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THE ERUPTIVE AND SEDIMENTARY ROCKS ON PIGEON POINT, MINNESOTA, AND THEIR CONTACT PHENOMENA

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WASHINGTON, D. C., *September, 1893.*

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No. 109

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1893

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE

ERUPTIVE AND SEDIMENTARY ROCKS

ON

PIGEON POINT, MINNESOTA

AND

THEIR CONTACT PHENOMENA

BY

WILLIAM SHIRLEY BAYLEY

WASHINGTON

GOVERNMENT PRINTING OFFICE

1893

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DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
LAKE SUPERIOR DIVISION,
Madison, Wis., July 1, 1892.

SIR: I have the honor to transmit herewith the manuscript and illustrations of a paper upon "The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and Their Contact Phenomena," by Assistant Geologist W. S. Bayley, to be published as a bulletin of the Survey.

This work had been planned and in good part executed while the division was under the charge of the late Prof. Roland D. Irving. His wide knowledge of the Lake Superior region enabled him to pick out Pigeon point as a locality in which exceptional relations exist between eruptive and sedimentary rocks, and which was therefore worthy of detailed study.

I am, sir, very respectfully, yours,

C. R. VAN HISE,
Geologist in Charge.

Prof. G. K. GILBERT,
Chief Geologist, Washington, D. C.

OUTLINE OF THIS PAPER.

Pigeon point is the northeastern extremity of Minnesota. It is one of a series of parallel points extending from Minnesota and Canada eastward into Lake Superior. Its backbone is a great east and west dike-like mass of a gray, coarse grained rock that has always been called gabbro. This consists of phenocrysts of plagioclase in a diabasic groundmass of the same mineral, olivine and diallage, and, consequently, it is a diabase porphyrite.

Upon alteration the gabbro gives rise to phases that differ in their general aspect from the normal rock. The olivine and diallage pass into chlorite, biotite and hornblende, of the latter of which three varieties may be recognized. When compact brown amphibole originates in this manner the resulting rock resembles Irving's hornblende gabbros. The plagioclase of the gabbro changes into chlorite, quartz, and a reddish feldspar, of which the last two mentioned minerals are often in micropegmatitic intergrowths. The change of the plagioclase into red feldspar is in all probability a contact phenomenon.

The rocks through which the gabbro cuts are evenly bedded slates and indurated sandstones of Animikie age. They dip south-southeast at 15° to 20°, except at a very few places near the contact with other rocks, where they are more or less contorted.

Small dikes also intersect these sedimentaries. Their width varies from an inch or two to 60 feet, and their material is a non olivinitic diabase that is often micaceous.

The most interesting features in the geology of the point relate to the series of rocks usually occurring between the gabbro and the clastic beds. Beginning on the gabbro side the series comprises in succession coarse-grained red rocks, a fine-grained red rock that is sometimes porphyritic and a well-marked belt of altered quartzites.

The fine-grained red rock has all the characteristics of an eruptive. It sends dikes into the contiguous bedded rocks, and consists essentially of a hypidiomorphic granular aggregate of plagioclase, anorthoclase, and quartz. The quartz and anorthoclase often form micropegmatite, while the plagioclase is in comparatively large grains, some of which have badly defined idiomorphic outlines. At a few places this red rock is porphyritic, with bipyramidal quartz crystals imbedded in a red granophyric groundmass. The rock is similar to many of the augite-syenites described by Irving as occurring in the Keweenawan series, and is in structure and composition a quartz-keratophyre.

The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between these two. The variety nearest the gabbro differs but slightly from the basic eruptive. In addition to the gabbro components it contains a little quartz and red feldspar—constituents derived from the keratophyre. As the latter rock is approached the augite, olivine, and plagioclase disappear, while increased quantities of quartz, red feldspar, and brown hornblende make their appearance, and the rock becomes more and more like the fine-grained red rock. Finally the hornblende disappears and the keratophyre is reached. Since the intermediate rocks occur only between the gabbro and the fine-grained red rock, and since all gradations in composition between the two end members of the series are represented, the coarse-grained red rocks are regarded as contact products formed by the intermingling of the gabbro and the keratophyre magmas. In general peculiarities they are identical with some of Irving's orthoclase gabbros.

In the undoubted contact belt between the keratophyre and the unaltered slates and quartzites three zones are distinguished. In the exterior zone (that nearest the unaltered clastics) the rocks differ but little from the corresponding unaltered forms. The enlargements of the quartz grains, that are so marked a feature in the latter, have been lost, and with them all traces of the original fragmental character of the grains. The quartzes now interlock by irregular sutures. Bleached biotite, sericite, and chlorite, are the only new minerals detected. The original regular bedding has not been disturbed.

In the middle zone of the contact belt the rocks are irregularly mottled in green and red. Sections made from the red portions of these rocks show rudely outlined bipyramidal quartz crystals in a matrix of globulitic red feldspar or of granophyre. The red feldspar, which is principally orthoclase, is much more abundant than it is in the rocks of the outer zone. The green portions contain but little feldspar. In composition and structure they are like the members of the exterior zone.

In the inner zone the rocks are of a uniform bright-red color, or they are bright red, spotted here and there with large green circular spots. In the spots the quartz grains interlock as in the least altered of the contact rocks. In the red ground mass, on the contrary, nearly all the quartz particles have the form of crystals, whose contours are more frequently than otherwise broken by embayments of the feldspathic mass in which they lie. Even in this, the zone of most intense action, but few new minerals are discovered. Long acicular zircons often occur traversing two or three quartz grains, thus showing plainly their contact origin, and bundles of sericite are not infrequently scattered through the red feldspathic matrix.

From the above-mentioned facts it is concluded that the contact belt represents Animikie slates and quartzites that have been altered near their contact with an intrusive rock. The metamorphism of the quartzites has resulted simply in the recrystallization of the quartz and feldspar of the fragmental grains, with the addition, perhaps, of a little orthoclase.

Since, in several instances, the gabbro is in direct contact with the metamorphosed rocks, while the keratophyre is not to be found in the neighborhood, it is inferred that the former rock and not the latter was the cause of the contact action.

Inclusions of fragmentals in the gabbro and the keratophyre have alike suffered the same alterations as have taken place in the various members of the contact belt, with this difference, that quartzite inclusions in the basic rock are often surrounded by a rim of red rock, identical in all its properties with the keratophyre. This suggests that the keratophyre itself may be of contact origin.

The question that now arises is this: Is the keratophyre a genuine intrusive between the gabbro and its contact belt, or is it merely an extreme phase in the alteration of the clastic rocks by the gabbro?

The eighth chapter of the bulletin is devoted to the discussion of this question. The conclusion reached is that, in all probability, the keratophyre is of contact origin—that is, it was produced by the fusion of the slates and quartzites of the Animikie through the action upon them of the "gabbro." The magma thus formed then acted in all respects like any intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda-granite under certain circumstances, and under others as a quartz keratophyre.

PREFACE.

The preparation of this paper is due to the fact that the eruptive rocks occurring on Pigeon point, Minnesota, may be taken as types of similar eruptives found so widely spread over the Huronian and Keweenawan areas surrounding Lake Superior, and to the peculiar nature of the alteration these have superinduced in the fragmental rocks through which they have broken.

The materials for the study were obtained during two field seasons under the auspices of the U. S. Geological Survey. The first visit was made during the summer of 1885 in company with Dr. George H. Williams, of the Johns Hopkins University, to whose carefully prepared notes the writer owes much for whatever success has attended his study of the region. The second visit occupied about three weeks in the summer of 1888.

The laboratory investigation of the specimens collected was begun at the Johns Hopkins University in the winter of 1885–'86. It was continued at the University of Wisconsin during the winter of 1887–'88, and has been completed at Colby University, during such time as could be spared from other duties.

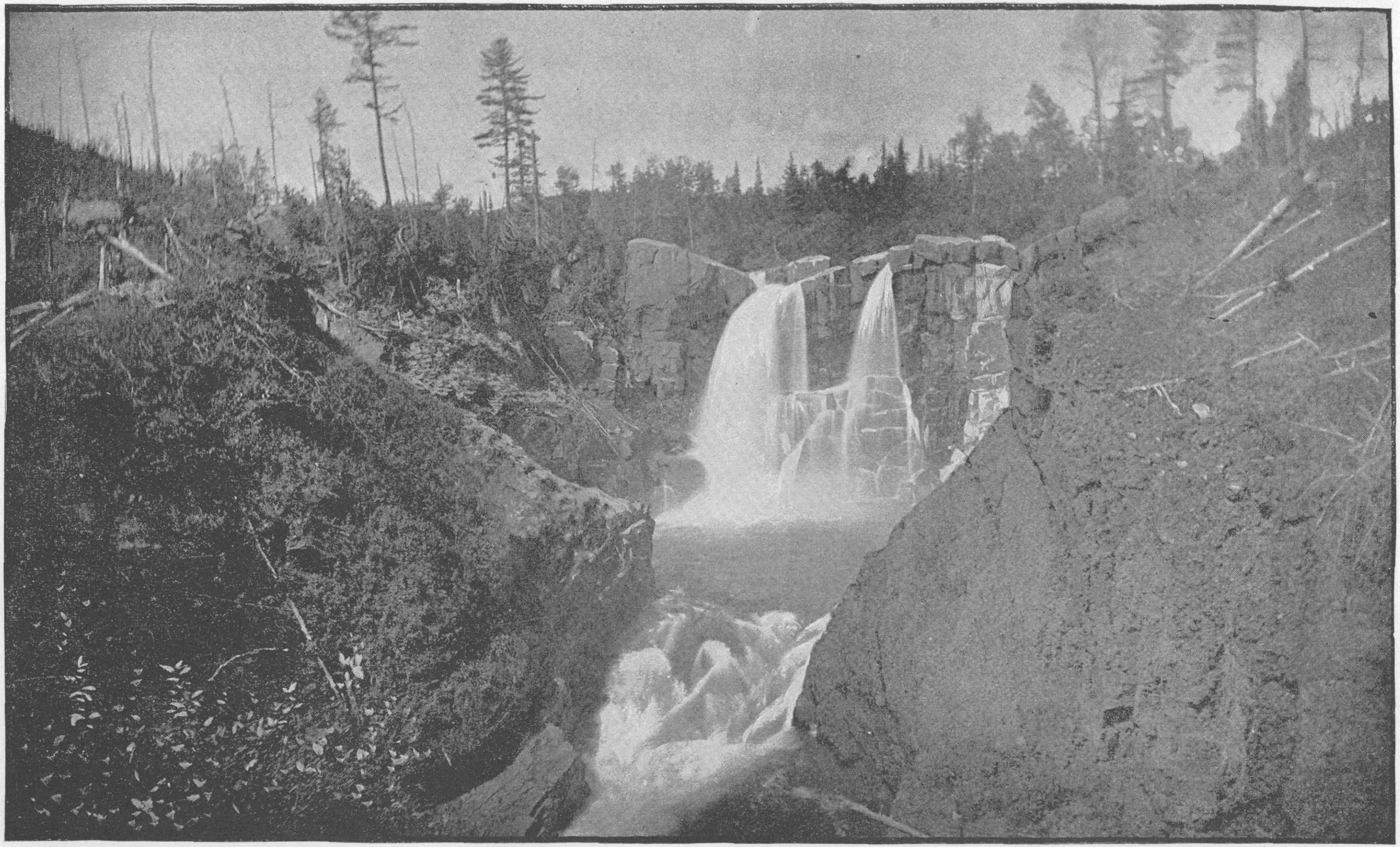
Thanks are due first of all to Dr. Williams for the suggestions offered during the earlier part of the study; to the late Prof. R. D. Irving, United States geologist, for his kindness in patiently explaining the lines which the investigation should pursue in order to be of general value; and to Prof. C. R. Van Hise, of Madison, Wisconsin, for his liberality in affording every opportunity for the comparison of the Pigeon point rocks with those from other localities in the Lake Superior region, and in providing everything that could be of use in advancing the work.

The writer would also acknowledge his obligations to Dr. Charles Barrois, of Lille, France, for his examination of thin sections of some of the sedimentary rocks, and their comparison with those of the altered quartzites[1] of Brittany; to Dr. K. de Kroustschoff, of Breslau, Germany, for his opinion in regard to the nature of the quartz of the altered quartzites; and to Mr. W. F. Hillebrand, Dr. R. B. Riggs, Mr. J. E. Whitfield, and Mr. L. G. Eakins, chemists of the U. S. Geological Survey, for the careful analyses, which have been of great value in discussing the nature of the contact rocks.

W. S. B.

COLBY UNIVERSITY, *Waterville, Maine.*

[1] Sur les grès métamorphiques du massif granitique du Guéméné, Ann. d. l. Soc. géol. du Nord., 1884, vol. XI, p. 103.



PIGEON FALLS, PIGEON RIVER MINNESOTA.
The stream plunges over a vertical cliff produced by joint cracks in gabbro. The rocks in the foreground are unaltered black slates with a dip toward the observer.

THE ERUPTIVE AND SEDIMENTARY ROCKS ON PIGEON POINT, MINNESOTA, AND THEIR CONTACT PHENOMENA.

By William Shirley Bayley.

INTRODUCTION.

RELATION OF PIGEON POINT TO THE SURROUNDING REGION.

Pigeon point is the name given to the northeastern portion of Minnesota, embraced within sections 25, 26, 27, 28, 29, 30, 31, and 32, T. 64 N., R. 7 E. of the fourth principal meridian. It extends from the main shore N. 77° E., into Lake Superior (Pl. III). Pigeon river and Pigeon bay separate it from Canada on the north; on the south it is washed by Lake Superior, and on the west by the waters of Wauswaugoning bay. Measured from the eastern side of Wauswaugoning bay to its easternmost extremity it is 5½ miles in length. Its width varies from a few hundred feet to as much as 1 mile in its western part, its average width being somewhere between a quarter and a half mile.

It is isolated from the mainland by a stretch of low swampy country, which runs from Wauswaugoning bay northeasterly to Pigeon river. The traces of former coast lines in the interior show that the swamp was at some earlier time covered with water, and that the point was consequently an island, or, rather, a group of islands, since all the lowlands on the point contain the remains of raised beaches.

One of these areas of lowland, formerly a strait, but now an isthmus, is situated about a mile and a half from the eastern end of the point. It is a narrow shingle beach, about 200 feet wide, over which the Indians are accustomed to portage in order to avoid the large stretch of open water at the mouth of Pigeon bay, and to which they have given the name of "Little Portage." This isthmus affords a convenient means of dividing the point (for purposes of description only) into an eastern and a western portion. The eastern portion is heavily wooded in the interior, and is so thickly covered with surface material that it is only with the greatest difficulty that the relations of the different rocks to each other can be determined. In the western portion, on the other hand, the rocks are well exposed in some places, in consequence of the destruction of the forest by fire. In other places they are concealed by thick windfalls, through which it is almost impossible to penetrate, and in the extreme western part by a second growth of low scrubby balsams and poplars. In this latter area, west of a line drawn north from Fishermans point, the representation of the distribution of the rocks is only approximately correct.

In the preparation of the geological map accompanying this report (Pls. XIV, XV, and XVI) sections were made across the point at intervals of 100 and 200 paces[1] in its eastern portion, and of 100, 200, and 300 paces in its western part. This means that from 7 to 20 traverses have been made for each mile.

A glance at any good map[2] of Lake Superior will show that Pigeon point is one of a series of parallel points extending from the main land a distance of 1 or 2 miles easterly into the lake. These points consist in greater part of large dikes of a heavy, dark, basic rock, which is, as far as known,[3] a fresh olivine-gabbro, very much like that occurring on Pigeon point. They are offshoots of an immense mass of the same gabbro, which, beginning on the north side of Grand Portage bay, runs northeasterly, crossing Pigeon river at the falls and extending as a high ridge far into Canada. The junction of the Pigeon point mass with that of the main ridge can not be seen, since it is separated from the latter by Wauswaugoning bay and the lowland extending from the head of this bay to Pigeon river. From the nature of the prevailing rock in this mass, however, it seems to be beyond dispute that it is merely a branch of the main ridge, similar to those branches which give rise to the parallel points which project from the lake shore for 16 miles northeast of the national boundary line.

PREVIOUS WORK ON THE GEOLOGY OF THE POINT.

The first recorded description of the rocks of Pigeon point is that given by Maj. Richard Owen,[4] who, on the 17th of July, 1849, under instructions from Dr. Norwood, made a trip in a canoe from Grand Portage bay to the mouth of Pigeon river. Maj. Owen reports the point as consisting principally of a number of parallel trap dikes, with a trend a little north of east. These cut slates and sandstones, altering them in places, and are themselves cut by smaller dikes of a slightly different character. Many of Maj. Owen's observations are valueless. His recorded dips for the sedimentary rocks can not be verified, and he is mistaken in supposing the area covered by these to be so large.

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[1] A mile contains 2,000 paces.

[2] Sketch map of the Thunder Bay mining region, accompanying report on mines and mining on Lake Superior, by E. D. Ingall, M. E. Ann. Rep. Geol. and Nat. Hist. Survey of Canada for 1887, part H.

[3] Monograph, U. S. Geol. Survey, vol. V. The copper-bearing rocks of Lake Superior; R. D. Irving, pp. 371-372.

[4] Report of a geological survey of Wisconsin, Iowa, and Minnesota, by David Dale Owen, Philadelphia, 1852, p. 396.

GORGE OF PIGEON RIVER BELOW THE FALLS.

From the top of the falls, looking southeast. The rock in the immediate foreground is gabbro, as is also that in the heavy shadow on the right in the middle ground. Slates are evenly and almost horizontally bedded near masses of gabbro.

In 1851 Messrs. Foster and Whitney,[1] on the authority of Prof. W. W. Mather, announced the occurrence of a large quantity of granite in the eastern portion of the peninsula, and consequently declared the age of the rocks there to be Azoic.

The next mention of the point was made by Prof. N. H. Winchell.[2] Prof. Winchell collected specimens along the coast from Wauswaugoning bay to the falls of Pigeon river, and also along the trail leading from the former place to Parkerville, a small settlement on the Pigeon river about three-quarters of a mile from its mouth. A second visit[3] to the point was made in the succeeding year, but the relation of the rocks to each other was not definitely determined, although Prof. Winchell thought there was evidence of a metamorphic effect produced on the slates and quartzites by the eruptive masses intruding them. The rocks collected on these two trips were not studied in detail until some years later, when, in 1887, Dr. M. E. Wadsworth[4] investigated the specimens microscopically, and published his descriptions in a bulletin of the Minnesota survey. References to these descriptions will be made in other portions of this paper.

In 1881 Prof. Irving[5] examined the rocks under consideration during a trip along the north shore of Lake Superior, in connection with his discussion of the copper-bearing series. He describes the point as made up essentially of quartzites and slates cut by dikes of gabbro and diabase. The fragmental rocks he regards as belonging to Hunt's Animikie[6] series, which occupies the stratigraphical position of Logan and Murray's[7] original Huronian. The granite described by Foster and Whitney he finds to be intrusive in the fragmentals.

In 1888 Mr. E. D. Ingall[8] published a report on mines and mining on Lake Superior, and in it recorded some facts in relation to the geology of the region north and east of the point. The report is accompanied by an appendix, in which the writer gives a brief account of the microscopical characteristics of some of the most interesting of the rocks occurring on the islands to the east of Pigeon point, a few of which show some of the peculiarities of the Pigeon point contact rocks.

Finally there have appeared two papers by the writer[9] treating of certain phases of the contact phenomena observed on the point.

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[1] Report on the geology of the Lake Superior land district, Washington, 1851, Pt. II, pp. 12, 37.

[2] The geological and natural history survey of Minnesota. Ninth Annual Report. St. Peter, 1881, pp. 63–71.

[3] Ibid, Tenth Annual Report, St. Paul, 1882, pp. 48 and 56–59.

[4] Preliminary description of the peridotytes, gabbros, diabases and andesytes of Minnesota. Bulletin No. 2, pp. 29, 53, 87, 96, 105, 108, and 120.

[5] Monograph, U. S. Geol. Survey, vol. v. The copper-bearing rocks of Lake Superior, R. D. Irving, pp. 368–370.

[6] Trans. Am. Inst. Min. Eng., Vol. 1, p. 339.

[7] Geol. of Canada. 1863, pp. 50–66. For a full discussion of the age of the Animikie series, see R. D. Irving, Am. Jour. Sci., Vol. 34, pp. 259–262.

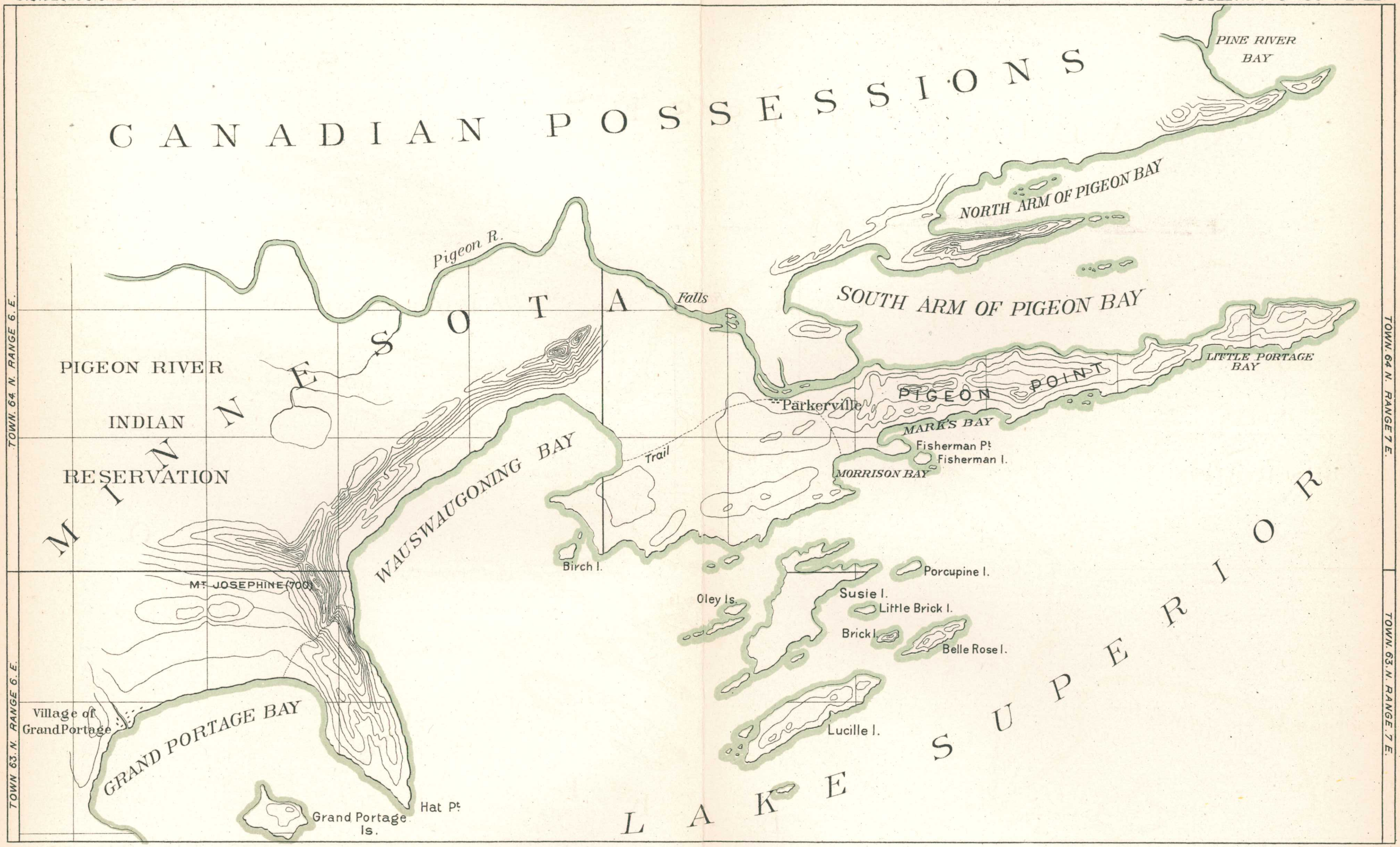
[8] Geol. and Nat. Hist. Survey of Canada. Annual Report for 1887, Part H.

[9] On some peculiarly spotted rocks from Pigeon point, Minnesota; Am. Jour. Sci., May, 1888, p. 388; and A quartz-keratophyre from Pigeon point and Irving's augite-syenites. Ibid., 1889, p. 54.

LIMITATIONS OF THE PRESENT PAPER.

In the present paper attention will be confined to that piece of high land south and east of the swamp referred to as separating Pigeon point from the main land. This area is isolated, not only in its position, but also in its geological features. It exhibits throughout nearly its entire extent a series of slates and quartzites that have been altered by eruptive rocks which intrude them. The alteration which these fragmental rocks have undergone presents features which have not been observed in similar rocks elsewhere. Even in the Lake Superior region it is confined entirely, so far as known, to the rocks occurring on Pigeon point and on a few small islands lying some 10 miles northeast of it. No evidence of similar alteration has been discovered on the main land, although large masses of eruptives have everywhere cut through clastic rocks of the same geologic age. In addition to the altered rocks there is also on the point a large quantity of a red drusy granitic rock, which is different from anything in the Animikie area to the north and east (with the exception of a rock occurring in a small quantity on the islands referred to above), but which is very similar to many of the interbedded flows in the Keweenawan series.

For these reasons it has been deemed best to treat only of those phenomena observed on the point, leaving the geology of the neighboring region for some future publication.



MAP OF PIGEON POINT AND VICINITY.

Topography compiled from Lake Survey Charts and Land Office Plats.

0 1/4 1/2 3/4 1 2 3 Miles.

Scale

Contour Interval 50 feet.

1891.

CHAPTER I.

THE GENERAL DISTRIBUTION OF THE ROCKS ON PIGEON POINT AND THEIR RELATIONS TO EACH OTHER.

The rocks on Pigeon point consist of a large mass of dark, heavy, olivine-gabbro; a light, drusy, red rock; diabase; fragmental rocks; and those which owe their origin to certain phases of contact action.

THE FRAGMENTAL ROCKS.

The fragmental rocks embrace, in the main, evenly bedded slates and quartzites, dipping at 15°–20° SSE., and striking nearly parallel to the axis of the point. They are cut by two systems of nearly vertical joint cracks at right angles to each other, along which the parting is so perfect that in many places the fragmental beds have the appearance of courses of masonry, in which the individual blocks have been squared and trimmed with the greatest nicety. These rocks are exposed on the south side of the point throughout almost its entire length. On its north side they occur in but two places (see map, Pl. XIV), and at both of these they have the normal southerly dip and easterly strike. The northern dip recorded by Owen[1] as existing here could not be found.

The displacements caused in these strata by the eruptions through them appear to have been very slight. No such general disturbances as those reported by Maj. Owen were seen anywhere. At only three places was any variation from the normal position of these rocks observed, and in each of these the variation was found to be due entirely to local causes. The first place where a deviation from the usual strike and dip was noted is on the south side of the point, just east of the little isthmus about a mile and a half from its extremity. Here a large diabase dike, running parallel to the shore, about 100 feet from the water's edge, has broken through the slates and quartzites and crumpled them in a most remarkable manner. The rocks are bent into many short, sharp folds, which are crowded together in the vicinity of the dike, but gradually disappear as they recede from it.

