a very feeble one for color.

* * * * * * *

The green substances which I have described so unsatisfactorily as being undoubtedly pseudomorphous after residuary-base, pyroxene, and plagioclase, have in themselves no physical properties, recognizable under the microscope, which are sufficiently *persistent* to invariably characterize them respectively. Often the best means of distinguishing between them is in the internal structure of the aggregate, since this is intimately connected with certain physical characteristics of the original mineral which predetermined the mode of growth and gradual arrangement of the secondary product. In other instances, the presence or absence of cracks stained with iron oxide are characteristic.

Thus the change of the residuary base has resulted in a tendency to form bands parallel to the contour of the area in a manner that indicates a gradual progress along concentric shells from the circumference inward or the reverse; while in the feldspar the growth appears to have begun without any regularity throughout the cleavage and twinning planes of the crystals. The pseudomorphs after pyroxene, are almost invariably defined by the red-stained cracks and slight mixtures of brown and green.

The "luster-mottling" described by Pumpelly as due to the crowding of the magnetite and olivine into the interspaces of the augites is so pronounced and constant a characteristic of these rocks that, even when they are too fine and too much altered to show it in the hand specimen, a single glance at the thin section with the unaided eye is always sufficient to reveal it.

As typical instances of these fine-grained olivinitic rocks may be mentioned "The Greenstone" of Keweenaw Point; the rock of the north shore of Bête Grise Bay, Keneenaw Point, S. W. ¼, Sec. 27, T. 58, R. 28 W.; that of the S. W. ¼, Sec. 17, T. 51, R. 42 W., Porcupine Mountains, Michigan; that of the bed of Moose Creek, Douglas County, Wisconsin, N. W. ¼, Sec. 2, T. 44, R. 13 W.; that of the falls of French River, Minnesota, N. W. ¼, Sec. 17, T. 51, R. 12 W.; that of the coast of Lake Superior between the mouths of French and Sucker Rivers, Minnesota, N. E. ¼, Sec. 16, T. 51, R. 42 W.; that of the south point of Agate Bay on the Minnesota coast; that of Caribou or Black Point on the same coast, and that of the copper mines on Michipicoten Island.

Tabulation of the results of a microscopic study of fine-grained olivinitic diabases (including melaphyrs).

Specimen number.	Place.	Quarter section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.* Angles on opposite sides of cross-hair.		Angle between maximum extinctions … Whole angle.
								°	°	°
	"The Greenstone," Eagle River, Keweenaw Point, Michigan.[1]	SE.	19	58	31 W.	Medium-grained to fine-grained; very compact; hard and brittle; uneven to semi-conchoidal fracture; dark-green to greenish-black; "luster-mottlings" 1/8 to 3/4 inch in diameter; occasional pinkish porphyritic feldspars 1/8 inch in length. Sp. gr., 2.95.	*Olivine*, in "integral and aggregated grains, and, very rarely in crystals with recognizable though rounded contours," partly fresh, partly altered along fissures to a "very pale-green substance, sometimes tinged with brown"; *anorthite*, "in very sharply defined and fresh, thin, tabular crystals .001 to .002 inch thick and .01 inch and less long," holding "scattering interpositions of an opaque black substance, which may be, or have been, glass"; *magnetite*, in irregular areas, moulded "sharply around the contours of the feldspar and olivine"; *augite*, very fresh and transparent, relatively to the other ingredients; in very large individuals, which often contain thousands of feldspars, but have crowded almost all of the olivine and augite into the interstices; *residuary magma*, largely altered to greenish, feebly polarizing substance, filling interstices between the feldspars not occupied by augite and penetrating the feldspars in cracks.			
	Lower zone Marvine's bed 64;[2] Eagle River, Keweenaw Point, Michigan.[3]	NW.	19	58	31 W.	Fine-grained to aphanitic; dark-green to nearly black. SiO_2, 47.74. Sp. gr., 2.69.	*Olivine*, wholly altered to a soft, dark-green mineral; *anorthite*, in small crystals; *augite*, fresh, subordinate; *titaniferous magnetite*.			47 64 67 73 74

[1] R. Pumpelly, in Metasomatic Development, p. 261.
[2] Geology of Michigan, Vol. I, Part II.
[3] R. Pumpelly, Metasomatic Development, pp. 291–293.

Tabulation of the results of a microscopic study of fine-grained olivinitic diabases (including melaphyrs)—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : \bar{i}\bar{i}$.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
1875...	North shore Bête Grise Bay, Keweenaw Point, Michigan, near junction with Eastern Sandstone.	SW.	27	58	28 W.	Fine-grained, greenish-black; greasy; "luster-mottled."	*Olivine*, very abundant, and wholly altered to a green substance with brown and red stripes and crowded with the magnetite into the interspaces of the augites; *anorthite*, fresh, tabular, small; *magnetite*; *augite* in the characteristic areas.	32 30 21	33 31 23	65 61 44
1884...	Hillside above old smelting works, north side Lac La Belle, Keweenaw Point, Michigan.	NW.	31	58	29 W.	Medium-grained, dark brownish-gray; much-weathered; "luster-mottlings," not pronounced.	*Olivine*, wholly altered to green substance with dark-brown streaks and patches, crowded between the augites; *anorthite*; *magnetite*, not abundant; *augite*, quite fresh, in the usual large areas, including many feldspars.			
1919...	Road from Lac La Belle to Delaware Mine, Keweenaw Point, Michigan.	SW.	30	58	29 W.	Black to dark brownish-gray; fine-grained; "luster-mottled."	*Olivine*, in rounded grains, very abundant, and crowded between the augites, wholly altered to a greenish and brownish substance; the large amount of ochre-staining seeming to indicate an olivine rich in iron; *anorthite*; *magnetite*; *augite*, very fresh, in the usual large areas.	22	26	48
2597...	Porcupine Mountains, Michigan.	SW.	17	51	42 W.	Fine-grained, brownish-gray.	*Olivine*, wholly altered to greenish substance with red bands; *anorthite*; *magnetite*; *augite*, predominant, mostly fresh, but partly altered to *viridite*, in the usual large areas; *chlorite* pseud-amygdules.	34 32 32	32 31 29	66 63 61
81 W[1]..	Potato River, Ashland County, Wisconsin.		17	46	1 W.	Very fine-grained, luster-mottlings of minute greenish spots one-twentieth inch in diameter, surrounded by brown alteration-product.	*Olivine*, wholly altered: *plagioclase*, fresh; *augite*, fresh.			

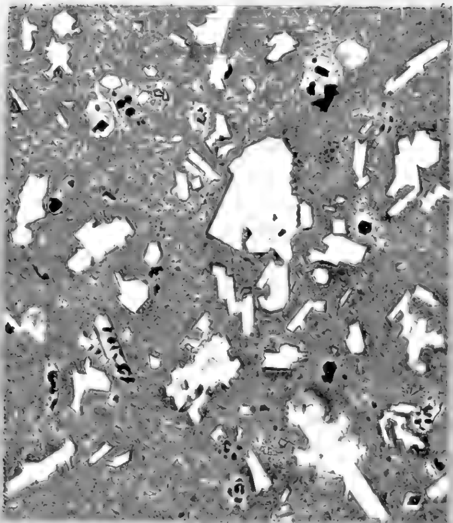
[1] R. Pumpelly, Geology of Wisconsin, Vol. III, pp. 38, 41, 42.

Tabulation of the results of a microscopic study of fine-grained olivinitic diabases (including melaphyrs)—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ii. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
365 S...	Totogatig district, Douglas County, Wisconsin.		12	44	9 W.	Fine-grained, compact, reddish-brown, small and inconspicuous "luster-mottlings."	*Olivine*, wholly altered to red product; *labradorite* or *anorthite*; very little *magnetite*; *augite*, in large individuals enveloping the feldspar crystals.	31 35	36 31	67 66
400 S...	Moose Creek, Douglas County, Wisconsin.	NW.	2	44	13 W.	....	*Olivine*, abundant, altered wholly to a soft green substance, crowded as usual into the interspaces of the augites; *labradorite* or *anorthite*; *magnetite*, chiefly in the augite interspaces; *augite*, in large individuals, including countless small crystals of feldspar; pseud-amygdules of chloritic substance. Resembles exactly the rock of "The Greenstone" of Keweenaw Point.	37 22	37 23	74 45
427.....	Near the upper Saint Croix River, Douglas County, Wisconsin.	SW.	15	43	14 W.	Fine-grained, bright red, altered. Sp. gr., 2.90.	*Olivine*, altered to a green and red product; *plagioclase*, fresh; *augite*, fresh; *chlorite* pseud-amygdules.	30 34 35	37 32 39	67 66 74
31.....	Bed of Lester River, Minnesota, north shore Lake Superior.	NW. cor.	4	50	13 W.	Medium-grained, crystalline, bright red, mottled with green and black.	*Olivine*, abundant, wholly altered to dark green substance, crossed by deep brown and red, to which alteration the color of the rock is due; *plagioclase* partly fresh, partly clouded; *augite*, fresh, in large areas including many feldspars; pseud-amygdules of *chlorite*.			
563.....	North shore Lake Superior, falls of French River, Minnesota.	NW.	17	51	12 W.	Fine-grained, rough fracture, dark purplish-brown, "luster-mottlings" not pronounced.	*Olivine*, altered to green substance, and crowded into the augite interspaces with the magnetite; *labradorite*; *magnetite*; *augite*, in the usual large areas.	25 29 28	25 32 28	50 61 56

Tabulation of the results of a microscopic study of fine-grained olivinitic diabases (including melaphyrs)—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.*		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
568....	North shore Lake Superior, between the mouths of French and Sucker Rivers, Minnesota.	NE.	16	51	12 W.	Fine-grained, dark gray, very pronounced lumpy fracture resulting from the deeper weathering of the augite interspaces.	*Olivine*, wholly altered to green and brown substance, crowded into the interspaces with the magnetite; *plagioclase; magnetite; augite*, fresh, greatly predominating in large areas.			
605....	North shore Lake Superior, one mile below mouth of Knife River, Minnesota.	NE.	29	51	11 W.	Greenish-gray, fine grained, minutely "luster mottled."	*Olivine*, wholly altered to green substance, abundant; *anorthite; magnetite; augite*, very fresh, in large areas, including great numbers of the tabular feldspars. A very typically developed "luster-mottled" rock.	35 32	31 37	66 69
628....	North shore Lake Superior, south point of Agate Bay, Minnesota.	NE.	11	52	11 W.	Fine-grained; dark purplish-gray; "lustre-mottling" not pronounced.	*Olivine*, wholly altered to green substance with red bands; *plagioclase* too much altered for measurement; *magnetite; augite*, fresh, predominant, in the usual large areas; *chlorite* pseud-amygdules.			
660....	North shore Lake Superior, from 5 feet dike, below mouth of Silver Creek, Minnesota.	NW.	22	53	10 W.	Very fine-grained, greenish-black, semi-conchoidal fracture.	*Olivine*, wholly altered to brown substance; *anorthite; magnetite; augite*, in the usual large areas. An excessively fine-grained rock.	34 33 32 31	36 32 32 31	70 65 64 62
688....	North shore Lake Superior, ¾ of a mile above the mouth of Gooseberry River, Minnesota.	NE.	27	54	9 W.	Very fine-grained; rough fracture; light brown.	*Olivine*, wholly altered to red substance, as usual in the interspaces with the magnetite; *labradorite; magnetite; augite*, very fresh, and in the usual relatively large areas, including many feldspars; but in this rock the "luster-mottling" is wholly microscopic.	27 27 26	31 29 33	58 56 59
696....	North shore Lake Superior, 2½ miles above the mouth of Split Rock River, Minnesota.	NE.	23	54	9 W.	Fine-grained; altered; mottled red and light gray.	*Olivine*, in very abundant and unusually minute particles, largely altered to green and red substances; *magnetite; anorthite; augite*, very fresh in the usual areas.	31 32 34 33 29 31	37 35 27 32 33 33	68 67 61 65 62 64



1

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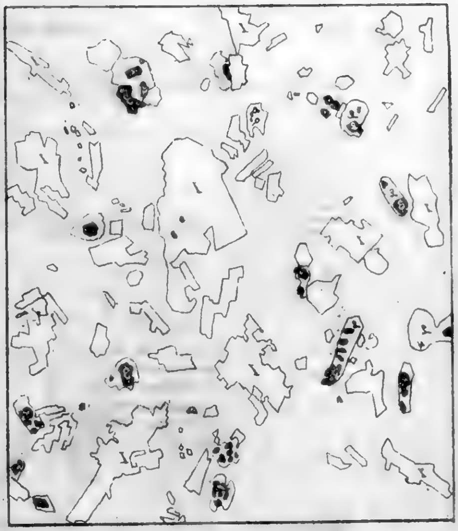
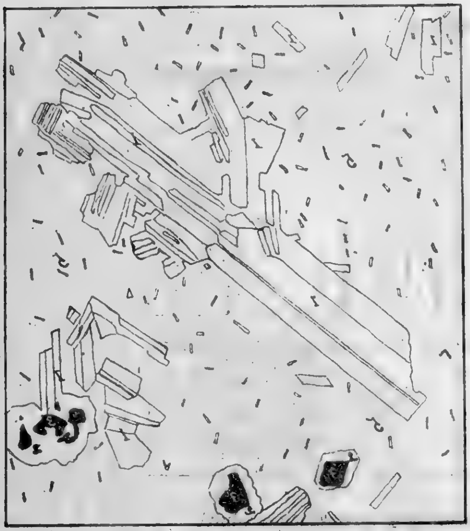
DIABASE PORPHYRITES AND ASHBED-DIABASE.





Figs. 1 and 2. diabase-porphyrite from Michipicoten Island. Fig. 1 scale 7 diameters, ordinary light. Fig. 2 scale 41 diameters, polarized light. See pages xii, 72, 86, 344. Porphyritic labradorite(1) and augite(2), with the latter is associated magnetite(3) and a greenish alteration product(4); red stained insoluble groundmass(5), carrying innumerable microliths of plagioclase. The latter are very inadequately shown in the engraving, their representation being beyond the engravers art.

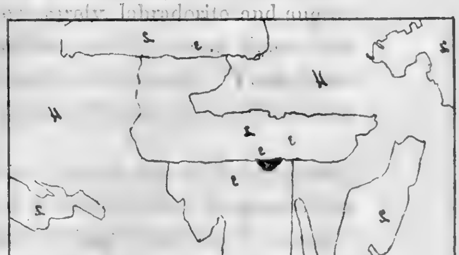
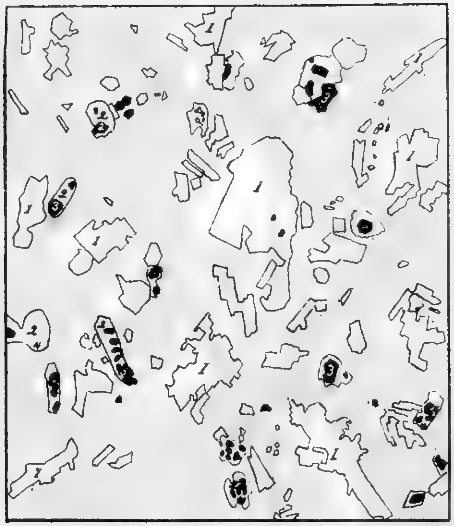
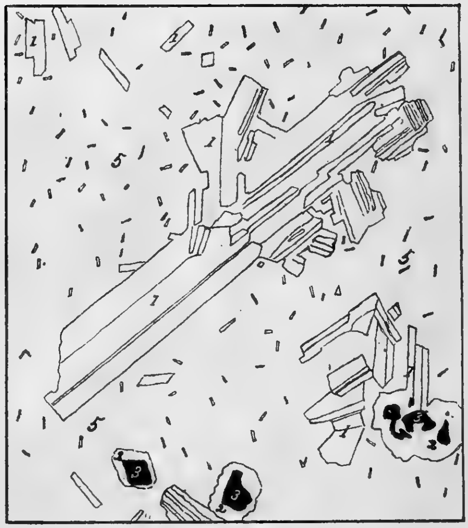


Fig. 3 diabase-porphyrite from Duluth, Minn. Scale 14 diameters. Ordinary light. See pages xii, 72, 477. Porphyritic orthoclase(1) and oligoclase(2) often with an epidotic alteration(3); base(4) consisting of plagioclase, magnetite, augite, pseudomorph(?) delessite, chlorite and an insoluble substance.

Fig. 4 ashbed-diabase from Tobacco(?) River, Mich. Scale 60 diameters. Polarized light. See pages xii, 73. Plagioclase(1); augite in grains(2); magnetite(3).





Figs. 1 and 2. diabase-porphyrite from Michipicoten Island. Fig. 1 scale 7 diameters, ordinary light. Fig. 2 scale 21 diameters, polarized light. See pages xii, 78, 86, 344. Porphyritic labradorite (1) and augite (2); with the latter is associated magnetite (3) and a greenish alteration product (4); red stained insoluble groundmass (5), carrying innumerable microliths of plagioclase. The latter are very inadequately shown in the engraving, their representation being beyond the engravers art.

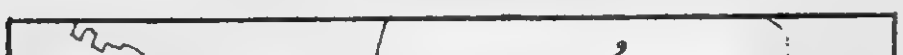


Fig. 3 diabase-porphyrite from Duluth, Minn. Scale 14½ diameters. Ordinary light. See pages xii, 83, 277. Porphyritic orthoclase (1) and oligoclase (2) often with an epidotic alteration (3); base (4) consisting of plagioclase, magnetite, augite, pseudamygdaloidal chlorite and an irresolvable substance.

Fig. 4 ashbed-diabase from Totogatig River, Wis. Scale 60 diameters. Polarized light. See pages xii, 83. Plagioclase (1); augite in grains (2); magnetite (3).

Tabulation of the results of a microscopic study of fine-grained olivinitic diabases (including melaphyrs)—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constitutents as determined by microscope, in order of age.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.*		
								Angles on opposite sides of cross-hair.		Whole angle.
958....	North shore Lake Superior, Caribou or Black Point, Minnesota, from a layer overlying red sandy shale.	SW.	11	60	2 W.	Fine-grained; dark reddish-brown.	*Olivine*, abundant, in small grains, wholly altered to a red substance and crowded into the augite interspaces; *anorthite; magnetite; augite*, in the usual fresh areas; an excessively fine-grained rock.	° 34 32 25 35	° 32 35 30 34	° 66 67 55 69

Diabase-porphyrite and ashbed-diabase.—The olivine-free, fine-grained diabases of the ordinary type pass into still finer-grained kinds, in which there is a black or brown color and a more or less perfectly developed conchoidal fracture. The finest of these rocks are completely aphanitic, and all kinds tend to a porphyritic development, carrying, as porphyritic ingredients, oligoclase and orthoclase, and, more rarely, labradorite and augite. The augite is always a subordinate ingredient, and appears at times to be almost wholly absent, at least as an individualized substance. These rocks play a very prominent *rôle* in the Keweenaw Series, and are always very strongly characterized in the field.

Some of the more distinctly crystalline of these rocks, as already stated, Pumpelly has described under the name of ashbed-diabase, the name being given from the fact that such a diabase forms the base of a flow, whose upper vesicular portion is the well-known and so-called ashbed of Keweenaw Point. As the external characteristics of this class of rocks, Pumpelly gives a light or dark gray or black color, a very compact texture, and a conchoidal fracture, and, as the accompanying microscopic characters, the subordinate position of the augite, and more especially its occurrence in rounded grains, whose contours are not determined by the feldspars.[1]

[1] Geology of Wisconsin, Vol. III, p. 32.

My own study has shown that the typical ashbed-diabases of Pumpelly are but phases of a large class of rocks; that between these typical kinds and the fine-grained, olivine-free diabase of the ordinary type there are various gradation-forms, in which the rounded grains of augite are mingled with more and more of the augite whose contours are determined by the feldspars; and also that, in the other direction, there are gradation-forms into aphanitic kinds, in which there is much non-polarizing, unindividualized material. In extreme cases, as in a rock from Michipicoten, figured at Plate IX., Figs. 1 and 2, the unindividualized base makes up the greater part of the rock. The presence of unindividualized base and the absence of recognizable olivine place these rocks among the diabase-porphyrites, according to Rosenbusch's nomenclature. But the ashbed-diabases are so plainly linked with these, both through intermediate kinds and through similarity of occurrence in the field, that all are considered here together. They all indicate rapidity of solidification, not only by the presence of unindividualized matter, but by the mode of occurrence of the augite.

The groundmass of these rocks externally varies from light-gray to dark-gray in color, in more distinctly crystalline kinds; and is from light-gray to jet-black, and in one phase deep reddish-brown, in the less crystalline kinds. With the former kinds the fracture is sub-conchoidal, with the latter very highly conchoidal and even glass-like, as in the case of some black semi-vitreous rocks that have a large development on Michipicoten Island.

Under the microscope the tabular oligoclases usually make up most of the section in the more distinctly crystalline kinds, the more acid phases containing also orthoclase with the oligoclase. The augite is in irregularly-outlined particles, commonly very subordinate in quantity, though occasionally, as in some dense black rocks from Portage Bay Island, at the east end of the Minnesota coast, it makes up most of the section. The augite particles lie in the little spaces between the feldspars, which, however, no individual particle ever completely fills. Several augite particles will occur together in such a space, or fill it along with the magnetite, or—and on the whole this is much more common—there is present more or less of a non-polarizing, cloudy, grayish, or red-stained substance, which represents the original magma. This substance, when present in small quantities, fills the sharper angles between the feldspars. From these smaller quantities it increases in amount until it becomes a preponderating ingredient in the denser and more highly conchoidally fracturing kinds, when the feldspars are seen floating about in it in wholly separate particles. The red ferrite, which is an important ingredient in all of the browner kinds, has evidently come from the alteration both of the original magma and the augite.

Among the porphyritic ingredients of these rocks the feldspars are much the most prominent. Commonly they are red, though occasionally white or colorless. The size usually is one-eighth to one-sixteenth inch in length or less. Orthoclase occurs among these feldspars, but they are more commonly oligoclase and rarely labradorite. Augite occurs as a porphyritic ingredient, but much more rarely than the feldspars. It is commonly much altered to chlorite. As adventitious ingredients may be mentioned epidote, quartz, calcite in pseud-amygdules and true amygdules, and apatite in the usual crystals.

These diabase-porphyrites frequently assume an amygdaloidal character in the upper portions of the flows, when they are commonly extraordinarily vesicular, very often with the vesicles elongated in a common direction. Frequently these extraordinarily vesicular amygdaloids have mingled with them, and often filling the vesicles, a red, shaly matter.

The rocks here included vary considerably in silica content, ranging from 48 to 60 per cent. It is possible that some of the more basic, blackish kinds may represent the half-glassy forms of the olivinitic diabases, but this has not been proved by analysis or recognition of olivine as an ingredient. On the other hand, there is evidently in some kinds, especially in some of the redder varieties nearly free from augite, a greater amount than usual of orthoclase material, and with this often is a little secondary quartz. These kinds make up much of the so-called quartzless porphyries, and are plainly the half-glassy form of the more acid orthoclase-gabbros. These kinds have about 55 to 60 per cent. of silica, and stand between the acidic and basic half-glassy rocks, just as the orthoclase gabbros do between the basic and acid granular rocks.

As typical localities for the rocks of this class may be mentioned, for the more distinctly crystalline kinds, Beds 45, 65 and 66 of Marvine's Eagle River section, Keweenaw Point;[1] for the kinds highly porphyritic with red feldspars, but without much non-polarizing matter in the base, the porphyry at the Duluth elevator, Duluth, Minn.; for the black and dark-gray kinds, with much non-polarizing matrix, the south shore of Michipicoten Island; and for the red aphanitic and brown aphanitic kinds, the north shore of Lake Superior, one mile below the mouth of Silver creek, N. E. $\frac{1}{4}$, Sec. 22, T. 53, R. 10 W., and the bay above the Great Palisades, on the same coast.

[1] Geological Survey of Michigan, Vol. I, Part II, Chapter VIII.

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O: \bar{i}\bar{i}$. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
1900...	Bohemian Range, Keweenaw Point, Michigan.		30	58	29 W.	Aphanitic; dark brownish-gray; of a conchoidal fracture.	*Oligoclase* predominates; *augite*, in minute grains; *magnetite; chlorite* pseud-amygdules.			
1963...	Old Suffolk mining location, Praysville, Keweenaw Point, Michigan.	SW. cor.	10	57	31 W.	Matrix aphanitic; mottled dark reddish-brown and black. Very abundant red porphyritic feldspars, which at times carry native copper and native silver as replacements. SiO_2, 59.52 per cent.	This rock presents a deeply-stained groundmass, in which are scattered very large and abundant porphyritic oligoclases and orthoclases, the former much the more abundant of the two. In some sections the groundmass presents much the appearance seen in 1799 (infra), except that the minute tabular feldspars are more often recognizable. In these sections also are found the same altered porphyritic augites that are characteristic of 1799. In other sections the groundmass presents a peculiar intertwisting of colorless and deeply brown-stained portions, often so arranged as to indicate flowage, and in some of these sections there are abundant, minute, elongated gas vesicles, now filled with quartz or a greenish chlorite. These vesicular sections are of specimens taken from nearer the upper surface of the bed. The proportion of unindividualized matter is large in the more vesicular sections and in those indicating flowage; the deep-brown portions representing the unindividualized material, the lighter portions being made up of completely individualized quartz and feldspar. The rock verges close on the limit between the more acid diabase-porphyrites and the quartzless porphyries.	5 12 13 7 5 6 0	3 12 14 11 6 7 6	8 24 27 18 11 13 6

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase —Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O: \bar{i}$. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
2560...	Porcupine Mountains, Michigan.	NW.	23	51	43 W.	Aphanitic; dark purplish-brown; conchoidal fracture; carries minute porphyritic feldspars. SiO_2, 59.38 per cent.	Groundmass:—*plagioclase*, in very minute tabular crystals; *unindividualized substance; magnetite;* much red and brown *ferrite;* rare and brilliantly polarizing particles belonging to *augite; secondary quartz.* Porphyritic ingredients:—rather rare *orthoclases* and *oligoclases;* much rarer *augites;* pseud-amygdules of *calcite.*			
1245...	Falls, Little Carp River, Porcupine Mountains, Michigan.	SE.	17	50	44 W.	Nearly aphanitic; dark-brown; conchoidal fracture; numerous porphyritic feldspars.	Groundmass:—in ordinary light, much stained with ferrite; consists of *unindividualized substance, oligoclase, magnetite,* and *ferrite* recognizable; *augite* particles very rare. Porphyritic ingredients:—*orthoclase* and *oligoclase* very abundant; *augites* rarer, of good size, almost wholly altered to ferrite and green substance.	8 2 5	9 5 6	17 7 11
2568...	Porcupine Mountains, Michigan.	NE.	23	51	43 W.	Aphanitic; dark chocolate-brown; holds minute porphyritic feldspars.	Groundmass as in 2560. Porphyritic *feldspars* larger and more abundant; the *augite* commonly much altered to greenish substance with bands of red and brown *ferrite.*			
2562...	......do	NW.	24	51	43 W.	Aphanitic; dark-brownish to black.	Groundmass:—*plagioclase; unindividualized substance; magnetite; ferrite; augite,* in minute, not abundant grains, often altered to a green substance; *secondary quartz.* Porphyritic ingredients:—not very abundant, good-sized *orthoclases* and *oligoclases,* much altered to chlorite; *augite,* much altered to green substance with bands of *ferrite.*			

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase—Continued.

Specimen number.	Place.	Quarter section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : ii$.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
2 W[1]..	Potato River, Ashland County, Wisconsin.		24?	46	1 W.	Nearly aphanitic; compact; black; conchoidal fracture.	*Labradorite*, in small strips; *augite*, in small grains; *green substance* in clouds of granular masses.			
9 W[1]..	Old Ironton trail, Ashland County, Wisconsin.		34	46	1 W.	Fine-grained; compact; black; subconchoidal fracture. Sp. gr., 2.98.	*Oligoclase; augite*, in aggregated grains; *magnetite* or *titaniferous iron*.			
386 S[1].	Clam Falls district, Polk County, Wisconsin.	NW.	24	37	17 W.	Aphanitic; black; conchoidal fracture.	*Oligoclase; augite*, in rounded grains; *magnetite; chlorite* and *quartz* pseud-amygdules.	Matrix. 8 0	10 4	18 4
393 S[1].	Totogatig district, Douglas County, Wisconsin.	SW.	28	42	11 W.	Aphanitic; black.	*Plagioclase*, predominant; *augite*, in grains; *magnetite*.			
426 S[1].	Upper Saint Croix district, Douglas County, Wis.	SE.	6	43	14 W.	Fine-grained; black; conchoidal fracture.	*Oligoclase; augite*, in grains; *magnetite*.			
1......	Mouth of Brewery Creek, Duluth, Minn. 75 north, 1,850 west.	SW.	23	50	14 W.	Aphanitic; chocolate brown; highly conchoidal fracture; carries very minute porphyritic feldspars.	Groundmass: — much stained with red ferrite; consists of *plagioclase* in minute tabular crystals; *unindividualized substance; magnetite; ferrite; augite*, in very minute grains. Porphyriticingredients:—rare *feldspars;* altered *augites*.			
13.....	Bed of Brewery Creek, Duluth, Minn.	SE.	22	50	14 W.	Matrix black; aphanitic; thickly crowded with small red feldspars one-sixteenth to one-fourth inch long; also pseud-amygdules of epidote and calcite.		Porphyritic crystals. 8 4 Matrix. 5 3	4 5 4 6	12 9 9 9
45.....	Bed of French River, Minnesota.	NW.	6	51	12 W.	Very fine grained; dark-gray; conchoidal fracture.	*Oligoclase*, both in the groundmass and in rare porphyritic crystals; *augite*, abundant in grains; *unindividualized substance; magnetite; ferrite; chlorite* pseud-amygdules.			
82.....	Bed of Beaver River, Minnesota.	N. line.	2	55	8 W.	Nearly aphanitic; black; conchoidal fracture.	*Oligoclase*, predominates; *augite*, in grains; *magnetite*.	2 13 8	7 17 8	9 80 16

[1] R. Pumpelly, Geology of Wisconsin, Vol. III, pp. 37–38.

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Constituents as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ĭ*.		
								Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
533....	Near mouth of Lester River, Minnesota.	SW.	4	50	13 W.	Very fine grained, but plainly crystalline; dark brownish gray; conchoidal fracture.	*Oligoclase*, predominates; *augite*, grains not abundant; *magnetite*; *ferrite*, abundant.	16 16	16 16	32 32
547....	North shore of Lake Superior, two miles below the mouth of Lester River, Minnesota.	SW.	34	51	13 W.	Aphanitic; very dense; dark brown; rare minute porphyritic feldspars.	*Plagioclase*; *unindividualized substance*; *augite*, in grains, not abundant; very abundant red and brown *ferrite*.			
589....	North shore of Lake Superior, one mile above the mouth of the Knife River, Minnesota.	SW.	31	51	11 W.	Very fine-grained; light gray; subconchoidal fracture.	*Labradorite* predominant, longer axes of crystals often in common directions; *magnetite*; *augite* in grains, abundant; a fresh rock.	22 27 27 30	26 34 33 31	48 61 60 61
655....	North shore of Lake Superior, one mile below the mouth of Silver Creek, foot of Encampment Bluff, Minnesota.	NE.	22	53	10 W.	Aphanitic; reddish brown; highly conchoidal fracture; carries elongated amygdules of calcite. SiO_2, 60.03 per cent.	Groundmass:—*oligoclase*; much *unindividualized substance*, saturated with red *ferrite*; *magnetite*. Porphyritic ingredients:—*oligoclase*; much altered *augite*.	7	8	15
712....	North shore of Lake Superior, one-half mile north of Split Rock River, Minnesota.	West side.	7	54	8 W.	Nearly aphanitic; indefinitely mottled red and black, weathers bright red; very highly conchoidal fracture.	*Oligoclase*; *augite*, abundant in grains; *magnetite*; ochre-stained, *unindividualized substance* abundant, filling sharply the spaces between the feldspars.	14 14	11 11	25 25
797....	North shore of Lake Superior, Beaver Bay, Minnesota.	SW.	12	55	8 W.	Very fine-grained; nearly black; conchoidal fracture.	*Oligoclase*; *augite* in rounded particles very abundant, unusually coarse for this class of rocks; *magnetite*.	9 5 12	6 4 13	15 9 25
884....	North shore of Lake Superior, bay above Great Palisades, Minnesota, underlies the palisade rock.	SW.	22	56	7 W.	Nearly aphanitic; chocolate brown, conchoidal fracture.	*Plagioclase*, predominant; *unindividualized substance*; rare minute grains of *augite*; *magnetite*; red *ferrite* completely saturating the entire section.			

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase —Continued.

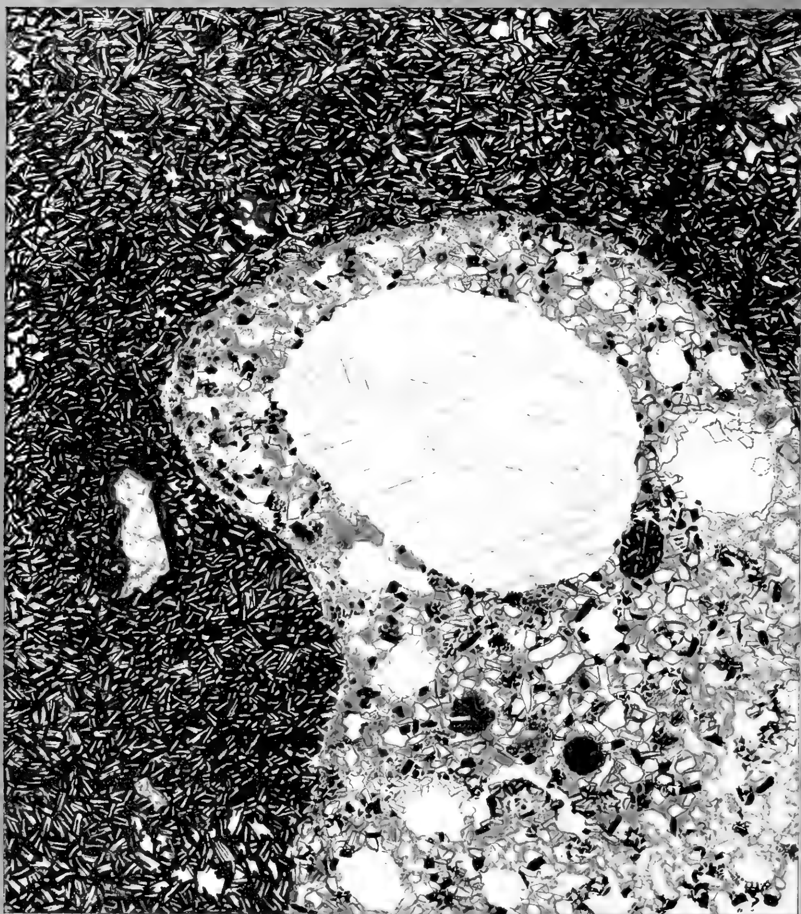
Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O : ii.* Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
907....	North shore of Lake Superior, 2 miles below the mouth of Baptism River, Minnesota.	SE.	11	56	7 W.	Minutely crystalline; dark-brown; semi-conchoidal fracture.	*Plagioclase; magnetite; augite* in grains; *unindividualized substance;* very abundant red *ferrite.*			
1051...	Bed of Cascade River, Minnesota.		23	62	2 W.	Aphanitic; dark brown; conchoidal fracture; an excessively dense rock.	*Unindividualized substance; plagioclase* needles; *magnetite* patches.			
1551...	North shore of Lake Superior, below Red Rock Bay, Indian reservation, Minnesota (not surveyed).			63	5 E.	Aphanitic; dark-reddish-brown; highly conchoidal fracture; comes out in thin slabs.	*Plagioclase; unindividualized substance; magnetite; augite,* particles rare; much red *ferrite.*			
1568...	Portage Bay Island, north shore of Lake Superior, Minnesota.					Black; aphanitic; rough fracture.	*Plagioclase,* in matrix and in porphyritic crystals; *magnetite; green and brown alteration-products.*	Porph. { 4 11 24	6 10 26	10 21 50
(1)	South side of Michipicoten Island.					Nearly aphanitic; dark gray; conchoidal fracture; no porphyritic ingredients.	Minute tabular *oligoclases* predominant; *magnetite; augite* in grains; some *residuary magma.*			
(2)	Southwest side of Michipicoten Island.					Completely aphanitic; very dark-gray; highly conchoidal fracture; no porphyritic ingredients.	With a medium power this rock presents merely a pinkish-tinted background, minutely dotted with gray, and no recognizable ingredients; with a higher power, in polarized light, there are recognized excessively minute tabular *plagioclases;* larger but still minute *magnetite* particles; rare and excessively minute brightly polarizing particles which may belong to *augite; residuary magma* predominating, producing no effect whatever between the crossed nicols.			

[1] Macfarlane's Michipicoten Collection, No. 2, "Compact Melaphyr."
[2] Macfarlane's Michipicoten Collection, No. 4, "Compact Melaphyr."

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O : ii*. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
(1)	South side of Michipicoten Island.					Aphanitic; dark chocolate-brown; conchoidal fracture; no porphyritic ingredients.	Tabular *plagioclase* for the most part, with the longer axes in a common direction, the crystals minute, but still several times larger than in No. 4, predominating; *magnetite* in not abundant small particles; *augite* in minute grains; some *residuary magma*.			
(2)	Copper mine, Michipicoten Island.					Like No. 4 of Michipicoten collection.	The base of this rock is much like that of No. 4 of this collection. In it are rare but quite large ($\frac{1}{16}$ to $\frac{1}{8}$ inch across) crystals of *augite*, largely changed to a greenish material, but with cores of fresh augite remaining.			
(3)	Southeast corner Michipicoten Island.					Matrix aphanitic; greenish-gray; very abundant porphyritic white feldspars, $\frac{1}{16}$ to $\frac{1}{8}$ inch long; also, rarer and much more minute black porphyritic particles.	Base:—light and dark brown, *unindividualized material*, producing little or no effect between the crossed nicols; this is thickly studded with minute *plagioclases* and holds rarer and more minute black particles of *magnetite*. Porphyritic ingredients:—very abundant, large-sized, and very fresh *labradorite*, several crystals often clustered in an interesting way; also *augite*, much smaller and rarer, commonly much altered to greenish material and associated with *magnetite*.	10 Porph. { 25 32 29 21	14 24 27 30 21	24 49 59 59 42
(4)	......do					Matrix aphanitic; dark brownish-gray; very abundant pink porphyritic feldspars, averaging $\frac{1}{16}$ inch in length. SiO_2, 60.89 per cent.	Close to preceding, differing only in having much red material in the base and the feldspars somewhat decomposed and dulled. Figs. 1 and 2 of Plate IX. represent this section.	Porph. { 16 16	20 19	36 35

[1]Macfarlane's Michipicoten Collection, No. 5, "Melaphyr."
[2]Macfarlane's Michipicoten Collection, No. 9, "Melaphyr."
[3]Macfarlane's Michipicoten Collection, No. 16, "Porphyrite."
[4]Macfarlane's Michipicoten Collection, No. 17, "Porphyrite."



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AMYGDALOID

Amygdaloid from Great Palisades Minnesota coast. Ordinary light. Scale 24 diameters.

Amygdaloid from Great Palisades Minnesota coast. Ordinary light. Scale 24 diameters.

Tabulation of the results of a microscopic study of diabase-porphyrite and ashbed-diabase —Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Composition as determined by the microscope.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : ii$. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
(1)	South side of Michipicoten Island.					Aphanitic; nearly black; highly conchoidal fracture; no porphyritic ingredients.	An excessively dense rock, in which are recognizable, with a high power in the polarized light, very numerous minute augite grains embedded in a non-polarizing matrix, along with much rarer plagioclase and magnetite. The rock is remarkable for its relatively large content of augite.	10	11	21
(2)	......do					Completely aphanitic; jet-black; greasy-vitreous luster; glass-like fracture. SiO_2, 57.92 per cent.	Has a base which in ordinary light looks much like that of No. 4 of this series; but there is more non-polarizing material, large areas remaining completely dark between the crossed nicols, and the plagioclases are still more minute. Occasional minute brilliant points belonging to augite are seen, as also some magnetite particles.			

[1] Macfarlane's Michipicoten Collection, No. 18, "Basaltic melaphyr."
[2] Macfarlane's Michipicoten Collection, No. 19, "Pitchstone."

Amygdaloids.—The flows of the finer-grained rocks are all commonly provided with upper vesicular portions, by the subsequent filling of whose vesicles, and the various degrees of alteration of whose matrices have been produced the manifold types of amygdaloid known in the Lake Superior region.[1] The coarse rocks—olivinitic and orthoclastic gabbros—are not furnished with amygdaloids save when tending to a distinctly finer grain than usual.

Externally, the matrix of the amygdaloid is commonly quite different

[1] Pumpelly has spoken of the olivinitic fine-grained kinds, his melaphyrs, as less commonly provided with amygdaloids than are the olivine-free diabases of the ordinary type, but in my observations this is only true when the melaphyrs have a distinct tendency to become coarse-grained, as in "The Greenstone" of Keweenaw Point. When they are fine-grained they appear to have amygdaloids quite as frequently as the olivine-free kinds.

from that of the rest of the bed. This difference consists principally in greater denseness of grain, from solidification while much of the matter was not developed into distinct minerals. The difference is least, then, in the case of those beds whose lower portions are composed of some phase of the diabase-porphyrites, in which there is also a greater or less proportion of unindividualized matter. In some of these beds, especially when the rock is of the dense brownish kind with highly conchoidal fracture, above described, there is no perceptible difference between the matrices of the vesicular and non-vesicular portions of the bed; but more usually there is a great difference in this respect between the lower and vesicular portions of a flow. The internal changes to which such an open vesicular substance, composed largely of a molecularly unstable material like glass, must always be liable, have greatly increased the difference, and have given rise, by the variation in the decomposition-products, to a great variety of amygdaloids, which it would seem at first sight hard to place together.

Under the microscope the matrix of the unaltered, or relatively little altered, amygdaloid shows nearly always much non-polarizing matter, commonly deeply stained with red ferrite. In this are developed needles of plagioclase to a greater or less extent, and often these needles seem to be but microliths arrested in the process of aggregation into crystals.[1]

Augite particles occur, but are usually relatively sparse, and frequently fail entirely. Very often there is a fluidal structure brought out in the arrangement of the plagioclase microliths and other particles, and in many cases the flowage direction is found to coincide with the longer axes of the elongated vesicles. The vesicles themselves, filled or empty, as the case may be, are always sharply outlined in the thin section, and there is immediately about them a crowding of the plagioclases and ferrite particles, as if by pressure in the cavity. Moreover, the individualized minerals, as Pumpelly has shown,[2] are often more minute in the vicinity of the vesicles than away from them. Porphyritic feldspars, macroscopically visible, are frequently developed in the matrix of the amygdaloids—so far as my observation has gone they are at least as often present as not—and in this

[1] R. Pumpelly, "Metasomatic Development," p. 282.
[2] *Ibid.*, p. 283.

respect we have yet another affinity between the amygdaloids and the non-vesicular diabase-porphyrites.

Macroscopically, the vesicles are seen to be commonly filled with secondary minerals—one or more of "calcite, chlorite, epidote, quartz, prehnite, laumontite, copper, orthoclase, or their products of alteration."[1] Often, however, I have observed the vesicles empty, either from the removal of the amygdules or from their having always remained empty. The walls of these empty cavities are commonly found to be smooth and dense, apparently from the pressure of the confined vapor.

Although a large number of sections of amygdaloids were cut with this object in view, I have not been able to find the time to extend the studies, so ably begun by Professor Pumpelly, of the changes which have brought about the fillings of the vesicles and the various stages of alteration of the matrix. He sums up the results of his studies on the alterations of both pseud-amygdaloids and the true vesicular amygdaloids in the following table, which is designed to show the course and final results of the most common process of alteration:

Pseud-amygdaloid stage .	I. Hydration of *chrysolite*, when present. II. Change of *augite*, loss of lime, and partial loss of iron and magnesia. III. Change of *feldspar* to *prehnite*, and formation of *prehnite pseud-amygdules*. IV. Change of *prehnite* to *chlorite*. IV*a*. Change of *prehnite* to *orthoclase*.
Amygdaloid stage.......	I. Filling gas vesicles with *prehnite*, or other minerals. Change of *matrix* to *ferruginous prehnite*. II. Change of the *prehnite*, in places, to *chlorite;* in others, to *calcite* and *green-earth;* in others, to *epidote* and *calcite*. III. Entrance of *quartz*, filling all the interstices, and replacing the *calcite*.

The following are Pumpelly's comments on this table:

This is the broader history. Orthoclase is here, as in the pseudo-amygdaloid, of sporadic occurrence, and a product of the prehnite.

The changes under II. may affect only the amygdules, or, if the matrix was prehnitized, it applies to the whole mass of the amygdaloid. It does this in such a manner

[1] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 31.

that, where carried to its extremes, considerable portions of the bed have lost every semblance of an amygdaloid, and consist now of chlorite, epidote, calcite, and quartz, more or less intimately associated, or forming larger masses, of the most indefinite shapes, and merging into each other. Sometimes portions of partially altered prehnite occur. In places, considerable masses of rich brown, and green fresh prehnite filled with copper occur; but, as a rule, this mineral has given way to its products.

To this process, the copper-bearing beds of Portage Lake—wrongly called lodes—owe their origin. Considerable portions of these beds are but partially altered amygdaloids, containing amygdules of prehnite, chlorite, calcite, or quartz, with more or less copper; other portions are in the condition described above.

This, too, (II. and III.), appears to have been the principal period of concentration of the copper. In the still amygdaloidal portions, this metal was deposited in the cavities and in cleavage-planes of some minerals, and replaced calcite amygdules, etc. But in the confused and highly altered parts of the bed it crystallized free, where it had a chance: more generally it replaced other minerals on a considerable scale. It formed, in calcite bodies, those irregular, solid, branching forms, that are locally known as horn-copper, often many hundred pounds in weight; in the epidote, quartz, and prehnite bodies, it occurs as thread and flake-like impregnations; in the foliaceous lenticular chloritic bodies, it formed flakes between the cleavage-planes and oblique joints, or in places—and this is more particularly true of the fissure-veins, which we are not now considering—it replaces the chloritic, selvage-like substance till it forms literally pseudomorphs, sometimes several hundred tons in weight.

When the amygdaloid has arrived at the condition we have been describing, it assumes some of the characters of a vein, in that, although it presents no open fissure, it contains greater or smaller masses of calcite and other minerals that are easily replaced by an intruder. To this period, probably, belongs the replacement of calcite by datolite; and here, also, the rather rare occurrence of analcite crystals, and the pseudomorphs of orthoclase after these.

As I have already remarked, the pseudo-amygdaloids are merely altered forms of the same rock as the lower zone. There seems to be a definite limit at which this progressive change stops, and that is when all augite is changed to its green pseudomorph, and a large percentage of the rest of the rock consists of pseudo-amygdules of delessite, and partial pseudomorphs of this after plagioclase. The occurrence of epidote and quartz is not general, and is then confined to scattering pseudo-amygdules, in which these minerals have succeeded prehnite, perhaps in the local absence of the conditions necessary to produce the usual delessite.

Thus I conceive that the extent of the change to the pseudo-amygdaloidal form is conditioned essentially by the amount of augite present, to supply first the lime necessary to aid in changing the plagioclase to prehnite, and next the iron and magnesia to form the delessite, whether by acting directly on the feldspar substance or on the prehnite.

The amygdaloids proper were, probably, both structurally and chemically, somewhat different from the lower zone, in that it is reasonable to suppose that, in addition to being more or less porous, they contained a greater or less amount of amorphous base, which is more easily altered than a crystalline aggregate. But, from whatever cause, the amygdaloids have, as we have seen, been capable of much greater changes than the lower zone: in them the tendency is undoubtedly towards the formation of quartz, chlorite, and epidote rocks as a more stable limit, through the mediation of prehnite and calcite.

There are other forms of alteration which Pumpelly's investigation does not cover, but none of so great importance as those above described.

SECTION II.—ACID ORIGINAL ROCKS.

As indicated in a previous chapter, I have been able to show that the several kinds of felsite and acid porphyry, which make the pebbles of the conglomerates and the material of most of the sandstones of the Keweenaw Series, exist in the same series in the original condition; and that while subordinated to the basic rocks in total amount they yet form a very important element in the make-up of the series, throughout its entire circuit about the Lake Superior Basin. These acid rocks may be conveniently described under the following heads:

1. Quartzless porphyry.
2. Quartziferous porphyry and felsite.
3. Augite-syenite, and granitell or granitic porphyry.
4. Granite.

Quartzless porphyry.—There are several phases of porphyritic rocks in the Lake Superior region, occurring both as pebbles in the conglomerates of the Keweenaw Series and as flows in the same series, which would formerly have been classed together as "quartzless porphyries," that name applying to felsitic rocks in which quartz is present neither in the base nor as a porphyritic ingredient.[1] These several phases have in common an aphanitic, dark-brown base, frequent abundance of porphyritic feldspars—although kinds occur in which the feldspars sink out of sight—and freedom from visible porphyritic quartz. They are also distinctly softer than the true acid quartziferous porphyries. A study of the thin sections, however, aided by silica determinations, has shown that in such a grouping we should really be placing together kinds which are but the half crystalline or cryptocrystalline phase of the less basic diabases, others which verge on

[1]Conf. R. Pumpelly in Geological Survey of Michigan, Vol. I, Part II, p. 16.

the true acid felsites in acidity (70 per cent. silica or over), and kinds again which are intermediate between these. There exist in the Lake Superior region, in fact, porphyritic rocks which range from the true basic kinds, with less than 50 per cent. of silica, to the very acid felsites and quartziferous porphyries with over 70 per cent., thus forming a continuous series. It thus becomes necessary to adopt some rather arbitrary divisions between the different phases. The kinds with from 50 to 60 per cent. of silica have already been considered under the heads of ashbed-diabase and diabase-porphyrite, while those reaching 70 per cent. are taken up below with the true felsites. There yet remain the kinds intermediate between these, both as to silica content (60 to 70 per cent.) and as to their microscopic characters. These are the kinds which are here considered under the head of quartzless porphyry. They are, in fact, the semi-crystalline phases which correspond to the completely crystalline augite-syenites described below.

Macroscopically these rocks show an aphanitic matrix of a dark reddish-brown or brown color, and more or less strongly developed conchoidal fracture. The porphyritic feldspars vary considerably in size and abundance, but are usually minute. They show habitually a red color, and include often striated as well as unstriated kinds. The thin sections generally show a reddish background, with abundant brown ferrite particles and needles scattered through it. In most sections more or less of this base is isotropic, being either cryptocrystalline or truly glassy in its nature. There are in some slices darker and lighter bands, plainly due to flowage. The darker bands are always the least crystalline. Minute tabular feldspars are nearly always rather abundant; far less so, however, than in the sections of the diabase-porphyrites; but always much more so than in sections of the acid felsites, from which they are often completely absent. The individualized particles are, however, for the most part irregular in outline, and appear to belong to both orthoclase and quartz, which latter mineral seems to be nearly always of a secondary origin, since it commonly occurs in the characteristic ramifying forms. It is, however, far less abundant in the rocks here included than in the felsites and the bases of the quartziferous porphyries. In a few places these quartzless porphyries were found with a tendency to a vesicular structure, and then the thin section shows flowage lines and isotropic material at the maximum.

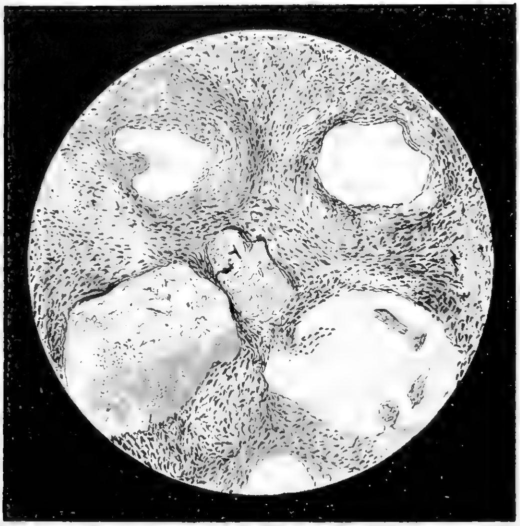
The porphyritic feldspars are orthoclase and oligoclase, the latter the prevailing one. Both are always reddened and clouded by alteration. Many sections show also porphyritic augites, with crystalline outlines often remaining, and always with the peculiar red and brown, opaque, ferritic alteration-product, which characterizes the augites of all of the acid rocks here described.

As instances of the occurrence of these porphyries—which are less common than any of the other original rocks of the Keweenaw Series—may be mentioned the rock of the Stannard's Rock reef; the prevailing pebbles of the Eagle River conglomerate, Keweenaw Point; the massive to vesicular rock of the old Suffolk mining location (Praysville), Keweenaw Point; many of the pebbles of the Portage Lake conglomerates; the rock exposed in the bed of the Gogogashugun River in the northern part of Sec. 8, T. 46, R. 2 E., Wisconsin; the rock at the falls of the Brunschweiler River, NW. $\frac{1}{4}$, Sec. 22, T. 45, R. 4 W., Wisconsin; and a rock showing on the southwest shore of Michipicoten Island.[1]

[1]Called by T. Macfarlane "porphyritic melaphyr," p. 138, Report of Progress of the Geological Survey of Canada for 1863 to 1866.

Tabulation of the results of a microscopic study of the quartzless porphyries of the Keweenaw Series.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic characters.
17[illegible]9...	Stannard's Rock, Lake Superior.	....	....	....	......	Aphanitic; dark reddish-brown; shows no visible porphyritic ingredients. SiO_2, 65.81 per cent.	In the ordinary light, the matrix of this rock presents a general red background thickly studded with opaque brown ferrites. The only porphyritic ingredients are augites, which are now represented by patches of red translucent, or opaque black ferrite, within which are little remnants of unaltered augite. These ferrite patches often show the crystalline outlines of the original augites. Elongated holes, worn in the section by grinding, were probably occupied by minute decomposed porphyritic feldspars. In the polarized light, the groundmass presents a considerable proportion of isotrope matter, in which are occasionally recognizable minute tabular feldspars. Brightly-polarizing, irregularly-outlined particles and clusters of particles in the ground-mass appear to belong to quartz, possibly also to orthoclase. Some of these clusters plainly belong to secondary quartz. The low percentage of silica (65.81), the abundance of altered augite and of ferrite particles, and the scarcity of secondary quartz, all serve to separate this rock from the more acid felsites; while it is separated from the diabase-porphyrites by its higher percentage of silica and rarity of tabular feldspars.
1781 A	Pebble from Albany and Boston Conglomerate, Keweenaw Point, Michigan.	NW...	8	55	33 W.	Aphanitic; dark chocolate-brown; conchoidal fracture; holds abundant minute, pinkish, porphyritic feldspars. SiO_2, 65.35 per cent.	Both in the ordinary and polarized lights the section of this pebble resembles closely that of the rock from Stannard's Rock; the large ferrite patches, representing altered augite, are, however, much less abundant in this rock, which also holds not unfrequent small porphyritic oligoclases.
2616...	Pebble from the conglomerate at the National Mine, Rockland, Mich.	Center	16	50	39 W.	Matrix aphanitic; dark reddish-brown; carries minute porphyritic tabular feldspars.	The groundmass of this rock is much like that of 1781 A, containing, however, rather more secondary quartz. The porphyritic feldspars are oligoclase.



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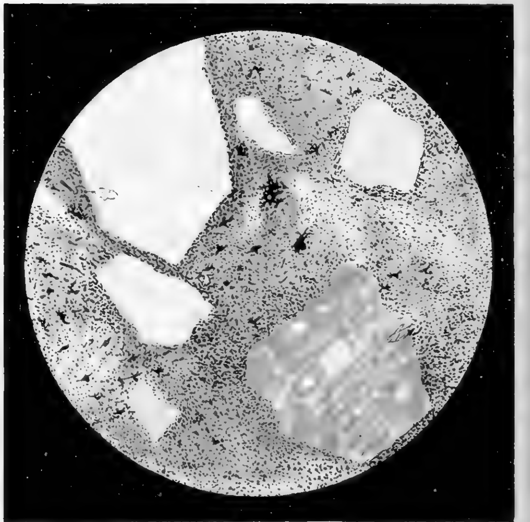

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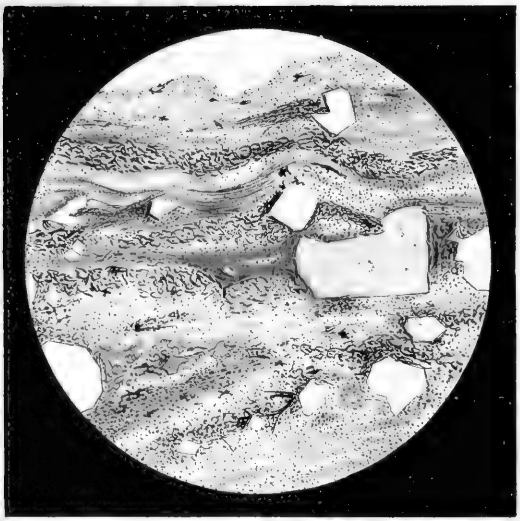

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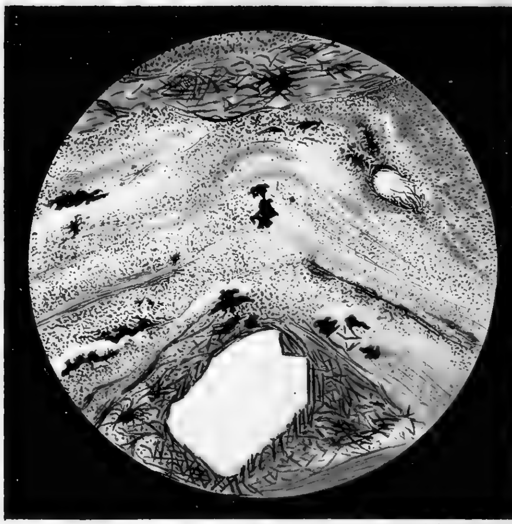

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QUARTZ PORPHYRIES

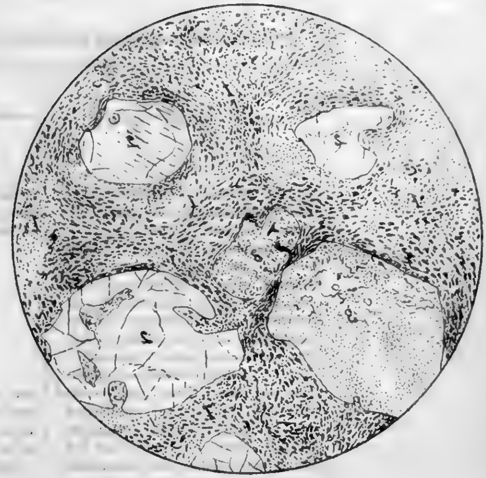
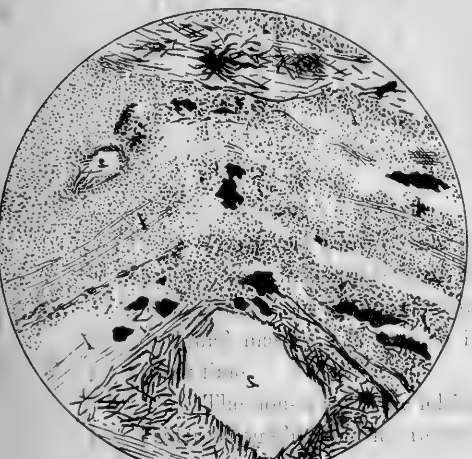


Fig. 1. Massive Quartz-porphyry from Torch Lake Railroad, Keweenaw Point. Ordinary light. Scale 18 diameters. Felsitic matrix (1) with flowage structure; corroded quartzes (2); orthoclase (3)

Fig. 2. Quartz-porphyry pebble, Calumet conglomerate, Keweenaw Point. Ordinary light. Scale 12 diameters.
Felsitic matrix (1) showing flowage; quartz (2); orthoclase (3)



Figs. 3 and 4. Banded Quartz-porphyry from Great Palisades, Minnesota coast. Ordinary light. Scales, Fig. 3, 9 diameters; Fig. 4, 32 diameters.
Matrix (1) showing flowage structure; quartz (2); orthoclase (3).

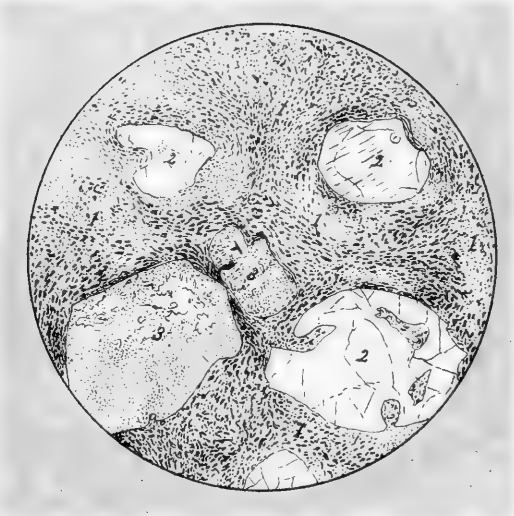


Fig. 1. Massive Quartz-porphyry from Torch Lake Railroad, Keweenaw Point. Ordinary light. Scale 15 diameters.
Felsitic matrix (1) with flowage structure; corroded quartzes (2); orthoclase (3)

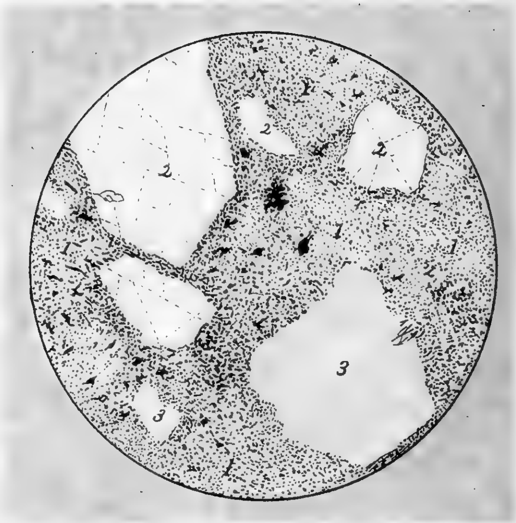
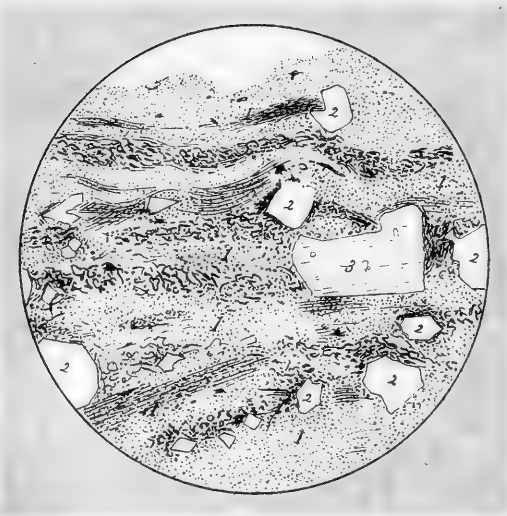
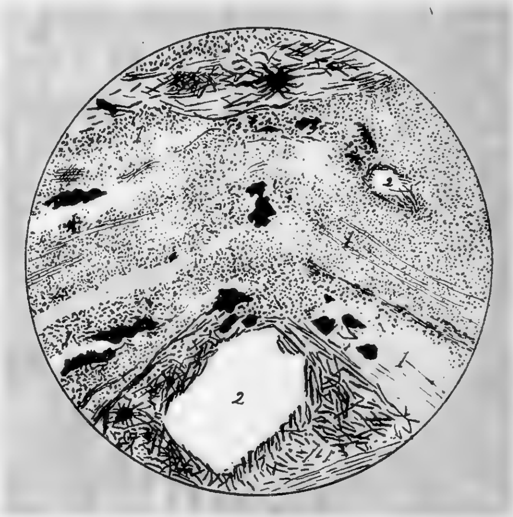


Fig. 2. Quartz-porphyry pebble, Calumet conglomerate, Keweenaw Point. Ordinary light. Scale 12 diameters.
Felsitic matrix (1) showing flowage; quartz (2); orthoclase (3)





Figs. 3 and 4. Banded Quartz-porphyry from Great Palisades, Minnesota coast. Ordinary light. Scales, Fig. 3, 4 diameters; Fig. 4, 32 diameters
Matrix (1) showing flowage structure; quartz (2); orthoclase (3).

Tabulation of results of a microscopic study of quartzless porphyries—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic characters.
65 I...	Brunschweiler's River, Ashland County, Wisconsin.	NW...	22	45	4 W.	Aphanitic; brown; carries porphyritic feldspars in long red crystals.	Groundmass close to that of 1799, 1781 A, etc., showing rather more tabular feldspars and little or no secondary quartz. There is a considerable proportion of isotrope matter, while minute points of augite, scattered in the matrix, suggest that the abundant minute ferrites are alteration-products from it, as the larger ones evidently are. The porphyritic feldspars are all oligoclases, and are much altered to a greenish chlorite.
3057...	Duluth, Minn.......	NW...	27	50	14 W.	Minutely crystalline to aphanitic; dark reddish-brown; carries minute red porphyritic feldspars.	In the ordinary light this section shows a groundmass much like that of the last-described rock, but in the polarized light it is seen to differ in containing less isotrope matter, there being a large proportion of distinctly individualized particles, most of which probably belong to orthoclase and quartz. The latter mineral occurs frequently in good-sized clusters of particles. Augite particles are not uncommon through the section. Porphyritic feldspars are in part oligoclase and in part orthoclase.
1729...	East end of Bead Island, mouth of Nipigon Straits, Ontario, Canada.	....	....		......	Minutely crystalline; light-brownish; carries very abundant porphyritic red feldspars, up to two-tenths of an inch in length; also rarer and much larger greenish-grey feldspars, reaching five-tenths of an inch in length. Comes out in thin tabular fragments. SiO_2, 64.73 per cent.	Groundmass contains little, if any, isotropic substance, but is made up almost entirely of relatively coarse particles of orthoclase and quartz, with triclinic feldspar and augite. Some, at least, of the quartz is secondary; magnetite is also present. Porphyritic feldspars are very large and abundant, and include both oligoclase and orthoclase, the latter often finely twinned. The rock stands between the more silicious of the orthoclase-gabbros and the quartzless porphyries.

Felsite and quartziferous porphyry.—Rocks belonging under this head play a very important *rôle* in the Keweenaw Series, not merely as pebbles and bowlders in the conglomerates, but also as extensive and widely spread original masses, a fact which is, as already stated, now recognized for the first time.

The non-porphyritic felsites and true quartz-porphyries are here considered together for the reason that, in the Lake Superior region, as elsewhere, they often form parts of the same rock, the groundmasses of the two rocks being identical in constitution.

These rocks belong to a class which is, as is well known, one of the most difficult of all the rock groups to study with the microscope satisfactorily. Very widely separated views have been held as to the nature of their aphanitic matrix, even since the use of the microscope in their study. The differences of opinion have been chiefly as to whether the matrix is crystalline, partly crystalline, or wholly uncrystalline. In his discussion of this subject, Rosenbusch has shown that both completely crystalline and partly glassy matrices occur, with many intermediate stages, and that uncrystalline and completely crystalline material often occur intermingled in the same rock. Calling all parts of the matrix which are doubly refracting, crystalline—so long as it cannot be shown that the double refraction is a result of mechanical strain—Rosenbusch designates as *microcrystalline* those porphyritic groundmasses, or parts of groundmasses, which are made up of mineralogically determinable particles; as *cryptocrystalline* those which are aggregates of mineralogically indeterminable, but still doubly refracting particles, and as *glass* or *glass basis*, those which show no polarization effects whatever, even when examined under the highest powers. In place of the true glass basis, there is often to be seen interwoven with the microcrystalline and cryptocrystalline material, a completely isotropic substance, which is colorless, grayish, yellowish or brownish, and which differs from the true glass, in that it is not wholly structureless, but is, on the contrary, made up of extremely minute scales, fibers, granules or aggregates of granules, and other grouped forms. This substance, "which is distinguished from the microcrystalline and cryptocrystalline aggregates by lack of action upon the polarized light, and, on the other hand, from the true glass by lack of structurelessness"—Rosenbusch calls *microfelsite* or *microfelsitic base.*[1] In the following descriptions, the Rosenbusch nomenclature is followed.

The matrix of the Lake Superior quartz-porphyries and felsites, as seen macroscopically, presents usually some quite marked shade of red; the

[1]Conf. H. Rosenbusch, Microscopische Physiographie der Mineralien und Gesteine. Band II, pp. 51–76.

various shades mentioned in my notes being "brick-red," "dark red," "dark purplish-red," "dark brownish-red," "brick-red, banded with lighter shades," "dark-purple, banded with indefinite markings of light-red," "dark purplish-gray, blotched and banded with brick-red," "pale-lilac," "pinkish-lilac," "pink" and "light-gray." Often there is no appearance of banding, but as often one produced by waving or contorted lines or rows of spots of lighter material. Occasionally this banding becomes very pronounced, as in the lower part of the flow at the Great Palisades on the Minnesota coast, where it is plainly a flowage result, even as seen macroscopically. In one case, that of a pink felsite on the Minnesota coast, in the SW. ¼, Sec. 28, T 56, R. 7 W., the flowage structure is brought out on a grand scale by curving bands and S-like forms, sometimes several inches in width, of a darker, more highly ferritic felsite. This rock is fully described and pictured in a subsequent chapter.

The matrix is always aphanitic, and has often a pronounced conchoidal fracture, but this is never quite so prominent as in the diabase-porphyrites above described, and is at times entirely wanting, the fracture surface presenting a rough and even hackly appearance. These felsites frequently come out of the ledge in sharp-edged, angular and even tabular fragments, while a very common result of weathering is the leaving of wedge-shaped or three-cornered cores, which fall from a cliff-side in showers at the slightest blow of the hammer. The silica content of the aphanitic matrix appears to be high, ranging in all cases where a determination was made between 72 and 77 per cent. The matrix is fusible before the blow-pipe, but with difficulty.

Of the porphyritic ingredients the feldspars are the most commonly present, appearing macroscopically in regularly outlined crystals, which are usually of a red color, though occasionally white and porcellaneous, and range in size from particles so minute as to be barely visible to the naked eye, to crystals a fourth of an inch and even half an inch in length. The porphyritic feldspars often show striated surfaces. In the banded porphyries they sometimes conform roughly to the contorted banding, forming strings of crystals; and again they lie across the course of the bands, which will then curve around them. The whole structure is plainly one due to flowage in a molten state. While often present without the porphyritic quartzes, when at all abundant and large the feldspars are almost always accompanied by the quartzes. These present an invariable appearance, *i. e.*, a glassy rough surface, which has a black color owing to the dark background in which the crystals lie. They are rarely very minute, running from one-twentieth to one-fifteenth of an inch in diameter. Both of the porphyritic constituents vary greatly in amount, at times sinking out of sight, when the rock becomes a felsite, and again nearly equaling the matrix in combined quantity.

In the thin section the matrix of these rocks is only rarely colorless, as seen in the ordinary light, being commonly more or less thoroughly stained red by minute particles of iron oxide. Some sections show red and white material blotched or interbanded in waving non-continuous bands. Very characteristic are the deep-brown, and deep-red to black, translucent to opaque, irregularly outlined, or needle-shaped ferrites. These range from the most minute particles to pieces which, with a low power, will run a quarter of the way across the field. They occur in both red and white portions, where the sections present a blotching or banding of these colors; but are more abundant in the red. They are at times without any apparent arrangement, and again may show a crowding in the neighborhood of the porphyritic ingredients; while in many sections they present a pronounced linear arrangement, as is shown, for instance, in Fig. 1 of Plate XII. In some of the sections in which the fluidal structure is brought out in especial prominence by a very marked interbanding of colorless and red-stained portions—as for instance in those of the banded rock of the Great Palisades of the Minnesota coast—the ferrite-needles are abundant and large-sized in the latter bands, and, while showing a general tendency to follow the courses of the bands, they yet lie across each other at small angles. The appearance produced is strongly suggestive of the common brush-fence, a simile used by Zirkel in describing a similar arrangement of ferrite-needles in some of the western rhyolites.[1] Figs. 3 and 4 of Plate XII illustrate this peculiarity.

The red-stained material which makes up the whole groundmass of

[1] Geological Exploration of the Fortieth Parallel, Vol. VI.

many sections, and much of nearly all sections, appears to be made up for the most part of microfelsitic and cryptocrystalline matter. Only very rarely—as in the light-gray and lilac quartz-porphyries of the islands off the north point of Beaver Bay, Minnesota—is there present a non-polarizing material without the red stain. Distinctly recognizable orthoclase and quartz particles—as, for example, in a brick-red felsite from the western part of the Porcupine Mountains—are not often to be found, though in some sections there may be seen floating in the isotropic material, as in a cloud, minute tabular crystals of some feldspar. True glass is supposed to be present in many sections, interwoven in minute particles with the cryptocrystalline and microfelsitic matter, but the determinations made are not regarded as satisfactory on account of the imperfections of the instrument employed. The large proportion of scaly and granular material which produces no effect on the polarized light, and the rarity of true microcrystalline matter, show, however, that we have here to do with a substance very close to the original glassy condition, even if it does not contain true glass.

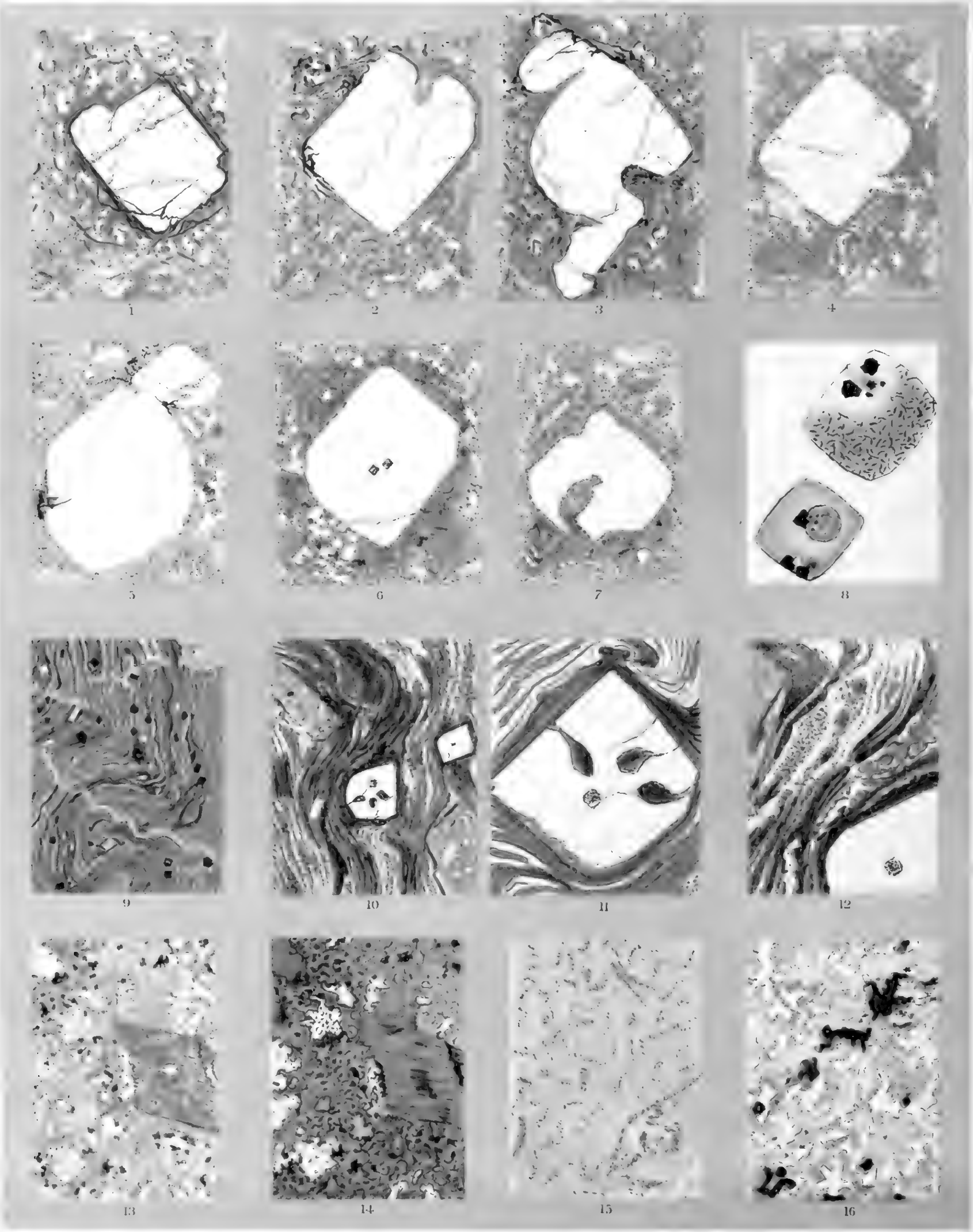
The white areas and bands, which in some sections interrupt the prevailing red background, are always found to be made up of completely crystalline matter, and to include orthoclase and quartz in aggregated irregular grains, although it is often difficult, in a given section, to separate these materials from one another. The peculiar interlocking of this more crystalline colorless material with the prevailing isotropic, ferrite-bearing, reddish base, is plainly and most beautifully seen in many sections to be the result of flowage. All of the peculiar and characteristic irregularities which accompany the flowage structure are present here, viz, sudden angular or curving bends in the bands, damming against the porphyritic ingredients, streams of ferritic particles, brief continuity of individual bands, etc. I have attempted to illustrate this fluidal structure in Figs. 3 and 4 of Plate XII, and in Figs. 8, 9, 10, 11, and 12 of Plate XIII.

Although wholly absent from some sections, a very highly characteristic feature of the sections of many of these rocks, and more particularly of the felsites without porphyritic quartz, is a networked quartz which can only be regarded as of secondary origin. I find no mention of such a feature in any of the descriptions of the felsites of other regions that I have examined. Only occasionally, as in the pink felsite from the S. W. ¼ of Sec. 28, T. 56, R. 7 W., on the Minnesota coast (see Figs. 15 and 16, Plate XIII), is this networked quartz coarse enough to be readily seen with a low power, in the ordinary light. Usually both a high power and the use of the polarized light are required for its detection, when it appears, in its most charac teristic development, as a delicate arborescent tracery or frost-work saturating the groundmass in all directions. In the polarized light all of the quartz network within each of numberless irregularly round areas, whose existence would not be suspected in the ordinary light, is found to be similarly oriented.

From these more pronounced developments the secondary quartz is found through many degrees of lessening amount, and less plainly marked character, until it disappears altogether. It is plainly of the same nature as the secondary quartz of the already described orthoclase-gabbro, diabase-porphyrite, and quartzless porphyry, and of the augite-syenite described below. It never, however, reaches in the rocks now under description the coarseness, nor presents the graphic form, with which it appears in the augite-syenites, its characteristic development here being the delicate arborescent clusters above mentioned. Whether this secondary quartz may ever be rather a result of devitrification than a truly secondary or alteration-product I have no means of deciding, though it is certainly the latter often, and I should suppose always. It surely can have had no connection with the original solidification of the rock.

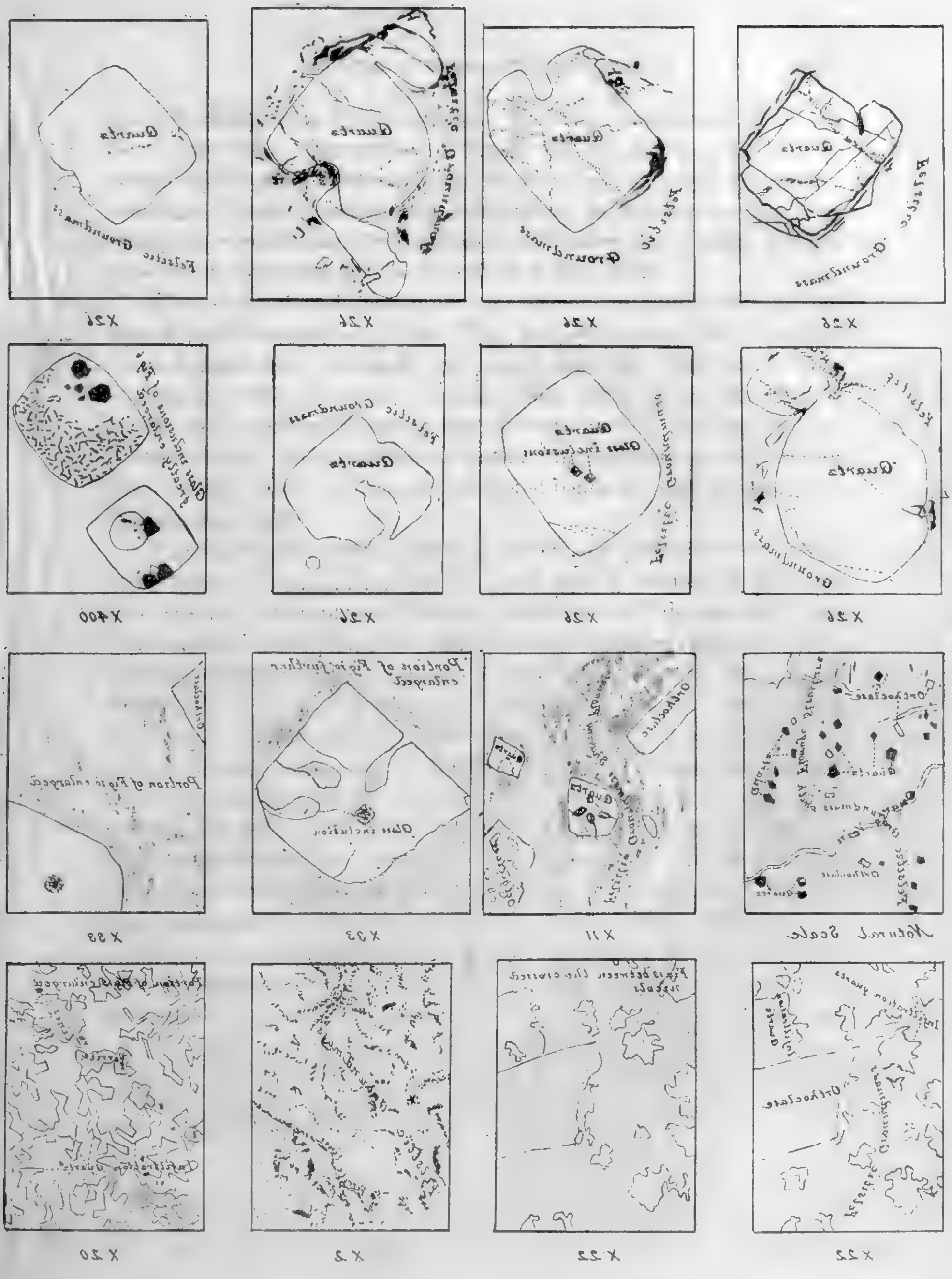
The absence in the Lake Superior felsites and felsitic porphyries, so far as my observations have extended, of anything like a true spherulitic structure, such as is so often met with in rocks of this class from other regions, is worthy of note. The occasional radial arrangement of ferrite needles and lines of secondary quartz may indicate such a structure, but these appearances are rare and feebly characterized.

One or two other unusual occurrences in the thin sections of the matrix of these rocks need description. One of these is a faintly greenish, wholly isotropic substance, which is present in some of the Beaver Bay porphyries in elongated bands and irregular patches. Whether it is to be regarded as

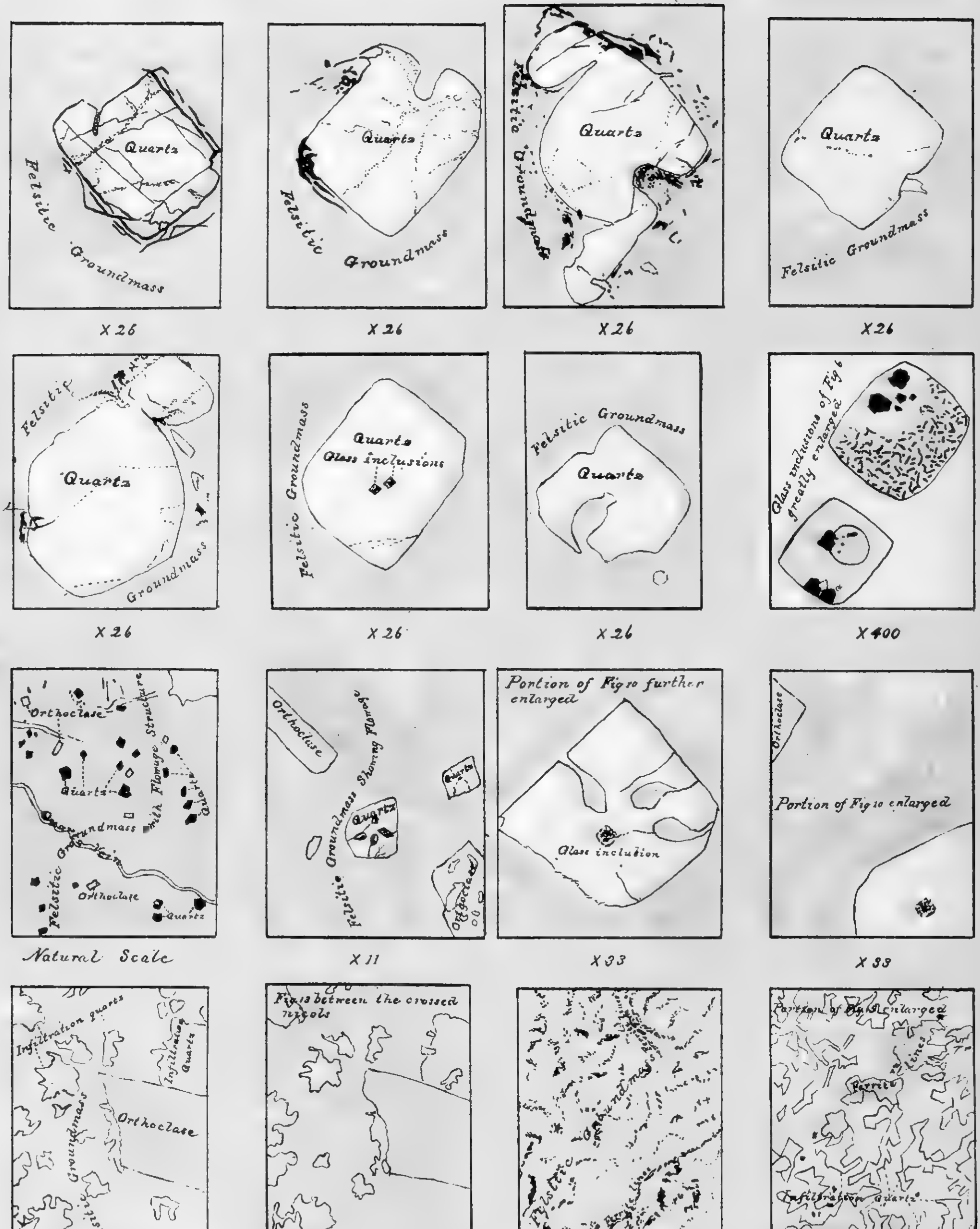


A Hoen & Co. Lith. Baltimore

QUARTZ-PORPHYRIES AND FELSITES



Figs 1 to 12 quartz-porphyries; Figs 13 to 16 felsites; for localities see page xxii.
Fig. 9 hand specimen, reflected light; Figs. 13 and 14 in polarized light; all other figures in ordinary light



Figs. 1 to 12 quartz-porphyries; Figs. 13 to 16 felsites; for localities see page xiii.
Fig. 9 hand specimen, reflected light; Figs. 13 and 14 in polarized light; all other figures in ordinary light

partially altered glass, I am uncertain. The other occurrence referred to is that of curvilinear aggregations of brown and red ferrite particles, large enough to be seen macroscopically, in the hand specimen, as hair-like markings. These characterize the felsite from the Minnesota coast above mentioned as remarkable for the coarseness of its secondary quartz network. This rock is illustrated in Figs. 15 and 16 of Plate XIII.

The porphyritic feldspars in the thin section are found to be either or both of orthoclase and oligoclase. They are always turbid from decomposition, and are more commonly red-stained than not. They have always crystalline outlines, or, when they have been eaten into by the still fluid matrix, as is not seldom found to have been the case, at least the remnants of such outlines. In a number of sections the feldspars are seen to have been not only eaten, but also much shattered before the solidification of the surrounding magma.

The porphyritic quartzes present all the usual characters of the quartzes of similar rocks the world over. They are random sections of dihexahedral crystals (double pyramids due to combination of the two rhombohedrons), with now and then some development of the lateral (prismatic) faces. The rhombohedral angle being only a few degrees over 90° (94°.15), the sections of these crystals present a nearly square shape.[1] Usually they are more or less rounded and eaten into by the matrix, many odd forms resulting from this corrosion. In nearly all cases, however, some traces of the original outline remain, with the aid of which, along with the behavior between the crossed nicols, it is always easy to ascertain the crystallographic directions of these eaten crystals. In the series of figures on Plate XIII, I have placed a number of these quartzes with the crystallographic axes in a vertical position so that they may be compared with one another.[2]

Included in the porphyritic quartzes are particles or patches of the red-stained microfelsitic or cryptocrystalline groundmass. In most cases these have had originally a connection with the rest of the groundmass by

[1] N. H. Winchell (Ninth Annual Report of the Geological and Natural History Survey of Minnesota, pp. 21, 33, &c.), has called the dihexahedral quartzes of the quartziferous porphyry of the Palisades and other points on the Minnesota coast, *adularia*.

[2] Rutley (Study of Rocks, p. 210), speaks of roundish blebs of quartz as characterizing quartz-porphyries generally, but his "blebs" are only rounded crystals.

channels through the quartz, either above or below the plane of section. In some cases, however, I have noticed these groundmass inclusions surrounded by the quartz in such a way as to render it probable, at least, that they are veritable inclusions of the groundmass dating from the time of crystallization of the quartz. In several sections of North Shore porphyries, and especially in those of the Great Palisades and of Baptism River point on the Minnesota coast, unmistakably genuine inclusions of a true glass are to be seen in the porphyritic quartzes. These glass inclusions are in doubly terminated "negative crystals," conforming in position exactly with the crystal in which they are found, and are of sufficiently large size and thickness to test satisfactorily with the polarized light. They show commonly more or less of a trichitic devitrification. Two of these glass "negative crystals" are figured on Plate XIII, at Figs. 6 and 8.

Porphyritic augites, while far less frequent than the quartzes, are yet not very unfrequently to be met with in sections of these rocks. They always have crystalline outlines, or remnants of them, being commonly more or less deeply eaten into like the other porphyritic ingredients. Their chief characteristic is the ferritic decay that they have undergone, the whole mass of the crystal being often represented by an opaque, brown, or deep-red, or black mass of iron oxide.

I have already discussed, briefly, the question of the origin of the Lake Superior felsites and quartziferous porphyries, and the same question is referred to hereafter in other connections. Here it is sufficient to say that the marked fluidal structure so often seen, both on the large scale and microscopically; the corroded quartzes; the glass inclusions in these quartzes; the near approach of the groundmass to the glassy condition; the complete identity of these felsitic rocks with others universally conceded to be of eruptive origin, and their very close similarity to the undoubtedly eruptive rhyolites—all combine to make up an irresistible argument in favor of an eruptive origin for these rocks also.

As typical localities for these rocks—including only places where they occur as original masses—may be mentioned the following: (1) for the non-porphyritic felsites—Mount Houghton, Keweenaw Point; the central area of the Porcupine Mountains, and especially the great ledges in Sec. 35, T.

51, R. 43 W., and again in Sec. 31, T. 50, R. 44 W.; the Minnesota coast in the S. W. ¼, Sec. 28, T. 56, R. 7 W.; the same coast immediately below Grand Marais; the bed of the Devil's Track River, Minnesota, for several miles from its mouth; and the islands off the harbor on the south shore of Michipicoten Island; (2) for the kinds carrying porphyritic orthoclase, but no quartz—the central area of the Porcupine Mountains, where much of the rock is of this character; the N. W. ¼ of Sec. 12, T. 37, R. 16 W., in the Clam Falls region, Polk County, Wisconsin; and the Minnesota coast, ten miles above the mouth of Split Rock River; (3) for the quartziferous kinds—the line of the Torch Lake Railroad, Keweenaw Point, Sec. 36, T. 56, R. 33 W.; the hill known as the "North Brother," near Rockland, Mich., N. E. ¼, Sec. 9, T. 50, R. 39 W.; the bold bluffs in the northern part of T. 49, R. 42 W., Mich.; the central area of the Porcupines, where, however, the prevailing rock is without porphyritic quartz; the bed of Potato River, S. E. ¼, Sec. 15, T. 46, R. 1 W., Wisconsin; the mouth of Tyler's Fork of Bad River, S. E. ¼, Sec. 17, T. 45, R. 2 W., Wisconsin; the islands off the north point of Beaver Bay, on the Minnesota coast; the Great Palisades, Baptism River point, and Red Rock Bay, all on the same coast; Bead Island at the mouth of Nipigon Straits on the Canadian coast; and the east shore of Michipicoten Island.

The detailed descriptions of the following tabulation cover a sufficient number of occurrences to substantiate the general descriptions above given. Other thin sections of these rocks are briefly described in connection with the detailed descriptions of Chapters VI and VII.[1]

[1] Mr. M. E. Wadsworth, who has described (op. cit., pp. 113–120) a number of these sections of pebbles of felsite and of the granite-like rocks which I describe below under the name of augite-syenite, was the first to note the occurrence of secondary quartz, and of an apparently spherulitic structure in these rocks.

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
1909..	Mount Houghton, Keweenaw Point.	W. line.	24	58	29 W.	Aphanitic; pink to brick-red; no visible porphyritic ingredients; very hard. SiO_2, 76.9 per cent. Difficultly fusible.	Much non-polarizing matter, through which are seen scattered, when viewed between the crossed nicols, minute bright points and lines; also a few relatively large, scattered nests of aggregated particles of quartz. The whole section is stained with red ferrite, which is also aggregated in numerous irregular, opaque particles.
1908..	Mount Houghton, Keweenaw Point.	W. line.	24	58	29 W.	Aphanitic; hard, light-pinkish; sharply angular fracture; no porphyritic ingredients. SiO_2, 77.2 per cent.	This section differs from the preceeding in containing much less red ferrite, and less non-polarizing matter; and in containing many polarizing particles often arranged in a felt-like mass. Many of the particles are plainly tabular feldspars.
1846*d*	Pebble from Eagle River conglomerate; mouth of Eagle River, Keweenaw Point.	NW.	19	58	31 W.	Matrix aphanitic, purplish-red, hard; abundant large black quartzes and flesh-red feldspars.	The matrix is much stained with red ferrite, and shows but feeble polarization in flocks of small particles; some small non-polarizing areas. In addition to the general red stain are abundant brown and black, opaque ferrite particles. Porphyritic quartzes large, in the usual doubly terminated crystals, with embayments and inclusions of the matrix. The porphyritic feldspars are oligoclase. Augite occurs also porphyritically in particles as large as the quartz, and with rounded contours; these augites are filled with a brown, ferritic alteration-product.
1838..	Torch Lake Railroad, Keweenaw Point.	S. part.	36	56	33 W.	Aphanitic; dark-red, hard; very abundant and large, black, porphyritic quartzes reaching two-tenths inch in diameter, and red feldspars two-tenths to one-quarter inch in length. Some of the feldspars are plainly striated. Resembles 1970 and 1846*d*.	Matrix irregularly mottled pink and nearly colorless, these mottlings being so arranged as to suggest flowage. The darker portions of the matrix are thickly studded with minute ferrite needles, so arranged as to emphasize the fluidal structure very strongly, especially in the neighborhood of the porphyritic quartzes. The darker portions of the matrix affect the polarized light only in a few minute points. The lighter portions, on the contrary, appear to consist of wholly individualized quartz and orthoclase confusedly intercrystallized. Calcite is also occasionally seen in these lighter por-

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
							tions. The porphyritic quartzes are very large and commonly much eaten, with the usual embayments and inclusions of the matrix. The feldspars are chiefly oligoclase, rarely orthoclase; both always much clouded from alteration. There are also present rare porphyritic augites, largely replaced by a black opaque substance. See Fig. I, Plate XII.
1970..	Pebble from the Calumet conglomerate, Keweenaw Point.		23	56	33 W.	Matrix dark reddish-brown, aphanitic; sharply angular conchoidal fracture; very abundant pink feldspars up to one-half inch in length, also black quartzes one-tenth to two-tenths inch in diameter; resembles 1846 *d*.	Differs from the preceeding only in having much less of the whitish individualized areas in the matrix, nearly the whole of which presents a brownish staining and produces no definite effect on polarized light. The ferrite needles are also somewhat more minute than in the preceeding section. One of the quartzes carries a sharply outlined, fresh, brilliantly polarizing augite crystal, the augite crystals of the matrix being wholly replaced by a blackish substance. See Fig. 2, Plate XII.
2514..	Porcupine Mountains, Michigan, 2000 N. 700 W.	N. line.	5	50	43 W.	Aphanitic; pale-lilac; no porphyritic ingredients.	Nearly colorless, faintly tinted with pink; minute tabular feldspars; some networked secondary quartz; some non-polarizing material; opaque ferrite particles not abundant.
2551..	Bed of Carp River, Porcupine Mountains, Michigan, 1420 N. 1400 W.	NW.	35	43	43 W.	Aphanitic; dark purplish-red; no porphyritic ingredients.	Blotched red and colorless; the reddish tinted portions chiefly non-polarizing, the white portions composed entirely of individualized, often relatively coarse quartz and orthoclase; networked secondary quartz rare; ferrite particles not abundant.
2574..	Porcupine Mountains, Michigan, 500 N. 1450 W.	SW.	20	51	42 W	Aphanitic; dark purplish-red; a few minute dark quartzes.	Thickly studded with minute brown ferrite particles, which are also aggregated into large patches; appearance in ordinary light pretty homogeneous. In the polarized light the matrix is seen to be completely saturated with secondary quartz, which presents itself in irregularly rounded areas each of which is a closely involved network of non-polarizing base and quartz. All of the quartz in one of these areas polarizing together, it follows that it all belongs to one individual. A few minute, altered porphyritic feldspars.

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
1247..	Bed of Little Carp River, Porcupine Mountains, Michigan, 1850 N. 600 W.	NE.	20	50	44 W	Aphanitic; dark purplish-red; some minute porphyritic quartzes and feldspars.	Matrix stained with ferrite, and saturated with secondary quartz as in the last described. There are also somewhat abundant larger quartz areas, apparently also secondary, besides which there are the usual sharply marked quartzes and feldspars, the latter much reddened and altered. Here and there a quite perfectly developed augite crystal is seen. The ferrite particles are arranged so as to indicate flowage.
1259..	Porcupine Mountains, Michigan, 270 W.	S. line	9	50	44 W	Aphanitic; bright-red very plainly banded with lighter shades; porphyritic white orthoclase rather abundant, often lying across two or three bands.	In the thin section the banding is seen to be produced by the presence of much oxide of iron in some bands and absence of it in others; the latter bands are also more highly crystalline, but all of the section presents an unusual quantity of individualized matter, apparently both quartz and orthoclase. The bands are non-continuous even in the breadth of a thin section.
1263..	Porcupine Mountains, Michigan, 200 W.	SE.	32	51	43 W	Aphanitic; dark-red closely banded with lighter red; no porphyritic ingredients.	In the thin section the lighter bands are seen to contain much more and relatively coarser secondary quartz than the other bands, which are in turn relatively rich in ferrite particles.
162 I.	Bed of Potato River, Ashland County, Wisconsin.	SE.	15	46	1 W	Aphanitic; pale lilac-tinted base, thickly studded with white porcellaneous crystals of feldspar reaching one-eighth inch in length, and smaller black glassy quartzes.	In ordinary light the matrix appears of a general gray color, with thickly scattered ferrite particles, which, for the most part transmit a reddish light, even when very thick. In polarized light this matrix appears to be saturated with networked quartz. The very abundant quartzes present all the usual characters. The feldspars are all turbid and appear to be wholly orthoclase. Some sections have the ferrite particles and the secondary quartz arranged in indefinite lines so as to suggest flowage.
37 I.	Mouth of Tyler's Fork, Ashland County, Wisconsin.	SE.	17	45	2 W	Much altered and softened, aphanitic, brick-red matrix, scattered through which are minute brighter red orthoclases and very abundant larger quartzes.	The base is like that of the rock last described, but is penetrated through and through by veinlets of quartz and calcite. The ferritic particles are more thickly crowded in the vicinity of the porphyritic ingredients, and now and then show a tendency to a linear arrangement. The quartzes are much eaten, and are penetrated to an

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
							extraordinary extent by club-shaped masses of the base. The orthoclases are very much reddened and kaolinized. Several inclusions of partially devitrified glass were found in the quartzes. A few porphyritic augites, largely altered to red iron oxide are contained.
809 S.	Clam Falls District, Polk County, Wisconsin.	NW.	12	37	16W	Aphanitic; pinkish-red matrix with minute feldspar faces.	The thin section shows a matrix completely saturated with a network of secondary quartz; the quartz network is coarser than usual. The porphyritic feldspars are wholly triclinic.
708...	North shore Lake Superior, two miles above mouth of Split Rock River, Minnesota.	NW.	13	54	9 W.	Aphanitic; brick-red, much decomposed and softened. Carries minute pink orthoclases.	Matrix largely of non-polarizing material stained red, and containing minute tabular crystals, also areas of secondary quartz. Confusedly intermingled with these deeper colored areas are lighter ones, occasionally colorless, in which there is a larger proportion of individualized material, apparently quartz. The section is dotted throughout with minute points of ferrite. The porphyritic ingredients are orthoclase and oligoclase in not very abundant, small, and much altered crystals, some of which present the appearance of having been much fractured before the solidification of the matrix.
711...	North shore Lake Superior, one-quarter mile east of 708.	NW.	13	54	9 W.	Light-red; obscurely banded with dark-red; aphanitic; subconchoidal fracture; carries abundant irregular, black, hair-like markings.	Similar to 708, but with very much more secondary quartz.
730...	Bed of Split Rock River, Minnesota.	NW.	1	54	9 W.	Aphanitic; dark red; conchoidal fracture; carries minute red feldspars.	Near to 708 and 711, with the red staining more general; in other words, there is but little of the lighter tinted, more individualized material; secondary quartz throughout in minute arborescent clusters.
790...	South shore of Beaver Bay, Minnesota.	SE.	12	55	8 W.	Aphanitic; light-gray, banded with non-continuous pinkish bands, the middle portion of each band being occupied by a quartz seam.	Colorless, merely varying in transparency. The more transparent portions, which are distinctly arranged in bands, are composed of quartz in relatively large areas. The clouded bands present, in the polarized light, a dark background, thickly crowded with minute polarizing points which are in

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
							part secondary quartz, but are not all evidently so; these bands also hold abundant minute opaque ferrites. In the transparent bands are quite large irregular patches of a yellowish-green material which might be altered augite or epidote, but which all remain dark between the crossed nicols throughout an entire revolution.
818...	Island on north side of Beaver Bay, Minnesota.	NE.	7	55	8 W.	Aphanitic; conchoidal; dark purplish-red, banded by indefinite waving bands of light-red. Porphyritic ingredients: quartz, very abundant in crystals one-tenth to one-twentieth inch in diameter, and pink feldspars one-twelfth inch in length. The feldspars tend to have their longer axes in the direction of the banding. SiO_2, 76.83 per cent.	Matrix nearly colorless, faintly tinted pinkish-gray, cloudy. In the polarized light this matrix is seen to be made up of individualized material, in large proportion, saturated with secondary quartz in an arborescent tracery suggestive of the most delicate frosting; the filaments of this quartz network polarize together in relatively large areas. Excessively minute, opaque ferrite particles abundant. Rare non-continuous bands composed of quartz particles, as in the last-described section, occur, and here again occurs the greenish-gray non-polarizing substance above described. Large-sized, doubly terminated, rounded quartzes are the chief porphyritic ingredients.
820...	Cedar Island, north shore Lake Superior, Minnesota.	NE.	7	55	8 W.	Matrix aphanitic, dark purplish-gray, blotched and banded with red; very abundant porphyritic pink feldspars one-tenth inch in length, and more minute quartzes. The arrangement of feldspars, and the fine red banding, indicate flowage.	Matrix very close to that of 818. The patches of the peculiar greenish-gray substance there described are here very plenty; they are often drawn out into long strings, and also occur in small particles dotted over the section so exactly in the manner and with the shapes of the usual ferrite particles, as to suggest the formation of the ferrites from them by alteration. Porphyritic ingredients: quartzes, with the usual characters and large and size; oligoclase. This rock and the two preceding are plainly nearer to the glassy condition than any others described in this list.
852...	North shore Lake Superior, Minnesota.	SW.	28	56	7 W.	Aphanitic, pinkish-violet; highly conchoidal fracture; no porphyritic ingredi-	Colorless, cloudy matrix, completely saturated with secondary quartz in a network coarser than usual; thickly scattered through this matrix are un-

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
						ents. This rock is thickly studded with brown and black, curving, hair-like markings. SiO_2 77.12 per cent.	usually large particles, and strings of particles, of red and brown ferrite. As already indicated, these strings of particles are sufficiently large to attract attention in the hand specimen. See Figs. 15, 16, Plate XIII.
853...	Same place as 852.	SW.	28	56	7 W.	Aphanitic; dark purplish-red and light pinkish-red, in intertwisted curving bands.	Colorless matrix, saturated with networked secondary quartz, and thickly studded with particles of red and black ferrite; the great abundance of these particles in portions of the section, and their nearly complete absence in others, produces a strong banding.
876...	Foot of north cliff of the Great Palisades; north shore Lake Superior, Minnesota.	NE.	22	56	7 W.	Matrix aphanitic; dark purplish-red closely banded with lighter tinted, non-continuous bands, and rows of lighter colored spots. White, kaolinized orthoclases one-tenth inch in length, are the most important porphyritic ingredients. More minute quartzes are abundant.	Matrix very strongly banded. The most abundant bands present a cloudy, gray appearance, and are seen in polarized light to be largely composed of non-polarizing matter, with which are abundant polarizing particles, some of which, at least, belong to secondary quartz. There are also present in these bands exceedingly minute particles of brown ferrite. Other bands are nearly colorless and transparent, and these are made up chiefly of individualized quartz. Still other bands present much of a brown, blotchy stain, and are thickly studded with long, black, ferrite needles. The needles are at times straight, but more often have a marked curvature; and, while they show a marked tendency to follow the general directions of the bands, they yet lie across one another in such a way as to suggest the appearance of a brush-fence (compare Zirkel, in Fortieth Parallel Report, Vol. VI). The narrow ones of these bands are not continuous even through the width of a thin section. All thicken and thin suddenly, and all are intertwisted in various curving forms, making abrupt turns when coming into contact with the abundant porphyritic quartzes and orthoclases. The bands containing ferrite needles are least continuous and are sometimes found making forms like the letter S within

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
							other bands. The whole appearance of this banded matrix plainly indicates movement while in a fluid condition, and is much the same as commonly observed in the modern rhyolites. The porphyritic quartzes and feldspars present the usual characters, the quartzes carrying often the usual embayments of the matrix, as also well-marked, partially devitrified, doubly terminated glass inclusions. See Figs. 3, 4, Plate XII; also Figs. 9, 10, 11, 12, Plate XIII.
902...	North shore Lake Superior, one mile below mouth of Baptism River, Minnesota.	SE.	11	56	7 W.	Close to 876. The porphyritic white kaolinized feldspars are very abundant. The arrangement of these feldspars and of the lighter material in the matrix tends to produce curving lines.	In the thin section the faint white banding noted macroscopically is seen to be produced, as usual, by the presence in these bands of relatively coarse quartz and their comparative freedom from the red stain which affects the rest of the rock. The usual excessively fine quartz network affects the whole rock, and in all portions, except the lightest-colored bands, the usual brown, opaque ferrites are abundant. The porphyritic quartzes and orthoclases present no unusual characters; the former show very large, doubly terminated glass inclusions (negative crystals). See Figs. 6 and 8, Plate XIII.
988...	North shore Lake Superior; bay below Grand Marais, Minnesota.	SW.	21	61	1 E.	Aphanitic; red, blotched with yellowish-white; no porphyritic ingredients, but minute flashing points, due to the secondary quartz, may be seen in a bright light. The rock is much altered and softened and comes out in sharp-edged tabular fragments.	In the thin section this rock is seen to be completely saturated with the usual quartz network, but shows also numerous polarizing particles, apparently independent of the secondary quartz. Red stain and ferrite particles rather less abundant than usual.
1539..	Red Rock Bay, Indian Reservation, north shore Lake Superior, Minnesota (not surveyed).	about	35	63	5 E.	Aphanitic; flesh-red; porphyritic red feldspars and black quartzes.	In the ordinary light the matrix of this rock is only faintly stained, and is peculiar from being strewn with irregular greenish blotches. In the polarized light the nearly colorless back-

Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

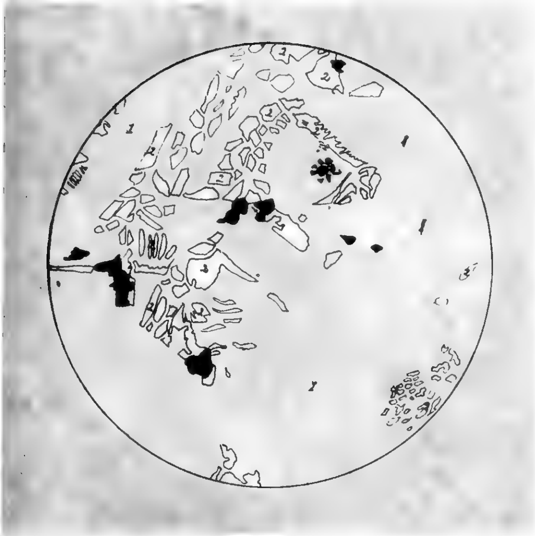
Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
							ground shows only the usual excessively fine quartz network, while the green blotches remain in large measure dark throughout an entire revolution. Porphyritic orthoclases are of very large size, red-stained and deeply eaten into by the matrix. The porphyritic quartzes present no unusual characters.
1540..	North shore Lake Superior, Minnesota, 200 paces east 1539.	About.	35	63	5 E.	Aphanitic; dark purplish-red. Very abundant, much altered red feldspars, up to one-half inch in length; also quartzes one-twentieth inch in diameter. Comes out in thin tabular fragments.	In the ordinary light a matrix much like the lighter portions of 1539, except that red and brown ferrites are thickly clustered in some portions. In the polarized light the distinction between the quartz network and other independently polarizing particles is plainly seen.
1728..	North shore Lake Superior; north side Bead Island, mouth of Nipigon Straits, Ontario, Canada.					Matrix dark purplish-red, aphanitic; porphyritic, flesh-colored feldspars, one-quarter to one-half inch long, extraordinarily abundant; quartz also very abundant, rarely exceeding one-tenth inch in diameter. Resembles 1838, 1846*d*, 1970, and Michipicoten 11.	In the ordinary light the matrix presents throughout a deep reddish-brown stain, produced by thickly-crowded ferrite particles, which, in the immediate vicinity of the porphyritic ingredients, present some indications of a fluidal texture; but, for the most part, the matrix is without such an appearance. In the polarized light the matrix is for the most part dark, presenting only very minute, feebly-polarizing particles. The usual quartz network appears to be entirely wanting. The quartzes are much eaten, which is also the case with the porphyritic feldspars. See Figs. 4, 7, Plate XIII.
1728 *b*	A few hundred yards east of 1828, the same rock-mass.					Matrix brick-red, banded with vaguely defined bands of lighter and darker red. The feldspars are less abundant than in 1728, and are whitish and porcellaneous from alteration.	Close to 1728, but in the polarized light the background presents more indications of individualization and is peculiar for its curvilinear clusters of ferrite particles. The quartzes are extraordinarily large and abundant, and are eaten by the matrix into many peculiar forms. See Figs. 1, 2, 3, Plate XIII.