About three-quarters of a mile west of the isthmus, on the same side of the point, is a beautiful exposure of gently bowed quartzites in the side of a cliff at the water's edge. Here layers of evenly bedded green slates and thicker beds of massive, jointed, brown quartzites have been

[1] Geol. Survey of Wisconsin, Iowa, and Minnesota, p. 397.

raised and thrown into gentle flexures by the intrusion under them of a mass of red rock, which has sent out apophyses into the overlying fragmentals, and has slightly altered them. (Fig. 1.)

The third point at which local disturbance was noticed is in the side of a cliff in the interior of the point, about 300 feet north and 125 feet east of the barite vein, whose position is indicated on the map (Pl. XIV). At this place the fragmental beds and the gabbro have come into con-

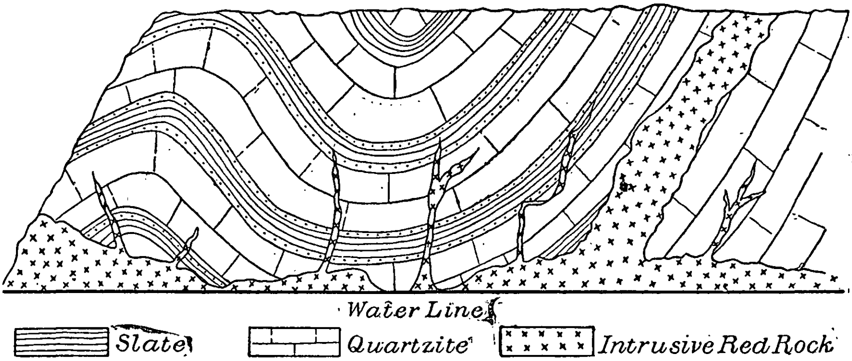


FIG. 1.—Sketch of the side of a cliff, showing crumpling of slates and quartzites by the intrusion of an eruptive beneath them.

tact, and in such a way that the former have lost their even bedding for a distance of about 3 feet from the latter. (Fig. 2.)

No other instances of contortion in the bedded rocks or of deviation from the normal southeasterly dip of 15° to 20° were observed on the Point, although close search was made for the vertically tilted beds pictured by Maj. Owen in his report on the region.

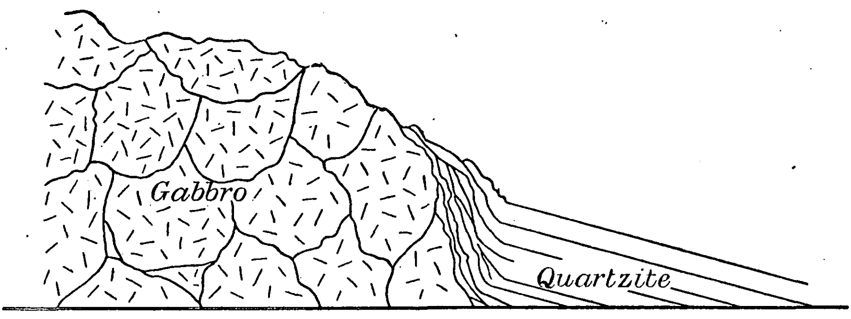


FIG. 2.—Contact of olivine gabbro and quartzite, showing crumpling of latter.

On the top of the high hill on the Canadian side of Pigeon river, near the falls (see map, Pl. III), there are twisted and contorted slates, some of which dip at a high angle to the north. But even here the northerly dip is maintained over only very small areas, for at the base of the same hill and along its southern side (see Pl. II) the rocks are again found with a low dip to the southeast. In this case the disturbing cause was the large dike over which the river falls.

The dip of 15° to 20° to the southeast is not confined to the fragmental rocks on Pigeon point. It is the prevailing dip for all of the Animikie beds in this region, as was shown by Irving,[1] and is in nc way due to the Pigeon point eruptives, as was supposed by Owen.

Interbedded with the quartzites and slates are certain layers in which there are numerous light-colored and green spherical bodies, which in cross section appear as spots on the surfaces of the rocks. In some areas these spots consist in large part of calcite; in others they are composed principally of epidote. The distribution of these spotted rocks with reference to the eruptives could not be precisely determined, because the beds in which they occur are exposed only on the lake shore, where they are found underlying unspotted beds, which spread over the former and cover them from view as we proceed from the water's edge toward the eruptive masses. These rocks have been designated "spotted rocks" to distinguish them from the "mottled rocks," which will be described later as characteristic of the contact belt occurring between the quartzites and the red rock. They are supposed to be due to the existence of calcite concretions in the beds, which have given rise to the quartzites upon silicification. Their origin will be explained in Chapter VI.

In addition to numerous dikes cutting the slates and quartzites there is a system of veins[2] penetrating them in a NNW. direction across the prevailing trend of the dikes. These veins are filled with white barite, crystalized calcite, and amethystine quartz, with occasionally a little chalcoyrite or other compound of copper, which is never found in sufficient quantity to repay the expense of working. On Susie island (Pl. III), however, there is an extension of one of the Pigeon point veins, from which a quantity of salable ore has been extracted. At present (1888) the mine is shut down, no work having been prosecuted for the last few years. On the point itself is a large vein exposed near the water's edge, on the south shore, about midway between Little Portage bay and Fisherman's point (see maps). This was worked for barite a few years ago, but evidently without success.

The Pigeon point veins form a part of a great system cutting the Animikie rocks throughout their entire extent. A careful description of this system has recently been given by Mr. E. D. Ingall[3] of the Canadian Geological Survey, and by him the relations between the veins and the joint cracks occurring in the sedimentary beds have been ably discussed.

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[1] Monograph, U. S. Geol. Survey, vol. v. The Copper-Bearing Rocks of Lake Superior. R. D. Irving, pp. 367–390.

[2] For a description of the independent veins occurring on the point, vide N. H. Winchell: Geol. and Nat. Hist. Survey of Minnesota, Seventh Ann. Rept. 1878, pp. 15–16; Ninth Ann. Rept., 1880, pp. 64–67.

[3] Annual Report for 1887, Part H.

THE ERUPTIVES AND THEIR CONTACT PHENOMENA.

The heavy dark gabbro constitutes by far the greater part of the point. It is included in two principal areas (Pls. XIV, XV and XVI). In one of these it extends as a series of hills from the eastern side of the swamp between Wauswaugoning bay and Pigeon river, with few interruptions, to the eastern end of the point. It is best exposed on the north shore, where it forms perpendicular cliffs, some of which are over 100 feet in height. Their perpendicularity is clearly the result of the existence of vertical joint cracks in the rocks composing them. Under the influence of even the slighest amount of weathering these cracks begin to open, and before the rock has undergone any considerable alteration, large square or oblong blocks break off and tumble from the sides of the cliff to its foot, thus exposing successively to the action of the waves new vertical faces of rock. At the falls of the Pigeon river the joint cracks have a direction S. 79° W. and N. 11° W., so that the loosening of large masses of the rock from the barrier of the falls results in the formation of a perpendicular wall over which the river plunges vertically to a depth of about 120 feet (see frontispiece), taking a second smaller plunge over a trap dike, which runs parallel to the larger dike at a distance of about 50 yards east of it. The large dike has already been mentioned as the one which begins north of Grand Portage and extends in a northeasterly direction into Canada. In the interior of the point the gabbro occupies all the higher portions, and along its southern edge presents a steep face to the south.

The second gabbro area begins at Wauswaugoning bay and runs parallel to the first area with many interruptions for about a mile and a half, ending a few hundred yards west of Morrison's bay. Besides these are two or three isolated small areas, whose position may be learned by reference to the map.

The most prominent features of these gabbro masses are those of dikes. As has already been mentioned, the larger one in many places presents perpendicular walls both to the north and to the south. It occupies all the highest portions of the point, and these are in a straight line. It has the appearance of an intrusive mass, and is like any one of those forming the numerous points to the north of the international boundary line. It has been regarded as a dike by both Irving[1] and N. H. Winchell.[2] Its contact with the sedimentary rocks is only occasionally to be seen. At several of these contacts the eruptive has the appearance of having escaped from between the dike walls and thrust itself for a short-distance between the fragmental beds, or of having piled itself up around the dike orifice and overlapped the intruded rocks. The gabbro in the cliff pictured in Fig. 2 is a coarse-grained porphyritic

[1]Monograph, vol. V, U. S. Geol. Survey. The Copper-Bearing Rocks of Lake Superior, R. D. Irving, p. 370.

[2]Ninth Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, p. 69.

rock in which the porphyritic crystals of feldspar are arranged in rude layers parallel to the dip surfaces of the quartzite. Their longer axes are usually in the direction of the dip of the sedimentary rocks, and the general effect is such as would have been produced if the gabbro had flowed down upon the surface of the quartzite. Again, on the north side of the point, at the mouth of Pigeon river, are slates and quartzites, capped by an overflow of a fine-grained variety of the gabbro. These two facts, coupled with the more general characteristics, seem to show that the larger mass of Pigeon point gabbro is in the form of a dike, which has broken through its walls at certain places and intruded itself between the strata of the surrounding rocks. That it is not an interbedded or a surface flow, like those so numerous in the Keweenawan series and in the Animikie beds in the vicinity of Thunder bay, is clearly seen when a cross section of the point is viewed from the deck of a steamboat lying some distance off from the extremity. Moreover, if it were an interbedded flow the slates and quartzites, which are so abundant on the south shore of the point, would make their appearance in the face of the cliffs on its north side at some distance above the water line. This, however, is not the case. At only two places on the north shore do the fragmental rocks appear, and at these places they are far below where they should be were they interbedded with the gabbro, and in neither case is the contact like that of interbedded eruptive and sedimentary rocks.

The view that the gabbro may be a surface flow on the eroded top of the Animikie beds, like the great gabbro flow at the base [1] of the Keweenawan series in the interior of northeastern Minnesota, it is not so easy to prove incorrect. The sedimentary beds in question are at the very top of the Animikie series; their contact [2] with the overlying Keweenawan beds being observable at Grand Portage island in Grand Portage bay, a few miles west of the western end of Pigeon point, nearly in the direct line of the strike of the beds. Here, however, the overlying rock is a diabase or diabase-porphyrite, very different from the rock occurring on the point. Moreover, there are no indications of the great erosion which would have been necessary to produce the relations now found, should we suppose the gabbro to have been a surface flow.

The red rock, to which reference has been made, is found in three distinct though indefinitely outlined areas (Pls. XIV, XV and XVI). The first is in the eastern portion of the point, where it occupies a position between the gabbro and the fragmental rocks. The second area begins at the Little Portage isthmus and extends about 3 miles westerly. For the first mile and a half, as in the case of the first occurrence, its position is between the gabbro and the slates and quartzites. Here it leaves the shore, near which it is found in the eastern half of the point, and

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[1] Am. Jour. Sci., Vol. 34. R. D. Irving, pp. 260-262.

[2] Monograph, U. S. Geol. Survey, vol. V. The Copper-Bearing Rocks of Lake Superior. R. D. Irving, p. 297.

bends inward, passing between the two gabbro areas for the remaining mile and a half. The third area begins at the eastern side of Wauswaugoning bay and runs about 2 miles easterly, on the south side of the second gabbro area, and between this and the fragmental rocks.

Throughout its greatest extent the rock possesses a fine to medium grained texture, and is non-porphyritic. At two places, however, it becomes porphyritic, through the development of quartz in two generations. The first of these places is on the top of a high bluff near the south side of the point, about a quarter of a mile west of the isthmus referred to above. Here the porphyry overlaps the gabbro. At the base of the cliff, on its south side, the contact between these two rocks can be traced for some distance. The relations of the porphyry and the gabbro are not those of interbedded flows, but rather of two irruptive rocks, of which the younger—the porphyry—has cut

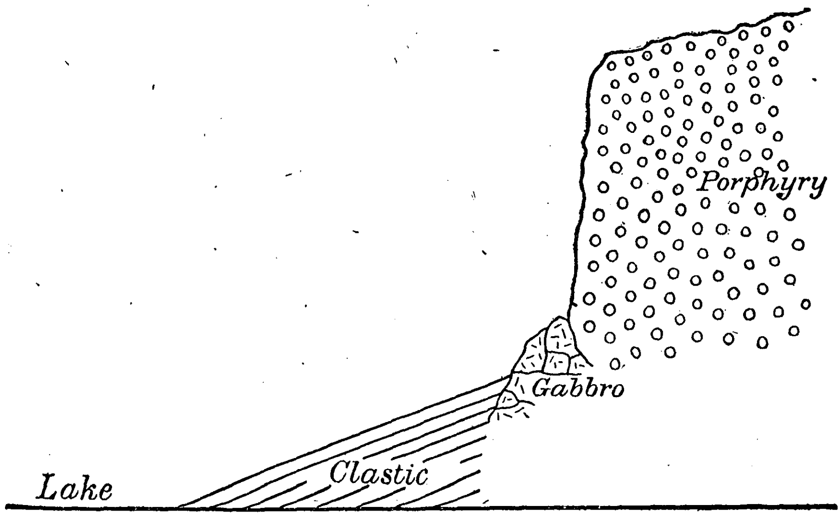


FIG. 3.—Contact of porphyritic red rock with olivine gabbro at the base of a bluff a little to the west of Little Portage.

through the other and slightly overlapped it on the edges (see Fig. 3). The second place where a porphyritic structure is developed in the red rock is at the eastern end of the western, or third, area. Here the relations between the gabbro and the red rock could not be clearly made out.

The relative ages of the rocks are difficult to determine. No undoubted dikes of either were observed in the other. On the north shore are small veins of a red rock cutting the gabbro, but these can not be traced directly to either one of the main masses of this rock, and although very similar in character to the material in the large masses, the identity of the two rocks can not be definitely proved, since a vein of this composition may easily have leached out of the surrounding gabbro. The relations of the diabase dikes (which are so prominent a feature in the geology of the point) to the gabbro and the red rock afford an indication as to the relative ages of the two rocks, but lead to no positive conclusions. These dikes, as will be seen from the map, are most numerous in the fragmental rocks. A few occur in the gabbro; but none were found in the red rock. Moreover, several of the dikes which occur in the gabbro and clastic rocks, run up to and abut against the red rock, but do not enter it. By no amount of search could any kind of diabase dike be found in the latter rock. Other dikes when they approach the neighborhood of the red rock appear to fray out and to become impregnated with the red material.

The true relations between the gabbro and the red rock are obscured by the occurrence on their contact of a rock which has some of the characteristics of the gabbro and others of the red rock. Wherever these are found in close proximity, except at the porphyry bluff described above, and at one or two other places in the interior of the point, the intervening space is occupied by a dark-red rock that becomes darker as it approaches the gabbro, and gradually merges into it; and, on the other hand, takes on more of the aspect of the red rock until finally it can not be distinguished from the most typical variety of the latter. This rock when analyzed is found to have a composition which is intermediate between that of the gabbro and the red rock, and one which varies according to the distance from the one or the other of these rocks at which the specimen analyzed is taken. (See Chap. v.)

The persistent occurrence of this rock only on the contact between the gabbro and the red rock; its peculiar characteristics, which are intermediate between those of the two limiting rocks; and its gradual merging into the gabbro on the one side and the red rock on the other, mark it as a product of contact action between the two rocks on whose borders it is found. As a result of this action the line of demarcation between the gabbro and the red rock has entirely disappeared except at the two or three points to which reference has been made, where the conditions were such as to prevent the interaction of the two rocks. At the porphyry bluff (Fig. 3) there is a very sharp contact line, but at this place the red rock contains porphyritic quartz crystals, and is thus different from the greater portion of the red rock on the point. If we may assume that the porphyry cooled more quickly than the nonporphyritic red rock, we have a ready explanation for the nonexistence of a zone of the contact rock at this place. The reason for the absence of the intermediate rock at the several other localities where a sharp contact line exists is not so apparent. In the interior of the western portion of the point is a very high cliff facing the west. At about two-thirds the way up the side of this cliff there is a very sharp wavy line which marks the position where the red rock and the gabbro come together. On each side of this line the rocks have all the characteristics of the same rocks at a distance from the contact, and no intermediate phases are present. A second place where the same phenomenon is noticed is in the eastern half of the peninsula. In every other instance more or less of the intermediate rock occurs along the border line of the gabbro and red rock.

The diabase dikes occurring on the point vary in width from an inch to more than 60 feet. They are most abundant in the slates and quartzites, where the majority of them have a trend in the direction of the strike of the sedimentary rocks, and a hade of 15°–17° to the south. In the gabbro they are less numerous, and have no one general trend, but are found running in all directions. In the red rock none were discovered although earnest search was made for them. Even those dikes which have a trend that would carry them into the area occupied by the red rock do not enter in, but end abruptly. They fray out on the edges, break up into many small dikes, are impregnated with red drusy material, and finally disappear.

The dikes in the quartzite are more numerous on the southern shore of the point than they are in its interior, and form many of the smaller

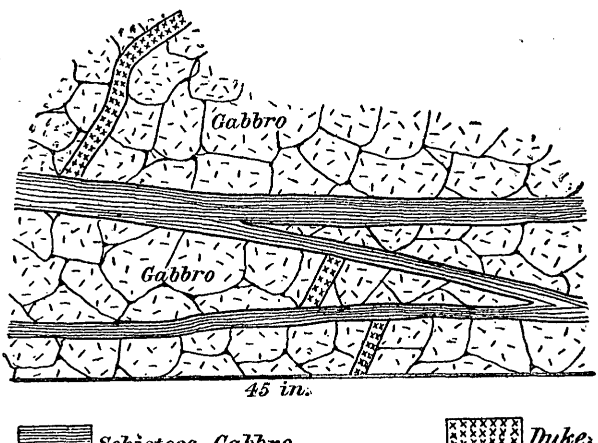


FIG. 4.—Sketch of faulted dike in olivine gabbro.

capes extending southward into Lake Superior. They can often be followed for quite a long distance along their trend, but more frequently they disappear under the slates and quartzites, after exposing on the surface but a few rods of their length. In the gabbro the dikes are as a rule much shorter. They can not be traced with certainty for any great distance because of their irregular courses. In most cases it is impossible to determine whether two apparently independent dikes are really parts of the same mass, whose junction is hidden by the moss and other surface covering, or whether they are in truth the fillings of distinct and disconnected orifices. In one instance, at the extreme end of the point, the parts of a small dike have been displaced by light faulting of the gabbro through which the dike cuts (Fig. 4). If the same faulting has taken place on a larger scale in the interior of the point, it is easy to see how a single dike may have the appearance of several. In the mapping of the dikes no attempt was made to determine whether closely occuring dikes in the gabbro are independent of each other or not. They have been mapped as they were discovered on the surface. It is believed that most of the dikes are independent geological bodies, since in no case, except in the one mentioned, was any evidence found that faulting has taken place in the gabbro. A glance at the map, however, will show that although independent of each other, most of the dikes are connected, in that they are nearly all dependent for their existence upon some great disturbance[1] that produced fissures in the existing rocks, whose prevailing direction was about ENE.

The largest of the dikes are quite coarse grained in the center and fine grained on the edges. They nearly all possess a well-marked cross columnar structure, which however is by no means as striking as is represented by Owen in his "Report of a Geological Survey of Wisconsin, Iowa, and Minnesota." From their great number and their similarity to the diabases of the Keweenawan flows, Irving[2] is inclined to regard them as marking the orifices through which the material of the flows was extruded.

Although the number of large dikes cutting the slates and quartzites is great, no contact phenomena of any kind were noticed in the intruded rocks, unless certain spots in the quartzites may be regarded as such.

THE CONTACT BETWEEN THE FRAGMENTAL AND OTHER ROCKS.

The most striking feature in the geology of the point is the development of a series ot mottled rocks as a contact zone between the fragmentals and the eruptives. The character of the rocks comprising this zone, and their peculiar relations to the red rock so prominent on the point, render them a subject of great interest.

As one approaches the red rock the sedimentary rocks beeome slightly redder in color when quartzose, and lose to some extent their vitreous luster. A little closer to the eruptive they are mottled with dark green and light red spots. At times the mottlings appear as ill-defined red spots on a dark green background. At other times the spots are green, while the ground mass is red. In neither case, however, are the spots as sharply defined against the ground mass as in the case of the "spotted rocks" referred to above. They appear merely as areas in which there are accumulations of some mineral, red feldspar in the case of the red spots, and green mica in the case of the green ones. In most cases these areas are sufficiently circular to merit the name of spots, but occasionally they are drawn out into long lenticular shapes, and threads so interwoven with one another as to produce a structure resembling the eutaxitic structure of eruptive rocks.

[1] Cf. Geikie: The History of Volcanic Action during the Tertiary period in the British Isles. Edinburgh, 1888, pp. 33 and 71.

[2] Monograph, U S. Geol. Survey, vol. v. The Copper-Bearing Rocks of Lake Superior, R. D. Irving. p. 144.

Very close to the red rock appears a belt in which the various rocks are in the most complicated relations imaginable. In the eastern portion of the point this belt is well seen on the southern shore, about one-third of a mile from the end of the point. (See Pl. XVI.) Here the red rock is exposed in low cliffs, and in it are small, sharp slate and quartzite inclusions, into which the red rock penetrates in every direction. The exact line of contact between the red rock and the bedded fragmentals can not be detected, as they appear to merge gradually into one another, the latter becoming redder and redder as they approach the former, which penetrates them in veins and dikes, and finally includes numerous pieces in such a way as to yield a good eruptive breccia.

A little to the north of this exposure the red rock is seen to pass imperceptibly into a coarse grained, gabbro-like red rock, similar to the intermediate rock mentioned a few pages back. Like the red rock, this also contains a large number of slate and quartzite inclusions, surrounded by narrow rims of pink feldspathic material, and occasionally by a bright red border of exactly the same character as that of the red rock. Many of the larger inclusions are distinctly mottled with red or green spots. In some of the quartzite fragments bright green circular spots, varying in size from a few millimeters to two decimeters in diameter, are scattered over a bright red ground mass, containing small dark green elongated spots faintly resembling some of the knots (Knoten) in the "Knoten Schiefer" of the Germans. The ground mass of these rocks, although of the same color as the typical red rock, differs from it a good deal in luster. The groundmass of the altered quartzite is much more vitreous than is the red rock, and its structure is less crystalline. (See Pl. IV.)

A little west of the point on the southern shore above referred to (Pl. XVI) the red rock with its inclusions of slate exhibits to a fine degree the effect of alteration in the latter. Some of the inclusions are very sharp and but little altered, while others are partially dissolved, and are surrounded by concentric zones, resulting from the action of the red rock upon the material of the inclusion, and the reciprocal effect of the partially dissolved inclusion upon that portion of the red-rock magma immediately contiguous to it. The inner one of these contact zones consists of a dark-green chloritic slate, dotted with little crystals of red feldspar. The same dotting of slates by little crystals of feldspar is observed wherever these rocks are in contact with dikes or veins of the red rock, and also in the upper and lower layers of strata interbedded with altered quartzites, as on the cliff side represented in Fig. 1. Again on the island off the southeastern shore, about 2,000 feet from the end of the point, the slates are cut by a vein of quartz and red feldspar, and are dotted along its side by the same red crystals.

In the western part of the point the contact belt is well developed along the entire border of the red rock area south of the northern gab-

POLISHED SURFACE OF MOTTLED ROCK, CHARACTERISTIC OF THE CONTACT BELT.

NATURAL SIZE.

bro belt. Here the red rock occupies a low valley, to the north of which are the gabbro hills and to the south a series of less lofty hillocks composed of the material of the contact belt. The character of this contact belt differs but little from that of the one described above. Mottled inclusions of quartzite and slate are common in it, and these by solution in the inclosing rock have given rise to a large amount of a product resembling the red ground mass of the mottled rocks. Just north of the barite vein (for the situation of which see map, Pl. XIV) there extends eastward a remarkable ridge, consisting of a mottled red rock full of inclusions. The inclusions are bent and twisted into a great variety of shapes, while the cementing material has a well-marked flow structure (see Fig. 5). Near the inclusions the surrounding rock is very markedly mottled with large green spots.

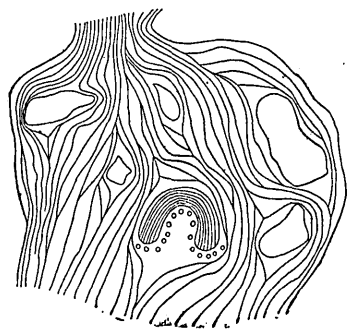


FIG. 5.—Sketch of a portion of the contact belt, showing included fragments in rock exhibiting apparent flow structure.

A third notable development of a belt of red rock holding inclusions is found along the southern side of the eastern end of the tongue of quartz-porphyry comprising the third area of the red rock. In this belt the phenomena met with are the same in character as those which distinguish the contact belt in other exposures.

A study of the contact belt throughout the entire extent of the point leaves no doubt in the mind that it is a constant accompaniment of the red rock, except in a few cases where this is present in the form of a porphyry. Thus it would seem to be a fact beyond controversy that the red rock is the immediate cause of the alteration noticed in the fragmental rocks and of the breccia observed along its contact with them. If, however, the contact belt is examined very closely it is found that although the red rock is always accompanied by a zone of this belt, there are localities in which the latter occurs without the presence of the former. In the description of a contact between the gabbro and the quartzites near that pictured in Fig. 2, the field notes state that "as the eruptive is approached * * * the regularly bedded slates and quartzites become reddened and much bent. They are succeeded by a band of pinkish rock filled with fine red mottlings on a green ground, which (band) apparently runs under the gabbro. The mottlings are often so arranged as to give a distinct flowage structure. Inclusions of the fragmental rocks are frequent in the eruptive and the whole is penetrated in every direction by veins of drusy red granite." Again, at a point just west of the barite vein, the metamorphosing rock seems to be the gabbro. Just as in the case of the contacts with the red rock, the quartzites become mottled as they approach the eruptive, and inclusions of the former in the latter are so frequent that there appears to be a gradual transition between the two rocks.

On the other hand, there are many places where the gabbro and the quartzites are in contact without the least evidence of any action between them. On the north shore of the point slates and quartzites are found separated by a very sharp line, on each side of which the respective rocks preserve their distinctive characteristics without any trace of alteration in either.

From a consideration of the facts above described, it is difficult to decide whether the red rock is the active agent in producing the phenomena observed in the contact belt, or whether the gabbro is the metamorphosing rock and the red rock merely one of the products of its contact action. The absence of contact rocks along the north shore of the point, where the conditions prevailing at the time of the eruption of the gabbro could not have been very different from those existing on its south side, would seem to prove that the contact action did not have its source in the gabbro. Other apparent indications of the correctness of this view are found in the non-existence of contact rocks in connection with the large masses of gabbro occurring on the shore of Lake Superior to the northeast of Pigeon point.[1] All along this shore there are immense dikes of gabbro which cut slates and quartzites like those present on the point, but at no single instance have they affected the fragmental rocks through which they broke, except at one locality—at the falls of Pigeon river.

At this place the slates are fissile and evenly interbedded with hard quartzites, the series dipping in the main at an angle of 17° to 20° to the southeast. On the top of the hill on the north side of the river the contact between the fragmental beds and the extension of the large dike forming the barrier of the falls is finely shown. The slates here dip to the north. They are jointed into small square blocks, and have become hard and black and apparently coarsely crystalline. They are mottled with fine dark spots, which are often arranged in lines resembling flowage lines. In them pieces of the harder siliceous beds appear as if included. It will be noted that the contact phenomena observed at this place differ in some respects from those observed on the point. No strongly marked mottled rocks are to be found here, nor is there present any of the vitreous red quartzites like those so prevalent among the contact rocks of the point.