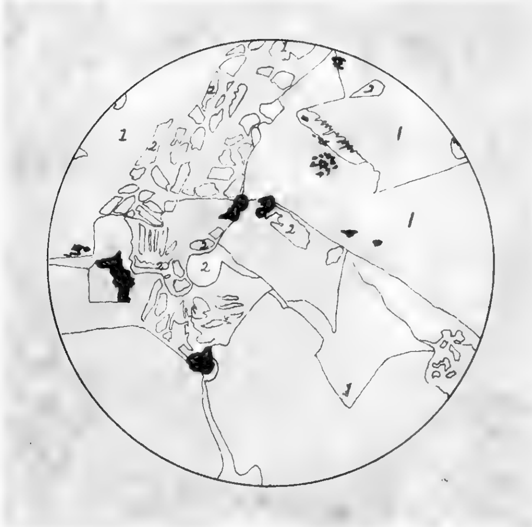
Tabulation of the results of a microscopic study of the felsites and felsitic porphyries of the Keweenaw Series—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions of thin sections.
(*)	East side Michipicoten Island.					Matrix dark purplish-red, aphanitic; porphyritic quartzes extraordinarily abundant, often reaching two-tenths inch in diameter. Red porphyritic feldspars also very abundant, two-tenths to three-tenths inch in length. Close to 1838, 1846*d*, 1970, and 1728.	The groundmass of this rock is faintly pinkish-tinted and cloudy; it contains numerous very minute ferrite particles, which, in the vicinity of the porphyritic ingredients, show crowding and a tendency to linear directions. In the polarized light the matrix shows a dark background strewn with particles and flocks of particles of feebly doubly refracting substances, but only rarely a distinctly recognizable quartz network. The porphyritic quartzes are very large and abundant, and much eaten. The feldspars are also unusually large, are both orthoclase and oligoclase, and are also much altered. See Fig. 5, Plate XIII.
(†)	Islands off harbor, south side of Michipicoten Island.					Aphanitic; light flesh-red; very rough fracture; resembles the rock from Mount Houghton, Keweenaw Point.	The groundmass is nearly colorless, cloudy, and thickly dotted with very minute ferrite particles, which are at times aggregated into waving lines. In the polarized light feebly polarizing flecks dot a dark background, some of which are recognizable as quartz network clusters. No porphyritic ingredients in the section.

*Macfarlane's Michipicoten Col. No. 11. "Felsite porphyry." Rep. of Progress, Geol. Sur. Canada, 1863-1866, p. 142.
† Macfarlane's Michipicoten Col. No. 13. "Trachytic phonolite." *Ibid.*, p. 142.

Augite-syenite and Granitell.—Occurring abundantly as pebbles and boulders in the Keweenawan conglomerates; in great irregular mountain masses in the lower part of the series; and again, in plainly intersecting masses, and even in thin seams in the coarse gabbros lying near the base of the series, on both north and south sides of Lake Superior—are found flesh-red to brick-red rocks, which present a plainly, and often quite coarsely crystalline structure and general granitic appearance. Red feldspars, unstriated alone, or both unstriated and striated together, appear always to make up the bulk of these rocks, and quite commonly are the only macroscopically recognizable ingredients. Quartz, however, is often visible, and especially in the more coarsely grained and more strongly granite-like





Figs 1 and 2 from Eagle Mountain, Cook County, Minn. Fig. 1 ordinary light. Fig. 2. polarized light. Scale 35 diameters.
Orthoclase (1) crystals, saturated with corrosion quartz (2). Fig. 2 is designed to show how numbers of neighboring quartz areas polarize together

Fig. 3. from vein in gabbro, Rice Point, Duluth, Minn.
Ordinary light. Scale 25 diameters.
Orthoclase decomposed, reddened by iron oxide, and saturated by secondary quartz.

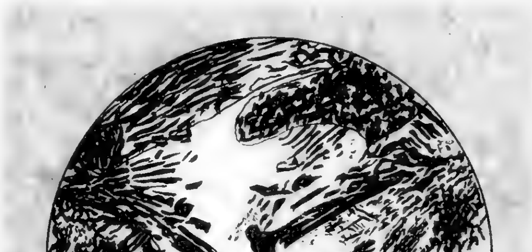
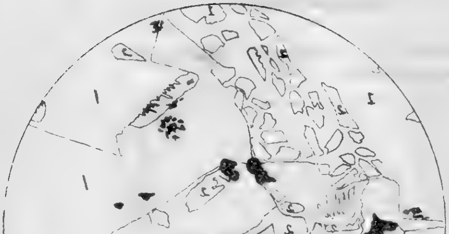


Fig. 4. from large area of red rock in the gabbro of Duluth Minn. Polarized light. Scale 25 diameters
Orthoclase decomposed and saturated with corrosion quartz, the numerous areas of which belong to only six individuals



Figs 1 and 2 from Eagle Mountain, Cook County, Minn. Fig. 1 ordinary light. Fig. 2 polarized light. Scale 35 diameters.
Orthoclase(?) crystals saturated with corrosion quartz(?). Fig 2 is designed to show how numbers of neighboring quartz areas polarize together

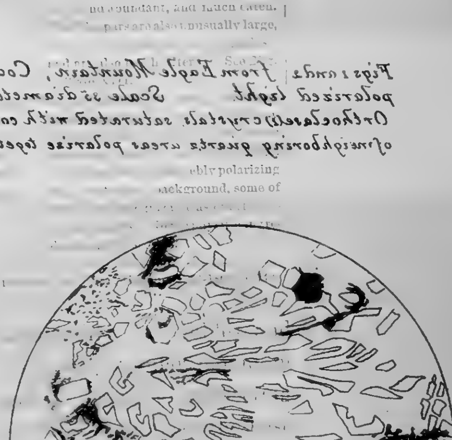


Fig. 3. from vein in gabbro, Rice Point, Duluth, Minn.
Ordinary light Scale 35 diameters.
Orthoclase decomposed, reddened by iron oxide, and saturated by secondary quartz.

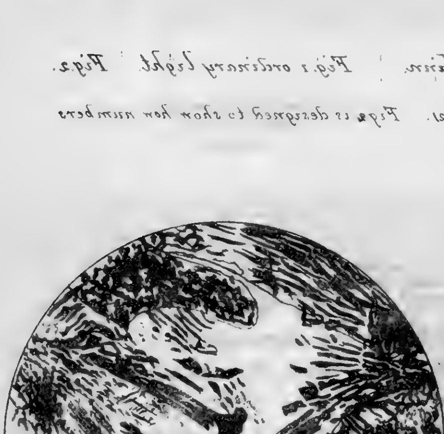
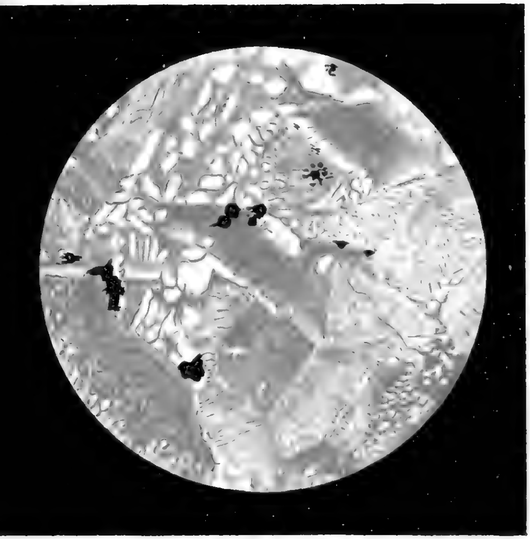


Fig. 4. from large area of red rock in the gabbro of Duluth Minn. Polarized light. Scale 35 diameters
Orthoclase decomposed and saturated with corrosion quartz, the numerous areas of which belong to only six individuals



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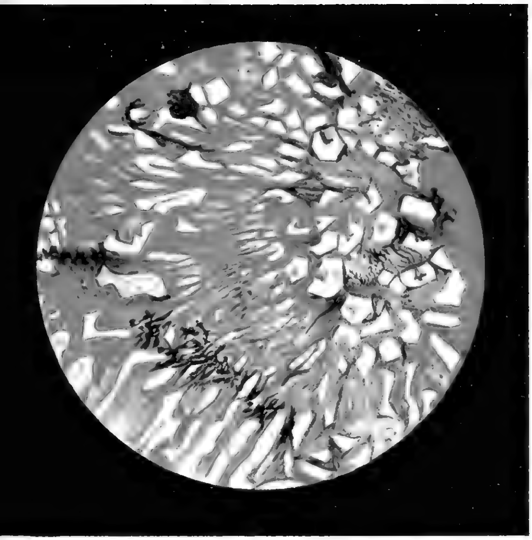

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GRANITIC PORPHYRIES ([illegible])

kinds. In some kinds blackish and greenish-black points dot the rock rather sparsely, while occasionally a greenish substance is coarse enough to be recognizable as softened hornblende or augite. With diminishing coarseness of grain, there comes to be present in these rocks more or less of a matrix whose crystalline structure is not macroscopically recognizable, when there appears to be a passage towards the uncrystalline felsites above described. An increasing amount of the softened greenish mineral, along with an increasing amount of striated feldspar, accompanies in other varieties what appears macroscopically to be a passage toward the orthoclase-gabbros of the preceding part of this chapter.

Under the microscope, as to the naked eye, these rocks are always found to be chiefly made up of the feldspars. These feldspars include, in most cases, a triclinic kind as well as the predominating orthoclase. In a few sections no plagioclases were recognized, but this may have been simply on account of their great alteration. The polarization angles obtained, and the general appearance of these plagioclases prove them to be oligoclase, or low down in the labradorite range. The feldspars are always turbid, and commonly also highly charged with red iron oxide. In the larger number of sections the feldspar crystals are charged also with secondary quartz, which occurs either in rows of club-shaped or "graphic" particles, which often follow the cleavage directions of the crystals, or in very fine lines radiating in fan-shape from a central line. As in the secondary quartz of the above-described felsitic porphyries, so also here, large clusters of adjacent and apparently separate particles are found to polarize together. In this case, however, it is the particles belonging to one feldspar crystal which are thus similarly oriented. Particles and needles of brown and black ferrite are also often present in these altered feldspars, and often arranged in the radial fashion just mentioned as showing in the quartz.

In the case of the radiating quartz and ferrite clusters, it is often difficult to tell if we are dealing with an alteration of a feldspar crystal or of unindividualized matrix, but in so many cases is it evident from the polarization effects that this alteration has progressed in orthoclase crystals, that it is reasonable to assume that the same is true for other sections presenting a similar appearance. This quartz saturation varies in extent, but is present in all sections examined. It is a curious fact that, although it has been found affecting the outer borders of the plagioclases, these are for the most part free from the quartz saturation. In many cases it is evident from the existence of a regularly outlined core without quartz within the feldspar crystal, and of an outer border, of greater or less width, saturated with quartz, that the replacing process has gone on from without, inwards. In other cases, again, the feldspar crystals have plainly been more or less shattered into fragments, and cracked across, before the deposition of the quartz.

In those kinds which macroscopically are especially granite-like, showing large feldspar and quartz areas one-twentieth to one-fifth inch across, the larger quartz areas appear much like the quartz of true granite, filling, as in granite, the spaces between the feldspars. But the same sections sometimes show the saturating, club-shaped, secondary quartz along with these larger interstitial quartz areas, and then the larger areas often polarize together with a number of the smaller, undoubtedly secondary ones in the immediate vicinity, in which case all must be taken as secondary. In some sections of these coarser rocks, however, none of the plainly secondary saturating quartz is found in the feldspars, and then it cannot be shown that the coarse quartz is not an original ingredient. In the figures of Plates XIV and XV, I have attempted to illustrate the occurrence of the secondary quartz of these rocks. Figs. 1 and 4 of Plate V, and Figs. 13, 14, 15, 16 of Plate XIII, showing secondary quartz as characterizing the already described orthoclase-gabbros and felsitic porphyries, should be referred to for comparison.

About two-thirds of the sections show sparsely scattered augite crystals, which present the same peculiar red and brown to black ferritic alteration that characterizes the augites of the felsitic porphyries, as above described. The unaltered augite is commonly present only in cores. A very few sections show, instead of the augite, a fibrous green hornblende, whose uralitic nature is extremely probable. Titanic iron or magnetite occurs in two or three sections.

A perusal of the following tabulation of observations on these rocks will serve to make it plain that they present a tendency to graduate in four

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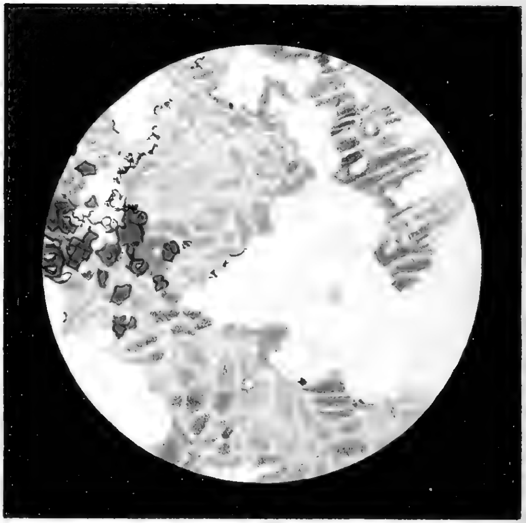

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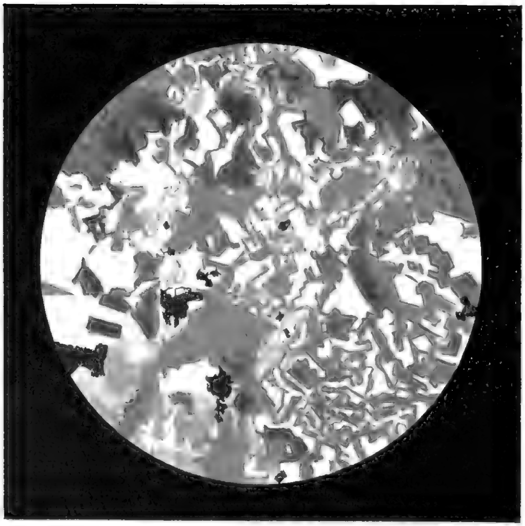

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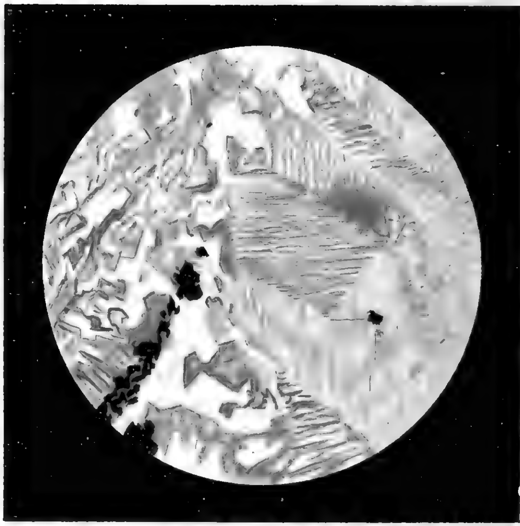

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A. Hoen & Co. Lith. Baltimore

AUGITE-SYENITES

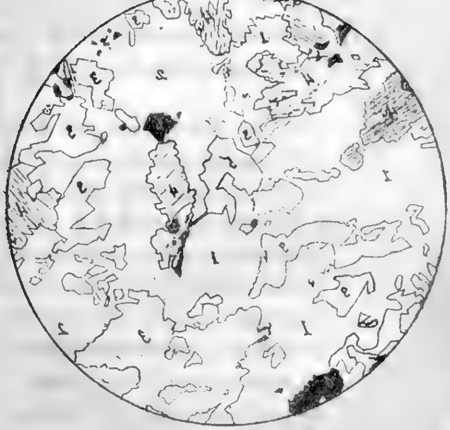

Fig 1 Uralitic augite-syenite. Duluth, Minn. Ordinary light. Scale 20 diameters.
Orthoclase(1) and oligoclase(2) saturated with secondary or corrosion quartz(3), which sometimes forms large areas; uralite pseudomorphs(4) after augite; chlorite(5), magnetite(6).

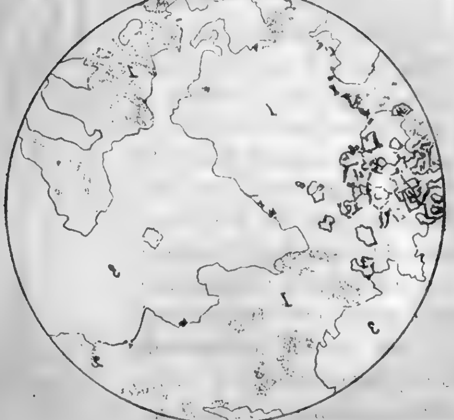

Fig 2 Augite granitell from the north shore of Lake Superior. Sec. 32, T61, R7W Minn. Ordinary light. Scale 10 diameters.
Orthoclase(1) and oligoclase(2) much altered; quartz possibly in part primary(3) green alteration product of augite(4) in clusters between the larger feldspars.

Fig 3 Granitic porphyry from Ironton Trail, Ashland County, Wis. Ordinary light. Scale 25 diameters.
Reddened feldspars(1) saturated with secondary quartz(2), magnetite(3); greenish alteration product(4).

Fig 4 Augite-syenite from pebble in conglomerate, Mt Bohemia, Keweenaw Point, Mich. Ordinary light. Scale 25 diameters.
Orthoclase(1)(twinned) and labradorite(2) both saturated with secondary quartz arranged in fine lines(3a) and irregularly outlined areas(3b), ferritic alteration(4) of augite.

Fig. 1. Uralitic augite-syenite. Duluth, Minn.
Ordinary light. Scale 20 diameters.
Orthoclase(1) and oligoclase(2) saturated with secondary or corrosion quartz (3), which sometimes forms large areas; uralite pseudomorphs (4) after augite; chlorite (5), magnetite (6).

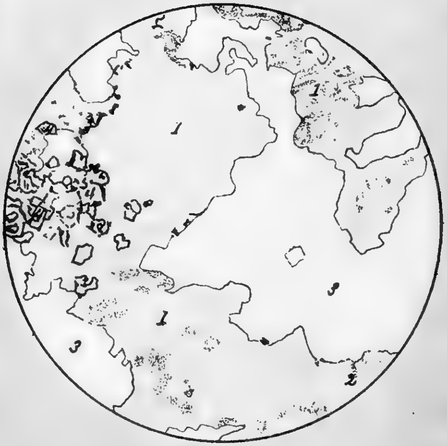

Fig. 2. Augitic granitell from the north shore of Lake Superior. Sec. 32, T. 56, R. 7 W. Minn. Ordinary light.
Scale 10 diameters
Orthoclase(1) and oligoclase(2) much altered; quartz possibly in part primary; green alteration product of augite (4) in clusters between the larger feldspars.

Fig. 3. Granitic porphyry from Ironton Trail, Ashland County, Wis. Ordinary light. Scale 27 diameters
Reddened feldspars(1) saturated with secondary quartz (2), magnetite (3); greenish alteration product (4)

Fig. 4. Augite-syenite from pebble in conglomerate, Mt. Bohemia, Keweenaw Point, Mich. Ordinary light.
Scale 27 diameters.
Orthoclase (1) (twinned) and labradorite (2) both saturated with secondary quartz arranged in fine lines (3a) and irregularly outlined areas (3b); ferritic alteration (4) of augite

different directions, viz: toward orthoclase-gabbro and the non-quartziferous porphyries on the one hand, and toward granite and the quartziferous porphyries on the other.

I have been somewhat at loss for a name for these rocks. In 1878 Pumpelly designated as "granitic porphyry" one or two specimens of a red rock, sent him by the Wisconsin Survey, but according to Rosenbusch and the accepted nomenclature generally, a granitic porphyry is a rock with a finely crystalline admixture of the usual granitic minerals—quartz, orthoclase, plagioclase and mica or hornblende—with porphyritically developed feldspar and quartz, and thus stands between the true granites and the felsitic porphyries. But all of the rocks under consideration in which the quartz is wholly secondary are essentially, or were, before the deposition of the secondary quartz, aggregates of feldspar crystals, with the orthoclase predominating. The altered augite is the only other ingredient worthy of any consideration in determining on a name for these rocks, while it is always so subordinate as to be hardly more than an accessory, and from about a third of the sections is entirely absent. Regarding it as an essential ingredient, and the quartz in most cases as a secondary product, resulting from the leaching of the original feldspar mass, these rocks are nearer to the "augite-syenite" of Rosenbusch than to any other previously described species among the pre-Tertiary rocks. The kinds in which the quartz is possibly primary would be then "augite-granite" or "granitell," but no exact provision is made for these rocks in any system of nomenclature.[1]

As typical instances of the occurrence of these rocks may be mentioned the pebbles of a conglomerate at the south foot of Mount Bohemia, Keweenaw Point, apparently included in the Eastern Sandstone; the irregular masses apparently intersecting the orthoclase-gabbro of Mount Bohemia itself; many pebbles of the conglomerate at Eagle River, Keweenaw Point, where are found both fine-grained and coarse granite-like kinds; the prevailing pebbles of the Albany and Boston conglomerate near Portage Lake; the irregular masses intersecting coarse olivine-gabbro at a number of points in the gabbro belt of the Bad River region of Wisconsin;[2] the

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[1] "Granulite" of Rosenbusch is without plagioclase, or the term might be used for the kinds almost free from augitic ingredient, and rich in large quartzes.

[2] See Plate XXII of this volume, and also Geology of Wisconsin, Vol. III, pp. 45, 195.

irregular masses and thin veins intersecting the coarse orthoclase-gabbro of Duluth, Minnesota; the great granite-like mass constituting the bold red point three miles above the mouth of Split Rock River, on the Minnesota coast; the similar mass on the same coast forming the south point of Beaver Bay; the bold point on the shore of section 32, township 56, range 7 west; the intersecting masses on the same coast two miles below the mouth of Baptism River; and the great mountain mass forming Eagle Mountain, Minnesota, thirty miles back from the lake coast.

Tabulation of the results of a microscopic examination of augite-syenites and granitells of the Keweenaw Series.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i\bar{i}$. Angle on opposite sides of cross-hair.		Whole angle.
								°	°	°
1903 A	Pebble from conglomerate at south foot of Mount Bohemia, north shore of Lac La Belle, Keweenaw Point, Michigan.	NE.	32	58	29 W.	Minutely crystalline; pinkish-red, mottled with minute green spots; epidote in seams; pinkish feldspars are plainly recognizable as the principal ingredient.	Appears to be chiefly made up of orthoclase and plagioclase crystals saturated with secondary quartz, which is arranged in two ways: 1st. In relatively coarse particles shaped like the quartzes of graphic granite. These particles commonly polarize in clusters; they are plainly separate from one another in the thin section, and therefore present quite a contrast with the networked quartz so commonly found in the matrices of the felsitic porphyries. 2d. In excessively fine radiating lines, diverging usually not from a point, but from a line, producing thus a fan-like arrangement. This fan-like appearance is also brought out by the arrangement of the minute ferrite particles, by which all of the rock, except the large quartzes, is stained. That the original rock was entirely made up of relatively coarse crystals is an	25 21 19 18 19 17 20	25 21 21 14 24 16 21	50 42 40 32 43 33 41

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : ii$. Angle on opposite sides of cross-hair.		Whole angle.
								°	°	°
							inference from the fact that there is in the most deeply decomposed places a tendency to polarize in large areas; it is not impossible, however, that this appearance is due to the polarization of the finer secondary quartz, and that these areas are merely quartz-saturated matrix, whose original spherulitic structure has produced the radial arrangement of much of the secondary quartz. The plagioclases give angles rather low in the labradorite range. Where still recognizable as plagioclase they never contain any secondary quartz. Besides the finer ferrite particles, there are clusters of coarse opaque black particles—some of which may possibly be magnetite—which, from their having associated with them brightly polarizing augite particles, may be regarded as alteration-products from augite. Little seams and nests of secondary calcite are here and there seen, and, with the calcite, occasionally particles of epidote. Brilliantly polarizing epidote-like particles are also seen dotting the plagioclases, as if from their alteration.			
1864 C	North shore Bête Grise Bay, Keweenaw Point, Michigan. Conglomerate pebble from Eastern Sandstone.	Near north line	35	58	29 W.	....	Closely similar to the section last described except in containing less red staining matter.	5 3 8	4 5 12	9 8 20

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ī. Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
1846 *b*	Pebble from Eagle River conglomerate, Keweenaw Point, Michigan.	NW.	19	58	31 W.	Finely crystalline; pinkish-gray; shows abundant feldspar facets and also dark greenish particles.	Closely similar to the two preceding. The still recognizable plagioclases are large and abundant, and some of them contain unmistakably the graphically arranged secondary quartz. Irregularly outlined augites, largely altered to ferrite, are not unfrequent. There is but little red stain, but ferrite needles of some size are rather abundant and always arranged in a sort of rude parallelism to the lines of the finer secondary quartz.	15 14 12 20 24	13 15 15 19 31	28 29 27 39 55
1846 A	Pebble from Eagle River conglomerate, mouth of Eagle River, Keweenaw Point, Michigan.	NW.	19	58	31 W.	Medium to fine-grained; pinkish; granite-like.	Made up chiefly of orthoclase and quartz, with rarer oligoclases. There is very little quartz which from its arrangement can be regarded as secondary, and none whatever of the fine radiating quartz characteristic of the preceding rocks. A few large-sized clusters of red and black ferrite, associated with brightly polarizing particles, are seen; they are supposed to represent altered augites. Here and there calcite fills spaces between the other ingredients. Though presenting some important differences from the previously described sections, its mineralogical composition and general appearance are strongly suggestive of its close affinity to them. It is a rather fine-grained granite or granitell.	7 18 13	4 13 11	11 31 24
1781 *b*	Pebble from the Albany and Boston conglomerate, Keweenaw Point, Michigan.	NW.	8	55	33 W.	Minutely crystalline; dark-brown, mottled with red; abundant evident feldspar facets.	Close to 1903 A, 1864 C, and 1846 *b*. In this section there is an evident gradation from the coarser graphically arranged secondary quartz to the finer kinds; while coarse	11 9	18 13	29 22

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ıī. — Angles on opposite sides of cross-hair.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ıī. — Angles on opposite sides of cross-hair.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ıī. — Whole angle.
								°	°	°
							and fine frequently polarize together in large clusters. It also appears evident in this section that the fine radially arranged quartz affects, in part at least, original crystals.			
1781 *d*.	Pebble from Albany and Boston conglomerate, Keweenaw Point, Michigan.	NW.	8	55	33 W.	Fine-grained; highly crystalline; dark brick-red; appears to be entirely made up of minute red feldspars.	Appears to have been originally chiefly made of feldspar crystals, in part triclinic, with possibly also some finer matrix material. The crystals are now, however, all much dulled and altered, and more or less blotched with iron oxide. In many crystals long, brownish ferrite lines follow the cleavage directions. An excessively fine secondary quartz fills some of the feldspars, corners between which are sometimes occupied by coarser particles of quartz; but large parts of the section are singularly free from the usual quartz saturation. Clusters of opaque black and brownish particles, with now and then a brightly polarizing core, represent augites.	5 4	7 6	12 10
502...	Duluth, Minn. From red vein 12 inches wide cutting coarse gabbro, Rice Point quarry.	NW.	34	50	14 W.	Flesh-red; highly crystalline; medium-grained; pinkish feldspar facets predominate.	Appears to have been originally made up entirely of feldspar crystals; but these are now completely saturated with secondary quartz in unusually coarse particles, arranged in a graphic form. See Figs. 3 and 4, Plate XIV.			
517...	Area of red rock in coarse gabbro, Duluth, Minn.	NW.	27	50	14 W.	Highly crystalline; medium-grained; red, mottled with green.	A granite-like rock, in which the chief ingredients are reddened feldspars and quartz. The quartz is in relatively large areas, filling spaces between the feldspars; but in the neighborhood of the larger areas, saturating the feldspars,			

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i\bar{i}$. Angles on opposite sides of cross-hair.		Whole angle.
							is a quartz in smaller areas, which is plainly secondary. Since large and small quartzes frequently polarize together, it is plain that all must be taken as secondary. A very few of the feldspars show banding in the polarized light. There are also present good sized pale-greenish, strongly dichroic, much shattered hornblendes, which often present much the appearence of uralite. Titaniferous iron and apatite are not uncommon ingredients, and the whole aspect of the rock suggests the possibility of its being an orthoclase-gabbro, in which the uralitic alteration of the hornblende and the deposition of secondary quartz have been pushed to an extreme. (Compare the description of pp. 50–56. See also Fig. 1, Plate XV.)	°	°	°
3055...	Mouth of Tischer's Creek, north shore of Lake Superior, Minnesota.	SE.	13	50	14 W.	Red; earthy; shows occasional feldspar facets, but is for the most part without crystalline structure; minute nests of quartz abundant; very rough fracture.	In the ordinary light the thin section presents a red-stained background, which is completely riddled by very coarse secondary quartz in such a manner as to suggest for parts of the section a complete shattering before the deposition of the quartz. The uncrystalline appearance of the red matrix in the ordinary light, and the networked arrangement of much of the quartz, suggest that this rock might more properly be included among the felsitic porphyries; but in the polarized light a considerable proportion of the background resolves itself			

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : ii$. Angles on opposite sides of cross-hair.		Whole angle.
							into fragments of orthoclase crystals. Another portion of the background, however, presents no appearance of crystalline structure; but has, throughout, a real or apparent spherulitic structure, brought out by the radiation of minute quartz veinlets and by lines of minute ferritic particles. Although much of the quartz is coarse enough to be seen with the naked eye, none of it is porphyritic, but all secondary. In this rock we have evidently a transition phase between the felsitic porphyries and the more completely crystalline granitic porphyries, or granitells.	°	°	°
762....	North shore of Lake Superior, three miles below the mouth of Split Rock River, Minnesota.	NE.	33	55	8 W.	Highly crystalline; rather coarse-grained; flesh-red; granite-like. Feldspar and quartz both easily recognizable to the naked eye.	With the exception of some rare magnetite areas, this rock is completely made up of pinkish, turbid, rather large-sized orthoclase and oligoclase and quartz. The quartz makes up fully half of the section, and is often in areas one-twentieth to one-tenth inch in width; it is, however, wholly secondary, the coarsest portions often penetrating deeply into the mass of an orthoclase crystal. Several of the large feldspar crystals were observed to have cores whose outlines form abrupt limits, beyond which the secondary quartz does not pass, a fact suggesting the decomposition and corrosion of the feldspar before the advent of the secondary quartz.	6 6	5 7	11 13

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Microscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone *O: ii.* Angles on opposite sides of cross-hair.		Whole angle.
								°	°	°
791 and 787.	North shore Lake Superior, Minnesota, south point of Beaver Bay.	SE.	12	55	8 W.	Pale flesh-red; medium to fine-grained; a large proportion of the rock appears to be made up of pinkish feldspars.	The thin section is made up chiefly of much dulled and clouded feldspars, a few of which are obscurely banded. Quartz occurs in little particles, filling corners, and in some few places is plainly secondary, but on the whole it is much less abundant in this section than in most of those previously described. There are areas in the section which present a cloudy, red-stained appearance, which may be either much altered feldspars or felsitic matrix. Magnetite is rather coarse and abundant for this class of rocks.	5 1	3 2	8 3
835.	North shore of Lake Superior, Minnesota.	NE.	32	56	7 W.	Medium-grained; flesh-red; granite-like; quartz and feldspars both plainly recognizable to the naked eye.	The thin section is close to that of 762, consisting for the most part of coarse, turbid, pinkish-stained feldspars and clear quartz. The feldspars show in large part a fine lineation in the polarized light, and give the low polarization angles of oligoclase. Probably half of the feldspars are, however, orthoclase. The feldspar crystals are always of quite large size, measuring often one to two inches in width. The quartz is not so coarse, but still is in very large particles for this class of rocks, and enters the feldspar in such a way as to render certain its secondary origin, or at least its deposition after the feldspars had become thoroughly eaten and honeycombed. There are one or two places in the section	3 11 14	4 13 13	7 24 27

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Microscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone $O : i\bar{i}$. Angles on opposite sides of cross-hair.		Whole angle.
							where a finer material, apparently feldspathic in its nature, has mingled with it numerous particles of brightly polarizing augite. Several other similar places present, in place of the augite, greenish particles, which revolve dark between the crossed nicols, and which are probably an alteration-product of augite. There are also small augites filling corners between coarser ingredients, and even in places lying directly within the feldspars. The quartz is thickly crowded with cavities, many of which hold a bubble-bearing fluid.	°	°	°
1035...	Near Baptism River, Minnesota.	S. line S. E. ¼	7	57	7 W.	Fine-grained; highly crystalline; flesh-red; appears to be mostly made up of red feldspars.	Appears to consist entirely of feldspar crystals, stained a deep-red with oxide of iron and completely saturated with "graphic" secondary quartz. The quartz particles frequently follow the cleavage lines of the feldspars; and even when not doing so, always show a tendency to a common direction within one feldspar crystal, which usually differs from the directions in the adjacent crystals. Some black, opaque clusters, including brightly polarizing particles, probably represent altered augite. None of the feldspars are recognizable as triclinic, but several show the characteristic twinning of orthoclase.			

Tabulation of the results of a microscopic examination of augite-syenites, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic characters.	Microscopic descriptions.	Angle between maximum extinctions of adjacent hemitropic bands of the plagioclase in sections cut at random in the zone O: ii.	
								Angles on opposite sides of cross-hair.	Whole angle.
1067...	Eagle Mountain, Minnesota (township not subdivided).	about	23	63	2 W.	Fine-grained; highly crystalline; brick-red; blotched with gray and black; appears to be chiefly made up of minute red feldspars.	Resembles closely the last section described, except that there are some coarser clusters of quartz which are plainly connected with that which saturates the feldspars. The latter attains, in this section, an extreme and most beautiful development. It often follows the cleavages in a most regular manner, and again forms groups of diverging lines. The tendency seems to be for each quartz particle to have one narrow or even-pointed end, while the other is broad, club-shaped, or even hooked. The deposition of this secondary quartz has plainly been from without inward in each feldspar crystal. This is evidenced by its common greater abundance and coarseness in the outer portions of the crystals, some of the feldspar crystals being provided with a core, in which there is no quartz. This core, when present, has linear outlines parallel to the sides of the original crystal.		
1520...	North shore of Lake Superior, one mile above the mouth of Maw-ske-quaw-caw-maw River.	SW.	12	62	4 E.	Brick-red; minutely crystalline; appears to be made up of minute red feldspars; crossed by parallel black stripes of relatively large size.	Allied to the last two described. It contains also long needle-shaped crystals of augite, largely altered to greenish and opaque ferritic substances; numbers of these needles are parallel and appear to be parts of one original crystal.		

Granite.—In the third volume of the Geology of Wisconsin, I have spoken of granite as occurring in intersecting masses in the coarse gabbros which form the base of the Keweenaw Series in that region, as also in the immediately underlying mica-schists of the Huronian; and a number of these granitic areas were mapped on the accompanying atlas plates. This granite[1] is there described as a red biotite-granite, with orthoclase and liquid-bearing quartz as the chief constituents, and with mica, rarer white plagioclase and still rarer apatite and magnetite, as subordinate constituents. For the sections examined this description is entirely correct; but most of these few sections were from the granites of the underlying Huronian. For the present memoir I have had a number of new sections cut, and find that the granites cutting the Keweenawan gabbro are more often hornblendic than micaceous, and that all of these granites, including those of the underlying Huronian, are very closely allied to the coarse-grained granitoid rocks of the immediately preceding tables, from which they merit separation only from their relatively large content of the hornblendic or micaceous ingredient. The hornblende of these rocks is of the basaltic variety, with an intensely deep-brown color and very strong dichroism. Here and there an augite core is to be noticed in the hornblende, which is thus plainly a secondary product. It is always in regularly outlined crystals. The feldspars are always much reddened and altered, and were evidently much shattered and corroded before or during the deposition of the quartz. The latter ingredient is very abundant, crowded with liquid-filled cavities, many of which carry a minute salt cube, and while not certainly a secondary product, was subsequent, as just stated, to much breaking and honeycombing of the feldspars. Besides the very coarse and more abundant quartz areas, there are in some sections aggregates of numerous little particles between the coarser constituents, and it is mingled with these finer quartz particles that the minute biotite flakes are found in those sections carrying this mineral.

Although, as already said, so closely allied to the augite-syenites and augite-granites, or granitells, of the preceding tables, rocks so completely granitic in character as these have not been observed elsewhere in the Keweenaw Series.

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[1] *Op. cit.*, p. 193.

SECTION III.—SUMMARY VIEW OF THE ORIGINAL ROCKS OF THE KEWEENAW SERIES.

To any one who will read through the foregoing part of this chapter it will become evident that between the several kinds of original rocks described there are no sharp lines, and that there is, in fact, a continuous series of kinds, from the most basic to the most acid. It will also become evident that, from the necessity of following some accepted nomenclature, it has been unavoidable to use names which cover very different ranges of acidity. In the following table an attempt is made to classify the various rocks with reference to silica content, as well as to texture and mineralogical composition, and thus to bring out more plainly than has been done in the preceding pages the relations of the different kinds to one another. The references B 1, A 1, &c., are to the several classes of basic and acid rocks, respectively, as given on pages 37 and 91.

Summary tabulation of the eruptive rocks of the Keweei

		Coarse-granular kinds.		Fine-granular kinds.
BASIC KINDS. Silica 45 to 52 per cent.	Silica 45 to 48 per cent.	*Olivine-gabbro* (B 1). Olivine. Anorthite. Diallage. Titaniferous magnetite.	Grading by increasing fineness of grain and loss of diallagic cleavage in the augite, which remains coarser than the other constituents, into ⟶	*Olivinitic diabase* and *melaphyr* ("lust tled" rocks), B 6 (in large part). Anorthite. Olivine. Augite. Titaniferous magnetite. *Pseud-amygdaloids* a special phase.
		Non-orthoclastic, olivine-free gabbro and *diabase* (in part only) (B 1). Anorthite or labradorite. Diallage or augite. Titaniferous magnetite. *Anorthite rock;* a special phase (B 4).	Grading by increasing fineness of grain into ⟶	"*Ordinary-type*" *diabase* (in small pa (B 5). Labradorite. Augite. Magnetite. *Pseud-amygdaloids* a special phase.
		Grading by loss of olivine, decrease in basicity of the plagioclases, and, in some kinds, by addition of orthoclase, into ↓		Grading by loss of olivine and decrea sicity of plagioclase, into ↓
	Silica 48 to 52 per cent.	*Non-orthoclastic olivine-free gabbro* and *diabase* (in part only) (B 1). Labradorite. Diallage or augite. Titaniferous magnetite. *Orthoclase-gabbro* (in small part only) (B 2). Labradorite or oligoclase. Orthoclase. Diallage and augite. Titaniferous magnetite. Apatite, uralite, common accessories. *Uralitic gabbro* (B 2). } Special phases. *Hornblende-gabbro* (B 3). }	Grading by increasing fineness of grain into ⟶	"*Ordinary-type*" *diabase* (the larger pa Labradorite or oligoclase. Augite. Titaniferous magnetite. *Pseud-amygdaloids* a special phase.
		Grading by decreasing basicity of plagioclase, increase of orthoclase, and introduction of secondary quartz, into ↓		Grading by decreasing basicity of fe into ↓
INTERMEDIATE KINDS.	Silica 52 to 60 per cent.	*Orthoclase-gabbro* (the larger part) (B 2). Oligoclase. Orthoclase. Diallage. Augite. Titaniferous magnetite. Apatite, uralite and secondary quartz, very common accessories. *Uralitic orthoclase-gabbro* (B 2). } Special phases. *Hornblende-gabbro* (B 3). }	Gradation forms not known, into ⟶	"*Ordinary-type*" *diabase* (in small part or Oligoclase. Orthoclase possibly in a few kinds (Augite. Titaniferous magnetite. (These roc never been found to contain over per cent. silica—rarely so muc when silicified by quartz infiltrat *Pseud-amygdaloids* a special phase.
		Grading by decrease of augitic constituent, and increase of orthoclase and of quartz, into ↓		Gradation phases not known, into ↓
ACID KINDS. Silica 60 to 78 per cent.	Silica 60 to 70 per cent.	*Augite-syenite* (in part) (A 3). Oligoclase. Orthoclase. Augite (very subordinate). Ferrite and abundant quartz characteristic accessories.	Grading by increasing fineness of grain, into ⟶	Fine-grained *augite-syenite* (A 3). Orthoclase. Oligoclase. Augite. Ferrite. Secondary quartz.
		Grading by decrease of oligoclase and great increase of quartz, into ↓		Grading by increasing amount of quart ↓
	Silica 70 to 78 per cent.	*Augite-granite* (A 4) and *granitell* or *granitic porphyry* (A 3) (in part). Orthoclase. Oligoclase (not always present). Quartz. Augite (always more or less thoroughly altered to ferrite or hornblende and very sparse).	Grading by increasing fineness of grain, into ⟶	Fine-grained *granitell* or *granitic porphy* (in part). Orthoclase. Oligoclase. Quartz. Augite (very sparse, altered to chlorite, or uralite). Ferrite. Secondary quartz.

Series, showing their mutual transitions and relations.

		Porphyritic kinds, *i. e.*, kinds containing some unindividualized matter.		Half glassy vesicular kinds.
:-	Grading, by addition of residuary magma, into →	*Melaphyrs* or "luster-mottled" rocks of Pumpelly. Have at times a little residuary magma, but it never amounts to much. Genuine porphyritic kinds of high basicity are unknown.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	*Fresher forms.*. { *Groundmass*: Devitrified glass. Feldspar microliths. Ferrite particles. Augite particles (often not seen). *Gas vesicles*, filled with one or more of calcite, chlorite, epidote, quartz, prehnite, laumontite and orthoclase, as secondary minerals. *Porphyritic* ingredients: Plagioclase, orthoclase, augite. *Altered forms.*. { *Groundmass*, in various stages of alteration and replacement by prehnite, laumontite, epidote, calcite, quartz and copper. *Amygdules*, the prehnite altered to chlorite, epidote, &c.
)	Grading by decrease in amount of augite and change of the augite into aggregates of rounded grains, into "*Ashbed*"-*diabase* (B 7) (in small part only) and this, by introduction of unindividualized material and increasing fineness of grain, into →	*Diabase-porphyrite* (in small part only) (B 7). Tabular plagioclases. Round augite particles. Magnetite Irresolvable base. Porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
a.		Grading by decrease in augite and general increase in acidity, into ↓		
).	Grading, as above, into "*Ashbed*"-*diabase* (in part) (B 7), and this as above, into →	*Diabase-porphyrite* (the larger part) (B 7). Tabular oligoclases. Round augite particles. Magnetite. Irresolvable base. Large porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
rs		Grading by increasing acidity of the feldspars, decrease in the amount of augite, and introduction of much ferritic matter, into ↓		
5). e 4 e	Grading through increasing fineness of grain, loss of crystalline outlines to the augite, and introduction of irresolvable base, into →	*Diabase-porphyrite* (in part, especially the reddish-brown and jet-black kinds with highly conchoidal fracture) (B 7). Tabular plagioclases. Round augite particles. Magnetite. Irresolvable base, often in very large proportion. Much ferritic material in the base. Porphyritic plagioclases and augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	*Amygdaloids.* (Amygdaloids occur, at times, with all the basic and intermediate rocks, but they are not separated by any physical or microscopic characters.)
		Grading by still further increase in acidity, introduction of orthoclase among the feldspars, and loss of augite in the base, into ↓		
	Grading by introduction of felsitic matter, and increasing fineness of grain, into →	*Quartzless porphyries* (A 1). Groundmass: Micro-felsitic matter. Crypto-crystalline matter. Ferrite. Tabular feldspars. Secondary quartz. Porphyritic ingredients: Oligoclase and orthoclase. Augite with ferritic decay.		Vesicular kinds not known among the acid rocks.
		Grading, by increasing acidity, loss of tabular feldspars in the matrix, and introduction of porphyritic quartz, into ↓		
3) e,	Grading by increasing fineness of grain, and introduction of felsitic matter, into →	*Quartziferous porphyry* and *felsite*. Groundmass: Glass (very little). Crypto-crystalline matter. Micro-felsitic matter. Micro-crystalline matter (subordinate). Ferrite. Secondary quartz. Porphyritic ingredients: Quartz (corroded dihexahedral pyramids). Orthoclase and oligoclase. Augite (rare).		

Summary tabulation of the eruptive rocks of the Keweenaw Series, showing their mutual transitions and relations.

Kinds	Silica	Coarse-granular kinds.		Fine-granular kinds.		Porphyritic kinds, *i. e.*, kinds containing some unindividualized matter.		Half glassy vesicular kinds.
BASIC KINDS. Silica 45 to 52 per cent.	Silica 45 to 48 per cent.	*Olivine-gabbro* (B 1). Olivine. Anorthite. Diallage. Titaniferous magnetite. *Non orthoclastic, olivine-free gabbro* and *diabase* (in part only) (B 1). Anorthite or labradorite. Diallage or augite. Titaniferous magnetite. *Anorthite rock*; a special phase (B 4).	Grading by increasing fineness of grain and loss of diallagic cleavage in the augite, which remains coarser than the other constituents, into →	*Olivinitic diabase* and *melaphyr* ("luster-mottled" rocks), B 6 (in large part). Anorthite. Olivine. Augite. Titaniferous magnetite. *Pseud-amygdaloids* a special phase.	Grading, by addition of residuary magma, into →	*Melaphyrs* or "luster-mottled" rocks of Pumpelly. Have at times a little residuary magma, but it never amounts to much. Genuine porphyritic kinds of high basicity are unknown.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	*Fresher forms*: *Groundmass*: Devitrified glass. Feldspar microliths. Ferrite particles. Augite particles (often not seen). *Gas vesicles*, filled with one or more of calcite, chlorite, epidote, quartz, prehnite, laumontite and orthoclase, as secondary minerals. *Porphyritic* ingredients: Plagioclase, orthoclase, augite. *Altered forms*: *Groundmass*, in various stages of alteration and replacement by prehnite, laumontite, epidote, calcite, quartz and copper. *Amygdules*, the prehnite altered to chlorite, epidote, &c.
			Grading by increasing fineness of grain into →	"*Ordinary-type*" *diabase* (in small part only) (B 5). Labradorite. Augite. Magnetite. *Pseud-amygdaloids* a special phase.	Grading by decrease in amount of augite and change of the augite into aggregates of rounded grains, into "*Ashbed*"-*diabase* (B 7) (in small part only) and this, by introduction of unindividualized material and increasing fineness of grain, into →	*Diabase-porphyrite* (in small part only) (B 7). Tabular plagioclases. Round augite particles. Magnetite Irresolvable base. Porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
		Grading by loss of olivine, decrease in basicity of the plagioclases, and, in some kinds, by addition of orthoclase, into ↓		Grading by loss of olivine and decreasing basicity of plagioclase, into ↓		Grading by decrease in augite and general increase in acidity, into ↓		
	Silica 48 to 52 per cent.	*Non-orthoclastic olivine-free gabbro* and *diabase* (in part only) (B 1). Labradorite. Diallage or augite. Titaniferous magnetite. *Orthoclase-gabbro* (in small part only) (B 2). Labradorite or oligoclase. Orthoclase. Diallage and augite. Titaniferous magnetite. Apatite, uralite, common accessories. *Uralitic gabbro* (B 2). / *Hornblende-gabbro* (B 3). } Special phases.	Grading by increasing fineness of grain into →	"*Ordinary-type*" *diabase* (the larger part) (B 5). Labradorite or oligoclase. Augite. Titaniferous magnetite. *Pseud amygdaloids* a special phase.	Grading, as above, into "*Ashbed*"-*diabase* (in part) (B 7), and this as above, into →	*Diabase-porphyrite* (the larger part) (B 7). Tabular oligoclases. Round augite particles. Magnetite. Irresolvable base. Large porphyritic plagioclases and rarer augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	
INTERMEDIATE KINDS.		Grading by decreasing basicity of plagioclase, increase of orthoclase, and introduction of secondary quartz, into ↓		Grading by decreasing basicity of feldspars into ↓		Grading by increasing acidity of the feldspars, decrease in the amount of augite, and introduction of much ferritic matter, into ↓		
	Silica 52 to 60 per cent.	*Orthoclase-gabbro* (the larger part) (B 2). Oligoclase. Orthoclase. Diallage. Augite. Titaniferous magnetite. Apatite, uralite and secondary quartz, very common accessories. *Uralitic orthoclase-gabbro* (B 2). / *Hornblende-gabbro* (B 3). } Special phases.	Gradation forms not known, into →	"*Ordinary-type*" *diabase* (in small part only) (B 5). Oligoclase. Orthoclase possibly in a few kinds(?). Augite. Titaniferous magnetite. (These rocks have never been found to contain over 53 or 54 per cent. silica—rarely so much save when silicified by quartz infiltration.) *Pseud amygdaloids* a special phase.	Grading through increasing fineness of grain, loss of crystalline outlines to the augite, and introduction of irresolvable base, into →	*Diabase porphyrite* (in part, especially the reddish-brown and jet-black kinds with highly conchoidal fracture) (B 7). Tabular plagioclases. Round augite particles. Magnetite. Irresolvable base, often in very large proportion Much ferritic material in the base. Porphyritic plagioclases and augites.	Grading by increasing amount of uncrystalline base, and introduction of gas vesicles, into →	*Amygdaloids.* (Amygdaloids occur, at times with all the basic and intermediate rocks, but they are not separated by any physical or microscopic characters.)
		Grading by decrease of augitic constituent, and increase of orthoclase and of quartz, into ↓		Gradation phases not known, into ↓		Grading by still further increase in acidity, introduction of orthoclase among the feldspars, and loss of augite in the base, into		
ACID KINDS. Silica 60 to 78 per cent.	Silica 60 to 70 per cent.	*Augite syenite* (in part) (A 3). Oligoclase. Orthoclase. Augite (very subordinate). Ferrite and abundant quartz characteristic accessories.	Grading by increasing fineness of grain, into →	Fine-grained *augite-syenite* (A 3). Orthoclase. Oligoclase. Augite. Ferrite. Secondary quartz.	Grading by introduction of felsitic matter, and increasing fineness of grain, into →	*Quartzless porphyries* (A 1). Groundmass: Micro felsitic matter. Crypto-crystalline matter. Ferrite. Tabular feldspars. Secondary quartz. Porphyritic ingredients: Oligoclase and orthoclase. Augite with ferritic decay.		Vesicular kinds not known among the acid rocks.
		Grading by decrease of oligoclase and great increase of quartz, into ↓		Grading by increasing amount of quartz into ↓		Grading, by increasing acidity, loss of tabular feldspars in the matrix, and introduction of porphyritic quartz, into ↓		
	Silica 70 to 78 per cent.	*Augite-granite* (A 4) and *granitell* or *granitic porphyry* (A 3) (in part). Orthoclase. Oligoclase (not always present). Quartz. Augite (always more or less thoroughly altered to ferrite or hornblende and very sparse).	Grading by increasing fineness of grain, into →	Fine-grained *granitell* or *granitic porphyry* (A 3) (in part). Orthoclase. Oligoclase. Quartz Augite (very sparse, altered to ferrite, chlorite, or uralite). Ferrite. Secondary quartz.	Grading by increasing fineness of grain, and introduction of felsitic matter, into →	*Quartziferous porphyry* and *felsite* Groundmass Glass (very little). Crypto crystalline matter. Micro felsitic matter Micro crystalline matter (subordinate) Ferrite. Secondary quartz. Porphyritic ingredients: Quartz (corroded dihexahedral pyramids). Orthoclase and oligoclase. Augite (rare).		


1


2


3


4

A. Hoen & Co. Lith. Baltimore

SANDSTONES

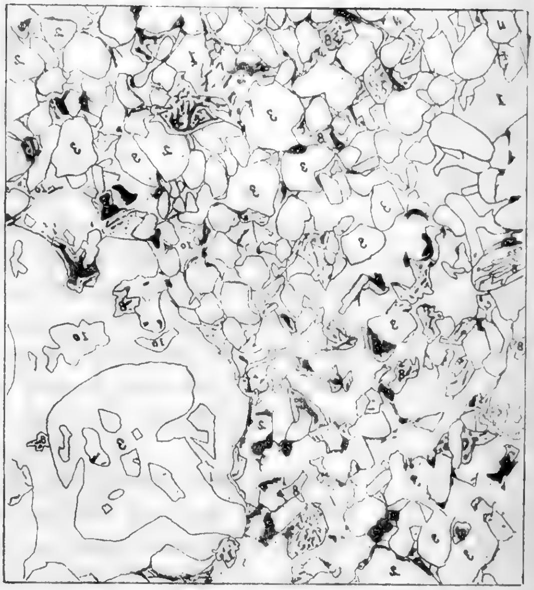


Fig. 1. Cupriferous sandstone, Nonesuch Mine, Mich.
Ordinary light. Scale 16 diameters.

Fig. 2. Basic sandstone, Montreal River, Wis.
Ordinary light. Scale 27 diameters.

Fig. 3. From near Copper Falls Mine, Keweenaw Point, Mich.
Ordinary light. Scale 27 diameters.

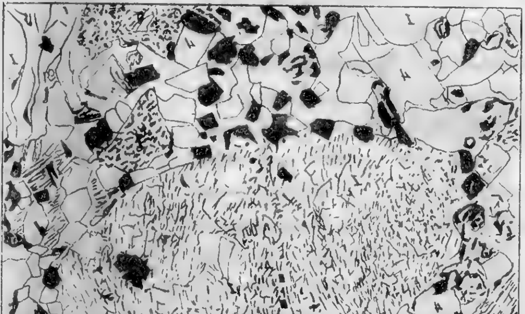


Fig. 4. From the "Calumet Conglomerate," Calumet Mine, Mich.
Ordinary light. Scale 28 diameters.

Diabasic detritus(1); fragments of the matrices(2), quartzes(3), and feldspars(4) of felsitic porphyries; fragments from a granitic porphyry(5); magnetite fragments(6); particles of an amygdaloid matrix(7); originally deposited native copper(8) and calcite(9); chlorite(10) as an alteration product.

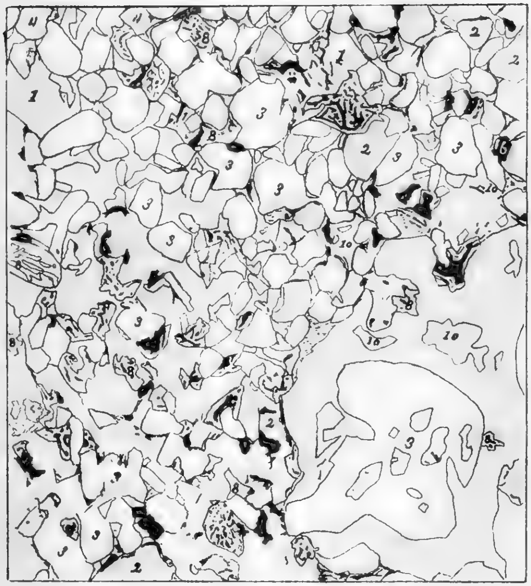


Fig. 1. Cupriferous sandstone, Nonesuch Mine, Mich. Ordinary light. Scale 16 diameters.

Fig. 2. Basic sandstone, Montreal River, Wis. Ordinary light. Scale 27 diameters.

Fig. 3. From near Copper Falls Mine, Keweenaw Point, Mich. Ordinary light. Scale 37 diameters.

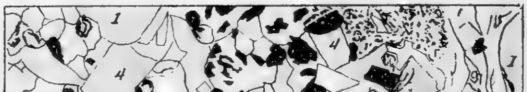


Fig. 4. From the "Calumet Conglomerate", Calumet Mine, Mich. Ordinary light. Scale 28 diameters.

Diabasic detritus (1); fragments of the matrices (2), quartzes (3), and feldspars (4) of felsitic porphyries; fragments from a granitic porphyry (5); magnetite fragments (6); particles of an amygdaloid matrix (7); originally deposited native copper (8) and calcite (9); chlorite (10) as an alteration product.

Section IV.—DETRITAL ROCKS.

The fragmental rocks of the Keweenaw Series include, as already shown, both conglomerates and sandstones. The former have already been sufficiently described in a general way, the several kinds of bowlders and pebbles of which they are made up having been also described in detail in the foregoing pages of this chapter in connection with the descriptions of the original massive rocks from which they have been derived. Descriptions of the more important conglomerate beds are also given in connection with the local descriptions of Chapters VI and VII. It is therefore unnecessary to give any further account of them here.

It may merely be said, in review, that the ordinary conglomerates are for the most part made up of pebbles and bowlders worn from the several kinds of acid rocks, viz: quartzless porphyry, quartziferous porphyry and felsite, augite-syenite, granitell and granite; that the same band of conglomerate will vary when followed along its course as to which of these kinds is the predominant one; that there are often pebbles of the basic rocks, but in greatly subordinated quantity; that the finer material between the pebbles is composed of a detritus of the same rocks as the pebbles themselves, the only difference being that the greater fineness of these particles has often resulted in separating crystals of feldspar and quartz completely from the matrix; that one, or more, of calcite, chlorite, epidote and copper—brought in by infiltrating waters—has often been deposited in the interstices of these conglomerates, or rather has replaced their constituent particles; and that these conglomerates tend, even when quite thin, to run laterally into sandstone or shale, the coarser fragments failing altogether.

The sandstones seem in large measure to be made up of particles of the same acid rocks whose fragments form the conglomerates. When they closely overlie beds of basic rocks, these sandstones often contain a greater or less proportion of basic detritus. This basic material presents itself in the shape of pieces of more or less altered amygdaloid matrix, particles of the more completely crystalline rocks with the constituent minerals still adhering to one another, and pieces of these minerals broken away from the mass. Magnetite, being the least destructible constituent of the basic rocks, is their most common representative. In the case of one belt of sandstone—the Nonesuch belt—which lies far above any basic flow, the basic detritus becomes unusually abundant, at times almost wholly excluding the usual acidic detritus.

On the other hand, there are sandstone beds, as those of Black and Nipigon bays, on the north side of Lake Superior, in which a large proportion of the constituent particles have been derived from gneiss and granite, and in these cases the quartz particles are unusually abundant. In the same region some of the sandstone beds are largely charged with magnesian and calcareous carbonates, which are even concentrated at times in thin seams of limestone, a thing unknown elsewhere in the Keweenaw Series.

As in the conglomerates, so also in the sandstone beds, secondary calcite, chlorite and epidote, and even copper, are occasionally to be met with.

The following tabulation includes enough examples to illustrate the different varieties of sandstone which occur in the Keweenaw Series. A number of other thin sections will be found described in connection with the local details of Chapters VI and VII.

Tabulation of microscopic observations upon sandstones of the Keweenaw Series.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
1943..	Eagle Harbor, Keweenaw Point, Michigan.	NW.	6	58	30 W.	Dark purplish-red; medium-grained; firm; gives slight effervescence with hydrochloric acid.	Subangular, or only very slightly rounded fragments, worn from the matrix and porphyritic ingredients of a quartziferous porphyry, along with fragments plainly derived from an augite-syenite, make up most of the rock. The fragments referred to the porphyritic ingredients of a quartziferous porphyry are almost wholly feldspars, both orthoclase and oligoclase, quartz particles being almost wholly absent. The particles referred to augite-syenite are pieces of feldspar affected by the peculiar

Tabulation of microscopic observations upon sandstones, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
							graphic secondary quartz, which is characteristic of that rock throughout the Lake Superior region. There are also present rarer, but not uncommon, particles worn from basic rocks. These are recognizable as for the most part derived from the matrices of amygdaloids, showing the peculiar feldspar microliths and deep-brown ferritic alteration characteristic of these matrices. There are also present, however, particles plainly derived from the more completely crystalline portions of the basic rocks, but always in a much altered condition. There are here and there magnetite particles. The constituent particles range, for the most part, from 0.55 mm to 0.70 mm in length. There is little or no original interstitial matter; but the spaces between the particles are often occupied by infiltrated calcite, with a little quartz, both presenting themselves in very fine particles.
1852..	Near Copper Falls mine, Keweenaw Point, Michigan.	NE.	12	58	31 W.	Medium-grained; dark purplish-red; of open texture; effervesces briskly with hydrochloric acid; rather more coarsely grained than 1943; contains an occasional pebble of felsite or porphyry.	The particles of which this rock is composed are from angular to sub-angular. Although generally showing some signs of attrition, they are never much rounded. They often reach 1.00 mm or more in greatest length. They have been derived, for the most part, from the matrix and porphyritic feldspars of a quartziferous porphyry; but particles referable to the augite-syenites are common, showing every phase of the characteristic secondary quartz of these rocks; whilst smaller particles from the basic rocks, as in 1943, are not wholly wanting. Quartz particles, plainly derived from the quartzes of a quartziferous porphyry, occur, but are not abundant. There is no original interstitial matter; but the often wide spaces between the grains are now wholly occupied by a coarsely crystalline calcite. Fig. 3, Plate XVI.

Tabulation of microscopic observations upon sandstones, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
1857..	From the base of the "Great Conglomerate" near Copper Falls, Keweenaw Point, Michigan.	NE.	12	58	31 W.	Fine-grained; very dark-red; firm.	The larger particles of this rock are fragments worn from quartziferous porphyries and augite-syenites, as in the two preceding rocks; except that the particles are smaller and the quartzes more abundant in this case. Thickly strewn among these larger particles are numerous smaller ones worn from basic rocks. These particles make up more than half the bulk of the rock, and to their presence the dark color is due. Much the larger proportion of these basic particles are fragments of magnetite, but there are also present numerous fragments of matrices of amygdaloids and of a nearly opaque red oxide of iron, which may be an alteration-product from some of the constituents of a basic rock. The latter particles are so opaque as to be readily mistaken for magnetite in the transmitted light. No infiltrated calcite is to be seen.
1969..	Sandstone of "Calumet conglomerate," Calumet mine, Keweenaw Point, Michigan.	....	23	56	33 W.	Fine-grained; dark-reddish; carries minute red felsite pebbles; effervesces with hydrochloric acid.	Composed of coarser particles imbedded in a matrix of fine particles, most of the former and all of the latter being highly angular. The larger particles consist chiefly of fragments of the matrix and porphyritic feldspars of a quartziferous porphyry, along with which are rarer ones of amygdaloid matrix. The finer portion consists of the same materials with a larger proportion of basic detritus, abundant magnetite particles, rather plentiful quartz particles, and some infiltrated calcite and epidote. See Plate XVI, Fig. 4.
1792..	Near the Atlantic mill, Portage Lake, Michigan.	NW.	34	55	34 W.	Medium- to coarse-grained; dark purplish-red, banded with light-red; some portions effervesce briskly, others not at all.	Larger particles, running from 0.5^{mm} to 1.5^{mm} in greatest length, and angular to sub-angular—rarely much rounded—are imbedded in a matrix composed of fine particles. The larger particles, which tend to aggregate along certain lines, are mostly of bubble-bearing quartz. There are also present among these larger particles pieces of reddened and clouded feldspars, for the most part orthoclase, others of porphyry matrix of the usual characters,

Tabulation of microscopic observations upon sandstones, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
							and still other much rarer ones, derived from the basic rocks. The fine matrix is largely composed of angular quartz fragments, along with which are others again of porphyry matrix, and still others stained of so deep a red that it is difficult to tell their original nature. Calcite has filtered in along certain seams, where it is found coarsely crystalline.
1976..	From quarry on north side of Portage Lake, Michigan.	SE.	28	55	34W.	Excessively fine-grained; dark-gray; thin-laminated; hard.	A very fine-grained rock. Subangular to rounded particles of quartz predominate. The other constituent particles are porphyry and basaltic detritus, minute fragments of muscovite, infiltrated epidote and quartz, and magnetite.
2504..	Foot-wall sandstone at Nonesuch mine, Porcupine Mountains, Michigan.	SE.	1	50	43 W.	Light reddish-brown, streaked with still lighter shades; fine-grained.	Angular to rounded quartz particles are predominant. Associated with these are numerous fragments of porphyry matrix and a still larger proportion of basaltic detritus. There is also a good deal of fine quartz that appears to be infiltrated.
2506..	Nonesuch "vein rock," Porcupine Mountains, Michigan.	SE.	1	50	43 W.	Dark greenish-gray; fine- to rather coarse-grained; carries small pebbles of red felsite. Abundant minute flakes of copper are visible.	This rock is composed of mingled porphyry and basaltic detritus. The former presents itself in the shape of quartz grains (which are quite abundant). and fragments of the matrix and of porphyritic feldspars. In several instances fragments of a quartz-porphyry still containing porphyritic quartzes are to be seen. The basaltic detritus, to whose presence the dark color of the rock is due, includes pieces of amygdaloid matrix, particles of the coarser grained diabases, with the several constituents together; fragments of triclinic feldspar; magnetite particles ; and greenish particles, which are at times recognizable as highly altered augite and diallage. In the interstices between the grains, which are from angular to round in shape, a fine detrital material is sometimes seen; but for the most part these spaces are occupied by infiltrated matter, in the shape of epidote, a greenish chlorite,

Tabulation of microscopic observations upon sandstones, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
							calcite, and native copper, all of which, with the exception of the last named, are very irregularly distributed through the section. The copper molds itself sharply around the constituent fragments, having in most cases a core of magnetite, an occurrence suggesting its precipitation by the ferrous oxide of the last-named mineral. The copper also is occasionally to be seen penetrating into the interiors of the more readily decomposable fragments. Plate XVI, Fig. 1.
2508..	Silver-bearing rock underlying Nonesuch vein, Porcupine Mountains, Michigan.	NW.	12	54	43 W.	Very fine-grained; dark-gray; quartzite-like; firm and hard; effervesces in places with hydrochloric acid.	This rock is composed of predominant quartz fragments, with a smaller proportion of porphyry detritus, and a large one—probably making up half the rock—of infiltrated quartz. There is also some infiltrated calcite, which is very irregularly distributed.
2524..	Union mine lode, Porcupine Mountains, Michigan; top of sandstone underlying "outer trap;" from bed of stream.	NW.	27	51	42 W.	Very fine-grained; dark reddish-brown; firm; effervesces readily with hydrochloric acid.	A very fine-grained rock; much resembling 1792. Larger fragments of feldspar and porphyry matrix are imbedded in a groundmass, composed of the same materials, with a large proportion of quartz. There is also present a notable proportion of basaltic detritus. The particles are for the most part quite angular. The interstices are everywhere filled with infiltrated calcite, along with some epidote.
2535..	Bed of Upper Carp River; immediately overlying amygdaloid; Porcupine Mountains, Michigan.	SW.	19	51	42 W.	Excessively fine-grained; dark purplish-red; firm; effervesces readily with hydro-chloric acid; finely banded with darker and lighter shades.	Very much like the last rock described, except that it is much finer in grain, and contains a small proportion only of basaltic detritus.
44 I.	Falls of Bad River, Ashland County, Wisconsin.	....	25	47	3 W.	Medium to coarse-grained; reddish. SiO_2, 69.78 per cent.	Larger angular grains of quartz and feldspars are imbedded in a fine matrix composed of the same materials, along with much porphyry detritus, largely in a decomposed condition, and an abundant brown ocherous cement.

Tabulation of microscopic observations upon sandstones, &c.—Continued.

Specimen number.	Place.	Quarter-section.	Section.	Township.	Range.	Macroscopic descriptions.	Microscopic descriptions.
1516 I.	Bed of Montreal River, Ashland County, Wisconsin.	NW.	20	47	1 E.	Fine-grained; dark-gray; very hard and firm; effervesces with hydrochloric acid. SiO_2, 55.91 per cent.	The predominating fragments are from basic rocks. With these are rarer ones of a felsitic porphyry. Quartz particles are very rare. A cement of coarsely crystalline calcite pervades the whole rock, and makes up probably as much as one-fourth of its mass. See Plate XVI, Fig. 2; also Vol. III, Geology of Wisconsin, p. 200, and Plate XIX A.
1709..	Silver Islet Landing, north shore of Lake Superior, Ontario, Canada.	....	....	....	......	Very fine-grained; light yellowish-gray; hard and firm; has a semi-crystalline aspect. A similar sandstone from the same bed yielded Macfarlane: silica, 72.89; iron oxide, 0.91; carbonate of lime, 13.04; carbonate of magnesia, 11.94. (Canadian Naturalist, new series, Vol. IV, p. 39.)	Small angular quartz particles make up the larger part of the rock. There are a few fragments of porphyry matrix. Infiltrated calcite and dolomite, along with some infiltrated quartz, occupy the interstices of the fragments. The cleavage lines of the two former are only very rarely to be observed.
1709A	Same place as 1709.	....	....	....	......	Dark-red; fine-grained; effervesces with hydrochloric acid. Macfarlane's analysis of a similar rock from this vicinity (*loc. cit.*) gives: silica, 73.45; ferrous oxide, 2.41; carbonate of lime, 12.54; carbonate of magnesia, 10.94.	Predominating angular quartz fragments are imbedded in an abundant red-stained earthy-looking matrix, in which must lie the calcium and magnesium carbonates indicated by the analysis.

CHAPTER IV.

STRUCTURAL FEATURES OF THE THREE CLASSES OF ROCKS OF THE KEWEENAW SERIES.

The basic rocks; their arrangement in distinct beds or flows.—Division of the finer-grained rocks into distinct portions.—The amygdaloids.—Stratiform amygdaloids.—Ashbed amygdaloids.—Noticeable absence of beds of true volcanic ash in the Lake Superior region.—The massive basic rocks, or so-called "traps."—Indications of viscous flow in the basic rocks.—Proof that the bedded basic rocks are "contemporaneous."—Minor undulations in the beds of basic rocks.—Lateral extent of the beds of basic rocks.—Lateral extent of the groups of beds.—Thickness of individual beds.—Effect upon the topography of the structure of the basic rocks illustrated by occurrences on the North Shore; on the South Shore.—Occurrence of cutting masses or dikes.—Character of these dikes as seen on the Minnesota coast; these dikes, and those of the underlying slates, fill the fissures through which came the bedded basic rocks.—The massive coarse-grained gabbros of the Duluth and Brulé Lake regions of Minnesota, and the Bad River region of Wisconsin; are they great flows, or do they represent the deep-seated portions of masses from which flows have come?—Structural features of the acid rocks.—Granite, augite-syenite and granitic porphyry in the Bad River country of Wisconsin and in the neighborhood of Duluth.—The same in northeastern Minnesota, and on the Minnesota coast.—Quartz-porphyry as seen on the North Shore; its occurrence at the Great Palisades.—The Palisade porphyry east of Baptism River.—Important theoretical bearing of these occurrences of porphyry.—Other occurrences of quartzose porphyry on the North Shore.—Quartzose porphyry on the South Shore; at Mount Houghton; in the Ontonagon country; in the Porcupine Mountains.—General conclusions as to the origin and relative ages of the porphyries and basic rocks.—Structural features of the detrital rocks.

The basic crystalline rocks make up the greater part of the thickness of the series. They occur for the most part in distinct beds, from a few feet to several hundred feet in thickness, which, while sharply defined from each other, do not commonly possess any subordinate bedding structure, though such a structure is at times to be observed, as noted below.

Often these beds present an easily recognized twofold division, into an upper, narrower, amygdaloidal portion, and a lower, compact, non-amygdaloidal portion. This subdivision is one characterizing especially the beds composed of the finer-grained diabases, which are, however, much the most abundant of the basic rocks. The coarser-grained diabases and gabbros are never, so far as my observation has extended, furnished with amygdaloids. Of the finer-grained kinds, the olivine-free diabases are perhaps somewhat more commonly supplied with amygdaloids than those carrying olivine, and have the amygdaloids more strongly developed. However, the olivine-bearing kinds are often provided with very highly vesicular amygdaloids, as for instance most of the succession of beds seen on the Minnesota coast between Knife River and Split Rock River, described on a subsequent page under the name of the Agate Bay Group.

The amygdaloidal and compact portions appear to grade into each other through an intermediate stage, in which the amygdules are less plentiful. This intermediate stage, recognized by Pumpelly and Marvine in their descriptions of Keweenaw Point geology as "amygdaloidal melaphyr," the first-named geologist has since shown to be essentially different from the upper amygdaloid, in that in the latter most of the amygdules fill sharply defined pre-existing cavities, while in the former they occupy the positions of primary rock constituents. A threefold division of these beds into true amygdaloid, pseud-amygdaloid, and compact portion is thus to be recognized. In a number of cases I have myself observed still a fourth division, viz: a true amygdaloid, occupying the base of the bed. This has little or no gradation-zone into the overlying compact portion, is thinner than the top amygdaloid, and shows sparser and larger amygdules, which, moreover, occupy cavities whose walls are unusually dense and sharply defined. All of these divisions are often present, but one, or all save one, may fail. When one division only is recognizable, it is commonly the massive portion, but in the thinner beds the pseud-amygdaloid or alteration-zone not unfrequently extends all the way to the base, there being then no massive unaltered portion.

The amygdaloidal portions of these beds present many complicated and much varied phases, the complexities arising chiefly from molecular alterations subsequent to the solidification of the rock, from admixtures of sediment, or from both of these causes at once. Still, by a study of fresher conditions, it is easy to recognize certain constantly recurring main characteristics, viz: a matrix always different from that of the more compact portion of the bed, in that it is much denser and often much less perfectly crystalline, and always much more prone to alteration; and amygdules of one or more of calcite, chlorite, quartz, epidote, prehnite, laumontite, copper, orthoclase, or the alteration-products of these, filling sharply defined and distinctly pre-existing cavities. The amygdules vary very greatly in abundance. Sometimes, as in the upper amygdaloids of the Montreal River, and, yet more strikingly, in some of the minutely vesicular amygdaloids of the Minnesota shore in the vicinity of Agate Bay, they nearly exclude the matrix, showing that the original rock must have been as vesicular as a sponge. The amygdules at times take on a cylindrical form, with the axis at right angles to the bedding, sometimes extending in this way to a length of several inches. I have noticed such "spike amygdules" in a number of cases in the thin basal amygdaloids. Again, the amygdaloidal cavities are found elongated laterally in a common direction, this being carried sometimes to such an extent that the amygdules are thinned to mere strings. This is to be finely observed in some amygdaloids on the lake shore at Duluth, as well as at a number of points on the coast further to the eastward, and, in general, some traces of this elongation are more often to be made out than not. It suggests a flow of the vesicular matrix while in a viscous condition.

The internal alterations that these amygdaloids have commonly undergone have been described in some detail in the last chapter. The alteration has in some cases been an extreme one; "large parts of the bed have lost their amygdaloidal character, and now consist of quartz, epidote, calcite, prehnite, chlorite and decomposed amygdaloid associated in the most irregular manner. Such are the beds worked for copper on Keweenaw Point,"[1] and similar beds occur throughout the entire extent of the series.

A kind of amygdaloid very interesting in its structural relations is to be seen largely exposed along the Minnesota shore between French and Split Rock rivers, in the Agate Bay Group of beds.[2] This is a highly vesicular, true amygdaloid, occurring in two phases which graduate into each other. In the one a crumbling light-brownish matrix holds large amygdules of radiating laumontite, to which zeolite the matrix itself has often partly altered. In the other phase a reddish-brown, iron-stained, hard matrix includes thickly studded minute amygdules of saponite and laumontite. The point of especial interest with regard to these amygdaloids is their stratiform

[1] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 32.
[2] See chapter VII, pp. , .

condition. They lie in layers one inch and upwards in thickness. The layers are quite irregular and non-continuous, but affect the whole mass. This structure is brought out with especial prominence on weathered cliff sides, the thinner layers falling away in fragments as from a cliff of shaly limestone. Occasionally seams of red sandstone are interleaved or overlie a thickness of the stratiform amygdaloid, into which the sandstone penetrates at times through fissures and irregular openings. This amygdaloid graduates laterally into kinds without stratification. It occurs in thicknesses running from less than a foot up to as much as 15 or 20 feet, but the usual thickness lies between 5 and 8 feet. Interbedded with and grading into these amygdaloids are massive layers of fine-grained olivine-diabase or melaphyr with a quite pronounced vertically columnar structure. A fine show of both is to be seen on the west side of Agate Bay, on the Minnesota shore, where a total thickness, measured, of 101.5 feet included seven massive layers running from 2 to 15 feet in thickness, and seven layers of stratiform amygdaloid running from 3 to 20 feet in thickness. A single seam of red shaly sandstone 2 to 3 feet in thickness is included.

The resemblance of these amygdaloids to beds of sedimentary origin, however striking at the first glance, is nevertheless lost on close inspection, for the vesicular structure is seen to be identical with that of the ordinary amygdaloids, while no trace of a fragmental nature can be detected either with the naked eye or in the thin section with the microscope. The thin section shows a completely interlocked crystalline texture, and a composition precisely the same as the underlying massive rock, except as to the alterations and amygdules, and the presence of a considerable amount of unindividualized altered magma substance. The stratiform condition may be in part due to a succession of thin scoriaceous flows, and in part to a true "fluidal" structure. It appears often to result from an arrangement of amygdules more plentifully on certain planes, subsequent molecular changes bringing out an apparent stratification by following the planes on which the amygdules were thickest. But, however this may be, there can be no question as to the identity of origin of these amygdaloids with all others of the series, although in Owen's Geological Survey of Wisconsin, Iowa, and Minnesota,[1] Norwood has called them "metamorphic shales," in which he has since been followed by N. H. Winchell.[2] The possibility of a sedimentary origin for them is absolutely excluded by the completely crystalline interior texture, the highly vesicular character, the presence of unindividualized magma, the microscopic flowage structure, and the graduation of each bed downward into vertically columnar, non-vesicular olivine-diabase.[3]

The peculiar type of amygdaloid characterizing the so-called Ash-bed of Keweenaw Point is somewhat related to the last-described. It appears as a peculiar and irregular mixture of red sand and amygdaloidal material, and bears at first sight some resemblance to those conglomerates, already described,[4] in which the pebbles are amygdaloidal. But in the Ashbed the apparent pebbles appear on close observation to be mostly connected, and I am disposed to follow Wadsworth[5] in considering that it represents a very scoriaceous and open layer, upon and within which more or less sand was subsequently deposited.

In this connection it may be said that materials to which the term "ash" could be applied, in the sense of volcanic detrital material, are almost wholly wanting in the Lake Superior country. It is barely possible that the basic ingredient of the dark-gray sandstone and black shale of the belt above mentioned as extending from the Gratiot River, on Keweenaw Point, westward to Bad River, in Wisconsin, may be in part of this nature, as also the material of which the somewhat allied gray sandstone at Duluth is composed; but, with these very doubtful exceptions, I have met with nothing in the entire Keweenaw Series which could have originated as volcanic ash. I had supposed in the field that some of the crumbly, more or less obscurely stratiform beds of the North Shore might be of this nature, their weathered surfaces presenting at first sight the appearance of aggregated

[1] Pages 345 to 361. In Norwood's descriptions of the Minnesota coast this term constantly recurs, and the coast line is represented as chiefly formed by "metamorphic shales," which term, having applied it first to the bedded amygdaloids, he spread to nearly all other amygdaloids, as well as to some of the more compact diabases. I could find no rock between Duluth and Grand Portage Bay to which the term would in any sense be applicable.

[2] Reports of the Geological Survey of Minnesota for 1878 and 1879.

[3] See further as to these amygdaloids, Chapter VII.

[4] Chapter II, p. 29.

[5] Notes on the Iron and Copper Districts of Lake Superior, p. 112.

angular particles, but all turned out to be completely crystalline rocks, owing their appearance of a fragmental nature to decomposition.

The more massive beds of basic rocks, or the lower massive portions of such beds as possess the crowning amygdaloids, are often without any definite structure. This is the common case in the typical region of Keweenaw Point, where a few beds only show a tendency to a transverse columnar structure. On the Montreal River, however, this structure is well developed in a series of quite thin beds, which are furnished with very perfect amygdaloids, and stand about vertically. On the Minnesota shore, a columnar structure is the rule, and since the beds lie at a very flat angle, cliffs of vertically columnar rocks are a prominent feature. Still, the structure never reaches a great perfection.

Allusion has been made above to the elongated vesicles of some of the amygdaloids. Other indications of flowage sometimes to be seen in connection with the more massive rocks are a slaggy or ropy texture, and an appearance as if a once solidified crust had broken, and the several fragments reunited by further solidification, suggesting the "clinkers" of modern volcanic regions. These appearances, while noted at a number of points, are not common. They are merely additional indications of the once fluid condition in which all of these basic rocks are sufficiently proved to have been by the common division into amygdaloidal (vesicular) and compact portions; by the mineralogical composition—augite, plagioclase, olivine, magnetite; by the completely crystalline condition; by the flowage lines formed by the tabular plagioclases in some of the finer-grained kinds, and by the occurrence in some of the kinds of remnants of the original glass magma. The interstratification of these rocks with wholly unaltered sandstones and shales must preclude at once any thought of a metamorphic origin. As already indicated, I can only regard these beds as true lava flows, owing their interstratification with the accompanying sediments to their having been poured out at surface while the sediments were forming.

A very beautiful additional proof of contemporaneousness is furnished by the peculiar relation of a sandstone to its immediately underlying crystalline rock, the sand penetrating the openings and cracks in the latter. A number of places were noted on the North Shore where the overlying sandstone bed has been removed and large surfaces of the underlying diabase, sometimes many hundreds of feet in length, present the singular appearance of being intersected by veins of sandstone, the seeming veins crossing each other, zigzagging and branching, like true vein-formed material.

On the Minnesota shore, where single beds can be followed on exposure for long distances, numerous minor bowings and corrugations are seen to affect the layers, which, nevertheless, preserve a constant lakeward slant at a low angle. Individual layers and sets of layers can be followed for miles, rising into arches, sometimes of short span, and again sinking out of sight to reappear in a short distance. These minor undulations are the only possible foundation Norwood could have had for his profile of the North Shore,[1] on which he represents a series of much-folded rocks. This peculiar warped structure I conceive to be in a measure due to the original irregularities of the beds.[2]

Laterally, the beds are, of course, not of indefinite extent. They must of necessity be far less extensive than sedimentary beds of the same thickness, and these, too, wedge out laterally. With a succession of beds much like each other, it is commonly difficult to prove the continuity or non-continuity of single flows over any great distance. On the Minnesota shore, however, I was able to trace individual layers for ten to fifteen miles with certainty, and with great probability much further than this. The Greenstone of Keweenaw Point, a melaphyr or olivine-diabase flow of considerable thickness, which can be readily traced by reason of its peculiar character and marked effect on the topography, runs beyond question from near the end of Keweenaw Point westward to the Allouez mine, a distance of nearly 30 miles, and in all probability is represented at Portage Lake, 30 miles further southwest, by a coarse-grained bed seen near the Atlantic mine. The so-called Ashbed of Keweenaw Point appears to have been recognized at points 30 miles from each other, but the reference of the rocks of the two places to the same bed is made on stratigraphical and lithological evidence only, no actual continuity having been proved.

Groups of layers of allied lithological characters are recognizable over

[1]Atlas to Owen's Geological Survey of Wisconsin, Iowa, and Minnesota.

[2]See Chapter VII for more specific descriptions of these irregularities, with illustrations.

much longer stretches. The belt of thin amygdaloids and diabases lying above the great conglomerate of Eagle River, Keweenaw Point, with a thickness of some 1,500 feet, must run uninterruptedly from the eastern extremity of Keweenaw Point to the Wisconsin boundary, a distance of 150 miles. Several of the groups into which I have divided the rocks of the Minnesota coast can also be recognized for many miles, and there is a strong probability that one or two of them exist on Isle Royale.

The thickness of the individual beds of these basic rocks has been already given as ranging from ten or under to several hundred feet, but for the greater portion of the series the thickness is less than 100 feet. Towards the base of the series, among the older flows, however, beds occur of great thickness, and present massive exposures in which it is very hard to see any sign of structure. At this horizon in the Bad River region of Wisconsin are immense structureless masses of a very coarse-grained gray gabbro, and similar rocks have a great development at a similar horizon in Minnesota. Fine-grained diabases also occur largely at these low horizons without any such distinct bedding as is characteristic of most of the series; for instance, on the so-called "South Copper Range" of Michigan, between the Montreal and Ontonagon rivers, and in the Duluth Group of the Minnesota coast. The apparent lack of bedding in the latter region is doubtless due to the much greater thicknesses of the individual beds, and to their nearly vertical position, but it is possible that the coarse-grained rocks of the Bad River and Duluth regions may owe their want of structure to a different cause, as is subsequently indicated.

The effect of the prevalent bedded basic rocks upon the topography is everywhere very marked, having a common character, varied only by the varying dips and varying thicknesses of the individual layers. Since the dip is almost always lakeward, the common effect is a longer lakeward or front slope, and a steep or precipitous back slope. Where the dip is flat, as all along the Minnesota shore, the front slope coincides with the dip slope, and the shore line of hills ascends at an angle of from 5° to 10°, to drop off suddenly in the rear. The valleys of the streams entering the lake nearly at right angles divide these hills into detached blocks. Such a series of blocks is well seen as one looks towards the west from Grand Marais.

From Grand Marais westward to Poplar River the trend of the strata is more easterly than that of the coast, so that in looking in that direction these hill blocks are seen succeeding each other in such a way as to have suggested the very apposite epithet of "Saw Teeth Mountains." An attempt to represent this appearance is made in the accompanying outline sketch.

FIG. 1.—Outlines of coast hills for 20 miles above Grand Marais, Minn.

In the woods of the North Shore away from the lake, the same feature is constantly repeated; ridges are everywhere met with trending with the strike of the formation, sloping gradually to the southeast, and dropping off abruptly to the northwest. This structure has been attributed by N. H. Winchell[1] to faulting, each drop being regarded as the result of a fault. There may be a few such faults, but it is evident enough that the case is just such as is found in every region of flat-dipping hard rocks, and especially where softer layers are interleaved, as in this case.

On the south shore of the lake the dip is commonly higher, and although the same structure occurs the front slope is often flatter than the dip slope. In the eastern part of Keweenaw Point, where the dip flattens, the structure comes out finely in a series of bold ridges. Towards Portage Lake, however, the dip becomes as high as 50° or more, and the several ridges merge into one broad swell. This holds until the Porcupine Mountains are reached, where, though the dip-angle is as high as 30°, the structure is most beautifully illustrated in the outer ridge. This ridge rises

[1] Report of the Geological Survey of Minnesota for 1878, p. 12.

from the lake shore somewhat more gradually than the dip, to a height of over 1,000 feet, and then drops off in a bold escarpment of 400 feet into the valley of Carp Lake. Further west again, as far as Bad River, the dips are high, often reaching 90°, and the harder rocks constitute merely rounded ridges and knobs with the cliffs facing indifferently in all directions. Beyond Bad River, and all across Wisconsin to the Saint Croix, the dips flatten once more, and the "saw-tooth" shape in the ridges is everywhere well marked.

True cutting masses, or dikes, of the basic rocks occur, though never a prominent feature of the series. They appear to characterize only its lower portions, and have been seen chiefly along the Minnesota shore, and on the east coast in the region of Mamainse. On the South Shore they are nearly unknown, though in all probability occurring largely in the lower portions, where the exposures are commonly not good. Throughout the entire basin they have never been observed more than one-third the way above the base of the series.

As seen on the Minnesota coast[1] these dikes are always small, commonly under ten feet in width, though seen occasionally wider than this, while a number were noticed under two feet in width. They are usually provided with a well-marked cross-columnar structure and coarser-grained middle portion as compared with the sides. They consist, so far as yet examined microscopically, wholly of augite-plagioclase rocks, and are not in any essential point different from the bedded diabases and melaphyrs that constitute the bulk of the series, the differences being only those that would arise from the different situations in which the rocks have cooled, and the different decomposition effects. Indeed, the thin sections of the dike rocks are often indistinguishable from those of the bedded rocks. The dikes of the Minnesota coast trend usually with the strike of the formation, less commonly directly across it. I cannot doubt that these dikes and others like them all around the rim of the Lake Superior basin, now unseen only because of unfavorable conditions of exposure, have been the source of the

[1] It should be said here that Norwood's descriptions of the Minnesota coast are entirely misleading as to the number and size of the dikes. As already said, small dikes occur somewhat abundantly at low horizons, but the greater number of Norwood's dikes are merely erosion points of the harder and more compact portions of the diabase flows.

upper flows. The immediately underlying series of slates known to the Canadian geologists as the Lower Copper-bearing Group, called by Hunt the Animikie Group, and regarded in this memoir as unquestionably the equivalent of the iron-bearing Huronian rocks of the South Shore, is intersected everywhere by a very much more powerful system of dikes. These are spoken of more especially on a subsequent page, and are cited here merely that I may express my belief that in them, and in the smaller dikes of the Keweenaw Series itself, we see the source of the volcanic strata of the lake basin, all around whose rim I conceive the eruptions to have taken place, rather than from any one vent, as some have supposed,[1] or from within any restricted portion of the basin.

The great structureless masses of coarse gabbro, which in the Bad River region of Wisconsin, and again in the Duluth region of Minnesota, and thence northeastward to the Brulé Lake country, constitute so marked a feature in the geology of those regions, have been above alluded to as possibly owing their lack of structure to the enormous thickness of the outflow. There are some things about them, however, that suggest another origin. The great coarseness of grain, the perfection of the crystallization, the abrupt terminations of the belts, the complete want of structure, and the presence of intersecting areas of crystalline granitoid rocks—all suggest the possibility that we have here to do with masses which have solidified at great depths. They certainly can not, however, be regarded as intrusive in the ordinary sense of the word; so that, unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come. The acid rocks cutting these coarse gabbros are clearly intrusive.

Of the original acid rocks of the Keweenaw Series, true granite has been observed only in the Bad River region of Wisconsin, where it is seen intersecting the coarse gabbro of the base of the series, and also the underlying slates. It is there a coarse, flesh-colored, completely developed granite, cutting the gabbro in irregular masses and in broad bands. In the same region a brick-red granitic porphyry or granitell occurs in the same

[1] See A. R. C. Selwyn, in Report of the Geological Survey of Canada for 1877–'78, p. 15 A.

position, as do also thin seams of a material midway between true granite and granitic porphyry.

Closely similar occurrences, both as to the containing and cutting rocks, obtain at Duluth, save that here we have none of the true granite, a brick-red augite-syenite being the principal intrusive rock. As seen at Duluth, this rock often verges closely on granite on the one hand, and on the other can be traced through finer kinds into felsite and true quartziferous porphyry. It intersects the gabbro in the most irregular manner, forming great irregularly outlined patches in it, often many hundred square feet in area, and again occurring in sharply defined veins, a few feet, or even inches, in thickness. Some three or four miles north and west from the lake shore at Duluth, N. H. Winchell reports that most of the hills are composed of a crystalline red rock, similar to that of Duluth.[1]

Mr. W. M. Chauvenet has carried the Duluth gabbro, with its accompanying red rocks, westward for some ten miles and northward for thirty-five miles, to the Cloquet River, where the gabbro appears in large exposures. To the northeast N. H. Winchell reports a similar rock with a similar accompaniment at the headwaters of Poplar River, some 20 miles back from the lake, while Mr. Chauvenet has examined a large area of like character at the headwaters of the Brulé and Cascade rivers, and about Brulé Lake, in townships 62 and 63, ranges 1, 2, and 3 W., where the red rock rises into mountain masses, a prominent instance of which is Eagle Mountain. This lies near the middle of T. 63, R. 1 W., and rises, a bald mass of red rock, to a height of 450 feet above the small lake at its western foot and 1,500 or 1,600 feet above Lake Superior. Similar granitoid rocks occur at higher horizons along the Minnesota coast, and are always in intersecting masses except when tending towards the quartziferous porphyries in character, when they appear to form flows, of a similar nature to those of the latter rock. Intrusive augite-syenites are also met with in the Bohemian Range of Keweenaw Point.

Quartziferous porphyries, in association with bedded diabases and mela-

[1]The Building Stones of Minnesota, 1880, p. 7; also Annual Report of the Geological Survey of Minnesota for 1879, p. 24.

phyrs, are met with at a number of points on the North Shore between Duluth and Saint Ignace Island, south of Nipigon Bay.

One of the most instructive occurrences of true quartz-porphyry that I have yet met with throughout the entire lake basin is at the Great Palisades, on the Minnesota shore, six miles below the little hamlet of Beaver Bay, Sec. 22, T. 56, R. 7 W. The Palisades, which constitute the most striking feature of North Shore scenery between Duluth and Pigeon River, rise in a sheer precipice from the water's edge to a height varying from 150 to 300 feet. The length of the precipice, whose main front looks southeast by east, and runs almost exactly with the general trend of the strata in the vicinity, is about three-fourths of a mile. At the north end, at the mouth of Palisade Creek, the cliff turns to the westward, and facing first north, and then west, is nearly as difficult in ascent in the woods as on the lake front. At the south end the shore of the lake runs back with an east and west course, in such a manner as to expose the mass, with the underlying rocks, in cross-section. The same underlying rocks are cut down into by Palisade Creek below the west cliff, so that the Palisade rock is a detached mass of porphyry three-fourths of a mile long, one-fourth wide, and from 300 to 400 feet thick.

The Palisade porphyry is a hard and dense rock, purplish-red on a fresh fracture, weathering to a light-red and even pink on the face of the cliff. The matrix is thickly studded with sharply outlined, white and partially kaolinized orthoclase crystals, running up to 0.15 inch in length, and somewhat rarer and smaller black quartzes. In many cases the matrix shows a fine banding, due to faint differences in shades of color, lighter colored laminæ appearing to alternate with darker. Sometimes these apparent laminæ are more definite, and from one to two-tenths of an inch in width. More commonly they are exceedingly indefinite, and due to rows of lighter-colored indefinite spots following one direction. Only rarely does the hand specimen show this lining plainly, but on the exposed and weathered surfaces it stands out prominently. In some places a decomposition akin to kaolinization has followed these lines on weathered surfaces, and then there is a cleavage parallel to them, and the resemblance to a material of sedimentary origin is still more pronounced. The lines preserve only a general parallelism to the bedding of the formation, being subordinately twisted and contorted into all sorts of shapes, so that on a cliff-side their inclination often changes from a nearly horizontal one to one of 20° or even 40° within a few feet. Where the lines are developed the crystals of quartz and orthoclase are noticed to bear no relation to them at all, commonly cutting across them, and at all angles, the larger orthoclases even extending across two or three of the lines. Very much of the rock is observed to be without any sign of this lining.

Under the microscope, as shown in the previous chapter, the Palisade rock presents the common characters of a quartz-porphyry, and there is no trace of a clastic nature. The quartzes are all in doubly terminated crystals, and streams of black particles run around them as if pushed aside when the rock was in a viscous condition.[1] The whole rock presents a vertically columnar structure, not developed so completely as in some of the diabases, but still very noticeable. The structure lies at right angles to the dip, which is some 10° to 20°, east-south-east, varying between those figures. In the main cliff, since it trends with the strike, the columns appear at first sight much more nearly vertical.

As already said, both in the Palisade Creek and in the bay at the south end of the Palisades, the underlying rocks are in sight. At the latter place a single cliff-side shows the great porphyry overlying a thickness of 100 feet of diabase and diabase-amygdaloid. These are disposed in two great flows 44 and 56 feet thick, respectively, while the top of a third is seen rising just above the sand. Each of these diabases has most perfectly developed crowning and basal amygdaloids. We have thus a most unequivocal case of the superposition of true quartziferous porphyry upon the typical diabases and amygdaloids of the series.

The same layer that forms the Palisades—or another one closely like it—appears again in a bold point of bare rock 150 feet high, on the northeast side of Baptism River Bay, a mile and a half below the Palisades. Here the underlying diabases and amygdaloids are again seen in position. The top of the point slopes off lakeward with the dip (about 8°). The more minute peculiarities of the rock, and its rude columnar structure at

[1] See Figs. 1 and 2 of Plate XII; also pp. 99 and 109 of this Memoir.

right angles to the dip of the mass, are here just as in the Palisades. The same fine banding also appears in places, but is warped up and down, so as to change from horizontal to vertical within short distances. This rock is traced along the coast for about three-fourths of a mile, when it again disappears *underneath* another series of diabases and amygdaloids, interleaved with which are thin seams of red shale, and one bed of curiously intermingled shale and amygdaloid, precisely resembling the Ashbed of Keweenaw Point. Still three-fourths of a mile beyond, to the northeast, these diabases are overlaid by a pebble conglomerate, in which the matrix is red shale and the pebbles rolled fragments of diabase and amygdaloid.

The occurrence of the porphyry of the Palisades and of Baptism River has thus been given at some length in this connection because the relations of the basic and acid rocks are here so unmistakably plain, and because upon these relations rest important conclusions. There can be no doubt whatever that we have here, between two sets of perfectly and typically developed diabases and amygdaloids, those on the upper side carrying the customary seams of red shale, a true layer of quartziferous porphyry several hundred feet in thickness, while in the previous chapter it has been shown that this porphyry is as truly an eruptive rock as the associated basic kinds, presenting as it does all characters of an eruptive porphyry, viz: a base made up of imperfectly individualized or incompletely devitrified material, doubly terminated quartzes with inclusions of the base and of unmistakable glass, and flowage lines.

Although these rocks show at numbers of other points on the North Shore, the relations of the porphyry to the diabase flows are not always to be so well made out at first sight as at the Palisades. Often the porphyry exposures occur separated from any exposures of other rocks by long pebble beaches. Again they form merely projecting points, or restricted areas between dark-colored rocks, apparently owing their preservation to a sudden bowing down of the strata, so that they represent subordinate synclinals impressed upon the general lakeward dip. In other cases they come into abrupt and vertical contact with dark-colored diabases, and form masses which have been faulted into their present positions. Wherever these less plain occurrences have been closely studied, however, it has become evident that in them, too, we have to do merely with interbedded porphyry masses.

As to the more minute characters of these other porphyries of the North Shore we may say that granitic porphyries are not common; that where they occur, except when almost granite in texture, they can generally be carried directly into true quartz-porphyries, often showing the fine contorted banding of the Palisade rock; and that a very common feature of the quartz-porphyries and felsites is a close, angular jointing, which, on a weathered surface, is often developed to such a degree that it is impossible to obtain a hand specimen of any size, or to get a fresh fracture, a slight blow of the hammer against the cliff bringing down showers of small angular fragments. Where the fine banding mentioned is developed it is frequently possible to trace the rock with contorted banding into massive and wholly unbanded kinds with very large porphyritic quartzes and orthoclases. This change is to be seen beautifully at several points on the Canada shore between Black Bay and Saint Ignace, notably at Bead Island, opposite Lamb Island lighthouse, at the mouth of Nipigon Straits. At one point on the North Shore, between Beaver Bay and the Palisades, was noticed a pinkish quartzose porphyry, in which the lighter matrix is filled with a darker porphyry, arranged in all sorts of fantastic and snake-like forms, single figures extending sometimes for several feet with a width of two or three inches, and running from these dimensions down to mere lines, the whole presenting the appearance of a somewhat irregularly figured carpet. This peculiar structure I attribute to flowing in a viscous condition. At several places, as for instance on the Devil's Track River, near the lake shore, and again on the shore of the Pigeon River Indian reservation, the porphyry was noticed with a tendency to come out in thin, flat pieces, or pieces with a corrugated surface, but in this case, as usual, it runs into the compact structureless kind.

Quartziferous porphyries are again largely developed on the South Shore, with the same structural features as noted on the North Shore. Mount Houghton and the Bare Hills of the eastern end of Keweenaw Point are portions of a belt of banded quartziferous porphyry. These were long since mentioned by Foster and Whitney, who describe the rock as hardened sandstone, but I have been able to detect no trace of fragmental origin, the rock under the microscope, as well as on the large scale, presenting all the characters of an original porphyry. The Mount Houghton porphyry seems to constitute a belt interstratified with the prevailing diabases and standing at a very high angle. It has a considerable lateral extent, and I am disposed to place with it the quartzose porphyry of the Torch Lake Railroad, south of the Calumet mine, which is evidently the source of the pebbles of the Calumet conglomerate.

In the region between the Ontonagon River of Michigan, and the Bad River of Wisconsin, true massive quartziferous porphyries are largely developed. The exposures appear to lie in certain horizons, at least two of which have been recognized, and so to constitute layers in the series, though evidently very much less regular ones than those of the diabase.

In the Porcupine Mountains a quartzose porphyry constitutes the central mass of the mountains, the beds of sandstone, conglomerate and slate dipping away from it on all sides save where it connects on the south with the Main Trap Range. Here the subordinate features of the porphyries of the North Shore are seen constantly repeated, but the mass as a whole is without any trace of stratification. The structure of these mountains is described and illustrated in some detail in a subsequent part of this report.

As already indicated, I conclude with regard to all of these porphyries that they are unquestionably of eruptive origin. That they were formed both after and before the more common basic eruptive rocks is shown by such occurrences as that of the Great Palisades of the North Shore. These porphyry eruptions were evidently more plenty in the earlier part of the time of formation of the series. Still, in the Ontonagon region they occur at quite a high horizon. The structure of the Porcupine Mountains has so much in common with that of the laccolitic mountains of Southern Utah, described by G. K. Gilbert, that they might be supposed to owe their existence to an eruption of the porphyry of their central portions, in which case we should have to believe in an eruption of acid rocks at a time quite subsequent to that of the formation of the latest of the basic flows. But, as shown subsequently, these mountains owe their existence in all probability to a fold, the porphyry of the central portions being one of the usual embedded masses laid bare by subsequent denudation.

The detrital members of the series do not present any structural features that are peculiar to them as compared with similar mechanical sediments of other regions. The conglomerate layers reach sometimes an extraordinary thickness, and are often made up so completely of large-sized pebbles that it is necessary to believe in the existence in such places of very powerful currents. Traced laterally, these conglomerate belts have often a great extent, but they never remain constant as to coarseness or exact nature of materials. The outer conglomerate of Keneenaw Point for instance—that seen from Copper Harbor eastward to the extremity of the point—is undoubtedly the same as the outer sandstone and conglomerate, immediately beneath the black slate of the Porcupine Mountains, and is the same as the great conglomerate of the Montreal, Potato and Bad rivers, in Wisconsin. It has thus a continuous lateral extent as a single layer of at least 170 miles, and possibly a much greater extent; but in this long distance it varies from less than 100 to 4,000 feet in thickness, is now pure sandstone, now nearly all conglomerate, now a sandstone with conglomerate bands, and again a coarse bowlder-conglomerate. Moreover, as already noticed, the nature of the pebbles, while always predominatingly of some one of the acid rocks of the series, presents many variations along the course of the belt, depending upon similar variations in their source of supply. The inner broad conglomerate of Keweenaw Point, which is developed so largely at the mouth of Eagle River, is also represented in the Ontonagon and Porcupine Mountain regions, but on the Montreal has narrowed down to a mere sandstone seam.

Of the thinner conglomerates which are intercalated at all horizons in the Keweenaw Point region, one, the so-called Albany and Boston, lying immediately underneath the Greenstone, has been traced for a distance of as much as 50 miles, but varies along its course from a full conglomerate to a mere red shale seam. From what I have seen I have little doubt that a number of the thinner conglomerates have even a greater extent than this.

CHAPTER V.

GENERAL STRATIGRAPHY OF THE KEWEENAW SERIES.

Separation of the series into a Lower and an Upper Division.—The Upper Division; its thickness; its wide spread underneath the waters of Lake Superior; its surface spread and general characters between Keweenaw Point and the Montreal River.—In Northern Wisconsin.—The sandstones of the Apostle Islands and the Bayfield coast do not belong here.—The Upper Division on Isle Royale and Caribou Island.—The Lower Division; from the nature of the case no subordinate stratigraphy can be laid down for the whole extent.—Characteristics of certain broad horizons.—The very coarse gabbros of Bad and Saint Louis rivers.—The sandstones of the east side of Thunder Bay.—Enormous total thickness of the Lower Division.—Variations in total thickness connected with the origin of the constituent beds.—Remarkable thinning on Bad River.—Thickness on Keweenaw Point.—Between Keweenaw Point and the Ontonagon; west of the Ontonagon.—On Bad River.—The thickness between Bad River and the Saint Croix.—In the Saint Croix Valley.—On the Minnesota coast.—On Isle Royale.—About Black and Nipigon bays.—In the valleys of Black Sturgeon, and Nipigon rivers.—On Michipicoten.—At Cape Gargantua.—At Mamainse.

The most prominent fact in regard to the stratigraphy of the Keweenaw Series is its separation into two grand divisions: an Upper member, made up wholly of detrital material, for the most part red sandstone and shale; and a Lower member, made up chiefly of a succession of flows of basic rocks, but including layers of conglomerate and sandstone nearly to the base, and more or less of original acid rocks.

The line of separation between these two divisions has to be adopted somewhat arbitrarily, since the sandstone gradually increases in quantity upward; but placing it at the base of the outer conglomerate of Keweenaw Point—which corresponds to the top of the upper amygdaloid of the Porcupines, and to the base of the great conglomerate of the Montreal, and which is above any known occurrence of eruptive matter—I estimate the Upper Division to attain a maximum thickness of about 15,000 feet in the middle portion of the Lake Superior basin. Towards the eastern and western ends of the basin the thickness must be much less than this.

The sandstones of the Upper Division are largely concealed beneath the waters of Lake Superior, whose basin has been in some measure carved in them, but they form the outer part of Keweenaw Point, attaining, in the neighborhood of Portage Lake, a considerable surface width. Westward from Portage Lake they underlie the flat land north of the Trap Range, sloping at a low angle lakeward, and are well exposed at a number of points along the shore to the Porcupine Mountains. The Porcupine Mountain fold throws them well out into the lake, but farther west they form a belt along the edge of the land, and, since they are here standing at high angles, a large thickness is embraced in this narrow belt. On the Montreal the angle reaches ninety degrees, and nearly the whole thickness of the Upper Division is crossed by the lower reaches of the river. Here the Upper Division consists of some 12,000 feet of red sandstone and shale, about 500 feet of black shale alternating with hard, gray, nearly quartzless sandstone, both shale and sandstone being composed largely of basic detrital material, and about 1,200 feet of very coarse bowlder-conglomerate. The same succession seems to hold all the way to where, on Keweenaw Point, the base of the Upper Division runs out into the lake—the only difference being that the basal conglomerate at times passes into a sandstone.

Westward from the Montreal River, also, the same succession seems to hold, the conglomerate and shale at the base, however, thinning out. The last seen of these northward-dipping sandstones and shales, which have thus been traced all the way from Keweenaw Point, is on the Brunschweiler River, in the western part of Ashland County, Wisconsin. West of this they have not been observed, the country which would be occupied by them being everywhere drift-covered. The underlying diabases, however, appear all across Wisconsin with a flattened dip, while on the upper Saint Croix River there is a large development of sandstones dipping southward, which are evidently the same that we have been following, forming now the other side of the great synclinal which here crosses the whole northern part of Wisconsin. The same southward-dipping sandstones are to be seen in the northern part of Ashland County.

The Apostle Islands and the adjoining coast of Wisconsin are underlain by horizontal sandstones. These are to be regarded as an overlying, unconformable formation belonging with the horizontal sandstones of the east side of Keweenaw Point;[1] but it is to be observed that it is not structurally impossible that these horizontal sandstones should be the same as those I have been considering, since, according to the structure I have worked out for this part of the basin, the upper Keweenawan sandstones should themselves have here a position not appreciably different from horizontality.[2]

The upper sandstones appear to view again on the south side of Isle Royale, with a considerable development. Caribou Island, south of Michipicoten, appears also to be made of them, but unless the sandstones east of Keweenaw Point represent their upward extension, a point which is subsequently discussed, and which I cannot doubt should be decided in the negative, they do not appear to view at any other point. Still they must have a very extensive development underneath the waters of Lake Superior in its eastern as well as in its western portions.

The Lower Division of the series must, from the nature of the case, present very considerable variations in subordinate stratigraphy and total thickness. For portions of the basin, and even over areas 50 to 200 miles in length, it is possible to recognize a pretty constant subordinate arrangement, the constancy increasing, of course, in inverse ratio with the size of the district considered. It is not possible, however, to lay down any scheme of subordinate stratigraphy which shall hold for the entire extent of the series. This results not only from the mode of formation of the rocks, but from the great similarity of the beds at different horizons, and through great thicknesses. Nevertheless it is possible to make a number of generalizations as to the characteristics of broad horizons which will hold throughout most of the geographical extent of the Lower Division of the series. These are enumerated in the next paragraph.

(1) Coarse-grained rocks, including both orthoclase-free and orthoclase-bearing kinds, though occurring now and then well up in the Lower Division (*e. g.*, some of the beds of the Greenstone Group of Keweenaw Point), are very much more common at low horizons, and the very coars-

[1] Geology of Wisconsin, Vol. III, Part I.

[2] See structural map, Plate XVIII, and the explanations of Chap. IX.

est kinds have been observed only at the base of the series (Bad River gabbros; Duluth gabbros). (2) Very heavy bedding is also much more common at low horizons; and this statement affects both coarse-grained and fine-grained kinds (*e. g.*, the fine-grained diabases of the Duluth Group of the North Shore). (3) The amygdaloidal texture is more frequent and more highly developed at high horizons than at low; the thinner beds generally having the most strongly developed amygdaloidal or vesicular portions. (4) As to the distribution of the different kinds of basic rocks, the fine-grained, olivine-free, or "ordinary" diabases affect very decidedly the higher horizons (*e. g.*, Keweenaw Point), though occurring throughout; olivine-bearing kinds, both the coarse-grained gabbros and fine-grained, luster-mottled kinds, are as decidedly more common at low horizons, though as before not restricted to them (*e. g.*, the Greenstone Group of Keweenaw Point); the ashbed-diabases and diabase-porphyrites are also very much more common at low horizons (*e. g.*, Lester River Group; Duluth Group, &c.); and the same is true of the orthoclase-gabbros. (5) Of the acid rocks all kinds affect especially low horizons, rarely reaching above the middle of the Lower Division. The porphyries of the region between the Ontonagon and Bad rivers on the South Shore seem to be an exception to this rule; but in this case their appearance at so high a horizon may be due in some measure to the thinning out of overlying beds. A more certain exception to the rule is probably to be found in the case of the red felsite of the islands of the harbor on the south side of Michipicoten Island. (6) Detrital beds, chiefly porphyry-conglomerates and red sandstones, occur throughout the series, having been seen all the way from the base to the summit, but they are rare in the lower third of the series, and as a rule increase in thickness and frequency towards the top, only one instance, to be noted hereafter, being known of a heavy bed at a low horizon.

The coarse gray gabbros so largely developed in the Bad River country of Wisconsin, at the base of the series, present the appearance of a certain sort of unconformity with the overlying beds. These gabbros, which lie immediately upon the Huronian slates, form a belt which tapers out rapidly at both ends, and seems to lie right in the course of the diabase belts to the east and west, since these belts, both westward toward Lake Numakagon, and eastward toward the Montreal River, lie directly against the older rocks, without any of the coarse gabbros intervening. The great extent of coarse gabbros in Minnesota seems to sustain somewhat the same relations to the more regularly bedded portions of the series. The Minnesota gabbro, with its accompanying syenite and granitic porphyry, occupies a belt from 5 to 20 or more miles in width, extending from the Saint Louis River at Duluth northward, to and beyond the Cloquet, and thence eastward to the region of Brulé Lake, in township 63; but where the base of the series comes out to the lake at Grand Portage the gabbro is absent, the regularly bedded diabases and amygdaloids resting directly upon the older slates.

For these reasons I was at one time somewhat inclined to place these gabbros with the Huronian, and to regard them as possibly the equivalents of the great flows that crown the so-called Animikie slates in the region of Thunder Bay. In the Bad River region, however, where the rocks all dip at a high angle to the northward, the coarse gabbro appears to cut across the Huronian at a very small angle, and in such a manner as to come into contact with successively lower members of the Huronian,[1] when the rocks are traced on the strike westward. This appears like an unconformity with the Huronian; and on this account, as also because of the close lithological relationship between the gabbros and the typical Keweenawan diabases, many of which approach gabbro in character, and because in a series made up chiefly of eruptive flows dovetailing into one another, there must often be sudden breaks, which in a sedimentary series would argue unconformity, I prefer to regard these coarse rocks as the earliest of the Keweenawan flows. I have already referred in the previous chapter to the possibility of their representing the slowly solidified and subsequently denuded reservoirs from which the later flows may have been in part derived.

I have alluded above to an exception to the general fact of the thinness of the detrital beds at low horizons. The reference was to a set of dolomitic sandstones, running upward into red marly clays and limestones, which are largely developed in the peninsula between Thunder and Black

[1] See Map of Plate XXII, Atlas of the Geology of Wisconsin.

bays, and reach a thickness, according to Bell,[1] of about 1,300 feet. These are the sandstones to which Hunt has proposed to restrict the term Nipigon Group,[2] and which he considers as newer than the Keweenawan, but I satisfied myself on the ground that Logan was correct in placing them directly beneath the whole mass of Keweenawan diabases and amygdaloids of the east side of Black Bay, and that they rest with slight discordance upon the nearly horizontal Thunder Bay slates. It is these slates that Hunt has called the Animikie Group,[3] he regarding them also as newer than the Keweenawan proper. I look upon them, however, as beyond question the equivalents of the iron-bearing Huronian of the South Shore. The relations of these several groups are considered more especially on a subsequent page, and are merely mentioned here, because I know of no other instance, in the entire extent of the formation, of the existence of such a thickness of detrital rocks at so low a horizon. Only forty miles southwestward from their occurrence on the east side of Thunder Bay, at Grand Portage Bay, the intervening space being water-covered, the Keweenawan diabases rest directly upon the slates of the Animikie Group, without any intervening sandstone.

The thickness of the Lower Division is always enormous, and may be placed, in round numbers, at from 25,000 to 30,000 feet. From this figure there are of course some great variations, and yet, considering the way in which most of the series has been built up, the variations must be regarded as surprisingly small. With the exception of the unusually great and sudden thinning in the Bad River region of Wisconsin, it does not appear probable that throughout all of its geographical extent the thickness of the Lower Division ever sinks much below 25,000 feet.

In the eastern part of Keweenaw Point the maximum thickness of the Lower Division at surface is some 25,000 feet. This measurement, however, does not go to the base of the series, but only to the junction with a newer sandstone, which overlies the continuation downwards of the Keweenaw Series, or rather both a repetition of more or less of the thickness included

[1] Report of the Geol. Survey of Canada, for 1867–'69, p. 319.

[2] Second Geological Survey of Pennsylvania "Azoic Rocks" "E," pp. 240, 241.

[3] Loc. cit., p. 240.

in the above 25,000 feet, and the downward continuation of the series. The amount to be added for this downward continuation can only be guessed at.

Eastward from the eastern part of Keweenaw Point to the Ontonagon River the total thickness of the Lower Division seen is from 12,000 to 17,000 feet, but in all this distance only the upper limit of this is in sight, the same fault line and newer sandstone as met with on Keweenaw Point bounding the exposures on the south, and rendering uncertain the total thickness.

West of Lake Agogebic the Eastern Sandstone does not extend far, and the two ranges of Keweenawan rocks, which to the eastward bounded it on the north and south respectively, come together; so that we have, for the first time, the whole thickness of the Lower Division at surface, with its lower limit well defined. On the Montreal River, taking the surface width and dip angles together, the apparent thickness is as much as 33,000 to 35,000 feet, but how much of this may be due to the continuation westward of the Keweenaw fault, or whether this fault extends so far as this, it is impossible to say. It certainly does not extend much farther, and, from its evident rapid decrease in throw from the Ontonagon River westward, it seems probable that its influence on the Montreal cannot be great.

On Bad River, 18 miles southwest of the Montreal, the Lower Division has a surface width, from the Huronian slates below to the sandstones of the Upper Division, of only 17,000 feet. Since the dip here is perpendicular, or nearly so, the thickness is not much less than this. As shown in another place,[1] this extraordinary thinning is connected with the presence below of a great belt of the coarse gabbro described in a preceding paragraph of this chapter. This coarse gabbro—whether with or without interbedded fine-grained beds is not now known—usurps most of the thickness, leaving only some 5,000 feet for the usual thin-bedded flows of the Lower Division. The explanation perhaps lies in the view that, while early in the history of the series there was poured out here an immense thickness of a rock which solidified into the coarse gabbro, later in its growth the vents were removed from here to either side. The coarse gabbro mass must have stood up to a great height, and the later flows terminated against

[1] Chapter VI.

it on either side, until they had accumulated sufficiently to overflow its upper surface.

Twenty miles west of Bad River the coarse gabbro has thinned out, and beyond it to the west and southwest, all the way to the Saint Croix Valley, the Lower Division must have its old thickness of 25,000 feet, to judge from the country covered and dip angles observed.

On the west side of the Saint Croix Valley the thickness must be as great, the surface width from east to west on Snake and Kettle rivers being as much as nine miles, which, with the high easterly dips in the lower layers (45° to 70°), must mean a thickness of nearly 25,000 feet, without reaching either the upper or lower limit of the division.

The Copper Range of Douglas County, Wisconsin, again, appears to indicate by its exposures nearly as great a thickness, for, although the belt of exposures is relatively narrow, its course is oblique to the courses of the constituent beds. The dip of these beds is southeasterly, and in going along the range eastward one is steadily descending in horizon. Here again the lower limit must be several thousand feet below the lowest rock seen.

On the Minnesota coast I estimate the total thickness above the Huronian or Animikie slates to be some 22,000 to 24,000 feet on the west end of the coast, and not more than 16,000 at the east end. This difference is due in large measure to the total disappearance of the coarse gabbro belt of the Saint Louis—a case analogous to that of the coarse gabbros of Bad River in Wisconsin—but also to the thinning eastward of higher layers. Several thousand feet must intervene between the highest rocks of the Minnesota coast and the summit of the Lower Division.

Isle Royale is formed of a succession of beds dipping southward at an angle which increases in amount, as the series is crossed from south to north, from 8° or 10° to a much higher but undetermined figure. The southernmost or highest layers belong to the Upper Division, while most of the island is made up of layers of the Lower Division, with a total thickness which cannot be much less than 10,000 feet, and may be much more. To judge from the courses of the rock belts on Isle Royale and the eastern end of the Minnesota coast, the higher beds of the latter are the same as the lower of the island, and the two together seem to indicate a total thickness of as much as 25,000 feet

About Black and Nipigon bays the Keweenawan flows dip at a low angle to the southeast and south, and reach a total thickness which does not exceed 7,500 to 8,000 feet, measuring from the older rocks upward. The greater part of the Lower Division must here be concealed beneath the lake.

Michipicoten Island, according to Macfarlane's measurements, displays a total thickness of 18,500 feet, all of which belongs to the Lower Division, neither limit of which is in sight. From the position of the island it appears that the thickness here must be 25,000 feet or over. At the promontory of Mamainse, again, according to the same authority, there are 16,000 feet of Keweenawan strata displayed, all belonging to the Lower Division. This thickness is measured from the base of the series, and does not reach as high even as that of Michipicoten. Judging from the lithological characters of the Michipicoten and Mamainse successions Macfarlane considers the rocks of the former to rise to a higher horizon by 4,000 feet, and so estimates the thickness of the Mamainse series at 20,000 feet, without any indication that the upper limit is reached.

CHAPTER VI.

THE KEWEENAWAN ROCKS OF THE SOUTH SHORE OF LAKE SUPERIOR.

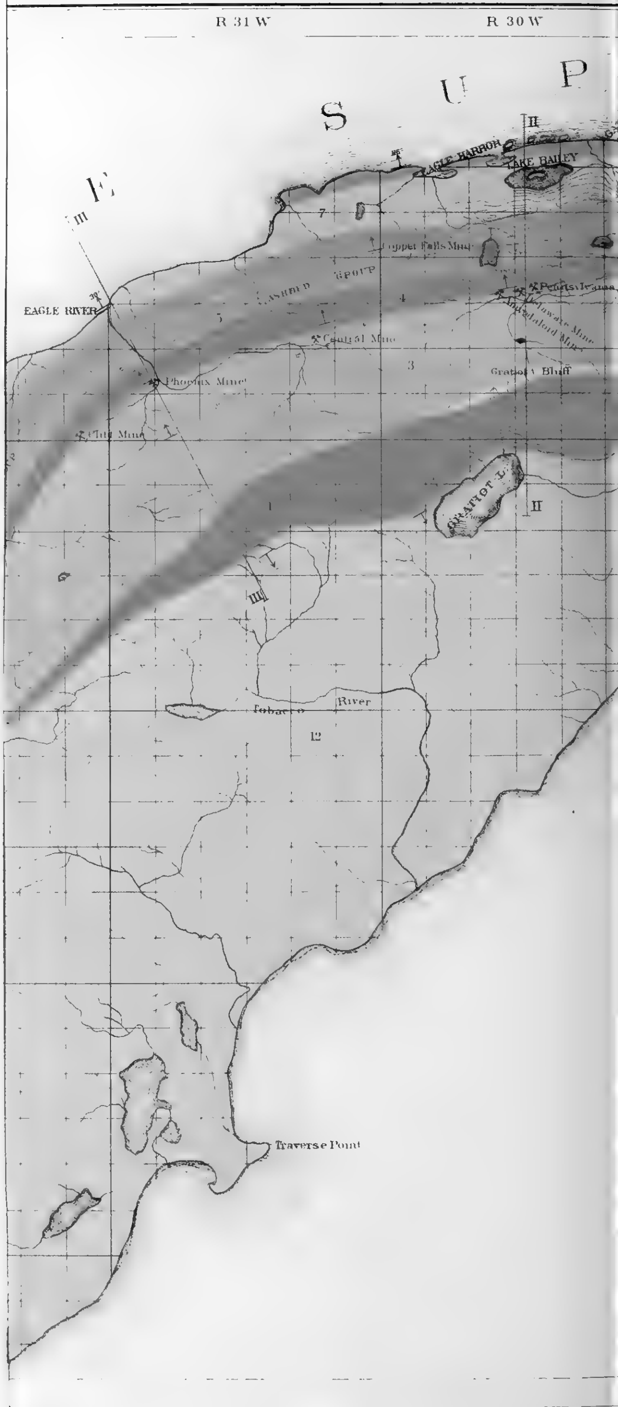
From the Sault westward to Marquette the formations of the country skirting the south shore of Lake Superior are flat-lying limestones and sandstones, ranging from the Niagara above to a sandstone below, which, in common with many preceding geologists, I regard as belonging with the fossiliferous Cambrian sandstone that forms the base of the Paleozoic column of the Mississippi. At Marquette the older granites and schists come out to the lake, and from here to Keweenaw Bay form the country immediately back of the coast, leaving in front, however, a narrow band of the flat-lying sandstone just mentioned.

The most eastern exposure of the Keweenawan rocks of the South Shore is found in the isolated reef known as Stannard's Rock, lying forty-three miles N. $9\frac{1}{2}°$ E. from Marquette and twenty-nine miles from the eastern end of Keweenaw Point. Keweenaw Point is formed of the same rocks, which, as already explained, stretch from here westward continuously into the State of Minnesota. They form the south shore of the lake as far as the Montreal River, beyond which to the head of the lake they are bordered along the immediate coast by a newer horizontal sandstone, but spread over a great width in the northern part of Wisconsin.

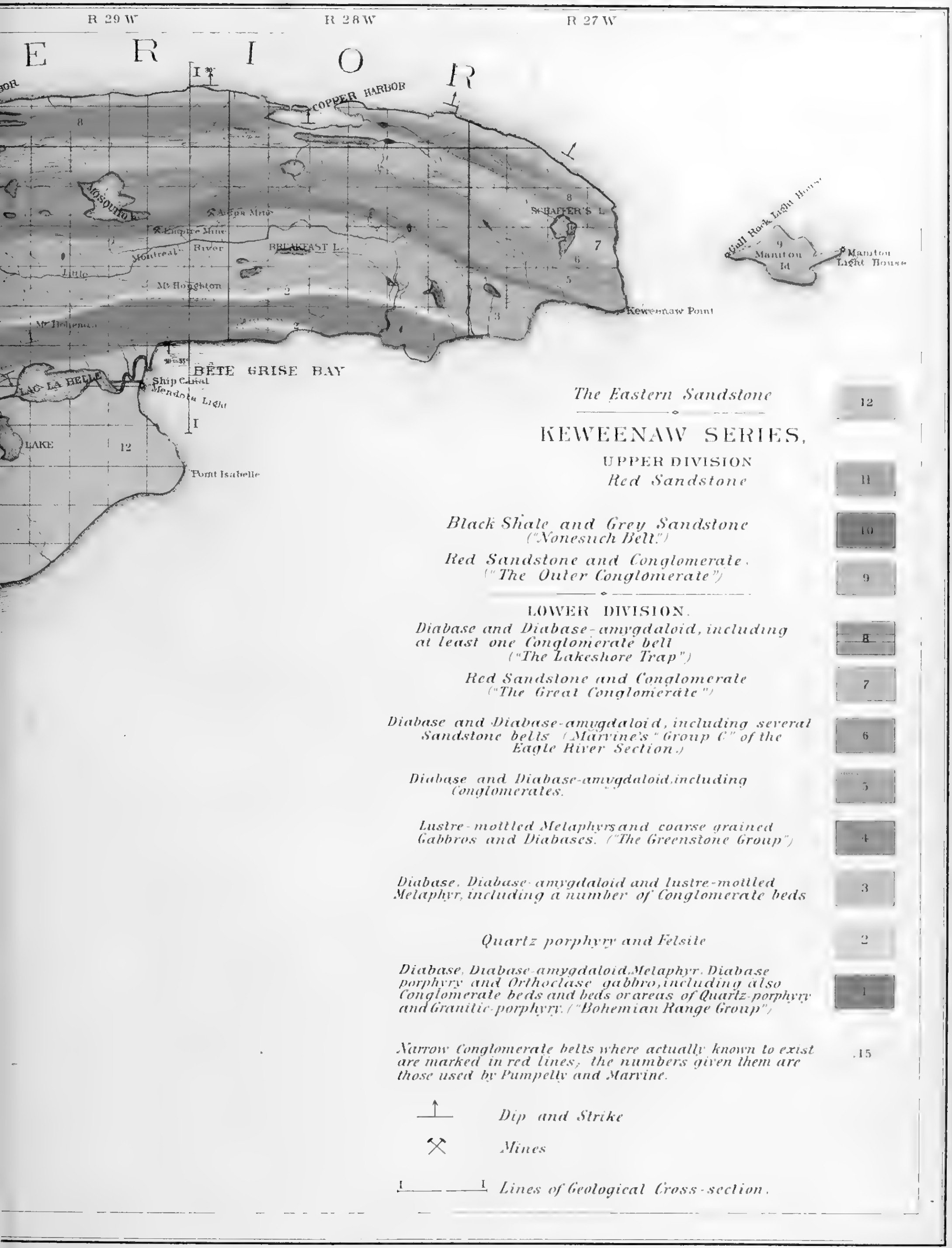
From Keweenaw Point to the Montreal River the Keweenawan rocks dip northward toward the lake. West of the Montreal they form two belts; a more southern one—the continuation of the Keweenaw Point belt—in which the northern dip is retained, and a northern one in which the dip is to the south. These two belts form the opposite sides of a synclinal trough, which has its western termination in the Snake and Kettle River district of Minnesota, where the two belts are found uniting. Beyond the neighborhood of Snake River, the Keweenawan rocks do not extend to the westward, older formations taking their place.

In the detailed descriptions of this chapter I find it convenient to divide the region traversed by the Keweenawan rocks into several districts, which are considered in order from east to west.

The mining region of Keweenaw Point serves as the best point of departure for these more especially local descriptions, since it has been so long known in geological literature, and so thoroughly opened up by mining enterprise. The exposures here are often large, and, for the most part, the structure is easily read. This district, too, embraces the only portions of the entire extent of the Keweenaw Series that have been subjected to



R 31 W
R 30 W
E
S
U
P
EAGLE RIVER
LAKE BAILEY
Phoenix Mine
Central Mine
Gratiot Bluff
GRATIOT L.
River
Traverse Point



A. Hoen & Co. Lith. Baltimore


GEOLOGICAL MAP
of
KEWEENAW POINT
MICHIGAN.
Scale or 1 inch = 3.157 miles
Contour lines 90 feet vertical distance
Topography compiled from U.S. Lake Survey maps and U.S. Land Office plats
Geology compiled by R. D. Irving from maps and reports by Foster and Whitney, Williams, Stevens and Hill, and Pumpelly and Marvine, and from original observations.
LAKE SUPERIOR
R 34 W
R 33 W
R 32 W
R 31 W
R 30 W
R 29 W
R 28 W
R 27 W
COPPER HARBOR
EAGLE HARBOR
LAKE HARBOR
EAGLE RIVER
BÈTE GRISE BAY
LAC LA BELLE
Ship Canal
Manitou Id.
Manitou Light House
Keweenaw Point
Traverse Point
TORCH LAKE
PORTAGE LAKE
TORCH BAY
The Eastern Sandstone
KEWEENAW SERIES.
UPPER DIVISION
Red Sandstone
Black Shale and Grey Sandstone
Nonesuch Belt
Red Sandstone and Conglomerate
The Outer Conglomerate
LOWER DIVISION
Diabase and Diabase amygdaloid including at least one Conglomerate belt
The Lakeshore Trap
Red Sandstone and Conglomerate
The Great Conglomerate
Quartz porphyry and Felsite
Dip and Strike
Mines
Lines of Geological Cross section

careful and minute stratigraphical measurement and study. The region thus furnishes a type to which the less minutely known occurrences in other portions of the Lake Superior basin may be compared, and its name has been appropriately given to the series which forms the subject of this volume.

SECTION I.—KEWEENAW POINT.

In the following descriptions of the Keweenaw Point district I draw freely, of course, from previous publications, and more especially from the reports of R. Pumpelly and A. R. Marvine. My own examinations of this district were devoted both to the obtaining a more thorough understanding of the published results of others, and to the study of points left obscure by former geologists.

The accompanying maps and sections (Plates XVII and XVIII) will serve to illustrate the main points in the topography and geology of the Keweenaw Point district. The topography is from the charts of the United States Lake Survey, including a large scale unpublished map for that part east of Eagle River. The geology is compiled from Foster and Whitney's map (1850), from a map by W. H. Stevens, S. P. Hill and C. P. Williams (1863), from the maps by R. Pumpelly, A. R. Marvine and L. G. Emerson in the atlas of the Geological Survey of Michigan (1873), and from my own observations.

Measured along its middle line from a base line running from the head of the Keweenaw Bay at L'Anse N. 60° W. to Fourteen Mile Point on the lake coast, Keweenaw Point has a total length of 68¼ miles to its eastern extremity. At its base, on the line just mentioned, the point is 34¾ miles in width. From the base the middle line trends N. 32° E. for 21½ miles to the north side of Portage Lake, where the width is 19½ miles; thence it runs N. 40° E. 27 miles to Gratiot bluff—width 12½ miles; thence N. 63° E. 6¾ miles to the bluff south of Mosquito Lake—width 6½ miles; thence due east 10 miles to a point half a mile west of Schlaffer's Lake—width 4½ miles; thence S. 56° E. 3 miles to the eastern extremity. This extremity lies not far from the middle of Lake Superior, being in air line distances 170.5 miles from Sault Sainte Marie, 212 from Duluth, 60 miles from Isle Royale, 38 miles from the south coast in a southerly direction, and 68 miles from the same coast in a S. 17° E. direction.

From the head of Bête Grise Bay eastward the entire width of Keweenaw Point is made up of bold ridges. Further west, however, the ridges that form the northern and northwestern side are bordered on the south by a belt of flat country, which extends in the neighborhood of Portage Lake to a width of some 10 miles, and at the head of Keweenaw Bay to a much greater width. This flat expanse rises to only inconsiderable elevations above the lake level, and ends abruptly against the high land on the north and northwest. Three lakes of some size, La Belle, Gratiot and Torch, lie in this low area just below the south face of the high land, while Portage Lake consists of a wide portion in the low land and a narrow extension cutting entirely through the high land.

East of Gratiot River, the higher portion of Keweenaw Point is made up of a series of sharp and narrow ridges lying parallel with the curving trends of the outer coast line, and coinciding perfectly with the trends of the strata. A line running directly northward across the point from Lac La Belle will cross four of these ridges. On the north shore of this lake the Bohemian Range rises abruptly to a height of over 850 feet. About a mile further north this range sinks rapidly for another mile to the valley of the Little Montreal River, which the line crosses at an elevation of 300 feet above Lake Superior. A little more than a mile beyond the river is met the bold southern cliff of the Greenstone Range, along whose southern foot are strung for more than twenty miles the active and abandoned vein mines that gave this district its reputation in former years. The Greenstone Range on this line rises to between 550 and 600 feet above lake level. Its northern face is a gradual slope conforming with the dip of the strata. The next depression is crossed at $4\frac{1}{2}$ miles, altitude 440 feet; at $5\frac{1}{4}$ miles the "Great Conglomerate" ridge—altitude 700 feet—is crossed; and at $5\frac{3}{4}$ miles the next valley—altitude 90 feet. The next or "North Trap" ridge, the northernmost of the series, is broken down where the line crosses it at $6\frac{1}{4}$ miles, but 2 miles to the east it reaches an altitude of over 700 feet. The north side of this last ridge is again a gradual slope to the lake, which is reached at seven miles. All of these ridges, save the Bohemian, or southernmost, which presents a rounded contour, show the same structure, viz, a steep, often cliff-like, southern face, and a gradual northern slope, coinciding more or less with the dip of the strata.

East of the line of profile just described these ridges continue well marked, some of them quite to the end of the point. Curving to the southward with the strata the more southerly ranges reach the lake soonest on the south side of the point. Westward also the same ridge structure continues well marked to beyond Eagle River, or well around the southwestern turn in the trend of the point. The most northern of the ridges named die out soonest, to the westward, running into the lake between Agate and Eagle Harbors; whence, for some miles westward, the trends of the strata and of the coast line make small angles with each other in such a manner that successively lower layers appear on the shore as it is followed westward. The Greenstone Range lasts the longest of the four, running as far west as Gratiot River.

Beyond Gratiot River the several ridges all merge into one broad swell, with a steep southeastern slope facing the eastern lowland, and a flat northwestern slope towards Lake Superior. As Portage Lake is approached the northwestern slope grows broader and flatter, until in the neighborhood of that lake there is a western as well as an eastern lowland, with this prominent difference, that the eastern lowland ends abruptly against the central ridge, while that on the west merges gradually into it. The same conditions continue to the westward as far as the Porcupine Mountains, viz: a low area bordering the lake, reaching ten or twelve miles in width, which merges southward into a high ridge, which again presents towards a southern lowland a bold south-facing cliff.

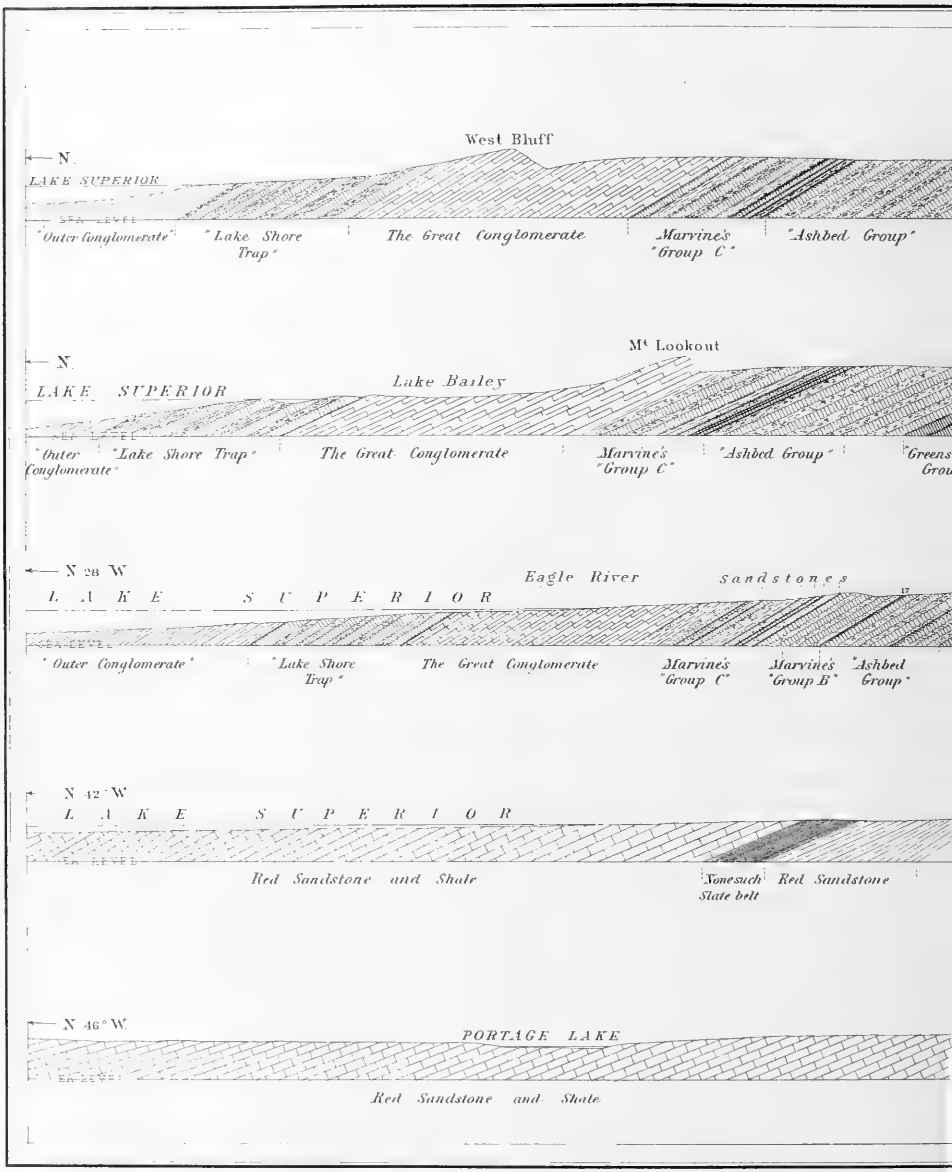
All of the topographical features thus described result directly from the underlying rock structure.

The abrupt break between the eastern or southern lowland and the central ridge is the junction line between a flat-lying sandstone and an older series of northward-dipping resistant crystalline rocks of great aggregate thickness. This line marks also the course of a great fault. The western or northern lowland is again underlain by a sandstone, which in this case, however, is the highest member of the same series that gives rise to the central ridge, whence the merging into one another of this ridge and the western lowland. In the Portage Lake region and westward from that vicinity there is one broad central ridge rather than a series of parallel ridges, on account of the comparatively high dip of the strata—38° to 65°. The western lowland only begins in the vicinity of Gratiot River, because further east the upper sandstones lie beneath the lake. The eastern part of Keweenaw Point is marked by a series of parallel ridges with cliffy southern and flat northern faces, because here the rocks lie flatter, the softer amygdaloids and more easily decomposable diabases wearing into valleys, while the more resistant melaphyrs, coarse diabases and bowlder-conglomerates are left in relief.

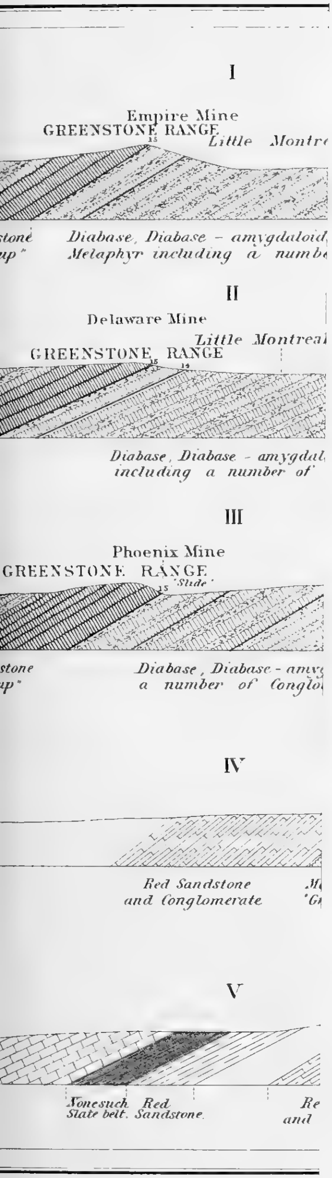
Many other connections between the topography and geological structure of this region might be shown to exist. Not the least interesting of these is the relation of the peculiar line of long narrow lakes and bays, which flank the northern side of Keweenaw Point in its eastern extension, to the easily eroded amygdaloids and other soft beds, out of which these bays are worn. Each bay has a sea-wall of some of the more resistant layers.

In the eastern part of Keweenaw Point, east of Eagle River, there is a maximum thickness of rock of about 25,000 feet below the base of the outer conglomerate, which horizon I have already selected[1] as the dividing line between the Upper and Lower Divisions of the series. This line in the eastern part of the point lies near its northern margin, the dip here being northward, and the strata trending with the curving course of the point itself. As already indicated, neither the upper nor the lower limit of the series is reached on Keweenaw Point, the downward extension being buried beneath the newer horizontal sandstone of the southern lowland, while the upper limit lies under the waters of the lake. Moreover, the southern limit of the exposures on Keweenaw Point is, as explained subsequently, a fault line, running the entire length of the point, and westward beyond the Ontonagon River. This fault does not follow the strike exactly, but cuts across it

[1] Chapter V, p. 152.


West Bluff
N.
LAKE SUPERIOR
SEA LEVEL
"Outer Conglomerate"
"Lake Shore Trap"
The Great Conglomerate
Marvine's "Group C"
"Ashbed Group"
Mt Lookout
N.
LAKE SUPERIOR
Lake Bailey
"Outer Conglomerate"
"Lake Shore Trap"
The Great Conglomerate
Marvine's "Group C"
"Ashbed Group"
N 28 W
LAKE SUPERIOR
Eagle River
Sandstones
SEA LEVEL
"Outer Conglomerate"
"Lake Shore Trap"
The Great Conglomerate
Marvine's "Group C"
Marvine's "Group B"
"Ashbed Group"
N 42 W
LAKE SUPERIOR
Red Sandstone and Shale
Nonesuch Slate belt
Red Sandstone
N 46° W.
PORTAGE LAKE
Red Sandstone and Shale

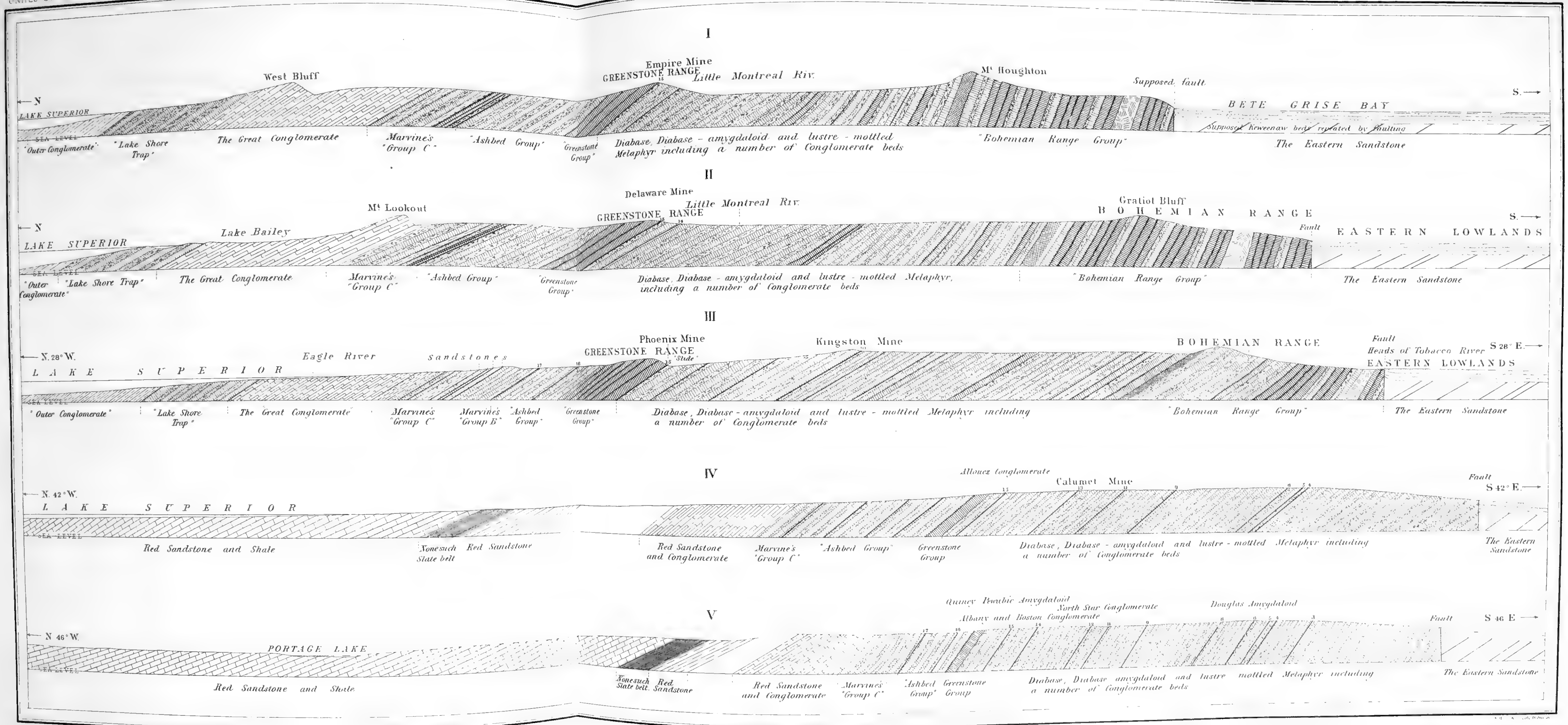
GEO



GICAL SECTIONS

MIC

Scale $\frac{1}{32000}$ or



GEOLOGICAL SECTIONS OF KEWEENAW POINT,

MICHIGAN.

Scale $\frac{1}{32000}$ or 1 inch = 2666 feet

somewhat irregularly, and it results that the thickness above mentioned—25,000 feet—is met with in only one section.

How this thickness is built up I shall try to show by first describing somewhat fully the section measured so carefully by Marvine in a S. 28° E. direction from the mouth of Eagle River to the Phœnix mine. This section I shall next extend roughly downwards to the Eastern Sandstone; adding then brief descriptions of the still higher and lower layers seen eastward from Eagle River, the maximum thickness will be reached. A brief summary of the results of this study will then serve to make them clearer to the reader.

Marvine's work on the Eagle River section did not include microscopic study, but this has since been added by Pumpelly, besides which I have myself examined a number of sections of specimens from here. I have also studied Marvine's descriptions on the ground.

The northernmost rock of this section, seen in the streets of the town of Eagle River and on the banks of the stream near its mouth, is a pebble- and bowlder-conglomerate of great thickness. The horizontal width of this conglomerate exposed is about 1,300 feet, corresponding with a dip of 31° to a thickness of some 700 feet. Higher layers are covered by the lake waters, the overlying diabases and amygdaloids forming a reef some 3,400 feet out in the lake from the mouth of Eagle River. The whole width of the conglomerate thus appears to be some 4,500 feet, and its thickness 2,000 to 2,300 feet.

The always rounded pebbles of this conglomerate, which average from 3 to 8 inches, sometimes reaching a foot, in diameter, and are coarser in some layers than in others, are of four principal kinds. The greatly predominating sort is of a chocolate-brown non-quartziferous porphyry, with a very hard, aphanitic, readily fusible matrix, scattered through which are numerous small, pinkish feldspar crystals. Under the microscope the section of these pebbles shows a matrix apparently wholly crystalline, all portions polarizing in some part of a revolution, and seemingly wholly of orthoclase particles. Thickly scattered through the matrix are minute brown, black and red particles, which must be chiefly iron oxide. The porphyritic crystals are mostly orthoclase, but some of the larger ones are oligoclase.

Next in abundance to these pebbles are others of a pink to red granite-like rock which macroscopically presents a fine-grained, apparently crystalline matrix, through which are thickly scattered porphyritic crystals of pink feldspar. In the thin sections good sized orthoclases and oligoclases greatly predominate. Augite occurs in crystals of some size, which are penetrated by bands and needles of opaque brown ferrite, arranged at definite angles. There is also a considerable portion of the section in which there appears a radial or spherulitic structure, which is either produced or emphasized by the process of alteration. In ordinary light only a radial arrangement of the minute brown particles can be seen, but in polarized light the structure is further brought out by fine lines, which polarize differently, and in which there is a good deal of secondary quartz. This radial arrangement often presents also the appearance of sheaf-like aggregations. It appears in some cases to affect what were originally crystals of feldspar, though it may be chiefly an alteration of the matrix.

Nearly as abundant as these pebbles are others of a medium-grained, very highly crystalline granite, which, macroscopically, is seen to be chiefly formed of fine orthoclase and plagioclase feldspars and gray quartz. Softened black crystals of hornblende, besides chlorite and epidote, are also visible. The thin section reveals a rock composed almost wholly of orthoclase, less abundant oligoclase, and original water-filled quartz. The feldspars are all highly clouded and pinkish-tinted. An opaque brownish substance represents biotite and hornblende in small quantity. Some particles of augite, calcite and secondary quartz are seen.

Much rarer than any of the preceding are pebbles of a true quartz-porphyry, showing a hard purplish matrix, with abundant large black quartzes and flesh-red feldspars. The thin section shows an iron-stained matrix, in which there is but feeble polarization in little flocks of particles, some small areas occurring in which no effect on the polarized light could be observed. Throughout the matrix are numerous minute brownish to black particles, varying in size from those readily seen with a low power to those which could barely be defined with the highest power at command. The quartzes are very large, and present the usual characteristics of rounded doubly terminated crystals and embayments of the matrix. Particles of the matrix, with the same sort of devitrification, are besides entirely included in the quartz, and do not form any part of a projecting neck, as was plainly to be made out with a high power. The porphyritic feldspars in the section are mostly triclinic, and yield the angles for oligoclase. Crystals of augite as large as the quartzes occur, and with similar contours and embayments of the matrix to indicate their corrosion while the rock was still fluid. These augites are filled with the brown ferrite characterizing the augites of the previously described pebbles.

The matrix of the conglomerate consists of the same material as the pebbles in a fine state, and more or less altered, being largely impregnated with calcite. Toward the base of the bed the matrix becomes relatively much more plentiful, until finally the conglomerate merges into a dark-red sandstone of varying coarseness of grain. There are included in this sandstone some layers much darker than the rest, the usual red color being darkened by the admixture of some black particles. The thin section of this portion shows a quite loose aggregation of particles worn from the several kinds of acid rocks, including the matrix, as well as the porphyritic feldspars and quartzes, which are readily recognizable as originally constituents of one of the porphyries. The peculiar secondary quartz so characteristic of the augite-syenites marks some particles as coming from that class of rocks. There is also a little infiltrated calcite and more or less earthy red iron oxide. So far, the rock is just like the predominating red sandstone of this bed, but there is in this section, in addition, an abundance of rounded particles of magnetite, to whose presence the dark color of the rock is undoubtedly due.

Below this sandstone comes a succession of basic eruptive rocks, mostly fine-grained diabases, with their amygdaloidal portions, and occasional interstratified sandstone and conglomerate layers. Marvine has measured in detail a total thickness of 4,845 feet to the southernmost rock in the Phœnix mine, from the base of the sandstone layer just described. This thickness gives a width on the surface of 9,510 feet, the average dip being placed at 30°. Marvine has divided this thickness into four subordinate groups, which are described below in descending order. The descriptions are condensed from the macroscopic descriptions of Marvine's detailed section,[1] and are made to include some of the results of Pumpelly's microscopic investigations.[2]

Of these four groups, the uppermost (Marvine's "c," including beds 1 to 44, inclusive, of his detailed section) has a horizontal width of 2,700 feet, and corresponding thickness of 1,417 feet, extending as far southward as the upper falls of Eagle River. It is mostly made up of sharply separable diabase flows, nearly every one having its well-marked vesicular or amygdaloidal portion, its pseud-amygdaloidal middle portion, and its compact lower portion. The beds, including always these several divisions, run from 6 to 80 feet in thickness, eighteen ranging from 6 to 20 feet, nine from 20 to 40 feet, and three from 40 to 50 feet, while one is 62 feet and one 80 feet thick. The amygdaloidal or true vesicular portions of these beds range from 2 to 10 feet in thickness, rarely exceeding 5 feet. The pseud-amygdaloids run from 5 to 16 feet in thickness, graduating imperceptibly into the compact rock below.

The predominant type of diabase of this group is "a rather fine-grained and compactly textured rock, breaking with an irregular to semi-conchoidal fracture, and somewhat brittle and elastic. The color is generally a dark but dull green, vaguely mottled with purple, the latter often predominating, having in it a mottling of green, and occasionally all is green, a darker shade mottling a lighter background."[3] One light-green bed and two greenish ones are of exceptional character. The green color of these beds is due to the green alteration-product of the augitic ingredient. The thin section sometimes shows much of the augite fresh, but always somewhat altered to the green substance, and in some sections the alteration is nearly or quite complete. The specific gravities range from 2.71 to 2.89. The amygdaloids carry predominatingly calcite in the amygdules, and next prehnite and quartz, the quartz-bearing amygdaloids having often a much indurated matrix. This matrix is only rarely similar to that of the underlying compact diabases, "being almost always very fine-grained to compact, sometimes inclined to earthy, sometimes indurated, and generally

[1] Geological Survey of Michigan, Vol. I, Pt. II, pp. 95–140.

[2] Metasomatic Development of the Copper-Bearing Rocks of Lake Superior. Proc. Am. Acad., Vol. XIII, p. 268 (1878).

[3] Geological Survey of Michigan, Vol. I, Part II, p. 102.

reddish brown in color, with sometimes red crystals of feldspar porphyritically imbedded in it."[1] In some of the harder amygdaloids the base is often greenish in color. In the intermediate pseud-amygdaloids a pinkish radiated prehnite is the chief pseud-amygdule.

Interstratified with the diabases and amygdaloids of this portion of the section are eleven beds of sandstone,[2] running from 3 to 63 feet in thickness, with a total thickness of some 860 feet, and increasing in thickness and coarseness towards the north. They consist of the same materials as already described, and are all of a dark-reddish color. They all contain more or less infiltrated calcite. The section of one of these sandstones, the first below the Great Conglomerate, is figured on Plate XVI, Fig. 3. It shows subangular particles worn from the several kinds of porphyry, chiefly from their matrices. A few of the single quartzes and feldspars of the porphyry are included. Very abundant secondary calcite fills up the spaces between the fragments.

Next below these layers there succeeds a group (Marvine's "*b*", including beds 45 to 66 of his detailed section) 618 feet in thickness, extending from the upper falls of Eagle River southeastward to the so-called and well-known "Ashbed," whose name may not inappropriately be given to the whole group. At both summit and base of this group are diabases of peculiar character.[3] The lower portion of each of these two beds is a hard, brittle, elastic rock, of specific gravity 2.93, with a very fine-grained light-colored purplish matrix, in which are porphyritically imbedded numerous minute plagioclases. The upper portion of each of these beds is a scoriaceous amygdaloid, separated from the main part of the bed by rather a sharp line of demarkation. This peculiar amygdaloid is

composed of irregular bunches or "bomb-like" masses of calcitic amygdaloid, 1.5 feet to .5 inch diameter, filled in with a very fine-grained to compact brick-red material, which often shows fine but irregular bands or lines, apparently of stratification. This material increases in amount toward the top of the bed, where it quite often incloses and surrounds the smaller irregularly round amygdaloidal balls. The strata-like bands are more evident when the material is in larger amounts, and they often

[1] Geological Survey of Michigan, Vol. I, Part II, p. 103.

[2] One more than counted by Marvine. This additional bed was pointed out to me by M. L. G. Emerson, who aided Marvine in preparing his section.

[3] Beds 45 and 66 of Marvine.

seem to separate or open out to inclose the imbedded balls. In appearance it is undistinguishable from the finer-grained sandstones, though perhaps containing more calcite, which is more often collected into small generally lenticular cavities, which are sometimes more numerous in rude narrow bands, parallel with the bedding, than is the case with the sandstones.[1]

That one of these beds which lies at the top of the group has a total thickness of 86 feet, of which 12 are the scoriaceous amygdaloid, 6 pseud-amygdaloid, and 68 compact portion. The corresponding figures for the basal bed of the group are 7 feet, 7 feet, and 31 feet—total, 45 feet. The porphyritic diabase characterizing the lower compact portions of these two beds is the type of the kind described in Chapter III, under Pumpelly's name of ashbed-diabase. This diabase is remarkable for its small amount of augite, the plagioclases making up most of the thin section, and also for its not having the augite contours determined by the outlines of the older feldspar crystals.

Between these two limits the Ashbed Group displays a considerable variation in its subordinate beds. Immediately below the uppermost bed just described (Marvine's 45) come ten thin layers, for the most part under 15 feet in thickness, with very strongly marked and thin amygdaloids and pseud-amygdaloids. The amygdules of the amygdaloids are chiefly calcite and prehnite, less commonly laumontite, while in the pseud-amygdaloids the pseud-amygdules are chiefly a greenish, soft, chloritic substance. Below these again comes a thickness of "curious, coarse, easily decomposable beds of irregular structure," of a dull reddish-brown color, mottled with dark green, or vice-versa, one bed being characterized by the very unusual production, on a large scale, of analcite as a pseud-amygdule. Beneath these layers again is first a bed of semi-columnar, hard, dark-greenish, very fine-grained rock, allied to the ashbed type of rocks. Then follows a thin seam of sandstone a few inches in thickness. Below the sandstone are two heavy beds (64 and 65) of the ashbed type of diabase, with strongly marked amygdaloids.

The massive portion of bed 64, according to Pumpelly, is a

dark-green, almost black, crypto-crystalline rock, which is easily scratched with the knife. Under the microscope, it is found to consist chiefly of plagioclase in very small

[1] Geol. Survey of Mich., Vol. I, Part II, p. 125.

crystals, a soft, green mineral, probably pseudomorphous after olivine, minute grains of augite, and occasional small, often wedge-shaped, occurrences of a green soft substance occupying the interstices between feldspar crystals.[1]

According to the same authority, the amygdaloid of this bed

has about sixty per cent. of its volume occupied by amygdules, sometimes wholly prehnite, sometimes an outer layer of white prehnite, and a central filling of calcite. The matrix is chocolate-brown, and has a crystalline texture wholly foreign to the melaphyrs, and more resembling that of a fine-grained, somewhat oxidized spathic iron ore.[2]

This matrix is seen under the microscope to be almost wholly altered to prehnite, with abundance of particles of iron oxide. The amygdaloid of bed 65 is the layer so well known as the Ashbed, though the name is certainly a misnomer so far as it means to indicate an origin in the condition of volcanic ash. The Ashbed has been much worked for the copper it carries. As already described, this bed is a peculiar mixture of sandstone and amygdaloid.

Below the Ashbed Group comes next a thickness of 925 feet (constituting Marvine's group "*a*," beds 67 to 90, inclusive). This includes a series of beds mostly of very considerable thickness, ranging, for the most part, between 40 and 80 feet, while several are 100 to 150 feet thick. The upper members of the series are made up of "a rather coarse and not closely-textured" rock, which is "tough but not brittle, breaking with a rough fracture. The colors are dirty light-green, strongly mottled with quite well-defined spots of dark-green, * * * ." The specific gravity is 2.87. The "capping amygdaloids are not very strongly developed."[3] One of these layers (69) has been examined microscopically by Pumpelly.[4] This bed

consists of 56 feet of the lower zone, 11 feet of pseud-amygdaloid, and 6 feet of amygdaloid. The lower zone is a fine-grained, dirty-green rock with uneven fracture. It is easily scratched, has specific gravity 2.87–2.95, and the powder yields a little magnetite. The thin sections resemble those of the lower zone of bed 87. The plagioclase is much altered—containing in the freshest many tufts of chlorite—and is often represented only by pseudomorphs of chlorite, and in places these are merged into chlorite pseudo-amygdules. The augite is in part very fresh, in part changed to its characteristic pseudomorph. The amygdaloid is a very compact, hard rock, with subconchoidal fracture. It consists of very irregularly

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[1] Proc. Am. Acad. Sci., Vol. XIII, p. 291.
[2] Proc. Am. Acad. Sci., Vol. XIII, p. 290.
[3] Geol. Surv. of Mich., Vol. I, Part II, p. 101
[4] Proc. Am. Acad. Sci., Vol. XIII, p. 288.

mixed brown and green portions, both hard, the brown abounding in amygdules, from one-third inch in diameter down, chiefly of prehnite; often of prehnite as an outer member, and a central filling of quartz in some, in others calcite. The green contains fewer apparent amygdules. Thin sections of the brown part show the sharp outlines of comparatively large porphyritic feldspar crystals, and of countless long slender feldspar microlites separated by an opaque brown substance. These feldspar forms are now occupied by brilliantly polarizing aggregates of prehnite. Splinters of this brown matrix fuse in the flame of an alcohol lamp. Some of the feldspar forms contain a large amount of soft, light-green, seemingly amorphous mineral, which is, probably, pseudomorphous *after* prehnite; the rest of the pseudomorph in these cases *seems* to be quartz. The amygdules have very sharply defined contours, and form brilliantly polarizing aggregates of prehnite. Quartz occurs in seams which cut through the prehnite of the matrix, and of the amygdules. An examination of thin sections of the green parts shows that they are derived from the brown. They consist still to a great extent of prehnite, and many pseudomorphs of this after the feldspar are visible; but it is everywhere more or less changed to the light-green, soft substance (of which some was seen in the brown variety), and considerable areas of the field are wholly changed to this substance, which is thoroughly cut up by curving cracks of irregular shape and size, which are evidently due to contraction, and are now filled with quartz. But little of the brown staining seen in the brown variety is present here; the iron oxide causing it has, perhaps, gone towards forming the green earth-like alteration-product of the prehnite. Splinters of this variety show under the loupe by transmitted light, nearly opaque, light-green portions, separated by transparent white.[1]

Further down in this division of this series the beds are not well exposed, but finer-grained, darker, and more evenly colored beds seem to prevail. Near the base of the group the beds are heavy and more like those near the summit. The bottom bed (90) is a hard, fine-grained, bluish-black, typically luster-mottled melaphyr.

Marvine's next subdivision (beds 91 to 108, inclusive), in descending order, which we may appropriately call the Greenstone Group, since its great basal bed forms the well-known Greenstone Ridge, he regards as a series of diorites, but Pumpelly has shown that all are pyroxenic. These beds form a massive group, sharply contrasted with all the rocks above them, and with those immediately below. The thickness is 1,200 feet, in heavy beds from 20 to 150 feet or more in thickness. There are no intercalated amygdaloidal bands. Excepting a very massive layer at the base and a thinner one upon the top, all the interior two-thirds of the group have a moderately coarse-grained texture, especially so as compared with the adjoining rocks.

[1] Proceedings American Academy Science, Vol. XIII, p. 280.

The specific gravities of these coarse rocks range from 2.89 to 3.03. They include kinds belonging both to the coarse orthoclase-free diabases and gabbros, and to the orthoclase-bearing gabbros. Bed 94 is of the latter kind. It is made of a coarsely crystalline rock, whose most prominent constituent is a feldspar in narrow tabular crystals. Magnetite, a green and black substance, and apatite are also macroscopically visible. The thin section shows, as original ingredients, apatite, orthoclase, oligoclase, magnetite and augite, with secondary quartz, ferrite, chlorite and magnetite.[1] The basal bed (108) is the type of the luster-mottled melaphyrs, and has been fully described in Chapter III.

These massive dark-colored rocks occur again and again about the Lake Superior basin in just such relations as here, always in a considerable aggregate thickness of relatively heavy beds, always without amygdaloids, and always, in any given district, less abundant than the finer-grained and more easily softened diabases and amygdaloids. To these last-named rocks they always offer a marked contrast, not only on account of their dark color and massive structure, but because of the bold ridges they always form by virtue of their greater resistant power.

Beneath the Greenstone (bed 108), and separated from it by a red clay seam, which is known locally as "The Slide," and is a thin conglomerate bed further east and west, a few hundred feet of rock are exposed to view in the Phœnix mine, which is one of the numerous workings just beneath the Greenstone on north and south, or crossing veins. The total thickness of these beds, which I may appropriately call the Phœnix Mine Group, is 685 feet, in beds ranging from 9 to 160 feet. In the upper part of this group, whose beds are all inclined through their entire thickness to the pseudamygdaloidal alteration, the rock is—

of a rather coarse-grained, inclined to loose texture, being rather soft and tough, and having a very uneven fracture. The feldspar is greenish-white, and occurs in elongated crystals, * * * and in the coarser varieties appears spread like a network upon a background of dark green [and pink, the greenish ingredient a chloritic alteration-product which is] separated into frequent and rather well-defined spots, while magnetic and specular iron are present in large quantities. In the finer-grained beds brownish-red largely prevails, with dirty white in the base, the colors, though dull as in nearly all rocks, being well marked and in strong contrasts. At one or two

[1] R. Pumpelly, *op. cit.*, pp. 275–280.

points the whole rock becomes a nearly uniform, decided brownish-red color. [In looseness of texture, and consequent rough and uneven fracture, these rocks somewhat resemble the typical kinds of the group immediately above the greenstone group (Marvine's "*a*")], but in colors they are decidedly dissimilar. [The lower layers of this group] become finer-grained and more compactly built, harder, more brittle, and elastic, and with more even and conchoidal fracture, while the color darkens, a dark-green predominating, indefinitely mottled with dark dull purple.[1]

In the upper part of the Phœnix Mine Group the amygdaloids are poorly developed, and appear to be mere modifications of the pseud-amygdaloids, "the matrix not being compact, but fine-grained and of a dull brownish-red color, and with but little calcite or prehnite" accompanying the chloritic pseud-amygdules. Further south the amygdaloids are better developed, "calcite predominating in some, prehnite in others."

Southward from the Phœnix mine the rocks are but poorly exposed in the valley between the Bohemian and Greenstone ranges, a few ledges of the typical fine-grained diabase appearing here and there above the surface. At a point 500 paces south of the center of Sec. 37, T. 57, R. 31 W., 4,650 feet southeastward from the lowest rocks of the Phœnix mine, the Kingston conglomerate is exposed,[2] with a thickness of 45 feet, and containing pebbles of an unusually compact brown-red quartziferous porphyry. The covered space between the conglomerate and the Phœnix mine corresponds to a thickness of 2,325 feet.

Southeast from the Kingston conglomerate, the line of section passes through a country for the most part drift-covered, though showing a few scattering ledges. One of these, in the south part of Sec. 4, T. 56, R. 31 W., shows a typical luster-mottled melaphyr, with nodular brown weatherings, closely resembling the rocks of the Greenstone. Another exposure, on the north slope of the Bohemian Range, near its summit, in the middle part of Sec. 9, T. 56, R. 31 W., is a typical brown and green pseud-amygdaloidal diabase, with abundant pseud-amygdules.

Still further southeast, near the southwest corner of section 10, on the old Suffolk mining location, one of the head streams of Tobacco River shows in its bed large structureless exposures of a brown quartzless porphyry, which shows, in an aphanitic, dark reddish-brown to purple, easily

[1] Geol. Survey Mich., Vol. I, Part II, pp. 103, 104.
[2] Marvine, Atlas Geol. Sur. Mich., Plate XXII.

fusible matrix, abundant porphyritic red feldspars, often as much as one-fourth inch in length, many of which are striated. Minute dark-green spots and an occasional tendency in the base to a finely crystalline texture are brought out by the lens. A vein carrying copper sulphide was formerly worked here, and the crystals of the porphyry occasionally carry native copper and silver in minute flakes along the cleavage planes.[1] This porphyry contains 59.52 per cent. of silica. Its thin section shows as porphyritic ingredients, oligoclase, less abundant orthoclase, much altered augite, apatite in large crystals, and magnetite. The matrix appears in the thin section to be composed of a translucent mineral much stained with red iron oxide, abundant black and red particles, and more minute and rare green ones. The principal mineral appears to be orthoclase, the opaque particles magnetite and ferrite, the green ones altered augite. From the older mine workings near these porphyry exposures, much typical prehnitized amygdaloid has been thrown out, showing that we have such rocks continuing close to the porphyry. A short distance down stream from the old mine workings the Eastern Sandstone comes in.

From the line of the Kingston conglomerate to the Suffolk or Praysville porphyry just described is a distance of about two and a half miles. At the usual 30° angle of dip, which holds everywhere north of the Kingston conglomerate, this would add some 6,600 feet in thickness to the section I have been describing. At the Suffolk location the dip was very unsatisfactorily made out, but further east the Bohemian Range shows higher dips than are met with in the more northern ridges, and we may reasonably suppose the same to be the case here. Allowing for this, the last-named figures should probably be increased to some 8,000 feet. The following is a summary of the section thus described, from the northern trap, off the mouth of Eagle River, at right angles to the general trend, and in a S. 28° E. direction, to the Eastern Sandstone:

	Thickness in feet.
The Great Conglomerate, from the outer trap reef, off the mouth of Eagle River, and including the sandstone at base	2,200
Marvine's Group "c"	1,417

[1] As to this, see R. Pumpelly, Geological Survey of Michigan, Vol. I, Part II, p. 39. The exposures are much more satisfactory now than at the time of Pumpelly's examination, owing to the draining of the mill pond and destruction of the old saw mill at this place.

	Thickness in feet.
Marvine's Group "b," or the Ashbed Group	618
Marvine's Group "a"	925
The Greenstone Group	1,200
The Phœnix Mine, or Subgreenstone Group	685
From the base of the Phœnix Mine Group, to and including the Kingston Conglomerate	2,325
From the Kingston Conglomerate to the Eastern Sandstone (estimated)	8,000
	17,390

or, say, between 17,000 and 17,500 feet.

Eastward from Eagle River the several subdivisions of the section thus described continue well marked. In this direction the trend of the strata changes a degree or two in the mile, curving around more and more to the eastward, until, between Agate and Copper Harbors, the N. 62° E. trend of Eagle River has become east and west. Still further east, this curving continues, until at the end of the point it has become some degrees south of east. The dip, too, in the more northerly ranges flattens towards the eastward, becoming in the vicinity of the Delaware mine as low as 24°. A still further flattening is reported towards Copper Harbor, and then between that and the end of the point another increase in the dip angle.

At Sand Point and thence eastward the Great Conglomerate of the Eagle River section is visibly overlaid by an upper series of diabases with strongly marked amygdaloids. These beds are well exposed at Eagle Harbor and at the several similar peculiarly formed harbors further east, all of which are worn in the softer amygdaloids, or in the underlying sandstone, the more compact beds forming the long seawalls of the harbors. This peculiar erosion may be often seen repeated on a smaller scale, as at Eagle Harbor, where each thin amygdaloid is worn back into a long narrow gorge, the harder rock on the south sloping away at the dip angle, that on the north rising precipitously.

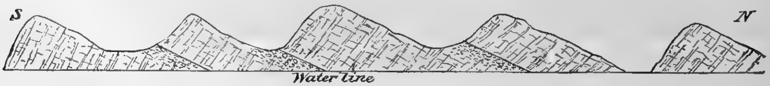

FIG. 2.—Surface contour and arrangement of beds at Eagle Harbor. Represents a distance of about 200 feet. Scale natural.

The beds seen at Eagle Harbor and thence eastward are clearly like many of those already described as occurring below the Great Conglomerate in the

Eagle River section. They are the typical fine-grained diabases, having a grain whose highly crystalline nature can yet be distinctly seen with the naked eye. In the compact portion, which forms much the greater part of each bed, the color is usually a dark brownish-gray to black, with a light shade in more altered layers. Some beds show numerous minute dark-green spots of chlorite, dotting the surface of the fracture. These lower portions have often a strong tendency to a columnar structure, much more marked than usually seen on the South Shore, though not nearly so striking as that often to be observed on the Minnesota coast. The amygdaloids are very thin, and have usually a dark reddish-brown, tough, aphanitic, often very hard, at times soft and earthy, matrix, with abundant calcite and laumontite. These amygdaloids show often a sort of rude stratified appearance of the same nature, though not so pronounced, as that of the stratified amygdaloids of the vicinity of Agate Bay on the Minnesota coast. The typical structure of the diabase flows of the Keweenaw Series is here most beautifully shown, each bed, with its thick, massive, columnar lower portion, and its thin, peculiar, slaggy upper portion, standing out sharply from the adjoining layers. Agates occur quite commonly as sparsely scattered amygdules in the middle and lower portions of the beds.

East of Agate Harbor the whole thickness of these upper diabases comes in—some 1,500 feet—and continues to the end of the point, being overlaid in all this distance by an outer conglomerate, the base of the Upper Division of the series. This Outer Conglomerate forms the greater part of Manitou Island, to the east of Keweenaw Point.

As in the section south from Eagle River, so in the more easterly part of Keweenaw Point, the exposures in the median valley south of the mines under the Greenstone are infrequent. Enough is seen, however, of these covered belts where they reach the shore of Bête Grise Bay, to prove that they are made up of the usual fine-grained diabases and amygdaloids with rarer luster-mottled melaphyrs and porphyry-conglomerates.

The Southern or Bohemian Range, however, shows in the vicinity of Lac La Belle many interesting exposures. The rocks of which this range is made up have been described as wholly different from those of the more northern belts, and have even been regarded, by more than one authority, as belonging to a different rock series. Speaking of the Bohemian Range, Dr. C. T. Jackson says:

> * * * if the rock was not connected with the more hornblendic trap, and in the same line of direction, bursting through the same kind of sandstone strata, I should feel disposed to regard it as of more *ancient origin*. Indeed, I am far from being satisfied that it is not more ancient, for the limited exposure of the rocks does not allow any geologist to be too confident in his opinion respecting its age.[1]

Foster and Whitney say that the Bohemian Range—

> differs from the northern both in lithological character and in the mode of its occurrence. While the former, before described, is composed of numerous beds of trap, in the main of the amygdaloid and granular varieties, interstratified with the detrital rocks, the southern range consists of a vast crystalline mass, forming an anticlinal axis, flanked on the north by the bedded trap and conglomerate, and on the south by conglomerate and sandstone. The contour of the unbedded trap is also very different from that of the bedded trap. We nowhere recognize the stair-like structure in the hills; they are either dome-shaped or rounded.[2]

Elsewhere Foster and Whitney speak of the Bohemian Range as formed by a *later* outflow than the more northern beds, and as having forced the more northern beds into their present inclined position. Charles Whittlesey speaks of the rocks of the Bohemian Range in the same vein, though he calls them Huronian, and hence older than the more northern beds; he refers also to the anticlinal structure described by Foster and Whitney.[3] Still more recently Dr. T. S. Hunt speaks in the same way of the rocks of the Bohemian Range, and quotes approvingly the opinion of Mr. Ernest Gaujot to the effect that they belong to an older series.[4]

Before visiting the Bohemian Range myself I was rather inclined to suppose that its rocks might possibly be, in part at least, more ancient than the typical Keweenawan, and more especially to believe in the existence there of an anticlinal axis, as described and pictured by Foster and Whitney; the existence of which anticlinal I conceived might help to explain

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[1] "Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in the State of Michigan." Ex. Doc. No. 5, p. 473, 31st Congress, 1st sess.

[2] Geological Report on the Copper Lands of the Lake Superior Land District, Michigan, 31st Congress, 1st session, 1849 to 1850, Ex. Doc. No. 69, p. 64.

[3] "Physical Geology of Lake Superior. Proc. Am. Assoc. Adv. Sci., Detroit meeting, August, 1875, p. 71." Col. Whittlesey here speaks of the Bohemian Range rocks as "intrusive Huronian," and yet as having caused the tilting of the more northern rocks of Keweenaw Point, so that it is difficult to tell exactly what he does mean.

[4] Special Report on Trap Dykes and Azoic Rocks of Southeastern Pennsylvania, 1878, p. 230.

some of the grander structural problems that present themselves to the student of Lake Superior geology. A week's study in the field, however, of the region about Lac La Belle, and Mount Houghton, and subsequent examination of a large number of thin sections, have served to convince me, not only that the rocks of the Bohemian Range are an integral part of the Keweenaw Series, but also that they are—with the exception of the brick-red augite-syenites, and possibly also of the orthoclase-gabbro of Mount Bohemia—distinctly bedded; that their rounded contours and lack of stairlike structure are due to a very high northern dip as contrasted with the flat dips of the more northern belts; that no anticlinal axis exists; that the contrast between these rocks and those of the more northern belts has been greatly exaggerated; that those rocks of this series which appear peculiar, viz: quartzose porphyry, and orthoclase-bearing gabbro, are just such as are repeatedly to be seen at similarly low horizons throughout the entire extent of the formation; and that interstratified with these, and predominating over them, are luster-mottled melaphyrs, fine-grained diabases, diabase pseud-amygdaloids, true amygdaloids and porphyry-conglomerates, in no way different from the more northern rocks of Keweenaw Point.

The opportunities for studying the structure of the Bohemian Range in the vicinity of Lac La Belle are very good. By following the south side of the range from the head of Lac La Belle a distance of seven or eight miles to the porphyry bluffs on the north shore of Bête Grise Bay, Sec. 29, T. 58, R. 28 W., one obtains gradually a nearly continuous cross-section of the range, while the large exposures on Mount Houghton and Mount Bohemia, and again on the road from Lac La Belle to the Delaware mine, help greatly towards a shorter and more direct cross-section.

Among the most northern and at the same time most interesting of the belts of rocks which compose the Bohemian Range, using that name now to cover all of the line of elevations south of the valley of the Little Montreal River, is the red felsite which constitutes the bold point known as Mount Houghton. This mountain, whose summit is crossed by the west line of Sec. 24, T. 58, R. 29 W., at 6,250 feet north of the north shore of Bête Grise Bay, is one of the most prominent topographical features on Keweenaw Point. It reaches an altitude of 847 feet, a height which is exceeded by only two or three elevations on the point, viz: Mount Bohemia, which rises to a height of 867 feet from the north shore of Lac La Belle; Gratiot bluff, and another point to the westward on the Bohemian Range, which exceeds 900 feet. Mount Houghton is rendered especially prominent by its isolation, the summit, which has a length of only about a hundred feet, being surrounded on the east and south sides by precipitous cliffs, while all around the ground falls off 200 feet within less than a quarter of a mile.

The rock of which Mount Houghton is composed, and which shows in bold precipitous faces all about the top, is a light-pink to brick-red felsite, without visible porphyritic ingredients. The thin sections of this rock show also no porphyritic quartzes, but some orthoclases which might be called porphyritic. The sections vary from nearly colorless to a deep red, according to the amount of iron oxide present. The matrix in some sections appears to be wholly composed of feebly polarizing, minute orthoclases arranged in a felt-like mass, rarely with linear outlines to the crystals, and is nearly or quite destitute of any non-crystalline matter. Other sections show a much larger proportion of non-polarizing matter, and the feldspars are in thin tabular crystals, with sharply linear outlines. No quartz recognizable as such could be detected with the microscope. Particles of black magnetite are often included, though never abundant. No other accessory minerals were observed. Before the blowpipe this rock is fusible with difficulty, the lighter varieties being somewhat more difficult to fuse than the darker colored ones. The silica content is 76.9 per cent., or greater than it would be were there no silica besides that in the orthoclase.

The general appearance of the mass of rock forming the summit of the mountain is such as to suggest a very high northern dip, some 75°, and this is further indicated by the abundant irregular parallel bandings in the rock of the top of the mountain. The appearance of lamination is produced by waving bands of lighter and darker shading, which are often emphasized by minute quartz seams following their direction.

To the eastward the same felsite shows in the Bare Hills, in Sec. 29, T. 58, R. 28 W., and beyond on the lake shore in section 28. Similar rocks appear on the east point of the bay into which the Little Montreal River empties, and again in Sec. 30, T. 58, R. 27 W., still further east. All of these exposures cannot well belong to the same belt, and it would appear probable that the Mount Houghton rock, along with some smaller elevations leading off from it in an easterly direction, belong with the more easterly of the exposures on the coast, while the Bare Hills belong to another belt.

These red rocks Foster and Whitney regarded as sandstones baked by the heat of the intrusive rock of the Bohemian Range, but they are plainly enough but one phase of the quartziferous porphyries and felsites, which I have heretofore recognized as characterizing the Keweenaw Series throughout its extent. They show no trace of fragmental origin, either microscopically or macroscopically; and if the other porphyries are eruptive, these are as well.[1]

Westward from Mount Houghton I have not seen anything of this porphyry belt, unless—as is very probable—a quartziferous porphyry on the line of the railroad from the Calumet mine to Torch Lake, in Sec. 36, T. 56, R. 33 W., should belong here. On the geological map of Keweenaw Point, by Stevens and Hill, this porphyry belt is indicated as far west as the eastern part of range 32.

South of the Mount Houghton porphyry belt, for a width of from one-half to three-fourths mile, the prevailing rocks are typical fine-grained diabases with the usual pseud-amygdaloids and true amygdaloids, which neither in the specimen nor in the thin section present any differences from the more northern diabases. With these prevailing kinds are several belts of the typically luster-mottled rocks which Pumpelly has called melaphyrs, and which are here very rich in much altered olivine, and are here, as always, sharply distinguished, both macroscopically and microscopically, from the associated olivine-bearing diabases. There are also one or more belts of typical fine-grained diabase of the ashbed type, and two or more porphyry-conglomerates. All of these rocks may be seen well exposed on the road from Lac La Belle to the Delaware mine, especially in the vicinity of the stream in the S. E. $\frac{1}{4}$, Sec. 30, T. 58, R. 29 W., where an arrangement into belts and the usual division of the diabases into massive lower portions and amygdaloidal upper portions is distinctly to be made out.

[1] See Foster and Whitney, op. cit., pp. 64, 65.

A northern dip of some 60° is also plain. The same beds are exposed on the north flank of Mount Bohemia, in the northern part of section 29, in the vicinity of the old Mendota mine, which was worked on a north and south vein. Immediately about the old mine buildings are exposures of a very fine-grained ashbed-diabase. The same beds show on the sides of the ravines immediately south of Mount Houghton.

Still farther south, luster-mottled melaphyrs and olivine-diabases appear to predominate. Mount Bohemia—the high point on the north shore of Lac La Belle—shows immense exposures of these rocks on its southern flanks, where are plainly to be seen all of the characteristics of the melaphyr of the type belt, the Greenstone of the more northern part of Keweenaw Point. There are also large ledges of the same rock, but crumbling and much altered, on the bluff rising behind the old smelting works on the north side of Lac La Belle. On the north shore of Bête Grise Bay again, in sections 25 and 26, where the contact with the Eastern Sandstone may be seen, the rocks are prevailingly luster-mottled melaphyrs, though much crumbled, altered, and seamed with laumontite and calcite. All of these melaphyrs are exceedingly rich in olivine, which, in the thin section, is chiefly represented by a brown or red alteration-product.

Mount Bohemia shows also large exposures of two other rocks, viz: a brick-red augite-syenite, or granitic porphyry, and a rather coarsely crystalline, uralitic orthoclase-gabbro. The former of these two is seen on the upper part of the mountain, and its relation to the adjoining rocks was not satisfactorily made out, though it seems most probable that it is intersecting. The other rock shows lower down, on the southeast side of the mountain, and appears to constitute an interstratified belt (not impossibly an intersecting mass). It is the rock on which were chiefly based the statements of Jackson, Foster and Whitney,[1] and others, that the Bohemian Range is altogether different as to its kinds of rock from the more northern belts. It constitutes, however, but a very small portion of the mass of the range, and

[1] "The lower portion of the elevation is here made up of a peculiar rock composed of chlorite and labrador in nearly equal proportions. These two minerals are each in a distinctly crystalline condition, and the feldspathic portion is of a light-reddish color. The mass is filled irregularly with crystals of magnetic iron ore, which occasionally form a large portion of the rock. Particles of copper pyrites are also scattered through it. This variety of rock seems to pass gradually into the dark-colored, fine-grained greenstone which occurs on the summit of the mountain."—Foster and Whitney, *op. cit.*, p. 65.

belongs plainly enough to a class of rocks which has been recognized at a number of other points in the extent of the formation, and which includes also some of the beds immediately over the Greenstone.

Externally this rock appears to be a mixture of a greenish mineral, with red feldspar and rare magnetite. The thin section shows the principal ingredients to be orthoclase, oligoclase, augite, diallage and titanic iron, the augitic mineral being largely altered to a green uralite, and this still further to a chloritic substance; while very abundant apatite, a gray substance secondary to titanic iron, a little secondary quartz and secondary magnetite, are all to be seen. The thin section of this rock is pictured in Fig. 3, Plate V.

All of the exposures on the bluffs immediately north of Lac La Belle, and of the shore cliffs at the head of Bête Grise Bay, seem to point to a very high northern dip, the strike in this distance varying between north of east and north of west.

Foster and Whitney speak of a belt of "chlorite" as always occurring on the south flank of the Bohemian Range, at the contact with the Eastern Sandstone. They also map it as extending all the way from Bête Grise Bay to Portage Lake.[1] It does not appear to me, after seeing this contact at Bête Grise Bay, at Lac La Belle and on the Douglas Houghton River near Torch Lake, that the supposed chlorite belt is anything more than the usual diabase or amygdaloid greatly decomposed, as it naturally would be along such a contact, and probably also much broken up, as would be the case along such a fault as must have taken place at this contact.[2] Even at these places the decomposition varied greatly in extent, and there was no evidence of any continuous belt, the sandstone being seen at times exactly in contact with a not unusually altered diabase. The contact line between the sandstone and north-dipping traps does not follow exactly any one horizon, but crosses the trend of the trappean belts back and forth in the more easterly part of the point, and farther west rises quite rapidly in the series.

It is worthy of note in this place that the account of the Bohemian

[1] Foster and Whitney, *op. cit.*, pp. 65–67.

[2] The original faulting is believed to have antedated the sandstone, but faulting has taken place here since this sandstone was formed.

Range rocks thus given shows that in this range we have the source of all the different kinds of porphyry pebbles and porphyry detritus which characterize the conglomerates and sandstones of the series, viz: felsite without visible quartz or feldspar (Mount Houghton belt), augite-syenite (Mount Bohemia), quartzless porphyry (old Suffolk location), and true quartziferous porphyry with large porphyritic quartzes and orthoclases (Torch Lake Railroad). The points named are of course not the only ones in which several kinds of porphyry respectively occur, but they serve to show that in these lower belts we are to find the source of all the porphyry detritus—a fact which has never been recognized before. It is shown elsewhere that these original porphyries characterize the formation throughout its entire extent around Lake Superior. Moreover, the variation of the conglomerates as to predominating pebbles, when followed along the strike, is to be connected with the varying characters of the original porphyries when followed in the same direction.

The lowest horizon reached east of Eagle River, or indeed anywhere on Keweenaw Point, would appear to be in the neighborhood of Gratiot Lake. The highest horizon east of Eagle River is reached in the outer conglomerate to the east of Copper Harbor. Between these two limits the eastern part of Keweenaw Point appears to be made up as indicated in the following summary:

	Thickness in feet.
UPPER DIVISION OE THE KEWEENAW SERIES.	
The Outer Conglomerate; porphyry-conglomerate and sandstone, about......	1,000
LOWER DIVISION OF THE KEWEENAW SERIES.	
The Lake Shore Trap; very plainly bedded fine-grained diabases, strongly marked amygdaloids, and one or more thin porphyry-conglomerates; about	1,500
The Great Conglomerate; porphyry-conglomerate and sandstone.............	2,200
Marvine's Group "c"; plainly bedded and separable fine-grained diabases, with strongly marked amygdaloids, predominatingly calcitic; and some 850 to 900 feet, in all, of interstratified sandstones..........................	1,417
Marvine's Group "b," or the *Ashbed Group;* made up mostly of thin, fine-grained diabases, which vary a good deal in appearance, but are generally provided with distinct amygdaloids; including some beds of the peculiar type known as ashbed-diabase; also several scoriaceous amygdaloids, being intermingled sandstone and amygdaloid; also one thin sandstone seam..........	618
Marvine's Group "a"; made up of relatively heavy beds without strongly developed amygdaloids; including one thin seam of sandstone................	925

	Thickness in feet.
The Greenstone Group; made up of relatively heavy beds, without amygdaloids, of rocks for the most part relatively coarse-grained; these belong mostly to the coarse-grained olivine-free diabases and gabbros and to the luster-mottled melaphyrs, or fine-grained olivine-diabases, the Greenstone at the base of the group being of the last-named class	1,200
The Sub-Greenstone Group, in which all of the fissure-vein mines are working; having at top a thin conglomerate, the equivalent of the "Allouez" and "Albany and Boston" conglomerates in the Portage Lake district; composed of fine-grained diabases, with not very strongly developed amygdaloids; about	1,600
The Central Valley Beds; the layers not well exposed, but evidently chiefly fine-grained diabases and amygdaloids, with a number of thin porphyry-conglomerates, in all respects like the overlying group; about	5,540
The Bohemian Range Beds; made up chiefly of diabases and melaphyrs in all respects like the higher layers, and including some of the usual porphyry-conglomerates; but also in part made up of quartziferous porphyry, felsite, and non-quartziferous porphyry, and coarse-grained orthoclase-gabbro; in all, about	10,000
Total	26,000

Southwestward along the strike from the Eagle River type section above described, both the topographical and geological characters of this section soon change. By the time the Gratiot River is reached the several ridges have all merged into one broad swell, the median valley disappearing. The geological changes of importance are: (1) A general thinning of the series, due in some considerable measure to the nearly complete disappearance of the group of coarse-grained diabases and luster-mottled melaphyrs which, under the name of the Greenstone Group, has been described as so prominent a feature in the geology of the eastern part of Keweenaw Point. This thinning, however, is by no means confined to the Greenstone Group, the rocks above and below thinning as well. In the Eagle River section, between the slide at the base of the Greenstone and the base of the Great Conglomerate, there is a thickness of some 4,000 feet, while the equivalent beds at Portage Lake cannot be more than 2,300 feet thick. (2) A considerable increase in the amount of lakeward dip, which at the Allouez mine, Sec. 31, T. 57, R. 32 W., reaches 46°; at the Albany and Boston, Sec. 8, T. 55, R. 33 W., 52°; and at the mines about Portage Lake, 55°. (3) The fault line, or contact with the Eastern Sandstone, is now at a much higher horizon in the trappean series than further east; so much so that in all of the region southwest of T. 57, R. 31 W., all save the very uppermost of the rock belts of the Bohemian Range, using that term in the wide sense of the summary of page 187, are beneath the Eastern Sandstone. (4) On the other hand, west of Eagle River the rock belts soon diverge in strike from the lake coast, striking more to the southward, and, as a result, a rapidly increasing amount of the Upper Division of the series is brought between the trap belt, or Lower Division, and the lake coast. At Portage Lake there must be upwards of 8,000 feet of this Upper Division between the trap belt and the west coast of the point.

Southwest of the Gratiot River, the outcrops and openings are chiefly on those belts whose equivalents in the eastern extension of Keweenaw Point are the ill-exposed and comparatively little known belts of the median valley. Beginning on the south side of Portage Lake, mining openings extend nearly continuously with the course of the layers some seven or eight miles to the northeast, and in the vicinity of that lake are pretty well distributed across the formation, so that Pumpelly's descriptive sections cover nearly all of the Lower Division here at surface. Northeastward from the Albany and Boston mine, as far as the Allouez, the openings are much rarer—one being the famous Calumet and Hecla mine—and the exposures very sparse, the only ones of consequence being at or near the contact with the Eastern Sandstone in the tributary streams of the west side of Torch Lake. This gap Marvine has bridged in his masterly correlation of the rocks of Houghton and Keweenaw Counties.[1]

The Portage Lake section will, then, be best next described, after which the rarer exposures to the northeast may be more briefly alluded to. This section, between the fault line and the conglomerate numbered by him 22, Pumpelly has worked out in great detail. The total length of his measurement is about 14,400 feet, corresponding, with the dip of 55°, to a thickness of about 12,000 feet. With the exception of a few relatively thin conglomerates, this section is made up of beds of diabase and amygdaloid, with some melaphyr, in no respect different from the prevailing beds of the Eagle River section. The lower layers are heavier than the

[1] Geological Survey of Michigan, Vol. I., Part II, Cap. IV.

higher. Certain portions of the thickness are marked by certain distinguishing lithological characteristics,

which, without in any instance being peculiar to a given horizon, still serve to mark decidedly those parts of the series where they are, respectively, most frequent. Thus, to begin towards the eastern part of the field, from the neighborhood of "Mabb's vein"[1] to within, say, 1,000 feet east of the Isle Royale "vein,"[1] there is a tendency, among the different traps, to a compact or fine-grained texture with a dark-green, almost black color, sometimes slightly mottled, especially on the weathered surface. * * * From this region till 1,500 feet or more west of the Isle Royale copper-bearing bed, the upper portions of very many of the beds have the amygdaloidal cavities filled with a light-greenish white or pale pink prehnite, which sometimes, for a width of 2 to 6 feet, form 10 to 40 per cent. of the rock, and lend it a very characteristic spotted appearance. During the next 2,000 feet or more, the traps have frequent seams 3 to 20 inches thick, consisting of distinctly individualized triclinic feldspar, delessite, prehnite and specular iron; these occur both parallel to the plane of the bedding and oblique to it. The traps through a portion of this distance are frequently impregnated with epidote, as is also the cement of the conglomerate beds. On the "Dacotah" property we come to a belt of the formation in which many beds have a tendency to a coarse-grained, crystalline texture, and in some, the character is highly developed. * * * * Still further west, on the "South Side" property, the brown amygdaloids often present a scoriaceous appearance which is quite characteristic. Some, at least, of these features are traceable for miles in the longitudinal extension of the zones in which they occur.[2]

Below the upper limit of Pumpelly's Portage Lake section—conglomerate 22—he recognizes twenty interstratified porphyry conglomerates, which he numbers from below upwards; the twenty-first, or No. 13, not having been met with on Portage Lake. It is the well-known Calumet conglomerate. Of the Portage Lake conglomerates, three—Nos. 1, 2, and 3—about 50 feet thick each, lie in the lower 2,900 feet. Then follows a zone of about 1,300 feet, in which there are five conglomerates—Nos. 4, 5, 6, 7, and 8—from 2 to 20 feet thick. Next follow 2,250 feet without conglomerates. Then for 5,000 feet in thickness are eight conglomerates from 200 to 1,000 feet apart, and from mere seams to 30 feet in thickness. These are Nos. 9, 10, 11, 13, 14, 15, 16, and 17. Then four conglomerates—Nos. 18, 19, 20, and 21—aggregating 200 feet in thickness, in a zone of only 550 feet. In the total thickness of 12,000 feet measured, the conglomerates aggregate about 580 feet, in twenty-one different layers.[3] According to Pumpelly,

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[1] Copper-bearing amygdaloids.

[2] Geological Survey of Michigan, Vol. I, Part II, pp. 17, 18.

[3] The figures here given are taken from Pumpelly's sections in the Atlas of the Geological Survey of Michigan, and do not in all respects conform with those given by Marvine in Vol. II, Geol. Surv. Mich., p. 61.

The conglomerates of Portage Lake differ from each other but little, if at all, in lithological characteristics. The pebbles vary from the size of a pea to one foot or more in diameter, being coarser in some beds than in others. * * * * The pebbles, in most of the beds on Portage Lake, consist almost exclusively of varieties of non-quartziferous[1] felsitic porphyry; two kinds predominate; one of these has a chocolate-brown to liver-brown, subcrystalline to compact almost vitreous matrix containing very scattered minute crystals of triclinic feldspar of the same color as the base. The other and rarer variety, also non-quartziferous, has a chocolate-brown, compact to minutely crystalline matrix, in which lie crystals, $\frac{1}{8}$ to $\frac{1}{2}$ inch long, of a flesh-colored triclinic feldspar. In some beds there appear pebbles of a flesh-red rock,[2] composed almost entirely of granular feldspar, containing small specks of a black undetermined mineral. In some instances the feldspar is wholly triclinic, in others the twin-striation is frequently absent. This variety of pebble is altogether absent in some beds, at least where they are opened, while in others they predominate, as in the Albany and Boston Conglomerate. Pebbles of compact melaphyr[3] and of melaphyr-amygdaloid[4] also occur, but are quite subordinate in number to those already enumerated. The normal form of cement is a fine-grained sandstone, composed apparently of the same material as the pebbles. Often the cement is very subordinate in volume, the pebbles touching each other. Frequently, however, the reverse is the case, and often, the sandstone forms layers from less than an inch to many feet in thickness.[5]

The large dump at the old shaft of the Albany and Boston mine is a good place to study these conglomerates. The pebbles are usually large, sometimes six inches or a foot in greatest diameter. They are commonly oblong, or flattened. A pink to brick-red, medium-grained, highly-crystalline augite-syenite predominates, but dark-red to chocolate-brown, aphanitic, felsitic porphyry is abundant. I have studied four typical samples of the pebbles of this conglomerate, both macroscopically and in the thin section.

Of these the first is a finer-grained but distinctly crystalline, dark reddish-brown augite-syenite, the predominant red color being thickly dotted with small black points. In the thin section the chief ingredient is seen to be oligoclase in quite good-sized and fresh crystals. Orthoclase follows next, and there is some quartz, most of which appears to be of a secondary origin. The black particles seen macroscopically resolve themselves into open aggregations of brown ferrite and black opacite (magnetite and ferrite), commonly of very irregular outline, but not unfrequently having linear boundaries. From the same appearances seen in many others of

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[1] Evidently meaning without visible porphyritic quartz.
[2] Granitic porphyry or augite-syenite of this volume.
[3] Diabase of this report.
[4] Diabase-amygdaloid.
[5] R. Pumpelly, in Geological Survey of Michigan, Vol. I, Part II, pp. 16, 17.

these augite-syenites, I take these aggregations to be altered augite, of which mineral a brightly polarizing core is now and then visible. Magnetite and apatite also occur in the section.

The second pebble shows a much lighter red and coarser rock than the last, with much rarer black particles. The thin section of this is composed chiefly of orthoclase, oligoclase—the latter less abundant than in the preceding pebble—and secondary quartz. A marked appearance of spherulitic structure runs through the slice, being produced by the radiating arrangement of the secondary quartz. Unmistakable augite is seen in this section, and is largely replaced by ferrite and magnetite. These aggregations are, however, much rarer than in the previous pebble.

The third pebble is close to the last, but deeper red in color. It shows in the section orthoclase and oligoclase predominating, and some secondary quartz, but no spherulitic structure. There is much red oxide of iron, plentiful needles of brown ferrite arranged in definite directions, and a little quite fresh augite.

The fourth pebble shows an aphanitic, hard, chocolate-brown matrix, fusible with difficulty, with a few minute porphyritic feldspar crystals. In the section of this pebble the matrix is made up chiefly of a translucent substance much stained with red iron oxide, and thickly studded with minute black, opaque particles. The porphyritic feldspars are triclinic, and there are also a few good-sized augites with the usual ferritic alteration.

Conglomerate 22 of Pumpelly's section[1] on the south side of Portage Lake corresponds either to the base of the main or Great Conglomerate of the Eagle River section, or to one of the sandstone layers immediately below that horizon. On the north side of Portage Lake, both on the road running westward from Houghton, and in the ravine just west of the Mineral Range Railroad, in the southern part of Sec. 22, T. 55, R. 34 W., are black shales, which are unquestionably the same that are found all the way to Bad River, in Wisconsin. These shales belong over the outer conglomerate of Keweenaw Point. Between these two horizons is a horizontal width of some 4,800 feet. In the southeastern part of this space the layers dip at a high angle—40° to 50°—northward, but this angle must rapidly decrease to the

[1] Atlas Geological Survey of Michigan, Plate XIV–XIX.

northwest, for at the Atlantic mill, on the south side of Portage Lake—N. W. ¼ Sec. 34—sandstone is observed dipping northwest 28° to 30°, while the shales in the ravines on section 22, near the railroad, dip at 26° only, so that the entire rock thickness in this space cannot be more than 2,500 to 2,600 feet.

Within this thickness must be crowded the equivalents of the Great Conglomerate, of the outer or Lake Shore Trap, and of the Outer Conglomerate of the district east of Eagle River, a total thickness of some 4,700 to 4,800 feet. Within this space must come also the dividing line between the Upper and Lower Divisions of the series. The only exposures in this interval, however, are those of the sandstone near the Atlantic mill, on the south shore of Portage Lake, and one conglomerate near the southeastern side of the gap. Between this sandstone and the base of conglomerate 22 is a thickness of some 1,400 feet, and it would appear probable that the sandstone belongs to the top of the Great Conglomerate. This sandstone is a reddish kind, much of the usual character, and is in its lower layers very conglomeratic, becoming even a moderately coarse conglomerate. This character may be very well seen on the road from the Atlantic mill to the Atlantic mine. The finer-grained sandstone was examined under the microscope, and showed a fine reddish matrix of subangular to angular fragments of the usual porphyry detritus, but with an abundance of angular quartz particles. Scattered through this finer matrix are large particles, many of which are single quartzes. There are also among them single feldspars, chiefly orthoclase, particles of porphyry matrix and here and there diabase fragments. The abundance of angular quartz fragments, both in the finer matrix and in the larger particles, is a matter of interest, since these fragments are unusually full of large cavities, filled with a bubble-bearing fluid, in many of which there is to be seen a little cube of salt. These characters seem to render it improbable that these quartz fragments should have come from a quartziferous porphyry. Their origin is very doubtful.

Of the Upper Division in the Portage Lake region the exposures are not plenty. The shales of the ravine near the Mineral Range Railway; the same shales with sandstones on the wagon-road west from Hancock; the dark sandstone belonging near the same horizon in the quarry on the north side of Portage Lake, two miles below Hancock; the sandstone on the Lake Superior coast, near the mouth of the ship-canal, and a few other small and indefinite sandstone exposures, are all that have come to my knowledge as occurring anywhere near the line of section now under description. That the whole distance between the upper limit of the Lower Division and the main lake coast is occupied by sandstone, at all events with not more than a very few subordinate layers of diabase near the base of the Upper Division, is not only inferred from the topography, and from all that can be learned of the Upper Division of the series farther west, where sections across most of its thickness can be seen, but also seems to be proved by the exposures along the coast of Keweenaw Point, north of the ship-canal entry.

The black shale and associated sandstone occurring west of Hancock are of peculiar interest because they unquestionably mark the same horizon as that of the black shale and sandstone of the Porcupine Mountains, and thence many miles both to the east and west. They vary from light-gray, rather fine-grained sandstones, to nearly black shales and shaly sandstones. They are closely associated with and even interstratified with coarser and redder kinds, which are yet of a darker shade than the usual red sandstone. All appear to consist chiefly of the usual porphyry detritus, but the particles are predominatingly either the originally porphyritic feldspar or quartz, particles of matrix being subordinate. There is also in every section more or less basic detritus, in the shape of rounded particles of magnetite and augite, the latter often much altered to a greenish substance, and particles of the basic rocks showing the several ingredients together.

On the lake shore, a mile below the entrance to the ship-canal, Sec. 29, T. 56, R. 34 W., begins a long line of low cliffs of sandstone, which extend westward for some miles. These sandstone layers dip lakeward about 8°, and strike more to the southward than the lake coast, so that higher layers come in to the westward, in which direction also the dip continues to flatten. The rock seen on section 29 is mostly red shale, but there are heavier layers of relatively coarse sandstone, sometimes light-gray, sometimes brownish-red, and again bright-red, irregularly mottled with the light-gray kind.

Briefly summarized, then, the Portage Lake section is as follows:

UPPER DIVISION OF THE KEWEENAW SERIES.

	Thickness in feet.
Largely covered, but apparently for the most part red shales and sandstone; towards the base there is a considerable thickness (upwards of 200 feet) of dark-colored, fine-grained sandstone and black shale, in which the usual porphyry detritus is mingled with more or less basic detritus; the lowest layers are also conglomeratic; in all about	9,000

LOWER DIVISION OF THE KEWEENAW SERIES.

Covered space of some 1,200 feet, in which must be the equivalents of the outer trap of the eastern part of Keweenaw Point, corresponding to a thickness of about	500
The Great Conglomerate, including the sandstone and conglomerate at the Atlantic mill and conglomerate 22 on the south side of Portage Lake, with some intervening exposures; about	1,500
Diabase	66
Conglomerate 21	15
Diabase and amygdaloid	51
Conglomerate 20	19
Diabase	100
Conglomerate 19	13
Diabase	94
Conglomerate 18	155
Diabases and amygdaloids	340
Conglomerate 17 (Hancock West)	32
Diabases and amygdaloids; including the South Pewabic cupriferous amygdaloid at 50 feet below 17	550
Conglomerate 16 (not seen on south side Portage Lake)	10
Diabases and amygdaloids; including, at 400 feet above conglomerate 15, the Pewabic cupriferous amygdaloid or "lode" so largely worked for copper on the west side of Portage Lake	900
Conglomerate 15 (Albany and Boston conglomerate on the north side of Portage Lake)	33
Diabases and amygdaloids	330
Conglomerate 14 (the Houghton conglomerate of the north shore)	2
Diabases and amygdaloids	1,460
Conglomerate 12 (north side of Portage Lake)	3
Diabases and amygdaloids	680
Conglomerate 11	20
Diabases and amygdaloids	200
Conglomerate 10	60
Diabases and amygdaloids	460
Conglomerate 9 (sandstone seam)	

	Thickness in feet.
Diabases and amygdaloids; including, at 670 feet above conglomerate 8, the Grand Portage cupriferous amygdaloid, and at 510 feet the Isle Royale cupriferous amygdaloid, largely worked on the south shore of Portage Lake	2,050
Conglomerate 8	12
Diabases and amygdaloids	420
Conglomerate 7	24
Diabases and amygdaloids	260
Conglomerate 6	3
Diabases and amygdaloids	181
Conglomerate 5	24
Diabases and amygdaloids	240
Conglomerate 4	12
Diabases and amygdaloids	1,149
Conglomerate 3	56
Diabases and amygdaloids	370
Conglomerate 2	35
Diabases and amygdaloids	1,140
Conglomerate 1	97
Amygdaloid	14
Total	22,680

The comparatively rare exposures to the northeast of Portage Lake and to the southwest of Gratiot River exhibit only a few points of particular interest. One of the most striking of these is the great change, already alluded to, that takes place in the nature of the conglomerate about six miles from Portage Lake. About Portage Lake the greatly predominant pebbles are compact felsites or porphyries with only feldspars, and no visible quartz, while augite-syenites are found in some beds. Porphyries with visible free quartz are unknown. Towards Calumet, however, all of the conglomerates show true quartz-porphyry predominating among the pebbles, while still further to the northeast the quartzless porphyries again predominate, although not to the exclusion of those with visible quartzes. This change, as pointed out by Pumpelly[1] and Marvine,[2] must be due to a variation in the nature of the source, in a direction parallel to the general trend of Keweenaw Point. This source Marvine and others would place north of the point where now lie the waters of Lake Superior. I have already shown several times that the porphyry conglomerates derived their pebbles

[1] Geol. Survey of Mich., Vol. I, part II, p. 17. [2] Geol. Survey of Mich., Vol. I, part II, p. 60.

from belts of rock within the same formation, and have also shown the existence of such a belt in that of which the Mount Houghton rock forms a part.

I was also fortunate enough to find in position, south of Calumet, on the Torch Lake Railroad, a quartz-porphyry precisely like the pebbles of the conglomerate about Calumet. The rock is poorly exposed, but unquestionably in place and unquestionably original. It lies in the southern part of Sec. 36, T. 56, R. 33 W., near the southern border of the Trap Range, and is just about the horizon of the Mount Houghton felsite belt, of which, or of a closely parallel one, it may be reasonably regarded as the continuation. The rock exposed here shows a dark-red aphanitic matrix, through which are scattered very abundant and large porphyritic quartzes and feldspars. The quartzes are black, and reach two-tenths inch in diameter; the feldspars red, partly quite fresh, partly much altered and whitened. They run from two-tenths to one-fourth inch in length. Some show striations plainly. Under the microscope the very large quartzes are seen to exhibit all the usual characters of the quartzes of such rocks. The grains are single crystals, or parts of single crystals, often showing plainly the rhombohedral planes, more rarely the prismatic. Commonly the grains are much rounded and penetrated by bays and lines of the matrix. The feldspars are chiefly oligoclase, but orthoclases are also frequent. Augite crystals, largely replaced by magnetite, appear porphyritically. The matrix presents, for the most part, a faint pinkish color and a cloudy appearance. Thickly scattered in it are minute brown particles and needles of ferrite, arranged in lines whose directions show most beautifully the so-called flowage structure. This matrix affects the polarized light but very little, if at all. Other portions of the matrix, of a white color, appear to consist of individualized quartz and feldspar, the former perhaps secondary. Calcite is also seen in small particles in these places. This rock is pictured at Fig. 2, Plate XII, where is also figured a section of one of the common porphyry pebbles of the Calumet conglomerate. The identity of the two is readily apparent.

The map and sections of Keweenaw Point accompanying this description (Plates XVII and XVIII), along with the general map illustrating the structure of the Lake Superior basin, will help greatly to convey a correct idea of the structure of this district. The map and sections of Keweenaw Point are compiled from all available sources, including original observations and original deductions from the work of others. In this connection should be studied, by any one desiring to understand the stratigraphy of Keweenaw Point more in detail, the correlation chart by Marvine, with his admirable explanations, given in Vol. I of the Geological Survey of Michigan.[1] The Eastern Sandstone, and the relations which subsist between the stratigraphy of Keweenaw Point and that of other parts of the extent of the formation are considered hereafter.

Stannard's Rock.—Twenty-nine miles S. 51° E. from the eastern extremity of Keweenaw Point, and 43 miles N. 10° E. from Marquette, there is an isolated reef rising abruptly from very deep water. Above water the rock is only a few feet square, but the entire reef is some 3,500 feet in length, as I learn from a large scale chart furnished by the United States Lake Survey. This length is divided into two portions by a gap some 600 feet wide, in which the water is some 40 feet deep, the depth in the open lake, just outside the reef, exceeding 600 feet. The northern portion of the divided reef trends northwest, and has above the 20-foot contour a length of some 1,300 feet and width of 800 feet. The southern part of the reef trends slightly east of north, and is 1,700 feet long by 50 to 300 feet wide above the 20-foot contour. To judge from the soundings of the Lake Survey chart, this reef and another more deeply buried ridge to the west of it, might be the outcropping edges of layers trending north and northwest, and dipping eastward at rather a high angle.

Foster and Whitney, quoting from Mather, speak of the rock of Stannard's Rock as a sandstone,[2] but the specimen furnished me by the kindness of Mr. John Chassells, of Houghton, Mich., is a dark-brown felsite. In the thin section this felsite shows a base composed of a mixture of quartz, which in part appears to be secondary, a considerable proportion of pink-stained non-polarizing matter, and many nearly to quite opaque dark-brown, black, occasionally (in transmitted light) red ferrite particles, of wholly irregular shape. There are also included numerous larger brown and black porphyritic particles, with crystalline outlines, which now and then appear

[1] Vol. I, Part II, Chapter IV.

[2] *Op. cit.*, p. 20.

as if rounded or eaten into by the matrix. Cores of brightly polarizing augite remain in many of these crystals, and where the black material is very thin it transmits a red light. The crystals are thus seen to be augite, with a ferritic alteration. The silica content is 65.8 per cent. Evidently we have, then, in the Stannard's Rock reef, one of the felsite belts of the Keweenaw Series which have furnished so many of the interbedded conglomerates with pebbles, the sections of many of these pebbles appearing precisely like that of the Stannard's reef rock. The shortness of the reef coincides perfectly with what is known of these felsite belts elsewhere. The belts themselves are often relatively short, and, moreover, tend to stand up in just such summits, some parts of the belt resisting erosion more than the rest. Mount Houghton is just such a summit, and it would not be a bold speculation to consider Stannard's Rock and Mount Houghton as parts of the same belt, or rather as belonging near the same general horizon. However that may be, Stannard's Rock certainly marks for us the course of the Keweenaw Point Range. At the end of the point the beds are trending directly towards Stannard's Rock, whose own curving trend coincides perfectly, as subsequently shown, with the general structure that I have worked out for the whole Keweenaw basin.

SECTION II.—THE REGION BETWEEN PORTAGE LAKE AND THE ONTONAGON RIVER.

In the 40 miles that intervene between Portage Lake and the Ontonagon River the exposures are not abundant until the latter stream is nearly reached. Evidently enough, however, the conditions observed at the former place continue throughout most, if not all, of the distance. There is the same southeastern lowland, with its horizontal sandstone; the same single Trap Range, with abrupt southern and gradual northern slopes, composed of the same strata, dipping at the same high angle towards Lake Superior, and having about the same thickness; and the same northwestern lowland bordering the lake and occupied by the sandstone of the Upper Division of the series. Near the Ontonagon River the main mass of sandstone, black shale, and conglomerate of the Upper Division, and the Outer Trap and Great Conglomerate of the Lower Division are all distinctly recognizable. No detailed measurements have ever been made in the Ontonagon country, but when there I saw enough to convince me that some satisfactory correlations could also be reached between the remainder of the Lower Division as here developed and as developed on Portage Lake, especially by the use of the interleaved sandstone and conglomerate bands, which here, as further east, continue down to quite low horizons.

There are, however, some important differences between the Portage Lake series and that of the Ontonagon. One of these is the characteristic epidote-quartz alteration of the amygdaloids, the so-called "veins" which carry the Ontonagon copper. A more important difference, however, is the occurrence in the Ontonagon region of massive quartziferous porphyries at what appear to be quite high horizons, an occurrence which continues to prevail for nearly a hundred miles to the westward, the porphyry occurring in irregular belts of greatly varying lateral extent. Large exposures of a dark reddish-brown porphyry, holding large crystals of orthoclase and oligoclase, occur north of the village of Rockland, in the NE. $\frac{1}{4}$ Sec. 9, T. 50, R. 39 W., but a very short distance south of a broad conglomerate that appears to be the equivalent of the Great Conglomerate of Keweenaw Point.

The black shale and gray sandstone belt of the Upper Division of the series, already recognized as occurring near Portage Lake, is strongly marked in the vicinity of the Ontonagon River, having been recognized as far east as Sec. 14, T. 51, R. 38 W., 10 miles to the northeast, along the strike, from the Ontonagon. Near the Ontonagon it has been traced across sections 22, 21, 28, 29, 32, and 31 of T. 51, R. 38 W., and sections 4, 5, and 7 of T. 50, R. 39 W., to the Ontonagon in Sec. 12, T. 50, R. 40 W. The exposure on the SE. $\frac{1}{4}$ Sec. 21, T. 51, R. 38 W., is on the banks and in the bed of a small stream just to the west of the Greenland and Ontonagon road. There are to be seen here several hundred feet in thickness of alternating dark-gray sandstone and black shales, overlaid by a considerable thickness of red sandstone, and underlaid by a broad porphyry-conglomerate, evidently the equivalent of the Outer Conglomerate of Keweenaw

Point and the Porcupine Mountains. All of these rocks trend N. 30° E., and dip 40° to the northwest, or at a lower angle than the beds of the Trap Range just to the southward. The exposures in the streams on sections 4, 5, and 7 of T. 50, R. 39 W. are closely similar to the last described, but much less extensive. In the NE. ¼ Sec. 4 the shale dips 48° NW. and trends N. 65° E., while in sections 5 and 7 the corresponding figures are 35° NW. and N. 50° E.

The shale seen at these several points is dark purplish-gray to nearly black, and from excessively fine-grained to aphanitic, the finest kinds being quite soft and highly argillaceous, the interbedded sandstone also varying in color from dark-gray to heavy black. Thin sections of it were examined both from the exposures on Sec. 21, T. 51, R. 38 (3009–3011), and from those on Sec. 4, T. 50, R. 39 (3008). All of the sections show the usual porphyry detritus, viz, matrix and single quartzes. With these, in all the sections, is mingled more or less basic detritus. This seems to be most abundant in the blackest kinds, in which there is also an abundant calcite cement, filling all interstices between the fragments. The basic detritus appears in the shape of particles of the basic rocks, showing more or less plainly the several ingredients, always much altered, and of particles of the single minerals, viz: augite, almost wholly altered to a greenish substance, triclinic feldspar and magnetite.

Everywhere north of the line of the black shale, between Portage Lake and the Ontonagon, the country is underlain by the sandstones of the Upper Division, which are now and then exposed in the stream beds, and form large cliffs on the lake shore. The inclination in these beds is everywhere lakeward, but the amount of dip lessens rapidly northward from the Trap Range, and on the lake shore becomes very slight.

From the Portage to the point between the Fire-Steel and Flint-Steel rivers the general trend of the layers is more to the south than that of the coast, which thus constantly ascends in the series, the sandstones on the point alluded to belonging near the top of the Upper Division. Further west the reverse is the case, the coast trending more to the south than the rock layers, and from the Flint-Steel to the Union River there is a steady descent, the base of the Upper Division lying not more than half a mile inland at the latter point.

The total thickness of the Keweenaw Series between the Eastern Sandstone and the lake coast on the line of the Ontonagon River is some 28,000 feet, of which about 12,500 feet belong to the Upper Division and the remainder to the Lower Division. This estimate is based upon the breadth of country occupied, and the trends and dips of the strata. The Lower Division, constituting the Trap Range, occupies much the narrower belt, on account of the higher northern dip of its beds, while the Upper Division has a broad spread, on account of the flat dips of the sandstones composing it, this dip lessening rapidly as the Trap Range is receded from, until at the lake it varies only a very few degrees from horizontality. The greater thickness of the Upper Division present in the Ontonagon as compared with the Portage Lake section is of course due to the rising of the coast westward in geological horizon, and not to any actual increase or decrease in thickness.

SECTION III.—THE SOUTH RANGE.

The low area lying south of the Keweenaw Point, or Main Trap Range, and underlain by horizontal sandstone, extends from Bête Grise Bay for over a hundred miles in a southwesterly and westerly direction, as far as the western part of T. 48, R. 44 W., west of Lake Agogebic. Keweenaw Bay occupies much of the eastern part of this depression, everywhere south of which is again a belt of high country. This southern margin, in the vicinity of Keweenaw Bay, is composed of the iron-bearing schists generally referred to the Huronian system. Farther west, however, these iron-bearing schists have between them and the horizontal sandstone on the north a belt of rocks closely similar to those of the Main Range, forming the northern border of the sandstone-filled depression; *i. e.*, they are bedded diabases and amygdaloids, including porphyry-conglomerates. This is the belt to which the name of South Trap Range was given by early explorers.[1]

[1] The information obtainable with regard to the South Range was very scanty previous to the beginning of the special work on which the report is based.

From T. 48, R. 44 W., where it unites with the Main or Keweenaw Range, eastward for 50 miles, the South Range shows typical Keweenawan rocks. Further east and north, in T. 48, R. 36 W., between the east branch of the Ontonagon and Sturgeon River, I am informed[1] of the existence of exposures of diabase and porphyry-conglomerate, which from their position and character must belong to the same belt. Still further east and north, on the S. E. ¼ of Sec. 1, T. 49, R. 36 W., a bold, rocky, isolated bluff, known as Silver Mountain, is composed of diabase, dipping northwestward 30°, and apparently belonging to the same belt, which is thus carried nearly to Keweenaw Bay. It is not meant to assert that these rocks form a continuous belt at surface, because the horizontal sandstone undoubtedly overlies them very often, extending quite over them to the Huronian or even Laurentian on the south. Silver Mountain appears to be surrounded by sandstone, and west from here for many miles sandstone appears to cover the Keweenawan rocks. On the west branch of the Ontonagon, in Sec. 13, T. 46, R. 41 W., sandstone is to be seen cutting quite across the Keweenawan and lying against the older slates.

Two or three of the points examined on this range deserve more detailed description. Beginning on the northeast, Silver Mountain first merits attention. This is a bold hill, three-fourths of a mile in length, trending northeast. It is on the S. E. ¼ of Sec. 17, T. 49, R. 36. Its northwestern face is a long gradual slope, its southeastern a bold precipice, 400 to 500 feet high, this contour being evidently due to the northwestern dip. The rock is very fine-grained, varying from nearly black to light greenish-gray in much altered portions. Scattered through the fine-grained mass are numerous red and white patches, or pseud-amygdules, containing quartz and orthoclase. Some specimens show also porphyritic feldspar. Under the microscope the rock is seen to be very much altered, and to consist chiefly of tabular feldspars, and fibrous, faintly dichroic hornblende, often showing the characteristic prismatic cleavage. Augite also occurs, and in such a way as to suggest very strongly that all of the greenish hornblende constituent has come from it, *i. e.*, is uralite, as some undoubtedly is. Chlorite, titaniferous magnetite, and its usual grayish product of decompo-

[1]By L. G. Emerson and B. N. White, both well acquainted with the formation.

sition are present also. Some of the feldspars show no banding, and may be orthoclase. The red porphyritic and pseud-amygdaloidal feldspars are orthoclase. The rock appears to be a uralitic diabase, somewhat allied to the rock found in sections 26 and 27 of T. 37, R. 17 W., and sections 23 and 28 of T. 37, R. 16 W., in the Saint Croix River district of Wisconsin, though without the epidote. It should probably be placed with the uralitic orthoclase-bearing gabbros. It cannot be regarded as certain that the Silver Mountain rock is Keweenawan. It may possibly be Huronian, though the probabilities are greatly in favor of the former supposition.

In the S. E. ¼ of Sec. 1, T. 46, R. 39 W., the Ontonagon River makes heavy falls—90 feet in six leaps—over diabase and diabase-amygdaloid, which rocks appear also largely in a low ridge east and west of the stream. Both in the hand specimen and under the microscope these rocks are indistinguishable from many of the finer-grained diabases and amygdaloids of Keweenaw Point. The massive portions are dark-gray and minutely crystalline; the amygdaloids have a brownish matrix, and in the specimens brought away show epidote, orthoclase, prehnite and chlorite in the amygdules.

The exposures on the west branch of the Ontonagon, in the northwest part of T. 46, R. 41 W., are of especial interest on account of the evidence they offer in proof of unconformity between the Eastern Sandstone and the Keweenawan. The exposures at this place are shown in the accompanying figure (Fig. 3.) The sandstone is horizontally bedded, showing in a south-facing cliff 60 feet high and 350 feet long. It is reddish, very coarse, and composed almost entirely of rounded grains of quartz. One hundred paces from the foot of this cliff are reddish schists, trending northeast and dipping 45° to 60° SE. Seven hundred paces northeast, near the southeast corner of section 11, is a small ledge of a dark-brown, weathered, medium-grained diabase, of a Keweenawan type, while beginning in the northeast part of the same section, and running thence westward through sections 9 and 10, and terminating in the S. E. ¼, Sec. 5, is a series of exposures of a fine-grained, greenish-gray diabase pseud-amygdaloid, with chlorite pseud-amygdules.

The relation of the rocks of the South Range to those of the Keweenaw Point Range is one of the greatest interest. A moment's inspection of the map of Plate I will serve to show that towards the east the two ranges are widely separated, the distance between them, even west of the Ontonagon, being as much as 18 miles, while still further west they rap-

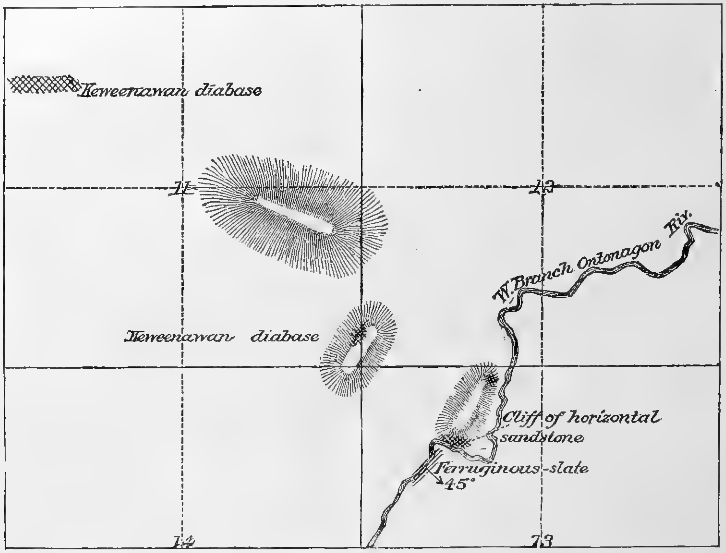

FIG. 3.—Map of Exposures in Vicinity of West Branch of Ontonagon River, T. 46, R. 41 W., Michigan.

idly approach, and finally join. The beds of both ranges dip northward. Should we suppose a continuous series beneath the intervening horizontal sandstone, we should obtain an incredible thickness, and one which westward must diminish with an incredible rapidity, for after the two ranges have joined the total apparent thickness of the Lower Division of the series does not exceed 33,000 feet, or only 8,000 feet more than on Keweenaw Point. That there is a fold beneath the sandstone-filled area seems improbable. There is no sign of a southern dip along the south side of the Keweenaw Range during all its course from Bête Grise Bay to its junction with the South Range. I had at one time the idea that such a fold might exist,[1] Foster and Whitney in their report indicating the existence of a

[1] See Geology of Wisconsin, Vol. III, Part I, p. 19, foot-note.

southern dip along the south side of the Keweenaw Range,[1] but I have since convinced myself by examination that no southern dip exists.