The view that the red rock is the metamorphosing agent finds confirmation in the fact that wherever the contact rocks appear in any quantity, there also is to be found more or less of the red rock. This is true not only of the occurrences on Pigeon point, but it is true also of those on Spar, Jarvis, and Victoria[2] islands, four small islands on the Canadian side of the international boundary line, about 10 miles northeast of the extremity of Pigeon point. On these islands are large

[1] E. D. Ingall: Rep. on Mines and Mining on Lake Superior. Geol. and Nat. Hist. Survey of Canada. Annual Report, 1887, Part H, p. 48.

[2] W. S. Bayley: Notes of Microscopic Examination of Rocks from the Thunder Bay Silver District. Rep. Geol. and Nat. Hist. Survey of Canada for 1887, Part H, p. 116.

masses of gabbro cutting altered slates and quartzites, and between them there is everywhere present a quantity of the red rock.

The existence of the red rock in dikes and veins, its great similarity in appearance and composition (as shown in the chapter on the petrographical characteristics of the red rock) to the Keweenawan flow rocks on the islands south of Pigeon point, the flow structure observable in it at various places within the contact belt, all point to an original condition of plasticity, if not liquidity. Its comparative freedom from the chemical constituents of the gabbro indicate for it an eruptive origin.

If, however, the red rock is eruptive, and is the agent which has produced the alteration of the sedimentary rocks, its distribution with respect to the gabbro and the fragmental rocks is peculiar. As has been repeatedly stated, the red rock is found almost exclusively between the gabbro on the one side and the fragmental rocks on the other. Its position is such as it would naturally have were it the end product in the alteration of the slates and quartzites by the gabbro. If it is original, its present position can be explained only on the supposition that a line of weakness extended the entire length of the point along the southern junction of the gabbro and the bedded rocks.

The distribution of the rocks under consideration and their relations to each other render it impossible to decide by field study alone whether the contact phenomena are to be ascribed to the action of the gabbro with the red rock as one of the alteration products, or whether they are due to the presence of the red rock. In opposition to the former view is the absence of a contact belt on the north shore of the point and along the sides of the large gabbro dikes on the shore of Lake Superior northeast of Pigeon point, as is also the composition of the red rock. In favor of the correctness of such a view is the distribution of the red rock.

CHAPTER II.

PETROGRAPHICAL DESCRIPTION OF THE FRESH OLIVINE-GABBRO AND ITS ALTERED PHASES.

THE FRESH OLIVINE-GABBRO.

The rock of the large dike-like mass forming the axis of Pigeon point, and the smaller areas in its western part, is, as has already been stated, an olivine-gabbro, very similar in structure to the olivine-gabbros[1] described as occurring so abundantly in other portions of the Lake Superior region. Since none of these has been subjected to a thorough petrographical examination, it is thought well to note in some detail the characteristics of the Pigeon point rock in order that it may serve as a type to which to refer the other rocks of like character in this region.

The Pigeon point gabbro is a coarse to medium-grained gray rock, which weathers light where it has not been subjected to much internal alteration. The greater portion is apparently quite fresh, and has an oily luster due to the large amount of olivine in its composition. When examined macroscopically the attention is immediately attracted by the glassy appearance of its feldspathic constituent. In many instances this is nearly as pellucid as the sanidine in the rhyolites and trachytes. It occurs both in large porphyritic crystals, and in smaller ones, which with olivine and augite form a groundmass in which the larger crystals lie. So far as was observed, there seems to be no general rule governing the development of the porphyritic structure in the rock, nor does there appear to be any sharp line between the truly porphyritic phases and those in which the feldspars are all large, but are not present in two generations.

The porphyritic crystals are frequently 1 to 3 inches long, and sometimes as much as 6 or 7 inches. Many are Carlsbad twins, in which the composition plane and the oblique angle formed at the junction of the cleavage cracks in the two halves are strongly accentuated by superficial weathering. The specific gravity of one of these crystals, as determined by the Thoulet method, is 2·717. It is consequently a plagioclase whose position in the series is between that of bytownite and labradorite. The specific gravity of typical bytownite[2] is 2·729; that of labradorite is 2·700.

[1] Aug. Streng: Neues Jahrbuch für Mineral., etc., 1877, pp. 113–138. Julien: Geol. of Wisconsin, Vol. 3, pp. 233–238. Irving, R. D.: Geol. of Wisconsin, Vol. 3, pp. 168–183. Irving, R. D.: The copper-bearing rocks of Lake Superior: Monograph, Vol. 5, U. S. Geol. Survey, pp. 37–50.

[2] Schuster: Tschermaks mineral. Mittheil., 1880, Vol. 3, pp. 184 and 203.

On flat, weathered surfaces the rock assumes a lighter color, as has been already stated. The feldspars become white and opaque. They project slightly above the general surface, which has a greenish gray tint and a rough, cellular aspect due to little projecting points of feldspar and knobs of chlorite, both of which appear as raised areas separated by depressions that have resulted from the easy decomposition of olivine. Pronounced as is this weathering, it extends but a fraction of an inch below the exposed surface. Large plates half an inch in thickness scale off, and leave the rock immediately beneath them as fresh as any specimens obtained from much greater depths. Where there are fewer large feldspar crystals, and where the rock has been subjected to greater alteration, it first becomes nodular, then separates into rude spheroids, and finally disintegrates into a brownish yellow sand. In the nodular phases the interiors of the nodules are quite fresh, while the internodular substance is slightly altered.

The joint cracks which everywhere cross each other at right angles have already been referred to. They divide the rock into large rectangular blocks measuring about 6 feet on an edge. Fine specimens of these are to be seen at the base of the cliffs on the north side of the point, and at the falls of Pigeon river. The freshest specimens of the rock come from these blocks. Under the microscope the gabbros are seen to be composed essentially of feldspar, olivine, and augite.

A triclinic feldspar constitutes by far the greater portion of the rock. It occurs in two forms: (1) in large porphyritic crystals, and (2) in smaller crystals in the groundmass of the porphyritic varieties, and in the body of the non-porphyritic varieties of the rock.

The porphyritic crystals are generally columnar in the direction of the $\acute{c}$ axis. The planes observed in them are the three pinacoids, and a series of macrodomes. Two series of cleavage lines are very well marked parallel to $\infty P \bar{\infty}$ and OP. Those parallel to OP make an angle of 63°–64° with the $\acute{c}$ axis (angle β). Under the microscope, twinning lamellæ are found to be quite prevalent, although occasionally absent when large areas of the feldspar show an undulatory extinction. Carlsbad twins composed of two individuals, each of which is polysynthetically twinned according to the albite law, are quite common.

The material of the crystals is usually quite fresh, except where slight kaolinization has taken place in the neighborhood of cleavage cracks. They contain but few inclusions, the most prominent ones being little negative crystals of devitrified glass, plates of augite and grains of magnetite. The augite and magnetite appear to have separated from magma included within the feldspar during its growth. The dust-like inclusions so abundant in the feldspar of the gabbros of other regions are entirely lacking here. The specific gravity of a piece of one of the feldspar crystals is mentioned on page 34. Other pieces taken from different crystals, all of which were fresh and free from inclusions, varied in specific gravity between 2·711 and 2·717. These figures correspond to those obtained in the case of the lower members of the labradorites. Labradorite, corresponding to the composition Ab_1An_3, has a specific gravity of 2·728 according to Tschermak[1], while Schuster[2] gives 2·703 as corresponding to Ab_3An_4.

The feldspar in the groundmass of porphyritic varieties of the rock, and that comprising the larger portion—some 60 per cent—of other varieties, occurs in lath-shaped crystals, varying in length from 1 to 20^{mm}. Each of these is composed of a number of smaller individuals, which by their union produce broad lath-shaped forms like those so characteristic of the gabbros from Volpersdorf, in Silesia, and from the Harz.[3] Each of the small crystals is polysynthetically twinned, and two or more frequently unite in a Carlsbad twin.

Like the porphyritic feldspars, the feldspar of the groundmass is fresh and often glassy, and is comparatively free from inclusions. In the freshest varieties only a few dust-like particles and minute flakes of kaolin can be detected. When examined under high powers some of the dust-like inclusions appear to be devitrified glass. The extinction of two contiguous twinned lamellæ, measured against their composition plane, is 24° on each side. The angle formed by the two series of cleavage lines on the macropinacoid is 95° to 96°. These results indicate a feldspar which belongs in the lower portion of the labradorite group.

An analysis of the feldspar which was separated by the Thoulet method from the powder of one of the freshest specimens (No. 11203)[4] yielded the figures in column I, in the table below. The specific gravity of the powder was 2·699. In column A is given the composition of a labradorite[5] of the formula $Ab_3 An_4$; and in B that of a plagioclase[6] of the specific gravity 2.700.

	I.	A.	B.
SiO_2	53·73	53·60	54·55
Al_2O_3	30·39	29·80	28·68
Fe_2O_3	1·26	....	1·03
CaO	10·84	11·70	11·28
Na_2O	*3·76	4·90	4·62
Total....	100·00	100 00	100·16
Sp. gr.........	2·699	27·03	27·00

*Difference.

It will be noticed that the specific gravity of this feldspar is lower than that of the porphyritic crystal, and that the latter is therefore

[1] Lehrbuch der Mineralogie, 2d edition, II, Aufl. 465.
[2] Tschermaks mineral. Mittheil, 1880, Vol. 3, p. 203.
[3] Rosenbusch: Mikrosp. Physiographie, 1887, Vol. 2, p. 155.
[4] The figures in parentheses refer to the numbers of the specimens in the series of rocks belonging to the Lake Superior Division of the U. S. Geological Survey.
[5] Schuster: Op. cit., p. 153.
[6] Tschermak: Sitzungsber. K. Akad. Wiss., I, July, 1869.

more basic than the former. That this difference was not a constant one was shown by powdering little chips taken from seven of the freshest specimens, and separating by means of the Thoulet solution. The greater portion of the plagioclase fell at 2·716, a value almost identical with that obtained for the porphyritic crystals.

Olivine makes up about one-tenth of the entire rock. It is present in rounded grains of a light yellowish green color, and is usually free from inclusions other than the fine, dust-like substances found in the feldspar. Occasionally lines of larger dark brown inclusions are met with. These are probably of secondary origin, since the lines pass uninterruptedly from the olivine over into feldspar or augite. The numerous black microlitic inclusions characteristic of olivine in most plutonic rocks (Tiefengesteine) were seen in but one instance (No. 11418). In no case is the olivine entirely unaltered. In even the freshest varieties a little chloritization has taken place. Sometimes there is a development of actinolite needles in the otherwise unaltered olivine, and in still other instances a few flakes of biotite occur, mixed with chlorite on the outer edges of a grain. From its relations to the feldspar and augite the olivine must, in most cases, be regarded as older than either, although in some instances it includes a few lath-shaped crystals of the former mineral. Since the feldspar occurs in two generations it is probable that the crystallization of the olivine took place in the interval separating these, or that it began to crystallize before the complete separation of the feldspar of the groundmass.

The augite is entirely allotriomorphic. It fills in the interstices between the other constituents, often including both olivine and labradorite. Where several crystals of the feldspars are included within a single augite the structure of the rock becomes pœcilitic.[1]

The greater part of the augite is perfectly fresh, and, like the feldspar and olivine, it contains no inclusions other than a few of the dust-like particles already mentioned. Its color in the thin section is purplish pink or violet. A faint pleochroism is often apparent in deeply colored pieces, the $\mathfrak{a}$ and $\mathfrak{c}$ rays being a deep purplish pink and the $\mathfrak{b}$ ray a yellowish gray. The two series of cleavage lines parallel to ∞P are very distinct on pieces cut parallel to the basal plane, where they make the usual angle of 87°. A parting parallel to the orthopinacoid is observable in only a few sections. That this is present, however, is proven by the fact that cleavage pieces frequently show an optical axis in converged light between crossed nicols. The extinction in plates cut parallel to the clinopinacoid is 44°. No twins were observed, but in several sections the effect of pressure on this mineral is beautifully seen in the production of an undulatory extinction and a bending of the cleavage lines. This is particularly well shown in the section of

[1] Cf. Williams: Am. Jour. Sci., Vol. XXXI, p. 30; and also Pumpelly: Proc. Am. Acad., Vol. XIII, p. 260; and Irving: Copper-Bearing Rocks, p. 42.

No. 11555, where a large, wedge-shaped piece of augite included between plagioclase has suffered a bending of its cleavage lines 13° and a twisting of its extinction plane an equal amount (Pl. V, a).

Accompanying the diallagic augite in the section of one specimen (No. 11206) from near the eastern end of the point, is a highly refractive yellowish mineral, with many of the properties of pyroxene. Its extinction, however, never reaches above 7° 30′, in most of the pieces being parallel to the cleavage; while the plane of its optical axes is also parallel to the cleavage. It is closely associated with the purple augite, from which it is easily distinguished by its yellowish tinge and dull polarization colors between crossed nicols. It is probably a monoclinic augite of a different composition from that of the purple variety, or a slightly altered form of this.

A partial analysis of the diallage isolated from the powder of five of the freshest specimens of the rock was made by Dr. R. B. Riggs in the laboratory of the Survey. The result obtained was as follows:

II.

SiO_2	48·34
Al_2O_3	2·90
Fe_2O_3	4·68
FeO	14·15
CaO	15·10
MgO	11·34
TiO_2	1·98
Total	98·49

The composition of this augite is that of a very pure diallage. An interesting feature is the large percentage of titanium in it—a fact which may explain the purple color. Knop,[1] who made an exhaustive study of the augite of the Kaiserstuhl in Baden, found that all the varieties that are rich in titanium have a violet color in thin section, except when they contain large amounts of iron. Although investigations in other regions do not fully substantiate Knop's conclusions, it will at least prove of interest, if all the purple augite and diallage so very widespread throughout the rocks of the Lake Superior region is found to contain titanium.

In addition to the labradorite, pyroxene, and olivine, the fresh gabbro contains only apatite and titaniferous magnetite as primary constituents. The apatite occurs in long, narrow, colorless crystals, with a parting parallel to the basal plane, and is sparingly present. The magnetite appears both in idiomorphic and allotriomorphic forms, with the latter predominating. Quite a large number of the grains are surrounded by rims of reddish-brown mica, and not a few show the beginning of an alteration into leucoxene.[2] A little quartz and a few flakes of brown and

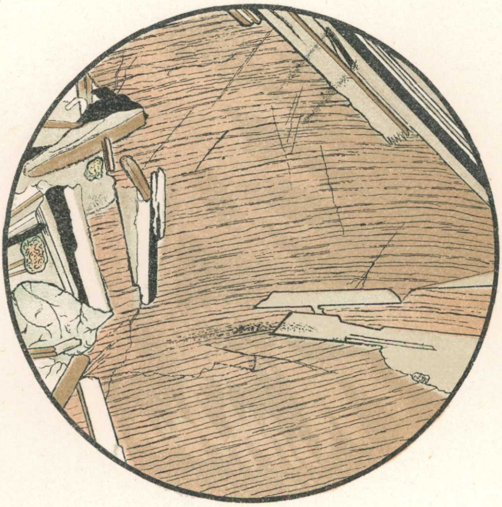
[1] Zeitschrift für Krystallographie, Vol. x, p. 58.

[2] At several places in the eastern portion of the Point the amount of titaniferous magnetite in the gabbro is so great as to cause a deflection of the compass needle 95°.

EXPLANATION OF PLATE V.

V. a. Thin section of olivine gabbro (No. 11555), showing the effect of pressure upon a piece of augite. The purplish-pink mineral is augite, in which the cleavage lines have been bent, presumably by pressure. The green mineral to the left is olivine. The white, lath-shaped crystals are bytownite. The latter are represented as seen in polarized light, between crossed nicols, while the augite and olivine are shown in natural light. Magnified 35 diameters.

b. Thin section of altered gabbro (No. 11222), with green isotropic mineral surrounding apatite. The yellowish-brown mineral to the left is biotite. The others are various decomposition products of olivine and augite. The specimen was taken from a place where the gabbro approaches the red rock, and is a variety of the intermediate rocks, another variety of which is represented in *a*, Pl. x. Magnified 175 diameters. Natural light.



a (X35)

b (X 175)

Sackett & Wilhelms Litho. Co. N.Y.

OLIVINE GABBRO.

red biotite are evidently secondary. The former is found in micro-pegmatitic intergrowths with feldspar, and the latter as an alteration product of olivine, augite, and magnetite.

In order to obtain the average composition of the rock, pieces of equal size were taken from five of the freshest specimens. These were crushed, and the powders were thoroughly mixed. A portion of the mixed powders was analyzed by Mr. W. F. Hillebrand, whose results are given in column III. In column C are the figures obtained by Streng and Kloos,[1] upon the analysis of a hornblende-gabbro from Duluth, Minnesota.

	III.*	C.
SiO_2	49·88	49·15
TiO_2	1·19	·18
Al_2O_3	18·55	21·90
Fe_2O_3	2·06	6·60
FeO	8·37	4·54
MnO	·09	....
CaO	9·70	8·22
BaO	·02	....
MgO	5·77	3·03
K_2O	·68	1·61
Na_2O	2·59	3·83
H_2O	1·04	1·92
P_2O_5	·16	·33
Total	100·21	101·31
Specific gravity	2·923-2·970	....

* During the pulverization of the rocks a small quantity of metallic iron became mixed with the powders, and this may have reduced some of the ferric iron to the ferrous condition through the agency of the hydrogen generated in the course of solution. The above figures are corrected for the metallic iron present, but could not be corrected for the amount of reduction produced, which was in any event very small, since the entire amount of metallic iron present did not exceed 0.3 per cent.

In referring this rock to its proper position among massive rocks, its composition, structure, and geological relations must be alike considered. Dr. Wadsworth[2] has recently given a résumé of the opinions of different investigators on the value of the orthopinacoidal parting as a characteristic of diallage distinguishing it from augite. The results are to the effect that there is no real difference between the two minerals, and that the presence or absence of the parting should not be used as a basis for separating the gabbros from the diabases. The distinction between these two rocks must therefore rest upon their geological and structural relations. They both contain augite and plagioclase, with or without olivine, as essential constituents. The diabases are defined by Rosenbusch[3] as rocks occurring in dike form or in intrusive layers and with a structure which varies within wide

[1] Streng & Kloos: Neues Jahrbuch für Min., 1877, p. 31.
[2] Bulletin No. 2, Geol. Survey of Minnesota, pp. 55-57.
[3] Mikroskopische Physiographie, 1887, vol. II., pp. 134 et seq. and 174 et seq.

limits. The granular varieties have an ophitic structure, which is due to the development of feldspar in long lath-shaped crystals. The structure of the gabbros is described as more granitic than that of the diabases in consequence of development of the feldspar in all directions equally (it is equidimensional), and its geological position is similar to that of granite.

All gradations between the typical gabbro and the typical diabase are, however, frequently met with, and nowhere are they met with in more profusion than in the Lake Superior region. The different rocks of this class are here so intimately related to each other, that seemingly the only structural distinction possible to make is one of coarseness of grain. The coarse-grained rocks of this region, where they consist of plagioclase and augite (or diallage), have been called gabbros; the fine-grained kinds are known as diabases. The classification is not as artificial as it appears to be at first sight, for Irving[1] states a fact when he declares that the gradation of the fine-grained kinds into the coarser varieties has never been observed in any one bed, and the differences in the external characteristics of the two are strongly marked.

According to this practice the Pigeon point rock must of necessity be classed with the gabbros, and such it has been called in this paper, because of its similarity to those rocks which have for so long passed under that name in the writings of those geologists who have done the most work upon them. If, however, we should adopt the suggestion of Prof. Judd,[2] and limit the term gabbro to the granitoid forms, the Pigeon point rock would fall among the diabases or the diabase-porphyrites. Both its composition and structure accord well with those characteristic of diabase-phorphyrites, and its geological position is not very different from that of these rocks. It occurs in the form of a boss-like dike cutting quartzites and slates, and bears a strong resemblance to rocks of the same composition, which are probably surface flows. This resemblance was so apparent to Irving[3] as to lead to the remark that the gabbro dikes of Thunder bay (and Pigeon point) "are noticeably much closer in character to the great gabbro (flow) at the base of the Keweenaw series than to those gabbros which are interleaved with the Animikie slates."

THE ALTERED VARIETIES OF THE GABBRO.

Although the fresh phases of the gabbro are so monotonous in character, its altered varieties present many peculiarities, some of which are quite interesting. These altered varieties are very much more abundant than is the fresh variety, and are found distributed indiscriminately

[1] The Copper-Bearing Rocks of Lake Superior, R. D. Irving: Monograph, U. S. Geol. Survey, vol. v, p. 69.

[2] Quart. Jour. Geol. Soc., 1885, pp. 344, 418.

[3] Is there a Huronian group? R. D. Irving; Am. Jour. Sci., vol. XXXIV, p. 261.

throughout the gabbro area. Olivine and augite are the constituents of the gabbro most prone to decomposition. As the final product of their alteration, a rock is produced whose habit is very different from that of the fresh rock described above. Its color is greenish and its structure fibrous. The feldspar crystals, so prominent a feature in the fresh rock, can not be detected in it without the aid of the microscope.

The first mineral to undergo change is the olivine. On its edges and along its cleavage tracks slight serpentinization takes place, and at the same time considerable magnetite separates out. Serpentine, however, is not the usual alteration product. Chlorite seems to have been formed much more frequently, and in this case also magnetite is an attendant product. This chlorite is sometimes cloudy and grayish, when it shows no decided effect in polarized light. Sometimes it forms an amorphous mass, occupying the place originally held by the olivine; but most frequently it is arranged in radially fibrous groups, when it polarizes with a deep blue color, and is nearly always associated with biotite and hornblende. When biotite and chlorite occur together, the former usually occupies an external position with reference to the chlorite, indicating a reactionary origin.

The alteration of olivine to chlorite is well known as being widespread, but its alteration to biotite is much less common. Julien[1] describes the alteration of olivine to biotite in an olivine diabase or gabbro from the NE. ¼ Sec. 31, T. 45 N., R. 2 W., Wisconsin, and gives a picture of it. Here the biotite is supposed to be due to the action upon the olivine of alkaline solutions emanating from the plagioclase. The same origin may be ascribed to the biotite in the Pigeon point rocks. The secondary origin of biotite from olivine has also been described by v. Foullon[2] in the melaphyres of the southern Alps; by Becke[3] in a bronzite olivine rock from the Lower Austrian Waldviertel; by Irving[4] and Wadsworth[5] in the gabbros of the Northwest; by Sjögren[6] in a gabbro in Western Norway; by Schuster[7] in an olivine-gabbro from Birchville, California; by Lenk,[8] and by Doss[9] in a minette from near Dresden.

Another prominent change of olivine is into hornblende. Little light green needles of this mineral extend from the edges of the olivine into its interior. These needles increase in number as the alteration progresses, until they finally fill the entire space formerly occupied by the olivine, with the exception of small areas containing chlorite. Such an altera-

[1] Geol. of Wisconsin, Vol. III, p. 225, and Pl. XXII, Fig. 1.

[2] Tschermaks mineral. Mitth., 1880, II, p. 481. Ref. Rosenbusch: Mikroskopische Physiographie, 1885, 1 Aufl., p. 412.

[3] Tschermaks mineral. Mitth., 1882, IV, p. 333.

[4] The Copper-bearing rocks of Lake Superior, R. D. Irving: Mon. V, U. S. Geol. Survey, pp. 39, 45-50.

[5] Bull. Geol. Survey of Minnesota, No. 2, p. 66.

[6] Geol. Fören. i Stockholm Förh., 1883, VI, p. 447. Ref. Neues Jahrb. für Miner., etc., 1884, I, p. 81.

[7] Neues Jahrbuch für Min., etc., Beilage Band V., p. 519.

[8] Zur geologischen Kenntniss der südlichen Rhön. Inaug. Diss. Würzb., 1887, p. 50.

[9] Tschermaks mineral. Mitth., 1889, XI, p. 53.

tion of olivine was first mentioned by Becke[1] under the name of pilite. Its origin, like that of the biotite, is also referred to the action of alkaline solutions derived from the plagioclase. Specimen No. 11446 shows this alteration most beautifully. Here complete pseudomorphs of pilite after olivine are frequent. (Pl. VI, a).

A fourth alteration of olivine met with in the Pigeon Point gabbro is to a brownish red homogeneous substance which is slightly pleochroic, but exerts no appreciable effect in polarized light between crossed nicols. It is probably a mixture of chlorite and serpentine stained brown by iron oxide.

The next mineral to undergo alteration is augite. Its most usual change is into hornblende. Both the bluish green fibrous variety known as uralite, and dark green and dark brown compact kinds occur. Chlorite, biotite, and magnetite are also frequent products of its alteration, the biotite being developed more abundantly near the contact of the gabbro with the surrounding feldspathic quartzites and red rock. As alteration progresses the amount of these secondary products increases until finally no trace of augite remains. In these most highly altered phases the secondary hornblende is found in the compact and fibrous varieties in about equal proportions.

The more common type of the compact variety is a very strongly pleochroic mineral with a well marked cleavage, and an extinction of 24°. It is occasionally in idiomorphic crystals, but more frequently in fibrous intergrowths with a second kind which is less strongly pleochroic and in different tints. The pleochroism of the first variety is $\mathfrak{a}$=light yellowish brown; $\mathfrak{b}$ and $\mathfrak{c}$=dark brown; that of the second kind is $\mathfrak{a}$=light yellowish green; $\mathfrak{b}$=yellowish green; $\mathfrak{c}$=dark bluish green. The two are found in parallel growths, with the green variety surrounding the brown. Although the line between the two is quite sharp, there appears to be no break in the continuity of their substance. They extinguish simultaneously and the cleavage lines pass from one into the other without deformation. The little spots known as pleochroic halos (Höfe) are occasionally seen in the compact hornblendes. They are almost black when the prismatic cleavage of the mineral in which they occur is parallel to the vibration plane of the nicol, and a greenish brown in other positions. They sometimes surround little apatite crystals, and at other times exist in round spots without reference to any included mineral. These spots are often surrounded by circular rims of the same character as that of the interior portion, from which they are separated by narrow zones of ordinary hornblende or chlorite.

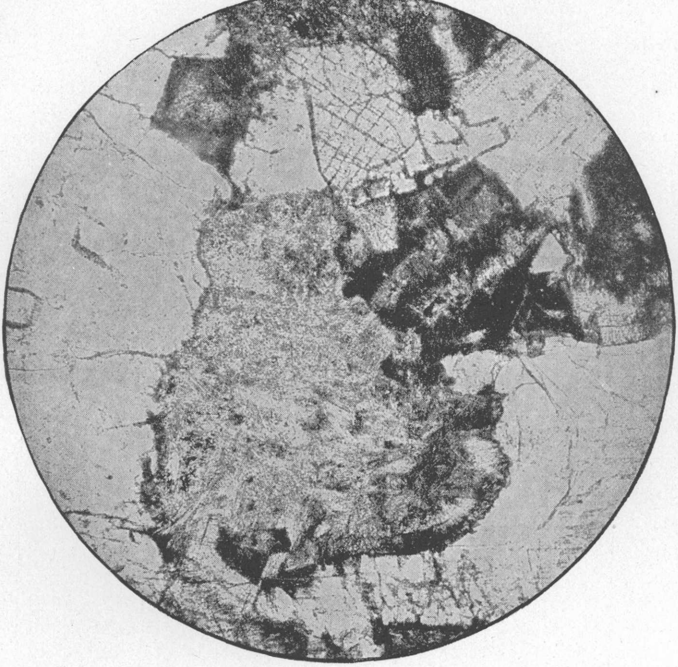
The fibrous hornblende is in long acicular crystals, with a dark bluish green color when their long axes are parallel to the vibration plane of the nicol, and a light yellowish green when perpendicular to this direction. It occasionally fringes both the compact varieties, but more frequently forms with chlorite a matted mass in which the compact brown and green varieties, the biotite, and other secondary products are imbedded.

[1] Miner. u. Petrog. Mitth., 1882. III, pp. 330, 355, and 450.

EXPLANATION OF PLATE VI.

VI. a. Section of altered olivine gabbro (No. 11446), in which the olivine has been entirely changed to pilite. The light-colored mineral is feldspar. That with the rectangular cleavage is augite, and most of the dark material is chlorite. From a photograph in natural light. Magnified 80 diameters.

b. Fibrous green hornblende surrounding brownish-yellow cores of the same mineral in altered gabbro (No. 11318). The dark acicular crystals in the lower left-hand corner of the figure are hornblende needles penetrating chlorite. The colorless mineral is plagioclase, and the black one pyrite. From a photograph in natural light. Magnified 80 diameters.



a. ALTERED OLIVINE GABBRO.

b. FIBROUS GREEN HORNBLENDE.

This fibrous mineral is probably the youngest of the three hornblendes. It appears to have been derived both directly from the augite and indirectly through the compact varieties and through biotite.

Rocks from the gabbro areas of the Northwest containing large amounts of compact hornblende have been described by Kloos, Pumpelly, Irving, Wadsworth, and others. Pumpelly[1] called them "augite-diorites," and supposed the hornblende to be original. Kloos[2] also appears to have considered it as original, and called the rock containing it "hornblende-gabbro." Irving[3] and Wadsworth[4] regard it as secondary, and as merely an extreme phase in the alteration of augite.

A second mode of alteration of the augite is into biotite. This mineral is present in large-sized folia and flakes of a reddish brown color when seen in basal sections, but very strongly pleochroic in sections showing the cleavage. The color of the light vibrating parallel to the cleavage is very dark brown; in a direction perpendicular to this it is light brownish yellow. It is usually associated with chlorite and hornblende. In the latter case the two minerals are frequently so intergrown that the cleavages of both are parallel. Since the hornblende is in many cases fibrous, and is commonly found surrounding the biotite, it is probably to be regarded as an alteration product of this mineral. When associated with chlorite the biotite presents the same general features as it does when accompanied by hornblende. In this case, however, the biotite occurs in larger flakes, and in shreds disseminated throughout the mass of chlorite. Between the folia little lenticular masses of calcite and a brightly polarizing, highly refractive, sphene-like looking substance are quite common, as are also pleochroic halos. That this biotite is secondary and that much of it has been derived from the augite is evident from the fact that this mineral, together with hornblende and chlorite, make up areas which have the characteristic wedge shape of the augite in fresh specimens.

The presence of biotite in the Lake Superior gabbros has been reported by Irving, Wadsworth, and others. Most of these writers have apparently looked upon it as primary, Wadsworth[5] alone stating positively that it is in many cases secondary after augite. In the rocks of other localities biotite has often been met with as an alteration product of augite.[6] It has recently been found by Schuster[7] in a gabbro from near Big Oak Flat, in California.

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[1] Geology of Wisconsin, Vol. III, pp. 35-36.

[2] Streng and Kloos: Neues Jahrbuch für Min., etc., 1877, pp. 27-31.

[3] Geology of Wisconsin, Vol. III, p. 170, and Copper-bearing rocks of Lake Superior, p. 56.

[4] Op. cit., pp. 57-58, 66-67, 84.

[5] Bulletin No. 2, Geological Survey of Minnesota, p. 65.

[6] Blum: Pseudomorphosen, Vol. I, p. 31; Vol, III, p. 93. Tschermak: Porphyrgesteine Oesterreichs, 1869. p. 264. Richthofen: Sitzb. d. Ak. d. Wiss. zu Wien, 1858, Vol. XXVII, p. 335. Lehmann: Untersuchung über die entstehung der Altkryst. Schiefergesteine, 1884, pp. 198, 231. Rohrbach: Tschermaks mineral. Mitth., 1885, Vol. VII, p. 27. Brauns: Neues Jahrb. f. Min., etc., Beilage-Band V., p. 289. Bergt: Tschermaks mineral. Mitth., 1888, Vol. X, pp. 320, 326. Doss: Tschermaks mineral. Mitth., 1889, Vol. XI, p. 41.

[7] Neues Jahrb. f. Miner., etc., 1887, Beilage-Band V., p. 515.

It is evident that the change of augite into biotite is attended with loss of calcium and silica and a gain in iron, aluminium, and the alkalies. In the gabbro from Pigeon point, aluminium and the alkalies could easily have come from the plagioclase, and the iron from the magnetite. It is noticeable that magnetite is nearly always very close to the biotite in those sections where this mineral is most plentiful. The calcium has probably passed over into the calcite, mentioned as present between the biotite folia.

The first stage in the alteration of the plagioclase is the loss of its glassy luster. Little flakes of a brightly polarizing, colorless mineral, probably kaolin, are developed throughout its mass; chlorite accumulates in its cleavage cracks; and between contiguous crystals there forms a micropegmatitic intergrowth of chlorite or a reddened feldspathic substance with quartz. This micropegmatite almost always radiates from the edge of an altered plagioclase, and in a few instances its feldspathic component is optically continuous with that of the original crystal. As alteration progresses the plagioclase becomes clouded. It loses its polysynthetic twinning striations and takes on the appearance of the orthoclase(?) in Irving's orthoclase-gabbro[1]. The amount of quartz present becomes very great. The spaces between the other constituents are filled with radially arranged quartz and feldspar, and the original structure of the rock entirely disappears. This alteration of the plagioclase with the production of micropegmatite is especially noticeable near the contact of the gabbro with the red rock. It proceeds hand in hand with the alteration of augite into biotite as described above, and gives rise to a rock which resembles in some respects the intermediate rocks to be described in Chapter V.

Magnetite, pyrite, and apatite are much more abundant in the altered gabbro than in the fresh rock. The former is highly titaniferous. On its edges leucoxene or biotite is nearly always to be detected. The apatite penetrates biotite, chlorite, and even magnetite, and occasionally contains fluid inclusions, in which are little air bubbles.

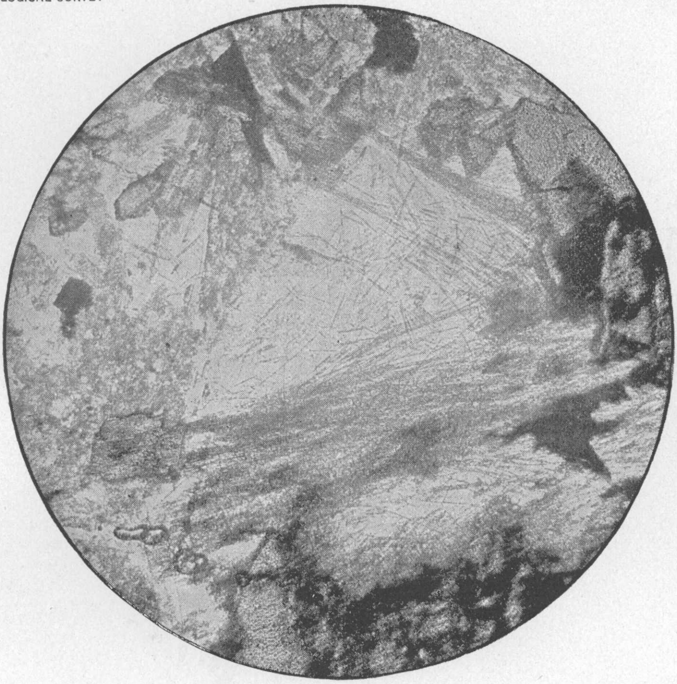
In addition to the minerals mentioned above there was noticed in one specimen (No. 11,222), taken from a place where the gabbro approaches the red granitic rock, a green, transparent, isotropic mineral with a hexagonal cross section. This mineral has a high index of refraction, and appears to form in little plates piled one upon the other in the manner of tridymite in the eruptive rocks, or of the plates of corundum so frequently seen in imperfectly developed crystals from North Carolina. Many of these little plates unite to form a group, which is always found associated with the alteration products of augite. Occasionally, as shown in b, Pl. V, they surround apatite. When occurring singly they resemble garnets with a diameter of 0.05^{mm}. Their quantity is so small that attempts made to isolate them in sufficient amount for chemical analysis proved futile.

[1] The Copper-bearing Rocks of Lake Superior, R. D. Irving. Monograph, U. S. Geol. Survey, Vol. V, p. 51.

EXPLANATION OF PLATE VII.

VII. a. Section of altered gabbro (No. 11446), in which long, slender needles of hornblende are seen to have attached themselves to compact pieces of the same mineral, which have undoubtedly been derived from augite. Chlorite, quartz, kaolinized feldspar, magnetite, and sphene are the other minerals shown in the figure. From a photograph in natural light. Magnified 80 diameters.

b. Pseudamygdule of hornblende in altered gabbro (No. 11247). The circular area in the center of the figure is the pseudamygdule, composed of green and yellowish-brown hornblende. Surrounding it are the altered remains of the original gabbro, in which the gabbro structure can still be detected. From a photograph in natural light. Magnified 80 diameters.



a. ALTERED GABBRO.

b. PSEUDAMYGDULE OF HORNBLENDE IN ALTERED GABBRO.

At several places near the contact of the gabbro with the quartzites and the granitic rock, and at one point, on the top of a high hill north of Fisherman's point (see map, Pl. III), are peculiar phases of the gabbro which merit a little attention. These peculiar varieties are remarkable for the extensive development of fibrous green hornblende in them. This hornblende occurs in irregular patches, in long, sinuous, and parallel ridges, and in circular areas. On a weathered surface it has disappeared and left in its place little hollows. The result is a rock presenting very much the appearance of an amygdaloid. Instead of disappearing entirely the hornblende in some specimens has passed into chlorite, which stands out in ridges and irregular and circular patches, just as does the hornblende when present, and is of a bright red color where it has suffered alteration in consequence of forest fires. When examined under the microscope these rocks are seen to have retained to a certain extent their original structure. The decomposed feldspar crystals can still be detected in lath-shaped forms. Epidote in green grains is added to the secondary products mentioned above as characteristic of the feldspar. Augite is found in every stage of alteration in a single thin section. Intermingled with the fresh variety is another in which a fibrous structure is marked. From this fibrous variety there is a gradual transition through compact brown and green hornblende into fibrous hornblende, and finally into long acicular crystals of this mineral. These hornblende areas have at first the general wedge-shaped outline of the augite. As the alteration progresses, the wedge-shaped outline is lost, and the groups of hornblende become circular in shape, and thus give rise to the pseudoamygdaloidal cavities referred to above. Olivine can not be recognized in any of the sections of the rocks of this kind, although the abundance of chlorite, hornblende, and other alteration products of this mineral leave no doubt of its original existence. Biotite, leucoxene, apatite, and lozenge-shaped crystals of colorless sphene are also present in all the specimens of these planes examined.

Pl. VI, b, shows a portion of a section of one of these rocks in which there are long needles of fibrous green hornblende, surrounding more compact cores of the brown mineral, and also slender acicular crystals penetrating chlorite. Pl. VII, a, represents an area in which augite has been replaced by quartz and hornblende. The quartz is without inclusions other than the long slender needles of light green hornblende which pass uninterruptedly from one quartz individual into another. Many of these hornblende needles, some of which are $0{\cdot}65^{mm}$ in length, have attached themselves to more compact hornblende,[1] and even to slightly altered augite. In b of the same plate one of the circular pseudo-amygdaloidal areas is seen. This is composed of brown and green compact hornblende, mingled with a little uralite and chlorite. The dark portion represents the green hornblende, and the light portion the brown.

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[1] Cf. Van Hise: Am. Jour. Sci., 1887, Vol. XXXIII, p. 385.

CHAPTER III.

PETROGRAPHICAL DESCRIPTION OF THE DIABASE.

The rock of the numerous small dikes on the point presents but few features to which attention need be drawn. Macroscopically it is a dark gray, heavy diabase, in the coarse varieties of which the diabase structure can readily be distinguished. It is more frequently altered than fresh. In the altered forms it possesses a slight greenish tinge, in consequence of the development of a small quantity of a fibrous green hornblende.

Under the microscope, the fresh, coarse-grained varieties are found to be composed essentially of plagioclase, augite, magnetite, apatite, pyrite, and chlorite. The plagioclase is in little lath-shaped crystals, with a maximum extinction of 27° on each side of their twinning bands. It is consequently a labradorite. The augite is in wedge-shaped areas between the plagioclase. When fresh it has a pale purplish pink color like the augite of the gabbro. The magnetite is in little grains and crystals in the coarser kinds, and in rods in the finer-grained varieties. Apatite is present in small colorless crystals, and chlorite in fibrous masses on the edges of the augite.

The altered varieties may be divided into two classes—the micaceous and the non-micaceous kinds. In the latter the constituents are the same as those described above, with the addition of uralite. In the former a brown mica is also present.

THE NON-MICACEOUS DIABASES.

In the least altered of the non-micaceous varieties, the diabasic structure is preserved. The augite, however, has undergone decomposition, with the development of magnetite or ilmenite in irregular masses intermingled with chlorite and a little uralite, or in little grains arranged in straight and curved lines. In some sections examined the monoclinic augite is found, not in the wedge-shaped forms characteristic of this mineral in diabase, but in long, narrow crystals. These appear in some cases to be older and in others younger than the accompanying feldspar. Their mode of alteration is somewhat peculiar. In the first stage a few green fibers extend from the sides of the crystals into the interior, and at the same time a cleavage is developed perpendicular to the long axes. Further alteration takes place, not along these cleavage cracks, but along the axes of the crystals. At this stage of their change the crystals appear as if perforated in this direction by cylindrical cavities, into which a quantity of dirty green chloritic substance has been forced. Pl. x, *a. b.*, represents two of these idiomorphic augites in this stage of their alteration.

In the final stages of the alteration of the rock all traces of augitic material have disappeared. Chlorite, uralite, and titaniferous magnetite have entirely replaced it. These minerals are not confined to the areas formerly occupied by augite, but are disseminated throughout the thin section and fill all the space between the plagioclase and its decomposition products and apatite. The magnetite (Fig. 6) is present in idiomorphic grains, in long rod-like forms, in little dots arranged in curved lines, and in fine dust scattered through all the other constituents with the exception of the apatite. The apatite is much more abundant than in the fresh varieties, but possesses no peculiar features. The plagioclase in these rocks has undergone change to such an extent that its original outline has entirely disappeared and with it the diabasic structure of the rock. Quartz and a red feldspathic substance, both of which are probably derived from the plagioclase, fill the little corners between the altered labradorite. The amount of this feldspathic substance present is often so great as to give the hand specimen a reddish tinge. No olivine was detected in any of the non-micaceous diabases, although a few round areas composed of pilite and chlorite render it probable that this mineral was originally present in some instances.

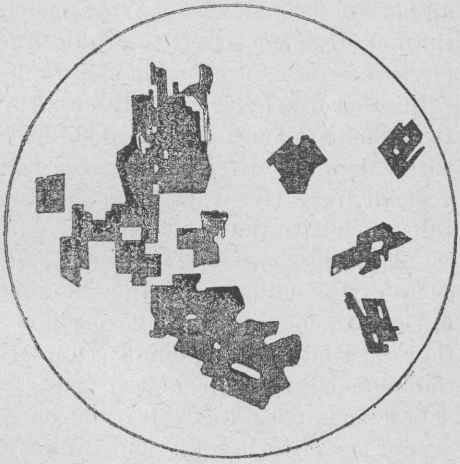


FIG. 6.—Idiomorphic secondary magnetite in altered diabase.

Round grains of a highly refractive, colorless, augitic-looking mineral are met with in a few sections of the least altered diabases. This mineral is older than the monoclinic augite, and has an extinction parallel to its cleavage. It gives rise upon alteration to a dirty green chlorite and a little uralite. Intermingled with these products are masses of magnetite, whose origin is evidently secondary. This magnetite is not only scattered through the chlorite and uralite, but it is also grouped around the exteriors of the highly refractive grains in such a way as to preserve their outlines even when all traces of their original substance has entirely disappeared. From its optical properties and the nature of its alteration products the colorless mineral is probably to be regarded as an orthorhombic pyroxene.

The fine-grained phases of rock occurring on the edges of the dikes are all highly altered. Between feldspathic and magnetitic microlites is a dirty green interstitial substance, which polarizes slightly, and shows under high powers little fibers of chlorite and hornblende. No glass was observed in any one of these rocks, but the impression left by a study of their thin sections is that this did occur abundantly, but has been entirely replaced by secondary substances.

The material of one or two dikes contains large porphyritic crystals of plagioclase in a groundmass differing but slightly from those types already described. In one instance (No. 11265, from the center of the third shingle beach from the end of the point on its south side) the porphyritic crystals are surrounded by little rims of pyrite.

In other dikes the rock presents the appearance of an amygdaloid. In the midst of an altered groundmass it contains circular areas filled with calcite, chlorite, a little green hornblende, a few flakes of mica and a small quantity of an almost colorless, highly refractive, isotropic substance with the appearance of garnet.[1] Around these areas lie little plagioclase crystals with their long axes tangent to the circumferences of the circles, as if they had been shoved aside by the expansive force of some gas formerly contained in a bubble. At the same time there is a faint indication of a fluidal structure in the arrangement of the feldspar crystals in the body of the rock. This amygdaloidal character is not noticeable in the hand specimens of any of these rocks, except as it is brought out by weathering. On weathered surfaces only a slight mottling distinguishes them from the nonamygdaloidal varieties. Pl. VII, b, shows the appearance of one of these areas when magnified 60 diameters.

A peculiarity characteristic of the rock from several of the larger dikes is noted only when their thin sections are placed on sheets of white paper. It is then observed that they have a mottled appearance, which is due to the development of augite in large pieces in such a way as to include within itself many of the small plagioclase crystals. This augite is quite fresh and free from magnetite, while the interstitial substance is altered and contains magnetite in large quantity. This structure is quite common among the diabases of the Lake Superior region, and is known as luster-mottling.[2] It has also been observed in the peridotites near Peekskill, New York, where it has been denominated "poicilitic."[3] (See b, Pl. VIII.)

[1] Cf. A. C. Lawson: Notes on some Diabase Dikes of the Rainy Lake Region. Proc. Can. Inst., 1887.

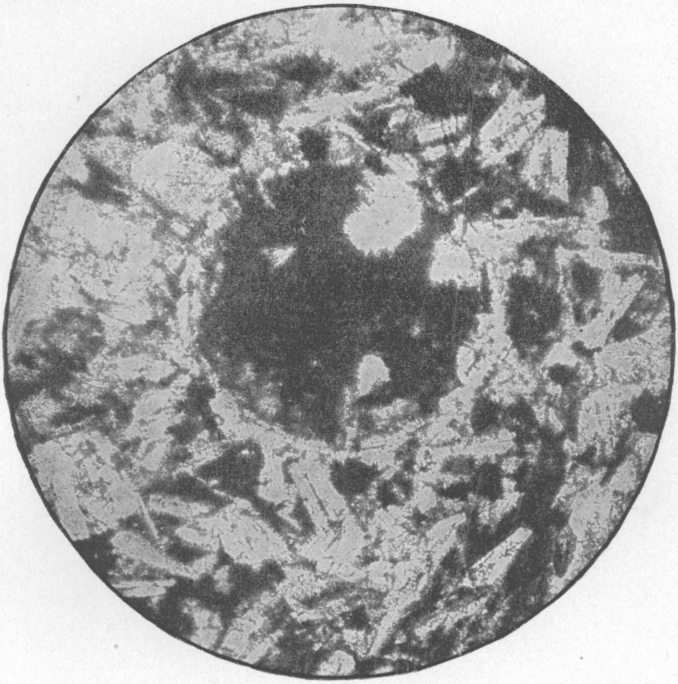
[2] Pumpelly: Proc. Am. Acad. Sci., 1878, Vol. XIII, p. 260, and Geology of Wisconsin. Vol. III, p. 33. Irving: Copper-Bearing Rocks of Lake Superior. Monograph, U. S. Geol. Survey, Vol. V, pp. 69-72, and 370.

[3] G. H. Williams: Am. Jour. Sci., Jan., 1886, Vol. XXXI, p. 30.

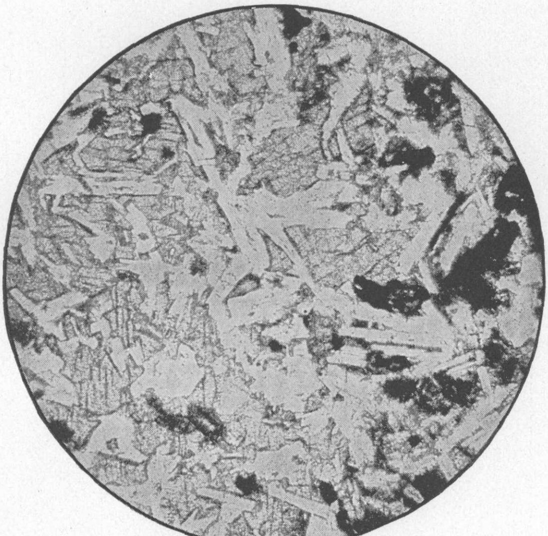
EXPLANATION OF PLATE VIII.

VIII. a. Amygdule in diabase of dike (No. 11406.) Around the edges of the amygdule, which is filled with chlorite and other secondary minerals, plagioclase crystals are arranged with their long axes tangent to the surface of the cavity. From a photograph in natural light. Magnified 60 diameters.

b. Pœcilitic structure in diabase of dike. The light-colored crystals are plagioclase, and the ground mass augite. This polarizes in two large areas, each of which incloses many feldspars. The black substance between the plagioclase at the right and left of the figure is chlorite. A narrow band of this crosses the center of the picture and separates the two augite individuals. From a photograph in natural light. Magnified 60 diameters.



a. AMYGDULE IN DIABASE OF DIKE.



b. PŒCILITIC STRUCTURE IN DIABASE OF DIKE.

THE MICACEOUS DIABASES.

The micaceous diabases are characterized by the possession of a strongly pleochroic brownish-red biotite. This is undoubtedly a product of the alteration of augite. It can be seen in parallel growths with this mineral, and also filling wedge-shaped areas from which the augite has disappeared. It includes all the minerals contained in augite, and in addition contains a large amount of secondary magnetite. The amount of the biotite present varies greatly. In some specimens only a few flakes are discoverable, while in others it constitutes the greater portion of the iron-bearing minerals present. Apatite is also abundant in these rocks. This mineral occurs not only in well developed forms, but also in skeleton crystals. Fig. 7 represents some of the forms assumed by the apatite in a rock from the large dike on the south shore, about three-fourths of a mile from the end of the point (Pl. XIV).

Upon carefully noting the relations of the micaceous diabases to the surrounding rocks it is found that in every case in which mica is present in any considerable quantity the dike rock is either cut by veins or dikes of the red rock or is thoroughly impregnated with its substance. And, on the other hand, wherever the red rock approaches very close to a dike the rock of this latter is found to contain mica. From these facts it would appear that the biotite is a secondary mineral, produced in the diabase upon its contact with the red rock, just as it is in the case of the gabbro, where the biotite is found most abundantly developed on or near its contact with the red rock.

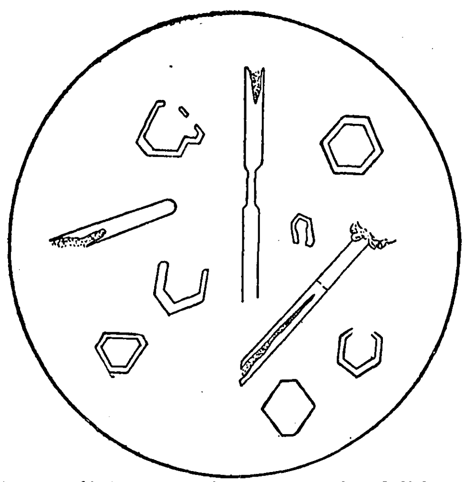


FIG. 7.—Skeleton crystal of apatite in altered diabase.

The properties of the rock present in the dikes cutting gabbro are not different from those of the rock occurring in the dikes penetrating the sedimentary beds. Both classes comprise dikes composed of comparatively fresh varieties of the same rock, as well as those consisting of decomposed material. As a general rule, the dikes in the gabbro are less fresh than those in the fragmental rocks, but otherwise no distinction can be drawn. Porphyritic diabases are as common in the gabbro as in the fragmental rocks, and those containing red feldspar are as frequently found in the one as in the other.

A comparison of the freshest of the diabases with the coarse olivine gabbro of the point reveals scarcely any differences in the structure of the two rocks save that due to the differences in coarseness of grain.

In composition they differ at present only in the presence of olivine, which is a characteristic constituent of the gabbro, but is represented in the diabases only by its decomposition products. In method of alteration the two rocks are likewise slightly at variance. An abundant product of the alteration of olivine and augite in the gabbro is hornblende, while in the diabase the most prominent secondary product is chlorite. The two rocks are thus found to have most of their characteristics in common, while those in which they differ are of secondary importance. Coarseness of grain and freshness of the mineral components mark the gabbro, while fineness of grain and secondary products characterize the diabases. These differences, although of little genetical value, are of importance in separating the two rocks practically. As has already been mentioned, the coarseness of grain in the gabbro has been used by Irving as a means of distinguishing these from the diabases, and for this reason the coarse-grained rock has been designated gabbro in the present paper. The diabases are similar[1] to many of the diabases in the flows interstratified with the Keweenawan beds. Since no diabase dikes, so far as the writer is aware, have been found in the Cambrian rocks of the Lake Superior region, it is probable that the numerous dikes in the Animikie rocks mark the orifices[2] through which the Keweenawan flows above them were extruded.

[1] Irving: Copper-Bearing Rocks of Lake Superior, pp. 61-91.
[2] Cf. Irving: Op. cit., pp. 143, 144.

CHAPTER IV.

PETROGRAPHICAL DESCRIPTION OF THE RED ROCK.

The red rock which is found so abundantly in the neighborhood of the gabbro has attracted the attention of all geologists who have visited Pigeon point.

Prof. W. W. Mather, according to Foster and Whitney,[1] regarded it as granite. Dr. Norwood,[2] assistant United States geologist, in 1851, described it as a reddish syenitic rock, containing but a small amount of quartz. About thirty years later Prof. N. H. Winchell[3] of the Minnesota State Survey, saw a red rock associated with gabbro near the extremity of Pigeon point, and a rock red with orthoclase on its north shore, about a mile from its eastern end, the latter[4] of which he mentions as having probably originated by the fusion and recrystallization of the sedimentary beds through which the gabbro cuts. A microscopical examination of this rock has very recently been made by Dr. M. E. Wadsworth,[5] who regards it as an altered phase of some eruptive, the original nature of which he is unable to determine from the single section at his command. In 1881 Prof. R. D. Irving[6] examined a rock from Brick island (Little Brick island), one of the smaller group of the Lucille group of islands, about a mile south of Pigeon point. He describes it as "pink to bright brick-red in color, thinly and very distinctly stratified, dipping southeast 8½°." He says further:

> Its 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.

On Pigeon point Prof. Irving also found a red rock which "resembles in every particular the rock from Brick island." Red rocks, similar in character to the red rock of Pigeon point, have been observed by various geologists at different places in the Lake Superior region, but have

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[1] Report on the Geology of the Lake Superior Land District, Washington, 1851, Part 2, pp. 12 and 37.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. By D. D. Owen, United States geologist, Philadelphia, 1852, p. 399.

[3] The Geol. and Nat. Hist. Survey of Minnesota for 1880. Ninth Annual Report, p. 70.