To explain the sudden break on the south side of the Keweenaw Range between the Keweenawan beds and the Eastern Sandstone, Foster and Whitney long since[2] supposed this line to be one of fault, and the Eastern Sandstone to be the equivalent of that on the west side of the range, the two separated only by the faulting. The latter position I shall show subsequently to be untenable;[3] and yet that some faulting has taken place on this line, even after the deposition of the sandstone, is proven plainly enough by the fact that at the contact the sandstones commonly rise in a remarkable manner, presenting for short distances from the junction high southern dips. On Bête Grise Bay these dips reach 50° at the contact, lessening to 40° and 30° within 200 feet, and to horizontality within a mile or less. Farther west the dips at the contact lessen in amount, becoming scarcely perceptible at Portage Lake, beyond which to the west they again become high. These phenomena are beautifully displayed at a number of points along the west branch of the Ontonagon, east of Lake Agogebic.

These facts render it plain enough that some faulting took place on this line after the deposition of the sandstone, but the main faulting, I conceive, took place before. By this fault the Keweenaw Range escarpment and the valley south of it were first made, the width of the valley depending on the amount of throw of the fault, which was thus greatest to the eastward. Subsequently the newer sandstone was deposited in this valley, and, after its deposition, a comparatively insignificant amount of faulting took place on the same line. On this view the South Range beds are the basal beds of the series, while the underlying basement of the intermediate sandstone-filled valley is composed, in a measure, of the same beds as those forming the Keweenaw Range.

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[1] *Op. cit.*, pp. 65–66. [2] *Op. cit.*, p. 68. [3] Chap. VII.

SECTION IV.—THE REGION BETWEEN THE ONTONAGON RIVER AND NUMAKAGON LAKE OF WISCONSIN; INCLUDING THE PORCUPINE MOUNTAINS.

This region is one of especial interest. Within it, as indicated on the map and sections of Plates XXII and XXIII, is included the entire thickness of the Keweenaw Series, both of the Upper and Lower Divisions. Within it the Eastern Sandstone reaches its western termination, and the ranges of Keweenawan rocks south and north of the valley occupied by the sandstone unite. Both the underlying formations—the iron-bearing Huronian and the gneissic Laurentian—are here largely developed, and in close proximity to the Keweenawan. Midway the district, in the vicinity of the Montreal River, a line drawn southeasterly crosses, in a distance of some twelve miles, the entire thickness of the Huronian and Keweenawan. Within this region we have also the eastern termination of the horizontal Western Sandstone. Here we have again far more extensive developments of quartziferous and felsitic porphyries than on Keweenaw Point. Augite-syenites also occur. Here, too, we have, in the Bad River country, a great showing of the coarse gabbro, which is developed in only one other district about Lake Superior, viz: about Duluth, in Minnesota.

In this area, moreover, occurs the peculiar fold producing the Porcupine Mountains, and here we have the axis of the great trough in which most of Lake Superior lies running on to the land. Here are found all degrees of inclination, from near horizontality to complete verticality. With all of this there is also a perfect development of the usual bedded amygdaloids, melaphyrs, conglomerates, etc. Thus, save that the structural relations of the acid porphyries are not to be so distinctly made out as on the Minnesota coast, had this restricted region been worked in such detail as those portions of Keweenaw Point examined by Pumpelly and Marvine, the Keweenaw Series would be nearly as well understood as from a study of the entire basin of Lake Superior, and what is to be seen elsewhere about the lake would be of little more than confirmatory value.

Unfortunately the whole district is wilderness, and with the exception of the workings on the gray sandstone of the Upper Division of the series, at the Nonesuch mine, in the Porcupine Mountains, there are no mining operations to assist in a detailed study. Foster and Whitney's brief account of the region between the Ontonagon and the Montreal rivers,[1] a short account of the Porcupine Mountains, by Col. Chas. Whittlesey,[2] and an equally brief description, by the same geologist, of the region between the Montreal and Bad rivers,[3] embody all the information obtainable previous to my own acquaintance with this district.

In the summers of 1873, 1876 and 1877 I made examinations of the regions drained by the Montreal and Bad rivers, and the results were published in 1880 in the Geology of Wisconsin.[4] In the same volume appears an account by Professor Pumpelly of the microscopic characters of a number of the specimens collected by me in this region. In addition to what is given in the above-named publications I have to base the following descriptions upon the results of a detailed examination of the Porcupine Mountains, by my assistants, Messrs. W. M. Chauvenet, A. C. Campbell, B. N. White and R. McKinlay, of a cursory examination by myself of the rocks in the vicinity of the Ontonagon, and of my own detailed microscopic study of all specimens gathered.

The conditions already described as obtaining at the crossing of the Ontonagon remain the same all the way to the Montreal River, so far as general stratigraphy and kinds of rocks are concerned, save that there is a very considerable expansion downwards, due chiefly to the appearance at the surface of layers which farther east are buried beneath the Eastern Sandstone. There are, however, noteworthy changes in structural features, in the courses of the rock belts, and in the width of country occupied by them. Save in the Porcupine Mountains, which lie to the north of the Main Trap Range, the usual northern dip everywhere prevails, but, after two townships are crossed west from the Ontonagon, it has flattened enough to increase very materially the width of country occupied by the Lower Division of the series. The rising from beneath the Eastern Sandstone of

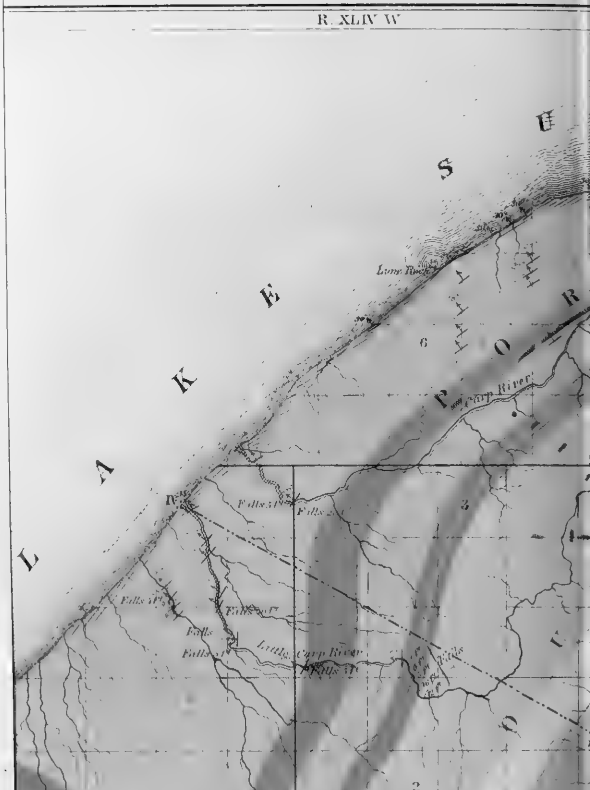
[1] Op. cit., pp. 74–80, 1850.
[2] Engineering and Mining Journal, Vol. 23, p. 254, April 21, 1877.
[3] Proc. Boston Soc. Nat. Hist., July, 1863; also Geology of Wisconsin, Vol. III, Part III, Appendix A, pp. 216–223.
[4] Geology of Wisconsin, Vol. III, Parts I and III.

layers previously concealed aids in increasing this width, which on the west line of range 41 is as much as five miles, as against only three on the Ontonagon.

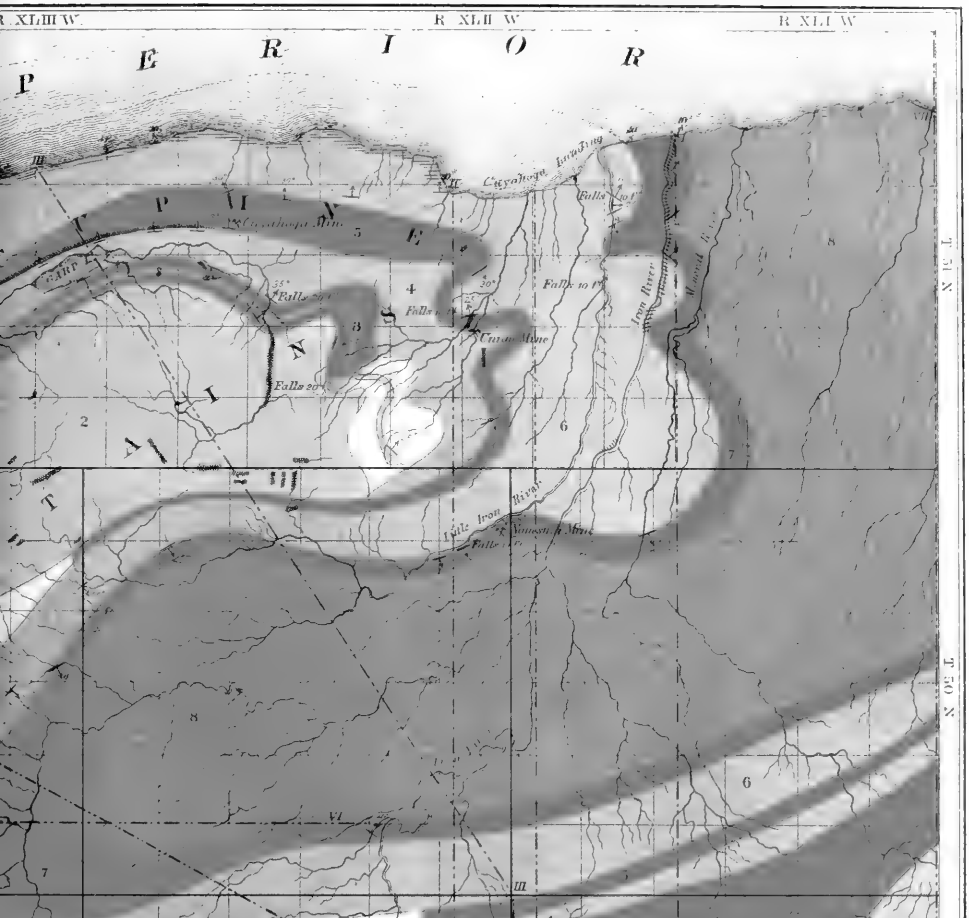
This increase in surface width becomes very rapid in the next ranges westward, the width in the east part of range 42 being as much as eight miles. Beyond range 44 the Eastern Sandstone and the depression it occupies come to an end, the South and Main Ranges coming together. As already explained, the South Range is made up of belts of the usual basic eruptive rocks dipping northward and constituting the lowermost part of the Keweenaw Series; their separation from the beds of the Main Range is due to faulting. It has also been shown already that this fault dies out to the westward, the South and Main Ranges coming together. As a result of this the width of country occupied by the Lower Division of the series becomes on the Black and Presqu' Isle rivers as much as ten miles.

East of the Ontonagon River the course of the rock belts is southwest, or even a little south of southwest. After crossing the Ontonagon there is a change to a direction only slightly south of west, and for the rest of the distance to the Montreal the general trend of the belts constituting most of the Lower Division oscillates between 5° and 20° south from west. On the Montreal a rapid change takes place to a direction only 30° to 40° west of south. With regard to these lower belts in this distance I have nothing new to offer, and can only say that so far as known they present the usual diabases, melaphyrs and amygdaloids, with some porphyries, and in the lowest portions coarser rocks belonging to both the olivine- and orthoclase-gabbros.

The upper belts of the series and all of the Upper Division are not included in the statement just made as to general trend. On following them westward they are found bending out to the north in a curious loop, returning on the western side of the loop to their original positions. The neck of the loop trends nearly north, or at right angles to the Main Range, but near the lake its end bends well around to the eastward. Within this loop are the Porcupine Mountains, whose interior portions are made up of felsitic and quartziferous porphyries, without any definitely traceable structure. These porphyries plainly enough belong to the same belt or belts which



GEOLOGICAL MA



A. Hoen & Co. Lith. Baltimore

F THE PORCUPINE MOUNTAINS,
MICHIGAN.

UNITED STATES GEOLOGICAL SURVEY

THE EASTERN SANDSTONE . 9

KEWEENAW SERIES.

UPPER DIVISION.

Red Sandstone	8
Dark-grey Sandstone and Black Shale	7
Sandstone with thin bands of Conglomerate	6

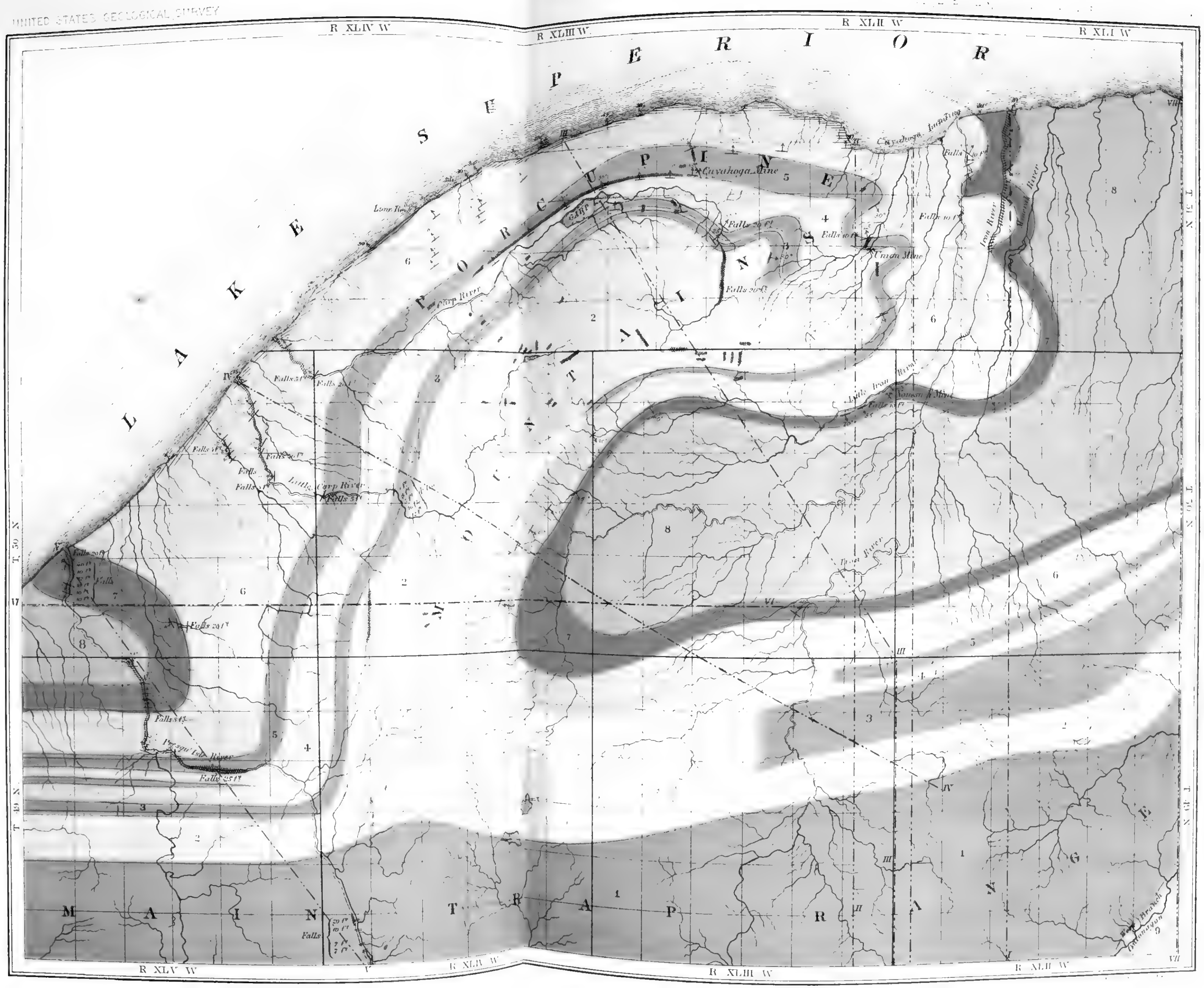
LOWER DIVISION.

Diabase, Diabase amygdaloid, and Melaphyr	5
Sandstone and Conglomerate	4
Diabase Diabase amygdaloid Melaphyr and Diabase porphyry with one Porphyry conglomerate	3
Quartz porphyry and Felsite	2
Diabase and Diabase amygdaloid, including narrow Conglomerate Belts	1

Scale 1/125000, or 1 inch = 1.973 miles

Prominent exposures of massive rocks

Exposures of detrital rocks showing dip and strike



GEOLOGICAL MAP OF THE PORCUPINE MOUNTAINS, MICHIGAN.

are first found to the east on the Ontonagon River, and thence extend westward all the way to and beyond Bad River, in Wisconsin. From this central mass of porphyry the remaining beds of the Lower Division, and those of the Upper, dip away on all sides in a manner that will be best understood from a study of the map and sections of Plates XIX, XX and XXI.

Above the porphyry comes first a succession of beds of diabase, melaphyr, amygdaloid and diabase-porphyry, with one included bed of porphyry-conglomerate, in all 400 feet in thickness. To this succeed 1,900 feet of sandstone and conglomerate; 300 to 400 feet of beds of diabase and diabase-amygdaloid; upwards of 3,000 feet of sandstone and conglomerate; 600 feet of dark sandstone and black shale; and then the main mass of sandstone of the Upper Division. This succession is plainly enough the same as that which obtains on the Ontonagon, while the black slate, outer conglomerate, trap, and lower conglomerate, are as plainly the equivalents of the shales, Outer Conglomerate, Lake-Shore Trap, and main or Great Conglomerate of Keweenaw Point.

The structure of the Porcupine Mountains having never before been worked out, nor indeed any of the constituent rock beds described, save in the roughest way, I may properly include here somewhat detailed descriptions of each of the members of the succession above laid down. Plates XIX, XX and XXI should be studied in connection with these descriptions.

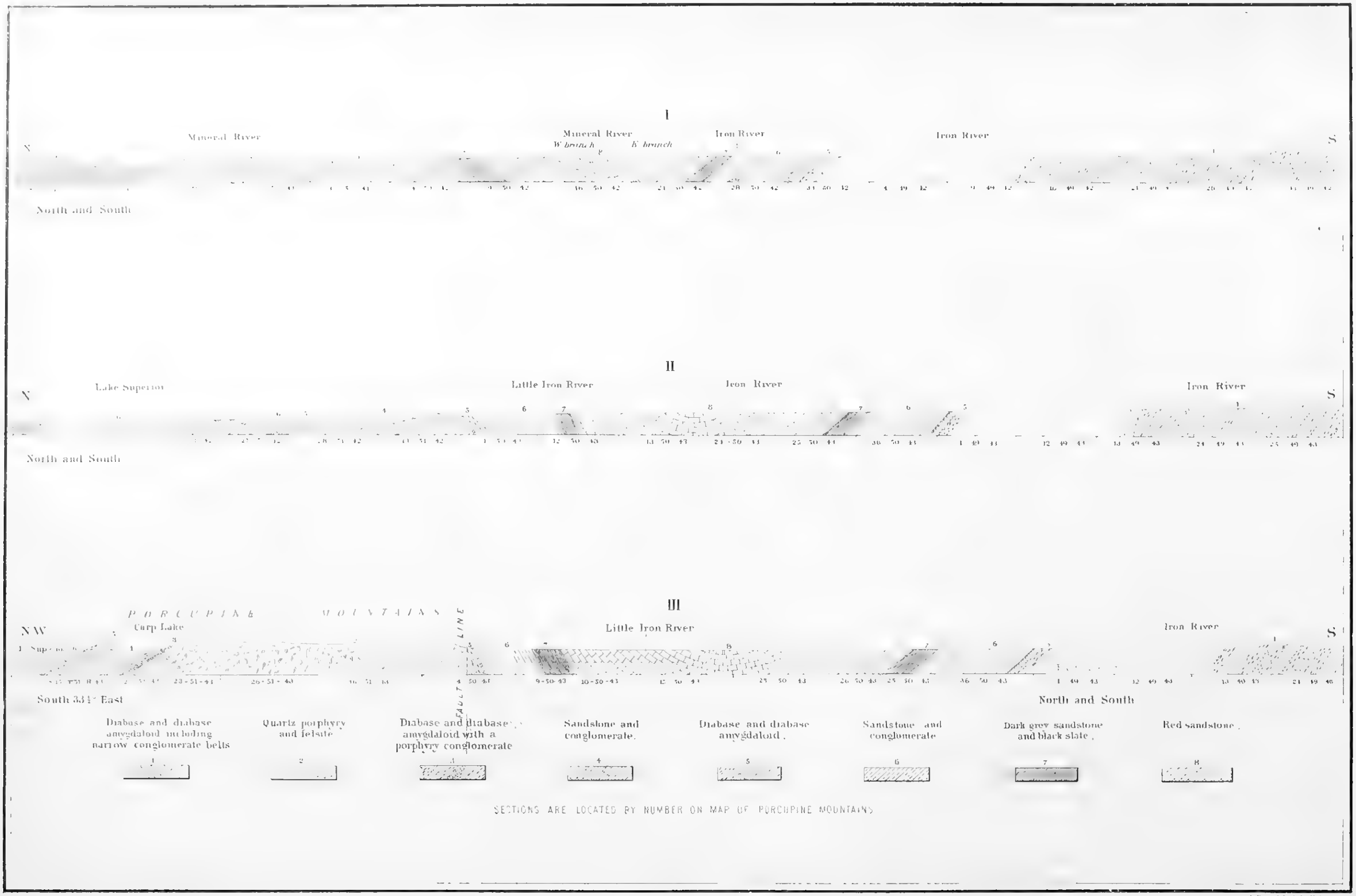
The porphyry which constitutes the central mass of the mountains appears in numerous bold, structureless exposures through the middle, from south to north, of T. 50, R. 44 W.; in the northern parts of the northwestern sections of T. 50, R. 43 W.; in the southwestern sections of T. 51, R. 42 W., especially on the upper Carp River; and over a large area in the southern and southwestern sections of T. 51, R. 43 W. The ridges in this area rise often 1,000 to 1,200 feet above Lake Superior, while the lower portions rarely sink to 800 feet above the same level.

The rock seen on the various exposures within this area varies in color through various shades of red, lilac and purple. It shows everywhere a distinct tendency towards becoming a non-porphyritic felsite, porphyritic quartz and feldspar being sometimes altogether absent, though more commonly present in small and sparsely scattered particles. There is occasionally visible a very distinct, but more or less irregularly curving, fine banding, such as is often found in similar porphyries from other regions, and which must be attributed to flowage in a molten state. Occasionally the matrix shows a tendency to a more distinctly crystalline texture, the rock tending towards granitic porphyry.

I have examined a number of thin sections of the Porcupine porphyries, with the following results. The first is pale-lilac felsite (2,514)[1] from the large vertical walls on the north slope of the hill on the north line of Sec. 5, T. 50, R. 43 W., at 700 paces west of the northeast corner. It shows a colorless base without porphyritic ingredients; and is apparently a minutely crystalline admixture of quartz and feldspar. Some of the quartz is secondary. Sparsely scattered through the matrix are black and brown opaque particles. The bright-red, blotched, rough-textured felsite (2515) from the same hill in the S. E. ¼, Sec. 35, T. 51, R. 43 W., (250 N., 900[2] W.), shows in the section very much the same appearance as the last described, but contains also some non-polarizing base. The lilac felsite (2516) brought from the continuation of the same great ledge in the S. W. ¼, Sec. 35, (500 N., 1100 W.) gives the same section as the last. The rock (2517) from the hundred-foot cliff, near the middle of the same section (720 N., 1000 W.) is somewhat different. Macroscopically it is an aphanitic bright-red rock blotched with white, and without porphyritic ingredients. In the thin section the red portions are excessively fine-grained and even non-polarizing, with abundant, minute, brownish, opaque particles and particles of red oxide of iron. The white portions consist of comparatively large particles of orthoclase and quartz. The dark purplish-red rock (2551) from the bed of Carp River, in the N. E. ¼, Sec. 35 (1420 N., 1400 W.), is very much the same felsite as those first described, being without porphyritic ingredients. The rock on the south side of the Carp Lake road in the S. E. ¼, Sec. 24, T. 51, R. 43 W., (800 N., 300 W.), is dark purplish-red with a few small red feldspars and minute quartzes. In the thin section the matrix presents an interesting appearance. Much of it is of a faint reddish tint

[1] These numbers refer to specimens, many of which will be found described in the tables of Chap. III.

[2] These numbers give the distances north and west from the southeast corner of the section, in each case.



GEOLOGICAL SECTIONS ILLUSTRATING THE STRUCTURE OF THE

PORCUPINE MOUNTAINS.

Scale $\frac{1}{100000}$ or 1 inch = 8333 feet

and non-polarizing, while thickly studded through this are minute particles of quartz, a number of which polarize together, thus showing that they are parts of one crystal. The section thus has a peculiar mossy appearance in polarized light. This quartz is doubtless secondary, but the particles are larger and more nearly like those of the original quartz than usual. The few porphyritic quartzes and feldspars present the usual characters. Much black dust is present in blotches and lines, and is in part undoubtedly magnetite. The dark purplish quartz-porphyry (2574) from Sec. 20, T. 51, R. 42 W. (500 N., 1150 W.), holds a few minute original quartzes, and shows under the microscope a matrix which in the ordinary light appears nearly homogeneous and thickly dotted with minute brownish and blackish particles, but in the polarized light presents an appearance analogous to that of the last rock described, except that the secondary quartz is in much more minute particles, large numbers of which polarize together. Orthoclases occur among the porphyritic ingredients, and a very interesting relation was noted between one of the orthoclase crystals and one of the original quartzes, the latter having grown around the end of the former. A few minute augites occur in the matrix. A closely similar rock (2586) appears in large exposures on the upper part of the stream which enters the southeast end of Carp Lake, in the S. W. ¼, Sec. 23, T. 51, R. 43 W. The sections of the dark purplish-red rock (1247 and 1248) from the bed of Little Carp River in the northeast corner of Sec. 20, T. 50, R. 44 W., appear much like the last described, having not very rare original quartzes and orthoclases, and abundant secondary quartz, some of which is arranged in curving concentric lines, apparently emphasizing a structure in the original rock. These sections show much fine ferrite, and now and then a quite perfectly developed augite crystal. The ferrite particles in places appear to indicate flowage. The ledge on the south line of Sec. 9, T. 50, R. 44 W., 270 paces west of the southeast corner, shows a very plainly banded felsitic porphyry (1259) with not rare, white orthoclase crystals which often lie entirely across two or three bands. The banding is produced by lighter and darker shades, and is quite irregular and wavy. Under the microscope the banding is seen to be produced by the presence of much red iron oxide in some bands, and its absence or relative scarcity in others. The bands are quite without regularity or continuity, the white bands being merely irregular rows of light blotches. The individual blotches do not average more than a small fraction of an inch in length, the red material closing together between them. Under the microscope both light and dark portions show little sheaf-like aggregations of orthoclase, which mineral in the whiter portions is often larger than in the red. A good deal of the usual secondary quartz and ferrite are present. The porphyritic orthoclases are much decomposed and reddened, and are not very abundant.

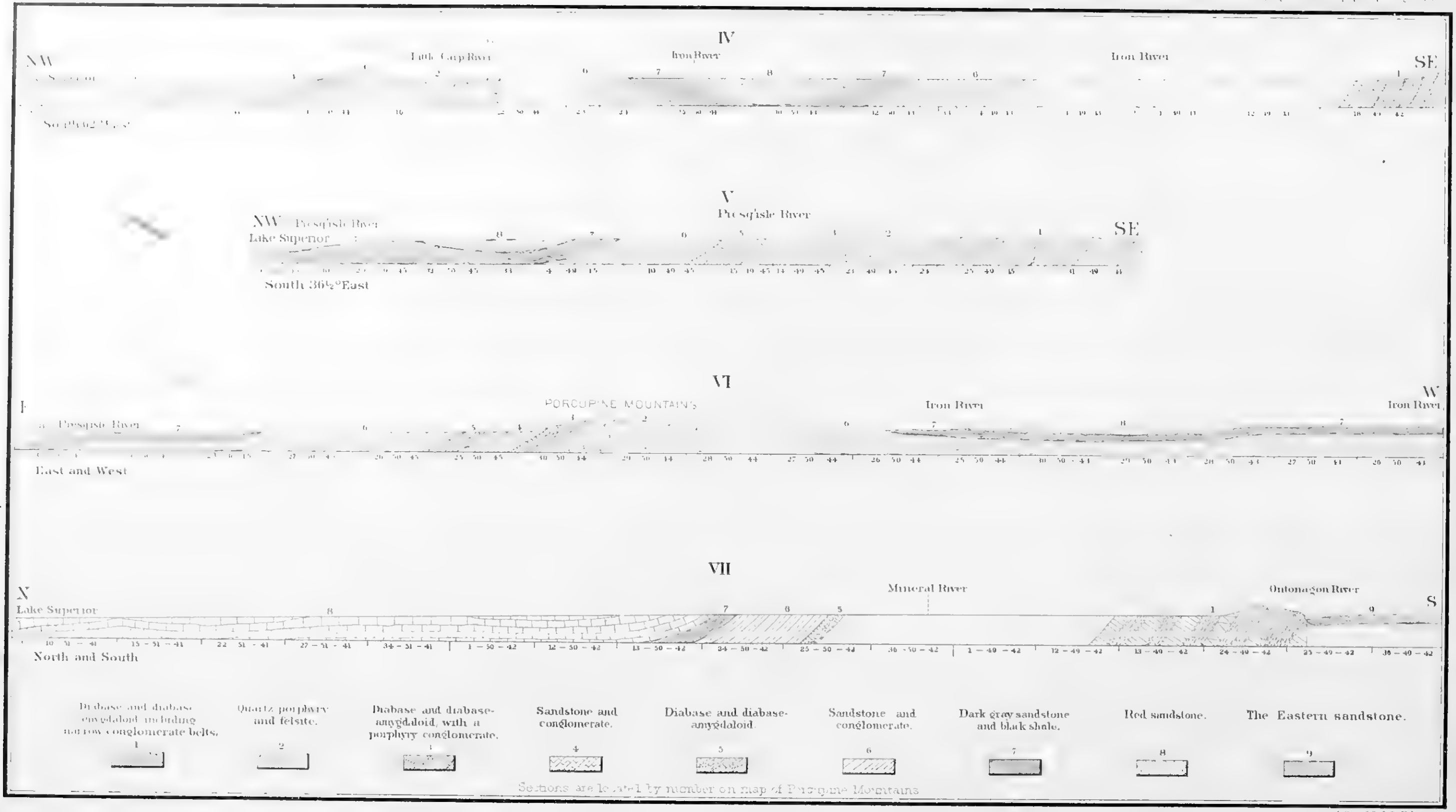
Another banded rock (1263) is shown in one of the numerous northeasterly trending ledges of the southern part of T. 51, R. 43 W., near the southeast corner of section 32. This is a dark-red felsite without porphyritic ingredients, looking much like a dark-red quartzite, with close and quite regular bands produced by variation in depth of color. Under the microscope the thin section shows but little coloring matter. The lighter bands are seen to be composed of rather coarser particles than the others, while the banding is further emphasized by fine lines of thickly crowded ferrite particles. The base appears to be composed of individualized orthoclase and quartz, and some little quartz that appears as if secondary, but there is none of the irregular mossy or radiating or concentric structure produced by secondary quartz, such as noticed in other sections, the base presenting a remarkably homogeneous, finely crystalline appearance The numerous samples brought from other ledges within the porphyry area of the Porcupines do not indicate the existence of any other phase of the porphyry than those described above.

The limits of the Porcupine porphyry area are pretty well determined by exposures, more especially on the north and northwest, where the exposures of the different rocks often lie quite close together. Thus in sections 30 and 31, T. 49, R. 44 W., the Presqu' Isle River exposes diabases and amygdaloids of the ordinary type, and the latter rock is seen again in the southwest of section 19. In the northeast of section 19 and the northwest of section 20 are large exposures of red felsite and felsitic porphyry, while in the middle of the west side of section 18 are seen the amygdaloids and diabase belonging to the belt north of the porphyry, the north and south limits of which on the Presqu' Isle are thus indicated. Again, at the rapids of Little

Carp River, in the northeast corner of Sec. 20, T. 50, R. 44 W., the contact of the porphyry with the overlying rock is in sight. The high ridge of porphyry in the east part of section 31 and the southeast of section 30 of the same township proves that the boundary of the overlying belt of diabase and diabase-amygdaloid makes here a considerable deflection to the westward from a straight line drawn between its positions on the Little Carp River in Sec. 20, T. 50, R. 44 W., and in the west part of Sec. 18, T. 49, R. 44 W. Sec. 32, T. 51, R. 44 W., exposes porphyry largely in the southeastern and southern portions, and diabase in the western and northern, while in the stream at the northeast corner of this section, lilac felsite and amygdaloids are largely exposed at only 200 paces from each other. South of Carp Lake, in sections 23 and 22, the porphyry and overlying rock are largely exposed at points not far apart, and several exposures of the two rocks between here and the junction in the N. E. ¼, Sec. 32, serve to fix this part of the boundary quite closely. The road running east and south from the head of Carp Lake, through sections 23 and 24, crosses ledges both of the porphyry and its overlying rock. In Sec. 30, T. 51, R. 42 W., the limit is again found in the northeast quarter of the section. Further southeast, in T. 51, R. 42 W., there is some doubt as to the exact limit of the porphyry to the eastward, or rather, the position of its overlying rock is left in doubt by lack of exposures; besides which some doubt is introduced by the uncertainty as to where the fault lying south of the porphyry ends. Closely approximated exposures of the porphyry and amygdaloid on the south fix the southern limit very closely in sections 3, 4, 5, and 6, T. 50, R. 43 W. In the eastern part of T. 50, R. 44 W., a gap without exposures leaves the exact position of the eastern limit in some doubt, as indicated on the map. The porphyry and felsite ledges are so generally distributed over the area colored for those rocks as to indicate that they underlie most of its extent, but in one place a large exposure of a rather coarse-grained very highly crystalline gabbro, such as is frequently associated with porphyry and felsite on the north shore of Lake Superior, was noted. This is on the south line of Sec. 3, T. 50, R. 44 W., 1,150 paces west of the southeast corner. The ledge is 100 feet high and 200 feet long in a southwest direction.

In attempting to trace the porphyry of the Porcupine Mountains eastward we find that across T. 49, R. 43 W., the region where it would lie is mostly drift-covered, but that in the northern part of T. 49, R. 42 W. there are large exposures of quartzose porphyry occupying a belt one to two miles in width, and trending east-north-east across the township to the northeast corner. T. 50, R. 41 W. is next crossed by the belt in its southern portions, without many exposures. One is reported by Mr. B. N. White at the center of Sec. 21, T. 50, R. 41 W. Across the middle sections of T. 50, R. 40 W. the government surveyors have written the words, "red slaty trap," which are evidently meant for the red porphyry. The same words are used in the plat of T. 50, R. 39, for the quartzose porphyry already described. Westward from the Presqu' Isle River to the Montreal I have no knowledge of any porphyry exposures. The country is mostly low and the rocks covered where the porphyry would be expected to appear. Beyond the Montreal it reappears, as subsequently described.

North and west of the porphyry area of the Porcupine Mountains there is everywhere found a belt of basic rocks having a surface width of from about one-fourth to one-third mile, and a thickness varying from 300 to 500 feet. Toward the middle of the thickness a porphyry-conglomerate is included, with a thickness of over 60 feet. The basic rocks of the belt are in very regular and rather thick flows, some half dozen beds appearing to make up the whole thickness. Among the massive portions of the beds a very fine-grained, dark-red, compact and semi-conchoidal rock is abundant, occurring both above and below the intermediate conglomerate. Under the microscope the slices of this rock, from points far apart along the length of the belt, show the characteristic arrangement belonging to Pumpelly's melaphyrs. Olivine, plagioclase, magnetite and augite are the ingredients in order of age. The augite occurs in crystals including numbers of the small plagioclases, while the magnetite and the olivine are crowded into the spaces between the augites, the latter mineral being usually much altered to both red (hematite) and green (serpentine) substances. Another rock of this belt—occurring in some places in two layers, one above and one below the intermediate conglomerate, and in others only above that horizon—is an aphanitic dark-gray to black or reddish-brown rock



GEOLOGICAL SECTIONS ILLUSTRATING THE STRUCTURE OF THE PORCUPINE MOUNTAINS.

Scale $\frac{1}{100000}$ or 1 inch = 8333 feet.

with few or many porphyritic feldspars. The thin sections show this rock in some cases as a typical ashbed-diabase, with a few porphyritic orthoclases, and in others as a true diabase-porphyrite. The latter presents very numerous porphyritic orthoclases in an excessively fine base, in which there are portions which polarize only very feebly or not at all, and in which minute tabular plagioclases with rare augite, magnetite and ferrite particles are the only recognizable ingredients. Some of the beds are of the ordinary type of fine-grained diabase, and the amygdaloids present no unusual characters. The rocks of this belt can be seen to best advantage on the upper Carp River, in sections 19 and 30, T. 51, R. 42 W.; on the road from Union mine to Carp Lake, in Sec. 24, T. 51, R. 43. W.; along the course of the stream south from the same road in the NE. ¼, Sec. 23, T. 51, R. 43 W.; in the NW. ¼ of the same section along the larger stream which runs into Carp Lake near its southeast corner; and on the Little Carp River in sections 17 and 20, T. 50, R. 44 W.

On the upper Carp the junction with the overlying conglomerate is seen at 450 paces north and 1,630 west of the southeast corner of Sec. 19, T. 51, R. 43 W., where the strike is northwest, and the dip northeast 25°. Hence up stream to the junction with the included conglomerate at 282 paces north and 1,630 west of the same corner the exposures are nearly continuous and show much of the fine-grained reddish melaphyr, besides several bands of amygdaloid and diabase of the ordinary types. The thickness between the two conglomerates is about 200 feet. The upward course of the stream follows the junction with the lower conglomerate to a point

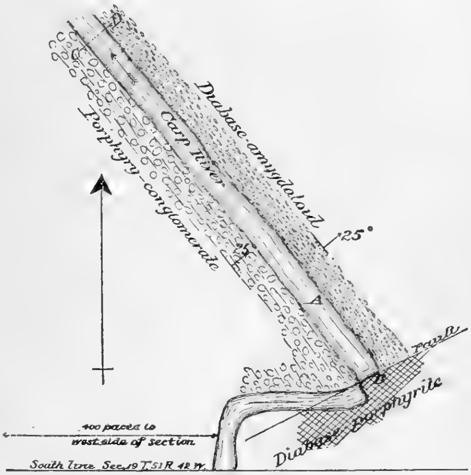


FIG. 4.—Map of exposures on upper Carp River, Porcupine Mountains. One inch = 90 paces.

100 paces north and 1,520 paces west of the section corner, the conglomerate forming the southwest bank, and the diabase the northeast, as indicated in the accompanying sketches, Figs. 4 and 5.

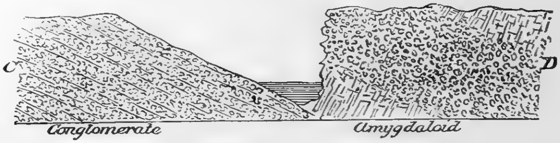


FIG. 5.—Cross-section on line CD of Fig. 4.

At the last point indicated, B of Fig. 4, the stream makes a sharp turn westward, and the diabase is faulted against a reddish diabase-porphyry, carrying orthoclase and triclinic feldspars as porphyritic ingredients, and having a confused, much altered base in which the minute tabular plagioclases are, however, very abundant. The whole rock is permeated by little strings and patches of calcite.

Further up the stream, in the northwest part of section 30, and as far as a point 1,675 paces north and 1,590 west of the southeast corner of the latter section, other basic beds are seen in place, including two or three amygdaloids, some reddish melaphyr and a heavy bed of diabase-porphyry.

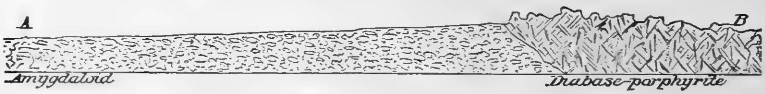


FIG. 6.—Section on line AB of Fig. 4.

All of these beds, from the junction of the upper conglomerate, trend northwest and dip northeast 25°. Still further up the stream, in section 30 (1,420 N., 1,400 W), the true felsitic porphyry begins to show. Judging by the surface width and dip angle, the thickness on this stream between the upper conglomerate and the last amygdaloid is as much as 600 feet, but some of the apparent thickness may be due to the faultings spoken of.

The two streams in Sec. 23, T. 51, R. 43 W. do not expose the upper conglomerate, but present above the lower conglomerate some 400 feet in thickness of very regularly-bedded melaphyrs and amygdaloids, including much of an exceedingly fine-grained diabase of the ashbed type, which at times carries numerous porphyritic orthoclases, and runs then into a diabase-porphyry. The exposures on the Little Carp River in sections 17 and 20, T. 50, R. 44 W. extend nearly continuously between the upper conglomerate and the red quartziferous porphyry below. The strike here is north and south, and the dip some 15° westward. The entire thickness between the conglomerate above and the quartz-porphyry below is some 280 to 300 feet, a considerable reduction on what is seen further east. The junction with the upper conglomerate is seen in section 17 (160 N., 1,000 W.). Between this point and the lower conglomerate there is a thickness of only some 75 to 100 feet, much of which is made up of a dark-brownish diabase-porphyry. The lower conglomerate is seventy-five feet thick, and below it comes a succession of amygdaloids and fine diabases to the junction with the quartz-porphyry below, which occurs at 1,850 paces north and 600 west of the southeast corner of section 20.

Southeast of the exposures on the upper Carp River in sections 19 and 30 of T. 50, R. 42 W., the belt of country in which the continuation of these basic rocks would be expected is without exposures, so far as known, except two of conglomerate, which from their position and character may very well belong with the median conglomerate of the belt I am now describing. One of these is in the creek-bed in Sec. 32, T. 51, R. 42 W. (840 N. 50 W.). A thickness of sixty feet is here seen, striking northwest, and dipping northeast 20° to 25°. The pebbles are large, usually from ten to one hundred pounds in weight, and are composed almost entirely of purple quartz-porphyry and felsite. The other point is in Sec. 29, T. 51, R. 42 W. (950 N. and 1,450 W.), where there is a large show of a conglomerate similar to the last, striking N. 10°–15° E., and dipping S. E. 30°.

The broad sandstone and conglomerate next succeeding in the Porcupine Mountains region, which I regard as the equivalent of the main or Great Conglomerate of Keweenaw Point, has not been seen in any one section across its width. Its existence as a single great layer is inferred from scattering exposures and from the topography. Its upper and lower limits are well seen in a number of places, but its middle portions underlie lowland and are but little exposed. The layer is largely sandstone, the conglomeratic portions occurring at the base, near its union with the underlying amygdaloid. The rock is made up of the usual reddish porphyry detritus, often permeated by secondary calcite. The upper portions of the layer are best seen in the face of the great cliff which forms the north side of the valley in which lie Carp Lake and Carp River. This cliff extends nearly continuously across T. 51, R. 43 W., a distance of over six miles. The crown of the cliff is from 800 to 1,000 feet above Lake Superior, and from 400 to 600 feet above the valley of Carp Lake. The base of the cliff is marked by a long slope of fragments fallen from the diabase and amygdaloid that form its upper portions, but through the greater part of its length there is a perpendicular face of about 400 feet above the talus. The base and lower portion of the cliff are composed of sandstone and conglomerate, but toward the east the sandstone rises nearly to the top of the cliff, while on the west side of the township it is found only at its base. At Carp Lake, which lies at about 400 feet altitude above Lake Superior, the cliff reaches 1,000 feet above the same level. Here the sandstone rises to about 400 feet above Carp Lake, while in the eastern part of section 13 it rises almost to the top of the hill. Other places where the top of the layer may be seen are on the tram-road from the Nonesuch mine to Lake Superior, in Sec. 27, T. 51, R. 42 W., at 1,050 paces north and 1,500 west, and again in the same section at 1,850 north, 1,600 west. At the latter point a creek follows the junction between the sandstone and overlying diabase for some distance. The lower portions are exposed on the upper Carp River, S. W. ¼, Sec. 19, T. 51, R. 42 W.; on Little Carp River, S. W. ¼, Sec. 17, T. 50, R. 44 W.; on the stream in the N. E. ¼, Sec. 13, T. 49, R. 45 W., and on the stream in the S. W. ¼, Sec. 15, of the same township.

As marked on the map and sections of the Porcupine Mountains, this layer has a thickness of some 1,800 or 1,900 feet. It is possible that in the middle of the thickness there may be some interstratified diabases and amygdaloids, but the existence of the long low valley of Carp River, under which lies all of the thickness about which there is any doubt, and the entire absence of exposures of any such rock on the Carp, Little Carp, and Presqu' Isle rivers, where they cross this belt, seem to forbid such a supposition. In the region of the Montreal River a number of interstratified diabase flows make their appearance, but they are to be seen on every crossing river.

Next in order to this conglomerate in the Porcupine Mountains comes the second belt of basic rocks, with a thickness of some 300 to 400 feet. The rocks of this belt are finely exposed in the great cliff which stretches in a curving direction entirely across T. 51, R. 43 W., on the north side of the Carp Lake Valley. As already explained, to the eastward these rocks are found just capping the cliff, and then extending to a relatively long distance down the north slope of the mountain; as, for instance, in Sec. 13, T. 51, R. 42 W., where this belt has a surface width of over half a mile. Further west the junction with the underlying sandstone is lower down in the face of the great cliff, the belt descending but a short distance down the north slope of the mountain, and as a consequence presenting but a narrow spread on the map. Beyond T. 51, R. 43 W., to the westward, this belt pursues a course at first southwest and then more nearly south through T. 51, R. 44 W.; T. 50, R. 44 W.; T. 50, R. 45 W., and T. 49, R. 45 W., to the Presqu' Isle River, where there is a sharp bend to the westward, as indicated on the map. The best exposures are on the Little Carp, in Sec. 18, T. 50, R. 44 W., and on the Presqu' Isle, in sections 14 and 15, T. 49, R. 45 W. On both streams the junction with the overlying sandstone is exposed, and both streams make falls over the basaltic rocks, those on the Presqu' Isle reaching a height of twenty-five feet.

Eastward from T. 51, R. 43 W., this belt continues on an easterly course for some three miles, and then, turning, pursues a tortuous southerly course to the south side of T. 51, R. 42 W., whence, turning again abruptly, it runs westward through the northern sections of T. 50, R. 43 W. Here it is found to come directly in contact with the central porphyry of the Porcupine Mountains, some 2,500 feet of rock that appears on the north side of the mountains being now absent, at least at the surface. This peculiar behavior I regard as the result of a fault, as indicated on the sections of Plates XX and XXI. The peculiar serpentine course of the belt through T. 51, R. 42 W. is not conjectural, having been very satisfactorily made out from the locations and inclinations of a number of exposures. Moreover, it corresponds entirely with the courses marked out for the overlying belts. In the vicinity of the Union mine, on sections 27 and 22 of T. 51, R. 42 W., both upper and lower limits of the belt are well exposed.

The beds of which this belt is composed are very sharply defined and regular, with strongly marked vesicular or amygdaloidal portions, and massive, often semi-columnar, lower portions. The massive rock is very fine-grained and commonly of a chocolate-brown to reddish-brown hue. Very often it carries mottlings, or pseud-amygdules, of dark-green chlorite, epidote and calcite. Nearly all appears to carry olivine in a much altered condition, and many of the sections show the characteristic arrangement of relatively large augites free from magnetite or olivine, but including numbers of plagioclases, while the interspaces are thickly studded with magnetite and altered olivine. One of these is figured on Plate X, at Fig. 1. The amygdaloids do not present any peculiar points. Dark-green chlorite, epidote, calcite, laumontite and prehnite appear to be the common fillings. At several points these amygdaloids have been worked for their copper, but unsuccessfully.

Next in order in the Porcupine section comes a thickness of over 3,000 feet of red sandstone with imbedded conglomerates. The sandstone, which is of the usual porphyry detritus, very greatly predominates over the conglomerate, the latter being disposed in the sandstone in very thin and irregular bands. The pebbles are, as usual, of porphyry and felsite, but pebbles of the basic rocks are not excluded. The exposures of this sandstone in the Porcupine country are too numerous for description. It is the best exposed belt of rock in the region, being seen in its entire width. It evidently includes no belts of crystalline rocks. Iron River exposes it largely, especially in the east half of Sec. 24, T. 51, R. 42 W. Little Iron River and Union River make large exposures in the same township. The whole thickness may be seen by following the coast line in T. 51, R. 42 W., and T. 51, R. 43 W.; and again from Lone Rock to the Presqu' Isle River. Numerous exposures are met with in the woods north of the Carp River Valley cliffs, while Carp and Little Carp Rivers, in T. 50, R. 45 W., and the Presqu' Isle, in Sec. 9, T. 49, R. 45 W., expose the entire width. The same sandstone is seen at a number of points in the eastern part of T. 50, R. 44 W., east of the north and south porphyry ridges of the central and western parts of that township.

Next in order comes the belt of dark-colored sandstone and shale which has been traced already from the vicinity of Portage Lake to the Ontonagon River. As further east, so also in the Porcupine region, this layer consists of a series of alternating dark-gray to black clayey shales and dark-gray sandstones; all dark-colored because of their comparatively large content of basic detritus. Calcite is very often found in the matrix, and one phase consists almost exclusively of basic detritus with calcite cement. The total thickness averages about 600 feet, varying somewhat from this figure. On the map of Plate XIX the belt is marked as very irregular in the surface width, the irregularity arising from the numerous changes it undergoes in direction and amount of inclination.

At the Nonesuch mine, S. E. $\frac{1}{4}$, Sec. 1, T. 51, R. 43 W., the shale is seen with a thickness of over 200 feet, trending N. 45°–50° E., and dipping S. E. 28°. Near the base of the shale is the sandstone seam, 4 feet thick, worked at the Nonesuch mine for its copper. This rock is a dark greenish-gray, fine-grained sandstone, which in the thin section is seen to be composed in some measure of basic detritus, along with porphyry detritus, and numerous single quartzes. The basic detritus appears in the shape of much decomposed red- and green-stained particles, showing both feldspathic and augitic ingredients. A good deal of magnetite is present, and native copper is very abundant, for the most part clustered around the magnetite particles. In a few places secondary calcite lies between the grains. The thin section of this rock is figured at Fig. 2, Plate XVI. Beneath the copper-bearing sandstone there come a few feet of shale, also carrying some copper, and beneath this some two and a half feet of a light-gray sandstone, harder than usual, beneath which again is the great sandstone layer previously described.

The thin seam just mentioned as occurring at this junction has been traced for a number of miles in the valley of Iron River, and is the one which has attracted so much attention in this region for the silver it contains. Under the microscope it is seen to differ from the Nonesuch copper sandstone, and, indeed, from the rock of the shale belt generally, in that it contains some water-deposited (secondary) quartz between the grains, which consist, as usual, of mingled porphyry and basic detritus and quartz particles. Calcite has also been deposited more or less plentifully in the interstices of the grains, and in some sections is the only indurating material.

From the Nonesuch mine eastward the shale belt runs through the southern parts of sections 6 and 5 of T. 50, R. 42 W. In the latter section the lower layers, including the Nonesuch bed, which is here also well charged with copper, are exposed on Mineral River at 250 paces north and 450 west of the southeast corner, with a southerly dip of 40°. From here the course of the belt makes a wide bow through sections 4 and 3, T. 50, R. 42 W., and sections 31 and 30 of T. 50, R. 41 W., to Mineral River, in Sec. 25, T. 51, R. 42 W., where it is seen exposed (1,200 N., 200 W.), with a northeasterly dip. In the same section, on Iron River (1,750 N.,800 W.), the junction with the underlying sandstone is again seen, and both rocks make here a sharp turn from a northwesterly to a northeasterly course, the dip at the same time being changed from a northeasterly direction to a southeasterly one.

The course of the belt is next on a bow to the eastward through Sec. 19, T. 51, R. 41 W., returning to Iron River in the S. E. ¼, Sec. 13, T. 51, R. 42 W. Here Iron River crosses the whole width of the belt, exposing both the underlying and overlying sandstones. The dip here is 35° east of north, and the thickness of the belt 600 feet. From here the course is westward to Little Iron River, in the S. W. ¼, Sec. 13. At this place there is a sharp synclinal, the belt turning abruptly and showing southerly dips. Returning now eastward to Iron River, the junction with the overlying sandstone is found in the northeast quarter of the same section (1,150 N., 250 W.). Thence to its mouth, Iron River is constantly on the layers of this belt, an anticlinal occurring near the N. E. ¼ of Sec. 13. The turns of the shale and of its overlying and underlying sandstones will be best understood by an inspection of the sections of Plates XX and XXI, and of the strike and dip notes of Plate XIX. At the mouth of Iron River the shale belt passes into the lake with a northwesterly trend, the junction with the overlying sandstone appearing just at the mouth of Iron River, and with the underlying on the lake shore on the west side of the N. E. ¼ of the N. W. ¼, Sec. 12, T. 51, R. 42 W. In all of these exposures between the Nonesuch mine and the mouth of Iron River the subordinate bedding of the shale stratum remains very much the same as at the former place, viz: a main body of dark-gray shale, varying a good deal in fineness in different layers, and occasionally becoming a sandstone; near the base a bed of sandstone, recognizable as the "Nonesuch vein," and below this always the light-gray calcitic sandstone known as the "silver belt."

On the lake shore, just southwest of Lone Rock, in the northern part of Sec. 26, T. 51, R. 44 W., the shaly belt appears again, with the usual characters and a considerable thickness. It is terminated eastward by a heavy dike of olivine-diabase, on the east side of which the sandstone is filled with calcite, the calcite being a vein following the course of the dike, which is N. 40° W. Thin sections of the shale and sandstone exposed here show them to be just the same as those exposed to the eastward. West of this point the shale belt remains under the lake as far as the mouth of Presqu' Isle River. Here it reappears, at first trending only a little west of north, with a dip slightly south of west, but changing rapidly as the river is ascended to a more nearly westerly direction, with a flat southern dip, the amount lessening to 5° in the southern part of Sec. 30, T. 50, R. 45 W., between which point and the lake the river makes a series of falls over the shale and interstratified sandstone.

From here the course of the belt is east and south, the shale and its underlying sandstone appearing in large exposures along a small creek in Sec. 34, T. 50, R. 45 W., with a N. 10° W. strike and a westward dip of 10°. Hence the course continues southerly for about a mile, when an abrupt turn westward is made, the belt crossing the Presqu' Isle in the southern part of Sec. 4, T. 49, R. 45 W. The exposures are nearly continuous along the river during its course through this section. At the line between sections 4 and 5 the overlying sandstone is horizontal—being at the bottom of the synclinal here crossed by the Presqu' Isle. A little further up stream a perceptible northerly dip begins, and at the junction with the shale, somewhat north of the middle line of the section, this has increased to 7°, with a due east and west strike continuing. Further up stream the dip steadily increases, and at the section line, where is the junction with the underlying sandstone, is as much as 20°

Returning now to the Nonesuch location, the shale belt may be traced by large exposures westward through sections 12 and 11 of T. 50, R 42 W. Further west, in the N. E. $\frac{1}{4}$ of Sec. 8, it is found trending still more to the south of west. South of here, in this township, the shale has not been observed, but a series of observations on the underlying sandstone, as recorded on Plate XIX, serve to fix the course of the belt very accurately.

The uppermost rock in the Porcupine region is the main mass of sandstone of the Upper Division of the series. It is seen at the mouth of Iron River, overlying the shale; again, in a similar position, on Iron River in the S. E. $\frac{1}{4}$ of Sec. 13, T. 51, R. 41 W.; and at several points in the low ground south of the Porcupines—for instance, on the upper part of Mineral River, near the south line of Sec. 9, T. 50, R. 42 W., and on the upper Iron River, near the south line of section 18, in the same township. On the west side of the Porcupine Mountains the same rock appears on the Presqu' Isle in Sec. 32, T. 50, R. 45 W., and Sec. 4, T. 40, R. 45 W.

In tracing the several rock belts which overlie the central porphyry in the Porcupine region east to the Ontonagon and west to the Montreal, I have to depend upon the geological notes of the township surveyors, upon the few facts given by Foster and Whitney, and upon the data communicated to me by Mr. B. N. White, of Ontonagon, who has a wide familiarity with the Ontonagon region. Moving eastward, then from the Porcupine area, I note first an exposure of the black shale on the headwaters of Mineral River, in the center of the N. E. $\frac{1}{4}$ of Sec. 34, T. 50, R. 43 W., where the dip is 40° to the north. Eastward from here the course of the belts makes a good deal of northing, the "trap" ledges marked on the township plats as occurring near the N. E. corner of Sec. 5, T. 49, R. 42 W., at the falls near the N. W. corner of Sec. 34, T. 50, R. 42 W., and again near the middle of the north line of the same section, marking the course of the upper trap band.

In T. 50, R. 41 W., Mr. White finds the Nonesuch shale as far north as the center of section 14. The same explorer reports red felsitic porphyry at the center of section 21; so that we have here a width of just one mile for all the belts between the porphyry and the black shale. This narrowing may be due in some measure to an increase in the dip angle, but must be chiefly caused by the thinning of the two intermediate conglomerates to the com-

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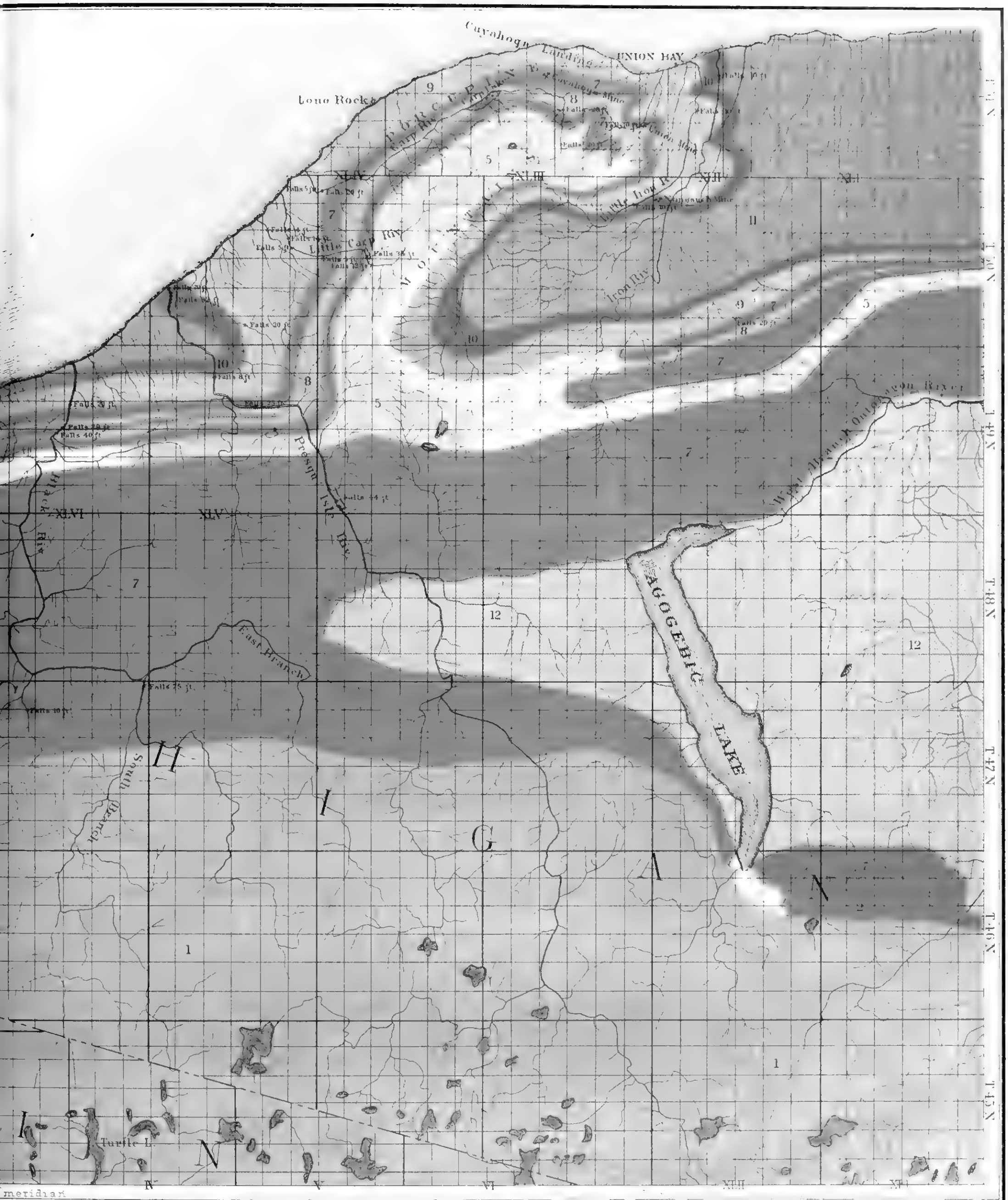
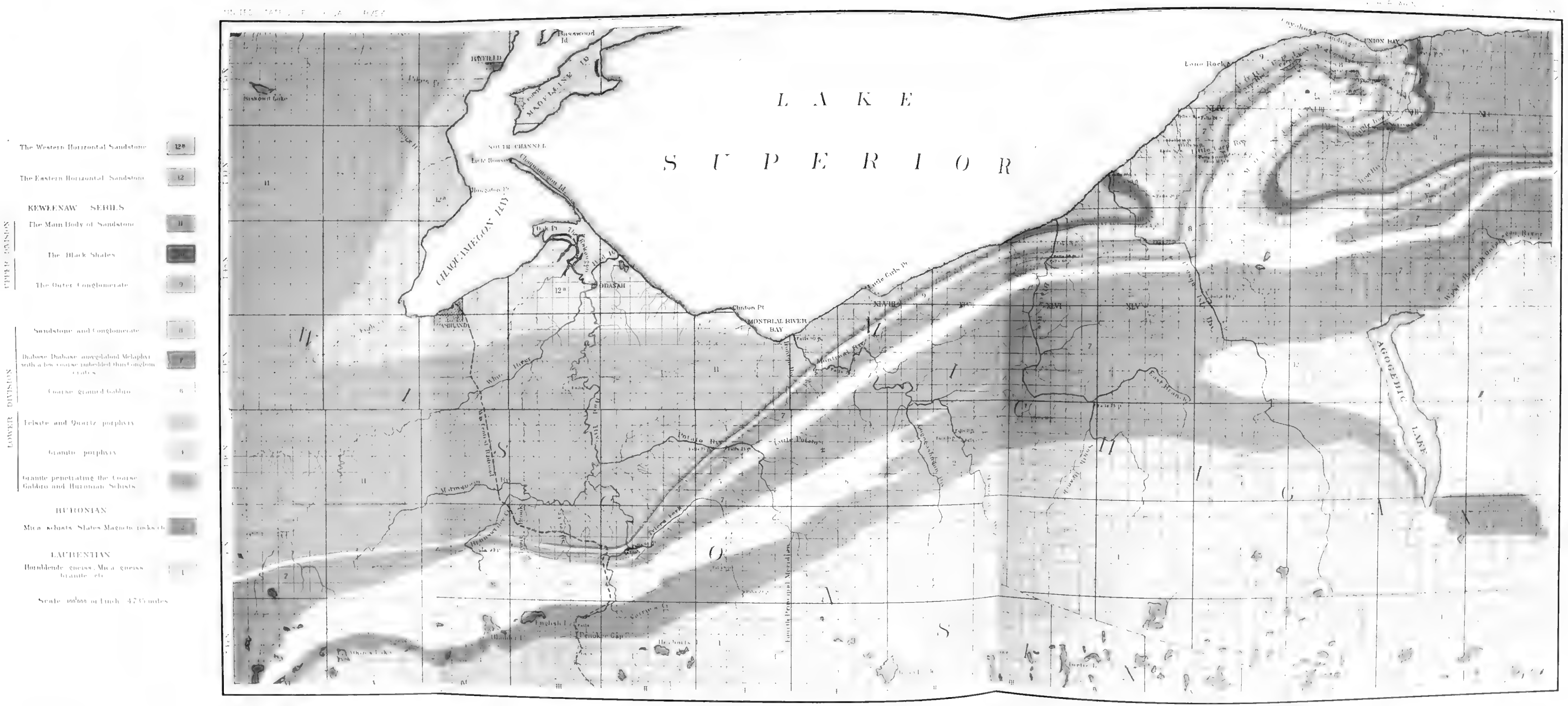


A. Hoen & Co. Lith. Baltimore

MICHIGAN AND NUMAKAGON LAKE WISCONSIN.



GEOLOGICAL MAP OF THE REGION BETWEEN THE ONTONAGON RIVER MICHIGAN AND NUMAKAGON LAKE WISCONSIN

paratively small thickness which they are observed to possess east of the Ontonagon. In T. 50, R. 40 W., the exposures indicate the continuance of the same conditions. The shale shows in the N. W. ¼ of the S. W. ¼ of Sec. 18, again in the the N. W. ¼ of the N. E. ¼ of Sec. 15, and again near the south quarter-post of section 11. These exposures, with those already noted on the other side of the Ontonagon, in Sec. 7, T. 50, R. 39 W., serve to fix the course of the shale belt across this township at a little north of east for the first two miles, then about N. 15° E. for two and a half miles, and then N. 30° E. to the Ontonagon River. "Red slaty trap and conglomerate" are marked on the township plat as occurring within a mile of the shale, and the succession is evidently the same as already noted to the east of the Ontonagon, viz: black shale, sandstone and conglomerate, traps, conglomerate, traps, porphyry. North of the black shale the main body of sandstone is everywhere the surface rock to the lake shore.

Westward from the Porcupine Mountains the upper belts are more easily traced. Following the coast line westward from the mouth of the Presqu' Isle, the main sandstone of the Upper Division forms the coast as far as the west line of T. 49, R. 46 W., just beyond which the black shale, which may also be seen a short distance up Black River from the mouth, appears at the coast for a short time, soon retreating from it again. From this point the main body of sandstone forms the coast continuously to the Montreal River. In this distance the layers trend more to the south than the coast line, which thus is constantly reaching a higher horizon. At the same time the dip angle rapidly steepens, being 45° about midway in range 47, and nearly 90° at the mouth of the Montreal River. It thus results that on the Montreal as much as 10,000 feet of the main sandstone is crossed by the lower reaches of the river, for some ten miles to the east of which stream it often forms bold cliffs forty to seventy feet high. On Black River there are falls in the N. W. ¼ of Sec. 15, T. 49, R. 46 W., over conglomerate and sandstone, which belong with the broad conglomerate beneath the shale. The conglomerate at the falls near the S. W. ¼ of the S. W. ¼ of the same section belongs with the Carp Lake band, and the "trap" at the falls just above in the N. E. ¼ of Sec. 21 with the underlying diabases of the band following just above the porphyry of the Porcupine region. The "trap-rock" of the old Chippewa location, S. W. ¼, Sec. 22 of the same township, evidently belongs with the main mass underlying the porphyry.

When the Montreal is reached, instead of finding one broad conglomerate between the outer or Carp Lake trap, and the belt next the porphyry, we meet with a succession of alternations of sandstone or red shale and diabase. It has already been indicated that even in the Porcupine Mountains the inner conglomerate may hold an interstratified diabase band, and a few miles west of the Presqu' Isle there certainly is one. Further west the sandstone and beds of basic crystalline rocks must dovetail into one another in some such manner as indicated on the map of Plate XXII. Exposures belonging to these trap bands are met with on the west line of the N. W. ¼ of Sec. 34, T. 49, R. 47 W.; on the west line of the S. W. ¼ of Sec. 31 of the same township; and on the south line of Sec. 34 of T. 49, R. 48 W. Further back from the lake shore there are other exposures belonging to the Main Trap Range, as far south as and nearly in contact with the underlying iron-bearing slates.

The section displayed on the Montreal River is next to be described. Ascending the Montreal River from the mouth, vertically placed ledges of red sandstone and red sandy shale belonging to the main body of the Upper Division, are the only rocks seen up to the S. E. ¼ of the N. E. ¼ of Sec. 20, T. 47, R. 1. E. (Wisconsin), two and a half miles above the mouth. Here begin exposures of the black shale and its interstratified sandstones. The shale of these alternations is dark-purple to black, very soft and clayey, and quite regularly laminated. The shale layers run from ten to fifty feet or more in thickness, and are quite subordinate in abundance and thickness to the associated sandstones into which they grade. The sandstone is dark-gray to brown, very close-grained and compact, and often appears macroscopically like a fine-grained, crystalline rock. This rock forms massive ledges in the bed and on the sides of the stream Under the microscope it appears much the same as the sandstones at the same horizon in the Porcupine and Ontonagon regions, but some sections show an unusually small amount of porphyry detritus, being almost wholly made up of basic fragments, with the calcite cement.

After crossing a thickness of these beds of some 350 to 400 feet—a much smaller thickness than was noted farther east—a broad belt of coarse conglomerate is crossed. The constituent bowlders are largely of the several kinds of acid porphyries, but there are many of the basic igneous rocks of the system. Much calcite is present between the bowlders and sand grains, and also occurs in veins of some size. The vertical bedding is well brought out by the few intercalcated sandstone seams. This conglomerate is exposed in cliffs several hundred feet high, forming the walls of the narrow tortuous gorge through which the Montreal River passes at the middle of Sec. 20, T. 47, R. 1 E. It is plainly enough the equivalent of the outer sandstone and conglomerate of the Porcupine Mountains. In the latter district this stratum has a thickness of some 3,000 feet, but at the Montreal it is not more than 1,200 feet.

Next in descending order on the Montreal is met an alternating series of thin and very regular beds of fine-grained diabase and red sandstone and shale. The beds of the crystalline rocks are sharply defined from each other by very strongly developed amygdaloids or vesicular portions. The lower portions of the diabase flows are characterized by a very distinct columnar structure at right angles to the bedding. The finest exhibition of both amygdaloids and columnar structure is to be seen at the head of the upper falls, where at low water there is a very large surface of bare rock. The following tabulation, copied from my report on the Geology of the Eastern Lake Superior District,[1] serves to show the main facts with regard to these alternations. It should be said that detailed microscopic examinations would possibly prove some of the layers to be melaphyrs:

	Thickness in feet.
I. *Diabase*	20
II. Red shaly *sandstone*	10
III. *Diabase*	4
IV. *Sandstone* and *shale*, including the following subdivisions: (1) thin laminated red shale, 4 feet; (2) purplish, lumpy, fine-grained sandstone, 8 feet; (3) like (1), $2\frac{1}{2}$ feet; (4) like (2), 6 feet; (5) like (1), very bright red, $1\frac{1}{2}$ feet; (6) like (2), 5 feet; (7) bright red clay shale, 14 feet; total	41

[1] Geology of Wisconsin, Vol. III, p. 191.

		Thickness in feet.
V.	*Diabase*, including the following subdivisions: (1) amygdaloid, with abundant amygdules of prehnite, laumontite, calcite and chlorite, and with seams of laumontite and large patches of calcite, in the more thoroughly altered portions, having at base a heavy laumontite and calcite seam carrying copper, on which some mining has been done, 25 feet; (2) pseud-amygdaloid, 5 feet; (3) compact portion with distinct columnar structure, the rock having on fresh fracture a grayish color and distinctly crystalline appearance, though very fine grained, 70 feet; in all	100
VI.	Covered	185
VII.	*Diabase*, with subdivisions as in V	92
VIII.	Red *sandstone* and *shale*	20
IX.	*Diabase*, with subdivisions as in V; compact portion dark chocolate-brown	50
X.	Reddish conglomeratic *sandstone*	60
XI.	*Diabase*, including: amygdaloid, 10 feet; compact portion, 20 feet; in all	30
XII.	*Diabase*, including: amygdaloid, 5 feet; compact portion, 20 feet; in all	25
XIII.	*Diabase*, with usual subdivisions	10
XIV.	*Conglomerate*	33
XV.	Red *sandstone* and *shale*	60
XVI.	*Diabase*, with usual subdivisions	60
XVII.	Red *sandstone* and *shale*	20
XVIII.	Compact, dark greenish-gray *diabase*, with amygdaloid at top, and showing a tendency to a cross-columnar structure	21
XIX.	*Diabase*, including: (1) amygdaloid, in many places showing a tendency to cross-columnar structure, some bands almost completely made of amygdules, and others with but few, 15 feet; (2) compact portion, highly columnar, 8 feet; in all	23
XX.	*Diabase*, including: (1) amygdaloid in distinct bands, as in XIX, some of the bands showing a change to laumontite and calcite, the amygdules, in order of abundance, being prehnite, pink orthoclase, orthoclase and calcite, orthoclase, prehnite and calcite, 11 feet; (2) compact portion, with columnar structure, 10 feet; in all	21
XXI.	*Diabase*, including: (1) amygdaloid, in many places altered into laumontite seams, 2 feet; (2) compact portion, 30 feet; in all	32
XXII.	Red clay *shale*	5
XXIII.	*Diabase*, without amygdaloid	10
XXIV.	*Diabase*, including: amygdaloid, mostly covered, 15 feet; compact portion, 40 feet; in all	55
XXV.	Covered	185
XXVI.	Red *shale*	40
	Total	1,212

These layers are exposed along the stream as far as the crossing of the Lac Flambeau trail, near the east line of Sec. 21, T. 47, R. 1 E. They undoubtedly include the equivalents of the outer trap, the Carp Lake conglomerate and sandstone, and more or less of the inner trap, with its conglomerate, of the Porcupine Mountains, but with a greatly decreased total thickness, which effect is wholly produced by the thinning of the sandstone and conglomerate. On the Montreal River the included detrital beds are nine in number, with a total thickness of 290 feet, as against some 1,900 or 2,000 in two (or three?) layers in the Porcupines. The diabase flows, however, evidently increase in number and total thickness between the Porcupine Mountains and the Montreal River.

Through the eastern part of T. 47, R. 1 E., and southern part of T. 47, R. 2 E., the Montreal is unfortunately without exposure. In this interval one would look for the extension of the Porcupine Mountains porphyry, and such a rock has been seen west of the river in the N. W. part of T. 46, R. 1 E. In this interval must also lie a large proportion of the beds which make up the Main Trap Range, further east.

On the Upper Montreal, and its tributary, the Gogogashugun, in T. 46, R. 2 E., there are again quite large exposures, continuing with but little break to the junction with the underlying Huronian schists. These layers must in large measure correspond to those of the South Range of the region east of the Montreal, and in a measure to those which in the Ontonagon region and farther east are buried beneath the Eastern Sandstone. One of the northernmost of these beds is a narrow one of red felsite-porphyry, exposed on the Gogogashugun, near the south line of section 8. Immediately beneath it comes a succession of beds, many of which are composed of a black conchoidal-fracturing aphanitic rock of the ashbed type, while still further south to the junction with the Huronian a peculiar dark-greenish diabase is the prevailing rock. The former of these two kinds of rock may be seen largely exposed along the Gogogashugun in its passage through Sec. 8, T. 46, R. 2 E., along the Montreal in sections 2 and 11 of the same township, and in a number of large ledges between the two rivers. The green diabases show on the Flambeau trail, in section 19, on the Gogogashugun, in section 16, and very largely at the falls on the Montreal, in sections 11 and 14 of T. 46, R. 2 E. These greenish to greenish-gray diabases are quite peculiar, and resemble closely rocks seen in the South

Range of the Ontonagon country, at what must be nearly the same horizon. They are furnished with imperfectly developed amygdaloids, quite characteristic of which are elongated (spike) amygdules, composed of quartz, epidote and chlorite in combination. The pronounced green color is due to the large amount of chlorite which is present, both as an alteration-product of the feldspars and in large green pseud-amygdules. A section of one of these rocks is represented at Fig. 3, Plate VIII.

The entire horizontal width of the Keweenaw Series on the Montreal is some 50,000 feet. Allowing for supposed flatter dips in the lower portions, we may estimate the thickness at 33,000 to 35,000 feet for the Lower Division, and about 12,000 for the Upper Division. As already indicated, this estimate for the Lower Division will be too great if the influence of the Keweenaw fault should extend so far as this, but it does not seem that the discrepancy can be more than two or three thousand feet at the outside.

In the vicinity of the Potato River, which crosses the series some ten miles west of the Montreal, along the strike, several important changes are to be noted. In the first place, the lower strata of the Upper Division and the upper strata of the Lower Division are greatly thinned. The black shale, with its accompanying sandstone, has thinned from 400 to 250 feet, and its underlying conglomerate from 1,200 to 800 feet, while all that is left of the 290 feet of sandstone and shale, which on the Montreal River are interstratified with the uppermost diabases, is one little seam of shale ten feet in width. This thinning of the sandstones is of course simply a continuation of the thinning process already described as obtaining between the Porcupine Mountains and Montreal River.

Now, however, a thinning of the crystalline members also has begun, the entire width of the Lower Division in the vicinity of the Potato being only some six and a half miles, as compared with seven and a half miles on the Montreal, and with the same high dips. But a yet more remarkable change is the apparent substitution of more or less coarsely crystalline gray to black gabbros for all the fine-grained diabases of the lower 10,000 to 12,000 feet of the Montreal section. This is a change which first begins on the Gogogashugun River, where a few ledges of the coarse gabbro are seen between broad belts of the finer kinds. On the Flambeau trail, in the western part of T.

46, R. 2 E., the coarse rocks appear more plentifully, and by the time the Potato River is reached the finer rocks have nearly or quite disappeared. These coarse rocks, as shown elsewhere, are much like the coarse gabbros of Duluth and the Saint Louis and Cloquet rivers, which they resemble, moreover, in being cut by masses of brick-red granitic porphyry, a large exposure of which rock is to be met with, for instance, on the old Ironton trail in the northern part of Sec. 3, T. 45, R. 1 W.

For the rest, the Potato section is chiefly made up of ordinary types of diabase and melaphyr. At least two bands of felsite and quartziferous porphyry are included. One of these, in the southern part of T. 46, R. 1 W., is evidently the same as that noted on the Gogogashugun, Sec. 5, T. 46, R. 2 E., while the other much broader band, which is exposed on the river in sections 14 and 15 of T. 46, R. 1 W., appears to belong with the porphyry of the Porcupine Mountains. The rock of the latter belt is largely a true quartziferous porphyry, with a lilac-tinted matrix, in which are thickly scattered minute black quartzes, one-twentieth inch in diameter, and whitish kaolinized feldspars, one-tenth to two-tenths inch across. Faint white lines are occasionally seen, and the whole aspect of the rock is very much that of the rock at the Great Palisades on the Minnesota coast.

Ten miles farther southwest, along the strike, Bad River crosses the series, and here the changes are carried to a yet greater extreme. The black shale and underlying conglomerate have thinned respectively to 125 and 350 feet, while the entire width of the Lower Division to the underlying Huronian is only some 17,000 feet, of which 12,000 feet are taken up by the coarse gabbro. The remaining 5,000 feet are made up chiefly of the typical fine-grained diabase and diabase-amygdaloid; but two beds of quartzose porphyry are included, the lower one of which is evidently the same as the broad belt of the Potato River section. One porphyry-conglomerate has been noted in this thickness.

Beyond Bad River the general trend of the formation changes abruptly to a westerly direction, but otherwise the conditions remain much as observed on that stream, as far as the Brunschweiler River, save that the gabbro below expands to a great width. In the townships between Bad and Brunschweiler rivers the gabbro makes such frequent exposures—those on the line of the latter stream being almost continuous from the head of Bladder Lake to the contact with the overlying fine-grained diabases—that there can be no doubt as to its occupying the whole of the width indicated. It is in this vicinity that the coarse gabbro appears to occupy a position of unconformity to the underlying Huronian slates.[1]

A few miles west of the Brunschweiler the coarse gabbro exposures begin to have scattered among them others of the usual fine-grained diabases, and beyond range 6 west the gabbro is no longer met with. It thus terminates to the westward much as it does to the eastward.

The entire length of the belt occupied by these coarse gabbros is some 40 miles, its width ranging from 1½ miles to 4½ miles. Three principal phases of the rock occur, viz: orthoclase-free gabbro, orthoclase-gabbro and hornblende-gabbro. The first of these is bluish-gray to black, and ranges from below medium-grained to very coarse-grained, the crystals reaching several inches in length. The usual constituents are a very basic feldspar—which, judging from the angles, is commonly near anorthite—diallagic augite or true diallage, titaniferous magnetite, and olivine. There are sundry alteration-products often present, but the rock on the whole is a very fresh one. The second variety of gabbro is found especially in the more northern portions of the gabbro belt, forming apparently continuous bands, which have in some cases been traced for a number of miles. It is a red- and black-mottled, or red-, black- and gray-mottled rock, and commonly quite coarse-grained, though never reaching the extreme degree of coarseness sometimes shown by the orthoclase-gabbro of the Saint Louis. It is also marked by very abundant and noticeably large grains of titaniferous magnetite. Oligoclase and orthoclase, both much altered and red-stained, diallage commonly largely altered to greenish uralite, and beyond this to chlorite, titaniferous magnetite and very abundant apatite are the ingredients.

Still a third variety, forming a belt or belts some 15 miles in length, near the junction with the Huronian, belongs to what I have called hornblende-gabbro in Chapter III. This rock is peculiar in containing much deep-brown intensely dichroic hornblende, which, however, I think can be

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[1] See pp. 144, 156.

satisfactorily proved to be secondary to the augitic constituent. Macroscopically it is medium-grained, and from black- and white-mottled to nearly black in color. The constituents are labradorite, augite, hornblende, titaniferous magnetite, apatite, uralite and diallage; with a little biotite, chlorite and quartz.

In the townships west from Bad River, within the gabbro belt, low exposures of a coarse, pinkish granite are often met with, and precisely similar exposures are found in the area occupied by the upper mica-schists of the Huronian. This granite is intrusive, cutting both the gabbro and the upper Huronian schists. It is a true biotite-granite, consisting of orthoclase, oligoclase, quartz very rich in large bubble-bearing cavities, and rather rare biotite.

Thus far, for the region west of the Montreal River, attention has been directed to the Lower Division of the Keweenaw Series, and to the lowermost members of its Upper Division. These lower rocks form the mass of a highland or range which, on the Montreal, is only some two miles from the lake shore, while on Bad River it lies twenty miles back of the coast, leaving in front of it a broad lowland, underneath which lies the main mass of sandstone of the Upper Division. On the Montreal most of the thickness of this upper sandstone is in sight, and on the Potato, Bad and Brunschweiler rivers some hundreds of feet of its lowest portions are to be seen. On the Montreal, Potato and Bad rivers it stands vertically or nearly so, with a slight inclination to the north, the northern dip flattening somewhat in the higher layers. On the Brunschweiler a perceptible flattening of the whole series has begun.

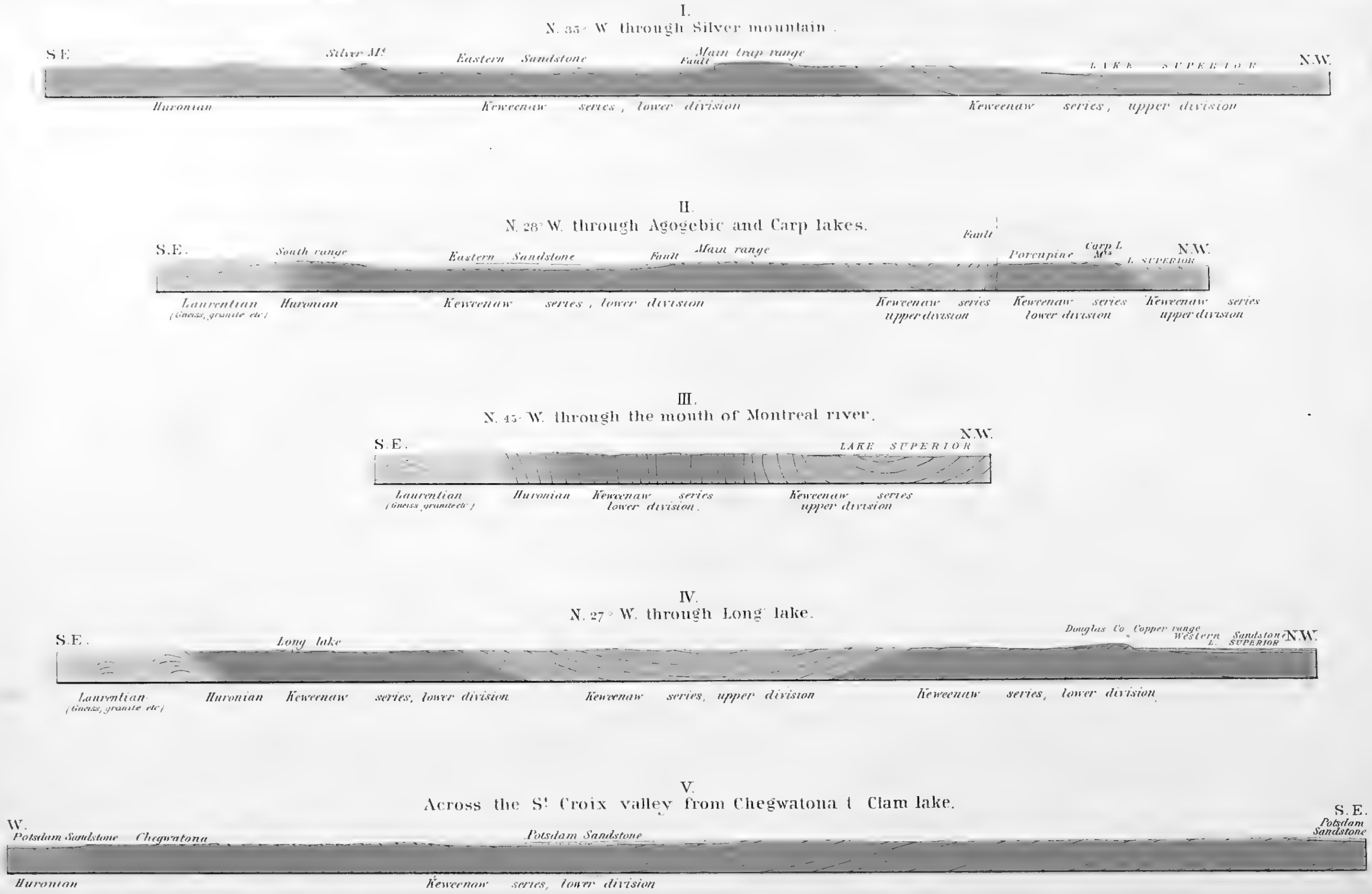
Throughout most of the lowland underlaid by these sandstones they are covered by red lacustrine clays, but at two points—on Bad River in Sec. 25, T. 47, R. 3 W., and on White River in the N. E. ¼, Sec. 6, T. 46, R. 4 W.—they appear in great force, inclining now to the southeastward. On Bad River, a thickness of 2,000 feet is in sight, trending N. 60° E., and dipping S. E. 38°; and on White River, 300 to 400 feet, with a N. 40° E. trend, and 25° S. E. dip. These southward-dipping sandstones indicate the existence of a synclinal in the Upper Division of the series, and explain the wide surface spread of the upper sandstones in this region.

SECTION V.—NORTHWESTERN WISCONSIN AND THE ADJOINING PART OF MINNESOTA.

This region was examined in considerable detail for the Wisconsin Geological Survey in the years between 1873 and 1879, by Messrs. Sweet, Strong and Chamberlin. The results of their work are given in Vol. III of the Geology of Wisconsin, which volume also contains brief descriptions by Pumpelly of a number of the specimens collected. A special trip was also made for this work by Mr. R. McKinlay under my directions, in the valleys of the Snake and Kettle rivers of Minnesota, with especial reference to determining the manner in which the Keweenawan rocks and the Lake Superior basin terminate westwardly. From the data collected by these several investigators I compile the following brief account of the region, adding some conclusions of my own.

This region includes two distinct belts of the Keweenawan rocks. One of these is a continuation of the belt we have been following all along from Keweenaw Point, with the dip as usual to the north and west, while the other is a parallel belt made up of strata presenting a southerly or southeasterly dip, and forming the northern side of a synclinal trough, which extends entirely across Wisconsin to the Minnesota line. The axis of this synclinal, where it first strikes the lake shore near the Montreal River, trends about southwest; beyond Bad River for some 35 miles it runs nearly due west. Turning then again, it follows a southwesterly course for about 80 miles, when it changes to a nearly due south course in the valley of the Saint Croix River, where the north and south belts finally unite, underneath the newer Cambrian sandstone of the Mississippi Valley. In this region the two main divisions of the series are plainly recognizable. It thus follows that the Upper Division, with its great thickness of soft sandrock, occupies the middle of the synclinal, while the ridges on each side are composed of the resistant crystalline rocks of the Lower Division.

The Southern Belt; Numakagon Lake to the Saint Croix River.—In the southern belt, including the northward-dipping rocks, with the one exception of the conglomerate at the base of the Upper Division, the only expos-



A. Hoen & Co. Lith. Baltimore

GENERALIZED GEOLOGICAL SECTIONS OF THE REGION BETWEEN PORTAGE LAKE AND THE ST CROIX RIVER.

Scale $\frac{1}{350000}$ or 1 inch = 5.524 miles.

ures are altogether of the beds of the Lower Division. The relative positions of the exposures, and the bedding directions observed at them, show that immediately west of the district last described, or in ranges 6 and 7 west, a rapid flattening of the northern dip takes place, and a proportionately great widening of the belt of country occupied by the formation. In range 7 west this width is as much as 9 miles, the dip flattening to 35° in the lowermost belts and to 25° in the upper belts. Farther west the dips flatten still more, getting as low as 10° to 15°, and the surface width becomes as much as 12 to 15 miles.

As to kinds of rocks, the exposures are sufficiently frequent to show that the constitution of the Lower Division of the series is the same in this region as farther east. The greatly predominant rocks are the usual plainly bedded fine-grained diabases with their amygdaloids. Melaphyrs or olivine-diabases are rarer, but occur somewhat frequently. Interleaved porphyry-conglomerate and sandstones have been observed at a number of points, while massive quartz-porphyry is occasionally to be seen. No coarse gabbro has been observed anywhere between Numakagon Lake and the Saint Croix River.[1]

A rather unusual phase of diabase is the diabase-porphyry of the ledges in sections 26 and 27 of T. 36, R. 16 W. These rocks, "in a greenish-gray, fine-grained matrix have a greater or less amount of red feldspar in porphyritic crystals, one-thirtieth and one-eighth inch in diameter." The specific gravity is 2.90.[2] Under the microscope the porphyritic crystals prove to be a somewhat altered triclinic feldspar, while the groundmass is chiefly made up of smaller plagioclases. Intermingled with these are fibrous, greenish, feebly dichroic or non-dichroic particles, which prove to be altered (uralitic and viriditic) diallage; epidote, in quite abundant grains; titanic iron largely altered to a white substance; and pseud-amygdaloidal chlorite. Closely related to this, and evidently at about the same horizon, is the dark greenish-gray porphyritic rock so largely exposed at the Dalles of the Saint Croix, in T. 34, R. 19 W.[3] In this rock porphyritic brown

[1] See Geology of Wisconsin, Vol. III, pp. 41, 42; 46–48; 391–395; 399–428, for lithological descriptions and complete local details.

[2] R. Pumpelly, Geology of Wisconsin, Vol. III, p. 41.

[3] Geology of Wisconsin, Vol. III; also A. Streng and J. H. Kloos in Leonhard u. Geinitz Jahrbuch für Mineralogie. 1877.

plagioclases and pseud-amygdaloidal epidote, chlorite and quartz are imbedded in a groundmass consisting principally of plagioclase, with which are augite, commonly much changed to viridite, magnetite or titanic iron and epidote. This rock passes into a true amygdaloid, and is associated, as is also the similar rock of T. 36, R. 17 W., with diabases in all respects like the common types of Keweenaw Point. It is of considerable interest that rocks closely allied to these are found at a similarly low horizon on Silver Mountain, in the South Range of Michigan, and again on the Minnesota coast of Lake Superior.

In the vicinity of Saint Croix Falls, as also again on the upper Saint Croix, and on its tributaries, the Kettle and Snake, in Minnesota, the Keweenawan rocks are visibly overlain by the horizontal fossiliferous basal or Cambrian sandstones of the Mississippi Valley, the sandstones lying horizontally in the erosion hollows of the previously tilted Keweenawan beds. As this is a matter of great theoretical importance, we may quote at some length from Professor Chamberlin's descriptions of the Saint Croix rocks.[1] The other places referred to are described in subsequent paragraphs.

At and in the vicinity of Saint Croix Falls, and southward from there to the neighborhood of Osceola Mills, there are numerous and very fine exposures of the Copper-bearing series and of the overlying Potsdam sandstone. * * * * For the greater part, they lie in the immediate valley of the Saint Croix river, and owe their exposure to the erosive action of that stream. The valley here is some 400 feet (aneroid) below the higher plateaus that approach the stream, within a mile or two on either hand. The Copper-bearing rocks appear in the slopes of the valley, at heights ranging up to 200 feet or 300 feet.

* * * * * * * * *

Just below Taylor's Falls, the river has cut a deep vertical gorge in the trappean rock, forming the beautiful and picturesque Upper Dalles. About two miles below this a similar cañon has been formed, constituting the Lower Dalles. The walls within these Dalles are almost absolutely vertical, and instead of showing worn faces, like the slopes above, present the regular rough surfaces common to fissure planes. It seems very probable that the original worn surface of the gorge has been riven and thrown down by the action of the frost and the undermining of the stream.

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In this vicinity, the relation of the Potsdam sandstone to the copper-bearing rocks is most satisfactorily shown.

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On the N. W. $\frac{1}{4}$ of Sec. 12, T. 33, R. 19 W., Osceola, there is an exposure of horizontally stratified sandstone in the side of a small ravine, and within a few feet is an

[1] Geology of Wisconsin, Vol. III, pp. 415–421.

exposure of melaphyr[1] of the Keweenaw series. The sandstone is quite hard and compact, but the stratification is undisturbed, and there is no indication of metamorphism. A short distance farther north, the road passes over an exposure of melaphyr on which the sandstone is seen deposited in direct contact with it.

In the south part of the village of Taylor's Falls, near the summit of the ridge, is a remarkable exposure of the Potsdam in connection with the Keweenaw series. Its occurrence is illustrated in Fig. 7, but somewhat idealized. All that is seen is an outcrop of melaphyr, and, on the exposed face, a conglomerate formed of rounded and waterworn fragments of melaphyr. These fragments are of all sizes, and the cementing material is a ferruginous sandstone of Potsdam age, containing occasional *Lingulepis* shells. In the vicinity of the melaphyr the greater part of the conglomerate consists of its fragments. After inspecting the locality, it seems evident that the melaphyr was an exposed cliff in the Potsdam sea; about whose base large and small water-worn fragments of the melaphyr were collected, and, the interstices being filled with sand, solidified into the conglomerate as it now appears. The junction of the two formations is not well exposed, as the sandstone graduates into the conglomerate, and the latter is banked up against the uneven surface of the melaphyr. The unconformability, however, cannot be doubted.

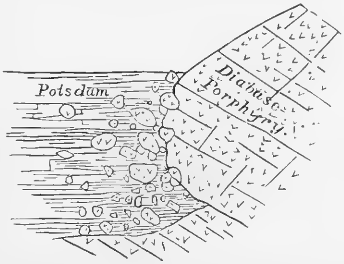

FIG. 7.—Showing unconformable contact between Keweenawan diabase-porphyry, and Potsdam sandstone at Taylor's Falls, Minn.; after Strong.

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On the west side of the river, about half a mile above Taylor's Falls, when the water is low, the junction of the Potsdam and Keweenaw formations may be found. * * * * The fossiliferous blue shales of the Potsdam are horizontally deposited on a melaphyr, containing small specks of pyrites. The melaphyr breaks out in thin pieces, having the shales firmly attached. The junction is marked by a dark line about one-eighth of an inch thick, which seems to cement the two formations.

* * * * * * * * *

The foregoing facts, corroborated as they are by much other data gathered from the vicinity and other parts of the district, and elsewhere, make it certain that the Copper-bearing series was subjected to much erosion during and previous to the formation of the Potsdam sandstone, by which valleys were cut into it to the depth of at least 300 feet. This, doubtless, represents but a small proportion of the total erosion which the series had suffered in the pre-Potsdam period.

This locality presents the most clear and unequivocal evidence that the Copper-bearing series is much older than the Potsdam sandstone of our state, so much older, indeed, that there was time for the very extensive wearing down of the former before the latter was deposited.

The crystalline rocks of the Copper-bearing series of this locality, while varying somewhat, possess a general similarity, and are not diversified by conspicuously distinct beds of different kinds of rock, as has been found to be usually the case in other

[1] Rather a porphyritic diabase, according to the nomenclature adopted in this volume.—R. D. I.

extensive exposures of the formation. So true is this, that it is quite difficult to distinguish the true bedding planes.

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In addition to these vertical planes of division, which are generally quite smooth and uniform, but not persistent to great depths, there is another prominent set which are much less smooth, but much more persistent and constant in direction. The surface of the layers separated by these joints is nearly uniform to the general view, but in detail is slightly uneven and undulatory, as though the separation took place not through the fracture of a homogeneous rock, but by separation along a natural division plane. These planes are usually separated by several feet. They are confidently believed to represent the dip of the igneous beds. It is not presumed that *all* of the layers so formed represent separate overflows of molten material, much less distinct periods of eruption; but that in the flowage and outspreading of the igneous matter, a somewhat parallel arrangement of the not perfectly homogeneous substance took place, giving rise to an obscure pseudo-stratification, sufficient to influence the jointing that subsequently took place. At the same time, the fact that the beds at different horizons present different textures, and, in a subordinate degree, different mineralogical composition, would seem to favor the belief that the several hundred feet of the formation exposed in the vicinity of Saint Croix Falls, represent a considerable number of distinct but closely successive overflows; all, perhaps, belonging to one great period of eruption. The latter statement seems to be demanded by the lithological similarity of the rock, the slight distinction between the beds, and the absence of detrital deposits between them. Notwithstanding their obscurity, however, the beds give to the outcrops the distinctive step-like or trappean contour that has been previously described and figured. This is best seen in the exposures about one mile east of Saint Croix Falls (N. E. ¼ of Sec. 29, and N. W. ¼ of Sec. 28, T. 34, R. 18 W.), where the inclined ledges follow each other with much regularity and persistence, giving to the profile of the cross-section a serrate outline, notwithstanding the fact that the glacial agencies acting from the northwest tended to plane down the edges of the beds.

It is upon the persistence of these inclined ledges, taken in connection with parallel lithological belts, that our determination of the dip, a matter of some theoretical interest at this extremity of the formation, is mainly based. The average of a large number of guarded observations gives a dip of about 15° W. by S. This inclination to the south of west is quite an interesting fact, however it may be interpreted. To the writer it seems to signify, taken in connection with other observations, that the trough of the Lake Superior synclinal, at this western extremity, curves rapidly southward, and is connected, over a sort of saddle-back anticlinal, with the broad stratigraphical basin that stretches southward into Minnesota; and that the igneous beds overlap this figurative saddle-back, so as, on their margin, to really lie in the southern or Mississippi basin. This low anticlinal is supposed to lie a little north of Saint Croix Falls, and to be the low, flattened extremity of the Laurentian and Huronian heights that lie to the eastward—the saddle-bow of our illustration.

The unconformity shown by Messrs. Sweet,[1] Strong,[2] and Chamberlin[2] to obtain in the Saint Croix Valley between the fossiliferous Cambrian

[1] Transactions of the Wisconsin Academy of Sciences, Arts, and Letters, Vol. III, p. 40.
[2] Geology of Wisconsin, Vol. III, Part VI.

sandstones and the bedded melaphyrs and amygdaloids upon which they lie being so plainly indisputable, the latest advocate of the old idea of the contemporaneousness of these sandstones with the copper-bearing or Keweenaw rocks has been driven to question the correctness of the identification of the bedded diabases and amygdaloids of the Saint Croix Valley with those of Keweenaw Point.[1] It is therefore proper that I should insist here that this identification is also indisputable; and that it is so because of the absolute identity in nature and structure of the rocks of the two regions, and because the Keweenaw belts have been followed continuously from the eastern end of Keweenaw Point to the Saint Croix River.

In support of the first of these assertions, I have to advance the following facts. The predominant fine-grained basic rocks of the two regions are so completely the same in mineral composition, even to the alteration-products, that thin sections of rocks from the two districts placed side by side are not distinguishable from one another. The only approach to an exception to this statement is the somewhat greater prominence of prehnite as an alteration-product on Keweenaw Point than on the Saint Croix.[2] The rocks of the two regions present precisely the same amygdaloidal, pseudamygdaloidal, and compact phases. The amygdules are made of the same minerals in both, associated in the same ways. Native copper occurs in the Saint Croix Valley in the same manner, and with the same associates as on Keweenaw Point. Here and there an exposure may represent a dike so far as can be perceived, but almost everywhere the Saint Croix Valley rocks present precisely the same bedded structure as seen in those of Keweenaw Point. This is displayed, not only in the common step-like contours of the exposures, but the individual beds may be readily separated from one another, each bed often showing sharply marked its upper

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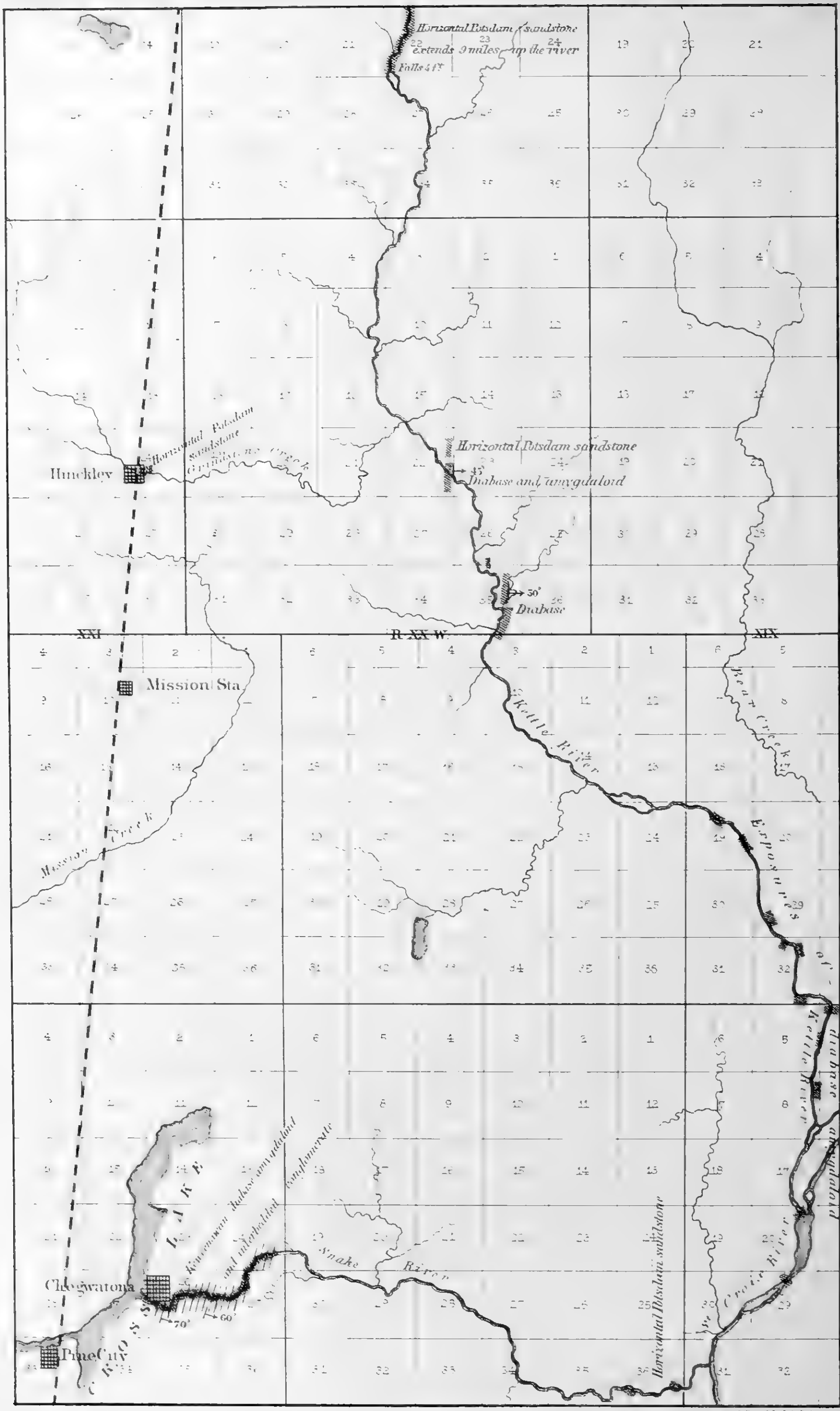
[1] "Notes on the Iron and Copper Districts of Lake Superior," by M. E. Wadsworth. Bulletin of the Museum of Comparative Zoology at Harvard College. Whole series, Vol VII. Geological series, Vol. I, No. 1, p. 107.

[2] Compare R. Pumpelly, Geology of Wisconsin, Vol. III, p. 36. "While the absolute identity of the diabases and melaphyr and of their varieties and amygdaloids, and of the interbedded porphyry conglomerates of the Wisconsin area with those of Keweenaw Point is evident, I am struck by the comparative scarcity in the former, of one of the most important forms of alteration that abounds in Michigan; I have found in the four collections but one instance of change of feldspar to prehnite." With regard to this it should be said that the specimens from Wisconsin examined by Pumpelly included very few from the uppermost belts of the Lower Division, which carry prehnite much more commonly.

vesicular and lower compact portions. Moreover, where the dip is high and the exposures are large, as on the Snake and Kettle rivers of Minnesota, there is to be seen a continuous series of beds, in all many hundred feet thick and in every respect similar to the alternations which obtain on Keweenaw Point. The same interstratified porphyry-conglomerates and sandstones are met with in both regions, and in both regions carry at times native copper. Interbedded original felsitic porphyries also occur in both regions.

In support of the second assertion, as to the actual continuity of the Keweenaw Point and Saint Croix rocks, I have to say, in the first place, that the evidence of this continuity is precisely the same for the distance between the Montreal and the Saint Croix, as for that between the Montreal and Keweenaw Point, or even the distance between the eastern part of Keweenaw Point and its western portion at Portage Lake; that the continuity has never been disputed for the two latter distances; and that it should therefore be accepted at once for the first-named distance. The evidence for all the distance between Keweenaw Point and the Saint Croix is just as strong as that ever appealed to to prove the continuity of geological formations anywhere, save in those very rare and exceptional regions where the rocks are completely bare. This evidence consists in the frequent recurrence, at short intervals, of the same kinds of rocks, with the same structure and stratigraphical arrangement; and such evidence is forthcoming in the present case. From Keweenaw Point to the Saint Croix, the formation has been traced mile by mile with a constant recurrence of precisely the same bedded basic rocks, with the same amygdaloidal and compact portions to the beds, of the same associated felsitic porphyries, of the same interstratified porphyry-conglomerates, and of the same native copper in veins, altered amygdaloids and conglomerates. The same division of the series into a Lower or prevailingly eruptive member, and an Upper or detrital member, is also everywhere present. From Keweenaw Point to the region of Long Lake, some even of the subordinate members are recognizable as continuous. For the particulars of this evidence, I refer to the detailed descriptions of Foster and Whitney's report, of Vol. III of the Geology of Wisconsin, and of the present work; to the United States Land Office township plats; and to the



MAP SHOWING POSITION OF THE EXPOSURES OF KEWEENAWAN ROCKS AND POTSDAM SANDSTONE

ALONG THE LOWER PORTIONS OF SNAKE AND KETTLE RIVERS, MINNESOTA.

collections of the Wisconsin Geological Survey, and of the survey made for this report. If this evidence does not constitute proof of continuity, then no geological formation in the United States has ever been proved to be continuous for more than a very few miles—rarely for more than a mile—except in the plateau region of the western territories.

In the distance between Numakagon Lake and the Saint Croix it is difficult to estimate the total thickness of the Keweenawan rocks. The Upper Division is not exposed on this side of the synclinal, and the position of the junction with the older rocks is rendered uncertain by heavy drift accumulations. Judging, however, from the dip and strike observations, and from the outside limits between which its surface spread must lie, it appears probable that the Lower Division of the Keweenaw Series must have here a total thickness of from 25,000 to 30,000 feet.

The Northern Belt; Snake River and Kettle River District, Minnesota.—The western end of the trough in the Keweenawan rocks is concealed by the unconformably overlying Cambrian sandstone and limestone. The final termination southward must lie on the Saint Croix, about half way between Hudson and Osceola, the exposures continuing down to the latter place. Rounding the turn and moving northward now on the Minnesota side of the Saint Croix, we find the Cambrian sandstone completely concealing the older rocks until Snake River is reached in township 39. Here, on the lower portions of Snake and Kettle rivers, and on the Saint Croix in the vicinity of the mouths of these streams, typical Keweenawan rocks are again exposed on a large scale with a trend but little east of north and a high easterly dip.

Snake River enters the Saint Croix on Sec. 30, T. 39, R. 19 W. Two miles below the mouth of the stream, in the N. W. $\frac{1}{4}$ of Sec. 7, T. 38, R. 19 W., there are cliffs of horizontal Potsdam (Cambrian) sandstone 50 feet high, in which the rock is the usual crumbling, quartzose, light-colored sandstone commonly seen in the Mississippi Valley. The same rock is exposed on the Snake River in the southern part of Sec. 36, T. 39, R. 20 W. Above this, Snake River is without rock exposures until Sec. 24, T. 39, R. 21 W. is reached. From here there are exposed continuously in the bed and on the banks of the stream to the dam at Chegwatona Lake, near the east line of section 27, beds of diabase and diabase-amygdaloid, with interbedded porphyry-conglomerates, trending N. 10° to 20° E., and dipping 60° to 75° south of east. The rocks, as shown by the thin sections, are in every respect identical with the fine-grained diabases and diabase-amygdaloids of Keweenaw Point. The following is an account, kindly furnished by Professor T. C. Chamberlin, of the succession displayed at this place.[1] His measurements were only rapid pacings, and his examinations did not begin quite so far down stream as the last ledges located by Mr. McKinlay.

The locality was, however, visited after having studied in detail the adjacent Wisconsin formations, and the observations were made especially with reference to the relations of these rocks to the Wisconsin and Michigan series, and, so far as general structural questions are concerned, were entirely conclusive in the judgment of the observer.