[4] Ibid. for 1881. Tenth Annual Report, p. 57.

[5] Geol. and Nat. Hist. Survey af Minnesota, Bulletin 2. Preliminary description of the Peridotytes, Gabbros, Diabases, and Andesytes of Minnesota, 1887, p. 81.

[6] The Copper-Bearing Rocks of Lake Superior; Monograph, U. S. Geol. Survey, Vol. v, 1883, p. 369.

received comparatively little attention. MacFarlane[1] seems to have looked upon them as eruptive in origin; the other observers regarded them as altered sedimentaries. As these writers have mentioned them only incidentally, references to their statements are unnecessary.

THE GRANULAR RED ROCK.

This red rock presents two phases differing markedly from one another. In its most typical aspect it is a fine-grained, brick-red, drusy, granular rock, speckled with little dark green spots. Its color is due to the prevalence of a red feldspar, which possesses at times a well-marked cleavage, but is rarely observed with crystal outlines. Scattered through this as a background are little particles of white quartz, and the green spots mentioned above, which microscopical examination proves to be chlorite. In a few cases a light-colored plagioclase can be seen intermingled with the red feldspar. The drusy cavities are lined with crystals of red orthoclase and quartz. The latter contain only the planes $\pm R$ and ∞R. The former have a specific gravity of 2·49, and are bounded by OP, ∞P, $\infty P\breve{\infty}$ and $P\bar{\infty}$. In some cases the interiors of the druses are partly filled with calcite, in which case the crystals project into its mass.

When fresh the rock possesses a tendency to break most easily in a horizontal direction. In certain exposures on the sides of cliffs this tendency is emphasized by weathering to such an extent as to produce a parting which is as regular as the parting along bedding planes in many sedimentary rocks. This parting is particularly noticeable in a cliff near the eastern end of the point (Pl. XVI), where the parting planes are nearly parallel to the bedding planes of the surrounding quartzite (Fig. 8). On Little Brick island, as announced by Irving (loc. cit.), the dip is 8½° to the southeast.

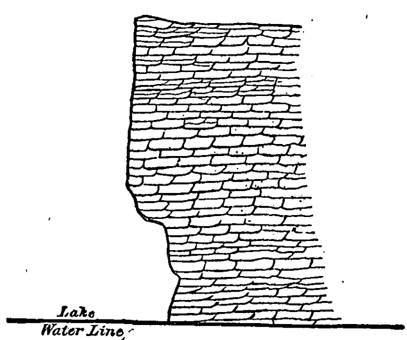


FIG. 8.—Sketch of cliff side, showing regular parting produced in red rock by weathering.

Under the microscope the coarser-grained specimens of this variety of the red rock are seen to be composed essentially of an hypidiomorphic granular aggregate of at least two feldspars, quartz, and chlorite, with a few subordinate constituents—muscovite, rutile, leucoxene, hematite, and apatite.

The feldspars embrace a striated plagioclase, twinned according to the Carlsbad law, and in one instance according to the Mannebacher law, and a second less well-individualized feldspar, which is younger than the plagioclase, but slightly older than the accompaning quartz.

[1] Geol. Survey of Canada. Report of Progress, 1863–'66, p. 142.

It surrounds the plagioclase and is intergrown with the quartz in micropegmatitic and granophyric forms, and is found also in rudely outlined crystals with a square cross section. Both the plagioclase and the granophyre feldspar contain little plates of hematite, but the number of these in the latter is very much greater than in the former, so that the plagioclase appears lighter in color. It has also undergone less alteration than the red variety, and is therefore much more transparent in the thin section. In some instances the twinning lamellæ were distinct enough to yield measurement indicating a composition near that of oligoclase. The specific gravity is 2·61 to 2·65. The red feldspar is so much altered that no measurements of extinction angles could be made, although traces of twinning lamellæ can still be detected. These lamellæ are broader than those in the plagioclase and frequently appear as if produced by Carlsbad twinning. In addition to the hematite plates there are present as inclusions in both varieties of the feldspar apatite, leucoxene, chlorite, and little shreds of muscovite or kaolin. The chlorite occurs principally in the plagioclase and the kaolin in the red feldspar. They are both secondary products, derived from the alteration of the minerals in which they occur.

The amount of the plagioclastic constituent present in the rocks of this type varies quite widely. Where it is most abundant the rock is lighter in color than are the varieties in which the predominant feldspar is the red variety. The micro-pegmatite is less common in the former and the quartz more often possesses the club-shaped outlines indicative of a secondary origin. Where the red feldspar is the predominant one, it is found in the rudely outlined crystals mentioned above, and also in micropegmatitic intergrowths with quartz. The crystals often show traces of Carlsbad twinning, but, as has been stated, they are so much altered that their extinction could not be measured. Other apparent crystals consist entirely of intergrowths of quartz and red feldspar with the crystal outlines of the latter mineral.[1] In these the structure of the rock is determined by the abundance of these skeleton feldspar crystals, and is like that of the typical augite-syenite, as represented in Pl. XIV, Fig. 1 of Irving's "Copper-bearing rocks of Lake Superior." Between these crystals the interstices are usually filled with club-shaped masses of quartz and feldspathic substance without any definite shape. Occasionally the place of this irregular growth of quartz and feldspar is taken by a mosaic of quartz grains.

In order to determine the nature of the red feldspar, a separation of the constituents of one of the freshest of the granular rocks was made in the usual way. Most of the feldspar fell at 2·577. When examined under the microscope the powder was found to be free from quartz, though slightly altered, and filled with hematite inclusions. An analysis yielded Mr. Whitfield the figures in column VIII. The composition

[1] Jos. P. Iddings: Obsidian Cliff, Yellowstone National Park. 7th Annual Report, U. S. Geol. Survey Pl. XV, Fig. 5.

of anorthoclase[1] from the rhyolite of Pantelleria is given in column D. In E. is the calculated composition of an anorthoclase corresponding to Ab_2Or.

	VIII.	D.	E.
SiO_2	65·00	66·06	67·248
Al_2O_3..........	18·22	19·24	19·165
Fe_2O_3..........	2·64	·54	....
CaO	1·06	1·11	....
MgO..........	·06	·11	....
K_2O	4·18	5·45	5·865
Na_2O	8·40	7·63	7·721
Ign	·46	....	....
Total	100·12	100·14	100·00
Sp. gr..........	2·577	2·581–2·592	....

It will thus be seen that the red feldspar has a composition corresponding to that of anorthoclase. Its optical[2] and physical properties, so far as they could be determined, are not in opposition to this view. They are, however, not to be relied upon as distinctive for the mineral, because of its great alteration.

The quartz is in irregular areas filling the interstices between the other constituents, and is also intergrown with the red feldspar in micropegmatitic and granophyric forms. The granophyre is almost always present in greater or less amount in the little angular areas between contiguous feldspar crystals, and it often surrounds a plagioclase crystal as a zone. In some instances the plagioclase is a comparatively fresh, clear mineral, with prominent twinning striations, while the zone is composed of a fibrous intergrowth of red feldspathic substance and quartz, in which the fibres of the quartz are developed with their long axes perpendicular to the surface of the internal plagioclase. The exterior of the zone is bounded by an outline parallel to that of the kernel. The most common inclusions of the quartz are fluid cavities with little dancing bubbles, red feldspar, and tiny, black, dust-like particles of some substance whose nature could not be determined.

The chlorite is, in all probability, the result of the alteration of a previously existing biotite. Traces of this mineral can still be detected in many sections, and in one (No. 11541) the biotite is quite fresh. The chlorite occurs both in little radiating spherulites crowded close together, and in plates enclosing quartz and feldspar. Calcite, rutile, magnetite or ilmenite, and leucoxene are its most common inclusions, while the little pleochroic halos (Höfe),[3] characteristic of this mineral when derived from biotite, are not rare.

[1] Förstner: Zeits, Chr. für Kryst. 1883, p. 125.

[2] For a careful description of the optical properties of anorthoclase, or soda-microcline, see Dr. J. S. Hyland: on Soda-Microcline from Kilimandscharo. Geol. Magazine, III, vol. 6, No. 298, p. 160.

[3] For the discussion concerning the nature of these halos, see Neues Jahrb, für Min., etc., 1888, I, p. 165.

Associated with the chlorite is oftentimes a very light-green fibrous mineral in groups of sheaf-like bundles. It is easily distinguished from the chlorite by its bright polarization colors and its silvery luster between crossed nicols. It is probably a secondary muscovite or sericite, derived in part from the biotite. In one or two instances bleached biotites were observed whose edges presented the appearance of frayed fibers of muscovite.

Rutile forms quite a prominent accessory constituent in some specimens. It is found in irregular masses of a dark brown color, and also in long, rod-like forms. In both instances it is intermingled with leucoxene, and frequently with chlorite. When present in the rod-like forms it is without doubt an alteration product of titanic iron. Rutile is also widespread as sagenite in the chlorite. Calcite is present as an alteration product of feldspar. It occurs in little nests in drusy cavities, and also in the interior of plagioclase crystals.

The structure of the rock, as has already been stated, is the hypidiomorphic-granular, in which the mica, the greater portion of the feldspar and quartz have separated in the order mentioned. Pl. IX, a, represents the structure of a specimen (No. 11541) collected in the interior of the western portion of the point.

THE PORPHYRITIC RED ROCK.

The second phase of the red rock resembles quartz-porphyry. Rudely outlined quartz crystals and occasional brick-red and greenish-white feldspars are scattered through a very fine-grained ground mass of a dark red or purplish color. Although a few of the light colored feldspars appear in the hand specimen to be homogenous throughout, a much larger number upon close inspection are discovered with a core of the brick-red mineral. The two feldspars are often united in Carlsbad twins, composed of two zones, the inner one red and the outer one white. On weathered surfaces the latter is dark and the former an opaque white. The red feldspar is also occasionally found forming the center of an area consisting principally of a yellowish green chloritic substance.

When one of these quartz-porphyries is broken, the little quartz crystals are observed projecting above the fractured surface. Examined casually, they resemble pieces of pebbles whose exteriors have been worn smooth by the action of running water. All traces of interfacial angles have been lost, and the general shape of the bodies is that of a cylinder, the ends of which have been rounded. Under the lens their surfaces are found to be pitted with little depressions that remind one of the depressions produced in the roughening of glass by the sand-blast.

Under the microscope these rocks are characterized by the beauty of their granophyre structure. All gradations between the granular structure described in the previous section and the typical porphyritic structure have been observed, and in all there is more or less of the true granophyre. In the porphyries the porphyritic crystals are quartz and feldspar.

In its less perfectly developed phases the quartz occurs in round, elliptical, and crescent shaped areas, and includes portions of the groundmass. When more completely developed, these areas have a lenticular cross section resembling in general outline that of a di-hexhedral crystal, always extinguishing as they do in the direction of their longest axis. The quartz is clear and transparent, and contains no inclusions other than fluid cavities with movable bubbles.

A very few irregularly outlined feldspar areas represent the porphyritic crystals of this mineral in their earliest stages of development. Other areas which appear in the hand specimen as crystals are seen under the microscope to be composed of granophyre substance with the outlines of crystals. Other apparently homogeneous crystals consist of a core of plagioclase, with an outer rim of granophyre, while others are composed of two kinds of feldspar in zonal growths. The red crystals in the midst of a green substance are cores of feldspar, that were originally surrounded by a zone of a different composition, which yielded chlorite upon alteration. The most interesting intergrowths are those in which the nucleus is a comparatively fresh striated plagioclase and the external zone a mass of secondary quartz and altered feldspathic substance. In these the outlines of the areas are always elliptical in shape. Figure *g* of Plate X represents one of these areas as seen between crossed nicols. The interior of the area is occupied by an irregularly-shaped piece of striated plagioclase, around which is a zone of secondary quartz and red feldspar.

The groundmass in which these porphyritic crystals are imbedded has the structure of Rosenbusch's typical granophyres.[1] It consists in large part of pseudospherulites (Pl. IX, b) composed of fibers of quartz and red feldspar in granophyric intergrowths. Between these are little areas of micropegmatite and sometimes mosaics of quartz-grains. In addition to the pseudospherulites there is often a growth of granophyre substance around the distorted and corroded porphyritic quartzes and in the undeveloped feldspars mentioned above. The granophyre surrounding the quartz crystals is composed of fibers which radiate from the surfaces of the crystals and form a zone, which, in ordinary light, resembles the "quartz globulaire" of Lévy, but in which the quartz fibers, between crossed nicols, are seen to be optically independent of the orientation of the substance of the mineral which they surround.

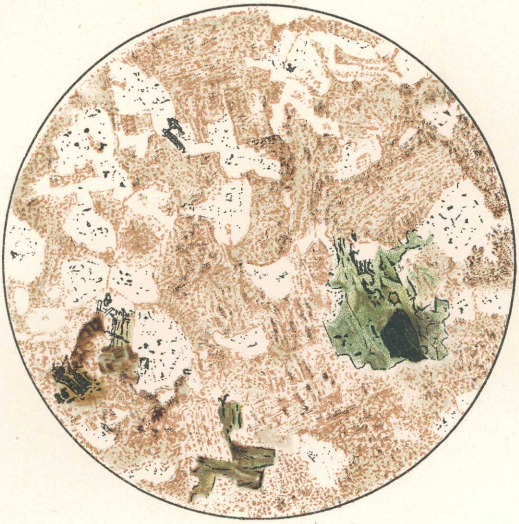
Chlorite, secondary brown biotite, and various undeterminable green alteration products of some constituent whose nature can no longer be recognized, but which in some cases appears to have been augite, are about as abundant as the corresponding secondary products in the

[1] Mikroskopische Physiographie, 1887, 2d ed., pp. 383–388.

EXPLANATION OF PLATE IX.

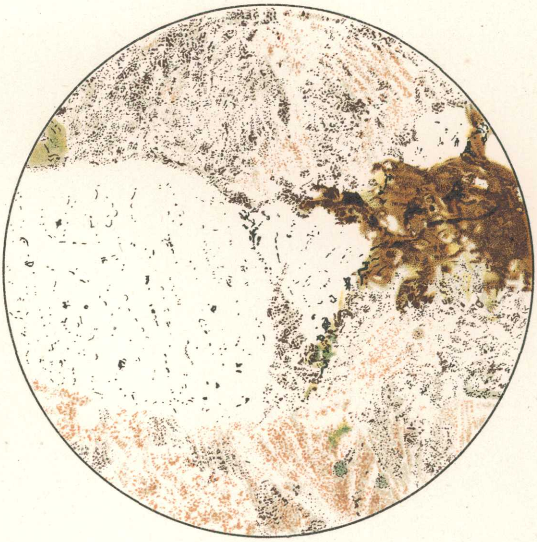
IX. a. Thin section of granular red rock (No. 11541), showing the structure. The red substance is feldspar, whose color is due to alteration, whereby little plates of hematite have been formed. The white mineral is quartz. It is in round granules, except in the upper portion of the figure, where it forms a micropegmatitic growth with the red feldspar. The green areas are chlorite that has been derived from mica. In the small area at the upper portion of the figure the cleavage of the mica can still be seen, and its pleochroism is still marked. The black spots are magnetite and the white substance inclosed in the chlorite is leucoxene. Under crossed nicols the apparently single area of red feldspar on the right-hand side of the figure breaks up into an aggregate of granules, many of which are striated in the direction of their longer axes. The figure represents the section as seen in natural light, magnified 40 diameters.

b. Thin section of porphyritic red rock (No. 11373). The large white body in about the center of the field is a quartz crystal whose extinction is parallel to a line drawn vertically from the apex of the figure. The irregularly shaped brown substance to the left of the quartz is some secondary product, perhaps chlorite, which has been stained by iron hydroxides. The rest of the figure is occupied by spherulites of red feldspar and quartz in very fine granophyric intergrowths. A few spicules and little nests of chlorite are scattered through these spherulites, and between them (as in the extreme lower right-hand side of the figure) are small areas of granular feldspar and quartz. Natural light. Magnified 40 diameters.



a (X40)

GRANULAR RED ROCK.



b (X40)

PORPHYRITIC RED ROCK.

Sackett & Wilhelms Litho Co. N.Y.

granular red rock. Some of these substances are arranged in long narrow lines, as if derived from microlites. Others are aggregated into clusters, or are concentrated around quartz crystals. Tiny grains of hematite and titaniferous magnetite, and little plates of a green chloritic mineral are scattered everywhere throughout the groundmass, but never in any large quantity. In the pseudospherulites they are arranged in a general way parallel to the fibers of quartz and feldspar.

Leucoxene and a highly refractive uniaxial colorless mineral, taken to be zircon, are occasionally met with. The former is mingled with biotite in the vicinity of magnetite, and the latter occurs in crystals with a rhombic cross section, which remains dark through an entire revolution between crossed nicols. The zircon forms little crystals whose cross section is rectangular. They are of a yellowish tinge, possess a zonal structure, show brilliant interference colors between crossed nicols, exhibit a shagreenous surface in natural light, and extinguish parallel to the sides of the rectangular cross sections. Calcite is quite abundant as an alteration product of some of the fibers intergrown with the quartz, and also in the little cavities contained in the rock. In Pl. IX, b, one of the pseudospherulites and a rounded quartz crystal are represented as they appear in one of the most typical quartz-porphyries. The rock in which they occur was obtained from the top of the quartz-porphyry bluff just west of the Little Portage.

COMPARISON OF THE GRANULAR AND PORPHYRITIC RED ROCKS WITH EACH OTHER, AND WITH OTHER ROCKS OF THE SAME NATURE OCCURRING IN THE LAKE SUPERIOR REGION.

The microscopical characteristics of the porphyritic and the granular varieties of the red rock indicate the probability of the identity of the two. Although the most typical quartz-porphyry is quite different in structure from the typical granular variety, gradations between these two types can be recognized. Their mineralogical composition is the same and, as is shown below, their chemical composition is identical.

In order to obtain an average composition for the two types of the red rock, pieces of equal size were broken from the freshest specimens and powdered, and these powders were analyzed by Mr. W. F. Hillebrand. In column IX is the result of an analysis of the powder of seven of the freshest specimens of the granular rock. In X is an analysis of the powder of three quartz-porphyries. F is an analysis of the granite from Bejby, Sweden, containing red orthoclase, gray, and brownish gray quartz, black mica, and a few flakes of golden yellow mica.[1]

[1] Gerhard: Neues Jahrb. für. Min., etc., 1887, II, p. 271.

	IX.*	X.*	F.
SiO_2	72·42	74·00	73·32
TiO_2	·40	·34	....
Al_2O_3	13·04	12·04	14·25
Fe_2O_3	·68	·78	....
FeO*	2·49	2·61	2·60
MnO	·09	·05	·09
CaO	·66	·85	·83
SrO	Trace.	Trace.	....
BaO	·15	·12	....
MgO	·58	·42	....
K_2O	4·97	4·33	4·96
Na_2O	3·44	3·47	3·21
Li_2O	Trace?	Trace?	....
H_2O	1·21	·86	1·22
P_2O_5	·20	·06	....
Cl	Trace.	Trace.	....
Total	100·37	99·93	100·48
Sp. gr	2·620	2·565	....

*During the pulverization of the rocks a small quantity of metallic iron became mixed with the powders, which may have reduced some of the ferric iron to the ferrous condition, through the agency of the hydrogen generated in the course of solution. The above figures are corrected for the metallic iron present, but could not be corrected for the amount of reduction produced, which was in any event very small, since the entire amount of metallic iron present was not greater than 0.35 per cent.

An inspection of the figures in columns IX and X shows that there can be but little doubt that the two rocks analyzed are parts of the same mass. The very slight differences noted in the amounts of silica, alumina and potassa are not greater than are frequently found in different hand specimens of the same rock.

The close agreement in composition between the Pigeon point rocks and the granite from Bejby (F) becomes a matter of interest, when we remember that the latter has been called a soda-granite because of the supposition, based on an earlier analysis, that the rock contained a feldspar rich in sodium. Gerhard, however, claims (loc. cit.) that the rock can not be regarded as a soda-granite, but makes no attempt to isolate the feldspars and subject them to examination. He states that the feldspars present in the rock are plagioclase, orthoclase, and microcline.

A separation of the components of one of the freshest of the granular rocks from Pigeon point yielded the minerals in the following percentages:

Feldspar	62.76
Quartz	34.94
Chlorite, biotite, etc	2.30

The feldspar fell in two stages; first, when the specific gravity of the heavy solution used was between 2.61 and 2.65, and, second, when the specific gravity was 2.577. The first feldspar is a plagioclase with a composition near that of oligoclase, while the second is probably anorthoclase, as indicated by its analysis.

Upon comparison of the composition of this feldspar with that of the rock in which it occurs, it will be noticed that whereas in the former the quantity of soda present is much greater proportionately than the potassa, in the latter the potassa is in excess. A calculation of the composition of the residue (*a*) left after allowing for the quartz and the small amounts of plagioclase, chlorite, apatite, and biotite present in the rock, gives a result which agrees very closely with the theoretical composition of a feldspar of the formula $Ab_1\ Or_1$ (*b*).

	a.	*b.*
SiO_2	63·52	66·51
Al_2O_3	22·00	19·05
K_2O	8·56	8·70
Na_2O	5·92	5·74

It appears probable from these figures that there is present in the red rock a series of potassium-sodium feldspars, of which some members contain more potassa than does the one analyzed. Those members which are richer in potassa, if Lagorio's hypothesis[1] of the order of crystallization in eruptive rocks is correct, would probably have crystallized toward the last stages of the rocks' solidification, and thus would be apt to be intergrown with quartz in the micropegmatite, and would therefore have fallen when the specific gravity of the separating solution was somewhat above 2·577—in the neighborhood of 2·65 (the specific gravity of quartz).

From the descriptions of the thin sections of the two types of the red rock, and from the close agreement in their composition, it is evident that they are parts of the same rock mass, whatever may have been its origin. There can be little doubt that the porphyry has solidified from a molten magma. It presents all the structural features of Rosenbusch's Vogesen granophyres.[2] It is very similar in macroscopic and microscopic appearance to the Keweenawan quartz-porphyries described by Irving[3] as flows in the copper-bearing rocks on both sides of Lake Superior, and which are undoubtedly of eruptive origin. The granular phase occurs in dikes and veins cutting slates and diabase, and is identical in structure with some of Irving's augite-syenites,[4] which were regarded by that geologist[5] as altered forms of an eruptive rock. It is identical with the red rock of Little Brick island, which appears as a flow, and is not very different from the material of one of the numerous ribbon-like dikes which constitute the principal portion of Brick island, a member of the same group to which Little Brick island belongs.

[1] Lagorio: Mineral. und Petrog. Mitth., 1887, VIII, p. 422.
[2] Die Steiger Schiefer. Strassburg, 1876.
[3] Copper-Bearing Rocks, p. 95.
[4] Loc. cit., p. 112, et seq. and p. 369.
[5] For a discussion of the nature of the augite-syenites and their relations to the Pigeon point rock, see Am. Jour. Sci., Vol. 37, Jan., 1889, p. 54.

An analysis of the Little Brick island rock was made by Mr. L. G. Eakins for another purpose. It is given in column XI below, and with it, in column X, is repeated the analysis of the quartz-porphyry of Pigeon point, as given on page 56.

	XI.	X.
SiO_2	73·70	74·00
TiO_2	·12	·34
Al_2O_3	12·87	12·04
Fe_2O_3	3·76	·78
FeO	·31	2·61
MnO	·07	·05
CaO	·14	·85
SrO	....	Trace.
BaO	....	·12
MgO	·11	·42
K_2O	4·56	4·33
Na_2O	3·63	3·47
H_2O	·57	·86
P_2O_5	tr.	·06
Cl	....	Trace.
Total	99·84	99·93

The very close agreement in the chemical composition of these two rocks accords well with the agreement in their mineralogical composition and structure. The Little Brick island rock is a bright red porphyry in which the porphyritic crystals are quartz and feldspar, and the interstitial substance is principally a granophyric intergrowth of quartz and red feldspar. The few secondary products present in it are the same as those in the Pigeon point rock. Augite is also present in an occasional light-colored crystal.

The conditions which in one case gave rise to a granophyre on Pigeon point, and in another allowed the development of a holocrystalline rock from the same magma, could not be determined. It appears that the normal development was the granular one, but that in certain localities where the magma cooled in contact with preexisting rocks, the porphyritic structure was assumed.

The classification of these rocks is a matter of no little difficulty. In a former paper[1] an attempt was made to show reasons for placing them among the quartz-keratophyres. A quartz-keratophyre, as defined by Rosenbusch,[2] is a paleovolcanic rock composed of quartz, a soda-potash feldspar, and usually a little augite. The Pigeon point granophyre contains quartz in porphyritic crystals. It contains also a soda-potash feldspar and decomposition products of a bisilicate which in all probability was augite. The characteristic structure of the quartz-keratophyres is porphyritic, like that of all other effusive rocks, while

[1] Am. Jour. Sci., Vol. 37, Jan., 1889, p. 54.

[2] Mikroskopische Physiographie, 1887, II, pp. 434–442.

that of the predominant variety of the Pigeon point rock is granular. This deviation from the normal structure of the quartz-keratophyre can readily be accounted for on the supposition that the Pigeon point rock represents only the more deep-seated portions of a mass which near its upper surface may have been porphyritic. There is no absolute method by which we can determine how much of the material of the Animikie beds upon the point has been removed by erosion. If we regard the rock upon Little Brick island as the bottom of a flow which once overspread the slates and quartzites in the Pigeon point region, the amount of material which was removed in reducing the point to its present altitude was over 1,100 feet. That this is by no means an exaggerated estimate is proven by the fact that the shortest distance between the red rock on the point and the southern limit of exposures of slates and quartzites on Susie island (see map, Pl. III) is over a mile, measured in the direction of the dip of the fragmental rocks, which with a dip of 15° would give a thickness of over 1,370 feet of sedimentaries that must have been removed before exposing what is now the surface layer of these rocks on Pigeon point.

The most acceptable name for the porphyritic variety of the red rock is undoubtedly quartz-keratophyre. It describes both the composition and structure of the rock and its general appearance. The granular variety corresponds most closely to the soda granites. It can not be regarded as an augite-syenite, since it contains a great deal of quartz that is not secondary. Rosenbusch[1] refers to the keratophyres as paleovolcanic equivalents of the augite-syenites. Following this view the quartz-keratophyres must be looked upon as paleovolcanic augite granites, and as we distinguish as soda granites those varieties of granite containing a sodium feldspar or anorthoclase, then the quartz keratophyre should be denominated augite-soda-granite. The augite constituent is, however, so small in amount that it would seem best to neglect it as an essential component, and to call the rock a soda granite. The designation of different portions of the same rock mass by different names is of doubtful propriety. In the present case it serves the purpose of calling attention to two of the most prominent types of structure derived by the cooling of a molten magma under different conditions.

[1] Rosenbusch: Mikroscopische Physiographie, 2d ed., p. 442.

CHAPTER V.

PETROGRAPHICAL DESCRIPTION OF THE ROCKS ON THE CONTACT BETWEEN THE RED ROCK AND THE OLIVINE GABBRO.

At the contact between the granular red rock and the gabbro is a series of rocks which partake partly of the nature of the former and partly of that of the latter. The most acid varieties differ but slightly from the typical red rock. They are a little darker in color and contain a little more plagioclase. The darker color is due to the increase in the number and size of the green spots, which have been described in the case of the red rock, as consisting of chlorite. In addition to these there is more or less altered hornblende, which can readily be detected in the hand specimen. As this rock approaches the gabbro it becomes still darker. The amount of plagioclase in it increases. It becomes much coarser grained and contains a much greater quantity of iron-bearing constituents. In this phase the structure is granitic, with a tendency to the ophitic. Still closer to the gabbro a rock is observed which is very dark in color. It contains a small amount of red feldspar and quartz, but otherwise is very little different from the gabbro itself.

These gradations between the gabbro and the granular red rock are noticed wherever the two rocks are in contact, except in the two cases previously referred to. In most instances the gradation is so uniform that no line of junction can be detected between the two rocks. In other cases quite a sharp line exists between them. But even at these places the rock on either side of the line of contact is very evidently modified by the presence of the rock on the other side, and there are present at least two of the varieties mentioned above. Along the contact between the granophyre and the gabbro, at the base of the quartz-porphyry bluff, for instance, the intermediate rocks are wanting. There is here a sharp contact between the two rocks. On the gabbro side no change in the character of the rock seems to have been effected. On the granophyre side the rock is a little darker than the granophyre at some distance from the contact, but this change in color is due to the presence of inclusions of the gabbro.

The best development of the intermediate rocks is found on the south side of the point near its eastern extremity. At this place the gradation of the acid red rock into the basic gabbro can be seen very beautifully. All the rocks are well exposed, so that the change in their character can be traced without any difficulty. Here the red rock is the granular variety. As it approaches the gabbro it becomes quite coarse grained. In the hand specimen large cleavage surfaces of red feldspar and long acicular crystals of a dark hornblende are very prominent. The dark crystals have a bronzy luster on their cleavage surfaces, which are very perfect. A little nearer the gabbro the rock is still coarser in grain. The feldspars now include not only the red variety, but also a light greenish yellow plagioclase. The bisilicate occurs in large lath-shaped crystals, a number of which are united into arborescent forms (Fig. 9). Very near the gabbro is a rock in which but a little red feldspar can be detected. The predominant minerals are a glassy, greenish white plagioclase with bright cleavage surfaces, and a dark augite. Its structure is like that of the finer-grained non-porphyritic gabbro. No line of contact between the gabbro and the red rock or between their intermediate varieties can anywhere be discovered.

The lighter colored of these intermediate rocks examined microscopically is found to be composed of broad lath-shaped crystals of red feldspar; irregular areas of the same mineral intergrown with quartz in micro-pegmatite; the remains of what were originally hornblende crystals; large irregular areas of a bright green chlorite; crystals and rod-like masses of a titaniferous magnetite; apatite, rutile and an occasional zircon(?).

The feldspar crystals are crossed by bands running in the direction of their long axes. These bands are broad, and in most cases are evidently due to Carlsbad twinning. All of this feldspar is more or less altered into kaolin and chlorite, both of which occur in small flakes mingled with tiny plates of hematite.

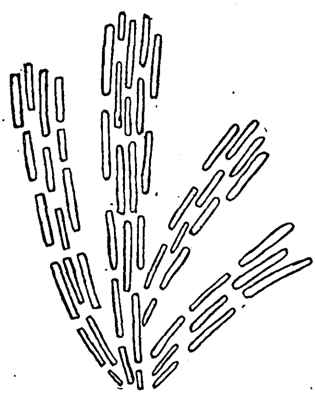


FIG. 9.—Grouping of hornblende crystals in one of the intermediate rocks.

The hornblende is much changed. Only occasionally can the original outlines of greenish brown idiomorphic crystals be detected. It is more frequently chloritized. Large irregularly shaped areas, composed of fibrous chlorite, are presumably a secondary product derived from the alteration of this mineral. Scattered throughout the mass of chlorite are grains of magnetite, surrounded by rims of leucoxene, little crystals of apatite and rarely an irregularly shaped piece of rutile. As in the case of the red rock the most common occurrence of the rutile is as a sagenitic web in the chlorite derived from the hornblende (Pl. X, *f*). Between these constituents, and more particularly in the angles between contiguous feldspars, is quite a large quantity of quartz and red feldspar in micro-pegmatitic intergrowths. This micro-pegmatite sometimes extends out from the edges of the feldspar, but more frequently exists in areas which are independent of all the other constituents. In these the different quartz areas extinguish simultaneously, as does also the feldspar.

In the second stage of the transition the thin section shows that the amount of red feldspar present has decreased considerably. In its place there has been added a large quantity of a clear, colorless plagioclase, with two systems of twinning lamellæ and cleavage cracks, cutting each other at angles of about 83½° and 96½°. The specific gravity of this plagioclase is about 2·65, and the maximum extinction of bands on each side of a twining plane in the zone $OP. \infty P \bar{\infty}$ is 9°. It is crossed by irregular fissures, in the crevices of which a green earthy substance has been deposited. In many places this plagioclase has undergone slight alteration with the production of flakes of chlorite and kaolin. The red feldspar is confined almost entirely to the micropegmatite, which occurs here, as in the former case, in the angles between the other constituents. The specific gravity of a powder consisting principally of this red feldspar was 2·583.

Hornblende is found in well-formed, fresh, idiomorphic crystals in quartz, and also in particles which have undergone chloritization. It occurs also in fibrous masses, which have probably been derived from augite. A peculiar feature of the fibrous hornblende is the interposition of a brown substance (probably limonite or some other hydrated oxide of iron) between the fibers, that gives the mineral the metallic luster noticed in the hand specimen. In addition to these two varieties of hornblende there is a third with the properties of uralite. It surrounds the second variety and occurs as isolated needles in the quartz.

Chlorite is less abundant than it is in the lighter rock described above. It is found in rosettes, intermingled with hornblende, magnetite, and apatite. The last mentioned mineral is very much commoner than in either the typical red rock or in the lighter phase of the intermediate rocks. It occurs as an inclusion in all the other minerals but the plagioclase, and is perhaps most abundant in the quartz and red feldspar. In both macroscopic and microscopic appearance this rock resembles some of Irving's orthoclase-gabbros,[1] as well as some of the altered phases of the olivine-gabbro, described in the earlier pages of this bulletin, as characteristic of this rock where it approaches the red rock. The main distinction between the altered phase of the olivine-gabbro and the transition rock consists in the presence of biotite in the former and its absence from the latter.

On Pl. X, *e*. is the representation of one of the intermediate rocks, which is just midway in composition between the gabbro and the red rock. In it can be seen an idiomorphic hornblende crystal in quartz, and also a portion of a large plagioclase crystal. The difference in

[1] Copper-Bearing Rocks, p. 50.

EXPLANATION OF PLATE X.

a, *b*. Idiomorphic augite from diabase (No. 11265). The augite is in long, narrow crystals with terminations at one end. Through their centers run little canals filled with a dirty green chloritic substance, and the same material extends from the peripheries of the crystals into their interiors, until finally all of the augite is replaced by chlorite. *a* shows a crystal in which the peripheral alteration is but just beginning. In the crystal represented in *b* all of the original augite has been replaced by chlorite, with the exception of a very narrow band between the axial canal and the peripheral chlorite. Magnified 40 diameters. Natural light.

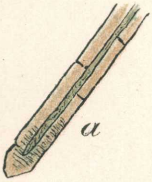
c, *d*. Thin sections of what were originally feldspar grains in sandstone (No. 11350). In *c* the grains are shown in natural light, where their outlines are clearly marked. *d*, in polarized light, shows how the different grains when changed into quartz give rise to differently orientated quartz areas. These by merging into the interstitial quartz produce a quartz mosaic between crossed nicols, in which the boundaries of the individual original grains are lost. Magnified about 40 diameters.

e. Thin section of intermediate rock on the contact between the olivine gabbro and the red rock (No. 11209). The area represented in this figure shows the general structure of the rock. The irregular white mineral on the left is quartz, containing microlites of apatite and a large idiomorphic crystal of brown hornblende. The white substance in the upper right-hand corner is plagioclase, and the light-green mineral just below this is uralitized augite. In the lower left-hand corner is a wedge-shaped area filled with little rosettes of chlorite and a few flakes of hornblende. The remainder of the field is occupied by a micropegmatitic intergrowth of red feldspar and quartz. Natural light. Magnified 23 diameters.

f. Rutile (sagenite) in chlorite of intermediate rock (No. 11356). The red needles and areas are rutile and the inclosing green substance is chlorite, in which is a little magnetite. Reflected light. Magnified 40 diameters.

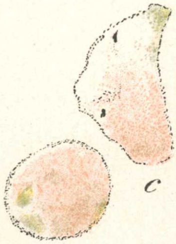
g. Plagioclase grain surrounded by a zone of micropegmatite from porphyritic red rock (No. 11371) in polarized light. The small dark irregular grains in this zone are quartz, and the lighter inclosing material is feldspar. Large areas of feldspar, with its included quartz, polarize together. Magnified 17 diameters.

h. Spotted quartzite, as seen in natural light in the thin section when this is placed against a white background. The green circular area consists of quartz grains and epidote crystals. The surrounding white circle is composed of quartz, and the inclosing matrix has the composition of the ordinary quartzite, i. e., it consists of grains of quartz and feldspar, a few very small grains of magnetite, and interstitial quartz and chloritic substances.

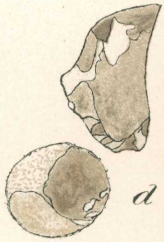


a

b

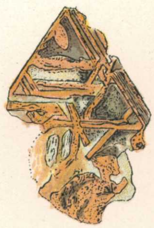


c



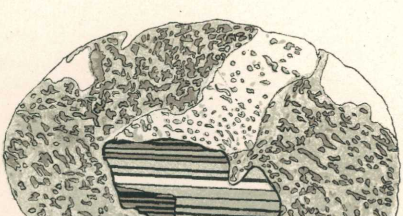
d

e (X23)

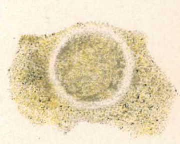


f (X40)

THIN SECTION OF INTERMEDIATE ROCK ON THE CONTACT BETWEEN THE OLIVINE GABBRO AND THE RED ROCK.



g (X17)



h (X÷)

structure between this rock and the typical red rock may be observed by comparison with Pl. IX a.

In the darkest of the intermediate rocks there is a large amount of augite, none of which is perfectly fresh. In the least altered pieces a fibrous structure is plainly evident. This structure becomes more emphatic as alteration progresses, and the individual fibers gradually pass over into hornblende. Chlorite and a green earthy substance are abundant as additional alteration products of this mineral. The plagioclase is very fresh, and is twinned according to two laws, the twinning lamellæ crossing each other nearly at right angles. Extinctions measured against the combination edge of two contiguous lamellæ are between 29° and 30°. It is therefore more basic than the feldspar in the next lighter-colored rock described above. With the increase of the quantity of plagioclase there has been a corresponding diminution in the amount of red feldspar and quartz present. This is now confined entirely to very small areas between the large plagioclase crystals. It is particularly noticeable for the large number of apatite crystals that cut through it in all directions. Apatite crystals are found also in the secondary products derived from augite, more especially in the chlorite, when they are sometimes surrounded by pleochroic halos.

Analyses of these rocks, when compared with those of the gabbro and the red rock, show conclusively that the former are transition phases between the two end terms of the series.

	III.	XII.	XIII.	XIV.	IX.	G.
SiO_2	49·88	50·69	57·88	57·98	72·42	61·09
TiO_2	1·19			1·75	·40	
Al_2O_3	18·55			13·58	13·04	15·34
Fe_2O_3	2·06			3·11	·68	5·74
FeO	8·37			8·68	2·49	3·69
MnO	·09			·13	·09	
CaO	9·72	7·94	4·68	2·01	·66	3·10
SrO	trace.			trace.		
BaO	.02			·04	·15	
MgO	5·77			2·87	·58	1·33
K_2O	·68			3·44	4·97	3·65
Na_2O	2·59			3·56	3·44	3·41
Li_2O				trace.	trace.	
H_2O	1·04			2·47	1·21	1·80
P_2O_5	·16			·29	·20	
Cl	trace.			trace.		
Total	100·12			99·91	100·33	
Sp. Gr	2·923		2·741		2·620	

III. Olivine gabbro, analyzed by Mr. Hillebrand.

XII. Intermediate rock (No. 11211) near the gabbro, analyzed by Prof. W. W. Daniells, of the University of Wisconsin.

XIII. Intermediate rock (No. 11209) midway between the gabbro and the red rock, analyzed by Prof. Daniells.

XIV. Intermediate rock (No. 11210) near the red rock, analyzed by Mr. Hillebrand.

IX. Granular red rock, analyzed by Mr. Hillebrand.

G. Intermediate rock from North Shore of Pigeon Point, analyzed by M. E. Wadsworth: Geol. and Nat. Hist. Survey Minn., Bull. No. 2.

In these results can be traced the gradual transition from the basic gabbro, rich in calcium and magnesium and poor in potassium, to the acid keratophyre, which is poor in calcium and magnesium and rich in potassium.

The relations of the intermediate rocks to the gabbro and the red rock are such as to leave no doubt that the former are the result of contact action between the two latter. The intermediate rocks are found only where the red rock and the gabbro approach very near to each other. In the case described above the line of contact between these can not be observed. In other cases their junction is marked by a well-defined line, on each side of which the rocks have undergone more or less change from their normal condition, and in this case the red rock usually has a granophyric or porphyritic structure. This contact action may be imagined as having taken place in one of two ways. It may have resulted from the passage of solutions from one rock into the other, or it may have been produced by the penetration of the molten magma of one into the other and a recrystallization of the mixed magmas thus formed. Messrs. Herrick, Clarke, and Deming[1] regard the orthoclase-gabbros of Duluth as having been formed in the first way. Dr. Wadsworth[2] thinks that all the quartz of a certain rock collected on the north shore of Pigeon point just west of the Little Portage is of secondary origin, and that the rock itself is an altered gabbro or an altered form of a more acidic rock. This rock is a very much weathered variety of what the writer has called an intermediate rock. Its analysis is given in column G, above.

The objections to this theory of the origin of this class of rocks are: First, the perfect freshness of the large plagioclase crystals in the darker varieties; second, the entire lack of even a trace of a line of contact between the more acid and the more basic phases; third, the occurrence of idiomorphic crystals of hornblende in some of the intermediate rocks; and, fourth, the perfect gradation in the composition of these rocks as revealed by the analyses. It is almost impossible to imagine the conditions under which a rock of the composition of the gabbro (III) could be changed into one of the composition of the intermediate rock No. 11210 (XIV) by means of solutions emanating from the red rock, unless these solutions contained in them the materials of the red rock in about the proportions in which they are present in that rock—a supposition which is not at all probable, since different minerals possess different degrees of solubility in any menstruum that may be employed to dissolve them.

According to the second theory, the production of the intermediate rocks is due to the intermingling of gabbro material with that of the red rock and a recrystallization of the magma thus formed. That the conditions prevalent on the point were favorable to this kind of contact action is shown by the presence there of a large quantity of rocks which

[1] Some American norites and gabbros. American Geologist, June, 1888, p. 343.
[2] Bulletin No. 2, Geol. and Nat. Hist. Survey of Minn., p. 82.

it is believed have resulted from the action of an eruptive upon the preexisting quartzites. In the case of the formation of the intermediate rocks, the intermingling of the gabbro and the red rock must have occurred at some considerable depth below the then existing surface of the earth, where the conditions were such as to allow of the production of a holo-crystalline structure. Under these conditions the magma of one of the two rocks may have penetrated the other, or it may have absorbed pieces broken from it, and thus given rise to a new magma, which upon cooling yielded rocks which varied in composition in accordance with their nearness to the gabbro or the red rock, i. e., varying with the number and size of the fragments dissolved.

At the contact of the granophyre and the gabbro the conditions were slightly different. In this case it seems that the red rock broke off pieces from the gabbro, but before it could entirely dissolve them it solidified. On the granophyre side of the contact pieces of the basic rock can still be detected in a groundmass which varies slightly in composition from the typical granophyre, in consequence, presumably, of the partial solution of gabbro fragments. The rock consists almost solely of quartz and feldspar in micropegmatitic intergrowths and a few spherulitic masses of chlorite. Large lenticular areas of quartz, with embayments of the feldspathic groundmass, represent the porphyritic crystals of this mineral, which are common in the typical rock at a distance from the contact. On the gabbro side of the contact the augite is very pale in color and is almost nonpolarizing. The olivine is serpentinized and chloritized. It is often stained brownish-yellow, and contains magnetite grains, particularly on its edges.

The features which are presented by the intermediate rocks in the two places referred to above are found also, with little variation, at all other points where the two rocks are in contact. All phases of the intermediate rocks are not always to be found, but it is certain that in every locality in which are exposed the borders of either the gabbro or the red rock near their contact one or more phases of the intermediate rocks are to be detected. The microscopical examination of these shows them to have about the same composition as some one of the three varieties above described. In a few cases there is a large development of brown biotite in irregular-shaped plates and folia. These do not seem to have crystallized from a magma, but to have been secondarily developed from some constituent already present in the rock, since the original gabbro structure of the rock remains. Ilmenite is abundant in most varieties, and in some it gives rise to leucoxene or sphene in great quantity. Magnetite occurs in little grains and in rodlike bodies, and on its edges is fringed with dark-brown biotite.

The formation of a holocrystalline rock at the contact of two eruptives is not uncommon among geological phenomena. In 1883 Michel-Lévy[1] described a rock formed at the contact of gabbro (or diabase)

[1] Sur les roches éruptives basiques, cambriennes du Mâconnais et du Beaujolais. Bull. Soc. Géol. de Fr., 1883, p. 273.

and granite in the region of Maconnais and Beaujolais, in France. On the diabase side of this contact the augite of the diabase was changed to hornblende and the plagioclase crystals gradually disappeared. The granite, on the other hand, lost its biotite and assumed plagioclase. In the parish of Helsinge, in Finland, a red microcline-granite, according to Wiik,[1] loses its microcline in the neighborhood of inclusions of diabase and has developed in its place white plagioclase. The granitite of Ehrenberg, Ilmenau, contains augite instead of hornblende at its contact with labrador-diorite.[2] The more usual case, however, is the formation of a glassy or porphyritic rock by solution of broken fragments in the magma of the rock which produced the fracturing. This kind of action is most common on basalt[3] contacts. Whether the intruded rock is a sedimentary or an igneous one, the basalt[4] in many cases dissolves fragments of it, and thus gives rise to a rock which differs in character from the basalt itself and also from the unaltered intruded mass. The resulting product is usually a glass containing porphyritic crystals, which have been generated by the contact action.

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[1] Referate, Neues Jahrb. für Mineral., 1888, II, p. 74.

[2] E. E. Schmid: Der Ehrenberg bei Ilmenau, 1876. Ref. Rosenbusch: Massige Gesteine, 1887, p. 43.

[3] Joh. Lehmann: Verh. d. niederrh. Ver. f. Natur. -und Heilk., 1874.

[4] Chrustschoff: Bull. Soc. Min. d. Fr., 1885, vol. 8, p. 62. Joh. Stock: Tschermak's mineral. u. petrog. Mitth., vol. 9, p. 429. Otto Beyer: Ibid., vol. 10, p. 1.

CHAPTER VI.

PETROGRAPHICAL DESCRIPTION OF THE FRAGMENTAL ROCKS.

The sedimentary rocks include slates, quartzites, and conglomerates. That these rocks are really sediments is shown in the field by their occasional conglomeratic character, and more decisively by the lines of false bedding observed on the quartzites and in the beautiful ripple markings seen on many of the slates.

In their unaltered forms the quartzites comprise evenly bedded light gray, pink, and black varieties. These are all very compact and hard. When struck with the hammer they yield a sharp, ringing sound, and break with a conchoidal fracture. The light gray and the darker kinds have the vitreous appearance characteristic of indurated quartzites. In the pink varieties this is not so noticeable. The color of the latter is due to the large proportion of red feldspar in them. This feldspar has undergone alteration and has consequently lost its luster and assumed an earthy aspect, which it imparts to the rock. The slates, interbedded with the quartzites in thin layers, are all black silicious rocks, differing from the dark quartzites mainly in texture. They are finer grained and break more readily along the bedding planes, but otherwise are not to be distinguished from them. The conglomeratic beds form but a very small portion of the fragmental series. They are found in but two or three places, where they appear to be only locally developed. They consist merely of the ordinary slates and quartzites, with included pebbles of quartz and red granite. Two series of vertical joint cracks, one running about north and south, and the other about east and west, divide the fragmental rocks into rectangular blocks. The walls of the cracks are covered with druses of quartz or epidote.

THE UNALTERED QUARTZITES.

Under the microscope the darker quartzites are found to consist mainly of round and irregular quartz grains embedded in a mass of colorless quartz in which are also a few grains of red feldspar, a little green mica, some chlorite, and a very few flakes of brown biotite and grains of magnetite.

The quartz grains are filled with tiny fluid inclusions with movable bubbles. These are arranged in straight lines in the interior of the grains, and are, besides, particularly abundant on their surfaces, when they define the original outlines of the grains with great distinctness. The feldspar grains are colored red by numerous inclusions of a red iron oxide. Although probably orthoclase, their true nature can not be determined because of the alteration they have undergone. This alteration has resulted in the production of green mica, chlorite, and quartz. The green mica is slightly pleochroic. In the neighborhood of magnetite it becomes brown and assumes the properties of biotite. The chlorite occurs in small quantity mingled with the mica and quartz. The latter mineral is the most abundant product. It is present in such large quantity as to completely obscure the other minerals when the thin section is examined between crossed nicols. Under these conditions it appears as a mosaic of interlocking areas, some of which extend out beyond the original surfaces of the grains and are continuous with similar areas in the interstitial cement. Pl. X, *c*, *d*, represents the appearance of two decomposed feldspar grains in one of these rocks (No. 11350). In *c* the grains are shown as they appear in natural light. In *d* they are represented in polarized light. The quartz areas within the grain are continuous with similarly orientated areas without it, so that its outline as seen in natural light is entirely obliterated between crossed nicols. In the figures the extensions of the areas beyond the original outlines of the grains are not pictured.

The quartz substance between the grains is broken up under crossed nicols into a mosaic of little areas interlocking by irregular sutures. Many of these little areas are optically continuous with the quartz grains they surround, while others are similarly orientated[1] with reference to the secondary quartz derived from the feldspar. All of the interstitial quartz is distinguished from the quartz of the grains by the small number of its inclusions. Pl. XI, a, shows the appearance of one of these quartzites in polarized light when magnified sixty diameters. In the lower left hand corner are two large grains of quartz with their original contours marked by dark lines of inclusions. Beyond these lines there is additional quartz material, which is optically continuous with that of the grain it surrounds. The dark minerals in the section are chlorite and other alteration products of feldspar.

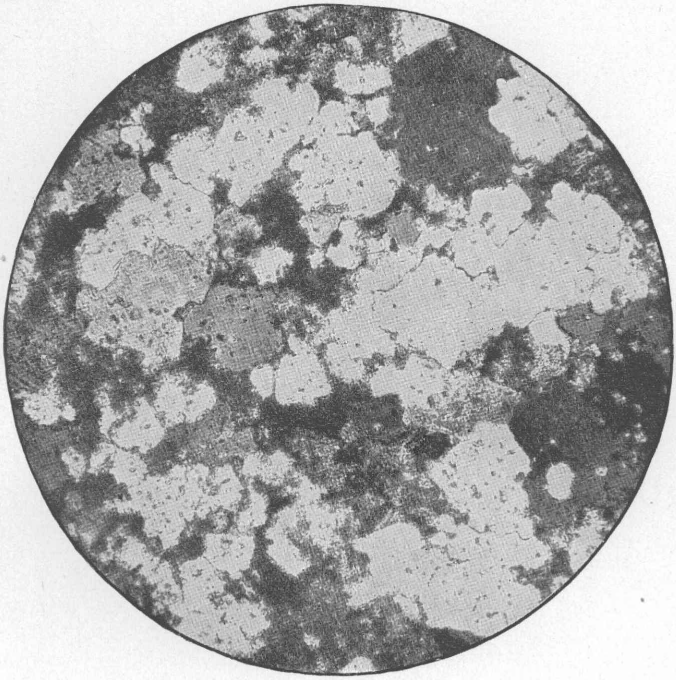
The pink quartzites contain a very much larger amount of feldspar than do the darker varieties. As in the more quartzose varieties, the feldspar has undergone alteration into chlorite, green mica, and quartz. The chlorite is more abundant than in the dark varieties. It not only occurs scattered through the feldspar, but is found also around the edges of both this mineral and quartz. It thus seems evident that the alteration of the feldspar had begun before the silicification process had been completed, and that some of the chlorite was derived from a clayey material which adhered to the grains of quartz. An additional mineral not found in the dark varieties is often present in the pink quartzites in the form of a light green, fibrous substance closely resem-

[1] Cf. Irving and Van Hise: Bull. U. S. Geol. Survey, No. 8, 1884.

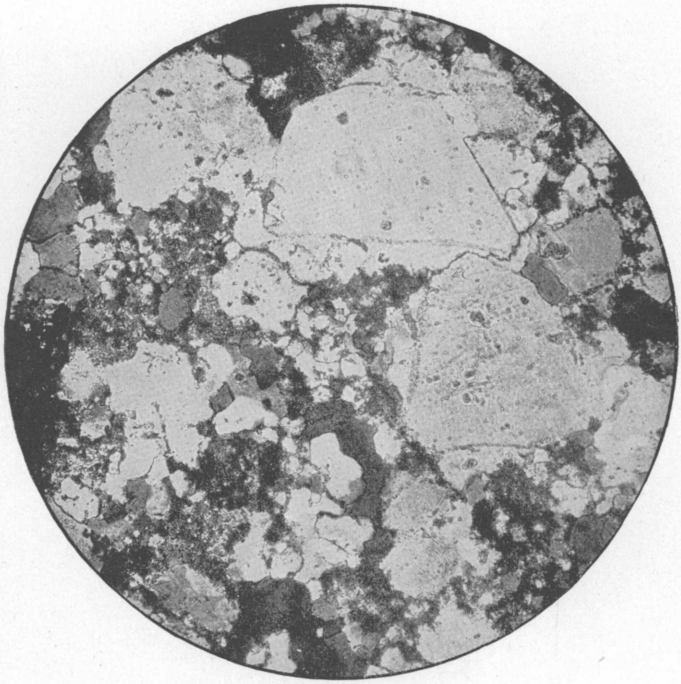
EXPLANATION OF PLATE XI.

XI. a. Section of quartzite (No. 11249) formed by the deposition of quartz around previously existing quartz grains in such a way that the added material has the same orientation as that of the original grain, which it surrounds. In the lower left-hand corner are two large grains, with their original outlines marked by dark lines of inclusions. Beyond these lines the new quartz enlargement is discovered to be optically continuous with the substance of the grain to which it is contiguous. The dark portions of the figure represent chlorite and other secondary products of feldspar. From a photograph in polarized light. Magnified 60 diameters.

b. Thin section of altered quartzite (No. 11213), from the outer zone of the contact belt. The light-colored quartz no longer shows the rounded outline of grains. The various individuals now interlock with irregular sutures and the enlargements have disappeared. The interstitial substance is a mixture of feldspar and chlorite. Polarized light. Magnified 80 diameters.



a. QUARTZITE.



b. ALTERED QUARTZITE.

bling the green biotite, from which, however, it is easily distinguished by its silvery luster and bright polarization colors between crossed nicols. This same mineral is very beautifully developed in certain phases of the altered quartzites, and will be more fully described in their discussion. It is probably a muscovite or sericite. A few grains of plagioclase, sometimes fresh, but more frequently much altered, a little magnetite, rutile, and earthy iron minerals make up the balance of the rock.