1. The uppermost exposure examined, *i. e.*, the one lowest down the river, the dip being eastward down stream, is a diabasic amygdaloid, much altered, containing malachite. The exposure is low and small.
2. Ten paces up the stream, *i. e.*, westward, there is a similar but less amygdaloidal rock in low exposures.
3. Fifteen paces further there occurs a similar rock which continues exposed for 26 paces.
4. This is succeeded by a conglomerate of the Keweenawan type, having a surface exposure of between 6 and 7 paces.
5. This is followed (underlain) by about 8 paces of mixed conglomerate and amygdaloid, that, for want of time, was not studied with sufficient thoroughness to determine its true nature. It appeared, however, to consist of the shattered fragments of the upper vesicular portion of a lava flow mingled by wave action with water-worn pebbles of more distant derivation.
6. This is followed by about 45 paces of diabase, more or less amygdaloidal, and belonging to the more common type of Keweenawan diabases.
7. This is underlain by conglomerate of the common Keweenawan sort, having a surface width of about 12 paces.
8. This is succeeded by diabase and amygdaloid, more or less concealed and varying in character, for a space of 79 paces.
9. This is followed (underlain) by a reddish very amygdaloidal rock, which, in 6 to 7 paces, graduates into
10. A bed of the common Keweenawan diabase, which has a surface extent of 12 paces.
11. This is succeeded by a reddish-brown amygdaloid for 10 to 12 paces.
12. Then follows a dark-gray diabase, including red diabasic rock, for about 12 paces.
13. This is followed for about 10 paces by amygdaloidal rock.
14. This again by diabase for 23 paces.

[1] From unpublished notes, made in 1878.

15. Then follows a mottled igneous rock for 44 paces, graduating into the common diabasic trap.
16. This gives place to a coarse red conglomerate of pronounced Keweenawan type containing porphyry pebbles. It has a surface width of 35 paces.
17. This is underlain by amygdaloidal diabase for 12 paces.
18. There follows this again a coarse red Keweenawan conglomerate with associated shale. This presented favorable conditions for definitely ascertaining the strike and dip, which were found to be, strike, N. 10° to 15° E.; dip, 60° eastward (E. 10° to 15° S). This stratum has a surface width of 10 paces.
19. Under this lies a fine-grained diabase, with a surface exposure of 18 paces.
20. This gives place to a band of amygdaloid, 3 paces across, followed by trap of varying character for a width of 75 paces.

A gap, estimated to exceed one-half mile, ensues, in which there appeared to be no exposures in the north bank of the river. On the south side, rock with harmonious dip could be seen at some points, but it was not visited.

At the dam at the outlet of Chegwatona Lake there are much altered amygdaloids and diabases in alternating series that strike from N. to N. 10° E., and dip from 60° to 70° eastward. The amygdaloidal bands are conspicuous, but not sufficiently sharply defined to give very precise strike and dip, but they harmonize well with the undoubted observations given above and the more general ones made along the whole section, so that the attitude of the series is perfectly certain. The rocks, whether compact diabases, amygdaloids, or conglomerates, are typically Keweenawan in aspect, and leave no room for doubt that they belong to the copper-bearing series and form the western and perhaps terminal margin of the Lake Superior synclinal trough.

Native copper occurs in these rocks on Snake River both in the conglomerates and some of the bands of altered amygdaloid, and in such quantity near the surface as to promise success to mining enterprise.

Returning now to the Saint Croix River, we find, on ascending from the mouth of the Snake, an exposure of the horizontal light-colored Potsdam sandstone in Sec. 30, T. 39, R. 19 W., and in the N. W. ¼ of Sec. 29, ledges of the usual fine-grained diabase striking north and south. On the N. E ¼ of Sec. 20, are again flat-lying ledges of a fine-grained diabase, apparently striking north and south with a very low eastern dip. At this place native copper has been obtained in a small trial shaft near the river edge. The lower part of the shaft penetrated to an amygdaloidal layer.[1] The usual light-colored horizontal Potsdam sandstone is exposed near by.

Kettle River enters the Saint Croix near the S. E. corner of Sec. 8, T. 39, R. 19 W. From this point the upward course of the stream is nearly due north for some three miles, this direction being apparently induced by the north and south strike of the rocks. In this distance are some five or

[1] Geology of Wisconsin, Vol. III, p. 427.

six long, low diabase ledges at the edge of the stream, apparently with a north and south trend. In the N. W. ¼ of the N. W. ¼ of Sec. 32, T. 40, R. 19 W. the east bank of the stream shows a diabase ledge 15 feet high and 35 rods long. Just opposite, on the other side of the stream, is a flat-lying reddish conglomerate. Porphyry conglomerate occurs again on the east bank of the river near the center of the S. E. ¼ of Sec. 29, T. 40, R. 19 W., and again in a large exposure a mile farther up stream in the N. E. ¼ of the S. E. ¼ of Sec. 19, where it plainly lies at a very flat angle. These three exposures appear all to be part of the same conglomerate bed. Six hundred paces up stream from the last exposure, typical diabase and diabase-amygdaloid are in sight.

Above this point the river is without exposure for about five miles, the upward course of the stream in this distance making over three miles of westing. On the north line of Sec. 3, T. 40, R. 20 W., however, large exposures of diabase begin again. Through Sec. 35, T. 41, R. 20 W. the river pursues a nearly southerly course, and on the east side, continuing for over half a mile, is a west-facing cliff 10 to 30 feet high of the typical fine-grained diabase. The east slope of the ledge is gradual, and the strike and dip are plainly to be made out, as respectively N. 6° E., and 50° E. On the north line of the same section, and again in section 22, similarly-placed ledges are largely exposed, the river making in this distance about a mile of westing, so that between the south line of T. 41, R. 20 W. and the exposures in section 22 the river crosses a mile in width of Keweenawan beds, with an average eastern dip of 50°. The last place is of great interest, for only 300 paces north of the stream, and directly in the course of the northward-trending diabases, is a cliff of horizontal light-colored Cambrian sandstone 40 feet high and several hundred paces in length. The occurrences at this point are represented in Figs. 8 and 9.

Four miles west of here, on the line of the Saint Paul and Duluth Railroad, near Hinckley, the same light-colored sandstone is quarried.

The exposures in section 22 are the last of Keweenawan rocks seen in ascending Kettle River. Six miles farther north, however, near the south line of Sec. 22, T. 42, R. 20 W., the horizontal light-colored Cambrian sandstone begins to make large exposures, which continue without break, either in the bed of the stream, or in cliffs 20 to 75 feet high, on either side, for 5 miles, to the north line of Sec. 35, T. 43, R. 20 W. Above this for 3½ miles the sandstone does not appear in the river, but is seen here and there on hillsides near the stream. Through sections 11 and 3, T. 43, R. 20 W. the sandstone reappears in the stream, the last exposure found lying 200 paces south of the north line of section 3.

From this point up stream for some nine miles no exposures were found. Then, through sections 9 and 4, of T. 45, R. 20 W., and 32, 29, and 28, of T. 46, R. 20 W., frequent outcrops of mica-schist are met with in the hillsides near the river.

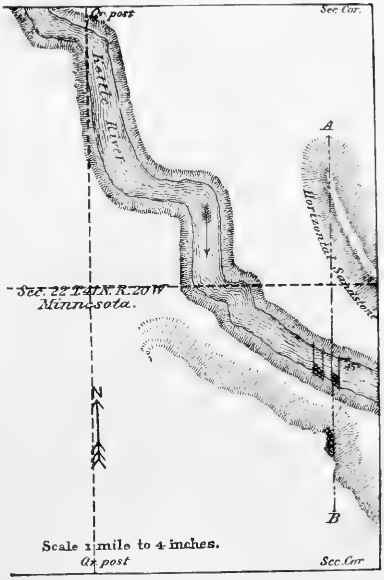


FIG. 8.—Map of Exposures on Kettle River, Sec. 22, T. 41, R. 20 W., Minnesota. Scale 4 inches to the mile.

These briefly-stated facts with regard to the region of the Snake and Kettle rivers, further illustrated by the map of Plate XXIV, will serve to render certain three very important conclusions, viz: (1) the diabases and diabase-amygdaloids and interbedded porphyry-conglomerates of this district are in all respects like those of Keweenaw Point; (2) the light-colored horizontal Cambrian sandstones overlie these beds unconformably; (3) these Keweenawan beds, with a trend but little east of north, present an easterly dip which at from 5 to 8 miles west of the Saint Croix reaches 50° to 75° and which flattens rapidly eastward, becoming very low on the Saint Croix

FIG. 9.—Section on line A B of Fig. 8. Scale, horizontal, 8 inches to the mile; vertical, 300 feet to the inch.

itself. The first two of these conclusions are but confirmations of those reached farther down the Saint Croix, but the last is of the greatest interest and importance in its bearing upon the structure of the western termination of the Keweenawan trough, as is shown in a subsequent chapter.

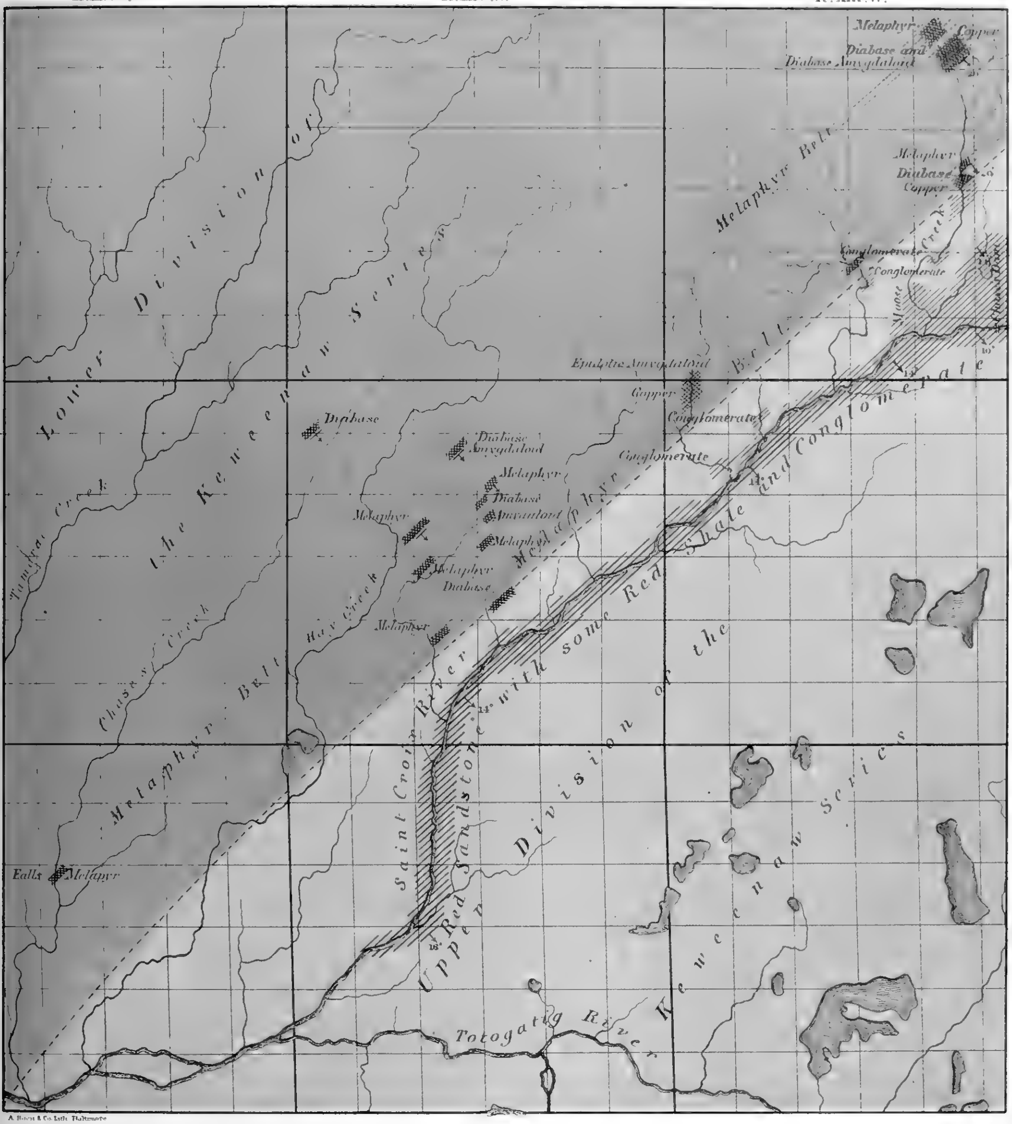
The exposures of Huronian schists on the upper Kettle River, taken together with those at Moose Lake, on the Saint Paul and Duluth Railroad, and those at Thompson, on the Saint Louis River, are also of great interest, since they form a line beyond which it is certain that the Keweenawan rocks cannot pass to the westward.

Upper Saint Croix.—For 30 miles above the mouth of the Kettle River the Saint Croix shows no rock of any kind. Then come large exposures of southeastward-dipping sandstone, extending for many miles along the stream. I quote in this connection from Professor Chamberlin's description:[1]

From Sec. 4 (T. 43, R. 13 W.) to the southern line of the county[2] (Sec. 33, T. 43, R. 14 W.), the bed of the stream[3] is almost continuously composed of sandstone and conglomerate. The greater portion of this is the common red sandstone of the series. The lower mile and a half is conglomerate, and probably corresponds in stratigraphical equivalence to the conglomerates of Secs. 27 and 14, T. 44, R. 13 W., above-described, as it lies in the line of strike, and bears a similar relation to the crystalline strata on the northwest. By consulting the map, it will be seen that from Chase's dam to the county line, a distance of about 11 miles, the river runs an almost direct course, and with slight interruptions is bedded on sandstones and conglomerates. A casual glance will show that the stream runs closely with the strike of the strata. A more careful study makes it appear that the river crosses the strata at a very small angle, passing from higher to lower beds. Near the county line, however, the river turns southward and pursues, for about three miles, a southerly course. This brings it over higher (geologically) strata. For a little more than a mile, however, it is bedded in drift, but near the north line of Sec. 9 (T. 42, R. 14 W.), the sandstone of the series reappears in the bed of the river and extends across it, causing rapids and forming occasional low exposures in the banks. The ledges show fine ripple-marks and occasionally rain-drop impressions. They are more indurated and seem to contain more quartz and less argillaceous material than those previously described. This sandstone again becomes concealed at the south line of the section, but reappears in the bed of the river in the Indian village in the N. W. ¼ of the N. W. ¼ of Sec. 21, (T. 42, R. 14 W.), about a mile below. These are probably the highest beds of the Keweenaw group exposed in the district.

Next immediately underlying this sandstone and conglomerate series, so far as the outcrops show, there appears to be a diabase, little exposed, underlaid by a stratum of easily-recognized melaphyr, forming at the surface outcrops along a belt lying parallel to the sandstones. This is the typical Keweenaw melaphyr described by

[1] Geology of Wisconsin, Vol. III, p. 424–427.
[2] Douglas County, Wisconsin.
[3] The Saint Croix.



MAP SHOWING POSITIONS OF EXPOSURES OF KEWEENAWAN ROCKS IN THE UPPER ST CROIX VALLEY, WISCONSIN,

BASED ON REPORT OF MOSES STRONG - GEOLOGY OF WISCONSIN, VOL III

Scale 2.3 miles to 1 inch.

Professor Pumpelly on page 32, and identical with stratum 108 of the Eagle river section.[1] It is found in the N. E. ¼ of Sec. 14 and the N. W. ¼ of Sec. 27, T. 44, R. 13 W., the N. W. ¼ of Sec. 28, T. 43, R. 14 W., and at the falls on Chase's brook, in the N. E. ¼ of the N. W. ¼ of Sec. 16, T. 42, R. 15 W.

The first three of these may be joined by a nearly straight line about 12 miles in length, whose course will be about N. 48° E., or nearly the average observed strike. If this line be projected it will pass to the southeast of the melaphyr exposure on Chase's brook, and, if extended in the opposite direction it will pass about an equal distance from an outcrop of precisely similar rock found on Moose creek, in the N. E. ¼ of the N. W. ¼ of Sec. 2, T. 44, R. 13 W. It would appear highly probable, then, that the first three exposures belong to the same stratum, and that the remaining two represent a lower bed. This is confirmed by the existence of a similar melaphyr near the center of the west line of the N. W. ¼ of Sec. 21, T. 43, R. 14 W., and also one in the S. W. ¼ of Sec. 10, either of which might readily be referred to the lower bed, though it is not so apparent that both could. Entering more into detail, we observe that the outcrop of the melaphyr in the N. W. ¼ of the N. E. ¼ of Sec. 27, T. 44, R. 13 W., rises only about 10 feet high and forms the bank of a creek. The rock agrees completely with the description of the typical Keweenaw rock previously referred to. The formation crops out quite continuously along the stream as far as the forks in the N. E. ¼ of Sec. 28. Here it is found to be dark, coarse-grained, rather soft, containing much chlorite, and crumbling readily on weathering, and no longer possesses the distinctive melaphyr characters. On the line between Secs. 22 and 27 we, however, find the typical melaphyr again.

Following the line of strike into the S. E. ¼ of the N. E. ¼ of Sec. 14 of this township (T. 44, R. 13 W.), we find on Moose creek the same melaphyr. Its dip here appears to be about 18° to S. 30° E. A few yards below the ledges are traversed by veins of epidote, with some indications of copper.

The rock is here very amygdaloidal, carrying chlorite as a cell-filling, dip 20°. A few rods below we find a heavy, firm, fine-grained, dark-greenish, diabase-like rock. The surface of this presents very finely preserved glacial grooves, having a direction S. 13° W. Some are wide and shallow, while others are narrow, sharply-defined hair lines. In the N. W. ¼ of the S. E. ¼ of this section there are also some small ledges of fine-grained diabasoid rock, and in the S. W. ¼ of the S. E. ¼ of the section we encounter the conglomerate before described. Following up Moose creek to Sec. 2, we find in the N. W. ¼ of the S. E. ¼ first a very hard, fine-grained, nearly black diabase, above which, about 100 yards, there appears a coarser crystalline diabase and diabase pseudo-amygdaloid, containing patches of epidote, quartz and considerable calcite, though the rock is not generally amygdaloidal. There are to be found occasionally specks of malachite. The dip measurements were 17° and 20° S. E. The ledges are much fissured and broken in all directions. Near the center of the section, low ledges, along the west side of the stream, exhibit a coarse-grained rock, somewhat resembling the melaphyr found farther up the stream, presently to be described. Above this in the N. W. ¼ of the section, there first appears a diabase of medium grain and greenish-gray color, and about 100 yards farther up, on the left bank of the stream, a low outcrop of soft, very dark, diabase pseudo-amygdaloid, containing chlorite, quartz, orthoclase and

[1] See Geological Survey of Michigan, 1869–1873, Vol. I, Part II, p. 136.

prehnite. About an eighth of a mile above this, and only a short distance below the town line, the west bank of Moose creek exposes the typical melaphyr previously mentioned, characterized by a dark-green color, fine-grain, peculiar irregular fracture and large reflecting surfaces of satin-like luster.

Passing due southwestward about seven miles into the S. W. ¼ of Sec. 6 we encounter a dark, fine-grained diabase, occasionally amygdaloidal, with calcite. A vein about two inches wide was observed, which carried considerable native copper in films and small particles, associated with calcite and epidote. In the rock there are also particles of epidote carrying copper. These are in the bed of the brook, and overflowed in high water. A short distance above, the rock becomes softer and contains large amygdules of chlorite with frequently a core of calcite. These ledges extend along the stream for about half a mile. At the dam, near the town line, there is a ledge of highly-altered diabase-amygdaloid containing calcite, chlorite and epidote.

* * * * * * * * *

To the west of the center of Sec. 8, T. 43, R. 13 W., there is a fine exposure of conglomerate, having a dip of about 14° in a direction S. 50° E. It is traversed by two regular systems of joints on courses N. 34° E. and N. 56° W., by reason of which it is cut into regular cubical blocks. Judging from the drift, the western portion of the S. E. ¼ of the adjoining Sec. 5 is underlaid by conglomerate.

Passing over an interval of about five miles, in which no outcrops are known to exist, we find in the S. E. ¼ of Sec. 6, T. 43, R. 14 W. a wide, low, northeasterly-trending ridge, presenting bared rock at one point, which appears to be a diabase of very fine, close grain, and dark color, coated with a thin, light-colored crust due to weathering. In the N. E. ¼ of Sec. 9 of this township there is a ridge composed of rather soft, fine-grained, dark, reddish-brown diabase amygdaloid (specimen 425), weathering to a dirty lilac hue. It appears to be much altered. This ridge, in common with those of the vicinity, presents an abrupt declivity on the northwest and a gentle slope in the opposite direction, the same phenomenon observed so frequently on the opposite side of the Saint Croix Valley, but reversed in direction. It is scarcely necessary to repeat that it is due to the inclination of the strata whose projecting edges form the ridges.

In the S. W. ¼ of Sec. 10 (T. 43, R. 14 W.) there is a similar ridge composed of melaphyr, and already referred to. A short distance south of this, in the adjoining section (N. W. ¼ of Sec. 15), there is a similar ridge, but of diabase, beyond which is still another, the rock of which is a dark brown and black, hard, fine-grained crystalline diabase, containing occasional amygdules of chlorite. It resists weathering well, and only shows a thin, light, dirty grayish coating of weathered substance. The trend of these ridges is northeasterly with the strike of the strata.

In the S. W. ¼ of Sec. 15 (T. 43, R. 14 W.), in a large hill, there is a small denuded area of rock, of hard, close, minutely crystalline texture, reddish-brown color, and rough, uneven fracture. It contains scattered aggregations of chlorite. It appears to be an altered melaphyr.

In the S. E. ¼ of Sec. 17 (T. 43, R. 14 W.) there is a long ridge of melaphyr that appears to be a continuation of that above noted in Sec. 10, and is probably to be correlated with that in Sec. 2, T. 44, R. 13 W., and that at the falls on Chase's brook, Sec. 16 (T. 42, R. 15 W.). There is a like rock found near the center of the west line of the N. W. ¼ of Sec. 21.

In the S. W. ¼ of Sec. 22 (T. 43, R. 14 W.) there is an outcrop of a fine-grained, hard, reddish-brown, crystalline rock, probably a diabase. It forms the nucleus of a hill.

In the S. E. ¼ of the N. W. ¼ of Sec. 28 there is a small uncovered area of typical melaphyr, which probably belonged to the same stratum as those situated in Secs. 14 and 27, T. 44, R. 13 W., as already stated. From this point, for a distance of about 30 miles down the Saint Croix, no exhibitions of rock in place of any kind are known to exist.

The following is a description of the same district by Mr. E. T. Sweet:[1]

In the banks and channel of Moose river, on Sec. 2, T. 44, R. 13 W., there are low ledges of melaphyrs and diabases, dipping 18° S. 35° E. These are conformably overlaid by fine conglomerates and coarse sandstones. The pebbles of the conglomerate have nearly all been directly derived from the underlying crystalline rocks, and are held together by a coarse, red, sandy matrix. None of the very coarse or bowlder conglomerates noticed on the northward-dipping belt, in Ashland county, and on the Saint Croix river, were observed here. In following Moose river southward, towards its mouth, several small exposures of the fine conglomerate were seen, but it apparently has no great thickness, for it soon grades into coarse, reddish sandstone, and that finally, after reaching the Saint Croix, into quite fine-grained, red sandstone, often somewhat argillaceous.

The most northern exposure of this sandstone on the Saint Croix, is at the head of a small lake about a mile above the mouth of Moose river. The outcrop is in the east bank. The layers are hard and thin, and contain many red argillaceous spots. Indurated smooth slabs come out readily. A few of the layers are finely ripple-marked. The strike is N. 53° E. and the dip 14° S. This place is a short distance below Chase's dam, on Sec. 36, T. 44, R. 13 W. For five miles along the Saint Croix below Moose river, a few small exposures only are seen. On Sec. 8, T. 43, R. 13 W. the sandstone is exposed in the banks five or six feet high. At the first considerable exposure, the rock is fine grained, very thin bedded, and argillaceous. Circular reddish and bluish spots of indurated clay are of frequent occurrence in the layers. The strike is N. 55° E. and the dip 13° S. There are two well-marked systems of joints; one trending N. 28° W., and the other N. 55° E. A short distance below here, there is a somewhat larger exposure, showing a strike of N. 53° E., and dip of 14° S. Below this, for a distance of ten or twelve miles, tilted sandstones often form the bed of the stream, although they are seldom seen in the banks. In the banks of Rocky Run on Sec. 9, T. 42, R. 14 W., a half mile from the Saint Croix, the sandstones are again largely exposed. In the banks and channel of the Saint Croix, at Pine Rapids, a quarter of a mile below Sawyer's old dam, on the S. W. ¼ of Sec. 16, T. 42, R. 16 W., is the most southerly outcrop of the southward-dipping sandstone observed. The rock is very similar to that above described. The strike is N. 52° E. and the dip 16° S.

These descriptions, with the map I have constructed from them (Plate XXV), will serve to show plainly enough that we have in this region some

[1] Geology of Wisconsin, Vol. III, p. 349.

thousands of feet[1] of sandstone underlain by a much greater thickness of fine-grained, basic eruptive rocks (diabases and melaphyrs), with included felsitic porphyries and porphyry-conglomerates; in other words, that we have the same Upper and Lower Divisions of the series recognized farther east. The upper sandstones are the same as those seen on White and Bad rivers, in Ashland County, Wisconsin, dipping southward, as was first shown by Mr. E. T. Sweet, who was, however, in error in supposing that the sandstones exposed on the Kettle River are also a continuation of these.[2] The latter, as already shown, belong with the light-colored Potsdam sandstone of the Mississippi Valley. The Keweenawan upper sandstones do not extend so far to the west.

Douglas County Copper Range.—For 12 or 14 miles northward from the exposures in the valley of the Upper Saint Croix the country is heavily drift-covered, and no exposures have ever been observed. On the northern side of this area, however, is again a belt, 2 or 3 miles in width, in which there are frequent exposures of bedded Keweenawan diabases, dipping southward. This belt forms a bold range, or series of ranges, north of which, and extending to the shores of Lake Superior, is a lowland underlain by horizontal sandstone. This district has been examined in some detail by Mr. E. T. Sweet, from whose description[3] I cull the following facts, quoting his own words whenever practicable:

The line of junction on the north[4] is somewhat curved, but in the main pursues an E. N. E. course, nearly parallel with the strike of the crystalline strata. * * * * Most of the northward-flowing streams in Douglas county leave the crystalline rocks and enter upon the sandstone district through deep gorges and in wild and precipitous falls. In the walls of these gorges both formations are usually beautifully exposed, but the sandstone, for a distance of from twenty to three or four hundred feet from where we would expect to find the point of contact, has evidently been affected by some great lateral pressure, for we find the layers broken into short lengths, and tilted at various angles, generally to the northwest or from the line of strike of the crystalline rocks. In following down the stream the sandstone layers in the walls of the gorge gradually show the effects of less disturbing influences, and finally assume horizontality and

[1] Mr. Sweet's estimate, Geology of Wisconsin, Vol. III, p. 350, is excessive.

[2] "Notes on the Geology of Northern Wisconsin." Transactions of the Wisconsin Academy of Science, Arts, and Letters, Vol. III, p. 48, 1876.

[3] Geology of Wisconsin, Vol. III, p. 336, *et seq.*

[4] With the horizontal sandstone just mentioned.

regular bedding. On Middle river the original lines of depositon have been entirely obliterated, and the very argillaceous sandstone transformed into a transverse cleaving slate, somewhat micaceous.

* * * * * * * * *

That the Keweenawan eruptive rocks are *bedded*, in a certain sense, there can be no doubt. The dip and strike * * * * can be determined at almost any locality, where the rocks are exposed, with but little difficulty. * * * * Owing to a great inequality in the hardness of the different beds, the softest have been eroded, and the hardest and firmest have remained; and now outcrop in the form of bare ridges of rock. These ridge-like exposures are very prominent and characteristic between Black river falls and the Aminicon river. They appear to arise directly from the soil, like a great stone wall, and, at least in one or two instances, pass across the country for a mile or more in an almost straight line, with a height of 30 or 40 feet, and a thickness of 50 to 100 feet. Other ridges vary in length from a few feet to a quarter of a mile or more. On the north, the face of each ridge is usually precipitous and somewhat jagged, owing to the exposure of the edges of the layers. The south side descends to the soil with the inclination of the bedding. Ordinarily the dip is readily obtained, and the trend of the ridges is usually the strike of the formation. East of the Aminicon, the wall-like exposures are less prominent.

* * * * * * * * *

By far the most common rock is a greenish to dark-gray diabase. Near the sandstones on the north, this rock often has an amygdaloidal structure. There are also beds or layers of amygdaloidal diabase 1,000 or 2,000 feet south of the sandstones. The amygdules are usually either epidote, prehnite or chlorite. A less common rock, but one forming massive beds, is a fine-grained, nearly black kind, having a marked conchoidal fracture, and differing much from the ordinary diabase (Pumpelly's "ash-bed type"). Coarse-grained, red-and-black-mottled basic rocks (gabbro) also occur. Felsitic porphyry has been seen only on Black River.[1]

Native copper occurs throughout this district in three ways, according to Mr. Sweet:—[2]

1. Indiscriminately scattered through belts of epidotic and calcareous rock of various thicknesses, and lying usually with the bedding of the formation, as at the Percival mine. 2. Irregularly disseminated fine particles of native copper in the layers or beds of diabase, as at the Fond du Lac mine. 3. In true fissure veins, as at the Wisconsin mine.

Mining has been attempted at a number of points, but unsuccessfully. The following are further quotations from Mr. Sweet's descriptions:

The most western exposure of the *eruptive rocks* of the Western Lake Superior district that I have seen, is a short distance west of the lower falls of Black river.[3]

* * * * * * * * * *

[1] Having examined in detail a complete suite of rocks from this region, I find them identical in all respects with those of the Keweenaw Series farther east. See also R. Pumpelly, Geology of Wisconsin, pp. 42 and 48. R. D. I.

[2] Geology of Wisconsin, p. 357.

[3] Do., p. 340.

The lower falls of Black river are near the S. E. corner of Sec. 21, T. 47, R. 14 W. In this vicinity, the exposures are the largest and most interesting of any observed in the district. Here the river has cut a gorge through the crystalline rocks of the Keweenawan and the breccia conglomerate and sandstone of the Lower Silurian, to a depth varying from 100 to 180 feet, and having a length of nearly one-half mile. Along the walls of the gorge, the measures are most beautifully exposed, but great difficulty has been experienced in satisfactorily making out their relations. * * * * At the head of the rapids, which extend about 100 feet above the falls, a dark-colored, fine-grained, hard diabase of the ashbed type occurs. Although quite indistinct, it appears to have a bedded structure. At the immediate head of the falls, this is succeeded by a red felsitic porphyry, and this, again, by the common diabase. The third bed, over which is the main fall, is a dark-gray, fine-grained diabase, having also an indistinct bedding. About 75 feet above the foot of the great fall, in the left or west wall of the gorge, there is a vertical fissure 8 inches wide, formed by two smaller fissures dipping towards each other, and making an angle of about 40°. Owing to talus, the fissure can be seen only a distance of 10 or 15 feet. It is filled with a soft, clay-like sandstone. The walls on either side of the fissure are very dark-colored, soft and unctuous. The rock is a chloritic alteration of the diabase.

Just above the head of a small fall, near the foot of the great fall, a fine-grained, reddish-brown diabase comes in, which is frequently amygdaloidal. The dip here is 46° in a direction about S. 20° E. This extends along the wall of the gorge nearly 300 feet, and gradually grades on the west side into a diabase-breccia. The transition, in fact, is so imperceptible that it is impossible to locate exactly the point at which the diabase ceases and the breccia commences. This is partially owing to the fact that both diabase and breccia walls are considerably decomposed, and partially to the further fact that the breccia contains immense inclosed masses of the diabase. In the east wall there is no breccia. Near the southern limit of the breccia the rock consists almost exclusively of angular grains and masses of diabase, while in the north, there is a notable proportion of reddish sand, which seems to be the matrix or cementing material. Imbedded in the face of the breccia are a number of highly indurated layers of reddish sandstone, from 4 to 50 feet in length, and inclined at different angles, some of them being vertical. About 50 feet above the stream, and near the foot of a cliff a hundred feet high, are two of these layers resting together. They are 2 feet thick, 40 feet long, straight, and dip 26° to the N. 70° W. These layers are really quartzite. They have a dark-brown color, coarse granular structure, and contain a few disseminated grains of delessite.

One hundred and fifty feet from the breccia, in the left bank of the stream, there is a bed of conglomerate, arising directly from the stream, 30 feet in thickness. Interstratified with the conglomerate are a few layers of sandy shale. The dip of this bed of conglomerate is 25° in a direction S. 20° W. The dip, however, is not uniform. For a few rods down the stream it is 20°, and 25 feet farther, only 15° in the same direction. The pebbles are from one-half an inch to three inches in diameter, and are principally white amorphous quartz. About a third of them are diabase, much more angular than the quartz pebbles, some are sandstone, and a few are themselves conglomerate. The matrix is red sand. On the east or right side of the stream there is also a bed of conglomerate, which is underlaid by thin-bedded sandstone. This bed dips 42° to the N. 10° E. * * * * In this conglomerate bed there are white quartz, gray quartzite, diabase and sandstone pebbles, with reddish sand as the cementing material. It forms so incoherent a mass that most of the pebbles may be readily picked out with the hand. In other respects it is very similar to the bed on

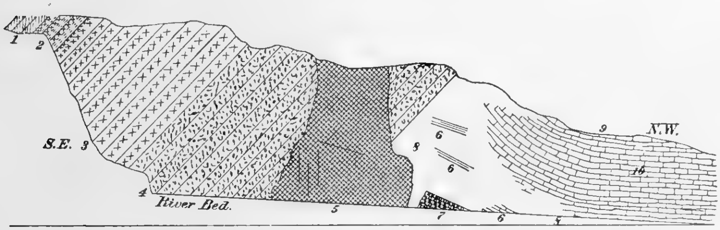


FIG. 10. Section on the gorge of Black River, Douglas County, Wis. (after Sweet). 1. Diabase, ashbed type. 2. Felsitic porphyry. 3. Gray diabase. 4. Reddish-brown diabase. 5. Diabase-breccia. 6. Shaly sandstone. 7. Porphyry and quartz-conglomerate. 8. Unexposed. 9. Broken and inclined red sandstone. 10. Horizontal red sandstone. Horizontal scale 300 feet to the inch. Vertical scale 150 feet to the inch.

the west side of the stream. The space above the conglomerate for about 50 feet is covered with talus which has fallen down from the nearly vertical cliff of diabase. Many hundred tons weight have recently fallen from this cliff. All of the fragments are very small, angular, and much weathered. Numerous stains of copper carbonate were noticed in the fragments. The dip here appears to be 36° to the SE.

On the opposite side of the stream, above the conglomerate, there are two small exposures of shaly sandstone. The upper exposure dips 29° to the S. 20° W., directly towards a diabase cliff only 50 feet distant and 40 feet high. Clinging to the face of the cliff are, at two or three places, patches of diabase-breccia, a foot or more thick. Seventy-five or one hundred feet northwest from the cliff of diabase, in the wall of the gorge, dark-reddish and somewhat indurated sandstones are found. The layers at first are broken into blocks from 4 to 10 feet in length, and are inclined at various angles, usually to the NW. Gradually they assume more and more of a distinctly bedded structure, and finally, in the distance of a few hundred feet, grade into regularly bedded reddish sandstone, with a dip of only 4° or 5° to the NW. The nearly horizontal sandstone is found in the banks of the stream at intervals for several miles. It resembles in all respects that occurring along the lake shore in Bayfield County and at the base of the Apostle Islands. In the east wall of the gorge, about 100 feet west of the conglomerate, there is a perpendicular ledge of the sandstone over 100 feet high. The layers near the top are thin and shaly, and dip 30° in a direction N. 10° W. Near the bottom, the layers have the same inclination, but are coarse-grained and from 6 to 8 feet in thickness. Scattered through the layers are diabase and quartz pebbles an inch or less in diameter. Several hundred feet still farther along the gorge, the layers upon this side become nearly horizontal, and are often interstratified with yellowish and white sandstone.

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[1]By the tortuous course of the stream, the *Upper Fall* of Black river is found $1\frac{1}{2}$ miles above the Lower Fall. Diabase crops out in low ledges, frequently on either side of the very rapid current. The fall is near the east quarter-post of Sec. 28, T. 47, R. 14 W. The descent is 31 feet vertical, over a layer or bed of diabase dipping about 40° to the S. 30° E. One hundred feet below the fall, in the bank of the river, amygdaloidal diabase occurs, having the characteristic greenish color from the presence of epidote. About 200 feet above the fall amygdaloid again comes in. This is the most southern exposure found on Black river.

* * * * * * * * *

[2]Starting off in a northeasterly direction from the Lower Falls of Black river, is a somewhat broken line of outcrops, in the form of rounded rock ridges. All trend in a more or less N.E. and S.W. direction; and vary in length from a few feet to a hundred yards.

* * * * * * * * *

[2]At *Copper creek*, the Keweenawan beds are found for a distance of nearly one mile along the channel of the stream, and in places arise to the height of about 100 feet above it. In the most southern outcrops the predominating rock is a dark-colored diabase. In the most northern, the rock is usually the more common reddish altered diabase. * * * * From the union of the forks, the creek has a tortuous course in a general northwesterly direction. It passes through a gorge or valley, a little wider than the cañon of Black river. The rock on each side, for a quarter of a mile, is close-grained, dark reddish-gray diabase, which frequently rises in great, smooth, rounded or sloping exposures, to the height of from 100 to 135 feet above the stream. Along the stream the bedding is quite indistinct. The layers, if such they may be called, are often 50 to 60 feet in thickness. The most northern exposure in the banks of the stream is on the west or left side, and slopes from the creek at an angle of 30° or 40° to the height of 90 feet. The rock is a dark gray amygdaloidal diabase, which readily weathers to a greasy-feeling, soft chloritic rock. It breaks into small, sharp angular pieces, which is due to the almost innumerable small seams or joints traversing the rock in every direction. On the north of this exposure there is a gully, about 15 feet across, showing nothing except sand, clay, and loose rocks from the adjacent cliffs. In the north side of the gully, there are short layers of sandstone having a high dip to the northwest. Immediately adjoining them is a cliff of dark reddish, coarse-grained, somewhat indurated sandstone. The layers are broken into short lengths, and dip 60° to the northwest. The bedding for a hundred feet is not well marked, and for several hundred feet still farther along the stream, it shows distinct evidences of having at some time been subjected to great lateral pressure, for the layers are broken into lengths of from 2 to 10 feet, the thickest often presenting the appearance of a transverse conchoidal fracture. Between the beds are frequently thin layers of fine-grained white sandstone, some portions of which have been manufactured into grindstones, said to be of very fine quality. Many of the reddish layers are themselves mottled, by containing spheres of white sandstone a quarter of an inch or more in diameter. In the course of a few hundred feet the broken layers gradually assume regular and undisturbed bedding, having a dip of only 4° to the N.W. The layers

[1] Geology of Wisconsin, Vol. III, p. 343. [2] Do., p. 344.

are from one half inch to two feet thick, often finely cross-laminated, and frequently show most beautiful ripple marks. They are also finer grained, and of a much lighter red color than the broken layers.

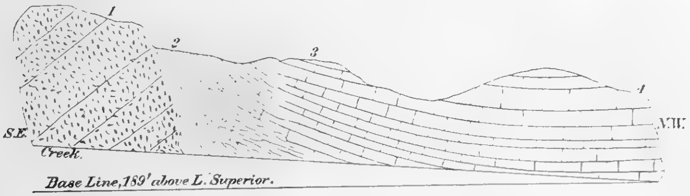

FIG. 11. Section in the gorge of Copper Creek, Douglas Co., Wis. (After Sweet.) 1. Diabase. 2. Talus. 3. Broken and inclined sandstone. 4. Horizontal red sandstone.

The following section illustrates the relations of the diabases and sandstones in the left bank of the creek. On the opposite side they were not exposed together. It will be observed that conglomerate and breccia do not occur. No sandstones were observed in the vicinity of Copper creek, except in the banks of the stream.

* * * * * * * * *

[1] About one mile northeast from the mining location at Copper creek, there commences a very remarkable exposure. It is in the form of a rock ridge or great wall of stone, almost perfectly straight, nearly a mile long, 40 feet high, jagged and nearly vertical on the north side; the top, for a considerable distance, as smooth and level as a sidewalk, from 10 to 30 feet wide; the south side, even and sloping, and 20 or 30 feet above the soil. * * * * [2] The trend of the ridge is N. 55° E., which is exactly the direction of the strike, and the dip is 36° S.

Passing off from the eastern end of this exposure, there are two lines of similar, but much smaller, outcrops. One goes nearly east to the Aminicon River, in Sec. 17, where it divides into two or three general lines, the individual outcrops lapping past each other, and each preserving its trend of N. 55° to 60° E. The second passes northeasterly across Sec. 12, and Secs. 7 and 8, T. 47, R. 13 W. Here the exposures are not numerous, but are in a nearly straight line. Most of them are in the form of short ridges. * * * * Upon Sec. 1, directly southeast from the Wisconsin mine, exposures are very numerous. They are usually short and ridge-like, varying in length from a few feet to an eighth of a mile; in width, at the surface of the drift, from ten or 20 to 200 feet; and in height from ten to seventy-five feet. They trend from 20° to 30° east of north; somewhat nearer north, it will be observed, than those a few miles to the west. They are separated from each other by drift-filled valleys from 100 to 700 feet wide. A short distance to the east of most of the small ridges is one very prominent ridge, or rather mound-like exposure, several hundred feet long and 75 feet high. The northern face is very precipitous, and the bedding is very distinct. The dip is 30° to the S. 60° E.

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[1] Geology of Wisconsin, Vol. III, p. 345. [2] Do., p. 346.

[1]Near the southeast corner of Sec. 32, T. 48, R. 12 W., is the most southern exposure in the banks of the Aminicon river. There are several between here and the crossing of the Superior and Bayfield post-road, a half mile below. The rock is a coarse-grained gabbro, composed of red-stained plagioclase, a gray plagioclase, and a soft greenish altered (chloritic) diabase, with bright, shining grains of magnetite. Below the bridge, a dark-colored, coarse-grained variety occurs, in which the several minerals show much less alteration.

* * * * * * * * *

[1]Near the east and west line, running between Secs. 20 and 29, is the junction of the reddish sandstones with the crystalline rocks. For 25 feet only have the sandstones been disturbed. In this distance they are broken into short lengths, and dip northwest from the crystalline strata at angles varying from 60° to 20°, after which they become horizontal and show two well-marked systems of vertical joints. The direction of one system is N. 60° E., and of the other N. and S. At the immediate line of junction, or where the sandstone is removed from the crystalline rocks but a very few inches, the layers of sandstone have a facing of fine conglomerate, from a few inches to a foot or more in thickness. The pebbles consist of quartz and melaphyr or diabase, and are cemented by sand. The sandstone layers at some distance from the junction also contain small pebbles of the adjacent crystalline rocks. The sandstone layers are much softer than usual, uniformly reddish in color, and in thickness vary from 1 to 24 inches.

Between the Aminicon and Middle rivers there are very few exposures of the copper-bearing rocks, and none in Secs. 33 and 34, where we would expect to find them. The country is somewhat lower than the remainder of the range, and covered with drift. Near the center of Sec. 4, T. 47, R. 12 W., there are two small exposures of fine-grained, blackish diabase, separated by a few rods of drift. Similar rocks are again visible in Sec. 3, and along the banks of Middle river, for about a mile in sections 2 and 35. They are all small exposures. In Sec. 35 the rock is often porphyritic. A perfect network of minute laumontite veins occurs at one or two localities.

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[2]Near the south line of Sec. 24, T. 48, R. 12 W., Middle river cuts through the northern face of the range, leaving a large surface of the rock exposed. On the south, the stream has exposed between 300 and 400 feet of a dark-brown diabase, being in places somewhat amygdaloidal. This outcrop is nowhere more than 25 feet in height. A hundred yards northwest of it, in the left bank of the stream, is an exposure of soft, dark-reddish, much altered and decomposed diabase-amygdaloid, carrying numerous small veins or "strings" of laumontite and calcite. This rock weathers easily, and is rapidly crumbling away. It is very similar to that described as occurring at the forks of Copper creek. Some of the small veins of calcite were noticed stained with copper carbonate. This rock is found along the stream for 200 feet, is about 50 feet in height, and is very indistinctly bedded. On the north it is separated from a southward-dipping and shaly rock by a gully 30 feet across.

* * * * * * * * *

[2]Near the crystalline rock, the bedding has been entirely obliterated, and the outcrop presents the appearance of a bed of shale dipping 79° to the S. 20° E. The layers are from one-sixteenth of an inch to an inch in thickness. All of them contain flakes of mica, and the most of the layers are reddish-colored. But thin, hard, light-

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[1]Geology of Wisconsin, Vol. III, p. 346. [2]Do., p. 347.

colored, slaty layers occur between the reddish, shaly layers. In the course of 75 feet, the exposure begins to show evidences of horizontal bedding with a transverse slaty cleavage, as shown in the cut. Beyond this, the layers are broken and dip somewhat, and only one or two of them show the slaty cleavage. After another bed of slate and shale, as shown, and attempts at slaty cleavage, the rock becomes evenly bedded and horizontal. It is fine-grained, and more aluminous than is usual with the Lake Superior sandstones. There are no conglomerates, breccias, or thick layers of coarse sandstone seen in the vicinity.

Eastward from Middle river, neither the copper-bearing rocks nor sandstones are exposed for a distance of about 7 miles. Between Middle river and the high ground, locally known as the Brulé range, the country is quite level, somewhat swampy, and has an elevation of about 400 feet. The Brulé range, commencing in T. 47, R. 11 W., attains an altitude on the broad summit of about 540 feet. Towards the western end are two or three small exposures of fine-grained, dark-gray diabase. On Sec. 29, T. 48, R. 10 W., is an exposure of diabase, fine conglomerate and sandstone, very similar to that described as occurring on the Aminicon river. In the NE. ¼ of Sec. 28, at the falls of a small stream, is an exposure of dark-gray amygdaloidal diabase, a few feet in height, and 10 or 12 yards long. A test pit was sunk here on what appears to be a small quartz and epidote vein bearing altered amygdaloid, by the North American Fur Company, in 1847. A small quantity of iron pyrites and copper carbonate were observed with the débris. The dip here is 30° S. 40° E.

No exposures are found from here to the Percival mining location, a mile to the east. At this location the natural exposures are small and few in number, but the underlying rock is lightly covered with drift, which may be easily removed. The rock is usually a dark greenish-gray amygdaloidal diabase, carrying in places shot and nugget copper. The bedding is not very distinct. At the wagon-bridge across the Brulé, on Sec. 23, and occasionally along the banks of the stream for a half mile below, there outcrop low ledges of a dark-colored amygdaloidal diabase. A quarter of a mile below these exposures there are low ledges of nearly horizontal, reddish, heavily-bedded sandstone in the banks of the stream. Similar sandstones are found along the banks and in the channel, forming numerous rapids nearly to the mouth of the river. No exposures were found on the steep sides of the valley, although, in the vicinity of the sandstones and crystalline rocks, it is over 200 feet deep, and not half a mile across from summit to summit. On the northeast quarter of Sec. 23, a short distance north of the Bayfield road, there is a very prominent and high exposure, forming the western end of that portion of the range east of the Brulé river. The summit of the bare, bald cliff is 301 feet above the bridge across the stream at its foot, or 553 feet above Lake Superior.

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[1]From the altitudes, trend, and general appearance of the ridges or abrupt elevations to the south, a few miles from the lake shore, in Bayfield county, we should expect to find crystalline rock exposures, occasionally, as in Douglas county. The streams are numerous, and, like those to the west, cut deep and narrow valleys through the drift, near the abrupt ascent of the country to the south, and nearly all expose small ledges of horizontal, reddish Lake Superior sandstone, but none of them appear to have uncovered the Keweenawan rocks. In the southwest part of T. 50, R.

[1] Geology of Wisconsin, Vol. III, p. 348.

7 W., between Frog and Cranberry rivers, there is a ridge having an altitude of over 400 feet, and covered with many large angular bowlders of diabase and other Keweenawan eruptive rocks. It presents a striking resemblance to the range a short distance west of the Brulé river. On the NE. ¼ of Sec. 20, T. 50, R. 6 W., a few rods north of the shore of Siskowit lake, there is a flat circular bowlder of brecciated conglomerate, 18 feet in diameter. A few of the angular and some of the round pebbles are diabase, but the most of them are felsitic porphyry. The matrix is reddish sand. The bowlder is evidently stratified, and, as it lies, has an inclination of 20° S. Owing to the frail nature of the rock, it probably never traveled any considerable distance. This is one of the numerous so-called outcrops of crystalline rocks to which I was directed by some of the citizens of Bayfield. Others were found to be large bowlders, trains of bowlders, or ledges of sandstone.

The most important points established by Mr. Sweet's investigations in this district are (1) the identity between the cupriferous rocks here exposed and those of Keweenaw Point; (2) the existence of a rather low southern dip, and of a northeasterly strike, ranging from east-northeast on the west, to north-northeast on the east; (3) the absence of diabase ledges on the highlands of Bayfield County; (4) the unconforamble contact between the red sandstone which borders Lake Superior west of the Montreal, and the Keweenawan beds.

The contacts between these formations described by Mr. Sweet as showing on Black River, Copper Creek, Aminicon River, and Middle River, are also of great interest on account of the peculiar disturbances they present. These disturbances find their explanation, in part, as it appears to me, in the irregularities of an unconformable contact, and in the pressure exerted by the deep-seated Keweenawan beds against the more shallow sandstone, but also in large measure in a faulting that has taken place along the contact line. There is much in common between this fault and that on the south side of Keweenaw Point. There are only two ways in which the conclusion might be avoided that we have here to deal with a true non-conformable contact. These are to suppose, either, as Whittlesey[1] and Norwood[2] did, that the crystalline rocks here are true intrusive or disturbing masses, or dikes, and hence newer than the sandstone with which they are now in contact, or that the sandstones belong to the Upper Division of the Keweenaw Series, let down here by a great fault to a lower level than that occupied by the diabases which belong normally under them.

[1] "Physical Geology of Lake Superior." Proc. Am. Assoc. Adv. Sci., Detroit Meeting, 1875, p. 67.
[2] Owen's Geological Survey of Wisconsin, Iowa, and Minnesota, p. 305.

The former of those suppositions is, however, at once forbidden by the bedded structure of the crystalline rocks, by their manifest identity with the bedded rocks of Keweenaw Point, which are never dikes, and also by the abundant occurrence in the sandstone, near its contact with the crystalline rocks, of pebbles worn from these rocks. The second supposition is much more plausible. It has against it, however, the nature of the sandstone—which resembles more nearly the Eastern Sandstone of Keweenaw Point than the sandstones of the Keweenaw Series—and also the occurrence in it of the pebbles just mentioned. Were these pebbles merely such as are apt to occur in the conglomerate bands of the upper Keweenawan sandstones, they would not be restricted, as they are, to the immediate contact of the two formations, but would be regularly distributed through the sandstone without any reference to the faulting line.

But a still greater difficulty to overcome on this theory is one connected with the general structural features of this part of the Lake Superior trough. If this sandstone belongs with the Keweenaw Series at all, *i. e.*, belongs with the diabases in contact with it, then it must belong with the Upper Division of the series. This must be so, because it is continuous with the horizontal sandstones of the Apostle Islands and Bayfield County coast, which, if they were to be placed in the Keweenaw Series at all, must belong in its Upper Division, because they lie directly across the trough of the north Wisconsin synclinal, where only upper Keweenawan sandstones could lie. Now, westward from the contacts on the Black and other rivers of Douglas County, the same sandstone continues until, on the Saint Louis River, above Fond du Lac, it is found resting on the Huronian slates in such a manner as to render certain its original deposition in that position. Westward from the eastern point of the contact in Douglas County, between this sandstone and the south-dipping diabases, the contact line cuts across the Keweenawan belts until it finally reaches the Huronian slates. It is impossible to conceive of a fault by which the upper sandstone could have been let down into such a position. There thus seems to be no escape from the conclusion that in the Western Sandstone we are dealing with the same overlying sandstone that presents itself on the south side of Keweenaw Point, and that the Douglas County contact line is one of unconformability complicated by faulting.

CHAPTER VII.

THE KEWEENAWAN ROCKS OF THE NORTH AND EAST SHORES OF LAKE SUPERIOR.

The north and east coasts of Lake Superior together form one of the finest lines of rock exposure in the world. From Duluth to the Sault—a distance of over 600 miles, without taking into account any but the greatest indentations — the rocks are in nearly continuous exposure. Short pebble beaches, usually not more than a few rods in extent, and very rarely over a mile, here and there interrupt the absolute continuity of the exposure; but even in these places the rocks on either side of the gap may often be connected by outcrops in the woods behind, by islands in front, or by continuous rock surfaces not too far beneath the water. Frequently the exposures are abrupt cliffs rising from the water's edge to a height more commonly from 20 to 50 feet, less commonly from 50 to 1,000 feet. Only rarely are the exposures of soft rocks like sandstone; and for the most part they are of some sort of crystalline rock.

The North Shore thus stands sharply contrasted with the South in its scenic characteristics. Except over short distances between Marquette and Keweenaw Bay, on the north shore of Bête Grise Bay, and on the north side of Keweenaw Point, the south coast of Lake Superior shows only sandstone or conglomerate as the shore rock, while even these rocks are absent for fully 200 miles of the distance between Duluth and the Sault, counting only those interruptions to rock exposures which are more than two or three miles in length. Low cliffs of sandstone are met with at several points on the South Shore, but the largest do not exceed 75 feet in height. Moreover, except on the eastern part of Keweenaw Point, and in the Huron and Porcupine Mountains, there is either no high ground or it is so far inland as to have little influence on the scenery of the shore.

From the head of the lake to Grand Portage Bay, or nearly to the national boundary line, a distance of about 150 miles, typical Keweenawan strata form the coast. At Grand Portage, slates, with interbedded and intersecting diabases and gabbros, rise from beneath the Keweenawan beds. These rocks make up the so-called Animikie Group or "Lower Division of the Copper-Bearing Series," which I take, however, to be undoubtedly Huronian. These slates form Pigeon Point, the north and west sides of Thunder Bay, and the islands at its mouth, including Thunder Cape. Isle Royale is composed of Keweenawan strata, undoubtedly in part the continuation of beds seen on the Minnesota coast. The peninsula between Black and Nipigon Bays is composed chiefly of sandstones belonging at the base of the Keweenaw Series, while typical Keweenawan diabases, amygdaloids and interbedded sandstones and porphyry-conglomerates, with the usual massive porphyries, form the coast and its numerous flanking islands from Black Bay to the east end of the Battle Islands, a distance of some 75 miles. Beyond the Battle Islands the north and east coast is formed chiefly of ancient gneisses and crystalline schists, part of which possibly belong with the Huronian, although, as indicated in a subsequent chapter, this still remains a matter of some doubt. Along the eastern coast, however, as far as the Sault, Keweenawan beds form now and then projecting headlands—in the case of the Cape of Mamainse reaching a very considerable development. Michipicoten Island is also made up of the same formation.

SECTION I.—THE MINNESOTA COAST.

In the following account of the geology of that portion of Minnesota bordering Lake Superior, I have not availed myself of any previous work, save where the fact is especially mentioned. Except in these few instances, the statements made are based exclusively on my own observations for the coast line from the Dalles of the Saint Louis River to Thunder Bay, and, so far as locations, trends, and dip are concerned, upon those of my assistants, Messrs. Chauvenet, Campbell, and McKinlay, for the back country along the Cloquet, Lester, French, Split Rock, Beaver, Baptism, Cascade, Devil's Track, and Brulé rivers. The rock specimens collected by these gentlemen I have studied myself.

Along this coast the rocks dip almost constantly lakeward, either trending with the general direction of the coast line or cutting it at a small angle. The only exception to this is the group of beds in the angle of the lake at Duluth, where the strike is at first even slightly west of north, but rapidly changes to north and east of north within a distance of three miles along the coast, which here trends N. 50° E. Except in the same place, where the dips reach 45° eastward, lessening to 15° or 20° within the same distance, the lakeward dips are at a low angle. The same flat lakeward dips prevail for miles back of the coast line.

The actual western termination of Lake Superior is near the village of Fond du Lac, Sec. 8, T. 48, R. 15 W. In this vicinity, on both sides of the Saint Louis River, are sandstones trending from north to north-northeast, with an eastward slant of 5° to 10°. Following the Saint Louis upwards these sandstones are found overlying slates of the Animikie Group (Huronian), on the southeast quarter of Sec. 11, T. 48, R. 6 W., three miles due west of the sandstone at Fond du Lac. The slates continue for many miles up the Saint Louis. Both slate and sandstone are described on a subsequent page. The same slates and sandstones appear on Mission Creek, north of Fond du Lac, beyond which to the northeast is a gap of three miles without exposures. Then begins a long series of bold rocky hills which continue along the north side of the Saint Louis to Duluth. These are composed of gabbro, associated with which is much of two kinds of red

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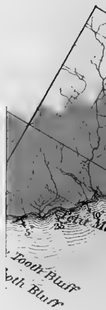

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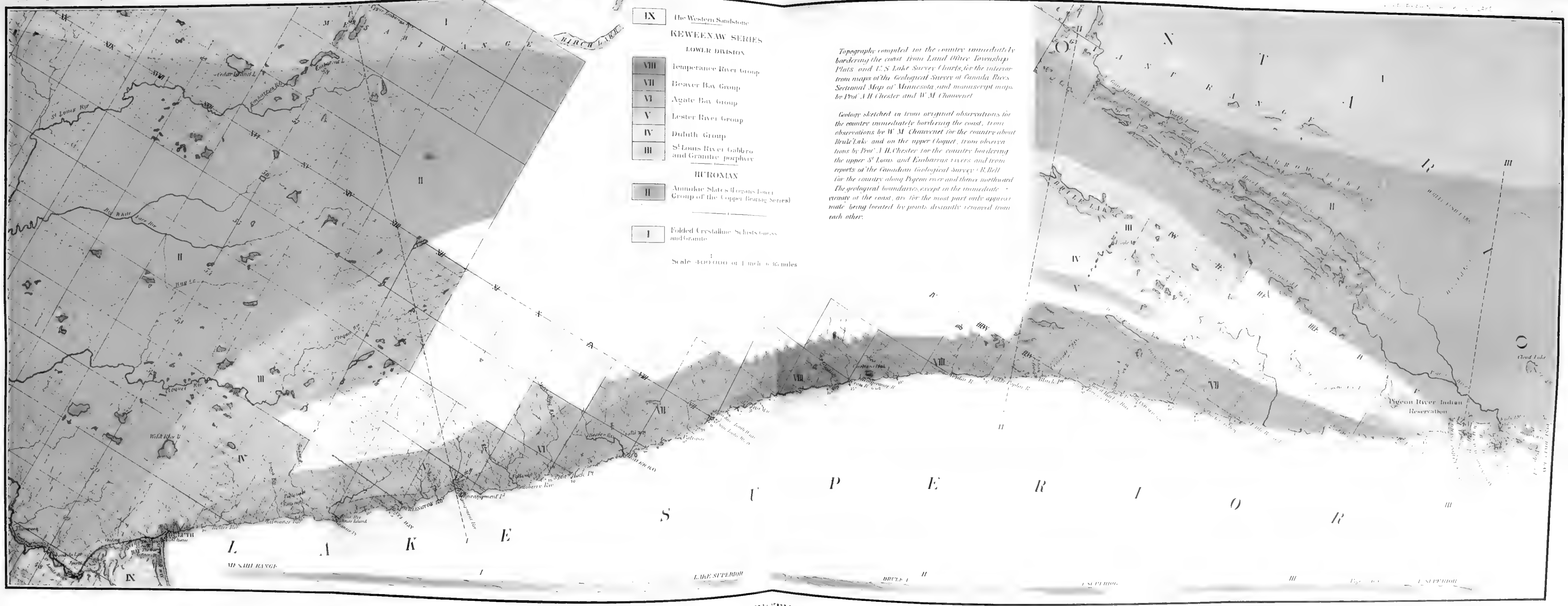

GEOLOGICAL MAP OF THE NORTH WESTERN COAST OF LAKE SUPERIOR.

porphyry. In the gap between this gabbro and the slate on the Saint Louis, the base of the Keweenaw Series lies concealed.

The Saint Louis River slates at Thompson, eight miles west of Fond du Lac, trend N. 85° E., and have a dip of some 30° to 40° southward. Farther down stream, towards the junction with the overlying sandstone, they trend somewhat more to the northeast. The gabbro does not exhibit any sign of bedding. However, the trend of the hills which it forms in the southeast part of T. 49, R. 15 W., is about N. 46° E., and near Duluth still more to the north. Eighteen miles north of Duluth, on the Cloquet River, in the southern part of T. 53, R. 14 W., the same gabbro reappears. It seems to form a belt running at first northeast and then more and more to the north until it finally takes a nearly northerly course. So far as these facts go there is no definite evidence of unconformity between the gabbro and the Saint Louis slates. The appearance is rather the other way.

In the eastern part of the city of Duluth we begin to find plainly bedded rocks flanking the coarse gabbro on the east, and for the entire distance to Grand Portage Bay these bedded rocks prevail, as also back in the country for many miles. They are diabases of several kinds; amygdaloids; typical luster-mottled melaphyrs, or fine-grained olivine-diabases; coarse-grained gabbros, belonging chiefly to the orthoclase-free kinds, but including also orthoclase-gabbros; anorthite-rock; felsites; quartz-porphyries; granitic porphyries; porphyry-conglomerates; and red sandstones and shales. In other words, we find here precisely the same rocks that characterize the Keweenaw Series on the South Shore. Detrital beds are here relatively rare, and the layers thin, as compared with those of the Keweenaw Point series, but we have here to do with quite low horizons which are in general comparatively free from detrital layers.

At Duluth, as already said, the trend of the layers in sight on the coast is at first even slightly west of north, with an easterly dip of 45°. These are rapidly changed for a due northerly trend, and 25° easterly dip, and these again, by the time the mouth of the Lester River, which is 5½ miles below Duluth, is reached, for a N. 30° E. trend, and a 15° S. E. dip. Between Lester and French rivers, the strike directions make more and more easting, becoming finally, on French River, 12½ miles below Duluth, N. 50° E., the dip remaining at 15° S. E. From Duluth to French River the coast line trends about N. 50° E., so that in this distance the rock beds, running more to the north than the coast line, intersect it at an angle which varies from 55° near Duluth to nearly 0° at French River. One interesting result of this relation between the trend of the strata and that of the coast line is the production of points projecting southwestward and formed of the harder beds. It is these projecting points, with other smaller ones along the Minnesota coast, that have been represented by Norwood as formed of a series of dikes. As shown below, dikes exist here, but they are relatively very infrequent, and nearly always of small thickness. From Duluth to French River, then, there is a constant ascent in geological horizon, and the thickness crossed cannot be much less than from 8,000 to 9,000 feet.

From French River to Burlington Bay there is again a somewhat more northerly trend in the rock beds, but since the coast line here also runs more around to the north, the dips at the same time flattening to 10° and even 6°, there is not much added in this distance to the thickness above given. After Burlington Bay is passed, the strike begins to cut the coast more sharply, and by the time Split Rock River is reached, 45 miles below Duluth, fully 10,000 feet of thickness have been crossed.

In the vicinity of Split Rock River the layers strike nearly due north, cutting the coast at an angle of 35°; but half way between Split Rock River and Beaver Bay, coast and strata are again trending together, at about 40° east of north. Below Beaver Bay, again, the strata turn away from the coast to the northward, and for some two miles below Baptism River strike only a very few degrees east of north, and by this time the coast must have crossed fully 16,000 feet in thickness of rock beds. Beyond the last point, however, both coast and strata begin curving more and more around to the east, the two coinciding at N. 50° E., somewhere between Petit Marais and Two Islands River. In the vicinity of Two Islands, Cross, and Temperance rivers, are the highest strata met with anywhere on the Minnesota coast, or, indeed, on the entire north shore of the lake, with the exception of Isle Royale. In the 80 miles between

Duluth and Temperance River, the coast line has crossed some 17,000 feet of strata.

Two miles below Temperance River, in Sec. 28, T. 59, R 4 W., a descent of the coast line in geological horizon begins to be perceptible. This descent continues without interruption for a distance of 70 miles, or to the end of the Minnesota coast, at Pigeon Point. From Temperance River to Grand Portage both coast line and strata curve more and more to the eastward, but the strata change direction more rapidly than the coast line, so that they cut it at a small angle all the way, producing points like those described as characterizing the coast line west of Temperance River, but with the difference that the points now project eastward, instead of to the southwest. At Grand Portage, the Keweenawan beds striking out under the lake, the Huronian or Animikie slates appear from beneath.

The Minnesota coast line, looked at as a whole, presents a sort of flat crescentic shape, with the concavity towards the lake. The same is true of the courses of the strata, but the crescents formed by them have a much smaller radius, and hence intersect that formed by the coast line, trending more to the north at the Duluth end, and more to the east at the Grand Portage end. In following the coast, then, from the slates of the Saint Louis River to Grand Portage, we ascend in geological horizon to a point near Two Islands River, and from a point just east of Temperance River descend again to the same slates at Grand Portage. Since the exposures are almost continuous, the coast line thus gives a complete cross-section of the whole thickness of Keweenawan beds present in northeastern Minnesota. Since the junction line between these Keweenawan strata and the underlying slates makes quite a large angle with the lake shore at both ends, and since the prevailing dips are so flat, it follows that the first-named rocks spread far back into the country. At the mouth of the Brulé River they lie some 12 miles back; at Grand Marais 18 to 20; at the middle of the crescent, near Manitou River, 30 miles, at about which distance they remain until near Duluth and the Saint Louis River. The slates themselves have about the same flat position, so that they, in their turn, spread over a wide belt of country.

Equally simple with the general structure as thus laid down, is the general stratigraphical succession displayed on the Minnesota coast. Certain groups of beds are plainly to be made out, and in many cases minute stratigraphical measurements could be made in detail through thicknesses of thousands of feet. Of course, the greater the detail attempted, the greater would be the obstacles met with, in the way of faults—which are numerous along the Minnesota coast—thinning out of beds, corrugations of beds, and similarity of lithological composition between different layers.

All of the Keweenawan beds of the Minnesota coast belong to the Lower Division of the series. The same statement applies to all of the Keweenawan rocks of the North Shore, except a small area at the southeast corner of Isle Royale.

The following are the subordinate groups of beds into which I have subdivided the Keweenawan rocks of the Minnesota coast, with a total thickness of upwards of 20,000 feet. The thickness of the first group is so uncertain, and indeed irregular, that it is difficult to give an approximately correct estimate of the total thickness. Above the lowest group, as already said, the thickness appears to lie between 17,000 and 18,000 feet. In all probability, 22,000 to 24,000 feet would not be very far from the truth as an estimate of the total thickness.

I. The Saint Louis River gabbro and associated red porphyries.—These rocks are chiefly coarse orthoclase-gabbro, but include also orthoclase-free gabbro, and a very few beds of fine-grained diabase. Red augite-syenite and granitic porphyry occur in large areas, constituting at times the entire mass of hills. Felsitic porphyries occur, but more rarely. Similar rocks, similarly associated, occur at the same horizon about the headwaters of Poplar, Cascade, and Brulé rivers, but are not found where they should appear at the Grand Portage end of the coast, though it is quite possible, and even probable, that some of the overflows of coarse gabbro found capping the slates of the Thunder Bay country belong here. The thickness of this group is difficult to estimate, but is probably not overstated at 6,000 feet.

II. The Duluth Group.—This group is a succession of heavy but sharply-defined beds of very fine-grained but aphanitic rocks, belonging to the ashbed type of diabases, and to the diabase-porphyrites. A very few beds of rather coarse-grained orthoclase-free gabbro are included; and there is a little interleaved detrital matter. Thin amygdaloids of peculiar character cap many of the beds of the upper two-thirds of the group, but the amygdaloidal character never reaches so great a development as in some of the succeeding groups. This group is distinctly recognizable at both ends of the coast, and at points in the interior, wherever its course has been crossed. Its thickness lessens as it is followed eastward; but at Duluth it is not far from 5,000 feet.

III. The Lester River Group.—This is a succession of heavy, distinct beds of fine-grained brown rocks, largely of the ashbed type. Diabase-porphyrites, some of the ordinary diabases, rare beds of coarse-grained gabbro, and two or three belts of granitic porphyry are also included. Amygdaloids are almost unknown, and no detrital material has been observed. The rocks of this group are known at both ends of the coast, and at intervening points in the interior. The thickness is about 2,600 feet.

IV. The Agate Bay Group.—This is a succession of relatively very thin beds with very highly vesicular, stratiform amygdaloids, which must make up two-thirds of the thickness of the group. The prevalent non-amygdaloidal rock is a fine-grained, olivine-bearing diabase or melaphyr. Towards the base are a number of layers of diabase-porphyrite, also with strongly developed amygdaloids. Thin seams of reddish sandstones and conglomerate are also included. This group forms the coast line for a distance of some 35 miles below the mouth of Lester River, and has been traced some miles farther east by exposures in the back country, but it does not appear at the eastern end of the Minnesota coast, having apparently quite thinned out. This fact is in accordance with the general law of thinning towards the east, which is obeyed by all three groups below, and by the one above. The thickness of the group is about 1,500 feet.

V. The Beaver Bay Group.—This group is especially characterized by a predominance of black, coarse-grained, olivine-bearing gabbros in very heavy layers without amygdaloids, and by the great abundance and prominence of its included red felsitic porphyries and granite-like rocks. There are, however, very considerable thicknesses included of fine-grained ashbed-diabases, with and without amygdaloids, while the ordinary fine-grained diabases with amygdaloids are not excluded—though they are rarely met with. No detrital material has been observed. In following the coast line eastward the beds of this group are crossed in ascending order between Split Rock and Baptism rivers, a distance of some 18 miles; and in descending order in the 28 miles below Grand Marais; besides which are also exposures of the same beds in the intervening country back of the lake shore. In its eastern extension this group does not exceed 4,000 to 5,000 feet in thickness, but to the west it must fully reach, if it does not exceed, 6,000 feet.

VI. The Temperance River Group.—This is a succession of very dis-distinctly and thinly bedded fine-grained diabases and melaphyrs, with strongly developed amygdaloids, and several seams of detrital matter, in the shape of red shaly sandstone and conglomerate, one sandstone layer exceeding 200 feet in thickness. Towards the base of the group are some layers of dense ashbed-diabase and diabase-porphyrite. The rocks of this group form the coast line from a point two miles below Baptism River to Grand Marais, a distance of 50 miles. They are the highest rocks seen on the Minnesota coast, and have a thickness in sight of some 2,500 to 3,000 feet.

In giving more detailed accounts of these several groups, it will be most convenient to take them up in ascending order, considering in each case first the more western exposures, and then the eastern extensions.

The Saint Louis gabbros and porphyries.—The rocks of this group form a bold range of hills, extending from Duluth in a S. 46° W. direction, seven miles on the north side of the Saint Louis River. They have also been carried northward from Duluth to the Cloquet River, and up that stream nearly to township 55, a distance of over 25 miles; the belt, as a whole, having apparently at first a northeasterly, then a northerly, and again a northeasterly trend, where left on the upper Cloquet River. How wide the belt is remains quite uncertain, a broad area of country without exposures lying west and north of it; but, judging from the relative positions of the westernmost exposures of the gabbro, and the easternmost of the underlying slates in the neighborhood of Fond du Lac, the width cannot there exceed two miles, if it reaches that distance.[1] Equally a matter of inference is the

[1] Directly north, or even northwest from Duluth, one can travel on gabbro and intersecting red rock for some miles, but this is because the belt here trends northward.

inclination of the mass as a whole; judging from the adjacent rock beds this is some 45° southeastward from the western extremity to near Duluth; about the same amount eastward at Duluth, and a good deal less than this to the south of east on the Cloquet. No sign of anything like subordinate bedding can be seen in the rock itself. It is massive and irregularly jointed, making great ledges facing in different directions, and furnishing bare, rounded summits to the hills which it composes.

The prevalent type of the gabbro of this belt and the kind constituting the hills at Duluth is of a light-gray color, and very coarse-grained, single feldspar crystals sometimes reaching even an inch or two in length. The augitic ingredient is plainly in greatly subordinate quantity, and often on a fresh surface its presence cannot be detected at all. On exposed surfaces, however, the weathering generally brings it out, and then it can be plainly seen to fill the spaces left between the feldspars. Titaniferous magnetite is also often perceptible to the naked eye in large particles.

Less commonly the grain is finer and the color darker, the augitic ingredient at the same time becoming more plentiful. In the thin section the predominant feldspar is seen to be a plagioclase belonging near the oligoclase end of the series. There appears also to be always a younger feldspar present, which has the character of orthoclase and fills corners between the plagioclase crystals, around whose contours it moulds itself sharply. Streng and Kloos found 1.61 per cent. of potash in the rock, which they very properly regarded as belonging to orthoclase. The spaces between the feldspars are filled with a diallage which is always more or less altered to greenish uralite. The alteration in many sections is carried beyond uralite, to chlorite. The magnetite is very large, abundant and titaniferous. Apatites of large size are found in all sections. Biotite is a not uncommon accessory. Olivine is absent from all sections. A large-sized figure of the thin section of the Duluth rock is given on Plate VI.[1]

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[1] Microscopic descriptions of the Duluth gabbro have been hitherto published by Streng (Ueber die Krystallinischen Gesteeine von Minnesota in Nordamerika—Leonhard u. Geinitz, Neues Jahrbuch für Mineralogie, Geologie und Paleontologie, 1877, p. 113), and N. H. Winchell (Eighth Annual Report of the Geological and Natural History Survey of Minnesota, 1880, p. 22). Streng calls the rock "hornblende-gabbro," regarding the hornblende as primary. His conclusions are summed up as follows: "The hornblende-gabbro of the Saint Louis River at Duluth consists of a greatly pre-

Farther west on this gabbro belt, as for instance on King's Creek, N. E. $\frac{1}{4}$, Sec. 12, T. 49, R. 15 W., the rocks appear largely to belong to the olivine-bearing, orthoclase-free kinds, having at the same time a very basic feldspar.

The red rocks that occur so largely associated with the gabbro of Duluth lie in it very irregularly, and form nothing like distinct belts, so far as I could make out. They may be seen in great patches, hundreds of feet square, and surrounded on all sides by the gabbro, and again, as at the quarry near Rice's Point, in irregular veins from two to three inches to several feet in width. Much the most abundant kind of these red rocks is one which presents macroscopically a wholly crystalline texture, and a pinkish color mottled with green. Pink feldspar facets, now and then striated, quartz, and a greenish mineral may all be made out with the naked eye. Under the microscope the rock is seen to be chiefly composed of reddened orthoclase, but similarly reddened oligoclase, greenish hornblende, quartz and magnetite are also present. The quartz occurs both in quite large

dominating plagioclase (labradorite), little orthoclase, some hornblende, diallage, magnetite, and titanic iron, and holds also very minute quantities of chalcopyrite and epidote, which is at times associated with quartz." My study leads me to agree in the main with these conclusions. I take, however, the hornblende to be wholly uralite, the plagioclase to be more often nearer oligoclase than labradorite, and the iron oxide ingredient to be wholly titaniferous magnetite rather than both magnetite and titanic iron. The epidote, quartz, and chalcopyrite are so rare as not to deserve mention in any general description of the rock. The following analysis is given by Streng:

SiO_2	49.15
Al_2O_3	21.90
Fe_2O_3	6.60
FeO	4.54
CaO	8.22
MgO	3.03
K_2O	1.61
Na_2O	3.83
H_2O	1.92
	100.80
P_2O_5	0.33
TiO_2	0.18

Winchell finds that the "chief ingredients, which are always present, are plagioclase and pyroxene, but the latter is sometimes very small in amount." He finds "also titaniferous iron, generally magnetic, almost always present, and sometimes in quantity sufficient to render it an iron ore of low grade. * * * Pyrite, calcite, epidote and chlorite also exist in some parts, * * * especially as geodes, nests, and vein-fillings, or as products of change. The plagioclase "is provisionally taken for labradorite," but in some places it is said to appear "more like anorthite." The pyroxene is taken to be diallage, much of it "fibrous from incipient change, the products being ferrite and viridite." Hornblende and uralite are not mentioned. The iron oxide is considered to be titanic iron, although magnetic, because of the presence of the white decomposition product.

patches and again in little strings running through and through the feldspars, in the usual manner of secondary quartz. A number of these small patches of quartz lying near each other will polarize together, showing that they are part of one individual. Moreover, the same is true of the larger quartz areas, and numbers of small particles lying near them, so that all of the quartz is considered to be secondary. This secondary quartz is frequently scattered through the feldspars in such a manner as to present the appearance of graphic granite, and again it is arranged in irregularly radiating lines. Chlorite is often present as an alteration-product of both feldspars and hornblende. No base finer than the rest of the rock was observed, so that the name should apparently be syenite, the quartz being taken as secondary. Since the hornblende is probably uralite, as in the similar rocks of other parts of the extent of the formation, the rock is probably an augite-syenite. We have in this rock precisely the same as is found in many pebbles of the porphyry-conglomerates of Keweenaw Point, and such as is found massive again along other portions of the Minnesota coast.

Another kind, less common than the foregoing, presents a red matrix with little green or black in it, but numerous facets of red feldspar difficult to distinguish from the matrix, save in certain positions. This is a true "granitic porphyry," standing between the granites and felsites. Under the microscope it appears originally to have been composed of a minutely crystalline base; but the whole is now saturated through and through with secondary quartz.

Less common than either of the foregoing, but still forming quite large patches in the gabbro, is another red rock which presents to the naked eye an aphanitic light-red matrix, in which minute orthoclases are very sparsely scattered. Underneath the microscope it shows a nearly white matrix so thoroughly saturated with secondary quartz that it is often difficult to tell its exact original nature. The quartz is arranged in arborescent clusters and in crossing forms, and all of a cluster will polarize together. Numerous black particles, some of them undoubtedly magnetite, others more minute and hair-like, are contained; also porphyritic crystals of orthoclase and augite. The whole section is dotted with minute brownish particles. One or two minute porphyritic quartzes were observed. The rock is plainly enough a felsitic porphyry, with various products of devitrification in the base.

These three varieties of red rock, thus described as occurring at Duluth, are evidently but different phases of the same rock, and without much doubt are connected with each other in the mass, though this was not proved in the field.

The exposures of gabbro on the Cloquet River regarded as belonging to this belt are on Sec. 10, T. 54, R. 13 W. (270 N., 1,500 W.); on Sec. 5, T. 53, R. 13 W. (1,700 N., 2,000 W.); at the falls on the N. E. ¼, Sec. 18, T. 53, R. 13 W. (1,650 N., 700 W.); at a number of points through Sec. 36, T. 53, R. 14 W.; in the S. E. ¼, Sec. 35, T. 53, R. 14 W. (75 N., 600 W.); and about the falls in the S. E. ¼, Sec. 34, T. 53, R. 14 W., where the showing is a very large one. The rock seen at these points is pretty uniform in character, and is a very fresh olivine-gabbro. It is light-gray in color, very coarse-grained, and composed chiefly of very fresh plagioclase (anorthite). Quite fresh diallage fills in the spaces between the feldspars. A few large, fresh olivines occur here and there in the section. Titaniferous magnetite is abundant and large-sized, and biotite occurs in a few small scales.

From the last exposure examined on the Cloquet, in Sec. 10, T. 54, R. 13 W., it is some eighty miles in a N. 50° E. direction to the vicinity of Brulé Lake, where Mr. Chauvenet found again a large development of coarse gabbros and red granitic porphyries. The intermediate country has not yet been surveyed, and is well-nigh unknown, save to the Indians. There can be little doubt, however, that the same belt runs through. I am informed by Professor N. H. Winchell that he found such rocks on what would be the line of this belt in making a northwesterly traverse from the mouth of Poplar River. Some sixteen miles back from the mouth of Baptism River in a northwesterly direction, Messrs. Campbell and McKinlay found a granitic porphyry, which may belong to the same belt, but the country was low and swampy, and no other exposures were in sight.

The exposures about Brulé Lake, and the headwaters of Brulé and Cascade rivers are on a grand scale, and of great interest. To reach them my assistants, Messrs. Chauvenet and McKinlay, started from the lake shore at Grand Marais, Sec. 21, T. 61, R. 1 E.; went thence northwest to Devil's

Track Lake, in the southern part of T. 62, R. 1 W.; canoed this lake to the western end; portaged to Cascade River in Sec. 26, T. 62, R. 2 W.; and thence ascended Cascade River to its source in a series of small lakes, in the southern part of what would be T. 63, R. 2 W., if the country had been surveyed. They crossed in this ascent a series of distinctly bedded diabases and amygdaloids, dipping southward at a low angle. The lake which forms the source of Cascade River lies in what would be about Sec. 2?, T. 63, R. 2 W. Thence they took a W. N. W. course to Brulé Lake, which lies east and west, with a length and width respectively of about ten and two miles. The shores of the lake are bold and rocky, and exceedingly irregular in outline. The rocks assigned to the horizon now under description were found first on and about Eagle Mountain, which lies ten miles north and two west of the northeast corner of T. 62, R. 2 W., or somewhere about the S. E. ¼ of Sec. 22, T. 63, R. 2 W. It rises abruptly on the east side of a small lake to a height of 450 feet, or to upwards of 1,500 feet above Lake Superior.

The mountain is a bold mass of bright red rock, and from its summit may be seen numbers of other elevations composed of the same red rock. This rock is a granitic porphyry, and over most of the mountain presents an appearance closely resembling that of the second kind of red rock mentioned as occurring at Duluth, while it is precisely similar to rocks seen cutting coarse gabbro at the same low horizon in the Bad River country of Wisconsin. It presents to the naked eye the appearance of being chiefly made up of small red feldspars, but there are areas which will not reflect any light. No other mineral is to be detected. Under the microscope the section presents precisely the same appearance as that of the Duluth rock, being made up of reddened orthoclases and matrix, the latter now so thoroughly saturated with secondary quartz arranged in bunches of radiating lines, that its original nature is difficult to decide. The quartz also penetrates some of the recognizable orthoclases, many of which are, however, without it. One or two particles of greenish hornblende were observable; minute black particles also occur. Near the top of the mountain a more dense kind than usual was noticed, which turned out to be a true felsitic porphyry. No line of demarkation was noticed between the kinds. All about the mountain the rock appears as if massively bedded, with an east and west trend, and a 10° to 15° southward dip. Eastward from Eagle Mountain three or four miles the red granitic porphyries were again found exposed. On the foot of the mountain on the south, moderately coarse dark-gray orthoclase-gabbro was in place, appearing to underlie the granitic porphyry.

Leaving Eagle Mountain, the course of the party lay in a northerly direction, through a string of four lakes. In the second of these, Pike Lake, massive ledges of gray gabbro 10 to 30 feet high run along both sides of the lake. This gabbro is very coarse, much weathered and iron-stained, and shows a great deal of very coarse titaniferous magnetite. Under the microscope it is seen to be closely allied to the Duluth gabbros, from which it differs, however, in having more orthoclase, a less-altered diallage, and in containing quite a little secondary quartz. The same rock continues largely exposed to the end of the last lake in the series in about what would be Sec. 15, T. 63, R. 2 W. From the last lake the trail leads through a gorge 10 miles in a direction slightly north of west to Brulé Lake. The walls of the gorge average some 50 feet in height, now and then rising into cones of bare rock 100 to 150 feet high. They are often not more than a few rods apart. That on the north is for most of the distance red granitic porphyry, and that on the south at first the coarse gray gabbro of the lakes below, while nearer Brulé Lake it is composed of a finer-grained brownish-gray orthoclase-gabbro. In this rock there is a good deal of augite with crystalline outlines, it having formed before the feldspars, besides diallage with the usual relation to the feldspars, which are both oligoclase and orthoclase. There is contained a great deal of titaniferous magnetite in black rods.

Brulé Lake is a sheet of water some ten miles in length by two in greatest width, with an exceedingly irregular outline, and numerous rocky islands. The lake lies in a rock basin, and its shores, especially the northern, rise into bold cliffs, and the whole landscape is unequalled for beauty anywhere in the Northwest. There was not enough time spent here to work out any details, but enough was seen to learn that the rocks lie in distinct belts trending slightly south of west. At the northwest corner a red granitic porphyry like that of Eagle Mountain has a great development. South from here are belts of fine-grained ashbed-diabase and of a diabase-porphyry with a fine-grained to aphanitic gray matrix and large red crystals of a triclinic feldspar. Still south of these belts are others of a medium- to very coarse-grained gray gabbro. One of these belts, consisting of a medium-grained kind, with much whitened feldspar, and much magnetite, can be traced for several miles from the end of the lake, through a line of islands to the north shore. Still south of these belts, and appearing both in the islands and on the northeast shore, are again others of a red granitic porphyry, running into a true quartz-porphyry; of fine-grained ashbed-diabase, and of a very coarse orthoclase-bearing gabbro like that seen farther south towards Eagle Mountain.

The gabbro sheets overlying the slates of Pigeon River and Thunder Bay, and above alluded to as possibly belonging to the same general horizon with the Duluth gabbros, are described in connection with the slates.[1]

The Duluth Group.—The rocks in the neighborhood of Duluth which I assign to this group were found exposed in the streets of the town itself, along the lake shore to the mouth of Chester Creek, and on the hillside in the triangular area between the latter creek and the lake shore. As explained on a previous page, these rocks trend at first west of north, and then about north to and beyond Chester Creek, dipping at first 45° eastward, but near Chester Creek not more than 20°. The whole thickness displayed is not far short of 5,000 feet. With the exception of two thin beds of a moderately coarse, black gabbro, and a little interleaved detrital matter, all of this thickness is made up of a succession of very fine-grained to aphanitic, gray to brown rocks, which are frequently porphyritically developed, with red and more rarely white feldspars as porphyritic ingredients; and which, in the upper two-thirds of the thickness often present amygdaloids as the upper portions of the flows. These amygdaloids have commonly a light-brown or reddish-brown matrix, and amygdules which are prevailingly epidote; but amygdules of epidote and quartz, of epidote and calcite, and of a green earthy substance, evidently a decomposition-product, also occur. A general epidotic decay is often presented in the shape of reticulated strings and blotches of epidote through the amygdaloids, and even, to some

[1] See also Chapter VIII.

extent, in the more compact portions of the beds. The amygdules are relatively small and not very thickly strewn. They are frequently elongated in a common direction and in a very striking manner. The same amygdaloids which exhibit this elongation of the amygdules in a common direction show also other signs of having flowed as lava, such as flowage lines, ropy texture in a common direction, etc. The most interesting of these phenomena is, however, an appearance of stratification presented on a weathered surface, which is evidently directly connected with the viscous flow of the original lava.

As to the thickness of the layers of this series at Duluth, it may be said that the thickness of the lower layers is exceedingly difficult to determine, the rock exposures showing the same material of great widths, and there being no amygdaloids. Evidently the thicknesses are very considerable, probably measured even by hundreds of feet. Higher up, however, the layers become plainly thinned, and alternate more rapidly, and in the upper third of the series amygdaloids and compact portions alternate with each other quite rapidly, as is well seen along the shore west of Chester Creek.

An examination of a large number of sections of these rocks under the microscope showed them all to be closely the same, varying only in texture and fineness of grain. The main ingredients in all are plagioclase, augite and magnetite. The triclinic feldspar occurs both in the groundmass and as the chief porphyritic ingredient, the reddish crystals showing frequently and plainly the striation to the naked eye. In both, measurements give the low angles indicative of oligoclase. The porphyritic crystals are commonly filled with brownish particles of ferrite, and are nearly always more or less thoroughly dulled by alteration. The augite is only rarely fresh, generally showing more or less of a change to a greenish, non-polarizing, viriditic substance, with which change there is also connected the formation of much magnetite in small particles. It exists both as a filling to the spaces between the feldspars, and in little rounded granules, the latter phase being especially characteristic of the finer-grained kinds. Magnetite is present, however, not only as an alteration-product of the augite, but also occurs abundantly in all sections as an original constituent. Besides these main ingredients, there are also to be observed apatite, which occurs in many sections in the usual slender needles; epidote, which in many sections is abundantly present in the groundmass, at times to such an extent as to form pseud-amygdules, besides occurring as a true amygdule in the amygdaloids; quartz, also as an alteration-product, associated with the epidote, and also in some of the excessively fine-grained kinds as true infiltrating secondary quartz.[1] Olivine is absent throughout. These rocks then are to be called, according to their texture and degree of crystalline development, fine-grained diabase, porphyritic diabase, diabase-porphyrite, and diabase-amygdaloid.

The two beds of gabbro above alluded to are in strong contrast with the rest of the rocks of this group. They show a black, rather coarse, highly crystalline, rough-textured rock, which in the thin section is seen to be made up of anorthite; diallagic augite, very coarse and abundant, partly fresh and partly altered to viridite and uralite; and very coarse magnetite or titanic iron.

With the exception of the last rocks described, Professor N. H. Winchell, if I understand him correctly, would regard all of these fine-grained rocks, and especially the amygdaloidal and porphyritic phases, as metamorphosed shales and sandstones, and as altered from the red sandstone of Fond du Lac, to which, as a result of alteration, he also refers the granite, granitic porphyry, and felsite of the Duluth gabbros, and indeed of the whole Minnesota coast. The usual proofs are present that the rocks now under description are entirely original and have flowed as lavas. These are, in brief, completely crystalline texture in most kinds; presence of some original non-polarizing base in some of the porphyritic kinds; complete absence in all of any traces of fragmental texture; true gas vesicles in the amygdaloids; elongation of these vesicles in a common direction; flowage lines

[1] One variety of the Duluth fine-grained rocks A. Streng has described in some detail under the name of "melaphyr-porphyry," the term melaphyr being used for any older plagioclase-augite rock. (A. Streng und J. H. Kloos: "Ueber die Krystallinischen Gesteine von Minnesota in Nord Amerika," in Neues Jahrbuch f. Mineralogie, etc., 1877, p. 42.) It is evidently the rock which is largely exposed near the elevator in East Duluth, N. E. ¼ of the S. E. ¼ Sec. 27, T. 50, R. 14 W., and again—the same belt—on Brewery Creek, at 250 paces north and 100 west of the southeast corner of Sec. 22, T. 50, R. 14 W. It presents a very dense groundmass, with very thickly scattered porphyritic crystals of red feldspar, mostly triclinic. The following is the analysis given by Streng: SiO_2, 50.03; Al_2O_3, 15.38; Fe_2O_3, 11.78; FeO, 3.90; CaO, 5.39; MgO, 3.60; K_2O, 1.14; Na_2O, 5.01; H_2O, 2.73; CO_2, 0.98=99.94; P_2O_5, 0.33. His analysis shows the essentially basic nature of this porphyry, which Messrs. Streng and Kloos class with the somewhat similar rock from Saint Croix Falls, Wisconsin.

and ropy texture in the amygdaloids; and division of the beds into lower compact and upper vesicular portions. To these we need only add that should we look on them as of detrital origin, we must do the same for all the amygdaloids of the Lake Superior basin, and for all of the crystalline rocks with which they occur. This would leave us only a few insignificant dikes to regard as of eruptive origin. Between the Keweenaw Point diabases and amygdaloids and those of Duluth there is no difference as to the general nature—the origin of the one is the origin of the other.

True detrital material was, however, observed interbedded in the Duluth series at two points; one of these was low down in the series, on the hillside above the Catholic church at Duluth, where a small exposure of a very finely laminated argillaceous slaty rock is to be seen; the other is on the lake shore between Brewery and Chester Creeks, where may be seen a light-brownish, quite plainly bedded fine-grained sandstone composed of a mixture of basic and acidic detritus, the former predominating.

Several small dikes were observed cutting the beds of this member on the lake shore between Chester Creek and Duluth. These dikes trend with the strata, but cut across them at right angles to the bedding. They are composed of a fine-grained black rock, which, near the middle of the dike, is plainly crystalline, while towards the sides it is aphanitic. This rock has not been examined under the microscope, but is precisely the same macroscopically as that of some similar dikes occurring five miles further down the coast, below the mouth of Lester River, which is a very highly augitic diabase, without olivine, and with but little magnetite.

Since these beds make so large an angle with the coast near Duluth, they depart rapidly inland. So far as our limited explorations went inland, the belt of country under which they are supposed to lie is largely low and without exposures, lying back of the first or lake range of bold hills. Following the range line between ranges 11 and 12 north seven miles from the crossing of Knife River in the S. W. ¼, Sec. 6, T. 52, R. 11 W., Mr. McKinlay found no exposures, but eastward from the last point three miles, in the N. W. ¼ of the S. W. ¼, Sec. 4, T. 53, R. 11 W., he found a large exposure of a very fine-grained massive gray rock, with porphyritic triclinic feldspars, which both to the naked eye and under the microscope resembles closely the gray

Duluth rocks, to whose horizon it may reasonably be referred. The rocks of the upper Cascade River, and the east end of the Minnesota coast, which may belong in part to the member now under description, are considered after the next two members are described.

The Lester River Group.—The third member of the succession on the Minnesota coast I have divided from the second by a rather arbitrary line. Its beds were seen best exposed on the lake shore from a point between Chester and Tischer's Creeks, in Sec. 24, T. 50, R. 14 W., to a point about two miles below the mouth of Lester River, in Sec. 34, T. 51, R. 13 W.; along Lester River, and in the woods west of the river, in Secs. 4 and 5, T. 50, R. 13 W., and Secs. 29 and 33, T. 51, R. 13 W.; along French River, in Secs. 6 and 7, T. 51, R. 12 W.; in scattering ledges in the woods in the southern part of T. 53, R. 11 W., north of Knife River; and again along Encampment River, in Secs. 3, 10, and 11, of T. 53, R. 10 W.

This group is made up chiefly of beds of fine-grained to nearly black, dark-gray, brown, or reddish-brown compact rocks, occasionally porphyritic with reddish plagioclases; but this character is not so marked as in the preceding group. No detrital material was observed, and only one or two amygdaloids, although feebly developed pseud-amygdaloids occur more frequently. A few coarse-grained beds are included, and there are two or three belts or areas of red granitic porphyry. Several narrow dikes were seen on the coast, like those of the Duluth Group, and, like them, trending with the general direction of the beds, now altered from what it was near Duluth.

The prevalent fine-grained beds were best seen on Lester and French Rivers. At the mouth of Lester River and for some distance below, and again up the river for half a mile, are large exposures of a very fine-grained, dark-brownish to dark-greenish, compact, very heavy rock, with a few minute porphyritic feldspars. The chief constituent is a plagioclase, in minute tabular crystals, which never give higher angles than for oligoclase. Quite subordinate in quantity are the minute particles of augite, many of which are largely altered to a greenish substance, with which is also associated more or less magnetite, evidently as a product of alteration.

Original magnetite and rare and small porphyritic oligoclases complete the list of constituents. The rock belongs to Pumpelly's ashbed type. The southeast dip, at 10°, can be plainly made out in this rock at the mouth of the river. Ascending Lester River, lower layers come to view. Near the middle of the west line of the N. W. ¼ of Sec. 4, T. 50, R. 13 W., the rock is very fine-grained, of a dark brownish-gray color, and under the microscope presents the typical appearance of Pumpelly's melaphyrs, namely, large augites, including numerous tabular plagioclases (oligoclase), and with numerous olivines, altered to greenish and brownish substances, magnetite, and much red ferrite in the spaces between the augites. Near the northwest corner of the section a coarse band is crossed. Next, through the greater part of Sec. 33, where the river makes four falls, whose height aggregates some 80 feet, the rocks are very dense, dark brownish-gray diabases, alternating with red- and dark-green-mottled varieties. These are seen in the thin section to be the usual pseud-amygdaloidal diabase, holding augite, often fresh, but often altered to a dark-green substance, much reddened plagioclase, magnetite, pseud-amygdaloidal chlorite, and occasional porphyritic oligoclases.

In Secs. 6 and 7 of T. 51, R. 12 W., French River makes nine falls over the rocks of this group, the individual falls running from 6 to 70 feet in height. Between these falls the river rushes down an inclined plane nearly on the slope of the S. E. dip. The rocks in sight are largely fine-grained, rough-textured, luster-mottled kinds, ranging from black to bright red in color, according to the amount of secondary peroxide of iron present. They are very highly augitic, with much magnetite and olivine in minute particles, wholly altered to a green substance, between the augite grains. All specimens show rare and small porphyritic oligoclase, and there is often pseud-amygdaloidal chlorite. The rock at the falls in the N. W. ¼ of Sec. 6, beyond which the river was not ascended, is very dense, with conchoidal fracture and of a dark-brown to nearly black color. Its thin section shows the common characters of this variety, viz, predominant plagioclase (oligoclase) in small tabular crystals, and the augite in minute rounded particles. One amygdaloid was noticed on French River, near the north line of Sec. 7, and 730 steps west from the northeast corner of the section. The amygdules are thickly crowded, small, often elongated, and chiefly composed of radiating laumontite in the specimen brought away. The fine-grained, conchoidal-fracturing, brownish rock, with accompanying laumontitic amygdaloid, seen on Encampment River, in the S. E. ¼ of Sec. 10, T. 53, R. 10 W., is probably to be placed with the fine-grained rocks of the Lester River Group.

It was not possible to determine whether all of the coarse-grained rocks of the Lester River Group are interbedded flows and not dikes, but most of them are plainly the former, and the rocks of those exposures whose relations were doubtful are in all respects identical with those of the undoubted beds. As an example may be mentioned the rock quarried below the mouth of Chester Creek. The thin section of this rock is figured at Figs. 3 and 4 of Plate II, and is further described in the table on page 46. It is a medium-grained, highly crystalline, black, rough-textured, olivine-gabbro or diabase, consisting chiefly of anorthite and diallagic augite, and containing also large particles of olivine and titaniferous magnetite. Externally it presents a luster-mottling, such as is seen in the finer rocks, and from the same cause. It is the same rock that forms the few coarse beds of the Duluth Group, the uppermost amygdaloids of which group it closely overlies. It forms a bed of very considerable thickness, and can be followed along the lake shore for many rods, varying somewhat in coarseness of grain. A similar rock closely overlies the fine-grained diabase of the mouth of Lester River. In it the olivines are more highly altered, being almost wholly changed to a brownish ferruginous substance. This layer can also be traced for a long distance on the shore. Similar rocks show again on French River, near the north line of Sec. 7, T. 51, R. 12 W., and in a great ledge 200 feet high on the west line of the S. W. ¼ of Sec. 26, T. 53, R. 11 W. The rock on French River occurs plainly interbedded with the fine-grained rocks already described. It is moderately coarse in grain, gray, minutely spotted with red, and of a rough texture. It consists chiefly of anorthite, diallagic, very fresh augite in large crystals, each one of which includes several detached areas, and olivine, which occurs in large patches crossed by black, brown, and red bands of iron-oxide. The thin section is represented in Figs. 1, 2, and 4 of Plate III.

The rock in Sec. 26, T. 53, R. 11 W., forms a ridge which presents a bold cliff to the northwest and a gradual slope to the southeast. Macroscopically it is somewhat different from any of the foregoing, presenting a very light-gray color, mottled with darker shades, but the thin section shows that it is essentially the same rock, and that the differences are due to smaller amounts of augite and to the great freshness of the rock. Even the very large olivines are unusually fresh, being traversed only by a few rifts bordered by a greenish alteration-product. Coarse-grained, rough-textured black olivine-gabbro belonging to the Lester River Group forms the barrier rock of the falls of Encampment River in the N. E. ¼ of Sec. 10, T. 53, R. 10 W.

Another kind of coarse-grained rock is presented in the ledges on the west line of Sec. 28, T. 54, R. 13 W. This is an orthoclase-gabbro, carrying orthoclase, oligoclase, diallage, augite in long-twinned blades, apatite and a good deal of secondary quartz. Externally it is brownish-black and resinous-looking from alteration, and peculiar for its long-bladed augite crystals. The thin section of this rock is pictured in Figs. 1 and 2 of Plate V.

The red porphyries of the Lester River Group can be best seen on the lake shore both above and below Lester River. The importance of the place not being realized at the time, sufficient attention was not given to it to determine the relation of these red rocks to those adjoining them. Some of the specimens brought away show a medium-grained, highly crystalline rock, which in the thin section looks as if it might be a very greatly altered orthoclase-gabbro. Quite a little augite, much of which is fresh, is contained, and the reddened feldspars are filled with secondary quartz. Other specimens show a rock more like the granitic porphyry of Duluth, and others again are distinctly felsitic porphyries. Even the latter kinds are saturated with secondary quartz, and all kinds so much altered that the original condition of the matrix is not easy to determine. At one point below the mouth of Lester River a coarse, black olivine-gabbro includes patches and vein-like bands of the red rock, in this case one of the more distinctly crystalline and augite-bearing kinds, while a few rods farther along the shore the same red rock forms the whole face of the exposure. Some of the bands of red in the black gabbro are only a few inches wide and have serpentine courses, intersecting one another. There can be no doubt that the rock and conditions are the same as observed in the case of the red rock penetrating the gabbro at Duluth. The red rock below Lester River becomes more and more fine-grained as it is followed down the coast, until it presents the appearance of a felsite, with distinct red orthoclases. Still farther it is much weathered and earthy, with seams of calcite and large sized "vugs," lined with fine crystals of the same mineral. In the same vicinity it is thickly dotted with amygdule-like spots of white calcite, one-fourth inch in diameter. Whether these are true amygdules or replacements has not been determined. True quartz porphyry and granitic porphyry are exposed along Encampment River in the N. W. ¼ of Sec. 11, T. 53, R. 1 W., with a width of 400 paces. This belt lies at or near the summit of the Lester River Group

Below Lester River these red rocks were observed to be cut by several narrow dikes, 10 to 20 feet wide, and trending N. 45° to 50° E., or with the strata. These dikes were marked by a very strong cross-jointing, and near the walls by a close-jointing parallel to the walls. In the middle of the dikes the rock is black, fine grained, but highly crystalline, and rough in texture. Towards the sides where the jointing parallel to the walls comes in it is aphanitic, dark-green in color, and greasy from the presence of chlorite. A section of the rock from the middle portion shows augite predominating, partly fresh, and partly altered to a brownish substance, in areas enveloping numbers of minute plagioclases (labradorite), just as in the "luster-mottled" melaphyrs of Pumpelly. Magnetite is present in small particles, and besides the viriditic and ocherous material, evidently resulting from a change of the augite, there are other particles of somewhat similar material, usually of a deeper tint, lying between the augites in small rounded forms which show no tendency to polarize together. These are evidently altered olivines, and the resemblance to Pumpelly's luster-mottled rocks, save in unusual fineness of grain, is thus complete. The section of the finer-grained rock from the side of the dike shows it to be the same, except that it is in an excessively fine condition, has its augite largely changed to a chloritic substance, and contains some non-polarizing base.

The Agate Bay Group.—The Agate Bay Group of beds is finely displayed in its entire thickness of some 1,500 to 2,000 feet, along the lake shore for a distance of some 34 miles, between a point in the S. W. ¼ of Sec. 34, T. 51, R. 13 W., a mile and a half below the mouth of Lester River, and one in the S. E. ¼ of Sec. 14, T. 54, R. 9 W., two miles above the mouth of Encampment River. These beds are also to be seen exposed on French, Knife, Encampment, and Gooseberry rivers, for short distances from their mouths.

The most striking external characteristics of this group, as compared with those previously described, are the relative thinness and distinctness of its beds; the great number of highly vesicular amygdaloids, which must make up more than half the entire thickness of the group; the peculiar appearance of subordinate stratification presented by both amygdaloidal and compact portions of the layers, when weathered; the prevalent fine grain of all save one or two of the beds, and the presence of two or three thin layers of red sandstone, shale and conglomerate.

The lower beds of this group, which are to be seen along the shore in Secs. 34, 35, 24, and 26, T. 51, R. 13 W., trending more to the northward than the coast and dipping southeast about 15°, are somewhat peculiar. The rocks exposed about the lower part of Encampment River in Sec. 11, T. 53, R. 10 W., appear also to belong here, as do, in part, those along the shore for two or three miles above the mouth of the same river, the broad bay into which this river empties setting back far enough to reach these lower layers. The non-amygdaloidal portions of these lower beds are composed largely of very dense conchoidal-fracturing diabases of the ashbed type, some having a dark-greenish to black color, while others have a more reddish-brown color, when the grain is excessively fine. There is often more or less unindividualized material, when the rock becomes a diabase-porphyrite. Other layers again have the compact portions a coarser rock, often much altered and crumbly, and of various purple and brown shades. These are the usual Keweenawan fine-grained olivine-free diabases. The amygdaloids of all these beds are plainly marked. They carry chiefly laumontite, calcite and quartz in the cavities, which are often of large size (⅛ to ½ inch), smooth-walled, and elongated in a common direction. Many are empty, and being thickly strewn, the result is a completely honeycombed rock. In one place, about two miles below Lester River, one of the hard reddish-brown dense beds above referred to was furnished not only with an upper, but with a basal amygdaloid, in which the cavities were large, smooth-walled, and quite regularly oval, often empty, or lined with drusy quartz.

A fine showing of one of these hard beds is to be met with on the coast near the center of Sec. 22, T. 53, R. 10 W., about ten miles above the mouth of Encampment River. Here is a bold cliff 25 feet high, of the hard, dense, light-brown rock, which below is without amygdules, but which as it is traced up the cliff becomes more and more amygdaloidal, finally becoming a highly vesicular amygdaloid, with large cavities elongated in a common direction, and carrying saponite, calcite and laumontite. Under the microscope the non-amygdaloidal portion of this rock is seen to be chiefly composed of tabular plagioclases (oligoclase) set in a brownish, iron-infiltrated matrix which will not affect the polarized light. Augite is present only in very rare minute rounded grains and in a few porphyritic crystals. Particles of magnetite and porphyritic oligoclases complete the list of ingredients. The rock is a diabase-porphyrite with the augite nearly or wholly wanting.

Some of the less dense beds showed pseud-amygdaloidal phases, with pseud-amygdules chiefly of a dark-greenish chlorite, and at several points on the shore of Sec. 25, T. 51, R. 13 W., a crumbling pseud-amygdaloid was found with a light reddish color, mottled with dark-green chlorite pseud-amygdules, and presenting at first sight, especially on cross fracture, a strong resemblance to a reddish sandstone, with angular grains. This resemblance is heightened by the fact that the rock has a bedded appearance. A careful examination, however, of the weathered surface of the rock shows that it probably has a completely crystalline texture, and this is abundantly proved to be the case by the thin section, which shows that the rock is nothing but one of the usual pseud-amygdaloids, of interlocking crystalline texture, and with no trace of fragmental origin. This rock would undoubtedly be taken for a sandstone by most observers at first sight.

The remaining two-thirds of the Agate Bay Group forms the most of the coast from Talmage River to beyond Gooseberry River, in which distance there is, on the whole, an ascent of the coast line in geological horizon; but there are minor descents and ascents according to the relations between the irregularities of the coast and the trends of the strata. The dips are flatter than further east, never exceeding 10°, and sometimes sinking to 5° for considerable distances. The prevailing rock of the non-amygdaloidal portions of the beds is fine-grained and olivine-bearing, having nearly always the characters of Pumpelly's melaphyrs, *i. e.*, large augites including numbers of minute plagioclases, and much olivine and magnetite crowded into the spaces between the augites, the olivine generally altered into a reddish or greenish material. Though generally much finer-grained than the typical melaphyr of the Greenstone of Keweenaw Point, these rocks often show, in the less altered portions, which are then quite black in color, a distinct luster-mottling. In less fresh kinds there is a tendency to weather to a semi-nodular surface, the augite resisting decomposition better than the interspaces. These more altered kinds run through various shades of brown and red, more or less mottled with green. There is a good deal of variation as to coarseness of grain in different beds, and an extreme coarseness carries the rock into a true olivine-gabbro, which plainly enough, as may be seen even with the naked eye, is a phase of the fine-grained melaphyr. Such a rock presents itself on a large scale, with bedding surfaces hundreds of feet in length and width shelving into the lake at a low angle, along the coast between Sucker River Bay and Knife River, in the northeast part of T. 51, R. 12 W. Sections of this rock are figured on Plate III. Encampment Island, a mile east of Encampment River, is again formed of one of these coarser kinds, which also can be seen forming a distinct layer between finer-grained beds, on a cliff side in the north half of Sec. 22, T. 53, R. 10 W., 50 to 75 feet above the lake.

The amygdaloids of the upper two-thirds of the Agate Bay Group are very strongly characterized. In the first place they are very highly vesicular; the vesicles are always small and often so closely crowded that when the amygdules are dissolved from them the rock is almost as open as well-raised bread. The common amygdules are laumontite, saponite, and calcite. This seems the order of abundance for the whole group, but in separate layers either one or the other of the first two may predominate. The small, rounded, white or greenish-white spots of saponite are very characteristic. Prehnite is a much rarer amygdule, and agate still rarer. Another equally important characteristic is the stratiform appearance taken on by these amygdaloids. This appearance, which has received some notice on a previous page, is also found, though to a less extent, in the interbedded massive layers, or rather in the massive lower portions of the beds of which the amygdaloids form the upper portions. In both amygdaloids and compact portions this stratiform appearance is especially brought out by weathering. This was seen beautifully illustrated at the mouth of a creek on Sec. 15, T. 52, R. 11 E., about two and a half miles above Agate Bay. The creek enters the bay over the low shore cliff, into which it has worn its way back for some distance. Just where the water flows over it the rock is hard and massive, without trace of stratiform appearance, but on either side it may be traced distinctly into the usual obscurely stratiform material.

At a little distance an exposed cliff presents much the appearance of a series of sedimentary beds, as for instance a set of rather heavily bedded sandstones alternating with shales; indeed, these rocks, as already indicated, were long ago called "metamorphic sandstone and shale" by Norwood, and are now regarded as such by N. H. Winchell. But a closer study shows that here, as everywhere, both heavier and thinner layers are made up of rocks identical with the amygdaloids and diabases of Keweenaw Point, whose completely interlocked crystalline condition in the lower portions, and highly vesicular condition in the upper portions—the massive and vesicular parts grading into one another—abundantly prove their origin as lava flows. The lower portions of the beds have, too, very frequently, a well-marked columnar structure, another characteristic of the Keweenaw Point flows, and of flows of eruptive rocks generally. As already said, microscopically, these rocks are olivine-bearing augite-plagioclase kinds identical with the Greenstone of Keweenaw Point, even to the peculiar crowding between the augites of the olivine and magnetite particles. They are also the same rocks, only finer in grain, as the coarse black diabases which Norwood and Winchell themselves regard as eruptive, and—which will be taken by some as still more conclusive proof of eruptive origin—they are identical, even to the same crowding of the olivine in the interspaces, with the rocks of the narrow dikes found along the coast westward to Duluth. As shown below, the rock of the dikes observed cutting the Agate Bay beds themselves is a true luster-mottled melaphyr.

The subordinate layers, of which both amygdaloids and compact portions appear to be made up, are never regular or persistent, and in this respect there is a contrast with the subordinate layers of true sedimentary rocks, the most irregular of which are never so irregular as these. When in the field it was thought that the peculiar combination of resemblances to sedimentary beds and to the usual eruptive rocks of the region shown in these stratiform amygdaloids and associated massive layers, might find explanation in the origin of the amygdaloids as volcanic ashes,[1] *i. e.*, fragmental volcanic material stratified by water. In this case the amygdules might be pseud-amygdules, which could of course originate as well from fragmental basic material as from the same material in the original massive condition. But the study of specimens, and more especially the microscopic study of thin sections, which develops the wholly non-fragmental character of the material, and the true vesicular nature of the amygdaloids, show that such an idea is wholly untenable.

The following section, made out along the cliffs just west of Agate Bay, serves well to show the sort of succession everywhere to be observed in these stratiform beds The section could have easily been extended both up and down, but is sufficient as an illustration. The layers dip some 6° to 8° to the southeast. The order is an ascending one.

		Feet.
IA.	Massive, vertically columnar layer of a medium-grained, distinctly crystalline, purplish rock, mottled dark and light on a weathered surface. Sparsely scattered pseud-amygdules of calcite and laumontite, and of chlorite, are contained. The thin section shows plagioclase; augite, inclosing plagioclases; magnetite; olivine, wholly altered to red oxide of iron and a green substance, and crowded with the magnetite between the augites; and pseud-amygdules of a pale greenish substance. Grading into the overlying rocks by increase of abundance of amygdules. Thickness seen above water	5

[1] Norwood seems to have had this idea with regard to some of these beds, though most of them he regarded as "metamorphic shales." See Owen's Geological Survey of Wisconsin, Iowa, and Minnesota, p. 351.