In order to obtain some idea of the chemical composition of the two varieties of quartzites the following analyses were made by Dr. R. B. Riggs. No. IV is the analysis of a dark vitreous quartzite from the little peninsula on the south shore of Pigeon point, about half a mile west of the isthmus connecting its eastern and western parts (No. 11399). No. V is the analysis of an interbedded lighter quartzite containing quite a large amount of altered feldspar (No. 11400). Under VI is given the percentage of silica and water present in one of the reddest of the quartzites occurring on the point. It was collected at the west side of the shingle beach east of the barite vein. (See map, Pl. XIV, No. 11409.)

	IV.	V.	VI.
SiO_2	74·22	73·65	74·88
Al_2O_3	10·61	11·08	....
Fe_2O_3	7·45	7·24	....
FeO	·85	·77	....
TiO_2	·16	trace.	....
MnO	....	trace.	....
CaO	·56	·40	....
MgO	1·48	1·52	....
K_2O	1·08	1·65	....
Na_2O	2·12	1·67	....
H_2O	1·79	1·88	1·63
Total	100·32	99·86	....

By a comparison of these figures it will be seen that the only appreciable differences in the composition of the two rocks are found in the amounts of silica and the alkalies present; and even in the latter case the total amount of sodium and potassium present in each is practically the same (3.20 in No. 11399 and 3·32 in No. 11400). This near identity of composition in typical specimens of the two principal varieties of the unaltered quartzites render the discussion of their altered phases somewhat simpler than it would otherwise be, as will be seen in the sequel. The figures given above do not represent the differences in composition between the most quartzose and the most feldspathic of the quartzites, but they show the difference in the composition of specimens representing the two most prevalent types on the point. The most quartzose varieties consist almost exclusively of quartz, while the most feldspathic kinds contain nearly 75 per cent of feldspar.

Quartzites similar to those described above have been mentioned by Irving and Van Hise[1] as existing throughout the entire extent of the Huronian area, and quartzites produced in the same way, viz, through the enlargement of quartz grains by the addition of new quartz material, have been found by these and other geologists[2] in the fragmental beds of different horizons at widely different localities.

The silicification of the quartzites of Pigeon point may, therefore, be regarded as due to conditions which have no connection with the occurrence of eruptive rocks in their vicinity, but which were the result of causes acting over large areas. In one case Irving[3] found the source of the new silica to be solutions arising from the weathering of exposed portions of the quartzites themselves. Crosby[4] ascribes it to the solution of siliceous organisms existing in the sediments from which the slates and quartzites were formed.

A peculiar feature of several of the darker quartzites found near contacts with diabase dikes, is noticed only when their thin sections are examined. This consists in the development of large quantities of epidote in plates and little granular masses. This epidote is pleochroic in bright yellowish green and light pink tints, and is intermingled with a brownish green viriditic substance, calcite and a little quartz. The nature of these minerals and their intimate association point to a secondary origin from plagioclase.[5] In section number 11426, a little plagioclase can still be detected, but in others no trace of this mineral is left. In the former case the plagioclase grains contain within themselves small grains of epidote. On their edges these grains extend out into the interstitial quartz cement and form plates. But very little chlorite is present in these rocks, while black and red iron oxides are absent.

It is impossible to arrive at any definite conclusion as to the conditions which gave rise to the formation of epidote from feldspar in these instances; whereas the ordinary alteration is into chlorite, quartz, and green micas. Solutions emanating from the dikes may have influenced this alteration to some extent. Other quartzites found in the same relation to dikes, however, contain no epidote, and since the epidotic varieties show no other evidence of alteration (the quartz grains present the same enlargements, and contain the same inclusions arranged in the same general manner as in the non-epidotic varieties), it would seem more consistent with the facts to regard this alteration as due to the nature of the original feldspar grains, together with the general composition of the rock itself. When orthoclase was the principal feldspathic constituent, and in addition there were present iron miner-

[1] Bull. U. S. Geol. Survey, No. 8, 1884; and Irving: Preliminary Paper on an Investigation of the Archean Formation of the Northwestern States, 5th Annual Report U. S. Geol. Survey, pp. 218-242.

[2] Cf. T. G. Bonney: Geol. Mag., No. 289, July, 1888, p. 297.

[3] Bull. U. S. Geol. Survey, No. 8, pp. 48-49.

[4] W. O. Crosby: Quartzites and Siliceous Concretions. Technology Quarterly, May, 1888, p. 397.

[5] Roth: Allgemeine und Chemische Geologie Bd. I, p. 321.

als and a little clay, the alteration has been to chlorite, quartz, green biotite and sericite (?); when the predominant feldspar was plagioclase, and the quantity of iron oxides and interstitial clayey substance present was small, epidote was formed.

Another peculiar variety of the unaltered quartzites was observed in one or two localities, where the red quartzite was mottled with green spots. These spots are sections of lenticular bodies, with the same composition as the dark quartzites, while the red groundmass possesses all the features of the pink quartzites. Neither the spots nor the groundmass show any evidence of alteration other than that due to weathering. Both contain enlarged quartz-grains, a little chlorite and green mica, and other decomposition products of feldspar. In some cases the spotted layers form thin beds with well-defined outlines between the beds of dark quartzites. In other cases the two rocks grade insensibly into each other, the green spots always having apparently the same composition as the unaltered dark rocks, with which the spotted layers are interstratified. The restriction of the spots to certain beds and their arrangement in planes with their longer elliptical axes parallel to the bedding plane indicate an origin connected in some way with the sedimentation of the rocks in which they occur.

THE UNALTERED SLATES AND CONGLOMERATES.

The slates differ from the quartzites in containing less quartz and more chlorite. The proportions of quartz and water in two interbedded rocks, one (No. 11409) a pinkish brown quartzite, and the other (No. 11410) a compact bluish-black slate, are as follows:

	SiO_2.	H_2O.
Quartzite	74·88	1·63
Slate	53·45	3·92

The slates are composed of enlarged quartz grains, red feldspar, and a little comparatively fresh, twinned plagioclase imbedded in a mass of chlorite, fine needles, and shreds of the brightly polarizing green mica, little irregular grains and dust-like particles of magnetite, some leucoxene, and occasionally a few plates of a brightly polarizing mineral not unlike sphene in general appearance. They may be looked upon as fine-grained quartzites in which there was originally a considerable amount of interstitial clay.

Upon their contact with the diabase dikes the slates appear to have suffered a little more alteration than the quartzites. Little plates of brown pleochroic mica have developed in them in large quantity. In section number 11307, from the contact of the straight dike half a mile from end of point (Pl. XIV), the mica makes up about a third of the entire rock, the other constituents being quartz, a very little chlorite, and magnetite dust scattered throughout the rock and included within the mica. A narrow band of lighter colored material in the same section contains less biotite, a little more chlorite, and a large additional amount of quartz.

The conglomerates interstratified with the slates and quartzites differ from these only in containing pebbles of quartz, granite, chert or quartzite. The quartz pebbles are usually composite and show enlargements around the edges, the added quartz orientating itself to correspond with that portion of the pebble nearest it. The material in which the pebbles are imbedded presents the same features as do the quartzites and slates described above.

THE SPOTTED ROCKS.

Associated with the unaltered quartzites in certain restricted areas on the south shore of the point, notably in the western half of section 25 and in the SW. ¼ section 27, are certain other quartzites on whose surfaces curious circular spots are developed. These spots vary in size from less than a quarter of an inch to more than two inches in diameter. On a weathered surface they appear as slight depressions surrounded by a raised rim of a light brick-red color. Their distribution is very irregular. Frequently a single spot stands alone. Sometimes two or more spots are united, and when this is the case one rim encircles the group. The accompanying figure (Fig. 10) represents the shape and general appearance of some of these spots as seen on a smooth weathered surface.

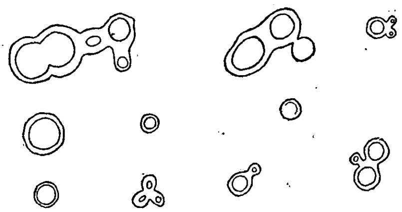


FIG. 10.—Shapes and groupings of spots on the surface of spotted rocks. (Natural size.)

When one of these rocks is broken open it is observed that the bodies producing the spots are themselves either lenticular in shape or spherical. They are pistachio green in color and possess a sugary texture. When moistened with hydrochloric acid they effervesce sometimes with an abundant, sometimes with only a slight evolution of gas. Like the spots on a weathered surface, the spheroidal and lenticular bodies are surrounded by a narrow brick-red rim. These rims are here fairly well defined against the substance which they inclose, but on their outer edges gradually shade off into the body of the rock. Pl. x, *h*, represents the macroscopic appearance of a thin section made through one of the spots. The central circular green area is a section through a spot. Around this is a colorless zone, which under the microscope is found to consist of only quartz and feldspar. Surrounding this is the rock mass composed of enlarged grains of quartz, feldspar, magnetite, etc.

In other parts of these same areas are quartzites which show no well defined spots on a weathered surface, but contain little concavities or irregularly outlined red areas with diameters of about the same magnitude as those of the spots described above. On a fresh fracture of these, instead of the green spheroidal bodies, are oval and circular areas which reflect the light evenly, as from a smooth cleavage surface, and have a silvery luster like that of calcite. When treated with acids they effervesce briskly with the evolution of carbon dioxide. It is evident that these oval and spheroidal silvery spots are nothing more than morpholites and other concretions of calcite like those so common in the States of the Connecticut valley and in the rocks[1] of other localities. The existence of this calcite in a state so highly crystalline as to yield large cleavage surfaces is not so surprising when we recall the perfection of the rhombohedral crystals of this substance in the Fontainebleau[2] sandstone. On the weathered surface the calcite dissolves, first producing a cream colored spot, which afterwards becomes red, and finally disappears, leaving a little hollow. Epidote druses on the walls of the joint cracks traversing the spotted rocks and those associated with them are particularly noticeable.

From the fact that the spotted quartzites are found only on the south side of the point near the water's edge, and further that the trend of this shore is about parallel to the strike of the rocks, it appears probable that they are all parts of the same bed, which has been exposed only where the water has washed away the overlying ordinary quartzites. The lateral extent of the bed could not be determined, nor was its continuity proven. Its thickness, where exposed, can not be greater than 4 or 5 feet.

Under the microscope the body of the rocks containing calcite concretions is seen to be composed of an aggregate of enlarged quartz-grains, feldspar, chlorite, and green mica, like the great mass of the unaltered quartzites already described. Much of the feldspar is triclinic and quite fresh. The green mica is slightly pleochroic, and appears to have crystallized in position. A few grains of magnetite are scattered throughout the sections, and small areas of calcite are occasionally found inclosing the other constituents.

The silvery spots consist of perfectly transparent calcite surrounding grains of quartz and feldspar, and flakes of the same minerals as are common in the main portion of the rock. The interstitial quartz substance is absent, and the amount of secondary minerals present is much smaller than in other portions of the same section. The calcite polarizes in large areas, several of which occur in a single spot.

The quartzites in the beds above and below the calciferous varieties are among the most typical of the unaltered kinds. They are usually highly vitreous, and show not the least evidence of any alteration other than that attendant upon ordinary weathering.

[1] Cf. Naumann: Lehrbuch der Geognosie, Bd. I, pp. 419-421. Dana: Manual of Geology; pp. 85, 86. v. Gumbel: Grundzüge der Geologie, pp. 244-246.

[2] Auger: Krystallisirte Sandstein von Fontainebleau, Tschermaks mineral Mittheil, 1875, p., 156.

The rocks in immediate association with those in which the green spots occur, but which are themselves unspotted, appear to have undergone more or less alteration. Chlorite is much more abundant than in the former varieties. It has been derived from biotite on the one hand and feldspar on the other. Closely intermingled with this, but more particularly in the neighborhood of little nests of calcite, irregularly shaped plates of a light green, pleochroic, and brightly polarizing epidote are frequent. In most cases, however, the epidote occurs in tiny rounded grains and rudely outlined crystals scattered everywhere through the feldspathic and chloritic ground mass in which the enlarged quartzes are embedded. These little grains are sometimes crossed by cleavage cracks, parallel to which extinction takes place. They have a faint greenish tinge and a very high refractive index. In addition to quartz, feldspar, epidote, and chlorite, the rocks of this class sometimes contain flakes of brown biotite, grains of magnetite, and a little calcite. As will be shown later, the development of biotite in the Pigeon point quartzites is a result of contact action. The occurrence of this mineral in the rocks now under consideration is an indication that these have been affected by the presence near them of eruptive masses. Those in which the epidote is most abundantly developed are very near diabase dikes, or are cut by stringers and dikes of the red rock.

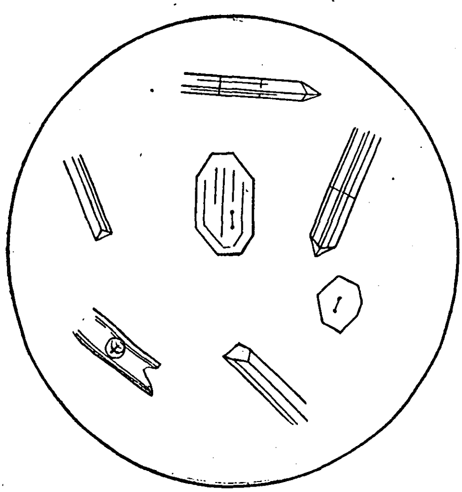


FIG. 11.—Epidote crystals in spots of spotted rock. (Enlarged 300 diameters.)

The groundmass of the rocks containing the green spots presents the same features as are observed in the epidote-bearing rocks just described, except that the epidote grains are much less common here and in some cases are entirely absent. The spots, on the contrary, are usually very rich in epidote. They consist of enlarged quartz grains, a little feldspar, and more or less chlorite, imbedded in a mass of calcite and epidote. The amount of calcite present varies within wide limits. It sometimes occupies nearly the entire space between the quartz, feldspar, and chlorite to the almost complete exclusion of the epidote. In other cases it occurs only sparingly, while the epidote is massed in little plates, grains, and crystals. Only rarely are well terminated crystals observed (No. 11463). These average $\frac{1}{25}^{mm}$ in length. A few forms are represented in Fig. 11. Although but very slightly pleochroic, the true nature of these crystals can not be doubted. In color they are of such a light green tint as to be almost colorless. They possess a cleavage and an extinction parallel to their long axes, have a high index of refraction, and are usually free from inclusions. They are distinguished from sahlite, which they closely resemble, by the fact that the plane of their optical axes is at right angles to their cleavage. The sahlite described by Irving and Van Hise [1] in a quartzite from Pigeon point is in all probability this variety of epidote.

Around the spots are clear zones corresponding to the raised rims, mentioned as surrounding the hollow interiors of spots on a weathered surface. These zones are sometimes composed of grains and plates of epidote larger than those found in the interior of the spots, either with or without calcite. When epidote is present in the rims there is a scarcity of this mineral in the interior of the spots. This is the rule in those rocks containing a large amount of altered feldspar and chlorite. In these both the interior of the spots and the body of the rock are composed of quartz, feldspar, chlorite, bleached biotite, little plates of hematite, and grains of magnetite. In the spot the chlorite is better crystallized than elsewhere. The surrounding rim contains only quartz, calcite, and epidote, except on its outer edge, where there is an accumulation of red iron compounds. In those cases in which the interior of the spots contains a large amount of epidote, the exterior zone is comparatively free from this mineral, consisting essentially of quartz and feldspar stained red by iron salts. In both cases chlorite is absent from the rim.

As has already been stated, the spotted rocks are found near eruptive masses of diabase or in the close vicinity of the red rock, and contain within themselves the evidence of partial alteration. The existence of these rocks in a well defined bed, between others which show no spots, would at once suggest that the origin of the spots is due to the occurrence in these beds of some substance which was absent from those which are unspotted. The shape of the spots and their grouping suggest concretions. Epidote is not known to occur in such forms in fragmental rocks, while concretions of calcite [2] are common. The existence of such calcite concretions in the unaltered quartzite of Pigeon point is established beyond question in the case of the rocks containing oval silvery areas. In these no epidote is present. In others in which the calcite is no longer so well crystallized as to yield good cleavage faces, epidote is found in small quantity, while in those which are of the brightest green color there is no calcite, but instead there is always a large quantity of epidote, either in the interior of the spot or on its edge.

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[1] Bull. U. S. Geol. Survey, No. 8, p. 36.

[2] Calcitic concretions in other parts of the Huronian area north of Lake Superior are described by Mr. Ingall, as characteristic of the upper division of the Animikie series in the neighborhood of Silver mountain. (Mines and Mining on Lake Superior, Part H of Geol. and Natural Hist. Survey of Canada, p. 84.)

From a consideration of these facts it would seem that the epidote and calcite are genetically connected. Epidote is one of the most common[1] of the new minerals produced when limestones have undergone change in consequence of the presence near them of eruptive masses. In the Pigeon point rocks it occurs only where these are in close proximity to eruptive masses, and when they contain within themselves evidences of contact action. It would appear, then, that we are justified in regarding this epidote as the result of the action of the intrusive rocks upon the calciferous sedimentary beds through which they break. Where the calcite was scattered in little nests through the mass of the fragmental rocks, epidote is now found in similar relations to the other constituents. Where it was present in spheroidal concretions inclosing quartz grains, feldspar, etc., little spheroidal bodies are now found consisting in large part of crystals of epidote. That the epidote rims give rise to spots whose interiors differ but slightly from the main portion of the rocks in which they occur, may be due to the original deposition of the calcite in annular concretions. The hard envelopes around the epidote spheroids, and those forming the raised rims around the concavities on weathered surfaces, owe their characteristics to the lack of chlorite in their composition. This absence of chlorite is in all probability the result of the formation of the epidote, which, in the effort to build itself up, was compelled to draw from that portion of the rock immediately surrounding the original calcite concretions those constituents of which it had need, and which were at the same time necessary to the formation of the chlorite.

An analysis (VII) of one of the epidotic rocks (No. 11274) free from spots shows it to have practically the same composition as that of the unaltered quartzites. The analysis was made by Dr. R. B. Riggs. In column IV is given the analysis of one of the typical quartzites (No. 11399) for comparison.

	VII.	IV.
SiO_2	73·14	74·22
Al_2O_3	12·60	10·61
FeO_3	7·57	7·45
FeO	1·31	·85
TiO_2	·04	·16
MnO	Trace.	....
CaO	·43	·56
MgO	1·67	1·48
K_2O	1·00	1·08
Na_2O	1·78	2·12
H_2O	·83	1·79
	100·37	100·32

[1] Cf. J. Roth: Allgemeine und chemische Geologie, Bd. I, p. 428, et seq.; and Rosenbusch: Mikroskopische Physiographie, 1885, Bd. I, p. 498.

The above table also shows the close agreement in composition between two quartzites of very different appearance obtained from widely separated localities on the point. The small amount of calcium present in the epidotic rock is due to the entire lack of plagioclase fragment among its components. Analyses of the spotted rocks would undoubtedly show a comparatively high percentage of calcium.

CHAPTER VII.

PETROGRAPHICAL DESCRIPTION OF THE ROCKS OF THE CONTACT BELT BETWEEN THE SEDIMENTARY AND OTHER ROCKS.

Although a general description of the rocks of the contact belt between the quartzite and red rock has already been given in Chapter I of this paper, a repetition of some of the statements made there may facilitate the clear understanding of the relations existing between the various rocks comprising this belt and between these and the red rock along whose southern border the former usually occur in their largest and best development.

The contact belt has been mentioned as comprehending a series of rocks existing between the indurated vitreous quartzites and slates in the southern part of Pigeon point and the eruptive rocks to their north. Except in one or two localities, the rock lying immediately to the north of the belt is the granular red rock. In it are numerous fragments of the sedimentary rocks, in which effects have been produced varying with the nature of the inclusion. Pieces of quartzite are reddened and mottled with green spots, as represented in Pl. IV. When the spots are comparatively few in number, they are sometimes an inch or more in diameter. In other cases they are very numerous, with diameters of only a few millimeters. The bright red groundmass through which the spots are strewn is crypto-crystalline in texture. It possesses a vitreous luster, and contains scattered through it small elongated spots of the same color as the larger mottlings. No feldspar grains can be detected in it, nor can any cleavage pieces be observed, as in the case of the granular red rock.

The slaty fragments are differently affected. It will be remembered that the unaltered slates are hard, black, vitreous rocks, with a finer grained texture than the quartzites and more thinly bedded, but otherwise of the same general character as these. When embedded in the red rock the fragments of slate take on an aspect somewhat resembling that of a chloritic mica-slate. On a fresh fracture, small shining folia of muscovite are prominent, and the rock has a greasy feeling, in consequence of the large amount of chlorite that has been developed in it. Throughout this dark-green background are scattered little red crystals of feldspar, like those occurring at the contact of the slates with dikes and veins of the rock. On a weathered surface the contrast between the feldspar cystals and the groundmass of the rock is very striking. The latter assumes a dark brownish-gray color, and the former have a pale red or pink color. Large areas with a smooth surface thus appear speckled with little light-colored dots. Around the inclusions of this kind are usually apparent two or more concentric zones composed of material differing slightly according to its greater or less distance from the center of the inclusions, but not distinguished by any striking characteristic features. In the first zone is an irregularly mottled red and green micaceous rock, in which the mottlings are so indefinite in outline as to seem to grade imperceptibly into the substance surrounding them. In some cases the red material is less in amount than the green, when the former appears as mottling the latter. In other cases the green material is in smaller amount when this forms spots in the red. Surrounding this is a second zone in which the red rock occurs with an occasional dark spot in it having the composition of the darker portion of the first zone. Beyond the second zone a third is sometimes met with. In this no darker spots occur, but the entire bands consists of red-rock material of a little darker color than that of the typical red rock.

The arrangement of the three zones and their composition would seem to indicate that the inclusion was impregnated with the magma of the red rock and was dissolved on its exterior, thus giving rise to a new magma, from which were separated upon its solidification certain dark minerals, to which is due the darker color of the surrounding red rock. A little farther within the inclusion there was an insufficient amount of the material of the red rock to completely dissolve the slate, and remnants of this remain in the dark portions of the second zone. In the inner zone the supply of red material was not large enough to melt any portion of the slate. It merely impregnated it and solidified, thus giving rise to the indefinite mottling observed. In the interior of the inclusion the molten magma may have penetrated to some extent, so that the feldspathic portion was enabled to separate out in indefinitely outlined crystals, but no thorough fusion resulted; or hot solutions carrying the constituents of feldspar may have permeated the slate and have deposited red feldspar in the little crystals which are now so prominent on fresh or weathered surfaces of the included rocks. Quartzite inclusions have produced very much less effect in the rock surrounding them than have the slates, presumably because the former are nearer the red rock in composition than are the latter.

The breccia, composed of these pieces of slate and quartzite cemented together by the red rock when it is present, forms quite a distinct zone immediately contiguous to the red rock. To the south of it are found the most altered members of the contact belt in very complicated relations to the red rock. As a rule no definite line of contact can anywhere be detected between them and the red rock. The original fragmental texture and bedded structure of the sedimentary rocks have entirely disappeared. They are now of a bright red color, and possess a highly vitreous luster. They are cut by innumerable veins and dikes of the granular red rock, and often include fragments of less altered slates and quartzites.

Beyond this, at a greater distance from the red rock, is another zone, like the mottled zóne around slate inclusions. This zone is neither well defined against the former, nor is it to be clearly distinguished from the least altered zone of the contact belt nearest the unaltered quartzites. In it the rocks are neither shattered nor are they pushed from their original positions. The bedding can still be distinguished, but it is by no means as well marked as in the case of the unaltered rocks. The more slaty portions of this part of the contact belt weather more easily than the more quartzose portions. The former, when they overlie the latter, are eroded off in such a way as to leave patches adhering to the quartzites, so that they appear as if included in this rock. In some instances this was at first sight thought to be the case; but closer examination proved it to be otherwise.

In certain other instances undoubted fragments of both quartzite and slate were observed in a rock resembling the altered slates. Since these, however, are found, upon microscopical examination to be completely crystalline, they may have acted as an igneous rock, and thus have really formed a breccia with the fragments of the less altered slates and quartzites.

In the exterior zone of the contact belt the rocks are but slightly altered. They are less vitreous than the unaltered fragmental rocks, but are redder in color, and not so evenly divided by joint cracks. Their bedding remains very distinct, and they emit a slightly earthy odor when breathed upon.

At the contact of the fragmental beds with the olivine-gabbro there has been less deep-seated alteration. On the north shore of the point slates and quartzites are in direct contact with a large mass of the gabbro, and in most of these no traces of alteration can be detected. From one point, however, in the easternmost slate area a rock was obtained which, under the microscope, is seen to be slightly altered. At this place a vein of red rock, a few feet in width, runs in a northeasterly direction across both the slates and the trap dikes that penetrate them.

On the southern border of the gabbro area there are two or three localities where the eruptive rock appears to have exerted some influence upon the quartzites contiguous to it. In most cases, though, the metamorphosing rock has the character rather of one of the intermediate rocks described as occurring between the gabbro and the red rock than that of the olivine-gabbro proper. Here altered fragments of quartzites and slates are embedded in a rock that is neither like the olivine-gabbro nor like the typical red rock. It is darker than the latter, but contains a great deal of red feldspar. Its structure is quite different from that of either one of these rocks, and its microscopical features are those of an intermediate rock. The slate inclusions that are abundant in this rock are all surrounded by a fringe, composed of small feldspar crystals radiating from the exterior of the fragments. Outside of this is often a rim of red drusy material exactly like that of the red rock. Large quartzite inclusions embedded in the same rock are also surrounded by a similar red rim. At this place, as at all others where there has been much alteration in the quartzites, both the included rock and the inclosures are penetrated by red veins and dikes. In the western portion of the point, near the barite vein, fragments of quartz occur in a fine-grained altered gabbro. The pieces of quartz vary in diameter from a millimetre to 2 decimetres. They are very irregular in outline and are surrounded by rims of bright red material.

Beyond the zone described above, viz, that in which the olivine-gabbro or one of the intermediate rocks forms a breccia with fragments broken from the sedimentary rocks, there is sometimes a second zone in which the rocks resemble those of the second zone of the red rock contact. This zone is, however, very narrow when present, and is not as well defined as the corresponding zone associated with the red rock.

The third zone, i. e., that in which the rocks are but slightly mottled, is usually absent, but is sometimes present when it has the same characteristics as the outer zone surrounding the contact of the slates and quartzites with the red rock.

From the above-mentioned statements relative to the contact phenomena observed in the neighborhood of the olivine-gabbro and in that of the red rock, it will be noticed that the effects produced in the slate and quartzite fragments of the breccia are the same in character, but that they are distinguished by differences in intensity. Around the red rock the three indistinct zones are always present. They are usually quite broad and the rocks in each are evidently much altered. At the gabbro contact one or more of the three zones may be absent. When present they are always much narrower than the corresponding zones at the red rock contact, and they are never as well characterized as the zones around the red rock. On the north side of the gabbro mass, and at several places on its south side, when it is in direct contact with the slates and quartzites, there is no evidence of contact phenomena of any description, except in the single instance mentioned above, where a quartzite in the easternmost slate area on the north shore of the point is cut by a vein of material resembling the red rock.

From the uniformly holocrystalline structure of the olivine-gabbro, and of the red rock when this is accompanied by contact rocks, it is evident that the surface of the point now exposed to view was not at the surface when the eruptions of the gabbro and the red rock took place. In other words, the structure of the two crystalline rocks indicates that those portions of these rock masses which at present appear on the surface were at the time of their solidification at some distance beneath the then existing surface of the earth, and that the contact phenomena now observed around their peripheries are the result of deep-seated contact action, under the influence of great pressure and probably under the influence of high temperature. The breccia found so widespread along the borders of the red rock, and the numerous veins and dikes of this rock ramifying the rocks of the contact belt, are further evidence of the pressure to which the former rock was subjected during the period of its solidification.