IB. Stratiform laumontitic amygdaloid, the irregular and non-continuous layers less than six inches in thickness. Matrix much as in foregoing; finer grained. Amygdules small, not exceeding ⅛ inch, thickly crowded, of laumontite, calcite, saponite. Thickness.....10

——15

IIA. Massive, vertically columnar layer, of a rock similar to that of IA., but finer grained. In places laumontite amygdules or pseud-amygdules run through the whole thickness. Subordinately stratiform when weathered. Thickness.................................... 3

IIB. Stratiform amygdaloid like IB. Thickness 6

—— 9

IIIA. Massive, vertically columnar layer of a rock closely resembling that of IA., but showing under the microscope larger olivines and more pseud-amygdaloidal chlorite. Exceedingly irregular in thickness, expanding and contracting suddenly from a few inches to several feet, and *vice versa*. Thickness from 4 inches to.................. 3½

IIIB. Stratiform laumontitic and calcitic amygdaloid; subordinate layers a few inches thick. Thickness 6

—— 9½

IVA. Massive, vertically columnar layer like IA., IIA., IIIA.; exceedingly irregular in thickness, running from nothing to.................. 2

IVB. Stratiform laumontitic amygdaloid, the amygdules larger than usual, reaching ½ inch, and even 1 inch. Thickness..... 20

——22

VA. Massive, vertically columnar layer; rock like that of IA.; very irregular. Thickness, nothing to..................................... 2

VB. Stratiform laumontitic and calcite amygdaloid; layers so thin as to appear shaly. Thickness 3

—— 5

VI. Massive, vertically columnar layer, somewhat amygdaloidal towards top; rock like IA. Thickness 15

VII. Red shaly sandstone; very irregular in thickness; running away down into crevices in the underlying massive rock, and in places curiously intermingled with the overlying amygdaloid. Thickness .... 2 to 3

VIII. Stratiform laumontitic amygdaloid, layers at times very thin. Thickness............ 10

IXA. Massive layer, with the vertically columnar structure strongly marked, of a fine-grained dark-gray to nearly black rock, which under the microscope is seen to be one of the usual olivine-bearing melaphyrs, peculiar only in unusual fineness of grain. This layer forms the greater part of the face of the west point of Agate Bay. It is exposed in an immense surface, sloping towards the lake, as much as a quarter of a mile in length, and at times several hundred feet wide. As one walks over this great surface the ends of the columns, which show in cross-section, are finely displayed, and are seen to lack, as usual, the regularity of the basaltic columns of some regions. They are made by the intersections of several systems of joints, here quite close, and have varying numbers of sides

	and varying sizes. Many of the columns are triangular. A fine cross-section of this layer is seen on the southwest side of Agate Bay. Thickness	10	
IXB.	Stratiform amygdaloid	8	
			18
			101½

The above section well illustrates the usual alternations, but the layers are not always so thin. The uppermost layers, seen farther down the coast, appear to be much heavier. This may be seen in the vicinity of Castle Danger, Sec. 27, T. 54, R. 9 W., and at the Falls of the Gooseberry, section 21 of the same township, where the massive beds at times exceed 50 feet in thickness.

While the Agate Bay Group, throughout its whole extent, is so plainly made up of a series of thin layers of alternating massive and vesicular material, and while the general flat lakeward dip is very evident, there are numerous minor irregularities, such as running out of individual layers, warping of the layers, and faulting. All of these render it very difficult to trace out the subordinate succession for any considerable thickness. The warping of the layers is very interesting. As one follows the lake shore single beds may be seen disappearing beneath the lake, and reappearing within a few hundred feet, while in some cases the warping is much more violent, the rocks for short distances presenting the appearance of steeply inclined strata, but soon recovering their usual position. The general flat lakeward dip, the slight deviation of the general trend of the strata from that of the lake coast, the warping just alluded to, and the minor irregularities of the coast line all combine to produce many peculiar effects in the appearance of the stratification, which at first sight are often puzzling.

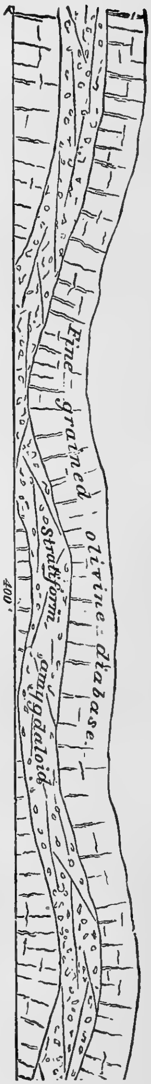


FIG. 12.—Sketch of a cliff-side near Agate Bay, Minn.; illustrating the warped bedding of layers. The dip is toward the observer.

Faults, apparently of small extent,—*i. e.*, under 100 feet—were seen at a number of points, and it is quite possible that greater ones exist, though hardly such as could affect very greatly the estimate given for the total thickness of the group.

Some peculiar appearances noted in the massive rocks in the upper part of the Agate Bay Group deserve further attention. At several points east of the mouth of Encampment River, bright-red bands an inch or two in width were noticed standing out on weathered surfaces. The bands are serpentine, making all sorts of irregular curls, and intersecting one another without any system. To the naked eye the bands and inclosing rock appear different only in color, even this difference being much less noticeable on a fresh surface. A thin section of one of these bands with some of the adhering wall rock, from the shore of the N. E. ¼ of Sec. 12, T. 53, R. 10 W., shows plainly under the microscope that both band and inclosing rock are the same, save for the numerous red hematite particles and greater abundance of altered olivines in the former. This peculiar appearance is probably a flowage result.

Another peculiar appearance is the resemblance to a bowlder-conglomerate presented in a few places by some of the more massive layers. For instance, on the shore of the S. E. ¼ of Sec. 14, T. 54, R. 9 E., about two miles above the mouth of Split Rock River, the shore cliff is formed of a compact, purplish, fine-grained rock, which on a weathered surface presents the peculiar light and dark mottling so characteristic of the fine-grained olivine-diabases or melaphyrs. In other words, it is the usual massive rock of the Agate Bay Group. At one point, near the water's edge, this very massive dense rock presented a marked stratiform appearance, though plainly grading on either side and upward into a rock without this structure. At the same time there appeared to be contained large, rounded, protruding bowlders. Close inspection showed these ball-like masses to be exactly the same as the rock inclosing them, into which they graded insensibly. The thin section of both rock and apparent bowlder proves to be a fine-grained, typical, luster-mottled melaphyr, with olivine and very abundant magnetite in the interspaces of the large augites. The structure is apparently referable to the spheroidal form so often taken on by basaltic rocks in cooling.

Yet another, but quite different appearance, as of foreign masses contained in the eruptive rocks, was noted on the shore near the east line of Sec. 1, T. 53, R. 10 E. Here the shore cliff for some distance is a black rock, coarser than the most of the massive rocks of the Agate Bay Group. This rock contains angular masses of a very coarse white-weathering anorthite-rock, of all sizes from fragments a few inches across to others three or four feet in length. These masses are irregularly and never abundantly distributed. The appearance is like what is often met with in the overlying or Beaver Bay Group of beds, and is further described in connection with that group.

The sandstone layers observed in the Agate Bay Group are all very thin, never exceeding three or four feet in thickness. They were met with at five different points along the coast between Lester and Gooseberry rivers, and probably at three different horizons. About three miles below Lester River, on Sec. 34, T. 51, R. 13 W., large water-worn surfaces of one of the dense, hard, brown, laumontitic amygdaloids, above described as characterizing the lower portions of the Agate Bay Group, are seen to be traversed by intersecting seams of bright-red sandstone, from a fraction of an inch to several inches in width Besides the larger areas of amygdaloid contained by the intersecting sandstone seams, there are smaller pieces completely surrounded by the sandstone of one seam. Fig. 13 represents these intersecting seams as seen in an area 20 by 10 feet. The sandstone of these seams is fine-grained, dark-reddish and argillaceous. The thin section shows it to be wholly fragmental, and to be composed of minute particles of quartz with other porphyry detritus, together with here and there dark-colored particles and particles of triclinic feldspar which probably are from some of the basic eruptives. When first seen these apparent veins of sandstone showed no connection with any other sandstone, but a few rods farther down the coast the amygdaloid in which they occur was found overlain by the remnant of a thin

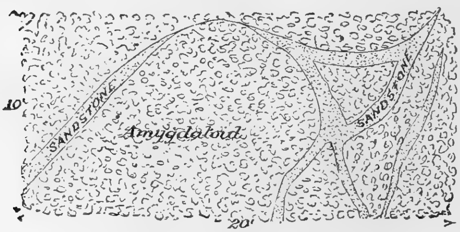


FIG. 13.—Sandstone "veins," Minnesota coast—plan.

red sandstone layer, or rather conglomerate, the pebbles being wholly of amygdaloid. Proceeding down the coast, the next sandstone met with is the seam already described in the section given of the succession at Agate Bay. This sandstone is much like the one last mentioned, descending in the same way far down into the crevices of the underlying rock, and intermingled curiously with amygdaloid. It is only two or three feet thick. Still farther down the coast, on the N. E. ¼, Sec. 32, T. 52, R. 10 E., red shaly sandstone was noticed occurring with stratiform laumontitic amygdaloid, as represented in Fig. 14. The sandstone layer with which this must connect was not seen here. At the projecting point near the S. E. corner of Sec. 1, T. 53, R.10 W., thin sandstone seams are to be seen interleaved with the melaphyr, and

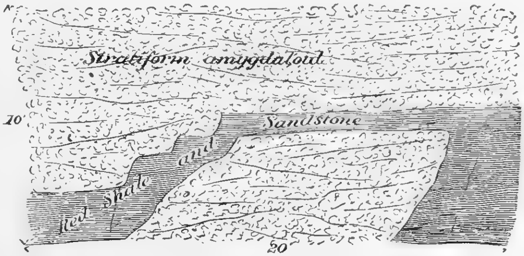


FIG. 14.—Sketch of cliff on Minnesota coast, showing penetration of fissures of amygdaloid by sandstone.

on the shore of Sec. 32, T. 54, R. 9 W., two and a half miles above the mouth of Gooseberry River, is a remnant of a porphyry-conglomerate—the pebbles small, usually less than one-eighth of an inch across, and subangular—with abundant calcareous cement.

A very few narrow dikes, much like those of the Lester River Group, were observed cutting the layers of the Agate Bay Group. One of these is to be seen on the shore of Sec. 34, T. 51, R. 13 W., two miles below Lester River. It corresponds in trend with the bedded rocks which it cuts, but lies at right angles to the dip. It is composed of a dense black rock, which has not been examined microscopically, is very strongly and closely cross-jointed, and is only a foot wide. A very prominent dike, five feet wide, is seen in the cliff on the shore of Sec. 15, T. 53, R. 10 W. Fig. 15 shows the occurrence of this dike, which is composed of a very fine-grained, black, luster-mottled melaphyr, the thin section of which looks much like that of the Greenstone of Keweenaw Point. It consists chiefly of very fresh augite in relatively large areas, inclosing numbers of tabular plagioclases (anorthite), and having in the interspaces, which are chiefly occupied by the same tabular plagioclases, many small altered olivines and particles of magnetite. The dike is strongly cross-jointed, save at the edges, which are traversed by joints parallel to the walls, and are composed of an aphanitic rock, much altered to chlorite. The rocks traversed are the usual stratiform amygdaloid and columnar melaphyr of the Agate Bay Group.

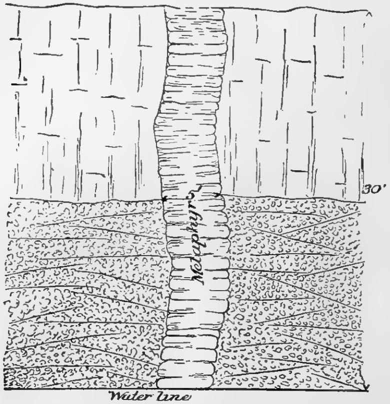


FIG. 15.—Dike traversing stratiform amygdaloid and columnar melaphyr, two miles below Lester River, Minnesota coast.

Equivalents of the Duluth, Lester River, and Agate Bay Groups at the east end of the Minnesota coast.—At the eastern end of the Minnesota coast there intervenes, between the Huronian slates and the base of the Beaver Bay Group, which next overlies the Agate Bay beds, a space only three and a half miles wide, measured at right angles to the east and west strike. With the flat dip prevalent in this region this width cannot include a total thickness of more than 3,000 feet, while at the Duluth end of the coast there lie between the same horizons the whole of the Duluth, Lester River, and Agate Bay groups, a thickness of some 9,000 feet; not to speak of the Duluth gabbros, which must add several thousand feet more. Forty miles west of Grand Portage, however, about Brulé Lake, in T. 63, R. 2 W. and R. 3 W., the gabbros are present in full force, while between them and the lower limit of the Beaver Bay Group there is a width of 10 miles, within which space, supposing the dip to be not more than 10°, a figure which the observations along Cascade River show to be closely right, there is room for a much greater thickness of the Duluth, Lester River, and Agate Bay groups. The small thickness on the lake shore near Grand Portage is probably to be assigned in part to actual thinning, such sudden thinnings being easily explicable when the rock layers are nearly altogether of eruptive origin; but also, in part, to some non-conformity with the underlying slates. However, the whole question of the way in which the Duluth, Lester River, and Agate Bay groups extend to the eastward is one which will have to be further studied in the interior along the various rivers entering the lake—especially along Brulé, Cascade, Poplar, and Temperance rivers.

Cascade River was examined by Messrs. Chauvenet and McKinlay above Sec. 26, T. 62, R. 2 W., but this was not far enough down stream to determine the existence or non-existence here of the Agate Bay beds. The first rocks met with by Mr. Chauvenet on the Cascade were found just where he first struck the river in Sec. 26, T. 62, R. 2 W. Here, for about half a mile, there are exposed in the bed and on the sides of the river, beds of a dark-gray to reddish-brown aphanitic rock with conchoidal fracture, much like some of the dense brown rocks of the Lester River Group. The only thin section made showed a diabase-porphyrite, composed chiefly of minute tabular plagioclases with a good deal of a matrix which shows but a feeble, flickering light when revolved between the crossed nicols. These rocks are quite plainly bedded, dipping southward at about 9°. In places they seem to show a subordinate structure parallel to the bedding, while most exposed surfaces are so weathered as to fall in showers of small fragments when struck with a hammer. One or two vesicular layers were noted, the vesicles smooth-surfaced, elongated, one-sixth to one-fourth inch in length, and either empty or lined with drusy quartz.

Continuing the ascent of Cascade River, no more exposures were found until reaching the falls in section 10. In the vicinity of these falls the rocks succeed one another in the following descending order: (1) dark-gray very fine-grained rock, resembling the fine-grained diabases of the Duluth and Lester River groups, not examined under the microscope; (2) brick-red quartz-porphyry; (3) medium-grained, black gabbro or luster-mottled melaphyr. The last rock forms the barrier over which the river falls. Five hundred feet above the falls comes in a medium-grained, brownish-gray orthoclase-gabbro, the thin section of which resembles closely that of the peculiar orthoclase-gabbro of the Lester River Group seen largely exposed on the west line of Sec. 28, T. 51, R. 13 W. It shows labradorite, orthoclase, pale-greenish-brown augite—often in twinned blades—titaniferous magnetite, apatite and a good deal of secondary quartz. The next rock noted was half a mile up stream at the 40-foot fall, which is somewhere near the southern part of Sec. 11, T. 62, R. 2 W. These falls are over a very fine-grained, grayish-brown rock, resembling the predominant gray diabases of the Duluth Group. There are strong appearances here of a southern dip at an angle between 10° and 15°. Above these falls for three-fourths of a mile the river is expanded into a lake; then comes another fall over the same compact, gray rock, which is exposed also above the falls on a large scale. The thin section of a specimen taken from the bed of the river above the falls bears out completely the external resemblance to the Duluth gray diabases. For a mile above this fall the river is again a lake, at whose upper end are again exposures of a fine-grained, gray to black rock, with luster-mottlings one-eighth inch across.

The prevalence among the rocks of the upper Cascade of fine-grained diabases closely resembling those near Duluth and Lester River; the occurrence among them also of quartz-porphyry, coarse-grained black gabbro, and of the peculiar orthoclase-gabbro with augite twins; the nearly complete absence, so far as observed, of amygdaloids; the geographical positions of the exposures with regard to the older rocks about Brulé Lake and Eagle Mountain, and the newer ones on the lake coast—all combine to render it highly probable that we have here to do with the eastern extensions of the Lester River and Duluth groups.

The exposures at the eastern end of the Minnesota coast between the base of the Beaver Bay Group and the Animikie slates are unfortunately not continuous, having between them long beaches. The base of the Beaver Bay Group intersects the shore about six miles above Portage Bay Island. Below here for about a mile were observed numerous exposures of a very dense brown, conchoidally fracturing rock, which is plainly bedded, and dips 8° to 10° south, with a due east and west trend, the rock appearing in a series of eastward projecting points, which make an angle with the lake shore of about 45°. The layers are distinctly columnar, and are often much shattered by close jointing, which in places is almost like a slaty structure, the rock coming out in thin slabs. The intervening beaches are presumably occupied by amygdaloids. This compact rock resembles, both externally and beneath the microscope, some of the conchoidally fracturing layers of the Agate Bay Group (as for instance that above described as occurring on the shore near Silver Creek, Sec. 22, T. 53, R. 10 E.), and also some of the layers of the beds of the Duluth and Lester River groups.

Below these brown rocks no exposures were found for about a mile, when, four miles above Portage Bay Island, dark-gray, fine-grained diabase pseud-amygdaloids alternate with amygdaloids in which the matrix is dark gray and the amygdules rather sparse and large and chiefly of stilbite and calcite. Similar rocks are seen again after a long beach, at about three miles above Portage Bay Island. After this another long beach intervenes, beyond which there is first a low, irregular exposure of a coarse-grained black gabbro, which is possibly a dike, and then, just at the west point of Grand Portage Bay, dark-gray, medium-grained diabases with amygdaloids like those just described. These gray diabases and amygdaloids are not much like anything else seen on the Minnesota coast.

On Portage Bay Island still lower rocks are visible. On the northeast corner of the island are the uppermost beds of the Animikie Group, seen near the water's edge. Overlying these beds, and forming the mass of the island, is a considerable thickness of an aphanitic black rock, which under the microscope appears to be made up chiefly of augite in aggregations of rounded grains and magnetite particles. The plagioclases are subordinated to the feldspars in quantity, the proportion varying in different sections.

FIG. 16.—Generalized section of Portage Bay Island, Minnesota coast.

Some sections show more or less of an isotropic material penetrated by minute plagioclases, as in the matrices of many of the amygdaloids. Other sections show numerous chlorite pseud-amygdules. In one place near the eastern point of the island this rock was seen weathering out into little spheroids usually under half an inch in diameter. These black rocks are somewhat peculiar, and although allied to the ashbed-diabases of the Duluth Group, they differ in the very high content of rounded augite particles, in which respect this rock differs, indeed, from any other as yet examined from the entire extent of the Keweenaw Series. The uppermost rocks of the island are coarser grained, and include rather coarse olivine-diabases, and at least one bed of an orthoclase-gabbro which, in the thin section, looks just like that of Lester River.

It is difficult to decide just how to correlate these eastern rocks with those near Duluth. It is evident that in a general way they resemble the rocks of the Duluth and Lester River groups. The resemblance to these groups of the brown and gray diabases of the coast above Portage Bay is very strong. On the whole, since the peculiarly characteristic stratiform olivine-bearing beds and associated shaly amygdaloids of the Agate Bay Group are not seen here at all, I am disposed to regard that group as having thinned out to nothing, and to divide the rocks that are seen here between the Lester River and Duluth groups, which must also, of course, have greatly thinned, if this reference is a correct one.

Beaver Bay Group.—The Beaver Bay Group was made out from the coast cliffs between Split Rock River and a point about two miles below Baptism River; from numerous inland exposures for five to eight miles back from the mouths of Beaver, Baptism, and Temperance rivers, and from the coast cliffs between Grand Marais and a point in the Indian reservation, about four and a half miles above the western point of Grand Portage Bay. This group is characterized by the great predominance of coarse-grained rocks, next in abundance to which are felsitic and quartziferous porphyries and granite-like rocks. Dense brown and gray diabases of conchoidal fracture occur to some extent, while amygdaloids and fine-grained diabases of the ordinary type, though rare, are not excluded.

While the prevalent coarse-grained rocks of the group are plainly enough flows, exhibiting the usual flat lakeward dip, and while the same is clearly true of much of the porphyry, there are other places where there is much difficulty in determining the positions which these rocks occupy. Some of these places are difficult because, between the porphyries and the nearest bedded basic rocks, there are gaps without exposure, such as shingle beaches along the coast, and these gaps are either so long that the relations of the rocks can only be guessed at, or else they are so short that it is hard to see how one rock can pass under the other. So many of these cases proved tractable under further study that there remains but little doubt that in nearly all the porphyry would be found plainly enough to overlie or underlie the other rocks in a regular way. In yet other cases, however, vertical contacts between the two rocks were found, and while these contacts are in some cases demonstrably due to faulting, in others this is not so evident, and there are certainly places where the coarse-grained basic rocks look much as if intrusive, while the red granite-like rocks always present this appearance. Undoubted dikes occur cutting the porphyries, and that much more frequently than in any of the preceding groups, but they are always of fine-grained rocks, unlike the associated coarse-grained kinds. The aphanitic, brown and gray rocks above referred to, as well as the rare amygdaloids and associated fine-grained diabases, are always plainly bedded. No rocks distinctly of detrital origin were observed in the group.

On the whole, the group may be briefly described as made up of bedded coarse basic rocks, with interbedded fine-grained basic rocks, only rarely amygdaloidal, and also of interbedded acid porphyries in very irregular areas, which are individually limited in extent, contracting suddenly from several hundred feet in thickness to nothing. The whole group is much faulted; fine-grained diabase dikes are not uncommon, while gabbros and coarse-grained granite-like rocks are present in intersecting masses. The total thickness is probably understated at 6,000 feet.

In describing this group more in detail, I find it most convenient to follow its exposures from west to east along the coast, taking the different kinds of rocks as they come. Beginning on the west, the basal bed of the group is a felsite, forming the bold point one and one-half miles above the mouth of Split Rock River. For some distance both east and west of the mouth of this river the rocks trend far around to the north, west of the river lying nearly due north, and to the east of it changing gradually more towards the N. N. E. The coast line is trending here as a whole just about N. E., but subordinately it gives a number of long trends corresponding to the more northerly trend of the rocks, as shown in Fig. 17. Until this unusual amount of northing

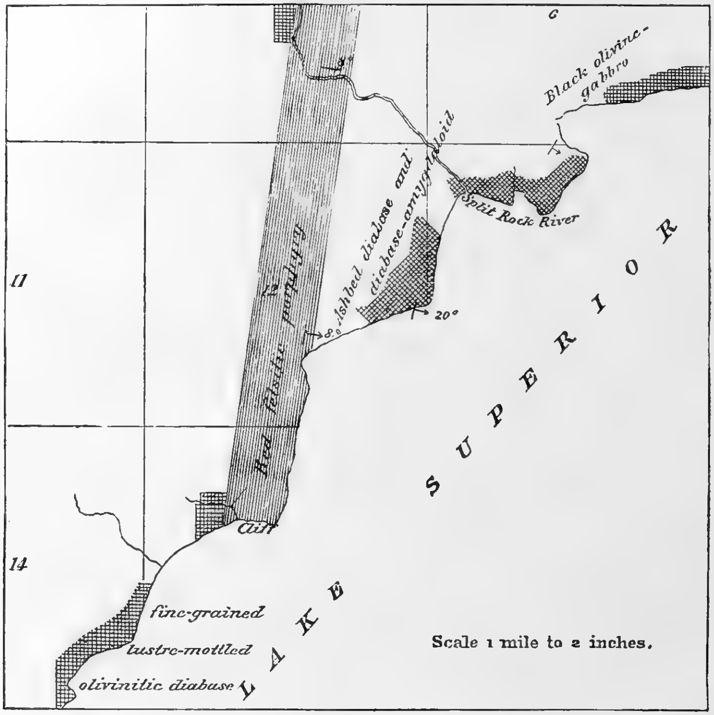


FIG. 17.—Sketch-map of rock exposures near Split Rock River, Minnesota coast, T. 54, R. 8 W.

in the strike is realized the exposures in this vicinity are confusing. The following is the succession of strata roughly made out for some four miles along the coast in the neighborhood of Split Rock River. There are probably some gaps in the succession, and the thicknesses given are only the roughest approximations. Nevertheless, the section in its general features is correct, and will well illustrate the nature of the lower beds of this group

Feet.

I. *Red felsitic porphyry.*—This rock shows finely on the coast two miles above the mouth of Split Rock River, where it forms a very striking red cliff 30 to 50 feet high. Close inspection of the cliff shows running through it a sort of banding which is brought out by narrow whitish strings, and also by lighter and darker shadings in the general red color of the mass. These bands curve up and down in the most irregular manner; for a while they will seem to be nearly horizontal, and then will suddenly change to vertical, and indeed to all sorts of directions within a few feet. That they represent a fluidal structure there can be little doubt. There is no tendency to split parallel to this banding. Under the microscope the thin sections show a matrix closely resembling that of the quartz-porphyry of the pebbles of the Calumet conglomerate of Keweenaw Point, figured on Plate XII, Fig. 2. It presents a reddish splotchy appearance, the minute ferrite particles which give the color being very irregularly distributed; and appears to be made up largely of what Rosenbusch calls crypto-crystalline matter. With this are particles which may be orthoclase, and a good deal of quartz, arranged in the peculiar ramifying way that characterizes the secondary quartz of the granitic porphyries. Scattered through this ground mass are numerous minute black particles. The porphyritic ingredients noted are comparatively small crystals of orthoclase and oligoclase, no quartzes having been observed. On the lake shore this porphyry has not been observed in contact with either the underlying or the overlying rocks, being separated from them by beaches. Two miles north, however, on Split Rock River, the contact with the underlying melaphyr is very nicely exposed. The dip here is to the east 18° to 20°, and several other observations along Split Rock River show the same eastern dip. At one point on the Split Rock River, about one and a half miles from the lake, the porphyry is cut by a dike, six feet wide, of a very fine dark-gray rock. The dike trends with the strata, nearly north and south, and dips at right angles to them, or 70° west. Thickness of this porphyry 600–700

II. *Ashbed-diabase and diabase-amygdaloid.*—Several layers (not more than four) each with an amygdaloid, of a very dense, light-gray to dark brownish-gray, conchoidally fracturing rock, which, in the thin section, shows tabular oligoclase (measurements on four different slices failing to find any angle above 25°); augite in aggregates of rounded particles; and magnetite, as the chief ingredients. In sections of the densest kinds there are areas which have little or no action between the nicols, and which appear therefore to be glass. More or less brown ocherous matter appears in the sections, the amount varying directly with the amount of brown tinge presented by the rock macroscopically. Of the two amygdaloids seen, one, which is exposed on the strike for several hundred feet at the foot of a cliff, on the first point above the mouth of Split Rock River, shows a weathered, greenish, earthy matrix, and rather sparsely scattered amygdules of laumontite. The other amygdaloid, seen on the face of the first point below Split Rock River, has a brownish, aphanitic matrix, and is so highly vesicular that the vesicles touch one another. These vesicles are small, very smooth-walled, elongated in a common direction, partly empty, but for the most part filled with amygdules of chalcedonic quartz, laumontite, or chlorite. These layers occupy a surface width, measured from west to east, of over half a mile, and must have a thickness, therefore, of at least 800 feet.. 800

III. *Dark-gray to black gabbro.*—This layer or series of layers forms the coast line for about a mile in the S. E. ¼ of Sec. 6 and S. W. ¼ of Sec. 5, T. 54, R. 8 W. The lower layers are rather fine-grained to medium-grained, dark-gray to nearly black, rough-textured, and marked by strong luster-mottlings. The thin section shows labradorites arranged in curving lines, which are evidently the result of flowage. The augites are relatively large, and inclose each countless minute feldspars. The magnetite is unusually abundant, being so thickly crowded between the augites as to render these interspaces nearly black. Quite large fragments of the rock are raised by the magnet. Though olivines are generally present in these luster-mottled rocks, none could be detected here. This section is figured on Plate VIII, Fig. 4. Higher layers become coarser in grain, and of a rougher texture, with less marked luster-mottlings. In the thin section of this coarser rock the augites are strongly diallagic and still larger than the plagioclases, but not nearly so much so as in the previously described rock. They are usually fresh, though occasionally altered to chlorite. Good-sized olivines, partly fresh, but generally traversed by broad brown and green bands of alteration, are here abundantly present. Still higher up, near the top of these layers, the grain becomes quite fine again, but no thin sections have been examined. Near the middle of the S. E. ¼ of Sec. 5, T. 54, R. 8 E., this gabbro is interrupted by a vertically placed mass of excessively coarse-grained anorthite-rock. The cutting mass is from 50 to 75 feet wide, and bears north and south. It shows on both sides of a little square-angled, rock-walled bay, on the south point of which it rises as much as a hundred feet above the lake. On both sides of the cutting mass the black gabbro is filled with large angular masses of the same coarse anorthite-rock. The included masses reach sometimes many tons in weight, and in some places predominate over the including gabbro, which then appears as if veining the coarser rock. At the west angle of the bay the included masses are nearly absent, and the gabbro resumes its usual vertically columnar appearance. At the north angle of the bay the anorthite-rock rises again to a height of over 150 feet. The inclusions of angular masses of the anorthite-rock in the gabbro indicate the more recent origin of the latter, and this conclusion is borne out by the thin section made from a specimen taken at its contact with the gabbro, in which the relatively fine gabbro surrounds the ends of the anorthite crystals, as the base of any porphyry does the porphyritic crystals which lie imbedded in it. Since the strike is now trending somewhat more around to the northeast, and the dip at the same time flattening somewhat, this gabbro probably does not exceed in thickness some 900

IV. *Ashbed-diabase and diabase-amygdaloid.*—The compact portions of this layer, which is a dark-gray or brownish-gray compact rock, macroscopically like the rock of II, is largely exposed along the coast, in the N. E. ¼ of Sec. 5, T. 54, R. 8 W., and Sec. 33, T. 55, R. 8 W. The overlying amygdaloid, which is seen at several points, has an aphanitic, dark-gray matrix, not unlike much of the compact rock below, while the amygdules are wholly of light pink laumontite lying in elongated, smooth-walled, closely crowded vesicles, averaging from ⅛ to ¾ of an inch in greatest length. The amygdaloid is 26 feet thick, and the whole thickness of the layer probably not more than 100

V. *Olivine-gabbro.*—This gabbro is in sight, directly overlying the above described amygdaloid at several places along the shore of Sec. 33, T. 55, R. 8 W. It is a medium-grained to rather fine-grained, dark-gray to black rock, much like that of III. The thin section shows numerous rather fresh olivines; large diallagic augites, often including many plagioclases (labradorite); and titaniferous magnetite. This layer shows a strongly marked columnar structure at right angles to the bedding, and in places the columns are even cross-jointed, so as to show a rude ball-and-socket jointing. In places also weathering brings out distinctly a spheroidal structure. At a projecting point in the N. W. ¼ of the N. E. ¼ of Sec. 5, T. 54, R. 8 W., this layer is crossed by a mass of coarse white anorthite-rock similar to that above described, and in the vicinity the gabbro holds numerous angular masses of the anorthite-rock. Thickness of the layer, about 100

VI. *Red quartziferous porphyry.*—The rock of this layer is to be seen at the point in the northern part of Sec. 33, T. 55, R. 8 W. The thickness of this layer is about 100

Total thickness of the section 2,600

The granite-like rock forming the end of this point may also be part of the last layer, and faulted down into its present position, but from its crystalline character is rather to be regarded as an intersecting mass. This rock resembles closely in the hand specimen a moderately coarse flesh-colored granite, much more closely than the similar rock at Duluth. Large cleavage facets of pale flesh-colored feldspar make up most of the specimen, which shows also quite distinctly large quartz areas. There are also indefinite dark-colored patches of small size. Under the microscope, however, the rock is seen to be essentially the same as that at Duluth, from which it differs chiefly in its relatively small amount of ferric oxide. The section is almost entirely made up of feldspars (orthoclase with a little oligoclase) and quartz, which occur both in quite small and quite large areas relatively to the feldspars. All of these areas are, however, *included within the feldspars,* never filling corners between them as with true granite; and since many areas polarize together within the mass of one or more feldspar crystals, it is evident that the quartz is all *later than the feldspars, i. e.*, either secondary to them, or filling spaces left in them by some solving process.

From the last point noted in the foregoing section (near south line of Sec. 28, T. 55, R. 8 W.), to the red rocks of the south point of Beaver Bay (S. E. ¼, Sec. 12, T. 55, R. 8 W.), a distance of eight and a half miles, the only rock noted was a very dark-gray to black diabase or gabbro, now olivine-bearing, now not, always very highly augitic, and often showing a very coarsely nodular weathered surface, resulting from the resistance to weathering of the very large augites. Usually the exposures are low lake-ward-dipping surfaces; but in the N. W. ¼, Sec. 27 are cliffs of the black rock 150 feet high. A rude columnar structure is often visible. For a while the high dip, 18° to 20°, is continued, but more to the south of east than before, and soon it flattens, and the trend becomes more nearly parallel to the shore-line.

At Beaver Bay a red granite-like rock and a quartziferous porphyry suddenly appear again among the black rocks. The occurrences are very interesting, and much like those described as presenting themselves at the close of the above detailed section (N. E. ¼, Sec. 33, T. 55, R. 8 W.), but more difficult to reduce to order. Fig. 18 is a sketch map of Beaver Bay, showing the exposures of the different rocks.

The common black rock of the vicinity, as seen for instance along the bed of Beaver River, and on the south point of Beaver Bay, is the same as that already described as showing for some miles along the coast above Beaver Bay. It is a moderately coarse, very dark-colored, and often nearly black, very highly crystalline rock, in which the three common ingredients—augite, anorthite, and titaniferous magnetite—can often be seen with the naked eye. The very dark color is due to the great abundance of the augitic ingredient, which, while commonly subordinate to the plagioclase

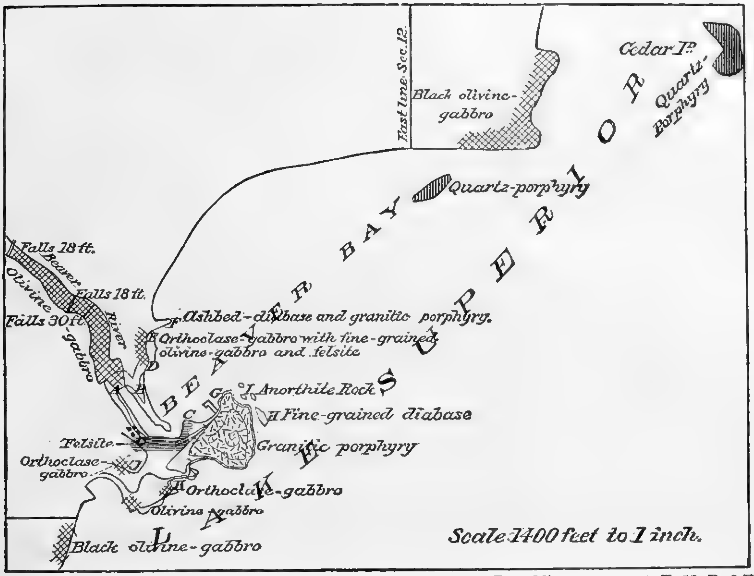


FIG. 18.—Sketch-map of rock exposures in the vicinity of Beaver Bay, Minnesota coast, T. 55, R. 8 E.

in this class of rocks, here greatly predominates. It shows all gradations between augite without foliation, and very highly foliated diallage. It is commonly quite fresh, but is also found more or less completely altered to a greenish material. It is not only the most abundant ingredient, but is also much the coarsest. Olivine is absent from some sections, and is never abundant, but when present is seen in very large areas, in which an alteration to a reddish-brown ocherous substance has always progressed very far. The brownish alteration-product often gives a resinous look to the hand specimen.

On Beaver River this black rock in one or two places shows indications of a southeasterly dip of some 18° to 20°, but on the north point of Beaver Bay, where it is to be seen in bold ledges, with a finely developed columnar structure, the dip is flatter.

At several points along Beaver River this black gabbro carries large masses of an anorthite-rock similar to that described as occurring further up the coast. The bowlder-like character of the anorthite-rock, though often pronounced, is not always so plain, and in some places it looks more like a dependency of the prevailing black gabbro. Thin sections of this rock occasionally show rare particles of augite or diallage between the feldspar grains.

The acid rocks of this vicinity are found forming the south point of Beaver Bay, along the shore of the bay at the points D E F, where they are confusedly intermingled with the basic rocks, on the small island on the north side of the bay, and on Cedar Island, which lies some 500 yards east of the north point of the bay. Both of these islands are composed of quartzose porphyry.

The bold point on the south side of Beaver Bay is a mass of pink granite-like rock, bounded on all sides by precipices about 100 feet high, and rising in the center to an elevation of 130 feet above the lake. The rock of which this point is composed has a pale flesh color, and presents to the naked eye the appearance of a highly feldspathic granite of medium to fine grain. Shining feldspar facets appear to make up most of the rock. The thin sections seem also to be almost entirely made up of feldspars, but always much altered and changed, with much secondary quartz. In some sections where this replacement has been carried far, it is impossible to tell whether we may not have also some replaced matrix. Black and opaque particles of magnetite, ferrite, and augite are the accessories. Some of the clusters of black particles appear as if due to the alteration of augite crystals. At the point C this red rock is seen surrounded on three sides by a mass of rather fine-grained diabase, in which the anorthite crystals are often inclosed in numbers by single augites.

In the same vicinity, a narrow dike of very dense greenish-black diabase zigzags about in the red rock. The islets I are composed of a coarse anorthite-rock, whilst the larger islet H is again of very fine-grained, dark-gray diabase.

Extending along the north side of the neck of the point, at the mouth of Beaver River, C C, for a distance of over 200 paces, as indicated on the accompanying sketch, is a black-tinted, banded felsite. The thin sections of this rock show an excessively fine granular mixture of quartz and orthoclase particles, which in some sections appears to include a good deal of isotropic matter. Opaque black and brown particles are abundant, and here and there an augite crystal is seen. The banding is produced by short seams of lighter-colored material, which under the microscope show more coarsely crystalline matter. The contact of this felsite with the crystalline rocks of the point was not observed.

The small island on the north side of Beaver Bay, and again the larger island to the northeast (Cedar Island), are made up of a quartz-porphyry with an exceedingly dense and conchoidally fracturing, purple-tinted matrix, in which are rather thickly scattered pink feldspars, averaging an eighth of an inch in length, and black quartzes one-fiftieth to one-thirtieth of an inch across. The feldspar crystals are often very distinctly arranged in curving lines indicating flowage, which is also shown by the similar lines of lighter shading in the matrix. Under the microscope the thin section of this rock shows much of a substance that does not affect the polarized light at all. Through the unindividualized base are excessively minute particles and arborescent clusters of quartz. The blackish and pinkish particles generally seen in these porphyries are here much sparser and smaller than usual, and the rock as a whole is one of the nearest to a glassy condition of any of the felsitic porphyries examined. The silica content is 76.83 per cent. On the outer island the quartz-porphyry has a very marked columnar structure, and presents at the same time a strong appearance of the usual flat lakeward dip.

At the point A of the map, the common coarse gabbro is involved with a fine-grained black rock, as indicated in the accompanying figure. The face represented is the east wall of the gorge of Beaver River, near the bridge, and cuts obliquely across the strike. The fine-grained rock shows in the thin section a mixture of rounded augite grains and tabular oligoclases, with some magnetite. It is close to the so-called ashbed-diabases. At B of the map the rock exposed is a reddish-weathering, medium-grained orthoclase-gabbro, with all the characteristics of the orthoclase-gabbros, as described in Chapter III, strongly developed, viz: presence of much ortho-

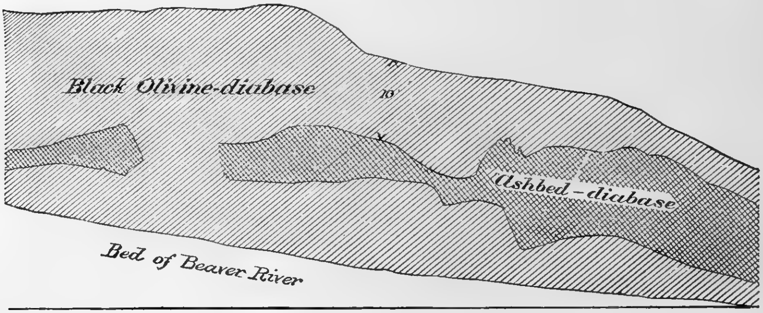


FIG. 19.—Section on Beaver River, Minnesota.

clase; the plagioclase oligoclase; much secondary quartz; much coarse titaniferous magnetite; diallage and augite with a viriditic and ocherous alteration, and large apatite crystals. The rock is strongly contrasted with the neighboring olivine-gabbros. Similar rocks show at K and J and again at D. At the latter point a fine-grained black diabase with augite filling the interspaces of the labradorites, and not in rounded grains, and containing small olivines, is involved with the orthoclase-gabbro, coarse anorthite-rock and pink felsite in the most confusing manner. The same confused appearance is met with at E, where fine-grained olivine-diabase has with it red granitic porphyry in a thin seam, and coarse anorthite-rock in irregular masses. At F an excessively fine-grained ashbed-like diabase is intermingled with granitic porphyry.

As indicated above, it is very difficult to reduce these involved exposures to an intelligible order. The prevailing black rock of the vicinity is plainly enough one of the usual lakeward-dipping flows. The quartz-porphyry of Cedar Island seems as plainly part of a similar flow. Possibly all of the acid rocks belong to one great belt overlying and in part involved with the coarse gabbros, since they appear to lie in a zone parallel to the general trend, and since they form unmistakable flows elsewhere along this coast. The fine-grained diabases at the contact of the two zones are then to be taken as subsequent intrusions, as those cutting the red rocks of the south point of the bay undoubtedly are. But this explanation is not entirely satisfactory. Probably a better one is reached by regarding the red crystalline rock at the south point of the bay as the intersecting mass from which came the flows of quartziferous porphyry.

In the country north of Beaver Bay, as far as the north line of T. 56, R. 8 W., Messrs. McKinlay and Campbell found numerous exposures of coarse-grained gabbro, frequently forming bold ridges trending N. 50 to N. 60 E., and presenting to the northwest precipitous rocky faces sometimes upwards of one hundred feet in height, and to the southeast gradual slopes. Commonly these exposures show coarse-grained dark-gray to black olivine-gabbros, such as characterize the Beaver Bay Group generally, but among the specimens brought back are some of orthoclase-gabbro in all respects like those figured on Plate V at Figs. 1 and 2. One orthoclase-gabbro is somewhat peculiar, and is interesting as exhibiting in an extreme way some of the characteristics of this class of rocks. It is found on the north line of Sec. 2, T. 56, R. 8 W., 760 paces west of the northeast corner. Externally it is quite coarse, mottled white and green, titaniferous magnetite making up fully one-third of the rock. Under the microscope the twinned augites are occasionally fresh, but are commonly wholly altered to greenish uralite.

Among these ledges of coarse-grained rocks are much rarer beds of fine-grained kinds, while Mr. McKinlay found, in the northeast part of T. 55, R. 8 W., quite a zone of fine-grained brownish diabases, occasionally showing some tendency to an amygdaloidal character, and including beds of the typical melaphyr or fine-grained, lustre-mottled olivine-diabase. These beds are to be seen well exposed along the north branch of Beaver River in Sec. 35, T. 55, R. 8 W., and in Sec. 2, T. 56, R. 8 W.

On the coast below Beaver Bay, for two miles and a half, coarse black gabbro, like that at and above Beaver Bay, is constantly in sight. It also forms the rocky island near the east line of Sec 6, T. 55, R. 7 W., where, as also frequently along the shore, it exhibits the usual rather flat lakeward dip, and strong cross-columnar structure. All along here the rock tends to be very rich in diallage and consequently dark in color. The diallage is always very much coarser than any other ingredient of the rock, inclosing a number of the feldspars, which, according to measurement, are always at the anorthite end of the series. Some of the diallages are two to three inches across, and show a brilliant brassy luster on the cleavage. This was noticed in a number of places, but at one point on the N. E. ¼ of Sec. 6 it was especially noticeable. Here one can walk across a pavement hundreds of square feet in area, made of the ends of the basaltic columns. The surface is weathered to a general brown hue, but in every direction flashes back the sunlight to the eye from the brilliant brassy diallages.

At several points in this vicinity the black rock was observed to include masses of coarse anorthite-rock. The latter did not appear to occur here in bowlder-like masses, but rather in large, irregularly outlined areas. At one point on the shore of Sec. 6, directly west of the island above referred to, the nearly white anorthite-rock rises like a dome in the black gabbro which is seen above and on both sides of it. The southern point of the island is formed of anorthite-rock; and due north from this point, on the mainland, is another area of white rock, apparently trending north and south.

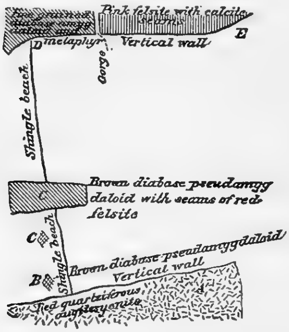


FIG. 20.—Sketch-map of exposures, Minnesota coast, Sec. 32, T. 56, R. 7 W.

On the shore of Sec. 32, T. 56, R. 7 W., the columnar black rock bows down suddenly in the direction of the general trend and disappears under a mass of a pink granite-like rock which forms a bold point much like that of the south side of Beaver Bay. This point projects into the lake in a nearly due east direction. On its north side is a bay, which is bounded on the north by another wall of red rock, while behind and on the beach are exposures as indicated in the following figure. The point A forms a vertical wall on the south side of the bay; the red rock of which it is composed looks much like that of the south point of Beaver Bay, but differs in having a large amount of quite coarse quartz. The thin section shows a rock composed chiefly of clouded orthoclase and oligoclase, and large quartz areas. A few clusters of rounded particles of augite are seen. The augite is older than the feldspars and the feldspars older than the quartz. The latter ingredient does not saturate the feldspars after the usual manner of secondary quartz, but molds itself around them or invades them in large areas, or even includes broken pieces of feldspars.

At B, of Fig. 20, the rock is a fine-grained, brownish-black, conchoidally fracturing diabase of the ordinary type, with chlorite and quartz pseudamygdules, rising in a low ledge above the shingle of the beach. Exposures C C, also low, are of the same kind of rock, mingled with which are seams and patches of brick-red felsite, the black and red presenting the appearance of having been in a semi-fused condition together. The red felsite in the thin section shows a red matrix, saturated with exceedingly thin fibers of secondary quartz arranged in sheaf-like bundles. Quite large quartz areas are also contained, which are not single individuals as in the quartzes of a quartz-porphyry. It is possibly only a phase of the pink rock of the south wall of the bay.

Beyond the point C there are 80 paces of a beach without ledge, beyond which again rises the north wall of the bay, D E. This wall is composed as indicated in the following figure. The west part of the wall is made up

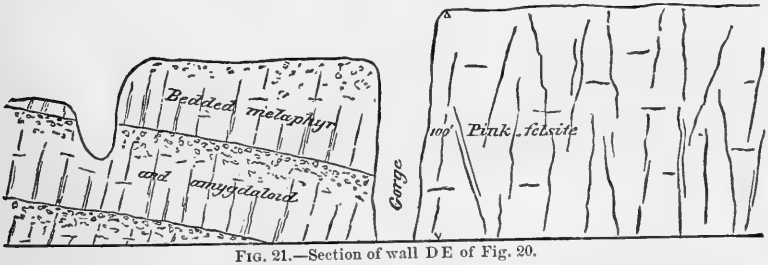


FIG. 21.—Section of wall D E of Fig. 20.

of plainly bedded fine-grained diabase, laumontitic amygdaloid, and luster-mottled melaphyr. These are terminated by a narrow ravine 15 feet wide and 100 feet deep, the east face of which is made up of the pink felsite which forms the rest of the point. This face is beautifully slicken-sided, being polished in some places to a glassy surface, and marked from top to bottom by grooves and striæ inclining 5° to 15° away from the vertical, towards the north. The red rock of this wall and of the rest of the point is a pink to purple felsite, often showing many lines of a lighter color than the rest, and seamed with strings and veins of calcite. The bedded diabases and amygdaloids of the bay seem to have been let down by faulting into their present position between the two walls of red rock.

Beyond this bay to the northeast the felsite of its northern point forms the lake coast for about a mile, in which direction it presents a very distinct and rather low southeastward dip (15°) with a trend more around to the north than that of the lake coast, so that new layers succeed each other somewhat quickly, and the total thickness of the felsite mass must be very considerable. The general southeastward dip has at times superinduced upon it a bowing, by which for short distances the rock will appear to plunge underneath the water at a high angle. Calcitic veins, and at times a general calcitic decay, affect the rock in many places, but much of it is without the calcite. Where the flat lakeward dip is plainest there is often a well-marked columnar structure at right angles to the bedding.

At one point on the shore of the S. W. ¼, Sec. 28, T. 56, R. 7 W., this felsite presents somewhat interesting appearances. The ledges here are very large, forming a cliff 20 feet high for a distance of many hundred feet, with broad surfaces shelving into the water at an angle of about 15°, and affected by a strong columnar cross-jointing. The rock of the upper layers is aphanitic, but of a rough texture and a flesh color. Thickly dotting it are very fine, dark-colored, hair-like lines, forming curves and curls of various forms, the whole appearance suggesting strongly that of a thin section of some modern rhyolite or of some glassy rock with hair-like bodies.[1] Under the microscope this rock is seen to have a matrix which is completely saturated with quartz, in the ramifying and network forms which indicate a secondary origin. The original matrix appears to have had some minute feldspars, but much of it seems to have been without crystalline structure. The hair-like bodies resolve themselves into linear clusters of red and black particles of ferrite, which I take to be the alteration-product of some original constituent, either crystalline or unindividualized. They are certainly

[1] Compare Zirkel, Microscopical Petrography, Plate VII, Fig. 1, and Plate IX, Fig. 1.

not products of infiltration like the so-called dendrites, since they run through and through the mass of the rock. They appear to me to furnish one more point of resemblance between the ancient felsites and quartz-porphyries and the modern rhyolites, and are another proof of the eruptive origin of these rocks.

Yet another proof of an eruptive origin is furnished by the rock of the

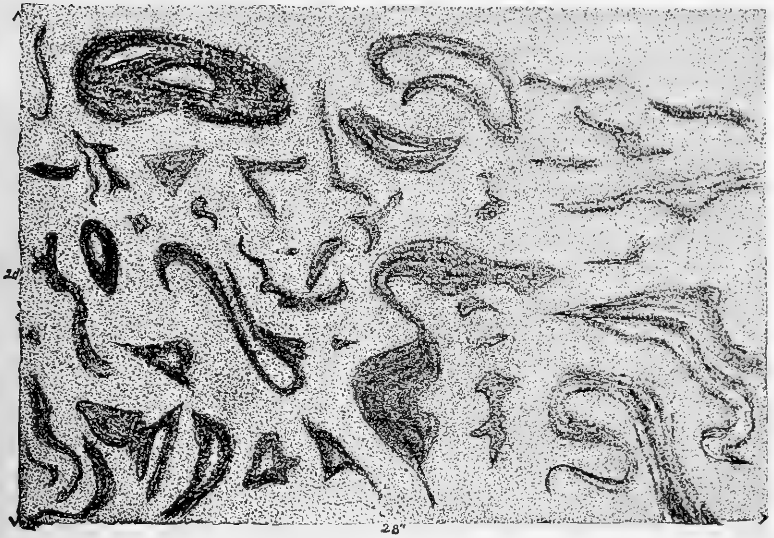


FIG. 22.—Flowage structure in felsite, Minnesota coast.

lower layers of this cliff. There are here large surfaces hundreds of feet square in which a fluidal structure may be seen on a large scale. Light-colored, pale-pinkish felsite and dark-brownish felsite are twisted together in various curling and snake-like forms; the mass as a whole dipping, as usual, 15° to the southeast. The contrast between the colors is very strong. The lighter material is the most abundant, and includes the darker. Fig. 22 represents an area of 20 by 28 inches. Some of the dark-colored bands are a foot or two in length and an inch to three inches in width, from which size they run down to mere threads. The brown bands themselves are often streaked with lines of the lighter kinds. Under the microscope both light and dark kinds are seen to be felsites with a quartz-saturated base precisely like that of the rock of the upper layers above described, and to differ from each other only in the amount of red, black, and brown ferrite particles contained. The ferrites are not arranged in lines as in the peculiar rock of the upper part of the cliff.

Beyond this point the felsite continues to be the coast rock through section 28, but in the northeastern part of this section, and the southeastern of section 21, it becomes involved with a black diabase, the diabase first appearing to intersect it, and then to become peculiarly intermingled with it in irregular areas. Finally the black prevails, with here and there a vein of the red, forming one of the usual rudely columnar flows of moderately coarse black diabase. These confused rocks, which were not examined thoroughly enough to warrant further description or conclusions, terminate at a shingle beach in the bay above the Great Palisades.

The rock exposures about the Palisades are of the greatest interest, because of their bearing on the question of the relation of the acid and basic flows of the series. Since we have here a great flow of quartz-porphyry unmistakably overlying a succession of plainly-bedded fine-grained diabases and amygdaloids, it follows that all idea of the greater antiquity of the acid as compared with the basic rocks of the Lake Superior region must be abandoned. This is a conclusion clearly indicated in all parts of the Keweenaw Series, but the exposures are here so fine and so unequivocal that I have described them already in some detail in connection with the general part of this report. The description need not be repeated here, but a few details may be added. All along this part of the coast the layers are trending more and more away from the coast line towards the north, as a result of which the harder rocks form points projecting towards the southwest. Two of these points, both formed of quartz-porphyry, are shown on the accompanying sketch-map. They are the Great Palisades and the bold point just below the mouth of Baptism River. Each has a shorter side trending east and west, and a longer side trending well around to the north, longer in the latter case than the former because of the increased amount of northing in the courses of the strata.

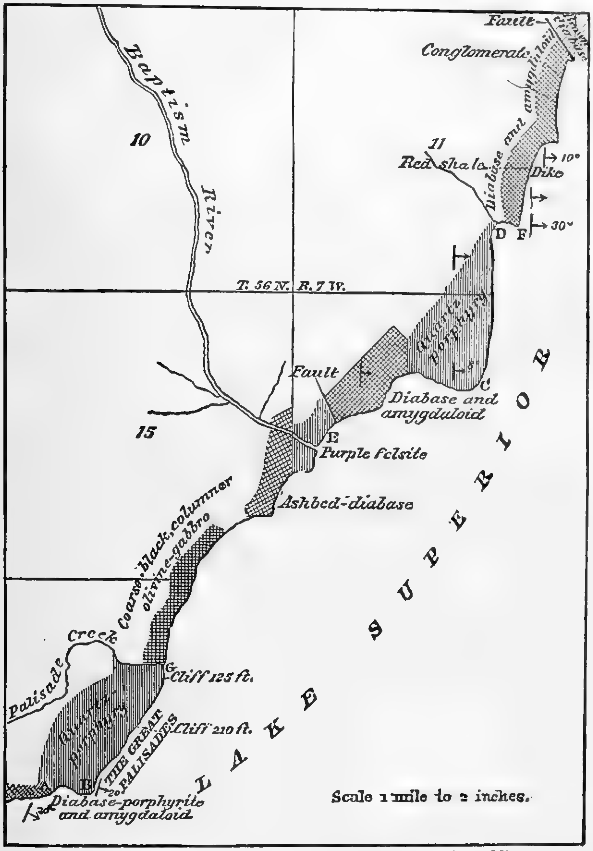


FIG. 23.—Sketch-map of exposures in the vicinity of Baptism River, Minnesota coast.

The south side of the Palisade Point shows the following section. A of this section is an amygdaloid, with dark-brown aphanitic matrix, just rising from the beach and here and there capped by a thin seam of red detrital matter. B is a flow-bed made up of 50 feet of massive, cross-columnar, fine-grained, chocolate-brown, semi-conchoidal diabase, with sparse laumontite and calcite amygdules increasing in number above, and

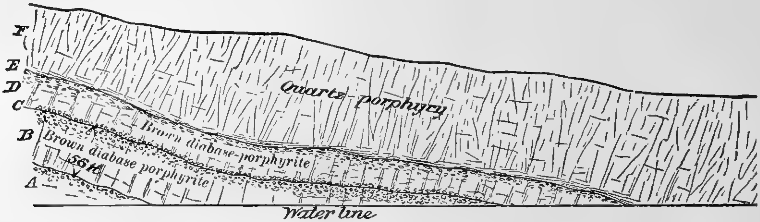


FIG. 24.—Section on south cliff of the Great Palisades, Minnesota coast. A, amygdaloid; B, columnar diabase-porphyrite; C, mingled amygdaloid and detrital matter; D, columnar diabase-porphyrite; E, amygdaloid; F, quartz-porphyry.

6 feet of true amygdaloid, of which the upper 3 feet is highly vesicular. C is a thin seam (6 inches) of mingled amygdaloid and detrital matter. D is another great flow of diabase, made up of 1 foot of basal amygdaloid or vesicular portion, 30 feet of massive cross-columnar diabase, as above, the sparse amygdules gradually increasing in number upwards, and 10 feet of true amygdaloid (E) growing more and more vesicular upwards.

The compact diabase of these beds belongs with the diabase-porphyrites, the augite being a quite subordinate ingredient, while there is often much non-polarizing matter. A specimen from the upper bed yielded 47.9 per cent. of silica. In the upper or amygdaloidal portions of these beds are scattered small hard red patches, a few inches across. At times these patches are round, and appear at the first glance somewhat like the pebbles of a conglomerate, but they are more often irregular and are mingled curiously with the surrounding diabasic material. Some of the apparently rounded particles are plainly seen, even by the naked eye, to fill original vesicles, often of relatively large size, and in these cases are either on the outer wall of the vesicle with calcite within, or have between them and the wall a lining of calcite and laumontite. In the thin section this material is easily seen to be fragmental, being composed of subangular quartz grains, with some reddish interstitial matter.

It is possibly this reddish matter that has caused Norwood and Winchell[1] to speak of the existence here of conglomerate and breccia rocks,

[1] Owen's Geological Survey of Wisconsin, Iowa, and Minnesota. Philadelphia, 1852, pp. 259, 362–364. Seventh Annual Report of the Geological and Natural Hist. Survey of Minn., p. 10.

which I myself failed to find. All I could find was a series of plainly-marked flows, with massive columnar lower portions and upper vesicular portions as strongly developed as anywhere in the typical region of Keweenaw Point. The red detrital material appears to me to always occupy the open spaces of the scoriaceous upper portions of the lava flows. In the thin section it is invariably sharply defined from the matrix, which always presents the usual appearance of the diabase-amygdaloids. The whole occurrence is closely like that of the ashbed rocks of Keweenaw Point, both as to the curious intermingling of scoriaceous amygdaloid and detrital material, and as to the peculiar kind of diabase forming the lower portion of each flow.[1]

Above these beds comes the mass of quartz-porphyry which forms the Great Palisades. The entire thickness of this porphyry is over 300 feet, but in the section under description only some 50 to 75 feet are in sight. The base of this mass of porphyry presents a most peculiar appearance. For a thickness of some 5 feet it is much weathered, and calcified—the contact line of the dissimilar rocks having evidently been the course of altering waters—and shows a strong appearance of contorted lamination, which is often intensified by the calcitic alteration. This peculiar alteration is the same as that which affects, in a less prominent degree, higher portions of the mass, as is very distinctly seen in the thin section. The feldspar crystals are found following the curving lines and again obstructing them. The quartzes are much smaller than the feldspars, and are in the usual doubly terminated crystals, with embayments of the matrix. There are also contained in the quartzes fine glass inclusions, in regular shapes corresponding to those of the containing crystal, and affected by a hair-like devitrification. Figs. 11 and 12 of Plate XIII represent this laminated porphyry, and Figs. 3 and 4 of Plate XII, the rock at the northeast end of the Palisades. All of these figures represent those portions of the rock which show the flowage structure most plainly. The columnar character of this rock is very noticeable, and is of especial interest, since a

[1] It should be repeated here that both Norwood and Winchell regard the amygdaloids, the diabases that go with them, and all of the felsitic porphyries as altered sediment. Compare Eighth Annual Report of the Geological and Natural History Survey of Minnesota, p. 26.

columnar structure is far less common in rhyolitic rocks than in basaltic.[1] The columns are peculiar. The intersecting joints do not lie at the same angle with the vertical, but incline slightly toward each other, so that they intersect in depth. This is especially well seen on the south side of the Palisades, and is roughly indicated on the accompanying figure.

Of all of the quartz-porphyries of the Lake Superior basin the Palisade rock presents the strongest appearance of sedimentary origin, on account of the lamination it shows, especially in its lower portions. This lamination presents great irregularities, but in places, while changing many degrees in inclination within a few feet, it preserves for quite long distances the same general direction. Nevertheless, as shown in a previous chapter, this rock, like all the other porphyries of the Lake Superior basin, is of eruptive origin, and the lamination is that which often characterizes felsitic porphyries and rhyolites the world over.

A mile and a half above its mouth, in the S. E. ¼, Sec. 10, T. 56, R. 7 W., Baptism River makes falls over a quartziferous-porphyry much like that of the Palisades. From its position it appears not impossible that this rock belongs to the same belt with that of the Palisades.

Below the Palisades for about a mile the coast is formed of a coarse, black, very highly olivinitic gabbro, with strongly marked vertically columnar structure. The diallages are large, producing a nodular weathering, and often show a shining metallic cleavage surface. The vertically columnar structure of this rock renders it evident that we have here to do with a flow and not a dike, from which it follows that there must be a fault between this rock and that of the Palisades, it being so different from the beds which belong beneath the Palisade porphyry. Beyond this rock again, and separated from it by a short beach, comes in a fine-grained, dark-brown ashbed-diabase with highly vesicular amygdaloids, the vesicles elongated in a common direction. After a short beach of only 20 paces, this is replaced on the shore by a purple felsite, behind which it passes, forming the bed-rock of Baptism River a short distance above its mouth. At the mouth of this river the purple felsite is the cliff rock, and at E is faulted against

[1] See illustrations to Clarence King's 40th Parallel Report, vol. i, plate xxi, and vol. ii, plate xxiii.

fine-grained diabase and amygdaloid, which in turn pass, with a steep dip, underneath the quartz-porphyry of the bold point C.

The rock of the latter point is precisely the same as that of the Palisades. It shows the same violet-tinted base, the same quartzes with glass inclusions, the same very abundant orthoclases, the same strongly columnar structure, and the same lamination. Here, however, the lamination shows much less tendency to confine itself to one direction, and therefore is less likely to be mistaken for sedimentary lamination. The point as a whole shows a very distinct dip to the eastward, and yet on the long face C D, parallel to the trend, where the laminæ should look horizontal, were the rock a sedimentary one, they wander up and down in a wholly aimless manner. At the point D, where this rock ends on a small beach, its laminæ dip 60° S. 65° W., while just beyond across the beach they dip 80° north of east. Here the porphyry is highly charged with calcite, which has impregnated it in cross seams, and along the lamination, and in places there is a general calcitic decay, large white pseud-amygdules of calcite dotting the rock. At D F of the map of Fig. 23, this porphyry passes beneath plainly bedded diabases and amygdaloids. This horizon I have selected as the base of the Temperance River Group.

The close similarity of the Palisade porphyry to that of the point just below Baptism River, and of the diabases immediately underlying these porphyries to one another, suggest that the two points are but portions of one layer faulted apart.

Beyond the point last described, in descending the coast, the Beaver Bay Group strikes back into the country, having between it and the shore a constantly widening strip of the beds of the Temperance River Group. The exposures, by which has been made out the continuance, in this region, of the Beaver Bay Group, until it emerges again on the shore at Grand Marais, do not merit any particular description. They are the usual steep-backed ridges, with flat lakeward slope, composed of the common black gabbro.

The exposures below Grand Marais which I have referred to the Beaver Bay Group may also be more rapidly passed over. The dips here are not more than 8° to 10° lakeward, and the trend much more to the east than that of the shore, being at times even due east. Since the coast line itself is trending here only some 20° to 25° north of east, it follows that each bed makes a very long exposure on the coast. Felsite and quartziferous porphyry have a great development between Grand Marais and the Brulé River, the ledges on the coast being usually comparatively low and often partly concealed by shingle beaches. On the Devil's Track River, however, the exposures are on a grand scale.

Quartziferous and granitic porphyries show again in the vicinity of the large bay in the east part of T. 62, R. 4 E., and again at Red Rock Bay in the Indian reservation (S. E. ¼, T. 63, R. 5 E.). The remainder of the coast between here and Grand Marais is formed chiefly of coarse black gabbro.

In the angle of the coast immediately below Grand Marais, S. W. ¼, Sec. 21, T. 61, R. 1 E., red felsite is cut by dikes of dark-colored rock, and the same thing recurs for two or three miles down the coast, the dikes producing projecting points and the felsite weathering down into shingle beaches. The shore-cliff just beyond Grand Marais is red felsite for a length of several hundred paces in a northeasterly direction. At the southwest end of the cliff is a broad dike composed of a medium-grained olivine-diabase, of which the surface presents a mottling like that of the luster-mottled melaphyrs. The olivine is wholly altered to a brownish substance, but the other ingredients are quite fresh. Near its junction with the red felsite this rock becomes finer in grain, until at the contact it merges into an aphanitic diabase-porphyrite, with much greenish alteration chlorite.

At the northeast end of this cliff is another broad dike of similar character, with two or three narrow ones, from a mere seam to one or two feet in width. The rock of these narrow dikes is a dense diabase-porphyrite with much non-polarizing matter in the base. The felsite cut by these dikes presents a quite distinct, though irregular, dip towards the lake, and has the usual wave-like pseudo-lamination markings. It presents the appearance of a hardened mud rock more here than at most points where the felsites were observed. In the thin section is shown a base with much non-polarizing material, with the usual ferritic devitrification-product, and much arborescent and netted secondary quartz. Calcite seams permeate much of the rock, and, in many places, the weathering has so affected it that a slight blow of the hammer on the face of the cliff will bring down showers of angular fragments. This peculiar result of weathering is very characteristic of the Lake Superior red felsites.

The large exposures of red felsite on the Devil's Track River have already been alluded to. From the mouth of the river nearly to the north line of Sec. 3, T. 61, R. 1 E., the exposures are almost continuous and the cliffs occasionally rise to a height of 150 feet. There is often an appearance of lamination, and across these markings a strong columnar structure is frequently seen. The thin section shows the usual non-polarizing base, with ferrite particles and net-worked secondary quartz.

Below the Devil's Track are long beaches of felsite shingle. In Sec. 9, T. 61, R. 2 E., typical brown ashbed-diabase and diabase-porphyrite form the shore, and at one point show a capping mass, five feet thick, of curiously intermingled sandstone and amygdaloid. From this point to the mouth of the Brulé River red shingle beaches are interrupted occasionally by exposures of brown and red diabase-porphyrite. Many ledges show no macroscopically visible porphyritic ingredients, but are porphyrites because of their content of non-polarizing base; others show numerous large porphyritic oligoclases and augites. In the groundmass in some slices more or less secondary ramifying quartz is seen, when we have a transition to the rock recognized in the pebbles of the South Shore conglomerates as a non-quartziferous porphyry.

Below the Brulé, coarse olivine-gabbro forms the coast for a number of miles, lying in flat, often cross-columnar flows. Just below the mouth of the Brulé this rock is peculiar, on account of its great richness in brassy-lustered diallage and its very large olivines, which are sometimes one-fourth to one-third of an inch across, and always altered to a black, resinous-looking substance with a concentric scaly structure (hyalosiderite). Below the large bay in the northeast part of T. 62, R. 4 E., these coarse rocks are interrupted by beaches with detached ledges of dense, brown diabase-porphyrite. One exposure, near the west line of Sec. 12, T. 62, R. 4 E., shows a red crystalline rock, which macroscopically presents a mass of red feldspar crystals, marked in places by a network of black lines. Under the microscope this rock turns out to be composed entirely of crystalline matter; reddened oligoclases and orthoclases, completely saturated with secondary quartz, making up most of the section. The black markings mentioned resolve themselves into altered augite blades, with whose alteration is connected the production of much magnetite. Numerous large apatite needles are included.

Below the mouth of the river forming the western boundary of the Indian Reservation, coarse olivine-gabbro forms the coast as far as Red Rock Bay, a distance of some five miles, lying in beds with cross-columnar structure, flat lakeward dip, and easterly trend. In many places this rock shows in a marked manner the luster-mottling due to the presence of relatively large diallages, including many feldspars.

At Red Rock Bay, in the Indian Reservation (southeast part of T. 63, R. 5 E.), these black rocks give place again to red felsite and quartziferous porphyry. The display of these acid red rocks here is very large and among the most interesting of this class of rocks in the Lake Superior region. The red rock at the bay is commonly a true quartziferous porphyry, with a base in which much non-polarizing matter is mingled with the usual ferrite particles, and saturated with arborescent secondary quartz. On the high point of red rock in the bay, areas of a slightly differently colored rock are included in the general red mass. Under the microscope the rock of these areas shows a base in which quartz and orthoclase are distinctly individualized in good-sized particles. The bold red bluff from which the bay takes its name shows no trace of banding, but at the point beyond the bay the curving and twisting pseudo-lamination so often seen in these red porphyries is shown on a large scale. For short distances the rock will appear like a much-contorted schist, and then again will pass into the general structureless mass. When seen, the banding is as often vertical as horizontal.

In this vicinity the red rock is cut by a heavy dike, of which part is represented in the accompanying figure. This dike shows for several hundred feet along its length, and with a width of some 75 feet. The junctions with the adjoining rock are sharp, occasionally showing irregularities, as in the figure. In places patches of red rock clinging to the top of the dike suggest that we have here its original top. The rock of the dike is a very dense, dark greenish-gray diabase-porphyrite, with a tendency to become somewhat coarser in the middle. The silica content of this dike-rock is very low, being only 45.88 per cent. The whole dike is intersected by two sets of very strong transverse joints, which dip respectively S. 13½° and E. 69½°. These are cut by others parallel to the walls of the dike and

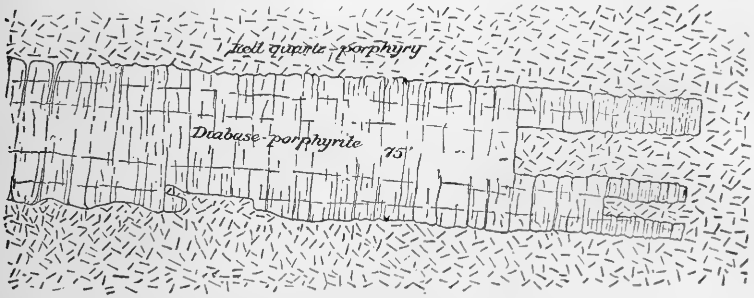


FIG. 25.—Dike in quartz-porphyry, Red Rock Bay.

the whole mass looks much like a pile of books. About one-fourth of a mile farther down the coast another dike, of more completely crystalline diabase, cuts the red rock, which soon after ends, being replaced by the rocks which I have already described in connection with the Duluth and Lester River groups.

Temperance River Group.—The rocks of this group are displayed along the coast from a point a mile and a half below the mouth of Baptism River to Grand Marais, a total distance of some 50 miles. The total thickness appears to be upwards of 2,000 feet. The highest beds of the group form the coast between Petit Marais and Temperance River. As already described, the beds of this group, where they first appear in descending the coast, just below Baptism River, trend sharply to the north, and even due north for a while, after which they swing around more to the east of north, the coast line and strata trending together for a long distance.

The easting in the trend of the layers continuing to increase at about two miles below Temperance River, they finally begin to trend more to the east than the coast line, so that from this point to Grand Marais, where the base of the group comes to view, there is a steady descent in geological horizon. The usual lakeward dip, of course, holds throughout the extent of the Temperance River Group. The angle ranges from 6° to 30°, and on the whole the inclination, especially in the western portion, is rather greater than usual.

In its kinds of rock the Temperance River Group, on the whole, contrasts strongly with the preceding one; indeed, with all of the Minnesota shore groups, except the Agate Bay Group, with which it has some characteristics in common. The rocks forming the greater part of its thickness are dark-brownish, fine-grained diabases of the ordinary type, in thin layers, with strongly developed vesicular or amygdaloidal upper portions, and often with a more or less plainly marked columnar structure in the lower portions. Much less common, but still occurring in a number of layers, are fine-grained, blackish olivine-diabases or melaphyrs, with the typical luster-mottlings. They are also furnished with amygdaloids. Layers of ashbed-diabase and diabase-porphyrite of conchoidal fracture, and furnished with amygdaloids, also occur, especially toward the base of the group. Several seams of reddish sandstone and shale are included, one layer exceeding 200 feet in thickness. Peculiar conglomerates also occur. The whole succession presents much the appearance of some of the layers in the middle and upper portions of the Keweenaw Point series.

The prevailing diabase and melaphyr of this group do not merit any especial description here, since they are only repetitions of what have already been described in full for other parts of the extent of the formation. They make many very interesting exposures, among which may be mentioned as especially fine those of the shore of sections 36 of T. 57, R. 7 W., and sections 30 and 31 of T. 57, R. 6 W.; that of the mouth of the Manitou River; and that of the point on the east side of Pork Bay, where may be seen a black luster-mottled olivine-diabase or melaphyr, which, under the microscope, shows all the characters of this rock as found in the typical region of Keweenaw Point. Another fine exposure is that of the bay in the S. W. $\frac{1}{4}$, Sec. 21, T. 58, R. 5 W., where quite a succession of diabases and amygdaloids is in sight, including one or more beds of luster-mottled melaphyr. Those of the

"Two Islands," which are columnar rocks with the outline of Fig. 26, and of the mouth of Temperance River, are also very instructive.

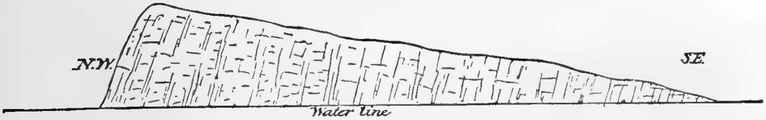


FIG. 26.—Profile of island at mouth of Two Islands River.

The last-named place is possibly the most interesting of all. A short distance from its mouth the river makes several falls, the first one into, the rest along the course of a narrow gorge, which sometimes reaches 50 feet in depth, but is so narrow that in places one can step from one to the other of the overhanging walls. The gorge is a succession of well-smoothed potholes broken into each other. There are displayed here a number of very thin layers, the massive columnar portions often not exceeding two to four feet, and the very strongly developed amygdaloids running even below these figures. A number of these beds have very plainly marked basal amygdaloids, with relatively sparse spike amygdules. At two or three horizons, streaks of red sandy shale were noticed between one of these amygdaloids below and a massive layer above. The detrital matter is often in mere films, and at times is entirely absent. In places it is found to have aggregated in irregularities of the underlying amygdaloid, when for a short

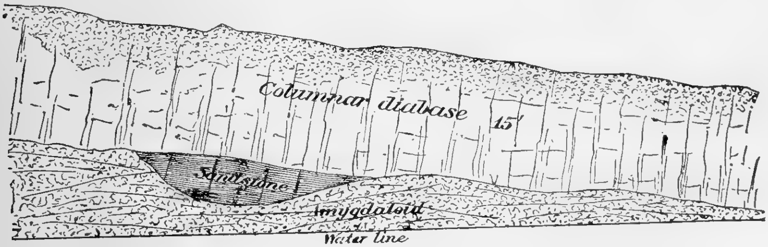


FIG. 27.—Section on Temperance River.

distance it may have something of a thickness. This is finely displayed on the northeast side of the basin at the mouth of the river, as shown in the following section, which represents a wall some 80 feet long and 20 high. The whole appearance at this place reminds one strongly of the alternations at the upper falls of the Montreal, on the South Shore,[1] save that the beds are thinner on Temperance River than on the Montreal.

The peculiar irregularities to which these eruptive rocks are subject were well seen in a cliff side below Temperance River, where Fig. 28 was drawn.

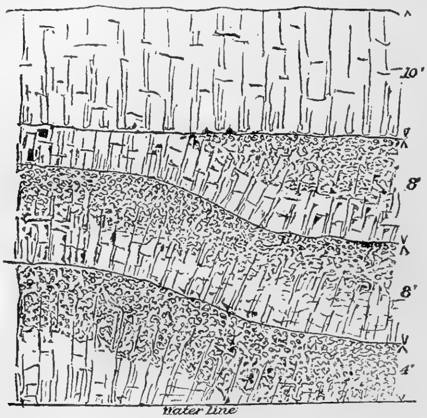


FIG. 28.—Section on Minnesota Coast, near Temperance River. The columnar portions are the lower massive portions of the flows; the dotted parts the amygdaloids or vesicular upper portions of the flows.

The ashbed-diabases of this group are only met with at low horizons, being found on the coast not far below Baptism River, and again at Grand Marais. Immediately overlying the quartzose-porphyry of the Beaver Bay Group, C of Fig. 23, is found the succession indicated in the following diagram (Fig. 29), in which the lowest layer is a brown, aphanitic diabase-porphyrite, with conchoidal fracture, and containing 52.56 per cent. of silica. The next is a black, medium-grained olivine-diabase or melaphyr, containing 50.76 per cent. of silica, with the olivine wholly altered to a green and brown substance, and furnished above with an amygdaloid, and the uppermost

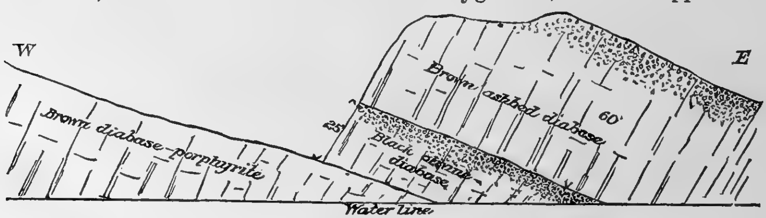


FIG. 29.—Section on Minnesota Coast, near Baptism River.

layer is a heavy one of brown diabase-porphyrite, resembling that at the base of the section, but not quite so dense in grain, and carrying 57.87 per

[1] Geol. of Wis., Vol. III, p. 191.

cent. of silica. Just where the sketch was taken the dip lakeward was unusually high. Further down the coast it soon flattens again.

The rock constituting the point at Grand Marais is again all ashbed-diabase, though for the most part coarser-grained than that described above. It has a brown color, is exceedingly dense and hard, and shows a well-marked cross-columnar structure in places. In the thin section it is seen to contain much augite, both in the round particles characteristic of the ashbed-diabases, and indicative of relatively rapid solidification, and in particles whose contours are determined by the pre-existing plagioclases. It is thus a well-marked intermediate stage between the diabases of the ordinary type and of the ashbed type. Besides the tabular plagioclases of the matrix there are also present larger porphyritic plagioclases.

The strong resistant power of this rock is shown in the existence of such an exposed ledge as that which forms the protecting reef of Grand Marais Harbor. The rock is in part more dense than that represented by the above description, and, to judge from the numerous angular fragments on the shingle ridge forming the east side of Grand Marais, must graduate downwards into an aphanitic diabase-porphyrite.

The detrital rocks of the Temperance River Group were noticed at several points along the coast. The westernmost of these is in the N. E. ¼, Sec. 11, T. 56, R. 7 W., where a thin seam of red shale, with very irregular thickness, holds balls and fragments of amygdaloid, and occasionally has amygdaloidal material strangely mixed up with the red sand of the matrix. This seam overlies a porphyritic amygdaloid, which graduates downward into a true ashbed-diabase, and is overlain by an excessively vesicular thin amygdaloid. The whole occurrence, then, is an exact repetition of the ashbed of Keweenaw Point, the same peculiar dense diabase being furnished with the same peculiar scoriaceous amygdaloid. What appears to be the conglomerate just mentioned, but thickened, is seen in a vertical wall 36 feet high at the bottom of a bay in the extreme northeast corner of section 11. The overlying and underlying rocks are not seen here, but at its eastern extremity this conglomerate comes into abrupt vertical contact (the contact being seen on a wall 30 feet high) with a dark brownish-gray, fine-grained rock. This rock the thin section shows to be a typical luster-mottled olivine-diabase or melaphyr, the olivine in which is wholly altered to a reddish and greenish material. This rock is alluded to further on.

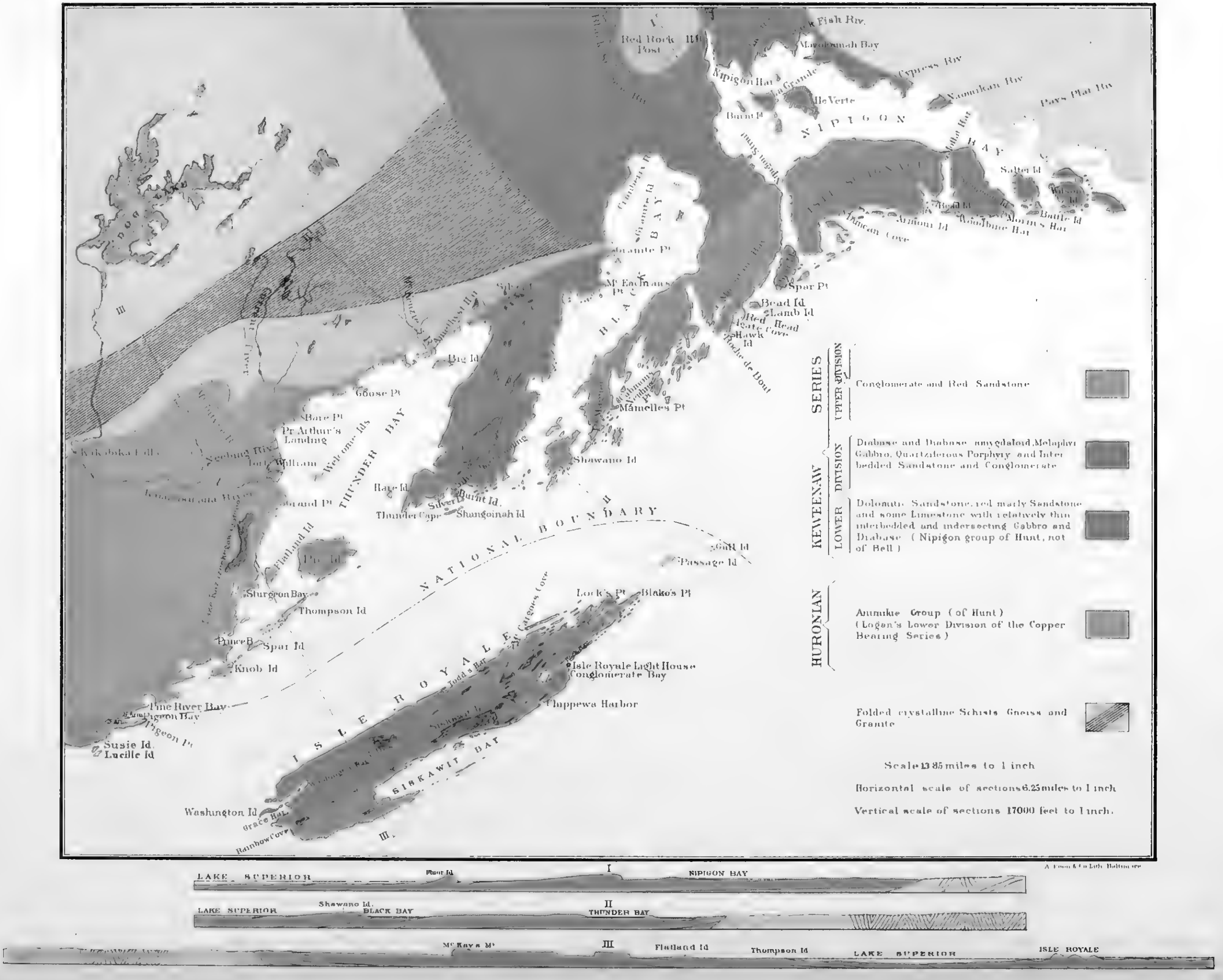
Just above Manitou River, Sec. 10, T. 57, R. 6 W., 15 to 20 feet of red shaly sandstone may be seen overlain by an amygdaloid, and this in turn by a columnar diabase. Numerous fragments of amygdaloid and decomposed diabase are contained in the sandstone. The fragments are all angular and under an inch in diameter. The occurrence of seams of red shale at the mouth of Temperance River has already been mentioned, and the peculiar irregularities to which these seams are subject shown in Fig. 27. A mile and a half below the mouth of Poplar River, in the northwest corner of Sec. 35, T. 60, R. 3 W., six feet of a conglomerate are seen overlain by black melaphyr or fine-grained olivine diabase. The pebbles are larger below, reaching four inches in diameter, and are principally of red felsite. Many are, however, of various types of amygdaloid and diabase-porphyrite. Several thin sections were made of these pebbles, and in all the amount of non-polarizing unindividualized matrix seemed unusually large, suggesting the possible origin of these balls as volcanic scoriæ.

At the mouth of the creek in the S. W. ¼, Sec. 19, T. 60, R. 2 W., the following section was noticed; the order is an ascending one:

1. Highly vesicular amygdaloid	2 feet.
2. Fine-grained diabase, including (*a*) basal amygdaloid, 1 foot; (*b*) less amygdaloidal, 1 foot; (*c*) massive portion, 8–12 feet; (*d*) very irregular summit amygdaloid, 6 inches to 2 feet; in all about	15 feet.
3. Red shaly sandstone, bunchy, irregular, mingled with the amygdaloid, 1 inch to	2 feet.
4. Amygdaloid	4 inches.
5. Sandstone	6 inches.
6. Amygdaloid	2 feet.
7. Sandstone	3 inches.
8. Massive melaphyr	10 feet.

The seams 3 to 7, inclusive, are very irregular, and in all the sandstone probably belongs to one horizon.

In the bay immediately behind Caribou Point, S. W. ¼, Sec. 11, T. 60, R. 2 W., red shaly sandstone underlies an excessively fine-grained but wholly typical melaphyr or olivine-diabase. Some twelve feet of the melaphyr and twenty of the sandstone are in sight. The large bay here is



GEOLOGICAL MAP OF ISLE ROYALE AND NEIGHBORING MAINLAND probably worn out in this sandstone, of which it is supposed that only the uppermost parts are in sight. Good Harbor Bay, four miles below, has certainly had this origin, the sandstone concerned being, however, a lower layer. At the latter place both underlying and overlying rocks are in sight, the former in a low ledge on the northeast shore of the bay, the latter in a vertical exposure of 20 feet. The sandstone is 225 feet thick, of which 120 feet may be measured in detail. The whole thickness dips 9° east of south.

The Temperance River Group is almost free from dikes, another feature which it has in common with the bedded diabases of the upper part of the Keweenaw Point series. One of aphanitic black rock, six feet wide, and with cross-columnar structure, was noticed cutting amygdaloid near the base of the group on the shore at the east side of Sec. 11, T. 56, R. 7 W. In the same vicinity, Sec. 11, T. 56, R. 7 W., at two points, masses of red augite-syenite were seen in vertical contact with the diabases of the Temperance River Group. It is possible that these are faulted up from the underlying Beaver Bay Group, though they look like cutting masses. The high bluff known as Carlton's Peak, Sec. 20, T. 59, R. 4 W., near Temperance River, shows at its summit numerous large angular fragments of anorthite-rock, such as has already been described in connection with the Beaver Bay Group. None was seen that could be certainly regarded as in place; nevertheless, the mountain is, without much doubt, composed of this rock, and I should regard the rock as having antedated the Temperance Group flows rather than as a cutting mass.

SECTION II.—ISLE ROYALE TO NIPIGON BAY.

All along the eastern part of the Minnesota coast, as described in the preceding section, the Keweenawan beds strike away towards the lake from the coast line, so that finally, at Grand Portage Bay, the older slates come out to the shore. The Keweenawan beds reappear, however, in Isle Royale, having exchanged their easterly course for a more northeasterly one[1] while concealed by the lake. This change already begins to be per-

[1] See the red lines of Plate XXVIII.

ceptible on the Minnesota coast before reaching Grand Portage, and shows also in the Lucille Islands, off Pigeon Point, the outer one of these islands being formed of a typical Keweenawan diabase.

The following brief account, with the accompanying map of Plate XXVII, will serve to present the main features of the geology of this region. So far as Isle Royale is concerned, I have had to depend upon the report of Messrs. Foster and Whitney, read in the light of a familiarity with most of the remainder of the extent of the formation, not having visited the island myself.[1] The detailed topographical map of the island, by the United States Lake Survey, aids not a little in the understanding of the structure. The region from Thunder Bay to Nipigon Bay I have examined myself, and am thus able to draw information more satisfactorily from the descriptions of Logan, Macfarlane, and Bell, as well as to judge of the correctness of the views advanced by these writers.

ISLE ROYALE.

Isle Royale is a very long, narrow island, trending in a general northeasterly direction. From point to point the island is just 45 miles in length; but from the Rock of Ages, the farthest outlying reef to the southwest, to the Gull Island rocks on the northeast, is 57 miles. The island varies in width from three to eight miles. It does not lie exactly in a straight line, but curves from N. 65° E. in the southwest part to N. 53° E. in the northeast part. On the southern side of the southwestern end is quite an area of low land, underlain by sandstone and conglomerate, dipping some 8° to the southeast. This sandstone evidently belongs to the Upper Division of the series. The remainder of the island is made up of very regularly bedded crystalline rocks, with here and there an interstratified conglomerate, all dipping southward at an angle which has not been satisfactorily determined, but which, probably, does not often exceed 25°.

The whole shape of the island, both as to outline and topography, expresses the geological structure in a most striking manner. It is traversed from end to end by a series of parallel ridges, which present always a steep, often a precipitous side towards the north, and a gradual slope towards the

[1] Since the above was written, N. H. Winchell has published some notes on the geology of Isle Royale, especially on the south side of the island. Tenth Annual Report of the Geological and Natural History Survey of Minnesota, pp. 49–54.

south. These ridges are, of course, made of the heavier, more resistant layers. They seldom reach 500 feet above the lake level. The intermediate linear valleys are worn in the softer amygdaloids and other less resistant rocks. At the ends of the island these valleys are occupied by long, narrow extensions of the lake, and between them the ridges continue, constituting the so-called "fingers" of Isle Royale. Ridges and valleys both change in trend as the island is followed to the northeast, as does the island itself as a whole, and this is evidently due to a similar curving in the trend of the underlying rocks.[1]

It is evident, from the descriptions of Messrs. Foster and Whitney, that we have here merely a repetition of what is seen everywhere else in the course of the Keweenawan rocks. They describe the beds as exceedingly well marked and mostly thin, and as provided with strongly-developed vesicular portions, and lower portions which are often columnar. The more coarsely crystalline kinds of which Foster and Whitney speak—such as that of the ridge along the northwest shore of the island, and that of Blake's Point, at the northeast—evidently belong with the coarse gabbros of this memoir; while the porphyritic kinds which they mention as occurring at several points would appear to belong with my diabase-porphyrites.

They say nothing, however, of the occurrence of red rocks, which might be quartziferous or granitic porphyries, although one would expect such to occur, especially on the north side of the island. One occurrence which they describe is of interest, namely, the sandstone veins running down from an overlying sandstone into the cracks of an amygdaloid at the mouth of Chippewa Harbor, on the south side of the island. The same thing may be seen at many places on the Minnesota coast, as already indicated.

THUNDER BAY TO NIPIGON BAY.

As shown in the following chapter, the slates of the west and northwest sides of Thunder Bay, and again those of Pie Island and Thunder Cape as far around as Silver Islet, belong with the iron-bearing rocks of the South Shore. The east shore of Thunder Bay, however, and the whole of the peninsula between Thunder and Black bays, are occupied by a

[1] See, also, Chapter IX.

series of quartzose sandstones, dolomitic sandstones and red marls, which plainly belong at the base of the Keweenaw Series. According to Logan,[1] the whole thickness of these rocks is between 800 and 900 feet; Bell, however, from later study, making it between 1,300 and 1,400 feet. The following is the succession, as given by Bell:[2]

	Feet.
Alternating red and white dolomitic sandstone, with a red conglomerate layer at the bottom, occurring on Wood's location, Thunder Cape[3]	40
Light-gray dolomitic sandstone, with occasional red layers and spots and patches of the same color. These sandstones occur along the southwest side of Thunder Bay and on Wood's location[4]	200
Red sandstones and shales, interstratified with white or light-gray sandstone beds, frequently exhibiting ripple-marked surfaces, and also with conglomerate layers composed of pebbles and bowlders of coarse red jasper in a matrix of white, red, or greenish sand	500
Compact light-reddish limestones (some of them fit for burning into quicklime), interstratified with shales and sandstones of the same color	80
Indurated red and yellowish-gray marl, usually containing a large proportion of the carbonates of lime and magnesia.[5] This division runs through the center of the peninsula between Thunder Bay and Black Bay, and may, in this region, have a thickness of 350 feet or more	350
Red and white sandstones, with conglomerate layers, the red sandstones being often very argillaceous and variegated with green spots and streaks, and having many of their surfaces ripple-marked. These rocks are found all along the northwest side of Black Bay as far up as the township of McTavish	200

This succession is of interest as presenting us with the only instance of a considerable accumulation of detrital matter at so low a horizon in the entire extent of the Keweenaw Series; and the only instance, also, so far as the immediate basin of Lake Superior is concerned—not taking local infiltrations of calcite into account—of the occurrence of calcareous and dolomitic matter in the sandstones of this series. The reference of these rocks to the Keweenaw Series has, in fact, been questioned by Macfarlane[6] and Hunt;[7] the former regarding them, along with the underlying slates, as the

[1] Geology of Canada, 1863, p. 70.

[2] *Op. cit.*, p. 319.

[3] Macfarlane finds the red sandstone to contain 12½ per cent. of carbonate of lime and 11 per cent. of carbonate of magnesia.

[4] Macfarlane found them to contain 13 per cent. of carbonate of lime and 12 per cent. of carbonate of magnesia.

[5] The amount varying, in the specimens analyzed by Macfarlane, from 21 to 34½ per cent. of the carbonate of lime, and from 7½ to 13½ of the carbonate of magnesia.

[6] Canadian Naturalist; New Series, III, p. 252; IV, p. 38.

[7] Second Geological Survey of Pennsylvania; Azoic Rocks; Part I, p. 241.

equivalents of the horizontal sandstones of the South Shore and therefore as newer than the Keweenawan, while the latter separates them from the underlying slates, but considers both groups as newer than the Keweenawan.

The underlying slates, however, I refer, as indicated in the next chapter, to the Huronian, while I can have little hesitation in following Bell and Logan as to the inferior position of these sandstones to the great thickness of unmistakably Keweenawan rocks which constitute Isle Royale, the peninsula between Black and Nipigon bays, and the line of islands in front of Nipigon Bay. This relation is indicated by the existence of a southeasterly dip of from 3° to 10° throughout the peninsula between Thunder and Black bays—the higher angle being reached on the Black Bay shore—and of the same southeasterly dip along the southeast shore of Black Bay, where reddish sandstone and conglomerate may be seen passing under typically Keweenawan diabases and amygdaloids. This sandstone and conglomerate seem to be the upward continuation of those on the west side of Black Bay. Further evidence is found in the occurrence of heavy calcite seams and veins in the sandstone, and of dikes intersecting it towards the southeast end of the peninsula west of Black Bay, both things unknown in the horizontal sandstone of the South Shore. Yet more conclusive than any of these points is the fact, that along the Black Sturgeon River and thence westward to the northeast corner of Nipigon Bay, red sandstones and marls, which are beyond question the continuation of those of the west side of Black Bay, are found to be overlain by heavy beds of olivine-gabbro.

According to Bell, the belt of level sandy country which runs from the northwest corner of Nipigon Bay westward to the Black Sturgeon River is bounded both north and south by "hills of columnar trap" resting upon the "indurated red marls and associated rocks."[1] This superposition of coarse gabbro to red marl may be beautifully seen on the northwest shore of Nipigon Bay, and on both sides of Nipigon Harbor near the Red Rock Post of the Hudson's Bay Company. The overlying rock is medium-grained to coarse-grained, white- and black-mottled olivine-gabbro. A section of a specimen from the cliff on the northwest shore of Nipigon Bay, just outside of the mouth of Nipigon Harbor, shows under the microscope

[1] *Op. cit.*, p. 338.

very abundant and extraordinarily fresh olivine, anorthite, predominant diallagic augite, and a little titaniferous magnetite; the whole rock being in an unusually fresh condition. Similar occurrences obtain in several of the islands which lie within Nipigon Bay.

On the south side of the sandy level belt above mentioned the sandstones and red marls pass beneath the great series of diabases and amygdaloids which form the southern half of the peninsula lying to the southeast of Black Bay. The latter rocks make up a great belt which, beginning in the islands about Point Magnet, takes at first a course north of northeast; but at Nipigon Straits this has veered around more to the northeast. Beyond the straits the same belt is continued in the line of islands which lie to the south of Nipigon Bay, changing its course to an easterly direction in the Saint Ignace Island, and to south of east toward the eastern end of the Battle Island Group.

Throughout this belt, which is bold in character and often makes elevations of a thousand feet or more above the lake, there is presented a constant lakeward dip of some 8°, the direction at first being southeast and then due south, as the middle of Saint Ignace Island is reached. According to Logan the rocks of which this belt is made up reach a total thickness of some 6,000 to 10,000 feet, consisting of amygdaloidal and non-amygdaloidal beds

> with intrusive masses of a more solid and a more highly crystalline character. These appear in general to consist of greenstone, sometimes passing into well-marked columnar basalt, and they are associated with other masses of a vitreous aspect, exhibiting the forms of pitchstone and pitchstone porphyry.[1]

The amygdaloidal layers are described by Logan as plainly stratified, as thinner than the associated crystalline beds, and as having the general characters of the amygdaloids of the South Shore, the usual vesicular fillings —calcite, quartz, agate, prehnite, epidote, copper, and various zeolites— occurring here also Wrinkles indicative of a viscous flow are described as characterizing some beds. Dikes are said to be numerous, for the most part of some kind of fine-grained, dark-colored greenstone, but also in part of a porphyry which "contains large crystals of feldspar disseminated through

[1] Geology of Canada, p. 71.

a base of greenstone." Still other porphyritic kinds are described as partaking "of the character of a syenite."

In this a dark-gray mixture of hornblende and feldspar, with magnetic oxide of iron and iron pyrites, similar to the greenstone already mentioned, incloses a multitude of irregular patches composed of red feldspar and of quartz, generally hyaline, and rarely of an opaque white resembling chalcedony. The quartz is also occasionally disseminated throughout the matrix without the red feldspar. More rarely red feldspar occurs without the quartz, and still more rarely small quantities of calcareous spar are met with. The whole mass of the dyke, however, sometimes passes into a uniform small-grained mixture of red feldspar and green hornblende with very little quartz, and ceases to have either a porphyritic or syenitic aspect.[1]

Still a third kind of porphyritic dike-rock is described as consisting of a very fine-grained mixture of red feldspar and quartz, holding distinct and not very large crystals of the same minerals; the quartz crystals being colorless transparent hexagonal prisms, terminated by a pyramid at each extremity, and rather uniformly disseminated through the mass. * * *

The greenstone dykes, whether porphyritic or not, possess, without a single observed exception, a well-marked transverse columnar structure, which is in general so truly at right angles to the plane of the dykes that their underlie can be correctly determined by it. This structure belongs equally to them, whether their dimensions are great or small; but the size of the columns increases with the breadth of the dyke, which sometimes attains 200 feet. The number of these dykes is very great: thirteen of them, of good size, have been counted in the width of two miles, and their parallelism for great distances is as remarkable as their number.

The directions of the greenstone dykes, as well as those of the other descriptions which have been mentioned, are in general two, one with the stratification and the other transverse, changing with any important change in the general strike; and they appear to maintain what might be considered a continuation of these courses into the older sedimentary rocks, with a less precise relation to their strike where stratified. The point of intersection of the two sets of dykes has been seldom seen. In one instance, however, on the island of Saint Ignace, a dyke of eighteen inches, coincident with the stratification, cuts another of nearly the same breadth running transversely. Both of these possess a columnar structure, which has not been observed in the dykes of syenitic trap.[2]

The dykes in general appear to be more durable than the rocks cut by them, from which results a peculiarity in the geographical features of the country. The destructive action of the water upon the coast is partially arrested in its progress upon meeting with the dykes, and those which run with the strike are in consequence often found to shield the shore for considerable distances. They sometimes run out into long prongs or promontories, with deep recesses behind them, or present a succession of long narrow islands, which act as breakwaters in defending the neighboring mainand; and it frequently happens that a narrow breach having been effected in a dike, it will be found to be the entrance to a spacious cove worn out on each side in the softer rock behind it.

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[1] Geology of Canada, p. 72.

[2] Geology of Canada, p. 73.

According to the same author this series includes also detrital beds:—

On Edward Island and other islands northward, grits and conglomerates are found interstratified with trap layers. The same interstratification is met with in the rocks bordering the southeast side of Black bay, while those fronting the lake on the southeast side of the peninsula are composed almost entirely of various descriptions of conformably overlying trap. This arrangement of the stratification, occupying a belt of from seven to ten miles in breadth (which on the lake front is carved out into a multitude of deep coves, and includes a great collection of small rocky islands,) runs in a northeasterly direction across Neepigon Strait, from the mainland to Saint Ignace Island. Gradually changing its direction about the middle of this island to due east, it continues on through Simpson's Island, and farther to the eastern extremity of the Battle Islands.

A high precipitous escarpment of red sandstone, with white bands and conglomerate layers all interstratified with occasional beds of variegated red shales, and having a pretty constant dip of 8° or 9° to the southward, keeps its place on the north side of each succeeding island standing in the line, which curves a little to the south of eastward towards the eastern extremity. A section from the gneiss through the large center island of the Battle group would shew in place both the blue shales and the succeeding sandstones, apparently diminished in their proportions. In the cliffs on the north side of the last island of the group the limestones are displayed, associated with white sandstones and a conglomerate layer beneath, resting on a trap of a porphyritic character, and overlaid by more porous volcanic products.[1] * * *

The last-named sandstones would appear to be in all probability the uppermost layers of the thick stratum which underlies most of the peninsula west of Black Bay, the sandy isthmus between Black and Nipigon bays, and much of Nipigon Bay itself.

These quotations from Logan show conclusively enough that he was correct in placing these rocks with those of Isle Royale and Keweenaw Point. My own examination of this region has served chiefly to convince me of the accuracy of Logan's general statements, but also enables me to add that the kinds of rocks here developed are precisely those which characterize the Keweenaw Series elsewhere, and no others; that Logan was probably incorrect in supposing any of them to be hornblendic, and that while his statements as to dikes are generally correct, one might draw from his descriptions a mistaken inference in supposing that all of the prominent points and fringing islands of this part of the Lake Superior coast are due to the resistant power of dikes. Many of these points and islands are plainly fragments of hard and resistant layers, and often have the usual lakeward

[1] Geology of Canada, p. 78.

dip very plainly brought out in a long front slope and precipitous back slope, and at the same time a most beautifully developed columnar structure. Some of these islands must be remnants of very heavy layers, the columnar back cliffs sometimes considerably exceeding a hundred feet in height.

I may add the results of a microscopic study of a few of the specimens collected by me from this region.

A rock from the cliff on the southeast shore of Black Bay is very fine-grained and black, with sparsely scattered and minute true vesicle-fillings of calcite, quartz and chlorite. The thin section shows a groundmass consisting of a dirty brownish-white, impellucid isotrope material (altered glass), with tabular feldspar microliths. In this are included as porphyritic ingredients abundant areas of augite, each made up of a number of detached grains. Small plagioclases (oligoclase) also occur porphyritically. The vesicles filled with the minerals named above are seen to have sharply defined outlines, and to have the material immediately about them more dense than the rest of the rock. Chlorite also occurs in pseud-amygdaloidal areas, when it is an alteration-product of the augite. The rock is somewhat peculiar from its great abundance of augite.

Another rock from the same cliff farther to the southwest is finely crystalline, and black, with a very rough, lumpy fracture. Under the microscope it proves to be a very highly augitic diabase of the ashbed type, and is plainly a non-amygdaloidal phase of the last described rock.

About a mile still farther southwest the east shore of Black Bay shows fifteen feet of red- and white-mottled and striped, cross-laminated sandstone, underlying black diabase The thin section of this sandstone shows that it is chiefly made up of angular and sub-angular quartz grains, which occur of two sizes, the prevailing small ones constituting a sort of matrix in which the large ones float. Large-sized particles of orthoclase, microcline and oligoclase are also noticeable in a tolerably fresh condition; and a fine cloudy material in the base is probably comminuted and decomposed feldspar. The red blotching is due to the iron staining. The sandstone is plainly made up of granitic *débris* and not of the usual porphyritic detritus, a fact which is easily explained by the proximity of this sandstone to the granites of the west and northwest sides of Black Bay.

A fine-grained, close-textured, brownish-black rock, with semi-conchoidal fracture, from a large island near Cabmous-Neiding Point, thirteen miles southwest of Lamb Island Light, at the mouth of Nipigon Straits, proved to be a typical diabase or diabase-porphyrite, having as its constituents tabular plagioclase (anorthite), abundant augite in irregularly rounded granules, titaniferous magnetite, and much of an interstitial substance now largely stained by red and brown iron oxide.

A similar but more dense and less highly augitic rock forms the small islets at the west side of the mouth of the large bay of which the Roche de Bout is the eastern cape.

A coarse-grained black- and-white-mottled rock, which forms the north point of the large island lying directly in the mouth of Nipigon Straits, turned out to be a typical orthoclase-gabbro, with plagioclase, orthoclase, twinned diallage, large augite granules, titaniferous magnetite, and secondary quartz as the constituents. A similar rock from the mainland immediately to the northwest of the last rock yielded the same results in the thin section.

Farther northward along the west side of Nipigon Straits the following rocks were encountered, among others: (1) A medium-grained to fine-grained, black rock, carrying numerous large brownish translucent porphyritic plagioclases, which, in the thin section, shows a wholly crystalline groundmass, consisting of plagioclase, orthoclase, augite partly in grains, and partly filling the interstices between the feldspars, titaniferous magnetite, secondary quartz, and epidote. The porphyritic feldspars yield the polarization angles of labradorite. The rock lies between the ashbed-diabases and the orthoclase-gabbros. (2) A fine-grained, brownish-black rock consisting of fresh tabular labradorites, arranged so as to indicate flowage, abundant and partly fresh augites and magnetite. The rock is a diabase of the ordinary type. (3) A black, conchoidally fracturing, aphanitic ashbed-diabase consisting of predominating tabular labradorites, augite in grains, and a little magnetite.

NIPIGON LAKE BASIN.

The red sandstones, shales, and marls which in the region of Thunder, Black, and Nipigon bays lie at the base of the Keweenaw Series extend, as

Bell has shown, northward from the last two of these bays, in a broad belt, spreading from the Nipigon River to some twenty miles west of the Black Sturgeon River. According to Bell[1] the rocks of this belt are chiefly the red sandstones and marls above referred to, with an overlying mass of "black trap," similar to the olivine-gabbro already described as overlying red marl at the mouth of Nipigon River. Still farther north the western half of the basin of Lake Nipigon is described by the same geologist as occupied by rocks which he assigns to the Keweenaw Series, and which he regards as a direct continuation northward of those of the valley of the Black Sturgeon River. The rocks thus assigned by Bell are stated to be chiefly "black trap,"[2] at times coarse, and again fine; but also to include "brick-red porphyry," sandstone, "argillites," "felsite," and green and gray limestones.

The "black trap" is nearly everywhere the only rock seen. Much of it is evidently coarse olivine-gabbro. It is described as only occasionally showing distinct bedding, but when it does so as lying sometimes at high angles to the east or west, though often as more nearly horizontal. It was seen both plainly interbedded with sandstone, and then generally standing at a high angle, and also apparently overlying all the rocks of the region. The red porphyry is described as presenting itself in one principal exposure on the east side of Lake Nipigon, where

> the lake shore and the islands from the Hudson Bay Company's farm at Nipigon House to English Bay, a distance of three miles, are occupied by a brick-red porphyry, composed of crystalline red orthoclase feldspar, with grains of translucent quartz, inclosing finer stratified patches of the same color, and others of white quartz. It also holds spots of a soft green earthy mineral, and small cavities lined with crystals of feldspar.[2]

This porphyry evidently belongs to my group of augite-syenites and granitic porphyries.

The sandstone is met with at several points on the east side of Lake Nipigon, where it is "rather fine-grained, hard, and quartzose," and flanks the granite, and strikes northward with the shore, dipping eastward at an angle of 15° at one place, and at another westward into the lake at an angle of 80°. Trap, either in the form of beds or great dykes, is associated with it.

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[1] Report of the Geological Survey of Canada, for 1867–'69, p. 338.
[2] Op. cit., p. 348.

On the west shore of the lake sandstone is said to occur interstratified with beds of "argillite," felsite," and "trap,"

all on edge, and running in a northerly direction. * * * Some of the felsite beds are soft greenish and earthy; others harder and schistose. The argillite is hard dark colored and compact, with a conchoidal fracture; while the sandstones are light-colored and soft. One bed of the latter, of a very light greenish-gray color, is composed of fine silicious and argillaceous particles, with scattered grains of translucent quartz. [At another point farther up the west shore there shows under high cliffs of trap] a band of light-gray tender harsh-grained sandstones, about 100 feet thick, dipping S. 80° W. (mag.) < 50°, which appears to come between great masses of coarse crystalline trap. Two miles farther south, or about a quarter of a mile north of the extremity of Black Sturgeon Lake, beds of a coarse light-gray sandstone, holding occasional pebbles, mostly of white quartz, are found lying against the side of a hill of gray splintery schistose felsite. The sandstone dips southwestward at an angle of about 40°, while the felsite dips in the opposite direction, with an inclination of about 60°.[1]

The limestones were seen in two places, one on the south side of Lake Nipigon and one on the west. In the former case the limestone is—

thinly bedded, and consists of alternating whitish and olive-green layers. The rock, which has a fine homogeneous texture and conchoidal fracture, is magnesian and argillaceous, and when burnt would probably form a good cement. Some indistinct forms, resembling fossils, occur in it, but nothing definitely organic was observed. The limestone band is generally horizontal, but in some places it is thrown into a series of small anticlinals, having their axes north and south. It is overlaid by the trap, which rises to a height of about 100 feet immediately above it.[2]

The limestone of the west shore shows on the north side of the Narrows at the mouth of Chief's Bay.[3] Here—

trap is overlaid by compact argillaceous magnesian limestone, with a conchoidal fracture, dipping S. 25° W. (mag.) < 5°. The beds are from three inches to two feet and a half in thickness, and present different shades of a grayish and olive-green color. Although the section exposed does not appear to exceed ten feet in thickness, so regular and slight is the dip that these rocks extend for a quarter of a mile along the shore, and are seen along a brook to the northwestward and in the bottom of the lake in front. Small pear-shaped bodies, about the size of peas, weather out on the surfaces of some of the beds, but they show no organic structure, either outwardly or in sections examined under the microscope. The same olive-green limestone occurs again on the northeast shore of Chief's Bay, about two miles from the Narrows. The beds are from six inches to two feet thick, and dip S. 40° W. (mag.) < 8°. A section of six or eight feet is exposed, and the strata are underlaid conformably by beds of fine-grained compact black trap, showing crack-marks on the surface.[4]

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[1] *Op. cit.*, p. 345.

[2] Op. cit., p. 342.

[3] See map accompanying Bell's report in Report of Progress of the Geological Survey of Canada for 1867–'69.

[4] Op. cit., p. 346.

These limestones are of interest, since no such rocks are anywhere else known throughout the entire extent of the Keweenaw Series.

Bell's statements, thus quoted, certainly seem to show that the Nipigon Lake rocks are Keweenawan, and that, to judge from lithological characters, they belong always low down in the series. I have already stated my disbelief in the existence of any one "crowning overflow" closing the entire series of Keweenawan eruptions in the Thunder Bay region. Still more doubtful to me seems the reference to this "crowning overflow" of much of the trap of the Nipigon region. The structural relations of the Nipigon Basin to that of Lake Superior would be an interesting subject for discussion, but while the structure in the Nipigon Basin itself is so little known, speculation on the relations would hardly be profitable.

Section III.—MICHIPICOTEN ISLAND AND THE EAST COAST OF LAKE SUPERIOR.

Beyond the easternmost of the Battle Islands the north and east coasts of Lake Superior, for nearly 200 miles, are composed wholly of rocks more ancient than the Keweenaw Series. As shown subsequently, there are reasons for believing the Keweenawan rocks continuous in this distance underneath the waters of Lake Superior. They first reappear to view, however, in Michipicoten Island, which lies about 100 miles southeast of the last of the Battle Islands. The following is Logan's account of Michipicoten Island:

> The strata of which it is composed have a general dip to the east of south, and the inclination appears seldom to fall short of thirty degrees. The lower strata, towards the north side of the island, particularly as indicated at the upper end, appear to be composed chiefly of amygdaloidal trap, with occasional beds of trap conglomerates, red sandstones, and shales; while towards the south these are overlaid by a considerable amount of compact earthy or sub-resinous red trap, assuming sometimes an obscure and sometimes a distinct porphyritic character, by the display of ill-defined crystals of red feldspar or well-marked crystals of transparent colorless quartz.
>
> Along nearly the whole of the south side of the island the trap assumes a more resinous aspect, and, its color becoming black, it presents the characters of pitchstone and pitchstone porphyry. Some of the beds associated with these are of an amygdaloidal character, and exhibit large agate veins, which run chiefly in the direction of the strike, but frequently also transverse to it.

About three-fourths of a mile out in front of the harbor, which is half-way down the south side, a few narrow islands occur, presenting beds of peculiar character, amounting to between sixty and seventy feet, dipping southward at an angle of twenty degrees. They are of a general red color, spotted and patched with yellowish-white, and wherever a crack exists the rock is blanched to a small distance on each side of it. The surfaces are uneven, and peculiarly marked with festooned and finely wrinkled forms, composed of very thin close-fitting laminæ, with a ligneous aspect, having a thickness sometimes exceeding one or two inches. The rock scarcely resembles a trap, nor does it bear the character of indurated shale; but it may perhaps be an indurated mixture of volcanic mud and ashes, in which the wrinkles result from a partial flow. The total volume of the formation developed in Michipicoten Island at the most moderate dip observed would not fall short of 12,000 feet.

Subsequently to the publication of this description of the Michipicoten rocks Macfarlane made a further study of them for the Canada survey. His more detailed examinations established a total thickness of over 18,500 feet of plainly bedded eruptive flows, with interstratified conglomerates and sandstones. From the numerous dip and strike observations which he records, it is evident that the beds throughout the island have, as Logan says, a southerly dip, but also that they take a sort of curving course as they are followed on the length of the island, the strike directions becoming more and more north of east as the eastern end of the island is reached. The dip also flattens to the southward, the beds on the north side of the island dipping south as much as 30° to 36°, while on the south shore the angle appears to be often less than 20°. Macfarlane also describes the existence on the east and northeast shores of the island of peculiar masses of red quartziferous porphyry, which occur in confused relations to the associated basic rocks, the very regular succession of beds seen on the east and south sides of the island failing to repeat itself here.

By the kindness of Mr. A. R. C. Selwyn, Director of the Geological Survey of Canada, I am in possession of a suite of nineteen type specimens of the Michipicoten rocks, collected and determined according to the older lithological methods by Mr. Macfarlane. These I have carefully studied under the microscope, and am thus the better able to institute a satisfactory comparison between the Michipicoten rocks and those of the typical Keweenawan localities of the South Shore.

The peculiar red- and white-blotched, wrinkled rock described by Logan as forming the small islands which lie about three-fourths of a mile south of the harbor on the south side of the island, I find to be a highly siliceous felsite, closely resembling and plainly belonging with the red rock of which Mount Houghton, on Keweenaw Point, is formed, which makes up much of the central mass of the Porcupine Mountains, and which forms so many of the red cliffs of the Minnesota coast of Lake Superior. The resemblance is both macroscopic and microscopic; while the peculiar "festooned and wrinkled" markings, "composed of very thin close-fitting laminæ, with a ligneous aspect," noticed by Logan, are precisely what I have repeatedly described in the foregoing pages as characterizing similar rocks in so many places in the western half of the Lake Superior Basin. These markings are due doubtless to a viscous flow, and are much the same as are found to characterize the modern rhyolites. The high stratigraphical position of this felsite, which is described by Logan as plainly dipping with the rest of the Michipicoten series, is particularly worthy of notice, since it places these acid rocks at a higher horizon than elsewhere in the Lake Superior Basin.

Of the peculiar resinous-looking rocks, which, under the name of pitchstone and pitchstone-porphyry, Logan describes as showing all along the south shore of the island, I find several specimens in Macfarlane's collection. One of these specimens,[1] labeled by him "compact melaphyr," presents a nearly aphanitic, dark-gray rock, with a conchoidal fracture, and without porphyritic ingredients. It bears a strong resemblance to the ash-bed traps of Keweenaw Point. In the thin section this resemblance is borne out completely, the rock proving to consist of predominant tabular oligoclases, with augite in the characteristic irregular grains whose contours are not determined by the feldspars. Magnetite and some non-polarizing material, which is taken to represent residuary magma, are also present. The rock is thus, according to the Rosenbusch nomenclature, a diabase-porphyrite.

Another specimen,[2] also called melaphyr by Macfarlane, is aphanitic, of a dark chocolate-brown color, has a conchoidal fracture, and shows no porphyritic ingredients. The thin section of this rock proves it also to be a diabase-porphyrite, the ingredients being the same as in the last, the only perceptible differences being that in this rock the tabular feldspars are two

[1] Macfarlane's No. 2.

[2] Macfarlane's No. 5.

or three times as large and have their longer axes arranged with a tendency to a common direction, while the augite is sparser and in more minute particles. The brown color appears to be connected with a ferritic alteration of the residuary magma.

Still another specimen,[1] called porphyrite by Macfarlane, and coming from the southeast corner of the island, presents an aphanitic, very compact matrix, of a greenish-gray color, in which are included very abundant porphyritic white feldspars, one-sixteenth to one-eighth inch in length, and also much rarer and more minute porphyritic black particles. In the thin section the base is seen to contain much of a light-brown and dark-brown stained non-polarizing material, which is thickly strewn with minute tabular plagioclases, and contains also rarer and more minute particles of black magnetite. The porphyritic feldspars turn out to be labradorite, the crystals of which mineral are often grouped in peculiar clusters, and are always very fresh. The porphyritic black particles, seen macroscopically, turn out to be augite largely altered to a greenish material, with which there is associated much black magnetite, also as an alteration-product. This rock, then, is another phase of diabase-porphyrite, with a larger proportion of uncrystalline matter. The thin section of this rock is figured on Plate IX at Figs. 1 and 2.

A fourth specimen,[2] called by Macfarlane basaltic melaphyr, is aphanitic, nearly black, has a highly conchoidal fracture, with an almost vitreous aspect, and shows no porphyritic ingredients. It is evidently one of the rocks especially referred to by Logan under the name of pitchstone. The thin section shows an excessively dense rock, in which, with a high power, and with the polarized light, are recognizable very numerous minute augite particles, embedded in a non-polarizing matrix, with very much rarer minute plagioclases and magnetite particles. This rock is again a diabase-porphyrite, but is nearer to the glassy condition than any of those previously described. It is also peculiar for its large content of augite. Still nearer to the glassy state is a specimen from Sir William Logan's collection, labeled "pitchstone." It is completely aphanitic, of a jet-black color, and greasy semi-vitreous luster, and has a glass-like fracture. In the thin sec-

[1] Macfarlane's No. 16.

[2] Macfarlane's No. 18.

tion the brownish-stained matrix is seen to be composed in a considerable measure of unindividualized material (large areas remaining dark between the crossed nicols) exceedingly minute tabular plagioclases, occasional minute brightly polarizing augite points, and magnetite particles in the groundmass.

The still lower strata which form the bulk of the thickness present in the island are not so well represented in the collection. One specimen[1] from the copper mines on the north side of the island, called by Macfarlane melaphyr, is fine-grained, plainly crystalline, and has a rough fracture, and a dark purplish-gray color, mottled with still darker shades. Its aspect is identical with that of many of the finer-grained, luster-mottled, olivinitic rocks to which Pumpelly has given the name of melaphyr. This resemblance is fully borne out by the appearance of the thin section, in which the characteristic relatively large augites include numbers of tabular plagioclases, while the abundant olivines, wholly altered to green and brown substances, are crowded with the magnetite into the interspaces of the augites. A number of large porphyritic plagioclases occur in the section, an unusual thing for this class of rocks elsewhere in the Keweenaw Series.

The copper-bearing "vein" at this place is evidently merely one of the usual altered cupriferous amygdaloids, and is, according to Macfarlane, almost identical with the cupriferous amygdaloid of the Pewabic and Quincy mines, Portage Lake. It has been traced for a considerable distance. Overlying this cupriferous bed is a rock which is represented in the Macfarlane collection. This rock[2] is completely aphanitic, of a dark-gray color and highly conchoidal fracture, and shows as porphyritic ingredients only rare black crystals of augite. The thin section proves it to be a typical diabase-porphyrite, with a predominating isotropic, pinkish-tinted, and cloudy base, in which may be recognized, with a high power, excessively minute tabular plagioclases, larger but still minute magnetite particles, and rare and very minute brightly polarizing particles, probably belonging to augite. The porphyritic augites are largely replaced by a greenish alteration-product. Aphanitic black rocks of similar appearance to that last described form, according to Macfarlane, a large proportion of the lower half of the Michipicoten section. Rocks of this character show all along the west shore of the island to its western point.

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[1] Macfarlane's No. 1.

[2] Macfarlane's No. 9.

One specimen[1] in the collection, from a bed near the middle of the series, is called by Macfarlane porphyritic melaphyr. It turns out, however, to be a quartzless porphyry, and is of interest as presenting a gradation phase between the wholly crystalline augite-syenites and the typical quartzless porphyries. Macroscopically it presents an aphanitic light-brownish base, with very abundant minute pink porphyritic feldspars. In the thin section the base proves to be chiefly made up of isotropic material and small, but not excessively minute, feldspars, which are in large measure orthoclase. Minute quartz particles and clusters, some plainly secondary, dot this background, which is also affected by a general red stain. The quartz also occurs in excessively fine radiating and parallel lines. This radial arrangement is also brought out by lines of brown ferrite. Small augite points are here and there recognizable. The porphyritic feldspars are orthoclase and oligoclase. A single rather large-sized apatite-crystal is contained in the section. There are splotches of green chloritic substance, which shows also macroscopically, but it is not evident which mineral has, by its alteration, given rise to them.

The red porphyry which Macfarlane describes as making so confused an appearance on the east shore of the island is represented in the collection. It is a quartziferous porphyry,[2] with a dark purplish-red, aphanitic matrix, in which the porphyritic quartzes and feldspars are extraordinarily abundant and large. It is near to the rock seen on the Torch Lake Railroad, south of the Calumet mine, on Keweenaw Point, to that of which many of the pebbles of the Keweenaw Point conglomerates are composed, and to that which makes large exposures on Bead Island, at the mouth of Nipigon Straits. In the thin section the ground-mass of this rock appears faintly pinkish-tinted and cloudy, and contains abundant and very minute ferrite particles, which in the vicinity of the porphyritic ingredients show crowding and a tendency to linear directions. In the polarized light the matrix shows a dark background, strewn with particles and flocks of particles, of feebly double-refracting substances, but only rarely showing any networked secondary quartz. The porphyritic quartzes are in the usual dihexahedral forms, which are generally much eaten into by the matrix. The feldspars are both orthoclase and oligoclase; and are much altered.

[1] Macfarlane's No. 15.

[2] Macfarlane's No. 11.

The facts given above, quoted from Macfarlane and Logan, together with the microscopic observations that I have added, establish, then, a complete identity between the Michipicoten Island rocks and those of the typical cupriferous districts of the south shore of Lake Superior. To judge from these data, the only peculiarity about the Michipicoten section appears to be the relatively great abundance of diabase-porphyrites.

EAST COAST OF LAKE SUPERIOR.

According to Logan and Macfarlane, several of the prominent points along the east coast of Lake Superior are formed of rocks of the copper-bearing series, the intervening shores being occupied by older formations. The appearance is as if the Michipicoten rocks, leaving that island with a north-of-east trend, run up well into the bight into which the Michipicoten River empties, and then, turning abruptly at more than right angles, skirt the east coast as far as the Sault, being, however, in most of this distance concealed by the waters of the lake. The northernmost point at which Keweenawan rocks have been recognized on the east coast is at or near Cape Choyye, 18½ miles south of the mouth of Michipicoten River. With regard to this point and others farther south I quote from Logan:

> About two miles north of Cape Choyye a coarse-grained bed, supporting some thickness of sandstone colored red, with white bands, and dipping a little to the south of west at an angle of about ten degrees, abuts against a precipitous cliff of the older rocks, as if let down by a north-east and south-west fault.
>
> About nine miles to the south of this, the peninsula of Cape Gargantua, and some of the small islands immediately near display amygdaloidal trap disposed in beds dipping to the south of west at an angle of about forty degrees, and resting unconformably on the gneiss. * * *
>
> To the south of Montreal Island, sandstones and amygdaloidal trap occupy the lower side of the cove above Pointe aux Mines. The sandstones, where first seen, are nearly in contact with the gneiss, against which they appear to abut, as if brought in by a dislocation. Their dip, at an angle varying from ten to twenty degrees, gradually changes from a direction N. 45° W., to N. 15° W. The trap, coming apparently from below, after an interval of about one hundred yards, in which it is difficult to ascertain its true attitude from its being worn down level with the surface of the water, exhibits a decided dip S. 80° W. $< 30^\circ$—40°, maintained for such a distance across the measures as to yield a thickness of 3,000 feet. This trap is interrupted at Pointe aux Mines by a south-easterly dislocation, which brings up the Laurentian gneiss, of which the extremity of the point is composed. From this point the line of demarkation between the gneiss and the overlying unconformable rocks, as has already been indicated, appears to run

across in a southeasterly direction to Batchehwahnung Bay, leaving the promontory of Mamainse between it and the lake.

This promontory is composed of amygdaloidal trap and coarse interstratified conglomerates, whose pebbles and bowlders consist chiefly of the ruins of the subjacent slate, gneiss, and associated rocks. The general dip of the strata which occupy this area is maintained with considerable constancy in a direction rather south of west, at an angle of twenty or twenty-five degrees, and the breadth across the measures is sufficient to give a thickness probably of not far from 10,000 feet, of which about 1,500 feet consist of conglomerate layers, one of them being 400 feet.

More recently Macfarlane has published a detailed section of the rocks forming Mamainse Point, in which he makes the total thickness of the Keweenawan beds here in sight 16,208 feet, the interstratified conglomerates aggregating 2,138 feet. The conglomerates are often bowlder-conglomerates rather than pebbly, and are peculiarly among Keweenawan conglomerates for carrying bowlders and pebbles of granitic and gneissic rocks, a fact evidently to be connected with the near neighborhood of such rocks in place. The rocks which are described as melaphyrs by Macfarlane, and which with their amygdaloids make up the greater part of the Mamainse section, are precisely the same types of diabase, etc., which characterize all the other Keweenawan regions about Lake Superior. This is in effect stated by Macfarlane and Logan, and their statements are confirmed by a collection made here for me by Mr. A. C. Campbell. Diabase-porphyrites and ashbed-diabases are very plenty among the specimens, but typical luster-mottled melaphyr and felsite are also represented. The usual amygdaloids are developed here, and native copper has been observed in several places.

Macfarlane describes the south side of Mamainse, on Batchewanung Bay, as presenting a confused appearance:

Although the sandstones occasionally protrude, they become much less frequent, while the overlying traps become much more regular, and gradually assume the same strike and dip as the strata on the west coast. The hills to the north of Anse aux Crêpes consist of the same beds of melaphyr and conglomerate as were observed on the west coast, with similar strike and dip.

According to Logan, amygdaloid shows again in the easternmost part of Batchewanung Bay, "where it reposes on the gneiss, with a dip S. 80° W. $<$ 42°." Trap and amygdaloid show again on the south side of the bay. "The worn condition of the rock renders the dip obscure, but it appears to be N. 60° W. < 22°." Similar rocks appear again "at the extremity of Gros Cap, where there is but a small quantity of the amygdaloid, and where trap of a porphyritic character appears to be associated with it. The dip is W. < 45°."

To these quotations I have only to add that the specimens brought to me from the above-described places, south of Mamainse Point, show only the typically Keweenawan kinds, including not only the basic kinds but also red quartziferous porphyry and felsite, the latter from Gros Cap. There is still much obscurity hanging about the structural relations of the rocks of the east shore from Pointe aux Mines to Gros Cap, and especially is this true of the rocks in and about Batchewanung Bay. To add to the difficulties, the horizontal Eastern Sandstone seems to be present here, and has been confounded with true Keweenawan sandstones. The peculiar way in which the traps and amygdaloids of the latter formation skirt the shores of Batchewanung Bay, appearing in a small patch even at the deepest point of the bay, suggests very strongly the thought that the existence of this bay is determined by a peculiar loop-like bend in the general course of the Keweenawan belt of the East Shore. Possibly the confused appearances noted on the south side of Mamainse by Macfarlane may have something to do with this convolution.

CHAPTER VIII.

RELATIONS OF THE KEWEENAW SERIES TO THE ASSOCIATED FORMATIONS.

Section I.—TO THE NEWER FORMATIONS.

THE EASTERN SANDSTONE.

By this term is meant that sandstone which, as already indicated, fills the valley between the Keweenaw, or Main Trap Range of Michigan, and the so-called South Range. The eastern end of this depression is occupied by the waters of Keweenaw Bay. The whole area has a characteristic flat appearance and sandy soil, standing thus in strong contrast with the highlands of crystalline rocks on both sides. On the northern edge of this depression the sandstone may frequently be seen exposed, from the head of Bête Grise Bay, on Keweenaw Point, westward to beyond Lake Agogebic; and on the southern edge may be traced east and northeast from the vicinity of Lake Agogebic to the head of Keweenaw Bay. On the west side of this bay the sandstone is constantly exposed in cliff; but on the east side the older crystalline rocks come out to the water's edge. Gneiss and schists form the mass of the peninsula between Keweenaw and Huron bays, but skirting the immediate shore of the lake is a band of sandstone varying in breadth from a few rods to one or two miles, the older rocks only now and then reaching to the lake. Similar conditions obtain from here to Marquette, beyond which point, to the eastward, sandstone forms all of the shore cliffs as far as the Sault.

The sandstones of Keweenaw Bay and its vicinity, and eastward thence to White Fish River, are reddish and often highly argillaceous. At White Fish River the red sandstone is overlain by a light-colored sandstone, which is in turn succeeded by a magnesian limestone, in which are casts of *Pleurotomaria*.[1] This limestone is the Lower Magnesian of the Wisconsin reports, and the Calciferous Sandrock of the eastern states. That it is succeeded in regular order by the fossiliferous limestones of the Trenton, Cincinnati, and Niagara groups was long since shown, and has been demonstrated anew of late years by the labors of the geological surveyors of Wisconsin and Michigan. There thus seems little room for doubt as to the correctness of the view held for years by a succession of geological workers in the Lake Superior region, from Owen to Rominger, viz., that in the Eastern Sandstone we have to do with the same

[1] Geological Survey of Mich., Vol. I, Part III, pp. 89, 90.

formation, or with its downward continuation, as the fossiliferous Cambrian sandstone which, in the Mississippi Valley, forms the base of the Paleozoic column. There appears to be but one way in which this conclusion can be avoided, and that is by supposing that where, east of Marquette, the red sandstone is overlain by the lighter-colored, there is a discordance of greater or less extent, the red sandstone having been thus separated by a relatively large time-gap from that which overlies it. This view was, indeed, held as long ago as 1841, by Houghton,[1] who, however, so completely altered his opinion in the next few years as to consider the red sandstone of Keweenaw Bay and Keweenaw Point the newer of the two, and as of Triassic age; while the light sandstones east of Grand Island he believed to antedate the Trenton limestone.[2]

It is needless to discuss the idea of a Triassic age for any of the Lake Superior rocks, since its incorrectness has been so abundantly and repeatedly proved, from the time of Foster and Whitney down to the publication of the third volume of the Wisconsin reports, in which the demonstration is clinched by the descriptions of the perfectly plain relations of the fossiliferous sandstone of the Mississippi Valley and the western extension of the Keweenaw Point rocks, in the region of the Saint Croix River. To judge from Rominger's account of the exposures in the vicinity of White Fish River, the falsity of the idea of an unconformable superposition of the lighter-colored upon the red sandstone is equally well proven.[3] In the same connection allusion should be made to the long-known occurrence of an isolated patch of fossiliferous Trenton limestone within the area of the Eastern Sandstone. This limestone forms a line of bluffs extending through sections 13, 14, 23, and 24, of T. 51, R. 35 W., Michigan, fourteen miles west of the head of Keweenaw Bay. The rock contains a number of well-known Trenton fossils.[4] In this occurrence we have demonstration of the former extension of the Lower Silurian limestones far to the westward of their present limit.

In presenting the facts upon which are based my conclusions as to the

[1] Fourth Annual Report on the Geological Survey of Michigan, 1841.
[2] American Journal of Science, 1843, XLV, p. 160.
[3] Geological Survey of Michigan, Vol. I, Part III, pp. 62–63.
[4] Geological Survey of Michigan, Vol. I, Part III, p. 69.

relations subsisting between the Keweenawan rocks and the Eastern Sandstone, I follow the northern junction westward from Bête Grise Bay to Lake Agogebic, and then the southern from that lake eastward.

The north shore of Bête Grise Bay, as shown on a previous page, is made of low cliffs of Keweenawan diabase and melaphyr, with some quartziferous porphyry, all dipping northward at a high angle; while the west shore of the bay lies in the lowland underlain by the Eastern Sandstone. In the angle of the bay the two formations come together, and their contact may be followed for a long distance. The sandstone, of which a considerable thickness may be seen in continuous exposure, dips southward at angles varying from 55°[1] at the contact to 30° and less at the point farthest removed from the contact. It is made up of alternating whitish, quartzose, fine-grained layers, and thinner ones of red shale; the latter running from a few inches to several feet in thickness. Some of the red layers are strongly conglomeratic, the pebbles being generally of small size and often angular, and composed in the main of red felsite, but also in some measure of the ordinary Keweenawan diabase and melaphyr. The accompanying section, repre-

FIG. 30.—Showing relation of the Eastern Sandstone and Keweenawan melaphyr, Bête Grise Bay. Length of section about 150 feet.

senting a length of about 150 feet, is designed to illustrate the nature of this contact. The junction line between the sandstone and the older rocks is quite irregular, and as the shore of the bay is followed eastward, patches of the sandstone are seen remaining in embayments of the older rocks on the cliff-side. Underneath the clear waters of the lake the beveled edges of the alternating bands of red and white sandstone may be traced for hundreds of feet in great sweeping curves. On the south point of Bête Grise Bay, below the ship canal, the sandstone lies horizontally.

[1] Not 78°, as reported by Foster and Whitney, *op. cit.*, p. 112.

As already shown, the contact line of the sandstone and northward-dipping Keweenawan rocks west of Bête Grise Bay is plainly marked by a sharp break in the topography. At a number of points along this line, phenomena similar to those observed at Bête Grise have been noted—*i. e.*, the sandstone inclining southward at an angle which lessens in amount very rapidly as one passes away from the contact. This may be seen, for instance, in the vicinity of Lac La Belle and Gratiot Lake, and on some of the head streams of Tobacco River. As long since shown by Foster and Whitney, the amount of southward dip in the sandstone, even near the contact, lessens westward, so that, in the vicinity of Torch and Portage lakes, it lies horizontally at the contact, or, at most, inclines but a very few degrees southeastward.

The contact line is crossed and exposed by several of the small streams entering Torch Lake on its west side. These streams run in quite deep gorges, which are carved in the Eastern Sandstone, and end abruptly, often with a vertical wall, where they reach the more enduring rocks of the Trap Range. The gorges of two of these streams, the Hungarian and Douglas Houghton rivers, were examined with some care. As the Hungarian River is ascended, the sandstone is first met with on the sides of the ravine, and then in its bed also, where it forms several falls. For the most part the sandstone is light-colored and quartzose, but conglomerate bands are included in which the pebbles are in the main of some of the red acid eruptives of the Keweenawan. Often the sandstone lies horizontally; at times it appears to have a slight northwesterly dip, and as often a slight southeasterly one. These deviations from horizontality are often plainly the result of the undermining on the side of the ravine. At the uppermost fall the contact with the older rocks is seen. The occurrences here, and for some distance below, are as shown in the accompanying sketch made on the ground by Mr. W. M. Chauvenet, in which B is the bank of the gorge without exposures; A, sandstone layers projecting from the sides of the bank; D, amygdaloid and pseud-amygdaloid dipping northwesterly; E, the continuation of the amygdaloid in a crumbling condition; C, porphyry-conglomerate; and F, an overlying diabase. At G, at the very foot of the fall, is a smoothed surface of sandstone jointed in two directions, the two joint

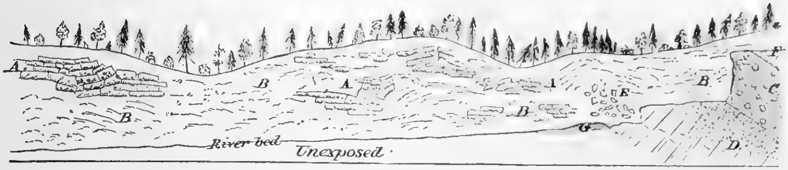

FIG. 31.—Section on the Hungarian River, Keweenaw Point.

surfaces dipping N. W. 25° and S. 20° E.; and a few steps farther down the sandstone is seen lying perfectly flat In the same vicinity true bedding, as shown by the differences in the coarseness and coloring of the sandstone, gave dips of N. W. 10°, S. E. 20°, N. E 20°. The irregularities seem to be due, in a measure, to undermining on the sides of the ravine, but are also apparently somewhat analogous to those described and figured on a previous page as occurring on the gorge of Black River, in Douglas County, Wisconsin—*i. e.*, are the product of faulting motion.

In his account of the occurrence on the Hungarian River,[1] Mr. M. E. Wadsworth has represented the Eastern Sandstone as presenting an gradually increasing northwesterly dip, as it is followed up the stream, until it is plainly seen plunging beneath the Keweenawan diabase and interbedded conglomerate. But neither the increasing northwesterly dip nor the subordinate position of the sandstone to the diabase could be detected by Mr. Chauvenet. Northwesterly dips are found in the sandstone for some distance below the contact, but southeasterly ones just as often, or oftener, and both seem distinctly subordinate to a general horizontality. Again, sandstone lies vertically beneath an amygdaloid, but the mass of sandstone appears to be a fallen one, and if it is not, the crumbling amygdaloid above certainly is.

The occurrences on the Douglas Houghton River are much like those seen on the Hungarian, with the exception that the true Keweenawan beds extend down stream for some 300 paces from the head of the ravine, for the reason that they include just here a considerable thickness of soft conglomerate. Below the last of these beds is a gap of some 200 paces, when the horizontal layers of the Eastern Sandstone come in, here and

[1] Notes on the Geology of the Iron and Copper District of Lake Superior, p. 113. Bulletin of the Museum of Comparative Zoology; Whole Series, Vol. VII, Geological Series, Vol. I.

there with a slight northwesterly dip (2°–5°), but more often with a southeasterly one. These conditions obtain for a mile or more down the stream. Mr. Wadsworth has also described the exposures on the Douglas Houghton River, and correctly, so far as showing—which he was the first to do—that the conglomerate for some distance below the falls does not belong with the Eastern Sandstone, but is really interbedded between diabases of the Keweenaw Series. When he represents, however, the sandstone still farther down stream as passing beneath the last Keweenawan diabase, he bridges in his imagination a covered gap of several hundred paces; beyond which, to the eastward, the sandstone lies flat, or inclines varyingly and indifferently slightly to the northwest, southwest, or southeast, not showing any sign of a persistent and gradually decreasing northwestern dip. Were this ravine the only place where the Eastern Sandstone could be seen in proximity to the north-dipping Keweenawan beds, and were there not other considerations rendering such a conclusion untenable, the idea that Mr. Wadsworth has advanced might perhaps suggest itself as a possibility, although so far as the exposures here are concerned it could be nothing more. There would remain even then as looking the other way a marked lithological difference between the intercalated sandstone and that farther down the stream; the latter being a much more purely quartzose rock, while at the same time containing pebbles of the porphyry whose detritus composes the usual interbedded sandstones of the trappean series.

About a mile south from the head of the Douglas Houghton ravine, on the line of the Torch Lake Railroad, is a large quarry in the Eastern Sandstone. The sandstone is disposed horizontally in heavy massive layers. It is nearly white and almost wholly composed of rolled quartz grains. It also contains here and there grains of feldspar, somewhat altered, but on the whole singularly fresh for such a rock, some particles showing the twin lamellation very beautifully. A very minute quantity of a brownish cement is present, and in each thin section may be seen two or three grains worn from some of the fine-grained diabases of the Keweenaw Series. Not a trace is to be seen of anything like the fragments of porphyry matrix, so abundant in the Keweenawan sandstones; nor was I able to discover any satisfactory indications that the quartz-grains are the quartzes of the quartziferous porphyries, although one might expect to do so. In his description of this quarry quoted below, Mr. Wadsworth speaks of the grains of the sandstone as furnished with crystalline outlines, and regards these outlines as showing the derivation of the quartzes from a quartz-porphyry. My sections fail to show any such outlines, but if they occur, they are probably rather in the nature of those of the crystal grains so frequently met with in the Potsdam sandstone of the Mississippi Valley, in which case the crystalline outlines are the result of a secondary deposition of quartz upon the surfaces of the originally rolled grains. Rare pebbles of quartz of some size are contained in this sandstone, and patches and lines of red clayey substance, which do not show any persistent inclination in any one direction. The clayey material often expands into large bunches of red clay, forming the usual clayholes, so characteristic everywhere of the Eastern and Western horizontal sandstones.

My description of the rock of this quarry differs from one published by Mr. Wadsworth, in which he says—

In the sandstone quarry at the head of the *incline* on the Hecla and Torch Lake Railroad, the sandstone layers have been regarded as being nearly horizontal. The joint planes that form the floors of the quarry are nearly so, having only a slight dip to the northwest; but these joint planes cannot be the bedding planes, for we find on close examination that numerous layers of coarser material, pebbles, clay masses, etc. occur in the rock. These layers extend for long distances through the sandstone, and are always parallel, having the same dip, which is N. 45° W. 15°. These of course, from their character and regularity, must mark the old planes of bedding, while the generally supposed bedding planes are secondary joint planes cutting the bedding planes at a small angle. This sandstone has been leached and acted upon by water the same as that below the Douglas Houghton Falls, and its feldspathic material converted into clay or entirely removed. Part of the materials composing the sandstone, especially in the coarser portions, are similar to those in the sandstone at Marquette. The quartz grains are partly water-worn, but a large proportion are seen to be short crystals formed of the hexagonal prism, terminated on both ends by the pyramid, or the usual form found in the acidic porphyritic rocks. It appears, then, as the facets of these crystals are comparatively unworn, that they were derived from the destruction or decomposition of trachytic and rhyolitic rocks (granitic and quartz-porphyries), the feldspathic material having been removed since by water, leaving a quartzose sandstone. It is a question worthy of examination whether any other sandstones have been formed from acidic volcanic material, from which nearly all the other parts of the rock have been removed by percolating waters; especially as other sandstones have been said to be composed of quartz crystals.

In my examination I failed to find any evidence of the northwesterly dip described by Wadsworth, and a subsequent examination by Mr. W. M. Chauvenet with Wadsworth's description in hand was equally futile. The reddish bands, as stated above, showed, so far as I observed, no one direction of inclination any more decided than the others, and even if they did, it would be necessary for any one trying to establish their direction as that of the general bedding of the rock, to prove that they should not rather be taken as instances of the cross-bedding so commonly affecting the similar sandstone of the Mississippi Valley, while both they and the larger clay bunches are precisely what may be seen in the plainly horizontal sandstones of the Apostle Islands. It would seem that Mr. Wadsworth, having previously formed a theory as to the relation of the Eastern Sandstone to the Keweeawan beds, has felt it necessary to explain away the plain horizontality of the rock in this quarry.

A similar process has led him to the view that the feldspathic ingredient has been leached out of the Eastern Sandstone, in order that he may explain the quartzose character of this sandstone and of that of the Douglas Houghton and Hungarian rivers—a character which is in fact a common one of the Eastern Sandstone, wherever met with on the line between Bête Grise Bay and Lake Agogebic, and again along the north face of the South Range east of Lake Agogebic. This leaching process would have but a slender theoretical basis at the best, and in the present case seems to be distinctly disproved by the appearance of the thin section, nearly the whole of which is formed of rounded quartz grains without any space for the feldspathic material to have been leached from; while the few feldspar grains present are singularly fresh for the grains of a fragmental rock. Moreover, the quartz particles cannot represent a secondary substitute for feldspar, such as so often occurs in the granitic porphyries of the Keweenaw Series. I cannot conceive of a leaching process which leaves neither space nor substitute for the original material. Possibly it is meant that the leaching has affected the rock as a mass, and that the remaining material has collapsed. But this could not happen so as to leave the rock so distinctly marked by the original bedding structure. The thin section shows, moreover, the quartz grains frequently in the often observed relation which indicates that they lie where rolled together by shifting waters—*i. e.*, one grain enters a depression in the side of another. Again, it is difficult to see why the supposed hot waters should have selected this one sandstone for leaching, removed as it is, now at least, from the heating lava-flows; while the beds directly intercalated with these flows should in no instance show any signs of such a leaching. Although Mr. Wadsworth seems to have felt it necessary thus to explain away the peculiarly quartzose character of the Eastern Sandstone as compared with the sandstones of the Keweenawan, this lithological dissimilarity seems to me really rather more in favor of his peculiar view, as to the structural relations of the Eastern Sandstone, than against it.

Southwestward from the vicinity of Torch Lake, the Eastern Sandstone may be seen in close proximity to the Keweenawan diabases, at a number of places, and always with the same relatively quartzose character, and horizontal position or southeasterly dip. Pumpelly figures such an occurrence, for instance, in the N. W. $\frac{1}{4}$, Sec. 6, T. 54, R. 33 W., on the south side of Portage Lake.[1] Again, the streams in sections 22 and 23 of T. 54, R. 34 W., run over horizontal quartzose sandstone, and the same is true of the streams in the central and southeastern parts of T. 52, R. 35 W., where the exposures are quite large. But still farther west, on and near the Ontonagon River, much larger and more instructive exposures of the Eastern Sandstone are to be found. The occurrences here are like those on Bête Grise Bay—*i. e.*, the sandstone dips away southward from the north-dipping Keweenawan diabases, at quite a high angle near the contact and rapidly grows flatter as the contact is receded from.

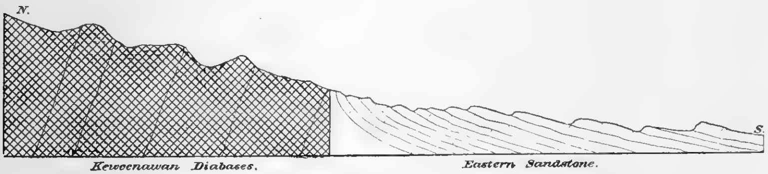

FIG. 32.—Section showing relation of Eastern Sandstone to Keweenawan diabase, T. 50, R. 39 W., Michigan. Length of section, one-half mile.

The above section was taken by Mr. W. M. Chauvenet along the course of the small stream in sections 23 and 24, T. 50, R. 39 W. The sand-

[1] Atlas Geol. Survey Mich., Plates XIV and XV.

stone seen here is the usual saccharoidal quartzose kind, often perfectly white, and at times mingled and streaked with more or less brownish material. It carries frequent pebbles of white quartz, but none of the Keweenawan diabase against which it rests. One mile south, in section 27, the sandstone was observed in a horizontal attitude, and in the S. W. $\frac{1}{4}$, Sec. 28 was seen in large exposures at the falls of the Ontonagon River. Here it dips southward at an angle of 15°, but as it is followed northward some 200 yards, this dip changes to 18° and 20°. A short distance farther north is a bold south-facing bluff of Keweenawan diabase. It should be said that these south dips are not wavering and uncertain like those observed on the Douglas Houghton River, but are persistent and pronounced, affecting many hundred feet in thickness, while the exposures are to be likened in extent and inclination to those seen on Bête Grise Bay.

Farther west again, as far as Lake Agogebic, the west branch of the Ontonagon River has its course just under an overhanging bluff of diabase, following closely the junction line of the two formations. Here and there it exposes the sandstone under conditions like those just described. Exposures of horizontal sandstone are also often met with in the country south of this line.

Along the north face of the South Range eastward from Lake Agogebic, the sandstone is not unfrequently met with in exposures. The principal point of interest in this connection is the way in which it completely overlaps the Keweenawan rocks, which, as previously shown, constitute this range. This overlapping is not merely an inference from the supposed continuation of the South Range Keweenawan beds beneath the sandstone—as for instance in the fifty miles southwest from the head of Keweenaw Bay—but may be directly demonstrated by closely approximated exposures of the formations concerned. This was first shown by Pumpelly[1] from exposures examined by him on the west branch of the Ontonagon in the northeast part of T. 46, R. 41 W. This place was subsequently visited under my direction by Mr. Robert McKinlay, who found the occurrences as shown in Fig. 3. The sandstone is horizontally bed-

[1] Geological Survey of Mich., Vol. II, Part II, p. 4. It will be seen that Mr. McKinlay found large exposures of the Keweenawan rocks much nearer the sandstone than indicated by Professor Pumpelly

ded, showing in a south-facing cliff 60 feet high and 350 feet long. It is reddish, very coarse, and composed almost entirely of rounded grains of quartz. One hundred paces from the foot of this cliff are reddish decomposed schists trending N. E. and dipping 45° to 60° S. E. Seven hundred paces northeast, near the southeast corner of section 11, is a small ledge of a dark-brown, weathered, medium-grained diabase, and in the northeast part of the same section, and running thence through sections 10 and 9, and terminating in the S. E. $\frac{1}{4}$ of Sec. 5, is a series of exposures of diabase pseud-amygdaloid and amygdaloid. Further west and again east of the sandstone are other exposures of amygdaloid, so that there can be no question whatever that the Eastern Sandstone lies directly across the course of the Keweenawan belt.

Four different views have been held, since the publication of the well-known report of Foster and Whitney, as to the relations of the Eastern Sandstone to the northward-dipping rocks against which it abuts.

Foster and Whitney's idea[1] evidently was that the Eastern Sandstone and that which, with a very great thickness, forms the west side of Keweenaw Point, were originally the same, but are separated by a longitudinal fault extending from Bête Grise to Black River. In the region of Bête Grise this fault was supposed to be accompanied by the protrusion of the mass of the Bohemian Range, to whose elevation was attributed the northward inclination of the whole succession of "bedded traps," with the overlying conglomerates and sandstones, which constitute the greater part of Keweenaw Point, and the inclination southward of the Eastern Sandstone in the Bête Grise region, the Bohemian Range being taken as the center of an anticlinal. Farther west this fissure was supposed to have been unaccompanied by any outflow, and the Eastern Sandstone to have been left horizontal.

I have shown on a previous page that the rocks of the Bohemian Range are simply a downward continuation of the Keweenaw Point Series, being made up of the usual flows, and that there is no evidence of anticlinal structure. Otherwise the theory of Foster and Whitney has some plausibility in it. I have myself already argued in favor of the view that the southern escarpment of the Keweenaw Range is a fault line, though with different

[1] Report on the Lake Superior Land District, Part I, p. 66.

reasons from those appealed to by Foster and Whitney. In its quartzose character the Eastern Sandstone has, too, something in common with the uppermost layers of the sandstone of the western side of Keweenaw Point, where a distinct tendency to become more quartzose is to be seen, although there is always a considerable difference in this respect between the two sandstones. It would also be easy to understand how to the eastward this uppermost sandstone might, by overlapping, pass on to the older rocks with a small thickness, while constituting to the west only the uppermost layer of a great series.

There are some difficulties, however, in the way of an acceptance of this view. The throw of the fault would have to be enormously great—at least 35,000 feet—and much greater than is needed for the fault which I have supposed to exist along this contact line. Subsequently to the faulting, or during it, an amount of hard resistant material 35,000 feet in height, several miles in width, and over one hundred in length, must have been denuded on one side of this fault, while on the other an insignificant amount of a fragile sandstone was left standing. A yet more serious difficulty is found in the way, already described, in which the Eastern Sandstone crosses the course of the beds of the South Range east of Lake Agogebic. Were it merely an upper member of a series of which they form the bottom portions, the two formations could not possibly sustain any such relations as they do. They were very plainly shown by Pumpelly, in his description of the place above alluded to, to be in true unconformity to one another, and the additional facts obtained by Mr. McKinlay amply sustain Pumpelly's descriptions.

Pumpelly's conclusion, after making these observations, was, that the junction line between the Eastern Sandstone and the inclined beds of the Keweenaw Range was an old shore-cliff, instead of a fault line, against which the sandstones were deposited. This conclusion was supposed to be corroborated by the finding of abundant pebbles of the Keweenawan diabase in the Eastern Sandstone near the contact, on the Douglas Houghton River. It is not impossible, however, that both he and Agassiz before him[1] did, as Wadsworth says, mistake a bed intercalated with the Keweenaw Series as

[1] Proc. Bost. Soc. Nat. Hist., 1867, XI, p. 244.

part of the Eastern Sandstone. However, on Bête Grise Bay, where there can be no possibility of doubt, the Eastern Sandstone at the contact contains layers in which diabase and amygdaloid pebbles are abundant, along with others of red felsite and quartziferous and granitic porphyries. In advancing this view Pumpelly was simply attempting to carry to demonstration what had before been suspected by Logan and other earlier geologists. In abandoning the idea of a fault along the south side of Keweenaw Point he saw that it would be necessary to account for the disappearance of the seven miles in thickness of rocks constituting Keweenaw Point—of which fully two miles are red sandstone and conglomerate of unquestioned sedimentary origin—in the few miles intervening between the point and the southern end of Keweenaw Bay, where the Eastern Sandstone lies directly upon the Huronian slates. This he did by supposing an enormous Pre-Cambrian erosion, thus making the break between the Keweenaw and Eastern Sandstone an immensely great one.

Recently Mr. M. E. Wadsworth has maintained a view, previously suggested by Credner,[1] namely, that the Eastern Sandstone passes underneath the entire copper series, forming its lowermost member, or lowermost member in sight. This conclusion he rests on observations made on the Douglas Houghton and Hungarian rivers. I have already shown that the exposures on the Hungarian River will not admit of any such explanation, while those on the Douglas Houghton, taken alone, could only be thus explained by imagining an appropriate structure within an interval where there are no exposures. But there is no necessity of going to these streams to prove the untenableness of Wadsworth's peculiar position, although he considers that it "settles the long-disputed question of the relative age of the traps and Eastern Sandstone of Lake Superior." The large exposures of south-dipping sandstone on Bête Grise Bay, at the contact with the Keweenawan melaphyr, and the similar exposures on the south side of the Trap Range in the vicinity of the Ontonagon River, are enough to disprove absolutely any such structural theory. In Mr. Wadsworth's view the Eastern Sandstone antedates all the Keweenawan eruptions, and yet it holds frequent pebbles of both acid and basic Keweenawan eruptives, whose characters are so pronounced

[1] Elemente der Geologie, 4th edition, 1878, p. 416.

that there can be no doubt as to the source of the pebbles. The more distinctly quartzose character of the Eastern Sandstone, as compared with the detrital beds of the Keweenaw Series, finds its explanation, I think, in the derivation of the larger part of its material from the granites and schists of the region south and east from Keweenaw Bay. Although Mr. Wadsworth feels obliged to explain away its silicious character by a supposed process of leaching by hot water, the lithological character of the Eastern Sandstone, but for its carrying pebbles of Keweenawan eruptives, would be more in favor of his view than against it. If the Eastern Sandstone antedates all of the Keweenaw Series it should present a strong lithological contrast with the detrital rocks of that series, having been derived from a wholly different source.

Moreover, there are general considerations which would make this view impossible of acceptance, even were the occurrences at the contact not so conclusively against it as they are. If the whole mass of the Keweenaw Point succession overlies the Eastern Sandstone, what has become of this seven miles of rock thickness to the eastward? It will not do to say that we are dealing here with eruptive rocks which thicken and thin suddenly, and cannot therefore be reasoned about in the same manner in which we would deal with beds of sediment. No eruptive agencies ever pile up seven miles of rock with a vertical wall of that height extending over a hundred miles in length. Besides, in this case the eruptive beds or flows are structurally just like beds of sediment, which thicken and thin also. Yet more, fully two miles of the thickness is of sediment. Nothing but an immense erosion on Mr. Wadsworth's view of the inferior position of the Eastern Sandstone can explain the disappearance of so great a thickness of strata. But an erosion which has stopped suddenly on so sharp a line, parallel to the general trend of the layers, and yet has left nowhere behind this line a trace of the former extent to the south and east of this immense thickness of resistant beds, while leaving undenuded over a wide area an inconsiderable thickness of an underlying fragile sandstone, is incredible. Again, east of Marquette the Eastern Sandstone appears to pass upwards insensibly into the beds of the Calciferous. Yet on Keweenaw Point, only a few miles away, this theory supposes that between these horizons there exists a thickness of seven miles of rock, of which two are of purely sedimentary material.

It seems to me that the south face of the Keweenaw Range is both a fault cliff and a shore cliff, against which the newer Eastern Sandstone was laid down, but not until after a large erosion; and that faulting took place again after or else continued until after the deposition of the sandstone. The original faulting seems to be demanded on this line by the general structural relations of the Keweenaw and South ranges, as shown on a previous page, and by the absence of outliers of the immense thickness of rocks of the Keweenaw Range to the southward. That the Eastern Sandstone was deposited subsequently to this first faulting is evidenced by its containing conglomerate layers in which the pebbles are frequently of Keweenawan eruptives, basic as well as acid (Bête Grise Bay), and by the way in which it cuts across the course of the South Range beds. That faulting motion took place along the fault line after or during the deposition of the Eastern Sandstone, is indicated by the way in which the sandstone dips southward along the junction at the south side of the Keweenaw Range.

THE WESTERN SANDSTONE.

The Apostle Islands and the adjoining coast of Bayfield County, Wisconsin, are composed of a horizontally placed sandstone, closely resembling in character the Eastern Sandstone of Keweenaw Point. I have described this sandstone somewhat fully in another place.[1] From the head of Chaquamegon Bay eastward there are no rock exposures on the coast until Clinton Point is reached, four miles above the mouth of Montreal River. Here are flat ledges of sandstone of some size at the water level. I take them to mark the easternmost point of the Western Sandstone, though this cannot, from their position only, be regarded as certain. At the mouth of the Montreal occurs the vertically placed sandstone of the Upper Division of the Keweenaw Series, with an immense thickness, as already described. Westward from the Apostle Islands this sandstone has been traced to the head of the lake, and in Douglas County, Wisconsin, may be seen at a number of points in direct contact with the south-dipping Keweenawan diabases. In all of this region this sandstone preserves its predominatingly

[1] Geology of Wisconsin, Vol. III, p. 207.

quartzose character, being at times just like the darker colored portions of the quartzose sandstone of the central part of Wisconsin.

The phenomena of the contact in the Douglas County Copper Range have been described in some detail on a previous page, where I have also shown that the Western Sandstone in all probability sustains the same relations to the Keweenawan diabases against which it rests as does the Eastern Sandstone of Keweenaw Point to the north-dipping beds of that typical region, this similarity of relation being carried out even to the faulting that I have shown to obtain in the latter district.

This similarity of structural relations, taken together with similarity in lithological character, renders it very probable that the Eastern and Western Sandstones are geologically equivalent. But they are nowhere connected, and the Western Sandstone has not been traced to any point where its relation to any of the Mississippi Valley fossiliferous formations can with certainty be made out, although the appearances in northwestern Wisconsin and northeastern Minnesota are decidedly in favor of its being the downward continuation of the Mississippi Valley Cambrian Sandstone.

THE MISSISSIPPI VALLEY CAMBRIAN OR POTSDAM SANDSTONE.

I have already shown that the Keweenawan diabases and interbedded conglomerates are traceable, mile by mile, from the typical region of Keweenaw Point to the Saint Croix River on the west side of Wisconsin; and that here they underlie the fossiliferous Cambrian Sandstone of the Mississippi Valley, in such a manner as to render certain the tilting and great erosion of the Keweenawan beds before the deposition of the sandstone; the latter for fifty miles in an N. E.–S. W. direction, with interruptions due to denudation, lying athwart the course of the tilted Keweenawn beds, which are here disposed in synclinal form. Whatever difficulties may hang about the structural relation of the Eastern and Western Sandstone of Lake Superior, there are here none; so unmistakable are their structural relations in this region, that any geologist still doubting the separation of the Keweenawan rocks from the overlying Cambrian Sandstones by an intervening disturbance and erosion should feel himself debarred from denial until he has thoroughly examined the facts in the field.

SECTION II.—THE OLDER FORMATIONS.

THE ANIMIKIE GROUP.

At Grand Portage Bay, on the east end of the Minnesota coast, there rise from beneath the typical Keweenawan diabases, beds of slate and quartzite. These beds are finely shown immediately behind the Indian village at Grand Portage. Here may be seen a large thickness of a thin-laminated, black to dark-gray slate, which is now aphanitic and clay-slate-like, and now more distinctly arenaceous. Some of the layers carry numerous shiny mica scales along the lamination planes, and the whole exposure is in striking contrast to anything in the Keweenaw Series above. The whole thickness trends N. 70° W. and dips 10° to the S. W. The cleavage planes are lamination planes and not due to slaty cleavage. A great dike, standing vertically, and trending east and west, with a width of 50 to 75 feet, cuts the slate, which for a long distance is weathered away, leaving the dike standing as a bold wall, in places over a hundred feet in height. The dike rock is a fine-grained, black diabase, which is peculiar for having the black iron oxide constituent in long rods, which often lie parallel for considerable distances, two parallel systems at times crossing each other. The augite individuals have their contours only in part determined by the feldspars.

At the northeast end of the large island at the mouth of Grand Portage Bay, these slates may be seen directly overlain by the Keweenawan diabases, as described on a previous page. The slates do not rise here very high above the water, most of the island being composed of the overlying diabase. Much of the slaty rock here is a very highly but finely arenaceous, nearly white quartzite, carrying pebbles of white quartz, and consisting, as seen under the microscope, of wholly fragmental material, in the shape of subangular to angular quartz grains, mingled with a few of decomposed feldspars, all imbedded in a finer material, which appears to be partly clayey and partly arenaceous. The dip of these slates, 10° S. E., is in entire conformity with that of the overlying diabases. The slates of Portage Bay Island belong above those of the cliff behind the village, having their low position by virtue of the southeast dip.

On Hat Point again, at the east side of Portage Bay, the slates are finely exposed on both sides of the point, where they are gray to black argillaceous quartz-slates, marked by thin lines of lamination, and strongly jointed by cross-joints. Cutting the slate on the east side of the point, where the dip is nearer 15° than 10° S. E., are several east and west dikes. One of these, twenty feet wide, is of a black rock, which under the microscope resembles the rock of the dike back of Grand Portage village, but is coarser in grain. It is distinctly an orthoclase-gabbro. The body of Hat Point, however, is formed by what may be a great dike, though it seems to be an immense overlying mass, upwards of 300 feet thick, of a medium-grained to coarse-grained, very highly crystalline, light-gray olivine-gabbro. Thin sections of this rock show very abundant olivines of large size—up to two-tenths of an inch across—and extraordinarily fresh, they being only here and there crossed by brown ocherous bands. The other ingredients are greatly predominant and very fresh anorthite, the usual titaniferous magnetite, and sparse diallage. In the gabbro are included irregular blotches of darker-colored rock, which in the thin section are seen to be almost or quite without the olivine, and to have the diallage relatively very abundant. The Hat Point gabbro is not to be distinguished in the thin section from the similar olivinitic rocks of the Bad River region of Wisconsin and of the Cloquet River of Minnesota. I have already suggested the possibility of the two belonging to a corresponding horizon, or rather to the same general time of outflow. At the end of Hat Point the overlying gabbro mass sinks to the water's edge, and the whole appearance is that of slight discordance to the underlying slate.

Hat Point forms the west side of Wauswaugoning Bay. All around the head of the bay are bold cliffs of slate, and of the gabbro of a great dike. At the east side of Wauswaugoning Bay are immense exposures of slate and cutting dike masses. Here the slates are often hard, dense, sharp-edged, ringing quartzites, in layers one inch to six and even eight inches in thickness. These hard kinds are interbedded with more slaty kinds, some of which are lustrous, dark-gray to black clay-slates, and others quartz-schists, in which the quartzose and argillaceous portions are mingled in various proportions. Some of these slaty layers are indistinguishable from the quartz-schists of the lower part of the Huronian Series at Penokee Gap; and the whole aspect is precisely that of the South Shore Huronian quartzites and quartz-schists of different horizons. A thin section of one of the more quartzose kinds showed it to be made up of angular quartz fragments, with a finer matrix, and some areas of quartz not so distinctly fragmental. The strike and dip, obtained at a number of places in this vicinity from large dip-surfaces, range between N. 55° and 65° E. for the strike, and 10° S. E. and 15° S. E. for the dip, the higher angles being the more common. The dikes on the east side of Wauswaugoning Bay run east and west, and are closely like those of Grand Portage Bay in character. The thin section of the rock of one of them showed the same peculiar rod-like magnetites seen in the Grand Portage dike-rock, but the rock is intensely altered, having all the augite turned into greenish material.

The inner ones of the Lucille group of islands are again composed of the slates, dipping in the same way; the outer ones, as already said, being formed of the overlying Keweenawan diabases. On one island, however —the one called Brick Island on the United States Lake Survey chart—the rock is very peculiar. It is pink to bright brick-red in color, thinly and very distinctly stratified, dipping S. E. 8½°, and is plainly part of the slate series. In the field this rock was taken to be simply a red variety of the usual quartzite seen all about on the adjoining coast and islands. But an inspection of the hand specimen shows that it is finely crystalline, while the thin section reveals a rock very close to those red rocks of the Keweenaw Series which I have described under the names of augite-syenite and granitic porphyry; that is to say, it is a mass of feldspar crystals, saturated with secondary quartz arranged in the usual graphic form, while other larger quartz areas seem also to belong with the secondary quartz. Here and there is an augite crystal to complete the resemblance, and there is no trace of fragmental texture.

Pigeon Point, the extreme eastern end of the Minnesota coast, shows the slates in fine exposure along its southern side, and with much the same characters as above described; *i. e.*, dark-gray to black, more or less highly argillaceous or clay-slate-like layers, alternating with others that are more quartzitic. Places, too, were noted on the point where a red rock, apparently bedded just like the slates, and dipping like them, was exposed on a large scale. The thin section shows that this rock is the same as that from Brick Island, above described. Its relation to the surrounding slates is worthy of very careful study. Unfortunately at the time of my visit its nature was not realized, and being taken merely as a phase of the slaty quartzites around, it was not given any especial attention. It is this red rock on Pigeon Point that has caused Foster and Whitney, on Mather's authority,[1] to mark this point as granitic on their large map of the Lake Superior region. The Pigeon Point slates maintain a constant lakeward dip at an angle of 15° to 20°, and even 25°, the usual trend being more to the north than that of the point itself. The high dip along most of the point is noteworthy.

Cutting the slates along the south side of Pigeon Point are a number of dikes trending often nearly east and west, and in other cases in a northerly direction. Some of these dikes are composed of the same orthoclase-gabbro as that noted in the dikes on Grand Portage and Wauswaugoning bays. One dike was observed, however, in which the rock was a fine-grained olivine-gabbro, or luster-mottled rock, close to the melaphyrs of Pumpelly. It is, in fact, save as to greater fineness of grain, identical with the type rock of the Greenstone of Keweenaw Point. On the north side of Pigeon Point are cliffs of a coarse, light-gray, fresh olivine-gabbro, which appear to form a dike of large size through much of the length of the point.

Following Pigeon River upwards from its mouth, slates and slaty quartzites are found all the way to the head of the stream, and beyond to Gunflint Lake, on the national boundary line. The general dip of these rocks, which have never been examined in detail, is southeast, at an angle of some 10°, which would give a thickness of some 10,000 feet for the slate series as seen along the national boundary line. Peculiar cherty layers are met with at low horizons in the slates, and also banded lean magnetic iron ores closely similar to the lean iron ores of the Penokee region of Wisconsin.

By all the geologists[2] who have traversed this region these slates are described as cut by immense numbers of large dikes, which often

[1] See large map of Lake Superior, accompanying Foster and Whitney's Report.

[2] Richard Owen, Bell, N. H. Winchell.

form bold ridges several hundred feet in height, crossing the country in straight lines. Dikes like the smaller ones of Pigeon Point also occur, and also great overflows and interbedded masses of basaltic rocks. At the first great fall, two miles above the mouth of the river, two of these great dikes are to be seen. One of these, over which the river falls, is, according to Richard Owen,[1] 212 feet wide, and its course northeast, which corresponds with the course of similar great masses noted on the west side of Thunder Bay. The rock of this great dike is a medium-grained to coarse-grained, light-gray, rough-textured, highly crystalline olivine-gabbro. The thin section shows exceedingly fresh and abundant olivine, along with tabular anorthite, very fresh diallage, and a little magnetite.

Following the west shore of Thunder Bay from Pigeon Point, the slates with interbedded and overlying masses of fine-grained diabase and coarse gabbro, and dikes of the same rocks, are displayed on a grand scale. The numerous islands in the mouth of the bay are also composed of the same rocks, many of the smaller islets showing only the dike rock, a whole line of islands marking often the course of a single dike. The shore of the bays south of the valley of the Kaministiquia is often overlooked by bold cliffs of slate and gabbro, 500 to 800 feet in height. The slates of these exposures vary from soft, thin-laminated, black or dark-gray clay-slates to hard, ringing, light-gray quartzites occurring in layers several inches in thickness. All show a distinctly fragmental character beneath the microscope, but many of the quartzites show also quartz areas like those of an ordinary gneiss. The dip of the slates continues to the southeast in this distance, the trend growing, however, more and more northerly as the valley of the Kaministiquia is approached, while the dip is usually flatter than 10°, being often not more than 2° or 3°.

Of the dikes in this distance one class, including the broader ones, in which the rock is relatively coarse-grained, are commonly of a very fresh olivine-gabbro like that of the great dike at the falls of Pigeon River, which belongs to this class. These larger dikes can be finely seen, for instance, on the north side of the south point of Big Trout Bay, where they project into the water in great buttress-like forms, 100 to 200 feet in height and trend-

[1] Owen's Geological Survey of Wisconsin, Iowa, and Minnesota, p. 405.

ing N. 60° E. The following are the results of the examination of some thin sections of the rocks from some of these larger dikes.

The coarse-grained, dark-gray, rough-textured rock from the island in the mouth of the south arm of Pigeon Bay shows fresh diallage predominating, labradorite, a little titanic magnetite, and a few grains of olivine altered to a brownish substance. The rock from the island in the mouth of Big Trout Bay is dark-gray, medium-grained to coarse-grained, and marked by very large-sized and noticeable luster-mottlings, due to the large augites. The thin section shows exceedingly fresh diallage, in relatively great areas; very fresh anorthite, numbers of crystals of which mineral are often inclosed within the diallages; olivine, often quite fresh, and not abundant magnetite. The rock is an exceedingly fresh one, and is very close to that of the Greenstone of Keweenaw Point.

Other dikes, nearly as large as these, are of an orthoclase-bearing gabbro, allied to that occurring in the Keweenaw Series as flows, as, for instance, the rock of a broad dike on the north side of Big Trout Bay, in which the constituents are orthoclase and oligoclase much reddened and clouded, and now and then replaced by secondary quartz; diallage partly fresh and partly altered to a greenish substance, and titanic magnetite. Apatite is also present, and the whole aspect is much like that of the finer-grained Keweenawan orthoclase-gabbro, as, for instance, that of the ledges just west of Lester River, and especially that of the Bohemian Mountain, just north of Lac la Belle, Keweenaw Point.

The coarse-grained, light-gray rock from just north of the mouth of Pigeon River is another orthoclase-bearing gabbro, in a much fresher condition and with relatively less orthoclase. Abundant and rather fresh diallage, labradorite, orthoclase, magnetite, a little secondary quartz, and apatite are the constituents. This rock is much like the Duluth orthoclase-gabbro, except that it is finer in grain. It is a kind nearer than usual to the non-orthoclastic gabbros. A pink- and black-mottled rock from Victoria Island, which is part of a dike continuing to the northeast through Spar and Thompson islands, is at the other extreme. The diallage is relatively sparse and wholly altered to uralite. The feldspars are very profoundly altered, and largely replaced by secondary quartz, which also is present in quite large areas, filling corners between the feldspars. This rock is as near to the augite-syenites as to the orthoclase-gabbros.[1] The smaller dikes, usually under twenty feet in width, are of a denser rock, the only section of which examined showed a very highly augitic diabase allied to the ashbed kinds. All of these dikes have a general northeasterly trend, but the amount of easting lessens as they are followed northeastward. This may be seen in a single dike in the case of the Victoria Island group of islands, which to the southwest trends N. 60° E. and to the northeast N. 52° E.

Of the crystalline rocks interbedded with the slates, the greatest masses, often over a hundred feet in thickness, appear to be olivine-gabbros and orthoclase-gabbros, identical with the two kinds of rocks of the broader dikes. These masses beyond question are interbedded with the slates, and though no direct connection was seen between them and the dikes, from the nature of the rocks such a connection is probable enough. The rock of the great mass capping the bluff just north of Sucker Brook, for instance, is an orthoclase-bearing gabbro very close to the dike rock of the mouth of Pigeon River, and on the same bluff, at a lower level, precisely the same orthoclase-bearing rock is seen cutting the slate, the probability being very strong that the two are connected. In thin section this rock shows labradorite, some orthoclase, abundant augite or diallage, partly much altered and partly in quite fresh, long, twinned blades, and very abundant magnetite in long, rod-like forms.

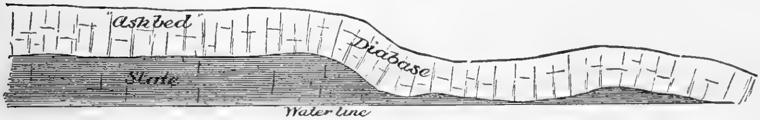

Fig. 33.—Bed of intrusive diabase in Animikie slates, Pigeon Bay, Canada.

Besides these greater imbedded masses, thinner, strongly cross-columnar beds of a dark crystalline rock are often seen. These are at times only four to six feet thick. They generally run in strict parallelism to the included slates, but in one or two places were noticed distinctly traversing

[1] To judge from other hand specimens brought away, the one from which this slice was made does not represent the dike of Victoria, Thompson, and Spar islands for any great distance. The other specimens, not sectioned, look more like some of the olivine-bearing kinds.

the slate for a short distance, as indicated in the preceding sketch, which was taken on the north side of the south arm of Pigeon Bay. The slate laminæ run against the crystalline rock without alteration or disturbance, and the whole structure is an unmistakable one. The columnar rock is black, excessively fine-grained, and breaks with a conchoidal fracture. Under the microscope it shows a groundmass in which are recognizable tabular oligoclases, rounded augite particles, magnetite, and some non-polarizing substance. A few porphyritic oligoclases are seen, and the section is close to that of the so-called ashbed-diabases. It might very well be a very fine-grained phase of the coarser orthoclase-gabbro that forms the neighboring large dikes and overflows.

The researches of Bell[1] and Logan[2] have shown that an area to the west of Thunder Bay, bounded on the north by a line from Gunflint Lake, on the national boundary line, to the Grand or Kakabika Falls, on the Kaministiquia, is very often underlain by the same series of slates that form the west side of Thunder Bay, intersected here by the same grand system of dikes, which are often met with crossing the country in great walls or forming bold linear ridges. The same overflows and interbedded masses also occur, and often form the tops of table-like elevations. Among the boldest of these is the line of bluffs forming the south side of the lower stretch of the valley of the Kaministiquia, McKay's Mountain, a portion of this elevation, rising to a height of 1,000 feet. Throughout all of this area the flat southeasterly dip prevails, though at times there is a little variation from horizontality, while occasionally there is a slight slant northward for short distances.

It is of the greatest interest in this connection that Bell reports the existence as part of the slate series in the valley of the Kaministiquia—as, for instance, at "a place called the Algoma mine"—of "thinly-bedded, flaggy, hard, dark-gray sandstone, largely composed of particles of magnetic iron, and weathering to a rusty color." There are exposed about twenty feet of the beds. An analysis showed 37.73 per cent. of metallic iron. "The same highly ferruginous sandstone, dipping very slightly east-

[1] Geology of Canada, 1863, pp. 67–70.
[2] Geol. Survey of Canada, Report for 1866–'69, p. 321, *et seq.*

northeast, is again exposed on the banks of a brook rather more than a mile north of the Algoma mine." The same interest attaches to the occurrences at numbers of places of layers of concretionary chert and "bands of a reddish jasper," and dolomite.

Bounding this slate region on the north is a district or belt of granite and contorted gneiss. From Kakabika Falls the southern boundary of the gneiss is "roughly indicated by a line drawn from the Great Falls to a point on the north shore of Thunder Bay, about six miles east of the mouth of Current River." All along this shore of Thunder Bay I found the conditions observed on the west shore repeated, save that the great bluffs of slate and gabbro are wanting. Numerous interbedded layers of black crystalline rocks were observed, however, dipping southeast 5° with the accompanying slates, and affected by a strong cross-columnar structure. At Bare Point, for instance, three miles below Prince Arthur's Landing, and a mile below the mouth of Current River, there is a thin interstratified bed, dipping 6° to 8° southeast,[1] of a very fine-grained, dark-gray diabase-porphyrite, with a groundmass composed of tabular plagioclases, augite granules, and non-polarizing substance, and abundant porphyritic crystals of labradorite, and a few of altered augite. The rock is closely allied to the ashbed traps of the Keweenawan.

East from Goose Point, nearly to the head of Thunder Bay, the older gneiss is generally seen at the bottoms of the coves, while the points and islands are formed of the slates with interstratified crystalline rocks. A ten-foot bed of cross-columnar, light-gray, coarse-grained rock from one of the islands nearest below Goose Point proves under the microscope to be, as was expected, a very fresh olivine-gabbro, with abundant olivine, diallage, augite, anorthite, and titanic magnetite as the constituents. A twenty-foot columnar layer, seen on some of the islands just opposite Caribou Island, and on an adjoining point of the mainland, is also olivinitic diabase or gabbro, but finer-grained than the last, and with the olivine much altered. Near the head of Thunder Bay some of the cherty layers of this series are to be seen. Some of these layers show chert interlami-

[1] Not 20° to 25°, as Bell has it. *Op. cit.*, p. 325.

nated with the usual slaty material of the series. Others show a peculiar concretionary arrangement.

Still nearer the head of the bay come in the dolomitic sandstones of the overlying Keweenawan. Where first seen these sandstones are often conglomeratic, holding pebbles of the older slates and especially of the chert layers upon which they directly rest. Along the southeast shore of Thunder Bay the slates are here and there seen at the water's edge, but above them the cliffs of newer sandstone, with one or more beds of chert-conglomerate, rise to a height of 200 feet above the lake. These conditions continue for a number of miles. Before reaching the deep bay on the north side of Thunder Cape a number of narrow dikes were passed which intersect these slates. Fifteen of these dikes were counted in a distance of about ten miles. They are usually under 15 feet across, the widest not exceeding 20 feet, while some are only 4 feet in width. Most of them stand vertically, trending from N. 75° E. to east and west. One was noticed dipping 60° south, with a strong columnar cross-jointing at right angles to this direction. It could not be made out that these dikes cut the overlying sandstones. The one thin section of the dike-rock examined showed an olivine-free diabase or gabbro of moderately coarse grain, containing predominating augite, partly fresh and partly altered to greenish material, labradorite, a little orthoclase, and magnetite. The rock lies between the olivinitic gabbros and the orthoclase-gabbros proper.

At the deep bay just above Thunder Cape the white sandstones, which have heretofore formed the cliffs of the entire southeast side of the bay, swing away from the coast to the southeastward, reappearing on the lake front near Silver Islet Landing, and leaving between them and the extremity of the cape a triangular area, which is occupied entirely by the slates I have been describing, capped by an immense overlying mass of olivinitic gabbro, upwards of 200 feet in thickness. The whole height of Thunder Cape is over 1,000 feet, from 700 to 800 feet of which must be occupied by the slates, which thus rise entirely across the horizon of the sandstones mentioned, and several hundred feet higher than they do. Such a relation can only be explained by supposing a great fault, as Logan did, by which these slates are brought up; or by supposing an erosion to intervene between the slates and the overlying white sandstones. The latter appears to me beyond doubt the true explanation, since all along the east coast of Thunder Bay, where these sandstones are found, the slates would naturally occur in large thickness, to judge from the exposures on the north and west sides of the bay. Such an unconformity is further strongly suggested by the fact that only a few miles to the east of Thunder Bay, on Black Bay, the sandstones are found lying directly against the older gneisses, without the intervening slate. This unconformity has been previously suggested by Hunt,[1] whom, however, I cannot follow in his supposition that both the slate and overlying sandstone are newer than the Keweenawan.

The capping rock of Thunder Cape is, as already indicated, an olivinitic gabbro, not in any respect differing from the rock described before as occurring in a number of places within the Keweenawan, and within the formation now under description, as dikes and overflows. It is medium-grained to coarse-grained, light-gray to dark-gray, and very highly crystalline. The diallage is predominant in large areas, often including a number of feldspars; the olivine is very plenty and coarse, and often fresh, but as often altered to an ocherous product; while the plagioclase is, as usual in these olivinitic rocks, anorthite, as shown by a large number of optical measurements. The rock is close to the coarse olivine-gabbros of Bad River, Wisconsin, standing between them and the coarser luster-mottled melaphyrs, which, as shown heretofore, are to be regarded as merely a finer phase of the olivinitic gabbros. This rock has been described by Macfarlane under the name of hyperite, with feldspar and hypersthene as the chief constituents, and hornblende and magnetite as accessories; a description which illustrates well the unreliableness of rock determinations made without the use of the microscope, even when the observer is a skilled one like Macfarlane.

The slates at Thunder Cape are quite arenaceous, in some layers so much so as to have received the name of sandstone from the Canadian geologists. They are from very fine-grained to aphanitic, in the more shaly layers, and vary from a dark-gray to black color. The layers are commonly very thin, and show a fine subordinate lamination. I have not

[1] Second Geological Survey of Pennsylvania, Azoic Rocks, Part I, p. 239.

made any section of them. From Macfarlane's analyses,[1] however, it is evident that the more arenaceous layers are made up chiefly of quartz-grains, along with some argillaceous and calcareous matter, while the shaly layers contain more of the argillaceous substance, which, from the presence of alkalies, is plainly in the nature of decomposed and partly decomposed feldspars. Macfarlane also considers that the presence of some carbonaceous matter is included in the loss on heating. The shaly layers never contain any lime or magnesia carbonates, but these carbonates are occasionally present in the more compact layers up to 20 per cent., or more.

Rounding Thunder Cape, the slates are found continuing as far as Silver Islet Landing, at which place they are overlain by the white and red sandstones of the Keweenaw Series. Here, again, they are only a short distance above the water, an amount of sinking being thus indicated which the very flat southeastward dip will not account for, but which, as already shown, must be attributed to an intervening erosion.

Between Thunder Cape and Silver Islet a large number of dikes are seen cutting the slates. Only one of these dike rocks, which appear for the most part to be the same as those which form the numerous dikes of the southwest shore of Thunder Bay, already described, was examined. This is the rock which forms the dike at Silver Islet. It is a nearly black, rather fine-grained rock, distinctly composed of a greenish-black and a white mineral, the latter being, of course, the feldspar. According to Macfarlane, its specific gravity is 2.7, and its silica content 53.34 per cent. It contains 5.02 per cent. of water, an amount indicating a considerable alteration; and this indication is fully borne out by a microscopic study of the thin section. This shows tabular plagioclases, with some orthoclases, as predominating ingredients. These feldspars are all much dulled by alteration, and are often penetrated by secondary quartz. In many places the larger feldspars have between them a mass of smaller, much crushed, and always highly altered feldspars. The augitic ingredient is only partly fresh, being commonly much altered to ocher and uralite, with which alteration is connected the formation of some magnetite. Rather abundant titanic iron, for the most part altered to its characteristic gray decomposi-

[1] Canadian Naturalist, New Series, Vol. IV, p. 37.

tion-product, and sparse apatite, complete the resemblance between this rock and the finer orthoclase-gabbros of the Keweenawan.

The dikes appear also to cut the overlying sandstone for some little distance beyond Silver Islet Landing, but as to whether they have actually filled fissures in the sandstone, or have had the sandstone deposited around them, I did not satisfy myself. At Silver Islet Landing, for instance, one narrow dike was noticed cutting the slate, and the overlying chert-conglomerate and sandstone. On one side of the dike the junction of the sandstone and slate is twenty feet higher than on the other, which fact might point either to unconformity or to faulting on the line of the dike.

So far, then, as I have been able to learn by original observation, and by reading in the light of the observations the accounts of others, the Animikie rocks of the Pigeon River-Thunder Bay region consist of a great series, probably upwards of 10,000 feet in thickness, of quartzites, which are often arenaceous, quartz slates, argillaceous or clay slates, magnetitic quartzites and sandstones, thin limestone beds, and beds of a cherty and jaspery material. With these are associated, in great volume, and in both interbedded and intersecting masses, several types of coarse gabbro and fine-grained diabase, all of the types being well known in the Keweenaw Series.

Any one familiar with the descriptions of the Thunder Bay region by Logan, Macfarlane, and Bell, will see at once that in the statements of the last paragraph I have departed widely from the conclusions of these geologists as to both the thickness and composition of the Animikie Group. Their descriptions are, however, misleading on these points, being based almost exclusively upon what is seen on Thunder Bay, which lies where only a relatively small thickness is exposed, and where the rocks sometimes come nearer to being "sandstones and shales"—the terms used by them—than elsewhere. Logan, moreover, evidently took as Huronian that part of the Animikie Group which occupies "the coast for a distance of ten miles immediately below the mouth of the Kaministiquia River on the north side, leaning in a narrow strip against the gneiss of the older series."[1] Bell includes these rocks with the rest of the Animikie Group, where, as I have indicated above, they unquestionably belong.

[1] Geology of Canada, p. 63.

The following is Bell's stratigraphical scheme for the Animikie Group, or "Lower Group of the Upper Copper Bearing Rocks."[1]

	Feet.
1. Conglomerates composed of pebbles of quartz, jasper, and greenish slate, in a greenish arenaceous matrix. Seen on the north shore of Thunder Bay. Estimated thickness	70
2. Chert layers, mostly thin and having a ribbon-like appearance in cross-section. The mass is generally dark, but some light-colored layers occur. Thin beds of dolomite sometimes separate the chert layers from one another, and argillaceous layers are also occasionally interstratified; while bands of dolomite, which are themselves sometimes separated by argillaceous beds, are interstratified with the foregoing. The chert bands contain iron pyrites in specks, nodules, and thin interrupted layers. A mineral resembling anthracite also occurs in the rocks of this and the following division. Seen at the eastern extremity of Thunder Bay, and near the five-mile post on the Red River road. Estimated thickness	300
3. Darkly-colored massive argillites and flaggy black shales, the mass being characterized by numerous vertical joints, running in two directions, and dividing it into blocks of a very symmetrical character. The shaly portions hold regularly formed spheroidal concretions of various sizes. Trap beds are associated with these rocks along the north shore of Thunder Bay, at the Thunder Bay mine, and in the township of McIntyre. The shales are seen on this part of the Kaministiquia River, especially at the Grand Falls, and along the coast of Lake Superior, between Fort William and Pigeon River, while an example of the massive may be seen in the workings of the Thunder Bay mine. Estimated thickness	450
4. Grey argillaceous sandstones and shales, mostly thinly and evenly bedded, fine-grained, and slightly calcareous. Examples of both of these rocks may be observed on each side of Thunder Cape, and in the township of McIntyre. In the southern part of this township, and at the northwestern corner of Neebing, bands of sandstone, supposed to belong to this division, occur, containing a large percentage of magnetic iron ore. Estimated thickness	400

This scheme, which is pretty much that of Logan, is obtained by building up from the exposures near the underlying gneiss in the northeast corner of Thunder Bay. But gneiss and granite evidently do not always come against the same horizon of the Animikie slates, so that such a scheme would be unsatisfactory in any case, even were its truth not distinctly disproved by the occurrences along Pigeon River and thence west and south, where it is plain, from the constant southward dip and broad area occupied, that there is a thickness of fully 10,000 feet. Even at the Silver Islet

[1] Geol. Survey of Canada, Rep't for 1868–'69, p. 318.

mine the hard quartzitic slates have already been carried down 1,000 feet or more below the lake level, a distance which would make the total thickness actually measurable in that vicinity far beyond Bell's total.

There are other serious objections to Bell's stratigraphical scheme. The conglomerates, which according to him form the base of the series in the northeast angle of Thunder Bay, seem to me rather—unless, as does not appear probable, I did not visit the place described by him—to belong to the overlying white sandstones of the Keweenawan. Then he fails to recognize the quartzitic character of the body of the formation, while the magnetitic arenaceous rock of the township of Neebing, which he places near the summit of the formation and as equivalent to the Thunder Cape beds, I should place many thousand feet below. These magnetitic beds are the same as those of the Mesabi Range of the Vermillion Lake region of Minnesota, of Gunflint Lake on the national boundary, and of Pokegoma Falls on the Mississippi River, and belong much nearer the base than the summit of the formation. It is very difficult to see how Bell could parallelize the Thunder Cape beds, manifestly near the top of the formation, with beds lying twenty miles to the northwest, when he at the same time admits a general southeasterly dip throughout the whole area.

Then, again, the great volume of included beds of gabbro and diabase is almost entirely ignored. In the third division of his scheme it is said that "trap beds are associated with these rocks along the north shore of Thunder Bay, at the Thunder Bay mine, and in the township of McIntyre,"[1] and yet the whole volume of this division is placed at only 450 feet. But, as seen, all the way from Wauswaugoning Bay on the Minnesota coast to the south side of the Kaministiquia Valley, and again in the Pigeon River country of Minnesota, these included beds must aggregate over a thousand feet, while they may be much more than this. This important omission is probably to be explained by Bell's having regarded all of these beds as part of the so-called "crowning overflow," which is supposed to have taken place after the accumulation and removal of the thousands of feet of newer Keweenawan or copper-bearing strata.

The only evidence of any such general overflow consists in the simi-

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[1] Op. cit., p. 319.

larity of the crystalline rocks found capping hills in different parts of this region. Not only is it much more in accordance with the geology of the entire Lake Superior region to suppose these occurrences to represent many different flows, but there is distinct evidence that they do so in many cases. This evidence consists in part in actual visible interstratification with the slates, in some places, of great beds of olivinitic gabbro, identical both macroscopically and microscopically with the rock capping Thunder Cape. Another evidence is the very great irregularity of level that this supposed flow must occupy, the height at which it is found varying back and forth through distances of several hundred feet. A yet stronger evidence is found in the general structural character of the region, by virtue of which each heavy, enduring, crystalline rock layer constitutes a ridge with a long front slope and a precipitous back slope. This structure is especially well marked in the region of the Pigeon River, Minnesota.[1] Even a general distant view of the belts to the west and south from the head of Thunder Bay is strongly suggestive of this structure.

I have no confidence, then, in the existence of any one crowning overflow, as supposed by Logan, Bell, and Macfarlane. Bell goes so far as to identify all exposures of rock, lithologically similar (macroscopically) to the Thunder Cape gabbro as parts of the crowning overflow, even as far north as the region about Lake Nipigon. Lithological similarity is no evidence of original continuity in this case, for all through the Keweenaw Series of the North and South Shores, similar olivinitic gabbros are visibly interstratified at all sorts of horizons.

As already indicated, the Animikie slates have been traced along the national boundary as far as Gunflint Lake by Bell,[2] and more recently by N. H. Winchell.[3] Thence their northern boundary extends southwest from Gunflint Lake. For many miles farther southwest the region traversed by these rocks has not been examined by any geologist, but their continuance here cannot be doubted, for in the Mesabi Range, in T. 60, R. 13 W., Minnesota, they show in full force. By the kindness of Prof. A. H.

[1] N. H. Winchell, in Ninth Annual Report of the Geological and Natural History Survey of Minnesota. Minneapolis, 1881. p. 76.

[2] Report of the Geological Survey of Canada, for 1872-'73, pp. 92-94.

[3] Ninth Annual Report of the Geological and Natural History Survey of Minnesota, pp. 82, 83.

Chester, I have a full collection of rocks from this place. He describes the Mesabi Range proper as a backbone of red granite, south of which occur the Animikie slates, which are here nearly horizontal, dipping 2° or 3° to the southeast. The exposures are large, presenting often a bold cliff side of nearly horizontal layers, and have been traced by Professor Chester a distance of some six miles along the strike, in the southwest part of T. 60, R. 12 W., and the southeast part of T. 60, R. 13 W. The principal rock is an arenaceous gray quartzite or quartz-slate, impregnated with magnetite, which is often aggregated into bands of some richness. The specimens kindly given me by Professor Chester are indistinguishable from much of the magnetitic quartzite of the Penokee Range of Wisconsin.[1]

Professor Chester writes me with regard to these rocks:

> On the south side of this range [the Mesabi Granite Range] magnetic iron is found in abundance, particularly in T. 60, R. 12 W. and 13 W. Here the ore body is of some magnitude, sufficient to induce a considerable exploration in this part, but no large bodies of ore have been found of sufficient value to warrant developments. The ore is magnetite, quite similar to that of the Penokee Range. It lies in nearly horizontal beds, interstratified with quartzite, so as to make it quite impossible to sort out any quantity of good ore. In places where it is exposed on the surface for some distance, smoothed and polished by glacial action, at first glance it would be considered valuable, but closer inspection shows that it is mixed with rock so as to have a striped appearance. This is particularly noticeable in the sides of the pits sunk down in it. A layer that shows the best ore on one side of the pit is white quartzite on the other. The layers of good ore are thin, about six inches being the thickest found that showed good ore all across, and would average 60 per cent. of iron. A cliff in Sec. 17, T. 60, R. 12 W., shows as follows, beginning at top: Ore of about 50 per cent., 2 inches; ore with some bands of 60 per cent., 1 foot 6 inches; ore much mixed with quartzite, 2 feet 6 inches; ore about 58 per cent., 2 inches; ore and quartzite poorer than above, 10 feet 8 inches; quartzite with very little ore, 10 feet. A great many such sections were examined, and about two feet of ore was the thickest layer found. The rocks are quartzites and slates, more or less altered. They lie more nearly horizontally than any other beds I have ever examined, changing dip very slightly from point to point, giving the idea of a sort of undulating surface, yet, on the whole, dipping slightly to the south.

This description, save as to the horizontality, would do as well for hundreds of exposures on the Penokee Range of Wisconsin.

Still farther southwest from here the same magnetitic rocks are exposed on the Mississippi River at Pokegoma Falls in the eastern part of T. 55

[1] See Geology of Wisconsin, Vol. III, pp. 118–136.

R. 26 W., and again on Prairie River in sections 33 and 34, T. 56, R. 25 W. The rocks at these points are described as arenaceous quartzites with magnetite, dipping gently southward, by Mr. Bailey Willis, of the United States Geological Survey.

The line drawn from the Mesabi Iron Range to Pokegoma Falls indicates approximately the northern limit of the Animikie rocks. What becomes of these rocks still farther west is unknown. South of this line, however, are immense exposures of slates on the Saint Louis River, beginning one mile above Knife Falls, in Sec. 14, T. 49, R. 17 W., and continuing thence down stream to the S. W. ¼, Sec. 11, T. 48, R. 16 W., several miles below Thompson, where they disappear underneath the red sandstones, as previously described. These slates dip constantly southward, more often at a higher angle than 45° than at a lower. The strike is not exactly east, but more or less north of east, the northing increasing in amount to the eastward. Throughout, the slate is affected by a strong cleavage, which stands vertically, and trends with the strike of the rocks. Across these slates at right angles to the trend is a distance of several miles, which, with the high angle of dip, would indicate an enormous thickness, unless there are some folds here, which, from the presence of slaty cleavage, would seem probable. South and west from the Saint Louis the slates are known to continue for some miles, but their extent in that direction has not yet been worked out. These slates are clay-slates, light- and dark-gray and greenish being the prevailing colors. Often they merge into and include beds of quartz-slate, which under the microscope shows the quartz largely as a fragmental material, but also, in considerable measure, as an original constituent. Great dikes are seen at several points cutting the slates, trending northward, and composed of a moderately coarse, strongly augitic diabase or gabbro.

The Saint Louis River slates are plainly the same as the Thunder Bay slates, but affected by a slaty cleavage. They are lithologically the same, and are cut by the same great dikes. They are the upper portion of the series of which the Mesabi iron beds form the lower portion.

The rock series thus described under the name of the Animikie Group—a name first used by Hunt,[1] and referring to the Indian name of

[1] Trans. Amer. Inst. Mining Engineers, I, 339.

Thunder Bay—has been placed by Logan[1] and Bell[2] at the base of the copper-bearing series, the former geologist, in his Geology of Canada, speaking of it as the "Lower Group of the Upper Copper-bearing rocks." Macfarlane[3] and Hunt,[4] on the other hand, regard the Animikie rocks as altogether newer than the Keweenawan, which they are believed to overlie unconformably. Hunt says that they, together with the overlying sandstone of the east side of Thunder Bay, may even be mesozoic for all the evidence there is to the contrary.[5] There can be no doubt, however, that Logan and Bell are correct in placing the Animikie Group beneath the copper-bearing or Keweenawan rocks proper. This seems plainly indicated by the exposures the east side of Thunder Bay, and thence to Black and Nipigon bays, but to any one approaching from the southwest along the Minnesota coast becomes so absolutely certain as to admit of no question at all. Not only does one in descending the lower part of the Minnesota coast constantly cross the Keweenawan beds in descending order until the Animikie slates are reached at Grand Portage Bay, but on the large island at the mouth of this bay he may see slates underlying Keweenawan diabases in a continuous cliff exposure.

So far, then, I agree with Logan and Bell; but from their view that the Animikie rocks are but a downward continuation of the Keweenawan I must dissent altogether. The erosion which intervened between the two formations, as indicated by the already described occurrences on the east side of Thunder Bay, and again by those at the east end of the Minnesota coast, and the pronounced lithological contrast between the sedimentary beds of the two groups, both bear heavily against any such view. Moreover, the essential identity between the Animikie rocks and those of the Penokee region of Wisconsin, and their close similarity to the South Shore iron-bearing schists generally, make it plain to me that we are dealing here with the North Shore equivalents of the South Shore iron-bearing formation.

We have in the Animikie series, as in the South Shore Huronian, siliceous schists, quartzites, dolomites, chert beds, and magnetite-bearing quartz-

[1] Geology of Canada, 1863.
[2] Report of the Geological Survey of Canada for 1866–'69, p. 318.
[3] Canadian Naturalist, New Series, III, 252, IV, 38.
[4] 2d Geol. Surv. Pennsylvania, Azoic Rocks, Part I, p. 240.
[5] *Op. cit.*, p. 241.

ites and quartz-slates. In the Animikie Group these alternate with great interbedded flows of diabase and gabbro, and are intersected by great numbers of dikes of the same rock, the equivalents of which are to be found in the interbedded and intersecting diabases of the South Shore Huronian. The thickness of the Animikie rocks is a great one, and is comparable only with that of the South Shore Huronian. The affinity of the Animikie rocks is especially strong with the schists of the Penokee Range of Wisconsin, and these I have elsewhere shown to be essentially the same as the iron-bearing schists of Marquette. The Animikie series presents the smallest number of rock kinds, the Penokee series a larger number, and the Marquette and Menominee Huronian the most. Some of these differences may be made to disappear on closer study of the still quite imperfectly known Animikie rocks; while much of the greater variety in rock kinds on the South Shore is the result of metasomatic change upon the included eruptive rocks. Even the "diorites" of the South Shore Huronian are in all probability merely altered diabases. The greater variety in the kinds of schistose rocks is directly connected with greater amount of disturbance, and is the result of the obscure and ill-understood process known as metamorphism.

THE ORIGINAL HURONIAN.

The original Huronian of Logan and Murray forms the north shore of Lake Huron from the Saint Mary's River eastward. Logan's description of 1863[1] makes the rocks have a total thickness of 18,000 feet, composed as indicated in the following scheme, which is given in ascending order:[1]

	Feet.
1. Gray quartzite, thin bedded in some parts; the thickness is very doubtful,	500
2. Greenish, red-weathering chloritic and epidotic slates, interstratified with trap-like beds; of this mass also the thickness is very doubtful,.....	2,000
3. White quartzite, the color sometimes passing into gray; the rock is principally fine grained, but the granular texture is often lost, and great masses of it become vitreous quartzite. The rock on the other hand often becomes coarse grained and assumes the character of a conglomerate from the presence of pebbles, consisting chiefly of white quartz, varying from the size of duck-shot to that of musket-balls. The beds, which are generally massive, are frequently separated by layers of fine grained greenish-gray siliceous slate, and considerable masses of greenstone are frequently intercalated in different parts of the whole thickness, ...	1,000

[1] Geology of Canada, 1863, p. 55.

	Feet.
4. Slate conglomerate, composed of pebbles of gneiss and syenite held in an argillo-arenaceous cement of a gray or more frequently of a greenish color, the latter arising apparently from the presence of chlorite. The pebbles, which are of reddish and gray colors, vary greatly in size, being sometimes no larger than swan-shot, and at others bowlders rather than pebbles, measuring upwards of a foot in diameter; the proportions of these also vary much; they sometimes constitute nearly the whole mass of the rock, leaving but few interstices for the matrix, and sometimes on the contrary, they are so sparingly disseminated through considerable masses of the matrix as to leave spaces of several feet between neighboring pebbles, which may be still several inches in diameter; with the pebbles of gneiss and syenite are occasionally associated some of different colored jaspers and others of quartz. The matrix appears to pass on the one hand into a gray quartzite by an increased proportion of the arenaceous grains, and on the other into a thin bedded, dark greenish, fine grained slate, which is sometimes very chloritic. A third form assumed by the matrix is one in which it is scarcely distinguishable from fine grained greenstone. In the slate the stratification is often marked by slight differences of color, in the direction of which it is occasionally cleavable; the bands in other instances are firmly soldered together, but in both cases joints usually prevail, dividing the rock into rhomboidal forms which are sometimes very perfect. Very heavy masses of greenstone are generally interstratified in the rock, which do not seem confined to any one stratigraphical place,	1,280
5. Limestone, usually of a compact texture, but sometimes partially granular; the colors are green, drab, and dark gray, the latter two prevailing. Some beds are occasionally met with of a dull white, with a waxy luster in fresh fractures; these weather to a yellowish-brown on the exterior, and appear to be dolomitic. The whole band is in general thin bedded, and a diversity of character in the layers, probably arising from the presence of more or less siliceous matter, causes the surface of the weathered blocks to present a set of bold but minute ribs of various thicknesses, which when the beds are much affected, as they often are by diminutive undulations, contortions, and dislocations, exhibit on a small scale a beautiful representation of almost all the accidents that occur in stratification, affording very excellent ready-made geological models,	300
6. Slate conglomerate of the same general character as that beneath the limestone, but the pebbles are not so large; it is interstratified with beds of reddish and gray quartzite and layers of fine grained, greenish-black and light olive-green siliceous slate, some of which yield hones of a very fine description; considerable masses of greenstone are interstratified in various parts of the deposit,	3,000

	Feet.
7. Red quartzite, interstratified with masses of greenstone; the quartzite is in general granular and of moderately fine texture, but it occasionally becomes a fine conglomerate. The color is sometimes only a light tinge of red and at others a decided red, seemingly derived from minute and thickly disseminated spots or from a diffused tinge of an orange-red, probably due to the presence of iron, but the spots are sometimes of a larger size, and so arranged as to give to the rock a speckled aspect. The rock is in general thick bedded; some of the beds shew oblique elementary layers, or what is commonly called false bedding, and the surfaces of other beds display well defined ripple-marks; masses of greenstone are interstratified in the deposit, some of them of great thickness,	2,300
8. Red jasper conglomerates. The rock is sometimes a moderately fine grained white quartzite, often with a vitreous aspect, but it very commonly becomes coarse grained and assumes the character of a conglomerate, the pebbles of which vary from the size of a duck-shot to that of grape and canister; these pebbles are almost entirely either of opaque white vitreous quartz or various colored jaspers; some of them are lydian stone, some hornstone, and other varieties, and many of them are banded, shewing their derivation from a more ancient stratified rock. The pebbles are often displayed at the top or bottom or in the middle of fine grained beds; they are sometimes arranged in thick bands, and blood-red jaspers often predominating in a nearly pure white base produce a brilliant, unique, and beautiful rock. Considerable masses of greenstone are intercalated in different parts of the group,	2,150
9. White quartzite, very frequently of a vitreous aspect; in considerable thicknesses of the rock the bedding appears sometimes to be so completely obliterated, and the whole mass presents so great a uniformity of appearance, that it becomes quite impossible to ascertain the dip or strike, or to distinguish joints from beds, but in other parts massive beds are separated by thin siliceous layers resembling chert, and greenstones occur intercalated between different masses of the deposit,	2,970
10. Yellowish chert in thin and very regular beds, interstratified with layers of green, buff, and gray siliceous limestone, and green and pale drab compact siliceous slate, with a stratum of red and yellowish fine grained sandstone at the bottom,	400
11. White quartzite, frequently of vitreous aspect, and occasionally mottled with lead-gray patches,	1,500
12. Yellowish chert and impure limestone, similar in its general aspect to the previous chert band,	200
13. White quartzite imperfectly examined,	400
	18,000

Of the interstratified greenstone flows of the above series, Logan says:[1]

The igneous rocks which, as overflows, it will be convenient to consider constituent parts of the stratified series, may be classed as a whole under the denomination of greenstone or diorite. The masses are sometimes very great, and in such cases the rock usually consists of a greenish-white feldspar, and dark green or black hornblende. The feldspar is sometimes however tinged with red, and the diorite then appears to pass into syenite by the addition of a sparing amount of quartz. These two forms of the diorite are almost always highly crystalline, and in general not very fine grained. Sometimes, however, the greenstone displays a fine texture, and in such cases a large amount of it, more particularly in the lower part of the series, frequently holds much disseminated chlorite, giving a very decided green color. Portions of it are found containing so great a proportion of this mineral as to yield with facility to the knife, affording to the aborigines an excellent material for the manufacture of their *calumets* or tobacco-pipes. In addition to the chlorite, epidote is a prevailing mineral in this description of rock, associated with which an amygdaloid, already alluded to, is in one place seen, some of the cellules of which contain quartz, others calcspar and bitterspar, and some few of specular iron. The amygdaloidal trap is very distinctly arranged in layers, which, though they do not exceed two or three in number, give, with beds of porphyritic greenstone containing large crystals of feldspars, occurring near the amygdaloid, a stratified aspect to the whole of the mass of the trap associated with them. No such decided appearances of stratification have been met with in the more crystalline greenstones. They usually, however, display parallel planes of division in several directions, and it frequently happens that some of these parallel planes are only moderately inclined; but there have not been observed on the surfaces or in the character of the rock any distinct evidences of stratification or of successive deposit, and no columnar structure at right angles to any set of planes such as sometimes so clearly marks an overflow. It is therefore, in most instances, only by a reference to its immediate relation to the sedimentary rocks on each side that the general attitude of any band of the greenstone can be made out.

Independent of the overflows, igneous rocks are connected with the formation in intrusive masses. These intrusive masses consist of greenstone and granite. The intrusive greenstones do not seem to differ much in mineral character from those composing the overflows: they constitute dikes which run in so many directions that it is difficult to determine the prevailing ones. These dikes vary in breadth from a few inches to several hundred feet; they cut all the stratified rocks of the series, igneous as well as sedimentary, splitting into branches which often join one another and inclose great fragments and masses of strata. The intrusive granite, in so far as observed, is in general of a decided red color, arising from the presence of a largely preponderating quantity of red feldspar, which is mingled with translucent white quartz: mica is not very abundant, and hornblende sometimes accompanies or replaces it. From large masses of the rock however both these minerals are often wholly absent, but epidote in general forms a constituent, sometimes in great abundance.

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[1] Geology of Canada, 1863, p. 57.

In regard to the nature of these greenstones, it is to be said that they are not improbably diabases, no microscopic analyses having been made of them, while the descriptions of kinds carrying much red feldspar are certainly suggestive of the orthoclastic gabbros of Chapter III of this memoir.

The red granitic rocks mentioned as intrusive are also suggestive of the red granitic porphyries and augite-syenites of the Keweenawan. Similar granites or granitic porphyries, according to Norwood and Winchell, are found among the Animikie slates of the Thunder Bay country. The rocks of Lake Huron, according to Logan's sections, are bent into gentle folds.

The whole aspect of the original Huronian, as thus described by Logan, is strongly suggestive of the Animikie Group of the North Shore. Both series are made chiefly of quartzites and slates, with some limestone and chert beds, and with interbedded greenstones, along with intersecting greenstones and red rocks. Some of this similarity was seen by Logan, who, however, could not have realized how strong it was, since he does not seem to have been aware that the Animikie Group was prevailingly quartzitic. However, on account of the similarity as he saw it, he maintained[1] for many years the equivalence of the Lake Huron rocks with the native-copper-bearing rocks of Lake Superior. Subsequently this view was abandoned, and since the Thunder Bay slates were regarded as merely the downward continuation of the copper rocks, these two were now considered as newer than the Huronian[2] Yet so striking was the resemblance then made out between some of the Animikie beds and those of the original Huronian, that a strip of rocks along the north shore of Thunder Bay, which are most plainly part of the Animikie slates, was separated from them by Logan and put down as Huronian.[3]

With my present knowledge it appears to me very probable that the original Huronian of Lake Huron, and the Animikie slates of Thunder Bay, and thence southwestward to the Mississippi River, are one and the same formation. The Keweenawan rocks, as shown later, are newer than either.

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[1] Report of Progress of Geol. Survey of Canada, for 1848, p. 29.

[2] See T. S. Hunt in Second Geol. Survey of Pennsylvania. Special Report on Trap Dikes and Azoic Rocks of Pennsylvania, Part I, p. 69.

[3] Geology of Canada, 1863, p. 63.

THE PENOKEE HURONIAN.

In the third volume of the Geology of Wisconsin, I have described in some detail the rocks of the Penokee region, which extends from the vicinity of Lake Agogebic in Michigan to Lake Numakagon in Wisconsin. The following is the succession of strata as I have given it in that volume:

		Feet.
I.	Tremolitic crystalline *limestone*	90
II.	(A) Arenaceous white *quartzite*, often brecciated, 35 feet; (B) *magnetitic quartz-schist*, 5 feet	40
III.	*Siliceous slaty schists;* including quartzite, "argillitic" mica-schist, and novaculite; all having much quartz, and none ever showing any amorphous material	410
IV.	*Magnetic belt;* including: (*a*) banded magnetic quartzite—gray to red quartzite, free from or lean in iron oxides, banded with seams, from a fraction of an inch to several inches in width, of pure black granular magnetite, only rarely mingled with the specular oxide; (*b*) magnetitic quartzite, the magnetite in varying proportions, pretty well scattered throughout, and mingled with the specular oxide in proportions varying from nothing to a predominating quantity; (*c*) magnetitic quartz-slate, the magnetite pervading the whole, and mingled with the specular oxide as before; (*d*) slate like (*c*), but largely charged with tremolite or actinolite; (*e*) arenaceous to compact and flaky quartzite, free, or nearly so, from iron oxides; (*f*) thin laminated, soft, black magnetitic slate; (*g*) hematitic quartzite, the iron oxide the red variety; (*h*) garnetiferous actinolite schist, or eclogite; (*i*) greenstone, which is restricted to the western end of the Huronian belt. Kinds (*a*) to (*d*) all carry much pyrolusite or other manganese oxide. These varieties have no persistent stratigraphical arrangement, and are named here in order of relative abundance. Total thickness, about	780
V.	*Black feldspathic slate;* consisting of orthoclase grains imbedded in a paste of biotite, pyrite, limonite and carbon	180
VI.	Unknown, always drift covered	880
VII.	Dark-gray to black, aphanitic *mica-slate*, having a wholly crystalline base of quartz and orthoclase, with disseminated biotite scales	120
VIII.	Unknown, but probably in large part the same as VII	290
IX.	Chloritic, pyritiferous, massive *greenstone*	150
X.	Black, aphanitic *mica-slate* like VII	25
XI.	Covered, but probably mica-slate	280
XII.	*Black mica-slate;* aphanitic, at times chiastolitic	225
XIII.	Chloritic *greenstone*	35
XIV.	*Black mica-slate*, like XII, often chiastolitic	375
XV.	To XVIII, alterations of black *mica-slates*, with *quartzites* and *quartz-schists*	675

		Feet.
XIX.	*Greenstone*; aphanitic	260
XX.	Covered, but probably like XXI	525
XXI.	*Mica-schist;* from aphanitic to medium-grained; including bands of light-gray quartz-schist, the mica becoming subordinate; all varieties having a background of quartz; the mica wholly biotite; penetrated by veins and masses of very coarse, pink to brick-red biotite-granite; total on Bad River, 4,960 feet; seen further east, higher layers 2,500 feet, in all	7,460
	Total	12,800

Later investigations have shown that some, at least, of the greenstones of the above series are diabasic rather than dioritic.

Here the resemblance to the Animikie rocks is very strong. The magnetitic quartzites, other quartzites and quartz-slates, and the argillaceous slates of the Animikie and Penokee series are identical in character, while much of the upper mica-schist member of the Penokee Huronian is very close to the mica-bearing quartzite of the Animikie. In each of the groups the magnetitic quartzites are near the base of the series, and in both there are interstratified greenstone beds. In both, the same relations obtain to the newer Keweenawan and older gneisses. The two groups are plainly enough the same.

THE MARQUETTE AND MENOMINEE HURONIAN.

The iron-bearing schists of the well known iron-regions of the northern peninsula of Michigan present one point of strong contrast with the Animikie Group and the Penokee Huronian, in that, instead of dipping uniformly lakeward, they are closely folded in troughs whose sides are gneiss and granite. At first glance, the greater number of rock kinds characterizing the Marquette and Menominee Huronian, as compared with that of the Penokee region, might seem a further difference. There is, however, so plainly a general stratigraphical equivalence between the two series, as I have shown elsewhere,[1] that there can be no doubt of their belonging together. There is probably even a direct connection between the two. Moreover, the lithological differences in a large measure disappear on closer study. According to Brooks[2] the rocks making up by far the greater part

[1] Geology of Wis., Vol. III, p. 163.
[2] Geology of Wis., Vol. III, table opp. p. 446.

of the Marquette and Menominee Huronian are quartzites, magnetitic quartzites, rich iron ores, limestones, dolomites, clay-slates, mica-slates and greenstones. The greenstones are for the most part diabases with rarer gabbro and peridotite. From Wichmann's microscopic descriptions I judge that the same kinds of diabase and gabbro are to be found here as in the Animikie Group, though for the most part more altered, *i. e.*, the orthoclastic and the non-orthoclastic kinds, while the olivinitic kinds are here represented by the altered serpentinitic peridotites.

So far the resemblance to the Penokee and Animikie rocks is striking. It is among the remaining less abundant kinds named by Brooks and Wichmann, that the seeming lithological differences between the schistose systems of these several regions are found. These less abundant kinds are: diorite, among the greenstones; syenite; gneiss; granite; sericite-schist; jasper-schist and chert-schist; amphibolites, including actinolite-schist, magnetitic actinolite-schist, hornblende-rock and hornblende-schist; augite-schist; chlorite-schist; and talc-schist.[1]

The diorites of this list I suspect to be mainly uralitic diabases. I suspect this on account of the frequency of a uralitic change in the orthoclastic diabases of the Lake Superior region generally; and my suspicion is confirmed by the fact that Wichmann finds both augite and uralite as constituents of his diorites, and speaks distinctly of a gradation between the diabase and diorite. Moreover, his descriptions of the diorites make them in other points very similar to the uralitic orthoclase-diabases and gabbros that I have examined from the Keweenawan and Animikie groups.[2] These points are the presence of orthoclase in greater or less quantity; of titanic iron and its gray decomposition-product; of a little quartz, and of very abundant apatite. Moreover, the quartz is described by Wichmann as occurring in such a way as to "recall the lapis Hebraicus"; a mode of occurrence which renders its secondary origin evident,[3] and thus seems to establish the complete identity of these diorites and my uralitic orthoclase-gabbros.

The syenite[4] mentioned by Brooks and Wichmann as occurring at only

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[1] Geology of Wisconsin, Vol. II, p. 600.
[2] Geology of Wisconsin, Vol. III, p. 627, *et seq.*
[3] Geology of Wisconsin, Vol. III, p. 629, § 91.
[4] Geology of Wisconsin, Vol. III, pp. 523, 620.

one point near Marquette, their descriptions show to be a mere phase of the diorite rich in orthoclase, and therefore, inferentially, a uralitic orthoclase-gabbro or diabase. Gneiss may be excluded from the list as being more than doubtfully Huronian, when a true gneiss,[1] or as being a mere phase of the mica-schist such as occurs also in the Penokee upper mica-schists. Granite occurs in large areas only in the Menominee region, where it has not been satisfactorily shown to be Huronian, and may be eruptive. The sericite-schist appears to be very close to some of the rocks of formation III in my descriptions of the Penokee Huronian,[2] and is very probably represented among the slates of the Animikie Group on Pigeon River. The jasper- and chert-schists are of course found also both in the Animikie and the original Huronian. Of the amphibolites the actinolite-schists and magnetitic actinolite-schists are known also in the Penokee region. Hornblende-rocks have also been described as occurring in the Penokee region,[3] but a schistose hornblende-rock has not been noticed there. Whether any of the massive hornblende-rocks here included are altered or uralitic diabases I am at present unable to say. Augite-schist is also mentioned as occurring at one point in the Marquette region.[4] Whether the hornblende-schists have any relation to it is not known. The chlorite-schists of the Marquette region belong to two distinct classes, of which one type plainly belongs with the greenstones as an alteration form, while the other may possibly be connected with the micaceous and hornblendic schists.

It thus appears that the Marquette and Menominee iron-bearing schists are essentially the same, lithologically, with those of the Animikie Group of the North Shore. Of the few unusual kinds of the Marquette and Menominee regions some may be attributed merely to metasomatic changes, while the remaining ones are possibly to be attributed to the processes of metamorphism,[5] which in turn may be connected with the complex folding of

[1] Geology of Wisconsin, Vol. III, p. 529.

[2] Geology of Wisconsin, Vol. III, p. 111.

[3] Geology of Wisconsin, Vol. III, pp. 137, 252, 288.

[4] Geology of Wisconsin, Vol. III, p. 645.

[5] Brooks (Geology of Wisconsin, Vol. III, p. 521) regards these greenstones as metamorphic, but Wichmann has shown plainly (*Ibid.*, p. 627) that this position is untenable; and I have convinced myself from my study of the Keweenawan and Animikie greenstones that all are of the same origin and all eruptive.

the rocks in these districts, as compared with the unfolded condition of the Penokee and Animikie beds.

CRYSTALLINE SCHISTS OF DOUBTFUL RELATIONS.

The original Huronian, the Animikie slates, the Penokee iron rocks, and the iron-bearing rocks of the Marquette and Menominee regions, appear to me, then, in all probability to belong together, and I may hence properly call them all Huronian. In each of the regions mentioned the areas of Huronian schists are limited by granite and gneiss. Commonly, when a contact of the schists with the gneiss and granite is to be seen there is more or less strong evidence of unconformity, and in all cases—save that of the so-called Huronian granite of Brooks and Wright, in the Menominee region of Wisconsin—the gneiss and granite plainly rise from beneath the schists. There are, however, a number of other areas and belts of crystalline schists, on all sides of Lake Superior, whose relations to the Huronian and to the older gneisses are in greater or less doubt. The doubt arises in some cases from a very imperfect knowledge of the rocks in question; but in others comes either from the structural difficulties involved in connecting these areas with the undoubted Huronian; or from greater or less contrast lithologically with the recognized Huronian; or from the difficulty in distinguishing between eruptive and non-eruptive granites. It is wholly possible that some of the granites are eruptive and relatively new, while others, and especially those distinctly connected with the gneisses, may be of some sort of not understood metamorphic origin.

The whole question of the nature and relations of these ancient rocks is in great confusion. It seems to be an open question as to whether there are schistose rocks belonging with the so-called Laurentian gneisses and granites in the Lake Superior region or not. The later Canadian geologists —especially Robert Bell—have worked on the latter view, and have described and mapped as Huronian all schistose rocks not distinctly gneissic, whether in apparent conformity to the gneiss or not. Nearly complete ignorance as to the true mineralogical nature of many of these doubtful schists adds another element of uncertainty to the question. The diorites and diorite-slates described by Bell as occurring in the Huronian north of Thunder Bay are, in all probability, in large measure diabasic rather than dioritic rocks, if we may judge from the rarity of true dioritic rocks generally in the Lake Superior region. I have already spoken of the uralitic nature of the hornblende of the Keweenawan and Huronian greenstones. Recent studies by myself and my assistant, Mr. C. R. Vanhise, of a number of hornblendic rocks from the valley of the Wisconsin River apparently plainly connected with the older gneisses, have resulted in showing that this uralitic change is found in many other kinds of rocks than the greenstones, true granites and even hornblende-schists frequently showing it.[1] So common have we found this change that it has led to the suspicion that hornblende does not occur as a primary constituent in any of these ancient rocks. While such a generalization is of course unwarranted from the relatively small extent of our studies, our experience should be enough to render any one studying hornblendic rocks very watchful for indications of the secondary origin of the hornblende.

I proceed to give brief accounts of some of these schistose areas of doubtful relations. The positions and sizes of the areas mentioned are indicated on the accompanying general map of the Lake Superior region.

In the Thunder Bay region, between the northern limit of the Animikie Group and the vicinity of Dog Lake, schists called by them Huronian have been studied by Murray, Logan and Bell. These schists appear nearly always, if not always, to be separated from the flat-lying Animikie rocks by a belt of gneiss and granite, which is, however, at times very narrow. Isolated areas of gneiss are found to occur within the schists, which are bounded on the north again by a large area of gneiss and granite. Still farther west-northwest, as seen about the west end of Lake Shebandowan, are other schists, succeeded in turn by gneiss and granite. These so-called Huronian rocks consist, according to Bell, of "slates, some of them dark-green and composed of hornblende; some grayish-green and dioritic; others are light-colored, fine-grained, quartzose, somewhat nacreous micaceous schists; while dioritic slate-conglomerates, quartzites, fine-grained felsites, massive diorites, ribboned jasper, and iron ore also occur."[2]

These descriptions are of course not based on microscopic study, and

[1] Geology of Wisconsin, Vol. IV, pp. 622–714.
[2] Report of the Geological Survey of Canada, 1867–'69, p. 326.

are to be taken as representing the nature of the rocks only in the most general way. Bell describes these schists as always standing at a high angle, with a strike varying between N. 25° E. and N. 80° W. The quartzite, chert, ribboned jasper and iron ore of these rocks certainly have much the look of the recognized Huronian. With regard to the other rocks it is impossible to draw any conclusions from the very general descriptions given; while there is no evidence presented showing that part of the so-called Huronian rocks might not really belong with the gneiss, which in some places seems to grade into mica-schist.

From the statements of Bell, N. H. Winchell, and Chester, it is plain that the schistose belts (or belt) of the Thunder Bay region continue for over two hundred miles to the southwestward, at a similarly short distance north of the northern boundary of the Animikie rocks, and similarly involved with gneiss and granite. Still farther north, in the vicinity of Rainy Lake, other like schistose bands occur, as shown by Bigsby, Bell, and other geologists.

The band of schists running west and south from the northern part of Saganaga Lake, on the national boundary, for instance, is described by Bell[1] as consisting of "rusty, brown, altered sandstone containing small white quartz pebbles;" "soft green argillite;" "dioritic schist;" "cherty felsitic slate;" "siliceous schist;" "chert-rock," which "resembles the chert near the base of the Upper Copper-bearing Series," *i. e.*, the Animikie Group; "gray granular quartzite;" and "fine-grained glossy clay-slate." All of these rocks are said to stand nearly vertically, inclining slightly on one side or the other, and to strike from 15° to 80° west of south.

A different belt of schistose rocks was crossed farther west by N. H. Winchell in making a canoe trip from Bois Blanc Lake, on the national boundary, to Vermillion Lake, in 1879. He speaks of these schists as soft greenish slates, siliceous slates, and hornblende rocks and schists of several kinds,[2] trending in a general southwesterly direction, and standing always at a very high angle, and apparently conformable with the associated gneiss. From the descriptions given by Winchell, and from specimens sent me by

[1] Report of Progress of the Geological Survey of Canada, for 1872-'73, p. 93.
[2] Ninth Annual Report of the Geological and Natural History Survey of Minnesota, p. 91, *et seq.*

Professor A. H. Chester of the rocks lying east and north of Vermillion Lake, I suspect that these greenish rocks are very close to schistose material interlaminated with the gneiss at Penokee Gap, in Wisconsin.

By Professor Chester's kindness I am also in receipt of a large number of specimens collected by him around the east and south sides of Vermillion Lake for several miles, and thence southward to the Mesabi Range in township 59. From these specimens and the notes accompanying them, and from the published notes of N. H. Winchell,[1] I gather that there is here a broad belt of schists trending in a general way something south of west, with a common very high dip, a little on one or the other side of vertical, and intricately folded. Professor Chester's specimens include: clay-slate, which he says is largely exposed about Vermillion Lake; silvery mica-schist, running into greasy-surfaced, aphanitic, siliceous schist, which often suggests the rock of No. III of the Penokee series,[2] and is commonly very much altered and charged with hematite to such an extent as to constitute beds of soft hematite analogous to those of the Marquette region; quartzites of several kinds; gray crystalline limestone associated with white quartzite, and precisely similar, both in nature and in this association, to beds in the Penokee, Marquette and Menominee regions; gray cherty schists like those of the Animikie Group; banded jaspery and cherty magnetitic schists; banded quartzite and magnetite; lean slaty magnetites precisely like those of the Animikie Group at the Mesabi Range and like those of the Penokee and Marquette regions; and rich specular iron ores. Between these schists and the flat-lying beds of the Animikie Group, in the region south from Vermillion Lake, is a broad belt of gneiss and granite which is plainly the one crossed by Bell between Gunflint and Saganaga Lakes.

The strong lithological similarity of the Vermillion Lake iron-bearing rocks to those of the Animikie Group, and of the South Shore iron-bearing formation, makes it almost a certainty that these also are Huronian; while the connection of the Vermillion Lake schists with the schistose rocks northeast as far as Thunder Bay renders it nearly as certain that the latter

[1] Ninth Annual Report of the Geological and Natural History Survey of Minnesota, p. 96 *et seq.*
[2] Geology of Wisconsin, Vol. III, p. 111

too are Huronian in large measure. My own suspicion is that in all of this region there are two distinct kinds of schists—the iron-bearing schists of the Huronian, and the schistose greenish phase of the older gneiss. These having been taken together by the Canadian geologists, and the whole region being relatively so poorly known, it is impossible now to separate them.

But the decision that both the flat-lying Animikie slates and some of the more northern folded iron-bearing schists are Huronian renders it necessary that I should present some suggestion as to the structural relations of the two. Though my knowledge of the region and of the nature of the older rocks is yet too limited to allow of very confident generalization, I have but little doubt that the relation is some such as indicated in the accompanying diagram. That this is the true relation is rendered probable not only by the lithological similarity and present attitudes of the two groups, but also by the fact that at several points a curving upwards of the otherwise very flat Animikie beds, where they come into contact with the underlying granite and gneiss, has been observed. I saw this curving myself on the north shore of Thunder Bay, where the two formations come together; N. H. Winchell, if I have understood him correctly, observed something of the kind on the national boundary; and Mr. G. W. Stuntz again at the Mesabi Range. The same sort of relation must certainly subsist on the South Shore between the eastern extension of the unfolded rocks of the Penokee Iron Range and the highly folded iron bearing schists of the Menominee region.[1]

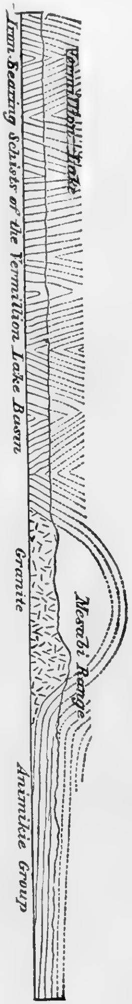

Fig. 31.—Generalized section, showing hypothetical relation of the Animikie Group to the Vermillion Lake schists.

On the South Shore the relations of the different schistose

[1] This was written in 1881. Since then (1882) N. H. Winchell has published (in the Tenth Annual Report of the Geological Survey of Minn.) some notes on the geology of the vicinity of Gunflint and Saganaga Lakes on the national boundary, in which region the unfolded Animikie and folded schists approach each other closely. Winchell notes the peculiar lithological similarity here obtaining between these two sets of rocks, and suggests their possible identity.

rocks have been more satisfactorily worked out, though there are many doubtful minor points, and probably some schistose rocks have been called Huronian that are not certainly so. However, it seems certain that here we have genuine schists interbedded with the older gneiss in such a way as to admit of no doubt of their being subordinate to it. Brooks has observed this in the Menominee region, and I have found it so in the Penokee region and the region of the Wisconsin Valley. In the Wisconsin Valley, in the neighborhood of Wausau, is found a southwestward extension of the Menominee Huronian in the shape of siliceous schist, chert-schist, siliceous limestone, mica-schist, quartzite, quartz-porphyry and greenstone (including diabase, gabbro and peridotite). Genuine hornblendic schists are unknown in this region in the Huronian, while they are frequently associated with the gneiss. Hornblende-rocks have been heretofore regarded as characteristic of the Huronian Series. But I have already shown good reason for suspecting that all of the so-called diorites, syenites and hornblende-rocks of the Marquette and Menominee regions are in all probability but uralitic diabases, while the hornblende-schists may be, in part at least, altered augitic schists. So far as our present knowledge of the microscopic characters of the rocks of the two systems goes, hornblende is very much more characteristic of the older gneisses than of the Huronian.

On the east shore of Lake Superior, Murray, Logan, and Bell have described rocks which they refer to the Huronian. To the south of Batchewanung Bay, for instance, is a large development of rocks which have a typical Huronian aspect, and are composed chiefly, according to Macfarlane,[1] of pyroxenic greenstones, slates, slate-conglomerates, quartzites, and jaspery iron-ores. The rocks are much folded.

Further north, according to Logan, Huronian rocks are "spread over what appears to be a triangular area, extending along the shore from eight to nine miles on each side of Michipicoten River, at the mouth, and about the same distance up the stream. A little further west it presents a very narrow strip running about twelve miles along the coast, and another one of eight miles about five miles south from Otter Head."[2]

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[1] Geological Survey of Canada, Report of Progress, 1863–1866, p. 123.

[2] Geology of Canada, 1863, p. 63. See general geological map of the Lake Superior region, accompanying this memoir.

In another place[1] the same writer gives a section of the "conglomerate or pebbly slates" of the Huronian "exposed at the mouth of the river Doré, near Gros Cap, about five miles above the mouth of the Michipicoten River." The section measures some 1,700 feet. A further thickness, not measured, is said to underlie this at this place. "The strike of the rock is very regular, being about east and west, while the dip is very highly inclined, the beds being not more than from ten to fifteen degrees from a vertical attitude; but the slope is for part of the distance to the north, and for the remainder to the south; there is not, however, supposed to be any repetition of the measures, * * *."[1] I have not been able to find any thing further of interest in the present connection with regard to the schistose rocks in the neighborhood of Michipicoten Island and River.

In the extreme northeastern corner of the lake, in the region of the Pic River, are again rocks as to the Huronian age of at least some of which there can be no doubt. Logan and Bell have described these rocks. Logan even doubtfully refers part of them to the copper-bearing series, though he maps all of them as Huronian. He says:

> They occupy the coast for about seven miles on each side of the New Pic River, while an interval from this to a point two miles beyond the Old Pic River, including the coast of Peninsula Bay and Harbor and Pic Island, is composed of trap. Beyond this the chloritic slates occupy about fifteen miles of the coast, extending to the neighborhood of the deep cove which receives the Pike River. It appears probable that the slates thus flanking the trap on either hand may be the sides of a trough converging to a point inland, the distance of which from the coast has not been ascertained. The Slate Islands are nearly on the strike of the northwestern side of the trough, and they may probably derive their name from being composed of slate rock;—but the islands have yet to be examined.[1]

With regard to the trap, Logan says in another place: "In a straight line across from one side to the other on the coast, it occupies a space of about fourteen miles. No rocks of a sedimentary character have been observed to be associated with it; but its stratification is very distinctly marked, with a dip southwesterly of about twelve degrees. Its character differs in different places; but no portion of it was observed to be amygdaloidal, except one bed, which exhibited a transverse columnar structure."[1]

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[1]Geology of Canada, 1863, p. 53.

[2]Geology of Canada, 1863, 63.

[3]Geology of Canada, 1863, p. 80.

Bell has much more recently examined this region, his explorations having extended far into the interior.[2] He carries the Huronian far beyond the area indicated by Logan, including, however, in the Huronian all the schistose rocks met with, and even large areas of gneiss and granite. It seems thus evident that there are, in the area outlined by Bell and copied on the accompanying general map of the Lake Superior region, true Huronian schists and older rocks.

RELATIONS OF THE KEWEENAW SERIES TO THE HURONIAN.

Having given thus an outline account of the rocks of the Lake Superior region which are to be referred with greater or less confidence to the original Huronian of Murray and Logan, I have next to consider the relations sustained by the Keweenawan or copper-bearing series to the Huronian, to which consideration the foregoing discussion was indeed preparatory. The data at hand upon which I have to base my conclusions as to this disputed question are, in the first place, the lithological similarities and dissimilarities of the two systems, and, in the second place, the structural relations between the two where they are found in proximity to each other.

If the basic eruptive rocks of the two groups are alone considered, the lithological similarity is very close. The vesicular or amygdaloidal character so common in the Keweenawan rocks is generally wanting in the Huronian, as are also the pseud-amygdaloids, and the peculiar fine-grained brownish and purplish diabases that are so common in the upper part of the copper series. The more massive rocks are, however, identical in the two groups, and the classification of the Keweenawan basic rocks given in Chapter III would cover those of the Huronian as well, so far as microscopic investigation has gone. The so-called diorites of the Huronian being taken as uralitic diabases, all the basic eruptive rocks of the two groups fall into the augite-plagioclase class, ranging between the orthoclase-bearing more acid kinds, and the more basic kinds holding no orthoclase, much olivine, and having the feldspar anorthite, or near it.

Even with the very similar basic rocks there are, however, structural

[1] Geological Survey of Canada; Report of Progress for 1870–'71, p. 322.

differences. These rocks occur in both groups in great interbedded flows, but the amygdaloidal or vesicular upper portions are wanting, or nearly so, in the Huronian, while the occurrences as dikes or cutting masses is far more common in the Huronian than in the Keweenawan. This is a fact evidently indicating, as shown before—since the dike rocks are often identical with and commonly very closely related to those that occur as flows in the Keweenawan—that in the fissures now filled by the Huronian dikes we find the vents through which came both Huronian and Keweenawan flows.

Passing from the basic eruptive rocks of the two groups to the acid kinds, the similarity does not hold. We look in vain in the Huronian throughout the entire Lake Superior region for the great flows of red felsite and quartziferous porphyry which constitute so marked a feature of the copper series. Nearly the same may be said for the red augite-syenite and granitic porphyry which form so great masses in the Lower Keweenawan, although it appears probable from Norwood's statements[1] that similar rocks on a smaller scale occur in the Huronian (Animikie) of the Pigeon River region of the North Shore. Logan's descriptions of the west shore of Lake Huron suggest also the possibility of the occurrence of such rocks there.

Between the distinctly bedded or sedimentary rocks of the two groups the contrast is strong. The Keweenawan red sandstones and shales have nothing in common with the quartz-slates and quartz-schists of the Huronian, even when the latter are hardly more than sandstone and clay-shale. The two groups are thus linked by the basic rocks of each, the basic eruptions having apparently begun in the later Huronian and continued uninterruptedly into the Keweenawan. They are separated by the absence or relative rarity of the acid eruptives in the Huronian, and by the strong contrast between the sediments of the two groups. That the separation was sufficiently great a one to allow of some intervening alteration is suggested by the occasional presence of pebbles in the Keweenawan conglomerates which may be regarded as derived from the Huronian. On Thunder Bay the Keweenawan sandstones carry chert and jasper pebbles from the underlying Animikie Group, and on the Montreal River, in

[1] Owen's Geological Survey of Iowa, Wisconsin, and Minnesota, p. 408 *et seq.*

Wisconsin, quartzite pebbles apparently from the underlying Penokee Huronian. But these occurrences, and the kinds of rocks involved, are too few to allow of our very confidently concluding from them the general alteration of the Huronian schists prior to the time of Keweenawan deposition. Pebbles of the older granite and gneiss occur more frequently in the Keweenawan conglomerates, so that those rocks must have reached their present conditions before the formation of the conglomerates.

But for the relations of the Keweenawan and supposed Huronian crystalline schists in the basin of Lake Nipigon, subsequently noted, the structural relations of the two groups broadly viewed would lead us to the conclusion that there was a time interval between the groups sufficiently long to allow of erosion to some extent, but not great enough to produce a true unconformity. On the South Shore, for all the miles between Lake Agogebic, in Michigan, and Numakagon Lake, of Wisconsin, the Keweenawan beds present a general parallelism in trend and dip to those of the underlying Huronian, all being tipped up towards the north at angles which are nearly always very high. So far, the appearance is one of complete conformity. Looking the other way in this region are the following facts, as I have shown in my discussion of the structure of Northern Wisconsin for the Wisconsin Geological Reports:

"In the Penokee country, the uppermost beds of the Huronian are gradually cut out, as we trace them westward, by the gabbro that forms the base of the Keweenaw Series—a fact which appears to me best explained by the supposition that the gabbro covers and conceals these missing beds. West of Lake Numakagon, the diabases and other eruptive rocks of the Keweenaw Series appear to completely cover the Huronian, in a great overflow. Nevertheless, the approach to conformity in Wisconsin is close, and were we to draw our conclusions from this region only, the nonconformity could hardly be regarded as proven. There are no such undulations in the Huronian of the Penokee district as in Michigan, the subordinate members making long and regular bands conforming to the general trend of the formation, and also, in a general way, to the trend of the several belts of the Keweenaw Series. Moreover, the lessening in dip towards the west, already noted as affecting the latter rocks, is observed also in the underlying Huronian, so far as can be traced westward."

So far as this region is concerned, the unconformity is only one, at most, of intervening erosion, without intervening disturbance.

On the North Shore, again, from the Saint Louis to Thunder Bay, a distance of some two hundred miles, there are just the same relations between the Animikie Huronian and the overlying Keweenawan as in the Penokee region. Both formations are exposed here on so large a scale, and both lie for the most part so flat, that there can be no doubt at all as to their relations. The parallelism in bedding between the two is complete. At the eastern end of the Minnesota coast, for instance, both incline lakeward at an angle of 10°, the contact of the two being in sight, with some hundreds of feet in thickness of each. The same perfect parallelism at a still flatter angle is to be observed on the east side of Thunder Bay, where the overlying Keweenawan has at its base several hundred feet of sandstone.

Indicative of an intervening erosion on the North Shore is the absence of the sandstone just mentioned only a few miles to the southwest, where, at Grand Portage Bay, the two formations come together; while the relation of these sandstones to the underlying slates at Thunder Cape amounts to a demonstration of this intervening erosion. Along the east side of Thunder Bay the Animikie slates may be seen for miles lying beneath the Keweenawan sandstones, but when Thunder Cape is reached the slate suddenly rises entirely across the horizon of some six hundred to seven hundred feet of the sandstone. Logan explains this peculiar behavior by supposing the Thunder Cape rocks to be separated from those around them by a fault. But, as I have shown on a previous page, a much simpler and more satisfactory explanation is reached by supposing an intervening erosion between the slate and sandstone.[1] The truth of this view is further confirmed by the occurrence of ledges of the overlying sandstone on the flanks of the Thunder Cape elevation, and by the occurrence in the sandstone of pebbles derived from the underlying slates.[2]

[1]As first suggested by T. S. Hunt, Second Geological Survey of Pennsylvania, Report E, Part I, p. 239.

[2]T. Macfarlane, Canadian Naturalist, New Series, Vol. IV, p. 459.

In the next chapter I shall attempt to show that the whole of the Lake Superior basin is a synclinal trough in the Keweenawan beds. From the relations of the Huronian and Keweenawan in the western half of the basin it is plain that they also partake in this synclinal—a fact in itself strongly indicating that they here underlie the Keweenawan without true unconformity.

Thus far, however, I have considered the structural relations of the Keweenawan rocks to the unfolded Huronian only. In the case of the folded Huronian the problem to solve is the time when this folding took place. Did it entirely precede the Keweenawan depositions and outflows? was it contemporaneous with them? or was it wholly subsequent? The solution of this problem is not easy to reach without more extended knowledge of the Huronian than we now possess.

On the South Shore, the folded Huronian beds and the Keweenawan are never in close proximity. They are nearest to each other in the Keweenaw Point and Marquette districts. On the east shore of the lake the Keweenawan beds are found near to folded Huronian, but unfortunately our knowledge of that coast is too meager to base any conclusions upon as to the relations of the two systems of rocks. The only other portion of the Lake Superior basin in which the Keweenawan and folded Huronian approach each other is that district lying northward from Thunder and Nipigon bays. Here again, unfortunately, our ignorance as to the Huronian leaves us in a good deal of doubt; for while it seems certain that folded Huronian schists exist in this region, it is also, as already indicated, a matter for grave doubt as to how far the schists called by Bell Huronian, belong in fact to an older formation.

The relations subsisting between the Keweenawan rocks of Keweenaw Point and the folded Huronian to the southeast form the subject of an article by T. B. Brooks, published in 1876, in which he urges the existence of a true unconformity between the two rock systems.[1] The same writer, along with Pumpelly, had only a few years previously held to a complete conformity between the two systems.[2] To this last-named view

[1] Amer. Jour. Sci., March, 1876, "On the Youngest Huronian Rocks South of Lake Superior."
[2] Geol. Surv. of Mich., Vol. I, Part II, pp. 1–6.

he and Pumpelly had been led by the strong appearance of conformity between the Keweenawan and unfolded Huronian of the Penokee region. Working myself a few years later, I was led to acquiesce in this view.[1] To Brooks's later view I again in a measure acceded, in my discussion of the structure of Northern Wisconsin for the third volume of the Geology of Wisconsin; though still maintaining an intervening erosion without true unconformity for the western half of the Lake Superior basin. The whole history of this discussion is but a new illustration of the danger of generalizing as to the structural relations of a system of rocks before the whole ground has been looked over.

So far as Brooks's argument is based on lithological grounds, it has been sufficiently considered in foregoing paragraphs. The structural grounds for his conclusions are (1) the unfolded condition of the Keweenawan beds as contrasted with the frequently folded Huronian, and (2) the absence of patches of the Keweenawan rocks in the numerous deep synclinals of the Huronian in the Marquette region. The first of these points merits no consideration, for the very point at issue is the time of folding of the Huronian. With regard to the second point it may be said that it is plainly to be seen that the absence of patches of the Keweenawan rocks overlying the Huronian in the Marquette region is quite as difficult of explanation, or even more difficult, on an hypothesis of complete unconformity as on one of complete conformity. On Keweenaw Point the Keweenawan rocks have a thickness measured by miles, ending to the southward in a bold escarpment beyond which no patch of these rocks is to be found. The absence of such outliers, especially of such hard rocks, would be incredible and contrary to all experience on any hypothesis of former extension southward. It has already been shown that the escarpment on the south side of Keweenaw Point must be a fault line, as Foster and Whitney long since urged; and their view is strongly confirmed by the very absence of outliers to the southward. The Keweenawan rocks are, then, not to be found in the Marquette region for the simple reason that they never extended so far; and but for some features in the geology

[1] "On the Age of the Copper-Bearing Rocks of Lake Superior," Amer. Jour. Sci., June, 1874.

of the Nipigon Lake region as described by Bell, precisely the same reason might be advanced for their absence in the region of folded Huronian schists north of Lake Superior.

The Keweenawan rocks, or Nipigon Series, as they are termed by him, are represented by Bell as lying in the Nipigon Lake basin, directly athwart the course of several belts of folded schists, and with a general horizontal attitude. These schists Bell regards as Huronian, and maps them as directly continuous with the schistose belts of the country immediately north of Thunder Bay. (See Fig. 34.) If these rocks are indeed Huronian, and their relation to the Keweenawan is as stated by Bell, no doubt can remain as to the existence of a genuine unconformity between the two systems. Bell's detailed descriptions, however, do not fully bear out his reference of the schistose rocks in question to the Huronian, nor his general statement as to the horizontal attitude of the Keweenawan rocks themselves.

FIG. 35.—Outline geological map of the Nipigon Lake Region, after a manuscript map by R. Bell.

In conclusion, then, it is to be said that the Huronian and Keweenawan rocks are linked together by the lithological affinities of their basic eruptive members, and by the close approach to conformity between them which obtains throughout the whole western half of the Lake Superior basin; and that they are separated from one another by the lithological contrast between their sedimentary members; by an intervening erosion, which has plainly taken place, even where there is a close approach to conformity;

and possibly also by an intervening period of alteration and folding. The Huronian sediments are metamorphic, whatever the nature of the metamorphosing process may have been—and the metamorphism has always been greatest where the folding has been greatest—while the Keweenawan sediments are unaltered. The metamorphism and folding may have taken place before or during the period of Keweenawan eruptions and depositions, or both. Our present knowledge of the Huronian is too incomplete to allow of a very firm opinion as to this point.

CHAPTER IX.

STRUCTURE OF THE LAKE SUPERIOR BASIN.

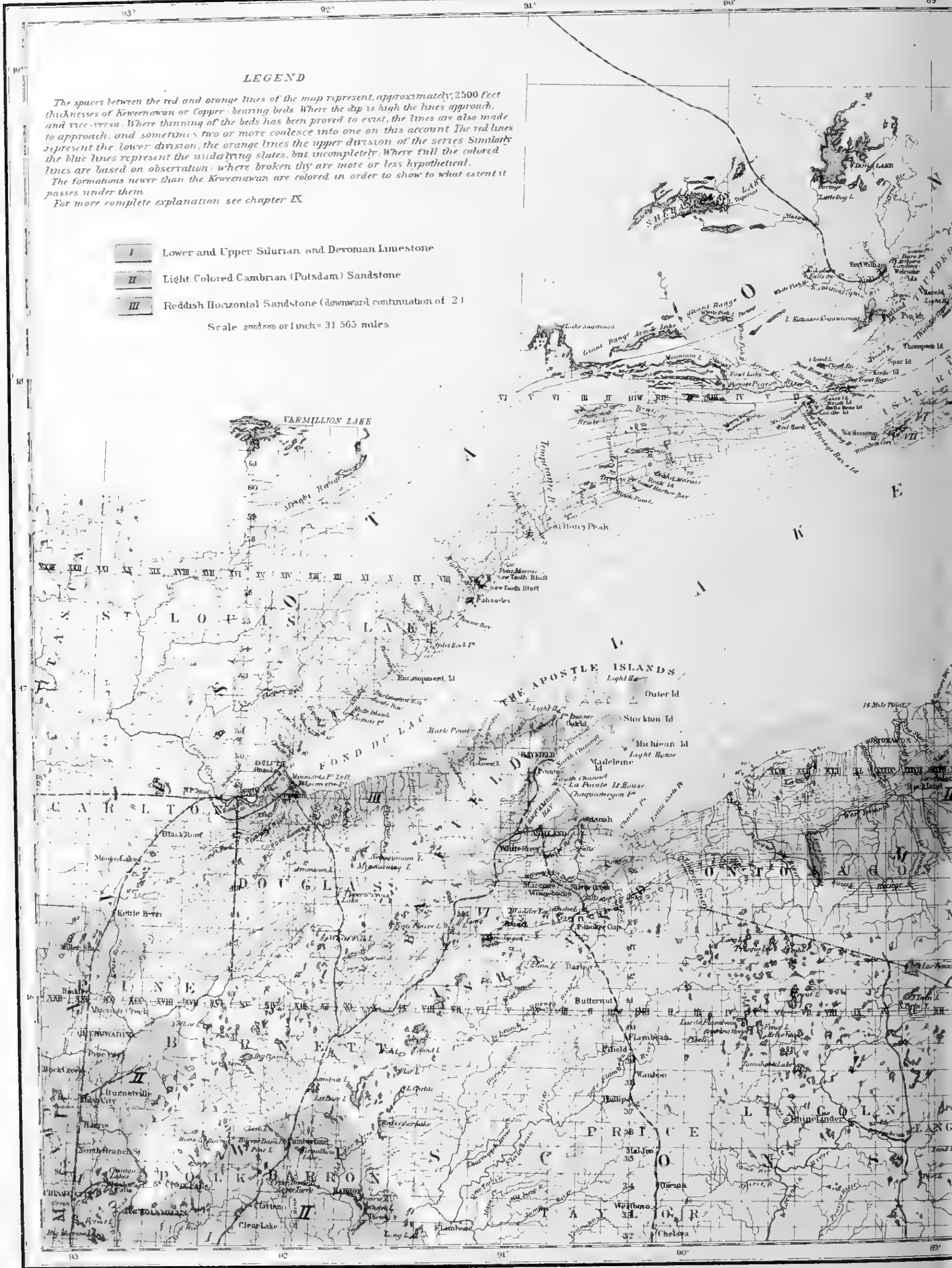
Foster and Whitney's views as to the existence of a synclinal between Isle Royale and Keweenaw Point.—Westward extension of the Isle Royale-Keweenaw Point synclinal; first shown to exist in 1873.—Course and structure of the synclinal as shown by the work of the Wisconsin Geological Survey.—Structure and extent of the synclinal as now worked out.—Parallelism between the courses of the Keweenawan belts of the North and South Shores; and of the coast lines with these belts.—Explanation of Plates XXVIII and XXIX.—Nature of the bottom of the synclinal.—Complications of the synclinal by faulting.

Foster and Whitney first pointed out the probability that a synclinal depression exists, underneath the waters of Lake Superior, between Isle Royale and Keweenaw Point,[1] being led to this view by the lakeward inclination of the rocks on both Isle Royale and the Point, and by the fact that, on the lakeward side of each, sandstone and conglomerate prevail, while on the side away from the lake the rock beds in each case are prevailingly crystalline.

During my first season's work on Lake Superior, for the Wisconsin State Geological Survey, in 1873, I collected facts in the Bad River country of Wisconsin going to show that to the westward the Isle Royale-Keweenaw Point synclinal runs on to the South Shore, the rocks being found there dipping both ways. The observations of my assistant, Mr. E. T. Sweet, made during the same season on the Copper Range of Douglas County, Wisconsin, tended very strongly to confirm this conclusion, since the rocks of that range were found to dip southward. My conclusions from the data then in hand were published in 1874, along with an outline map and section.[2] The subsequent work of the Wisconsin Survey, during the years from 1874 to 1878, by Sweet, Strong, Chamberlin and myself, served to place beyond question the truth of the main points of my conclusions of

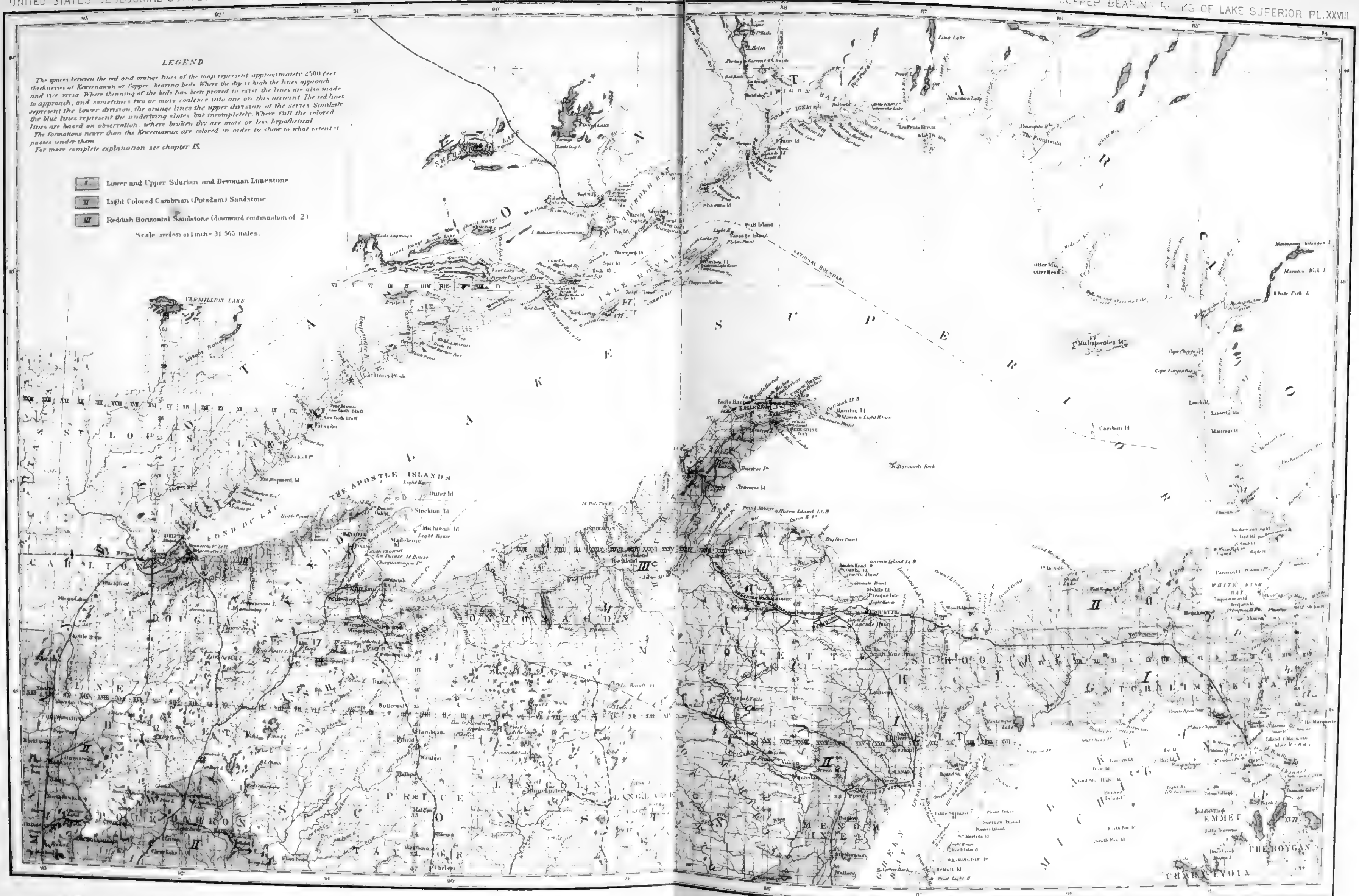
[1] Report on Lake Superior Land District, Part I, p. 109.

[2] "On the Age of the Copper-Bearing Rocks of Lake Superior; and on the Westward Continuation of the Lake Superior Synclinal." American Journal of Science and Arts, Vol. VIII, July, 1874.



MAP OF THE LAKE SUPERIOR BASIN DESIGNED TO SHO

STRUCTURE AND EXTENT OF THE KEWEENAWAN TROUGH.



MAP OF THE LAKE SUPERIOR BASIN DESIGNED TO SHOW THE STRUCTURE AND EXTENT OF THE KEWEENAWAN TROUGH.

1873, while at the same time modifying them in some respects, and developing a number of new facts with regard to the structure and course of the synclinal.

The most important modification was that with regard to the supposed occurrence of horizontal Potsdam or unconformably overlying sandstone in the trough of the synclinal. On my map of 1874 I had marked such a sandstone as occurring along the upper Saint Croix, as indicated by the descriptions of Dr. D. D. Owen,[1] but this sandstone was subsequently shown by Sweet[2] to belong in the Upper Division of the Keweenaw Series, it being in fact but the westward continuation of the south-dipping sandstones of White and Bad rivers. The upper Saint Croix was again further examined by Sweet and Strong in 1876, and the sandstone in question found to be underlain conformably by fine-grained diabases and melaphyrs with interbedded conglomerate and sandstone. My map and section of 1874 had also shown horizontal sandstones filling the trough of the synclinal in the Bad River country. This conclusion was based on an observation by Dr. I. A. Lapham, which subsequent examination by myself failed to verify. There then remained, to indicate the presence of this newer sandstone in the trough of the synclinal, only an exposure of flat sandstone on the shore of Lake Superior at Clinton Point, four miles west of the mouth of Montreal River; and this, as shown on a previous page, is rather to be regarded as the eastern termination of the horizontal sandstone of the Apostle Islands and of the coast of Bayfield County.

The chief new developments as to the structure and course of the synclinal, resulting from the later work of the Wisconsin Survey, were (1) the connection by Strong of the Keweenaw Range of north-dipping rocks with the similar rocks of the Saint Croix by exposures all across the previously wholly unexamined interval between that river and Numakagon Lake; (2) the determination of the comparative flatness of the northward dip across this interval; (3) the determination by Chamberlin of a curve to the southward of the belts of this range, with a flat westerly dip, in the imme-

[1] Geological Survey of Wisconsin, Iowa, and Minnesota, p. 161.

[2] "Notes on the Geology of Northern Wisconsin," by E. T. Sweet. Trans. Wis. Acad. Science, Vol. III, 1876.

diate vicinity of the Dalles of the Saint Croix, of the similar southerly course with high easterly dip of the Keweenawan beds of Snake River, Minnesota, and, as a consequence, of the southerly direction of the axis of the synclinal near its final termination; and (4) the determination by Sweet of the existence of a southward dip in the Saint Louis River slates, and the consequent probability that the Huronian rocks form the bottom beds of the synclinal.

In Vol. III of the Geology of Wisconsin, published in 1880, I embodied these points in a brief discussion of the structure of Northern Wisconsin, accompanied by a map, which I now modify only as to the exact extent of the upper sandstones of the Keweenawan, and as to the western extension of the horizontal sandstone of the lake shore, which, on the map of 1880, was made by misprint to extend to the north side of the Saint Louis River at Duluth. No such sandstone is to be seen near Duluth.

At the beginning of my study for the present memoir, North Wisconsin had been shown to be traversed by a broad synclinal in the Keweenawan rocks, possibly also in the Huronian, which was presumably the continuation of the Isle Royale-Keweenaw Point depression. The exact nature and position of the western termination of the synclinal, the relation to the synclinal of the rocks of the Minnesota coast, and of the Porcupine Mountains, and the behavior of the depression to the eastward of Isle Royale, were all points left in doubt, though it appeared exceedingly probable that the entire western half of the Lake Superior basin is a synclinal depression affecting both Huronian and Keweenawan rocks.

Now, however, I feel able to announce with confidence that the entire lake basin, including not only the western half, but the eastern half as well, is a synclinal depression; that this depression certainly affects the Keweenawan rocks throughout their entire extent; that it as certainly affects in very large measure the underlying Huronian rocks, which, while they are greatly folded where extending without the limits of the depression, within its limits form without folds its bottom layers; that the axis of the depression has, like the lake itself, at first a northwesterly and then a southwesterly direction, with minor bends corresponding to the several bends in the axis of the lake; that the eastern termination of the depression is buried beneath the newer formations in the vicinity of the Sault Saint Marie; that the western extension passes on to the south shore of Lake Superior with a course curving more and more to the southwest until, at the termination in the Saint Croix Valley—and therefore without the present hydrographic basin of Lake Superior—it becomes nearly due south, the exact termination here again being buried beneath the newer horizontal Cambrian formations; and that, in the region of the Porcupine Mountains of Michigan, and the Douglas County Copper Range of Wisconsin, there are minor folds superinduced upon the grand synclinal, accompanied in the former case at least, by further complications, due to faulting.

The evidence upon which these conclusions are based is to be found in (1) the nearly constant dip inwards of the Keweenawan strata towards the middle of the basin; (2) in the frequently similar dip of the Huronian; (3) in the constant order of Upper Keweenawan, Lower Keweenawan, Huronian, and gneiss with granite and folded crystalline schists, met with on all sides on going from within the supposed trough outwards; and (4) in the parallelism between the courses of the Keweenawan belts of the North and South Shores, and of the shore line with these belts.

The details of the evidence under the first three of these heads are given in Chapters VI and VII, and on the maps and sections of Plates I, XVII, XVIII, XXII, XXIII, XXVI, and XXVII, and need not therefore be repeated here. That under the fourth head, however, needs some further remarks. In the first place it is to be observed that the drawings, from which the accompanying maps of Lake Superior, Plates I and XXVIII, are reduced, are much more accurate than any previously made with geological data, being compiled directly from the maps of the United States Lake Survey, from Captain Bayfield's chart, and from the United States land-office plats; and that, consequently, correct ideas may be obtained from them as to the courses of the coast and other topographical lines, and of rock belts.

Directly north of the east and west portion of Keweenaw Point, between Agate Harbor and Copper Harbor, with its east and west rock belts, dipping north, we find the east and west part of Isle Saint Ignace again made up of east and west rock belts, which now, however, dip to the south. Westward from Agate Harbor and Eagle Harbor, on Keweenaw Point, the coast line of the Point and the course of the constituent rock belts swing around to the southwest. Correspondingly, we find, on the North Shore, a southwest trend (participated in by rock belts, coast lines, and lines of islands), beginning in the western part of Isle Saint Ignace, and continuing through the peninsula which forms the south side of Black Bay, through the adjoining islands, and through Isle Royale.

Isle Royale does not lie on a straight course, but on a curving one, its outlines, projecting points, ridges and rock belts at the western extremity trending 10° to 12° more to the south than at the eastern extremity. This curvature to the westward is continued to a nearly due westerly direction in the rock belts, projecting points and other topographical features of the Minnesota coast between Pigeon River and Grand Marais, although the coast line in this distance trends as a whole some 20° south of west. The counterpart of this swing to the west is found on the south shore of Lake Superior in the course of the Main Trap Range and its constituent rock belts, and of the coast line between Fourteen-mile Point and Black River.

West of Black River, the Main Trap Range of the South Shore and its rock beds curve again to the south of west, and as Bad River is neared the direction is only some 30° west of south. The corresponding curvature on the North Shore is to be found in the distance between Grand Marais and Split Rock River. For much of this distance the coast line follows the trend of the strata, until the latter comes around to only a few degrees west of south, when the rock belts depart from the coast, and run with a eastward curvature over to the South Shore. Still further west, both sides of the synclinal are on the South Shore, the strata, and with them many topographical features, on both sides, trending at first well around to the west, and then more and more towards the south, until the termination is reached in the Saint Croix Valley.

Beyond Copper Harbor to the eastward, on Keweenaw Point, the point and its strata begin to swing around to the south of east, and this direction is continued on Manitou Island, and in Stannard's Rock, which is, as previously shown, a mass of quartzless porphyry. Parallel to this curving course is the coast line of the lake between Huron Bay and Marquette. Now on the North Shore, in the line of islands lying south of Nipigon

Bay, and in the rock belts composing them, a similar curvature to the south of east is begun. That this continues until it becomes nearly or quite a southerly course is shown by the trend of the northeast coast line of the lake, which is composed of the older rocks, between the Pic and Michipicoten Island, where the Keweenawan rocks again appear. The parallelism of the northeast coast, of the line marked out by the eastern end of Keweenaw Point and Stannard's Rock, and of the south coast between Keweenaw Bay and Marquette, looks also the same way.

Still further to the east, the South Shore shows only rocks newer than the Keweenawan, but at the east end of the lake a continuous belt of the latter rocks is marked by Michipicoten Island, Capes Choyye and Gargantua, Pointe Aux Mines, the peninsula of Mamainse, the coast of Batchewanung Bay, and Gros Cap, the beds always dipping lakeward. The most striking thing about this belt is its parallelism to the lake coast behind it, and the consequent abrupt turn, at more than right angles, in the Michipicoten bight.

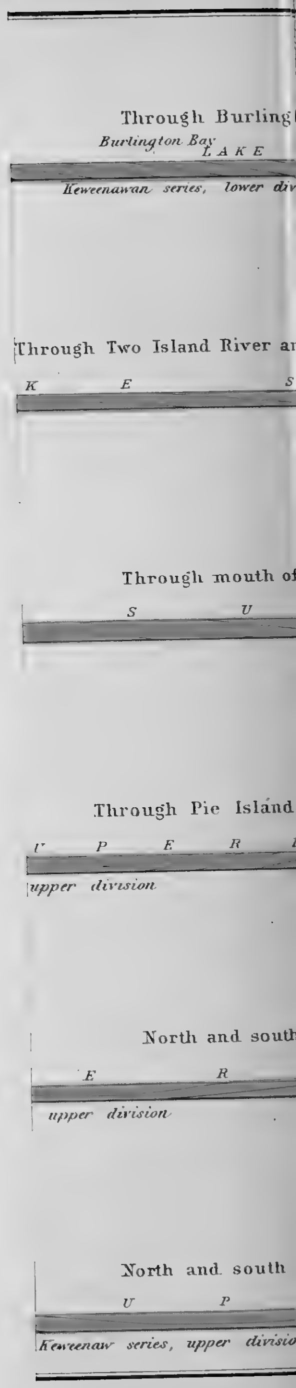
In the map of Plate XXVIII and the accompanying sections of Plate XXIX, I have attempted to summarize the facts bearing upon the subject of this chapter, and to generalize from them to the structure of the synclinal. The spaces between the red lines of this map are each supposed to represent 2,500 feet of rock thickness, the spaces being narrow where the dip is high, and correspondingly broad where it is low. The lines were constructed by first platting out the spaces in those districts where actual measurements had been made of strike and dip, the width of each space being made to correspond to the width of the surface outcrop of a 2,500-feet thickness at the measured angle of dip. Where actual thinning on a large scale had been proved by careful measurement to exist—*e. g.*, on Keweenaw Point—the lines were approached on this account also to the determined amount. Then the broken connecting lines were sketched in, taking into account the general lithological characters of different horizons —often recognized for over a hundred miles—the relations of the belts to the junction with the Huronian below and to the line between the Upper and Lower Divisions of the Keweenawan, and the angles of inclination and trends indicated by the nearest exposures.

The spaces between the lines do not, of course, represent single continuous beds, or even, in many cases, groups of beds, for in their course around the lake such beds must constantly thin out and be replaced by others. The spaces are, however, designed to cover the same general horizons, so far as practicable. Of course there must be many imperfections in such a map, under the very best of circumstances, for not only do the courses of the belts under the lake have to be hypothetical, but, from the general similarity of the beds of the Lower Division at very different horizons, there must always be more or less doubt as to the correctness of the connecting lines, even on the land. Then, again, the map is very irregular as to accuracy in those places where the courses and inclinations of the beds can be marked out. On Keweenaw Point, for instance, the detailed measurements of Pumpelly and Marvine make it possible to locate the courses of the 2,500-feet spaces with far greater minuteness of detail than it is possible to show on such a map as this. From this downwards there is every degree of accuracy to cases where the lines are purely hypothetical.

Notwithstanding all these defects, the general correctness of the structure of the great synclinal indicated by the red lines appears to me to be beyond question. One objection that I anticipate to this map is that it is an attempt to apply the methods used in studying sedimentary beds to a series largely formed of eruptive ones; to which I have to answer beforehand that this series is just as much made up of layers as any sedimentary one, and that in a sedimentary series beds thicken and thin and disappear just as here.

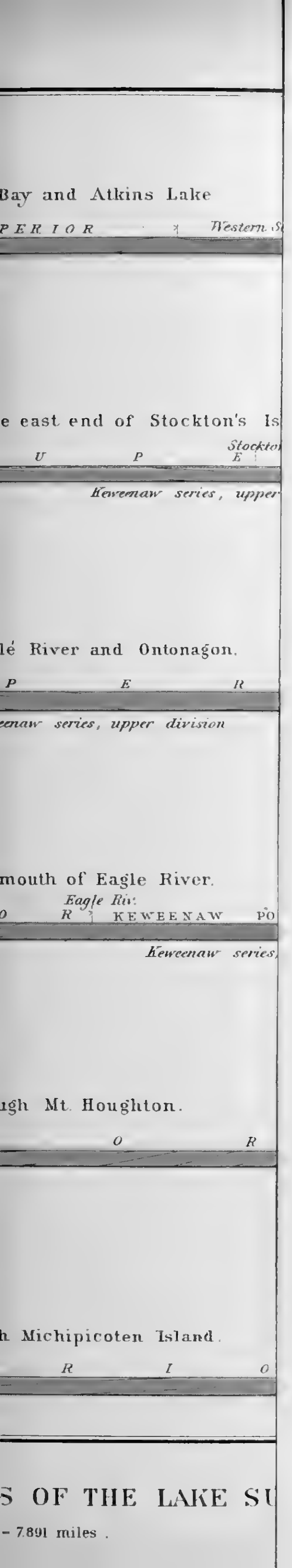
The map and sections do not show the nature of the bottom of the trough. I believe this bottom to be made up of Huronian slates below, resting upon the older gneiss, and of Keweenawan strata above, but both greatly thinned, since the eruptive rocks, which constitute so large a part of these groups around the edge of the basin, appear to me to have reached the surface there.

The simplicity of the synclinal has been further complicated by faulting. The fault to the south of the Keweenaw Point Range, it seems probable, may have been connected with a sudden change in the dip of the strata from a flat to a steep lakeward inclination. It seems a plausible



GEOLOGICAL SECT

Scale $\frac{1}{500000}$



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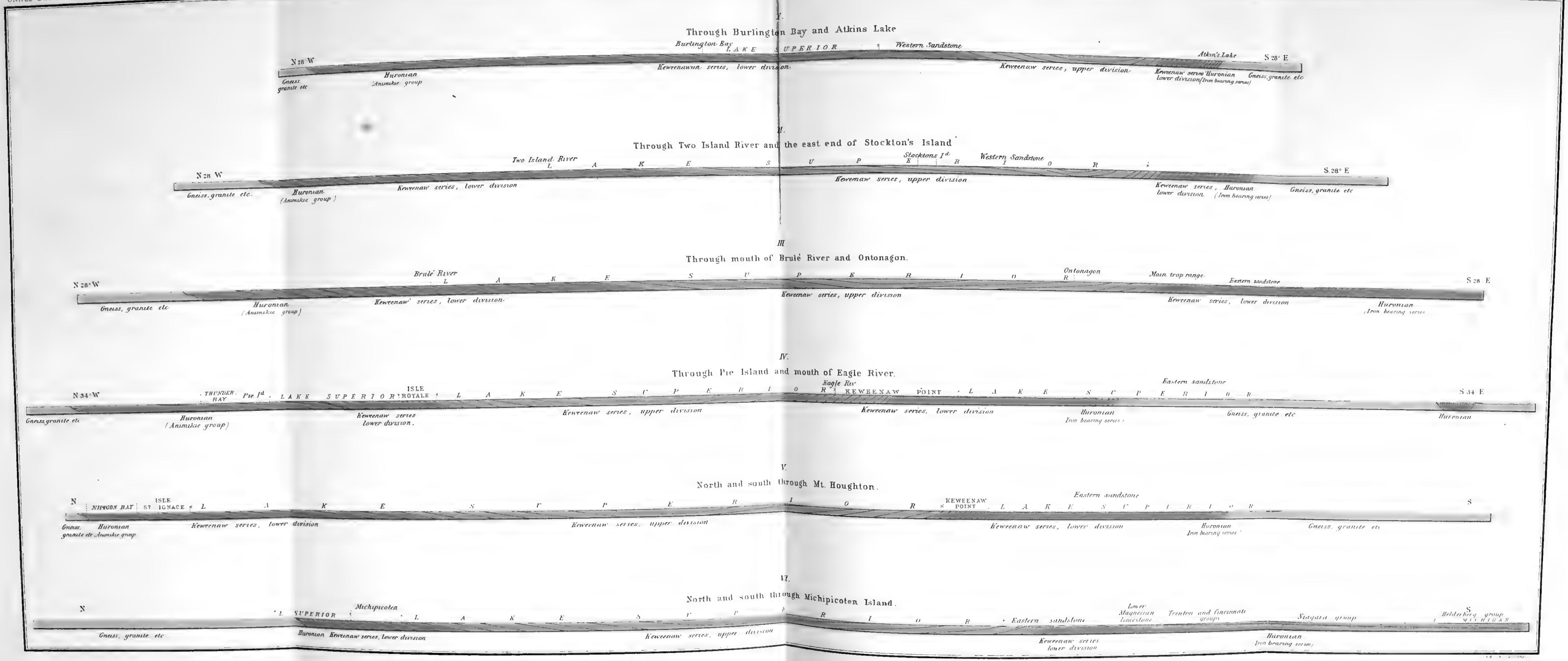

GENERALIZED GEOLOGICAL SECTIONS OF THE LAKE SUPERIOR BASIN.

Scale $\frac{1}{500000}$ or 1 inch = 7.891 miles

speculation that this fault is met at a large angle by another, coming from the southeast, at a point behind the line from the end of Keweenaw Point to Stannard's Rock, the junction of the two being the lowest part of the dislocation. Behind the Porcupine Mountains, as previously shown, is again a fault, of much smaller extent, which is again connected with a fold, though a subordinate one. I have also already indicated the probability of the existence of a fault on the north side of the Douglas County Copper Range of Wisconsin. The connection of the belts of this range with those of the North Shore is one of the least satisfactory parts of the map of Plate XXX. It is evident, however, from the trends on the North Shore, and in the Douglas County rock belts, that some such connection must exist, though whether with so much of a fold as I have indicated is not so plain.

The relation of the Huronian to the synclinal is a point of great interest. Beyond question, in the western half of the Lake Superior basin, it bottoms the great trough, for its beds are found dipping inwards on both sides; on the North Shore at a low angle, and on the south generally at a high one. It appears highly probable that the eastern part of the trough is similarly bottomed by the Huronian. The Huronian beds are, however, here found, just without the rim of the synclinal, folded in a complicated manner; for instance, beyond the western end of the trough in Minnesota, in the iron regions of Michigan, on the east shore of Lake Superior, and about the head of Lake Huron. Other folded schists, which possibly belong with the Huronian, occur in Canada, north of Lake Superior. The connection of these folded beds with the unfolded is a structural problem still needing investigation. So far

FIG. 36.—Hypothetical section of Lake Superior basin.

as present knowledge will allow, it has been discussed in the previous chapter.

In the preceding generalized hypothetical section of the Lake Superior basin, which may be looked on as taken across from the Pigeon River region of the North Shore, through Ontonagon, the South Range, and the Menominee region of Michigan and Wisconsin, but not on a straight line, and not drawn to any scale, I have attempted to bring out the following points: (1) the synclinal structure of the lake basin; (2) the partial unconformity of the Keweenawan to the unfolded Huronian; (3) the supposed relations of the folded and unfolded Huronian; (4) the limitation of the Keweenawan outwards by the higher Huronian land; and (5) the origin of the Keweenawan eruptive rocks through fissures arranged around the rim of the trough. If this sketch represents actual conditions, then the downward bowing of the great trough, which subsequently was filled with the Keweenawan accumulations, was begun in the Huronian and continued through the Keweenawan. Accompanying this downward bowing was a crumpling of the Huronian to either side of the broader bow—and this crumpling, so far as this sketch is concerned, may have taken place in large measure before the Keweenawan—and an extravasation of molten matter around the rim of the trough.

CHAPTER X.

THE COPPER DEPOSITS.

No special investigation made of the copper deposits.—Different kinds of copper deposits.—Cupriferous sandstones and conglomerates.—Cupriferous amygdaloids.—Epidote belts.—Transverse veins.—Similarity in origin of the several forms of copper deposit.—Source of the copper, and cause of its precipitation; different views.—Rules to guide the explorer for copper.—Portions of the Keweenaw Series favorable and unfavorable to the occurrence of copper.—Prospects of future developments of copper without the present producing districts: in the Bad River country of Wisconsin; between Bad River and the Saint Croix; in the Saint Croix Valley; on the Douglas County Copper Range; on the Minnesota side of Lake Superior; on Isle Royale.

A special study of the copper deposits of the Keweenaw Series formed no part of the plan of the investigation upon which this memoir is based. These deposits, were, of course, already the best known things about the series, and any study made with the hope of adding materially to the facts collected by the numerous geologists who have hitherto written upon them would have occupied far more than the whole time at command. For the sake of rounding off the subject, however, I may appropriately offer a general account of the structural and genetic relations of these deposits, adding a few general considerations of an economic bearing as a guide to the future explorer for copper, both within and without the present producing districts.

All the workable deposits of copper heretofore discovered in the Lake Superior region fall into one or other of two classes, which we may term belt or bed deposits, and transverse vein deposits. The first class includes the cupriferous conglomerates and sandstones, the cupriferous amygdaloids, and most, if not all, of the so-called veins carrying much epidote and coinciding with the bearing of the formation; the second class includes those veins which traverse the formation in a direction more or less nearly at right angles to the bedding. No copper has ever been observed in connection with the acid eruptives of the series, nor have any workable deposits been discovered in the massive non-vesicular diabase beds, except as distinctly subordinate to, and directly connected with, the amygdaloid deposits or epidote courses, and always accompanied with an extreme degree of alteration.

The conglomerate and sandstone deposits are simply portions of the beds of these rocks, in all respects of the ordinary character, save that they are impregnated with the native copper. Cupriferous deposits of this character are for the most part confined to the thin conglomerate beds which are interstratified with the ordinary diabase flows; but one cupriferous bed of sandstone is known within the upper or purely detrital division of the Keweenaw Series, and separated from the nearest trappean flow beneath it by a thickness of many hundred feet of sandstone layers. This is the belt of dark colored sandstone and shale in which occurs the Nonesuch copper bed of the Porcupine Mountains. This belt has been traced from Keweenaw Point to Bad River, a distance of about 150 miles; and has been found to contain copper at a number of points in the vicinity of the Porcupine Mountains, and again on the Montreal River, the boundary line between Michigan and Wisconsin.

In the cupriferous conglomerates and sandstones the copper occurs as a cementing material, and as a replacer of the constituent grains, being in all cases plainly of secondary origin, and a result of deposition from an aqueous solution. Moreover, the cementing copper itself, *i. e.*, that which is to be seen in the thin section between the constituent grains molding itself sharply around their contours, is often also plainly a replacer of still smaller constituent particles. In the case of the Nonesuch sandstone of the Porcupine Mountain region a large proportion of the particles of cementing copper have within them a core of magnetite. It is indeed not improbable that in all cases the cementing copper is not a deposit in the original interspaces of the fragmental particles, but is always a replacer.

In the thin sections of these cupriferous conglomerates the larger particles of porphyry matrix, and fragments of the feldspars, are found to be replaced by copper in varying degrees, the metal in the case of the feldspar fragments tending to follow the cleavage directions. In the famous conglomerate of the Calumet and Hecla mine in the Portage Lake region the copper has not only saturated the matrix, but has also entered into and more or less completely replaced large-sized pebbles and even bowlders several inches to a foot or more in diameter. Hundreds of such bowlders are picked each day from the heaps of rock, before it is taken to the stamps

In these bowlders the copper has replaced both the matrix and the porphyritic feldspars, occurring in the latter, when the replacement has not been carried very far, often along the cleavage lines only. Pumpelly has shown that the deposition of this copper has always followed other great changes in the condition of the porphyry fragments, and notably the replacement of both matrix and feldspars by chlorite and epidote; these minerals having in turn been replaced by the copper. This relation, between copper, epidote and chlorite, is one which exists also in the altered amygdaloids; and the source of the constituents of these minerals may be found either in the particles of amygdaloid matrix and other basic materials which not unfrequently occur in the conglomerates themselves—in the Nonesuch sandstone forming a predominating quantity—or in the overlying trappean beds, from which they may have descended along with the infiltrating carbonated waters.

The ordinary cupriferous amygdaloids, such as those which are so largely mined about Portage Lake, are, as Pumpelly was the first to show, simply the more or less completely altered and copper-saturated upper vesicular portions of the old lava flows, and are neither independent layers, nor "veins" parallel with the formation. The copper has been introduced into these amygdaloids during one of the later stages of a long chain of replacements, whose history has already been briefly outlined, as worked out by Pumpelly, on a previous page. Several paragraphs of his descriptions may appropriately be quoted again in the present connection.

> Considerable portions of the bed have lost every semblance of an amygdaloid, and consist now of chlorite, epidote, calcite, and quartz, more or less intimately associated, or forming larger masses, of the most indefinite shapes, and merging into each other. Sometimes portions of partially altered prehnite occur. In places, considerable masses of rich brown and green fresh prehnite filled with copper occur; but, as a rule, this mineral has given way to its products.
>
> To this process the copper-bearing beds of Portage Lake—wrongly called lodes—owe their origin. Considerable portions of these beds are but partially altered amygdaloids, containing amygdules of prehnite, chlorite, calcite or quartz, with more or less copper; other portions are in the condition described above.
>
> In the still amygdaloidal portions, the copper was deposited in the cavities and in cleavage-planes of some minerals, and replaced calcite amygdules, etc. But in the confused and highly altered parts of the bed it crystalized free, where it had a chance; more generally it replaced other minerals on a considerable scale. It formed, in

calcite bodies, those irregular, solid, branching forms, that are locally known as horn-copper, often many hundred pounds in weight; in the epidote quartz, and prehnite bodies, it occurs as thread and flake-like impregnations; in the foliaceous lenticular chloritic bodies, it forms flakes between the cleavage-planes and oblique joints, or in places—and this is more particularly true of the fissure veins, which we are not now considering—it replaces the chloritic, selvage-like substance till it forms literally pseudomorphs, sometimes several hundred tons in weight.

The copper in these deposits is not restricted to that portion of the bed which was originally vesicular, but runs from it downward irregularly into the originally compact portions, following always a great alteration of the rock. The copper, however, tends always to be very irregular in distribution, and, even in the longest worked and most reliable amygdaloids, has frequently to be searched for through many feet of barren rock. In this search the diamond drill is now extensively used, the miners being guided in its use by the occurrence of seams of calcite and epidote, and other alteration forms, which, when followed up with the drill, are often found to lead to pockets containing much copper.

In one class of amygdaloids, those of the ashbed type,—which I agree with Wadsworth in regarding as merely very highly scoriaceous and open lava flows, into whose interstices the intermingled detrital material has subsequently been washed—the distribution of the copper is sometimes more uniform than in the ordinary cupriferous amygdaloids, so that the whole of the bed may be broken down and taken to the stamps, as is done for instance at the Atlantic mine.

The copper deposits of the Ontonagon region have not had the study given to them that has of late years been devoted to those of the Keweenaw Point and Portage Lake districts; so that it is not possible to be quite so positive in our statements in regard to them. The copper of this region never occurs in transverse fissures, but either lies in irregular accumulations—often solid masses many tons in weight—associated with much epidote and calcite, distributed along the course of diabase beds, or else occurs with more persistent and vein-like aggregations of epidote and calcite. The latter coincide always with the bearing of the formation, and commonly also with its dip, but in some cases, as for instance in the once famous Minnesota mine, dip at a higher angle than that of the formation, which they consequently slowly traverse in depth. According to Foster and Whitney, deposits like that of the Minnesota mine show another indication of a vein-like character in the shape of slickensided and generally sharply defined walls The "vein" at the National mine is also peculiar in lying at the base of one of the great lava flows, and immediately above a conglomerate bed, while coinciding with them in both bearing and dip.

It is evident, even with our present knowledge of the deposits of the Ontonagon district, that their history has been essentially the same as that of the Portage Lake deposits. In the case of that copper which occurs irregularly distributed, along with epidote and calcite, throughout certain of the trappean beds, the process of replacement has gone on irregularly, because of some irregularity of texture in the original rock. Deposits like that of the Minnesota mine may have resulted from the deflection of the altering waters along the course of a pre-existing but not open fissure; the "vein" being in this case, as before, a replacement, at least in large measure, of original rock substance.

The transverse veins have been mined for copper on Keweenaw Point only, where they are found varying in width from mere seams to 10 and even 20 and 30 feet. For the most part, however, they do not exceed one to three feet in width, the expanded portions being met with where they traverse the amygdaloidal or otherwise open textured portions of the flows. The same veins which, in the amygdaloid and looser textured diabases, are expanded and often rich in copper, will, when in the more compact and massive beds, such as the well-known Greenstone, contract to mere seams without metallic contents; and the same is in large measure true of their intersections with the sandstone belts. The veins lie always very nearly at right angles to the trend of the beds which they traverse, standing always very near the perpendicular. Quartz, calcite and prehnite make up the common veinstone, but they are mingled with more or less of the wall rock of the vein, which frequently predominates greatly over any true veinstone. The veins are in fact for the most part not sharply defined from the surrounding rock, but consist in each case of a network of smaller seams traversing the shattered wall rock. Veins composed almost wholly of calcite are not unknown, but they are never productive of copper. The copper in these veins occurs both in smaller fragments and minute particles intimately mixed with veinstone, and again in masses many tons in weight. The larger masses frequently are found to contain within them portions of the wall rock.

Nearly all of the productive mines based on these transverse veins are working directly beneath the Greenstone, the layer which is described in a previous chapter as constituting so prominent a feature in the geology and topography of Keweenaw Point. This position of the mines is one not due to the non-occurrence of copper elsewhere on the course of these veins, but results from the fact that further south they become buried beneath a heavy coating of drift, while to the northward they pinch out and become barren in the broad Greenstone belt.

These veins, on account of their transverse position to the bedding of the formation, of their often slickensided walls, and from their carrying often a true veinstone, have commonly been regarded as "true fissures." That they are on the lines of pre-existing fissures or transverse cracks in the formation there can, I think, be no doubt; but they are not true fissure veins in the sense that the veinstone and metallic matter occupy, along with wall-rock fragments, original fissure space. I see in them simply the results of a rock alteration entirely analogous to that which has brought about the deposition of copper and its associated veinstone minerals within the cupriferous amygdaloids. They are alteration zones which traverse, instead of following, the bedding, simply because the drainage of the altering waters has been given this direction by the pre-existing fissures. All of the phenomena of these veins coincide completely with this view: the common occurrence of wall rock within the vein, or rather the embracing of the wall rock masses by the vein; the replacement of wall rock by copper masses; the occurrence of wall rock within these masses; the expansion of the veins and their greater richness where traversing the more readily alterable amygdaloids and looser textured diabases; their contraction and barrenness within the compact and less readily changeable Greenstone; and the coincidence of the paragenesis of the vein minerals with that of the cupriferous amygdaloids, are all facts better explicable on this view than on any other.

Thus the differences in origin of the several classes of copper deposits —conglomerate beds, cupriferous amygdaloids, epidote veins parallel to the bedding, and "fissure" veins transverse to it—which at first sight seem to be great, on closer inspection for the most part disappear. They are all the result of the percolation of carbonated waters, which, in the lines of fissure, the open textured amygdaloids, and the nearly equally open conglomerates, found the least resistance to their passage, and at the same time the greatest susceptibility to their altering power. This susceptibility depended partly upon the very openness of these different rocks, but also, in the case of the amygdaloids, in the presence of a large proportion of glass basis, the most readily alterable substance among rock constituents.

The source and the cause of the arrest of the copper which was carried in with the altering waters are other and more difficult questions. Its home has commonly been regarded as being within the mass of the trappean flows themselves, with which it is supposed to have come to the surface. Another view is that it was originally deposited in a sulphuretted form along with the detrital members of the series, from which it was subsequently leached, partly in the shape of a sulphate, but principally as a carbonate and silicate. The latter is the view which Pumpelly has elaborated;[1] to whom also is due the credit of having advanced the only satisfactory view as to the cause of arrest of the copper in the places where it is now found. He has shown the existence of an intimate relation between the precipitation of the copper and the peroxidation of the ferrous oxide of the augitic constituent of the basic rocks; a relation so constant as to render irresistible the conclusion that in this ferrous oxide is to be found the precipitating agent of the copper. To this I would add that the ferrous oxide of the magnetite, and of the unindividualized magma of the vesicular layers, has also been concerned in this reaction.

While this explanation of the precipitation of the copper seems satisfactory, we have too little to go upon in deciding between the two views above referred to as to the source of the metal. Too few signs have been observed of the existence of copper in the upper sandstones of the series, such as would be expected were this its home, to allow of an easy acqui-

[1] Geology of Michigan, Vol. I, Part III, p. 43.

escence in Pumpelly's view. On the other hand, the trappean rocks themselves are for the most part devoid of copper, except such as is plainly secondary. Copper in a sulphureted form I have, however, observed in the coarse gabbros of Duluth, in the green uralitic gabbro of Mount Bohemia, and in similar coarse rocks in one or two places on the north shore of Lake Superior. It is commonly said that copper occurs in the conglomerates and sandstones only where it could have leached directly downwards from an overlying trappean mass; and with one exception the statement is undoubtedly correct. The exception is that of the Nonesuch cupriferous sandstone, which is, however, a very important exception, since this rock not only has no overlying diabase, but is separated from the nearest trappean flow beneath it by many hundred feet of detrital material. As previously shown, this sandstone is unusual for its large proportion of basic detritus. Its copper can only be connected with a trappean source by supposing it to have formed part of this detritus in the sulphuretted condition, and afterwards to have been dissolved and redeposited in a native state. This is a supposition which would seem on the whole, however, to be rather more violent than to regard the copper as having come from the overlying sandstones, and as having been arrested in its descent on meeting a layer so rich in basic detritus as to be able to furnish the requisite supply of precipitating agent.

From the facts and theoretical considerations thus given, may be formulated a few simple rules to guide the explorer for copper in the regions traversed by the Keweenaw Series. Thus the explorer, should he be searching for transverse veins, should bear in mind that epidote, prehnite and chlorite are the favorite associates of the copper; that veins carrying a greatly predominating quantity of calcite are not likely to be cupriferous; that laumontitic veins have hitherto not proved to be sufficiently rich for exploitation; that a vein which may be very rich and wide in the amygdaloidal or other soft and easily decomposed rocks will pinch to a mere seam and become barren within the massive and more compact layers; that, hence, the intersection of a vein with such amygdaloidal or other soft beds should always be searched for; that the copper occurs in these veins with extreme irregularity; and finally, that a vein found traversing decomposed amygdaloid beds with the favorable veinstone, even though it show only a little copper at surface, is worthy of examination.

Should our explorer be looking for cupriferous belts, he should see that they are well defined; that they present evidence of much alteration such as is above indicated; and that one or more of the favorite associate minerals of the copper are present. These favorable indications, along with a more or less well preserved amygdaloidal character to the rock, and the presence of some copper at surface, are sufficient to warrant further examination. In searching for these belts care should be taken not to be misled by the occurrence of seams of native copper without veinstone along the joint cracks of an unaltered massive diabase, and of isolated pockets of epidotic and calcitic material carrying some copper.

In the case of sandstone and conglomerate deposits the explorer is to bear in mind that thus far they have been found only where a thin seam of conglomerate is directly overlain by a trappean mass; or if away altogether from the trappean beds, only in sandstone which is very rich in basic detritus. Beyond this, there is nothing to guide him except the finding of the copper itself. Any one of the numerous conglomerate seams which from Keweenaw Point to Minnesota are everywhere interbedded with the prevailing basic flows, might become cupriferous at any point along its course.

Large portions of the Keweenaw Series may be thrown out of the question in considering the possibilities of future discovery of copper in the Lake Superior region. Thus the whole extent of country occupied by the Upper Division of the series, with the one exception of the Nonesuch sandstone belt, appears to be non-cupriferous. The extent of the Upper Division is indicated on the accompanying maps. Again, all of the belts and areas of acid eruptive rocks, such as the central area of the Porcupine Mountains, and the great spread of red rock in the Brulé Lake country in Minnesota, are without copper. The same is true also of all belts and areas of coarse-grained basic rocks, such as the great area of coarse gabbro in the Bad River country in Wisconsin and the similar area which occupies so large a belt of country between Duluth and Brulé Lake in Minnesota. The favorable phase of the formation for the existence of copper in any form of deposit is the thin and regularly bedded one, with well-developed amygdaloids.

Thus far native copper mining has proved profitable within the limits of the State of Michigan only, and it seems to be true also that all or nearly all of the producing deposits have been opened on and worked by the ancient miners, whose attention was of course attracted by those deposits which by the accidents of erosion had been left prominently exposed. It is incredible that even in the long-settled districts of Michigan all of the workable deposits of copper have been discovered. Thus on Keweenaw Point the valley south of the Greenstone Range, in which lie buried beneath a surface coating of drift the equivalents of the Portage Lake cupriferous beds, has never been explored by trenching or mining operations. The same is in a measure true of the Bohemian Range of Keweenaw Point.

Without the boundaries of the State of Michigan, the attempts at copper mining have been but feeble, and utterly inadequate to prove or disprove the existence of workable copper deposits. In Wisconsin native copper has been met with all along the course of the southern Keweenawan belt from Montreal River to the Saint Croix. Running from the Montreal, in Sec. 2, T. 47, R. 1 E., southwest and west, is a belt of distinctly bedded and often amygdaloidal diabases in which copper has been seen in greater or smaller quantity both in crossing veins and in altered diabase belts, at the crossing of each stream, the intervening areas being drift covered At the crossing of Montreal and Bad rivers this belt is worthy of further examination.[1] Beyond Bad River, to the southwestward, float copper is exceedingly common, and traces of it are here and there met with in the ledges themselves. Unfortunately the country is one covered with heavy drift accumulations, through which only the harder and more enduring, and therefore non-cupriferous, beds ordinarily project. The indications are that, but for the overlying sheet of drift, this region would be as productive in copper as that of Keweenaw Point.

Rounding the turn at the western end of the great Keweenawan synclinal, in the Saint Croix Valley, we find the drift covering lighter, and here, in the vicinity of Snake and Kettle Rivers, and thence northeastward into Douglas County, in Wisconsin, are found plainly bedded diabases and

[1] See Vol. III, Geol. of Wis., pp. 205, 206.

amygdaloids carrying copper with interbedded cupriferous conglomerates. The region is one which in the early days of mining excitement on Lake Superior was so remote and inaccessible that the flood of copper hunters which at that time spread west from Keweenaw Point failed to reach it. It still lies almost wholly unexplored, while promising more to the copper hunter than any other portion of the entire extent of the formation outside of the State of Michigan.

Further north and east from the district last described lies the Copper Range of Douglas County, Wisconsin.[1] This range has already been fully described on a previous page as to its position and structural characters. Copper has been found along its course in a number of places, chiefly in epidotic altered amygdaloids, and the general structural characters are such as to indicate the possibility of the occurrence of copper in quantity along this belt. Some little mining has been done at several points, but not enough to lead to any satisfactory conclusions.

On the Minnesota coast of Lake Superior, copper has been met with at only two or three points. Of the five subordinate groups into which I have divided the rocks of this coast, only two, the Agate Bay and Temperance River groups, are of such a nature as to encourage the expectation that copper might be found in them. The great thickness which makes up the other three groups—and the same is true of considerable portions of the two groups named—is for the most part composed of very massive compact beds such as have never yielded copper on the South Shore. The beds of the Agate Bay and Temperance River groups are often thin, much altered, and highly amygdaloidal, and might perhaps be found to carry here and there workable deposits of copper. The distribution of the rocks of these two groups is approximately shown on Plate XXVI of this volume, from which it will be seen that the extent of country within which there is any likelihood of the discovery of copper in this region in the future is a small one, lying for the most part in the immediate vicinity of the lake shore. It is also to be observed that the most probable mode of occurrence for copper within this restricted area is the amygdaloid belt, the form in which occurs the copper of French River, where the metal is associated with

[1] See Chapter VI, p. 250. See also Geol. of Wis., Vol. III, pp. 357, 362.

much prehnite; that such amygdaloid belts will dip towards the lake at a very flat angle; and that cupriferous conglomerates are not to be looked for.

Isle Royale is the only remaining portion of the copper-bearing rocks within the territory of the United States. It has long been known to be cupriferous; the copper occurring here in the three forms of transverse veins, epidote courses and amygdaloid belts. Thus far mining has never prospered on the island. It can, however, hardly be said that the ground has as yet been sufficiently tested.

NOTES.

NOTE 1.

(Page 13, line 1.)

N. H. WINCHELL ON THE GEOLOGICAL POSITION OF THE COPPER SERIES.

Since this was printed, N. H. Winchell has published (Tenth Annual Report of the Geological and Natural History Survey of Minnesota, pp. 123–126) a more definite statement of his views as to the geological position of the Copper-Bearing Series, which he places, as before, as the equivalent of the Potsdam Sandstone of New York, regarding the Eastern Sandstone, however, as in part newer than, and unconformably superposed upon, the Copper-Bearing Series. He had not before stated definitely his views as to the position of the Eastern Sandstone. See further as to this, Note 22.

NOTE 2.

(Page 14, foot-note.)

LITERATURE LIST.

Mr. M. E. Wadsworth's bibliography of Lake Superior Geology, referred to in this foot-note, covers references, not only to the Copper-Bearing Series, but to all other formations represented in the Lake Superior region. It is arranged alphabetically, and brought down to 1880. The references in the literature list of this volume are all taken directly from the originals, my indebtedness to Mr. Wadsworth's bibliography consisting in its having led me to a number of references which might otherwise have been overlooked.

NOTE 3.

ADDITIONS TO LITERATURE LIST.

(Page 18.)

Insert, as last reference under 1854:

WHITNEY, J. D. Metallic Wealth of the United States. Philadelphia, 1854, 510 pp.

(Page 21.)

Insert under the year 1871, as the second work:

KLOOS, J. H. Geologische Notizen aus Minnesota. Zeit. der deutsch. geol. Gesell., 1871.

(Page 23.)

Insert under 1880 the following additional reference:

IRVING, R. D. The Mineral Resources of Wisconsin. Trans. Am. Inst. Min. Eng., 1880, viii, 478–508.

(Page 23.)

The following works, referring more or less fully to the Copper-Bearing Rocks, have appeared since the literature list was printed:

1882.

POWELL, J. W. Report of the Director of the U. S. Geological Survey, for the year ending June 30, 1881. Contains a brief preliminary announcement (pp. xxxi–xxxix) of some of R. D. Irving's most important results.

WINCHELL, N. H. Tenth Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, 254 pp.

1883.

CHAMBERLIN, T. C. Geology of Wisconsin, Vol. I, Part I. General Geology, 1–300.

IRVING, R. D. Mineralogy and Lithology of Wisconsin. Geology of Wisconsin, Vol. I, Part II, 309–361.

NOTE 4.

(Page 32.)

CHRONOLOGICAL RELATIONS OF THE DIFFERENT CLASSES OF ERUPTIVES OF THE KEWEENAW SERIES.

The facts upon which is based the statement of page 32, to the effect that no such chronological relations are found to obtain between the Keweenawan eruptives of different degrees of acidity as are said to hold true in so many Tertiary and Post-Tertiary volcanic regions, are given in various places in subsequent pages of the memoir. It will, however, be convenient to summarize and classify them here briefly, including the results of some analytical determinations made since the memoir has been in type.

The chronological relations referred to as obtaining, according to the geologists who have examined them, in many Tertiary and Post-Tertiary volcanic regions, and notably in those of the western cordilleras, consist in this, viz, that the eruptives of different acidity have followed one another in a certain unvarying order. The earliest eruptives of any one district are found to have been of rocks of intermediate acidity. Next in order have come rocks of high acidity; whilst last of all have been erupted those of low acidity, ordinarily known as "basic." Among the Keweenawan eruptives there has been no such chronological relation. The facts upon which this conclusion is based may be classed under the following heads: (1) the positions of the different kinds of eruptives in the stratigraphy of the series; (2) the occurrence of acid flows directly and visibly superposed upon basic flows; (3) the occurrence of flows of intermediate acidity overlying acid flows; (4) the occurrence of flows of intermediate acidity overlying porphyry-conglomerates; (5) the occurrence of flows of intermediate acidity overlying basic flows; (6) the intersection of basic by acid rocks. On the other hand we may cite as showing not only the absence of the ordinary Tertiary order, but the failure of order of any kind; (7) the occurrence of basic overlying acid flows; (8)

the occurrence of basic flows superposed upon intermediate flows; and (9) the intersection of acid by basic rocks.

(1.) *The position of the different kinds of eruptives in the general stratigraphy of the series.*—Acid rocks, while on the whole decidedly affecting low horizons in the series, here and there occur at quite high ones, as, for instance, in the Porcupine Mountain region (pp. 155, 206—224, and Plates XIX, XX, and XXI), and on Michipicoten Island (pp. 155, 342, 343). In the latter case the acid rocks occur at the summit of a series of over 18,000 feet of plainly bedded eruptive flows, both intermediate and basic, with interstratified conglomerates and sandstones. But, wherever occurring, at low horizons or high, the beds of acid rocks have commonly above and below them basic beds. The instances of such an occurrence of acid rocks are altogether too numerous for all to be here referred to. I may merely mention the following cases: Mount Houghton, on Keweenaw Point (pp. 181–183, Plates XVII, XVIII), is a mass of red felsite, having both on the south, or below it, and on the north, or above it, great thicknesses of basic flows. The belt of red porphyry which forms so prominent a feature to the west of the Ontonagon River, and as far as the Bad River in Wisconsin, has in a similar manner basic flows both above and below it (pp. 199, 209, 220, 231, Plates XXII, XXIII. See also Geol. of Wis., III, pp. 195, 198, Plate XVI, and Atlas, Plate XXII). On the Minnesota coast the larger number of flows of acid rocks occur in the subordinate series of beds which I have called the Beaver Bay Group (pp. 298–323). Both above and below the Beaver Bay Group occur great thicknesses of basic flows (Agate Bay Group, Temperance River Group, pp. 267, 268, and Plate XXVI); besides which, within the Beaver Bay beds themselves, the acid rocks are found overlain and underlain by basic flows.

But not only is it plain from their stratigraphical relations that the acid and basic eruptives alternated with one another in formation; the flows of intermediate acidity also evidently alternated, as to time of formation, with both basic and acid flows, for the beds of intermediate acidity occur at many horizons throughout the series. For instance, the peculiar, resinous-looking diabase-porphyrites of the south side of Michipicoten Island (pp. 86, 87, 343), having about 60 per cent. of silica, lie above many thousand feet of basic flows. Numerous instances of the occurrence of sub-basic diabase-porphyrites on the Minnesota coast might also be cited in this connection, as, for instance, the brown diabase-porphyrite, with strongly-developed amygdaloid, which forms the shore cliff one mile below the mouth of Silver Creek, NE. ¼ Sec. 22, T. 53, R. 10 W., Minnesota (pp. 80, 84, 285). An interesting case of the interstratification of a rock of intermediate acidity with basic kinds is furnished by the trap belt which overlies the felsitic porphyry of the Porcupine section (pp. 209, 214, 217, Plates XIX, XX, XXI). This belt has a surface width of one-fourth to one-third miles, and a thickness of from 300 to 500 feet. Towards the middle of the thickness a porphyry-conglomerate is included, with a thickness of over 60 feet. The rocks of this belt include diabases and diabase-amygdaloids of the ordinary types, and luster-mottled melaphyrs. Interstratified with these, both above and below the intermediate conglomerate, are layers of a diabase-porphyrite which is distinctly of intermediate acidity, containing, so far as determined, about 60 per cent. of silica. Clearly, then, we have here an acid porphyry succeeded by flows of a wholly basic material, following which come, in ascending order, a rock of intermediate acidity, others which are completely basic, a porphyry-conglomerate, basic flows, again more rocks of intermediate acidity, more basic rocks, and finally a great thickness of porphyry-conglomerate and sandstone. No possible explanation of this section can be offered by which a succession of intermediate, acid, and basic eruptions can be made out, for even if the acid porphyry lying at the base of the section should be taken as intrusive, and therefore possibly subsequent to the overlying rocks, there remains the intervening porphyry-conglomerate to prove the existence of acid porphyries prior to the eruption of both the intermediate and basic rocks of this belt; whilst the diabase-porphyrite cannot in any way be made out as antecedent to all of the basic rocks with which it is immediately associated.

It should be said that in all cases here cited of the occurrence of rocks of intermediate acidity, care has been taken to refer only to those in which the intermediate acidity is plainly an original character, and not in any measure one due to a subsequent infiltration of secondary quartz.

The question might arise in some minds as to whether the cases here cited of the indiscriminate stratification of acid, intermediate, and basic rocks might not be due to the subsequent intrusion in the form of sheets of all of the basic rocks concerned. That some of the basic rock beds of the series, and especially those formed of coarse-grained rocks, may be of an intrusive nature, has been indicated in the memoir (pp. 27, 144), though definite evidence of this is lacking. However this may be, in the present connection, care has been taken to consider only those basic rocks which are furnished with well-developed amygdaloids and are consequently the results of flowage at the then existing surface in each case. Indeed, should we, for the sake of argument, admit—what I do not at all believe—that all of the basic and intermediate beds which are not furnished with amygdaloids are intrusive, those furnished with amygdaloids being always taken as surface flows, we should immediately find ourselves at the same result, namely, that there has been no definite order among the eruptions of different acidity.

Many more instances than are here mentioned might be cited, but it is thought that those given are sufficient for the sake of the argument.

The Huronian, beneath the Keweenawan, contains many beds of eruptive material. True acid rocks are extremely rare, if indeed they occur at all, but basic and intermediate eruptives are plenty. There is much doubt, with our present knowledge of them, as to how far these eruptives are intrusive, and though it is not deemed probable, some of them may be intrusive sheets, contemporaneous with the surface flows of the Keweenawan. Many of these beds partake of the folds of the folded Huronian and hence antedate the folding. On the whole, it now seems probable that by far the greater part of the Huronian eruptives preceded all of the Keweenawan eruptives, acid and basic.

(2.) *The occurrence of acid flows directly and visibly superposed upon basic flows.*—Acid rocks directly overlying basic flows are met with in several places on the Minnesota coast, but in the case of the Great Palisades, fully described in the memoir (pp. 146–148, 314–318, Figs. 23 and 24), the occurrence is so striking and conclusive that no others need be cited. To the descriptions given in the memoir, I may merely add here that analytical determinations made since these descriptions were in type show that the diabases (or rather diabase-porphyrites, since they contain much non-polarizing matter) underlying the quartz-porphyry of the Palisades belong with the more basic of the basic rocks, having less than 48 per cent. silica. Of course the presence of strongly-marked amygdaloids and of intervening red shaly seams proves that these diabases succeeded each other regularly as flows at the then-existing surface, and that the last of them was succeeded in turn by the flow of the quartz-porphyry which makes up the mass of the Palisades.

(3.) *The occurrence of flows of intermediate acidity immediately overlying acid flows.*—The porphyry of the Palisades just alluded to, or another flow closely like it, at the mouth of Baptism River, passes under a series of beds seen in a single cliff, in which the succession is as follows, beginning below: (1) brown, aphanitic diabase-porphyrite, with 52.5 per cent. of silica, thickness not measured, but under fifty feet; (2) black olivine-diabase, with crowning amygdaloid, and containing 50.76 per cent. of silica; and (3) brown diabase-porphyrite, with 57.87 per cent. of silica, and also furnished with a crowning amygdaloid. Thus, overlying a quartz-porphyry, we have in order a sub-basic, a basic, and an intermediate flow.

(4.) *The occurrence of flows of intermediate acidity overlying porphyry-conglomerates.*—Intermediate flows are of course often met with at horizons in the series higher than occupied by beds of conglomerate. In the case of the inner trap belt of the Porcupine Mountains (pp. 214–217) a diabase-porphyrite, with 60 per cent. of silica, very closely overlies a porphyry-conglomerate, a small thickness of basic flows separating the two.

(5). *The occurrence of flows of intermediate acidity immediately superposed upon basic flows.*—A number of occurrences of this kind are to be met with among the Agate Bay and Lester River beds of the Minnesota coast (pp. 267, 279–294), but the only case in which the silica contents of the adjoining rocks have been determined is that of the cliff side one mile below the mouth of Baptism River, cited in the last paragraph, in which case an olivine-diabase, with 50 per cent. of silica, is overlain by a diabase-porphyrite with 58 per cent. of silica, both rocks being plainly surface flows, since both are furnished with well-developed amygdaloids.

(6.) *The intersection of basic by acid rocks.*—Coarse olivine-gabbro is intersected by granite in a number of places in the Bad River region of Wisconsin (Geol. of Wis., III, pp. 168, 183–193; this vol., p. 125). The coarse orthoclase-bearing gabbro of Duluth (49 per cent. silica) is intersected by granitic and other acid porphyries (pp. 270–272). Granite-like rocks, apparently intersecting basic flows, occur at several points on the Minnesota coast (pp. 303, 305, 310, 329). On the Bohemian Mountain, on the north side of Lac La Belle, Keweenaw Point, red granitic porphyry apparently intersects a melaphyr (p. 184).

(7.) *The occurrence of basic flows overlying acid rocks.*—The quartziferous porphyry of Baptism River, already several times cited, is closely overlain by a basic flow, and a number of other instances are to be met with on the Minnesota coast. In the region of the Ontonagon River and the Porcupine Mountains (pp. 206–225), and again in the Bad River region of Wisconsin (Geol. of Wis., pp. 195–198, and Atlas, Plate XXII) are similar occurrences.

(8.) *The occurrence of basic flows overlying those of intermediate acidity.*—A number of cases of this occur among the Agate Bay beds of the Minnesota coast (pp. 284–294), and the same thing is met with in the inner trap belt of the Porcupine Mountains, as already described.

(9.) *The intersection of acid by basic rocks.*—Dikes of basic rocks are to be observed cutting acid porphyries at a number of places on the north shore, as for instance near Lester River (p. 283), at Beaver Bay (p. 307), at Grand Marais (p. 320), near Red Rock Bay (p. 322). In the last case the dike-rock is a diabase-porphyrite with only 45.8 per cent. of silica, whilst the rock intersected is a typically developed quartz-porphyry.

NOTE 5.

(Page 32.)

COMPARISON BETWEEN TERTIARY AND KEWEENAWAN ERUPTIVES.

In a first brief announcement of the results of my study of the Keweenaw Series (Report of the Director of the United States Geological Survey for the year ending June 30, 1881, p. xxxiii), Director Powell says that the acid eruptives of the Keweenawan "are regarded by Irving as ancient rhyolites and trachytes, from the degradation of which the conglomerates of the series have resulted." In the notes I furnished the Director as to my results, I had not meant to convey the meaning that I regarded the Keweenawan acid eruptives as *lithologically* identical or equivalent with the Tertiary rhyolites and trachytes—though his words perhaps might be so understood—but merely to indicate that they occupied the same general position as to acidity and general lithological characters among the Keweenawan eruptives as are occupied among the Tertiary eruptives by the rhyolites and trachytes. My acquaintance with the Tertiary eruptives is too limited to allow of my passing an opinion on the accuracy of the view commonly accepted by the most eminent lithologists of the day, viz, that the Tertiary eruptives are always distinct and deserving of separate names from those that preceded Tertiary time.

NOTE 6.

(Page 32, eighth line from bottom; also page 138, last paragraph.)

VOLCANIC ASH IN THE KEWEENAW SERIES.

Mr. A. R. C. Selwyn has published (Science, Vol. I, No. 1, February 9, 1883; also, Vol. I, No. 8, March 30, 1883), since this volume was in type, a statement that volcanic ash exists in the Keweenawan rocks of Michipicoten Island, but he has not yet published any description of this material. Macfarlane, in his descriptions of the Geology of Michipicoten Island (Geol. Surv. Canada: Report of Progress, 1863–'66, p. 138 *et seq.*), speaks of "breccias," which, as I understand him, are the rocks to which Selwyn refers. Macfarlane describes the breccia in one case as consisting of "small fragments of melaphyr, some fresh looking, but the greater part bleached to a reddish-gray color, inclosed in a reddish-brown earthy matrix, consisting most probably of finely comminuted melaphyric material, as it is readily fusible before the blow-pipe." In another case he speaks of "a trap breccia, composed of fragments of dark-brown melaphyr, cemented together by a brownish-red trappean sand." I have not observed anywhere on the south or north shores of the lake any rocks which resemble these, if I understand Macfarlane's descriptions correctly, unless they are somewhat like the Nonesuch sandstone of the Porcupine Mountains. I have said in the text that this sandstone may be in part of volcanic ash nature. Though it is not impossible that the Michipicoten breccias may, in part at least, have originated as volcanic ash, I imagine that it would be exceedingly difficult to prove such an origin for them. Constant angularity of the particles might perhaps point that way, but a genuine vesicular character to each fragment would be about the only proof of such an origin, and in such ancient rocks, so profoundly altered as these must be, it would be extraordinary if angularity and vesicular character should be preserved. Dr. T. S. Hunt writes me that he observed nothing on Michipicoten Island that reminded him of the typical volcanic ash of such regions as those of Vesuvius and the Eifel, and suggests that these brecciated rocks may be due to the disintegrating effect of waters upon material extravasated beneath the sea. Such an origin is, of course, possible, and it may be true in a measure also of the common red sandstones of the Keweenaw Series, though these are very plainly in large measure composed of water-rolled and water-worn fragments. But, whatever the origin of the Michipicoten breccias may be, I have never met with anything just like them on either the north or south shores of Lake Superior, if I understand Macfarlane's descriptions correctly.

NOTE 7.

(Page 39.)

PLAGIOCLASTIC INGREDIENTS OF THE KEWEENAWAN BASIC ERUPTIVES.

Since this volume has been in type, a number of separations, by Thoulet's specific gravity method, of the plagioclastic ingredients of the several kinds of Keweenawan basic rocks have been made by my assistant, Mr. C. R. Vanhise. These separations were undertaken with the view of determining whether only one plagioclase feldspar, as indicated by the optical method, or more than one, is concerned in the make-up of the Keweenawan basic eruptives. The investigation is not yet completed, but so far as it has gone it has tended to strengthen the conclusion already arrived at, namely, that only one plagioclase feldspar is ordinarily present, except in some of the porphyritic kinds, in which the porphyritic plagioclases are different from the microliths of the groundmass. Especially in the case of the coarse olivine-gabbros and olivine-free gabbros did the experiment confirm the conclusions before arrived at, namely, that only one plagioclase is concerned, and that commonly lies, in its silica content, between anorthite and labradorite. The silica determinations made upon the separated plagioclases in no case showed less than 46 per cent. But if we accept, as it seems almost necessary that we should do, Tschermak's theory of the nature of the intermediate plagioclase feldspars, this high silica content is easily explicable on the view that only one feldspar is concerned. Tschermak's view is still further confirmed by the fact that, in every instance where the optical measurements stood near the border between anorthite and labradorite, the silica content also more nearly approached that of labradorite.

See also Note 10 for the results of experiments made with the coarse anorthite-rock of the Minnesota coast.

NOTE 8.

(Page 46.)

NATURE OF THE FELDSPATHIC INGREDIENT OF GABBRO FROM CLOQUET RIVER.

The feldspar of specimen 1103, separated from the other ingredients by Thoulet's method, gave 52.40 per cent. of silica, or almost exactly that of labradorite, the feldspar indicated by the optical measurements, as will be seen by reference to the table on page 46.

NOTE 9.

(Page 50.)

NATURE OF THE FELDSPATHIC INGREDIENT OF THE GABBRO FROM NEAR THE MOUTH OF NIPIGON RIVER.

The feldspar of specimen 1752, separated out by Thoulet's method, yielded 49.28 per cent. of silica. The optical measurements indicate anorthite. A separation of the feldspars into two parts by Thoulet's method was tried, but without success.

NOTE 10.

(Page 113.)

SECONDARY QUARTZ.

The secondary quartz of the orthoclase-gabbros (p. 51), augite-syenites, and granitoid porphyries of the Keweenaw Series (p. 113) is chiefly of the kind called by Fouqué and Lévy (Minéralogie Micrographique, p. 193), "quartz de corrosion." Some of the secondary quartz of the last-named rocks may also correspond to their "quartz globulaire" (op. cit., p. 194), but I find nothing in their descriptions or figures which recalls the peculiar arborescent secondary quartz so commonly met with in the matrices of the Lake Superior felsitic porphyries (p. 92).

NOTE 11.

(Page 59.)

ANORTHITE-ROCK.

Since this account of the rock of the anorthite bowlders and masses, met with inclosed in the olivine-gabbro of the Minnesota coast, was put in type, the following analytical determinations have been made upon the anorthite:

	729	729 A	729 B	822	822 A	822 B (single crystal.)	822 C
Silica (SiO_2)	47.50	48.91	48.19	47.25	47.41	46.56	46.54
Alumina (Al_2O_3)				31.56			
Iron protoxide (Fe O)				2.29			
Lime (Ca O)				15.39			
Magnesia (Mg O)				0.27			
Potash (K_2O)				0.37			
Soda (Na_2O)				2.52			
Water (H_2O)				0.40			
				100.05			

No. 729 is from a great mass of anorthite surrounded by black olivine-gabbro, near the mouth of Split Rock River, on the Minnesota coast (see p. 59). The sample for analysis was broken from all parts of the specimen, care being taken to select particles free, so far as could be detected, from any included substance. Nos. 729 A and B, are from portions separated by Thoulet's method (iodide of mercury solution). At a specific gravity of 2.713 a very few dark-colored particles separated out. On gradually diluting (by the slow addition of water, and mixing after each addition) no more fell until the specific gravity was reduced to 2.691, by which time two-thirds of the powder had separated out. This was drawn off and constitutes 729 A. On continuing the dilution the deposition continued, until at 2.663 specific gravity nearly all the powder had fallen. This was then drawn off and constitutes 729 B. Thus the deposition was a continuous process from 2.713 specific gravity to 2.663 specific gravity, and there was no sharp separation. This, taken together with the similarity between the silica percentages of 729 A and 729 B, seems to indicate the simplicity of the feldspar, whose crystals were so large that on crushing each must have been broken into many thousand pieces, so that the deposited material could hardly have been compound because of an interlocking of crystals. Two thin sections of 729, in addition to the ones described on page 59, were made, and the following angular measurements obtained from the feldspar individuals:

Angles on opposite sides of cross-hairs.		Whole angle.
33°	38°	71°
31	36	67
31	28	59
33	25	58
24	29	53
39	38	77
32	34	66

No. 822 is from a large, bowlder-like mass included in the black olivine-gabbro of the Minnesota coast two miles below Beaver Bay (p. 61). The complete analysis is made upon material carefully selected from all parts of the hand specimen; the silica determination of 822 C being upon less carefully selected material; 822 A is the mass of the powdered rock separated out by Thoulet's method at 2.70 specific gravity, a very small portion being left suspended; 822 B is a single crystal very carefully separated from the rock. From these figures, and especially from the close correspondence of the silica content of the single crystal with that of the powdered rock, it is evident that there is no admixture of feldspars in this case.

The following additional optical measurements were made from new sections of 822:

Angles on opposite sides of cross-hair.		Whole angle.
23°	24°	47°
29	23	52
23	25	48
40	41	81
28	28	56
33	38	71
37	32	69
24	25	49
33	36	69
30	29	59
32	35	67
33	29	62

Although these investigations plainly indicate that there is only one feldspar concerned in this rock, yet this feldspar does not correspond in composition to typical anorthite, which contains, according to Dana, silica, 43.1; alumina, 36.9; lime, 20; equals 100. This composition corresponds, for R : R̶: Si, to the quantivalent ratio 1 : 3 : 4; whereas the analysis above given gives a ratio of about 1 : 2.4 : 4.15. Since a single crystal, showing no sign of interpenetration by other feldspar individuals, or of admixed impurity of any kind, gave nearly the same silica content as shown in the complete analysis, it appears evident that the latter is the true composition of the anorthite composing the rock now under consideration. Dana gives a number of analyses of anorthite which are closely like the one given above.[1] If the view of Tschermak as to the nature of the intermediate triclinic species be accepted, then, of course, the composition expressed by this analysis requires no further explanation.

NOTE 12.

(Page 72.)

ERRATUM.

T. 51, R. 42 W., should read T. 51, R. 12 W.

NOTE 13.

(Page 82.)

DIABASE-PORPHYRITE OF THE PORCUPINE MOUNTAINS.

Specimen 1245, diabase-porphyrite, contains 59.75 per cent. of silica.

NOTE 14.

(Page 84.)

DIABASE-PORPHYRITE OF THE GREAT PALISADES.

Specimen 884, from the compact portion of one of the flows underlying the quartz-porphyry of the Great Palisades, contains only 47.90 per cent. of silica, and is hence one of the most basic of this class of rocks.

NOTE 15.

(Page 85.)

DIABASE-PORPHYRITE FROM TWO MILES BELOW THE MOUTH OF BAPTISM RIVER.

Specimen 907, diabase-porphyrite, has of silica 52.56 per cent.

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[1] System of Mineralogy, p. 339.

NOTE 16.

(Page 109.)

COMPOSITION OF QUARTZ-PORPHYRY OF THE GREAT PALISADES.

Specimen 876, representing the quartz-porphyry of the Great Palisades of the Minnesota coast of Lake Superior contains 71.10 per cent. of silica.

NOTE 17.

(Page 110.)

QUARTZ-PORPHYRY OF BAPTISM RIVER POINT.

Specimen 902 has 73.87 per cent. of silica.

NOTE 18.

(Page 152.)

ERUPTIVE MATERIAL IN THE UPPER DIVISION OF THE KEWEENAW SERIES.

A slight exception to the general absence of eruptive material from the Upper Division of the Keweenaw Series is found in the olivine-diabase dike described on page 223. A small exposure of diabase was also noted among the sandstones of the Upper Division on the Saint Croix River in Sec. 35, T. 44, R. 13 W., Wisconsin, by the late Moses Strong (see Geol. of Wis., p. 424). It is not evident whether this exposure represents a thin intercalated seam or a dike. Both these occurrences are in the lower part of the Upper Division of the Series.

NOTE 19.

(Page 224, line 14 from top of page.)

ERRATUM.

T. 40 should read T. 49.

NOTE 20.

(Pages 253–258.)

THE UNCONFORMABLE CONTACT OF BLACK RIVER, DOUGLAS COUNTY, WISCONSIN.

The quotations here given from Mr. Sweet's descriptions of this contact are perhaps not extensive enough to bring out all the important facts. As the occurrences on Black River and on the other streams of the vicinity have a very considerable importance, I add three cross-sections of the gorge (constructed from Mr. Sweet's descriptions), whose southwest wall is represented in Fig. 10, with the design of bringing out more distinctly the relations of the exposures here seen.

FIG. 37.—Cross-sections of gorge of Black River, Douglas County, Wisconsin. I, at about 4 of Fig. 10; II, at 5 of Fig. 10; III, at 7 of Fig. 10. Scale natural, 200 feet to the inch.

These cuts will serve to make plainer Mr. Sweet's reading of the structure at this point. If the reading is correct, of which I have no doubt, it is evident not only that we have to do here with an unconformable contact, but also that the newer sandstone is here deposited within the sinuosities of the old coast-line.

NOTE 21.

(Page 316.)

DIABASE-PORPHYRITE OF THE GREAT PALISADES.

The compact diabase-porphyrite of the layer immediately beneath the quartz-porphyry of the Palisades contains 47.9 per cent. of silica.

NOTE 22.

(Page 350.)

GEOLOGICAL POSITION OF THE COPPER-BEARING ROCKS.

The question of the equivalency of the Copper-Bearing Rocks with geological formations of other regions is not directly touched upon in the discussions of Chapter VIII, in which I have contented myself with an attempt to demonstrate their complete distinctness, structurally, from any of the immediately associated formations and their consequent right to a distinct name, of at least local significance. I have shown that they are not Huronian, and that at the same time they are separated by a great unconformity from the overlying fossiliferous Cambrian sandstones, with which they come in contact. Heretofore most of the differences of opinion in this connection have been upon these very points. A number of writers, and especially Messrs. Foster and Whitney, maintaining the unity of the Keweenaw Series and the Cambrian sandstones above referred to, and maintaining at the same time the equivalency of these sandstones with the so-called Potsdam of New York, have been led to include the Copper-Bearing Rocks also with the Potsdam sandstone. On the other hand, those who have maintained the pre-Potsdam age of the Copper-Bearing Rocks, including the writer of this volume, accepting the reference of the overlying sandstones to the Potsdam of New York, have thought it sufficient, in order to establish their point, to show the existence of a great unconformity between the Copper-Bearing Rocks and the overlying sandstones.

Recently, however, two writers, Messrs. Selwyn[1] and N. H. Winchell,[2] while admitting the existence of this unconformity, and the consequent distinctness of the Copper-Bearing Series from the overlying sandstones, have yet maintained the Cambrian age of the former rocks. These two writers, however, differ somewhat between themselves, Selwyn merely maintaining that the Copper-Bearing Rocks, along with the overlying Cambrian sandstones and the underlying Animikie slates, "occupy the geological interval elsewhere filled by those divisions of the great Paleozoic system which underlie the Trenton Group," without more definitely parallelizing them with the older Paleozoic formations of the Eastern States. He also says that he prefers "to call them all Lower Cambrian, which includes the Potsdam sandstone and the Primordial Silurian."

Winchell, on the other hand, would make the Copper-Bearing Rocks the direct equivalent of the New York Potsdam, while regarding the sandstones which unconformably overlie them, *i. e.*, the "Eastern" and "Western" sandstones of this volume, and the fossiliferous Cambrian sandstone of the Mississippi Valley (his Saint Croix sandstone), as later than the New York Potsdam. Stated in his own words, the following are Winchell's conclusions:

1. "The Taconic Group was correctly established by Professor Emmons, though its limits, stratigraphically and geographically, were at first wrongly defined by him.

2. "The Georgia Group of Vermont, and the Animikie Group of Thunder Bay, and the Acadian of New Brunswick are the equivalent of the Taconic of Emmons.

3. "The Taconic has the true Primordial fauna of Barrande.

4. "The Potsdam, which lies conformably above it in the east, is represented by the rocks of the Copper-Bearing Series in the west.

5. "No fossils, representing the true Primordial fauna, have yet been discovered in the west, nor have any been found in the western representative of the Potsdam.

6. "The 'second fauna' of Barrande is found in the Quebec Group of Canada, and in the Saint Croix sandstone of the west, lying in each case above the Potsdam sandstone."[3]

Elsewhere[4] Winchell suggests the probability of a former continuity, in the region north of Lake Superior, of the Animikie slates and the schists, which in that region have been called Huronian, a position which I have regarded in the preceding pages as much more than probably true. If it is so, and Winchell's reference of the Animikie to the Taconic of Emmons is correct, then the Huronian and Taconic are also the same, which would extend Winchell's use of the term Cambrian over the Huronian as well as over the Copper Series.

Into a discussion of the question as to how far downwards the term Cambrian should be stretched, I have no desire to enter at length, since I think it would be a profitless one. I will only say that, in using the word Keweenawan, I have never designed to give to this term a scope equivalent to that of the terms Cambrian, Silurian, &c., but

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[1] Science, Vol. I, pp. 11, 221.

[2] Tenth Annual Report of the Geol. and Nat. Hist. Surv. of Minnesota, pp. 123–136, also Science, Vol. I, p. 334.

[3] Tenth Annual Report of the Geol. and Nat. Hist. Surv. of Minnesota, pp. 135, 136.

[4] Op. cit. pp. 90, 94, 95; also Science, Vol. I, p. 334.

have merely designed to indicate by it the entire structural distinctness of the Copper-Bearing Rocks from the oldest of the fossiliferous Cambrian sandstones of the region, as well as from the underlying Huronian. I may also add that it appears to me very unreasonable to stretch the term Cambrian over such an unconformity as subsists between the last-named sandstones and the Keweenaw Series, and yet more to stretch it over the unconformity between these sandstones and the Huronian. Everywhere throughout the Northwestern States, where the Cambrian sandstones come in contact with the Huronian, there is evidence of an enormous time-gap between the two formations. As one illustration of this relation, out of many that might be cited, I may mention the occurrences in the Baraboo region of Wisconsin, where a great series of quartzites, including siliceous schists and immense beds of a felsitic porphyry, are overlain by the fossiliferous Cambrian sandstones in such a manner as to prove beyond all question that the time which elapsed between the two periods at which these formations were deposited was sufficiently great to cover, (1) the folding and alteration of the older series, measuring upwards of 20,000 feet in thickness; (2) the denudation of the elevations of land thus produced to such an extent that ridges approaching in height the highest existing mountains of the globe were entirely removed, and depressions made in their place; and (3) the depression of this area beneath the sea and the wearing by wave action of the older rocks to supply the material for the newer. Now the older of the formations in this case I take to belong, beyond question, to the same horizon as that to which belong the Animikie slates and the Huronian rocks of the Lake Superior region generally. Certainly no one ever has referred or ever would refer them to a lower horizon, while Winchell even regards them as the equivalent of the New York Potsdam and of the Copper-Bearing Rocks of Lake Superior. Inasmuch as neither the Huronian nor the Copper-Bearing Series has thus far afforded any fossils, it does not seem to me reasonable to extend to them, in spite of these great unconformities, the name of Cambrian, even though the fossiliferous rocks immediately overlying them be not, as Winchell has argued from their paleontology, the equivalents of the oldest of the typical Cambrian divisions of Barrande.

But, however this may be, it seems sufficiently evident that Winchell's reference of the Copper Series directly to the horizon of the New York Potsdam is untenable. If I understand him correctly, he supports this reference by three kinds of evidence, stratigraphical, lithological, and paleontological. The stratigraphical evidence consists in the occurrence in the east of the following succession, in ascending order: (*a*) A series of slates, sandstones, &c., of considerable thickness, and carrying Barrande's first fauna, conformably succeeded by (*b*) the typical Potsdam sandstone, of very inconsiderable thickness, with only a very few fossils, grading up into (*c*) the Calciferous Sandrock, in which, and in whose continuation in Canada, is found a large fauna, corresponding to the second fauna of Barrande. The members of this succession he parallelizes, respectively, with (*a*) the Animikie Group (and hence with the Huronian of the Lake Superior country generally), (*b*) the Keweenaw Series, and (*c*) the Saint Croix sandstone, including the Eastern Sandstone of this volume, and the lowest fossiliferous Cambrian sandstone of the Mississippi Valley. Now, not to speak of the grave doubts which still hang about the relations of the older rocks in the Eastern States, there are serious objections to this scheme of stratigraphical equivalence. (1) It disregards the entire absence, so far as known, of fossil remains from the Animikie and Keweenawan rocks, which are often full as favorable in nature to the occurrence of such remains as their supposed equivalents in the east. (2) It disregards the unconformity between the Animikie (and Huronian generally) and the Keweenaw Series, which unconformity finds no parallel in the eastern series, as given by Winchell. (3) It disregards the immense and far more striking and pronounced unconformity met with in the western succession between the Keweenaw Series and the overlying sandstones, which break not only finds no parallel in the east, but is to be contrasted with the gradation of the New York Potsdam into the overlying Calciferous Sandrock. (4) It parallelizes the Keweenaw Series, which approaches a thickness of 50,000 feet, of which fully 15,000 are of purely detrital matter, with a sandstone only a few hundred feet thick.

The lithological evidence advanced is hardly worth discussion, because of the well-recognized untrustworthiness of such evidence when applied to the comparison of rock formations at long distances apart. Winchell's assertions, however, of a lithological correspondence between the New York Potsdam and the Keweenaw Series will not bear examination. In his own words, the New York formation "is a red or gray loose sandstone, often tilted or faulted, also metamorphosed, and then having the name of quartzite." We look in vain in it for the great beds of porphyry-conglomerate, the immense thicknesses of basic and acid eruptive rocks, and the black shales of the Keweenaw Series. Even the sandstones of the two formations do not approach each other in character, those of the typical Potsdam being described as distinctly quartzose, whereas those of the Keweenaw Series are only very subordinately so, being composed almost wholly of fragments of the feldspars or felsitic matrix of the acid eruptives of the same series. The occurrence in the Keweenaw Series of beds of metamorphic origin, including "gneiss, syenite, and hard, red quartzites," as stated by Winchell, I do not admit. Gneiss is never met with. Peculiar red rocks, to which the name of syenite may be applied, are met with in the series, but are plainly of an intrusive nature. Rocks to which the name quartzite could be applied I have never seen; certainly they must be very rare, if they occur at all. Portions of sandstone beds locally indurated by a quartz infiltration I have occasionally seen, but such rare and unimportant occurrences would hardly warrant the mention of quartzite as a characteristic of the formation. On the other hand, there is a distinct similarity between the typical Potsdam as described and the so-called Potsdam of Central Wisconsin, where a quartzose composition, with local indurations due to quartz infiltration, and local developments of red sandstone, often of considerable thickness, are prominent features.

The paleontological evidence advanced by Winchell consists in the occurrence, in the Calciferous Sandrock of New York, and in its extension into Canada, of a fauna nearly allied to that of the lowest fossiliferous sandstone of the Mississippi Valley. Accepting the statement as to this similarity so far as it goes, I have to say, (1) that the evidence is too meager to establish a complete equivalency between the Calciferous Sandrock and the Mississippi Potsdam; (2) that even if it were not so, it would remain to show that the Potsdam itself is not merely a downward continuation of the Calciferous, the few fossils that occur in it being insufficient to disprove this relation, while the gradation of the Potsdam into the overlying Calciferous is a distinct indication of such a relation.

In conclusion, then, I have to say that it seems to me quite plain that the horizon of the New York Calciferous and Potsdam together is represented in the west by the following succession, given in descending order: (*a*) The Lower Magnesian Limestone, grading, by alternations with sandstone, and decrease of calcareous matter into (*b*) the basal sandstone of the Mississippi Valley, of whose total thickness of about 1,000 feet, from one-half to two-thirds, is quartzose and non-calcareous, and whose lowermost portions are equivalent to (*c*) the Western Sandstone and to the Eastern Sandstone of the Lake Superior region, while it is regarded as probable that the lowest portions of the last-named sandstones are at a lower horizon than any met with in the Mississippi Valley. Probably the New York Potsdam finds its near equivalent in these lowest sandstones and in the lowest portions of that of the Mississippi Valley, while the Calciferous Sandrock is represented in the West by the upper half of the last-named sandstone, which alone is fossiliferous, and by the Lower Magnesian Limestone. The question then arises as to whether the Keweenaw Series is the equivalent of any of those fossiliferous rocks which in the east are said to be beneath the typical Potsdam. A discussion of this question, however, would hardly be profitable, until the stratigraphical relation of these eastern formations to the true Potsdam is more satisfactorily made out. When any such discussion is undertaken, however, it will be necessary to keep constantly in mind the great unconformity between the Keweenaw Series and the western representative of the Potsdam sandstone.

NOTE 25.

(Page 417.)

ERUPTIVES OF THE ANIMIKIE GROUP.

The cut on page 417 does not differentiate the eruptives of the Huronian from the rest of the series. Some of these eruptives may of course have been contemporaneous, or nearly so, with those of the Keweenawan, having been formed intrusively, while at the same time those of the Keweenawan above were poured out at the surface. The Huronian eruptives are commonly without amygdaloids, which may, of course, be because of their intrusive nature. Still, they ordinarily partake of the folds of the folded Huronian, and must therefore have preceded the Keweenawan eruptives at least in large part.

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