THE LEAST ALTERED OF THE CONTACT ROCKS.

In the outermost zone of the contact belt the rocks differ but slightly from the unaltered slates and quartzites in appearance. As has already been stated several times, they have a redder color than these, are less vitreous in luster, and break less readily along their bedding planes. Occasionally there is developed in some of the quartzites a slight mottling, but since rocks of this kind are more characteristic of what has been described as the second zone of the contact belt, and since their microscopical features are the same as those of the members of this zone, their description is deferred until the mottled rocks of the second zone of the contact belt are discussed.

Although the macroscopic appearance of the least altered of the contact rocks differs but slightly from that of the unaltered slates and quartzites, their microscopical features are quite different. All traces of the enlargements around the quartz grains, that are so prominent a characteristic of the unaltered quartzites, have disappeared in the rocks now under consideration. The quartz now forms a kind of mosaic in which the individual grains interlock by irregular outlines. It contains as inclusions numerous fluid cavities, with dancing bubbles, irregularly shaped glass enclosures, containing devitrification products, tiny transparent needles of some indeterminable mineral, and little masses of an earthy substance. The feldspar grains have lost their outlines. On their edges they merge gradually into the quartz (see Pl. XI, B), so that no line of demarcation between the two minerals can be detected. They have undergone deep-seated alteration with the production of large quantities of fibrous chlorite, more or less of a brightly polarizing, slightly pleochroic, fibrous sericite, a few flakes of kaolin, sometimes a little calcite, a very little brown biotite, grains of magnetite or ilmenite, and a dirty green or brown earthy substance. Since the outlines of the original quartz and feldspar grains have in most cases entirely disappeared, it would be difficult to determine from a mere microscopical examination of these rocks that they were once fragmental. Their true nature, however, admits of no doubt, since in the field they can be traced directly into rocks which, under the microscope, can not be regarded as anything but true slates and quartzites of fragmental origin.

The characteristics of all the rocks belonging to this zone are the same. Their differences are found only in the varying amounts of bleached biotite, sericite, chlorite, and earthy substances present in them, and these seem to be dependent upon the various amounts of feldspar and earthy interstitial substance originally existing in the unaltered rocks. When the chlorite is in large quantity it appears to have resulted partially from the alteration of feldspar and partially from the alteration of biotite, which in turn may have been derived from the clayey substance originally present between the grains of sand that afterwards became compacted into slate or quartzite. The constituent that varies most widely in amount is the sericite. In the most quartzose rocks it occurs only as an occasional flake between the grains of quartz. In the more slaty members it makes up a very large portion of the thin section. Since the slates differ from the quartzites principally in fineness of grain and in the greater abundance of interstitial clayey substance, it is probable that the sericite is in large part the result of the alteration of the interstitial material.

The formation of the secondary minerals discovered in these phases of the contact rocks, and the corrosion of the quartz-grains to such an extent that all traces of their enlargements have disappeared, are results that are not due to the ordinary weathering processes that have acted on the rocks of the point, since most of the slates and quartzites occurring there are not affected in this manner. The changes, however, are such as may be ascribed to the action of water alone without the aid of any great amount of heat, as the secondary minerals most characteristic of these rocks are such as are known in many cases to be the result of ordinary weathering processes. In the case under consideration the water may have emanated from the masses of eruptive rock, around whose borders the altered rocks are found. These waters may have held in solution some materials derived from their eruptive sources, or small quantities of other substances dissolved from the rocks through which they percolated before reaching the outer zone of the contact belt, and these substances may have aided in the formation of the biotite and some of the other constituents of the altered rocks, although all of these might as well have resulted from reactions set up within the quartzite upon the solution of its different components.

The result of the analysis of one of the quartzitic rocks collected just west of the cliff, represented in Fig. 1 indicates that little if any substance has been added to the original quartzite by the agency which effected the change in its structure and mineralogical composition. All the constituents necessary to the formation of the minerals characteristic of the altered rocks already existed in the original rock. The conditions requisite for their rearrangement into the minerals of the contact rocks would have been afforded by the presence of heated water. In column XV is the analysis of the quartzite referred to above (No. 11394). It was made by Mr. R. B. Riggs of the Survey laboratory. In column XVI is the composition of an unaltered quartzite (No. 11421) obtained on the lake shore, at the first small point east of the barite vein. In column H is the average of the three analyses of unaltered quartzites, quoted in the present paper.

	XV.	XVI.	H.
SiO_2	71·00	73·64	73·85
TiO_2	·44	trace.	·05
Al_2O_3	12·88	11·25	10·91
Fe_2O_3	6·69	6·24	6·98
FeO	·65	1·04	·89
MnO	trace.	....	....
CaO	·21	·36	·44
MgO	1·68	1·57	1·52
K_2O	2·95	1·42	1·39
Na_2O	1·43	3·04	2·28
H_2O	2·03	1·98	1·88
	99·96	100·54	100·19

From these analyses it is clear that there was no addition of material to the substance of the quartzites during the change of these to the condition in which they exist at present in this portion of the contact belt. The amount of potassium present in them has been increased, but the total amount of alkalies remains practically the same. The changes have probably been superinduced through the agency of water alone.

The analysis of a very slightly altered slate (No. 11552) collected at some distance from the contact points to the same conclusion. In it no constituents occur that can not be found in the unaltered slates, and none are present in abnormal quantities. The result of the analysis of this specimen, made by Mr. R. B. Riggs, is given in column XVII.

	XVII.
SiO_2	59·71
Al_2O_3	18·32
Fe_2O_3	8·11
FeO	·85
TiO_2	race.
CaO	1·05
MgO	3·54
K_2O	3·43
Na_2O	1·93
H_2O	3·24
	100·18

THE MOTTLED ROCKS OF THE MIDDLE CONTACT ZONE.

In the middle zone of the contact belt the rocks are possessed of an indistinct irregular mottling, consisting, sometimes, of indefinite red blotches on a dark green background, like that of the altered slates. At other times the red portions of the rock exceed the green portions to such an extent that the latter appears as blotches or spots on the former. In both cases, as has been indicated, the dark portion has the general aspect of the altered slates. It is dark green in color, contains minute scales of a glistening, silvery mica, and has a slightly greasy feeling. The red portions resemble somewhat certain phases of the red rock. When this is abundant large cleavage surfaces of red feldspar can frequently be detected in it.

Rocks of this class are found quite near the eruptive, whether this be the red rock or the olivine gabbro. The nearness to the eruptive is indicated by the amount of the red portion present, it being greater in proportion as the mottled rock approaches the eruptive, until finally the dark portion disappears entirely and a rock colored uniformly red replaces the mottled rock. At a little greater distance from the eruptives the mottling on the altered rocks is so very faint and indistinct that it can, in many cases, be detected only when the thin section is placed against a dark surface. Here it is seen as a light cloudy mottling against a transparent background through which the dark surface shows.

A third type of this class of rocks occurs very near the red rock, when the rocks to be described later as characteristic of the inner contact zone are absent. In this type the mottling of red and green takes rather the character of an irregular intermingling of two distinct rocks, as if two pasty magmas had been stirred together and had cooled without mingling, producing a structure resembling the entaxitic structure of some volcanic rocks. Here, as before, the red portions contain red feldspar in pieces that exhibit cleavage surfaces, and their general appearance is like that of the granular red rock.

In this zone have also been placed those slates near the red rock that are spotted with little crystals of red feldspar. These are found on the contact of the slates with veins and dikes of the red rock, on the borders of inclusions imbedded in this rock, and on the upper and lower portions, and sometimes in the centers of layers of slate interbedded with altered quartzites. When viewed in the mass these slates have more of a purple color than those of the altered slates that have been described. Their bedding is not very distinct, although they always break with an uneven, nearly horizontal fracture, and when exposed in the side of a cliff weather into platy layers like the red rock.

Under the microscope the faintly mottled quartzites are seen to differ markedly from the unmottled quartzites belonging to the outer zone of the contact belt. In the red portions of these the quartz has lost all traces of its fragmental nature. It now appears in rudely outlined bipyramidal crystals in a groundmass that for the most part consists of globulitic red feldspar, or of a granophyric intergrowth of this mineral and quartz. The quartz is sometimes in quite well-formed crystals. At other times it has the appearance of corroded crystals, containing embayments of the feldspathic substance. The extent of the corrosion varies in different specimens. In some instances the corrosion has merely destroyed the regular outlines of the crystals and has made them ragged, while in other cases it has resulted in the breaking up of the original grain or crystal into separate pieces and has moved them apart. The general outline of such parts taken together suggests that of a shattered bipyramidal crystal, whose different portions have been moved asunder and consequently extinguish in different positions. Fig. 12 represents one of these broken crystals whose parts extinguish nearly, but not exactly, simultaneously.

In the interstitial feldspathic substance is often a little chlorite, a few fibers of the brightly polarizing mica which has been called sericite, and an occasional flake of brown biotite. Figure a of Pl. XII shows the structure of this portion of one of the mottled rocks (No. 11414).

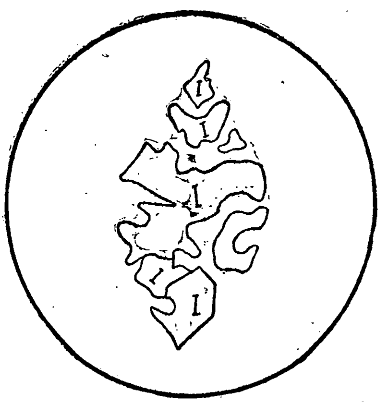


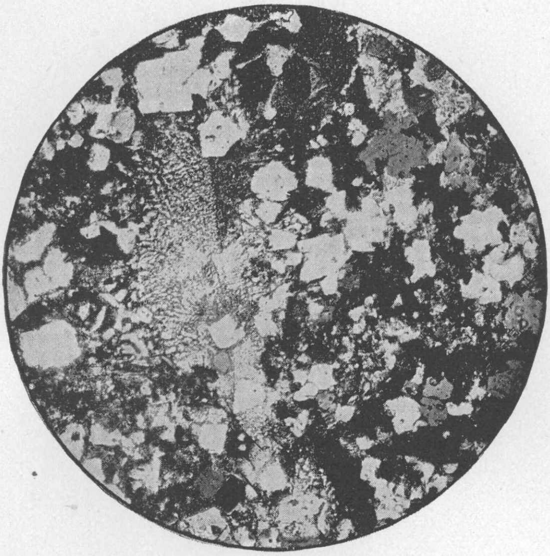
FIG. 12.—Broken crystal of quartz in red portion of mottled quartzite.

Between the red mottlings, in that portion of the rock resembling a dark green slate, the predominant mineral is quartz. This is full of liquid inclusions, lines of which run uninterruptedly from one grain into another without the least break or change in direction. It occurs in grains intimately interlocking by irregular sutures. In isolated cases a single grain appears to retain a portion of its added silica, but usually no enlargements can be detected. In addition to the quartz there is present in this portion of all these rocks a few large flakes of strongly pleochroic, brown biotite, some chlorite in bundles of fibers, more or less sericite, and a very little feldspar, without well-defined contours. The sericite exists both between the quartz grains, in fan-shaped groups intergrown with chlorite, and in needles penetrating the quartz in all directions, regardless of the boundaries of the individual grains. A few dust particles are scattered through all the other constituents, but are apparently most common in the quartz. A few colorless, highly refractive, brightly polarizing acicular crystals of zircon are also occasionally present in the materials occurring in the interstices between the grains of quartz. In general, the appearance and the composition of this portion of the rock is not very different from that of the least altered quartzites at some distance from the

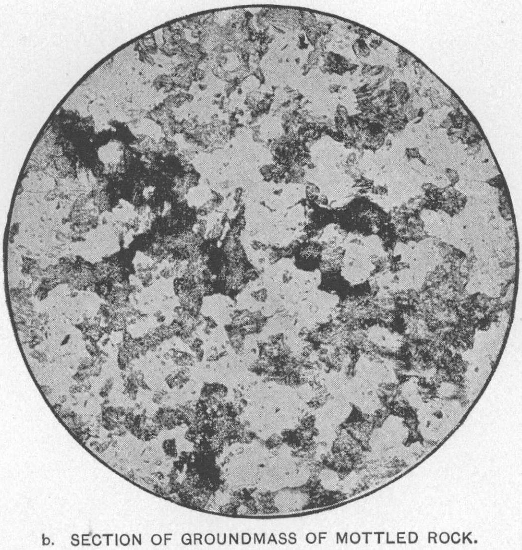
EXPLANATION OF PLATE XII.

XII. a. Thin section of red mottling (No. 11414) in mottled rock from the middle zone of the contact belt. As in the other sections, the white mineral is quartz and the darker substance feldspar. The characteristic structure of the mottling is shown in the center of the figure, where there are granophyric intergrowths of quartz and feldspar and bipyramidal crystals of quartz. The most marked feature of section is the outline of the quartzes. Polarized light. Magnified 80 diameters.

b. Thin section of groundmass of mottled rock (No. 11414) from the middle zone of the contact belt. This figure shows the structure of the groundmass in which the mottlings occur. The amount of feldspar here is much less than in the mottling (as may be seen by comparison with a) and the amount of quartz much greater. The latter have crystal outlines, but these are not as distinct as in the former case. Polarized light. Magnified 80 diameters.



a. SECTION OF MOTTLED ROCK FROM CONTACT BELT.



b. SECTION OF GROUNDMASS OF MOTTLED ROCK.

eruptive rocks. In Pl. XII, b, is pictured the structure of the darker portion of the same rock whose red portions are figured in a of the same plate.

While the most universal features of the spotted rocks are those that have been described above, there are many peculiarities characteristic of certain specimens that should be briefly considered before a correct idea as to the processes incident to the formation of these rocks can be gained. In one specimen (No. 11877), for instance, a portion of the quartz is in grains, while another portion is corroded. The sericite in this rock undoubtedly originated, on the one hand, from biotite and on the other from feldspar. In another section (No. 11288) the quartz is corroded on the edges so as to resemble the peripheral granulation of certain minerals in dynamometamorphosed rocks.

A study of the last two sections, and of very many others, seems to show that much of the corrosion to which the quartz grains have been subjected is a result of the action of solutions, which have attacked the outer envelopes of the quartz grains, i. e., the enlargements, and removed them, and in many cases have begun to attack the inner nuclei.

The composition of one of the least mottled of these contact rocks, (No. 11414) as found by Dr. R. B. Riggs, is given in column XVIII. By comparison with the figures in column H it will be seen that the mottled rock has nearly the same composition as the unaltered quartzites. Nothing has been added to it during the processes which resulted in its mottling, except perhaps a little iron and potassium. The total amount of alkalies has apparently increased, but this increase is so slight that it would be unsafe to base any general conclusion upon it. If analyses of the red portion and of the dark portion of the rock were at hand for comparison, it is probable that the latter would be found to be much less rich in the alkalies than those specimens of the unaltered quartzites whose composition is given, and that the red portions would show a very high percentage of this constituent. A mixture of the two in the proper proportions would yield a rock with the composition of the feldspathic quartzites. The high percentage of potassium in the red portions would indicate that these contain constituents derived from without—from a source where a potassium feldspar is more abundant—a fact which may be regarded as sufficiently shown by the mineralogical composition of these portions of the mottled rocks, as revealed by the microscopic examination.

	XVIII.	H.
SiO_2	72·25	73·85
TiO_2	trace.	·05
Al_2O_3	10·73	10·91
Fe_2O_3	8·01	6·98
FeO	·38	·89
MnO	trace.	....
CaO	·42	·44
MgO	1·85	1·52
K_2O	2·56	1·39
Na_2O	2·03	2·28
H_2O	2·05	1·88
	100·28	100·19

The major portion of the slates spotted with little red crystals when viewed under the microscope, resembles the material of the altered slates It consists of small interlocking quartz grains, in and between which are little fibres and bundles of sericite and chlorite. These two minerals are of a light green color and are slightly pleochroic. When examined in natural light they are very near alike, but between crossed nicols they can readily be distinguished. The chlorite polarizes with its usual blue color, and the sericite in bright blue and scarlet or crimson tints of a high order. Irregular grains of brown rutile always accompany the chlorite. A small amount of red feldspar occurs in the interstices between some of the quartzes and as a globulitic mass surrounding the other constituents. A little ilmenite in grains is changed on the edges to brown rutile. A few brown biotite flakes, partly chloritized, complete the resemblance of the rock to altered slates.

The red crystals scattered through this mass sometimes consist of large areas of red feldspar polarizing together, and including small quantities of chlorite, quartz, grains of magnetite, and a very small quantity of sericite. The outlines of the areas are not well defined, but are rendered indistinct by projections of the same substance extending for short distances into the surrounding material. At other times the apparent crystals are composed of granophyric intergrowths of quartz and feldspar, with the outlines of feldspar crystals. As in the former case, the substance of the pseudo-crystals includes grains of quartz and fibers of chlorite and sericite.

The cause of the mottling of slates by crystals of red feldspar can best be learned by the study of an exposure in the little bay on the southern shore about a quarter of a mile from the end of the point. Here a mottled slate is in contact with a rock resembling the granular red rock. The description of this contact is given in the field notes in the following words:

The brick-red rock is most abundant below and under a darker altered slate, in which are patches of the same rock mottled with small red feldspar crystals. Both the red rock and the mottled slate weather in horizontal plates. Along the eastern shore of the bay the two rocks appear in very complicated relations. Each occurs as patches in the other, and each shows every possible gradation into the other.

At one place, however, a distinct line of contact is observed. On one side of this line is a platy bright red rock, like the granular red rock in structure, but differing slightly from it in containing more dark spots scattered throughout its mass. On the other side of the contact line the rock is a purplish slate, containing many very small crystals of red feldspar and small glistening scales of mica. Occasional patches of a darker color than the main mass are observed in the rock, and these have the appearance of altered slate. A study of this exposure alone would indicate that the darker rock has been impregnated with material from the red rock, and that some of this material had crystallized in the form of the crystals occurring so abundantly in the dark rock.

Viewed microscopically the red rock presents all the features of the granular red rock. It is composed essentially of red feldspar, occasionally in crystals, with a square cross-section, irregularly shaped quartz grains and a good deal of chlorite. Sometimes the red feldspar surrounds a core of fresh, clear plagioclase, with distinct twinning striations, and sometimes it is present with quartz in micropegmatite between the other constituents.

The purple rock on the other side of the contact has all the properties of the mottled slates. Brown grains of rutile are more abundant in it than in the above-mentioned rocks, and much chlorite is present as an alteration product of biotite. Large quantities of sericite are everywhere scattered throughout the thin section, and a few small crystals of apatite appear in the feldspar and chlorite. Very near the contact round and irregular areas of red feldspar represent the feldspar crystals seen in the hand specimen. These are very numerous close to the contact, and decrease in number as the distance from it increases. The analyses of specimens of the two rocks throw some light on the origin of the dark rock and aid somewhat in understanding the processes which have changed the indurated slates and sandstones into mottled rocks, which have lost all traces of their fragmental nature. XIX is the composition of the purple rock (No. 11228) as found by Mr. J. E. Whitfield; XX is the analysis of the red rock (No. 11227) made by the same chemist; H is the average composition of the unaltered quartzites, as given on pages 84 and 88; XVII is the analysis of a very slightly altered slate.

	XIX.	XX.	H.	XVII.
SiO_2	63·82	68·36	73·85	59·71
TiO_2	2·66	1·57	·05	Trace.
Al_2O_3	14·65	13·76	10·91	18·32
Fe_2O_3	3·16	2·65	6·98	8·11
FeO	5·12	2·75	·89	·85
MnO	....	Trace.	....	....
CaO	·70	·70	·44	1·05
MgO	2·08	·68	1·52	3·54
K_2O	2·81	4·48	1·39	3·43
Na_2O	1·95	3·56	2·28	1·93
SO_3	·33	·66	....	....
P_2O_5	·19	·33	....	....
H_2O	2·62	·98	1·88	3·24
Total	100·09	100·48	100·19	100·18

A comparison of the amounts of silica and magnesia present in the purple slate with the amounts of the same substances in the slate and quartzite, shows the former to be somewhat intermediate in composition between these two rocks. The large amounts of titanic oxide and ferrous iron in the former, and the presence of sulphuric and phosphoric acids, seem to show the effect of the presence of the red rock in its vicinity. The composition of the red rock differs from that of the typical red rock in the presence of a large amount of iron, and of a comparatively small quantity of silica, a result attributable to the solution of pieces of slate in the magma of this rock before its solidification. The reason that greater differences are not noticed is due to the fact that the slates and quartzites formed from the detritus of granitic rocks have very nearly the same composition as that of the red rock.

Among the rocks of this character are a few that in small chips are only with the greatest difficulty to be distinguished, on the one hand, from some specimens of the transition or intermediate rocks on the contact between the red rock and the olivine gabbro and, on the other hand, from certain of the altered slates. The mottlings are very coarse and their contours very ill defined. In the dark portions there is much more of the light-colored mica than in any of the rocks that have been described thus far. In the red portions the red feldspar is in large crystals, and with them are mingled blebs of quartz and various dark iron-bearing minerals. The crystals of feldspar reveal themselves by the reflection of light from large cleavage surfaces, many of them measuring 4^{mm} in cross section. The reflection is not always equally brilliant from all parts of one of these surfaces, since a single crystal sometimes includes within itself numerous little dark bodies, which the microscope shows to be chlorite. The green portions of the rock weather more readily than the red portions, leaving these standing out as globular masses from exposed surfaces. The bedding of the rocks is also difficult to detect, as they break with a very uneven fracture into rough plates, somewhat like the weathered plates of the granular red rock pictured on page 54.

Under the microscope the red portions of these rocks look so much like the granular red rock that it is impossible to conclude that they are anything but special phases of this, to which certain features have been added by the addition of small quantities of material from the slates that are represented in the darker portions of the same rocks. Large pieces of red feldspar with an indefinite crystal outline include bundles of fibers of sericitic mica, fan-like aggregates of fibrous chlorite, irregular grains of quartz, rods and grains of magnetite, an occasional flake of chloritized biotite, little brown grains of rutile surrounded by rims of magnetite or ilmenite, small flakes of kaolin and rarely a little calcite. Around its edges the feldspar contains so many of these inclusions, particularly chlorite, sericite, and quartz (which are the essential constituents of the groundmass of the rock), that it seems gradually to merge into the surrounding groundmass. The outlines of the feldspar crystals are indistinct in consequence of the inclusion of the minerals mentioned, or they are rendered very uneven through the addition to the nucleus of an outer rim of granophyre, which extends by little tongues into the body of the rock. The feldspar crystals with their zone of granophyre are imbedded in an irregular assemblage of quartz, feldspar, and all of the minerals mentioned above as existing as inclusions in the feldspar crystals. The quartz appears generally with irregular jagged outlines as if corroded. Sometimes it has the shape of a bipyramidal crystal and at other times it unites with a neighboring quartz by irregular sutures. The feldspar is not clearly crystalline, but has rather the appearance of a globulitic mass or a residual base, approaching in character the felsitic base of some quartz-porphyries. Between the different quartz grains, and indiscriminately throughout its mass, are the chlorite and sericite. The same minerals, together with a little biotite, magnetite, rutile, and an occasional crystal of zircon are found also in the feldspathic ground mass surrounding the quartz and crystals of feldspar. The biotite is in quite large flakes. It is partially chloritized, and around its edges is changed into sericite. It retains much of its original brown color and is weakly pleochroic in brown tints. Some of the magnetite is idiomorphic, but most of it is in irregular masses, surrounded by brown decomposition products, mixed with grains of leucoxene. The leucoxene is also occasionally in little octahedral grains, in which case it is evidently a pseudomorph after titaniferous magnetite. Nothing present in the sections examined points with clearness to the origin of the chlorite and sericite, but from the relative positions of these minerals and the feldspar, it is undoubtedly true that, in some instances, they have been derived from the latter mineral. In most cases they seem to be the result of the alteration of some other substance that has entirely disappeared and left no traces by which its true nature can be detected.

The darker portions of the rock are in nowise different from the darker portions of the other mottled quartzites.

From the microscopical appearance of the red portions of these rocks it can not be doubted that the material composing them is almost identical with the material composing the granular red rock. It is probable that the rocks were originally slates, and that these were penetrated by the red rock magma, which dissolved portions of the slates and then cooled, yielding a rock resembling the granular red rock in its most striking features, but possessing also distinctive characteristics, which are due to the substances added to the magma by solution. The portions of the slate which were not dissolved would, in this case, be altered like the slates on the contact with the red rock.

No analyses of these rocks are at hand for comparison with those of the slates that have been but slightly altered. The structure of the red mottlings, however, is such that no supposition other than that which has been outlined above will explain the appearances of the different minerals and their mutual arrangement.

THE RED QUARTZITES AND MOTTLED ROCKS IN THE INNER ZONE OF THE CONTACT BELT.

The quartzitic rocks in immediate contact with the gabbro, and in very many cases those immediately in contact with the red rock, are the coarsely mottled rocks described in the last section. In certain localities, more especially in the contact belt in the western portion of the point, there are certain rocks with peculiarities quite different from those of any rock of which descriptions have been given. These are found, when they occur, between the red rock and the coarsely mottled slates, and as inclusions in the former. They have a bright red color, very much like that of the granular red rock, but are easily distinguished from this by their compact texture, their cryptocrystalline structure, their vitreous luster, and the little elongated green spots scattered over their surfaces. Among these are some that have throughout the appearance described. Others contain irregular circular green spots, varying from a few millimeters to several decimeters in diameter, as illustrated on Pl. IV, p. 28. These spotted rocks are easily distinguishable from the spotted rocks in which the spots are the result of the alteration of calcite concretions, and are as clearly to be distinguished from the mottled rocks described in the last section of this chapter. They are easily recognized in hand specimens by the sharp contrast in color between the bright green of the spots and the bright red of the groundmass, by the distinctness of the outlines of the spots, and by the vitreous luster of both these and the groundmass. They are also characterized by their compact texture and the lack of macroscopic crystals of red feldspar. They are cut by a few dark veins containing much biotite, and their joint cracks are covered with druses of quartz crystals.

The microscopic appearance of these red and mottled rocks is as distinctive as their macroscopic appearance. The description of a few specimens taken from several widely separated exposures will serve as a description for the entire class.

On the eastern side of the little bay on the southern shore, about a quarter of a mile from the end of the point, Pl. XVI, and in the interior of the point a few hundred steps north of the water's edge, a large quantity of the granular red rock occurs.

To the west of the place where this comes out at the shore is a large ledge of moss-covered rock, extending back into the woods. It is composed of a rock with a gray or pink, fine-grained base, curiously speckled with black elongated spots. The rock has a glazed appearance as if full of infiltrated quartz. Below, the ledge grades into a fine-grained red rock, generally more or less porous or drusy and closely resembling some of Rosenbusch's Vogensen granophyres. This contains patches of a darker colored rock, but is otherwise quite uniform in character. It forms the lower portion of the high cliffs rising abruptly around this bay and shows a decided tendency to part into horizontal plates [the typical granular red rock].[1]

The vitreous rock is discovered in thin section to be composed of thickly crowded quartz grains or crystals, more or less perfectly bounded by crystallographic planes, in a globulitic red feldspathic groundmass, which appears to have forced its way into many of the quartzes and now occurs as embayments in them. In many cases the quartz has the outlines of bipyramidal crystals; even when corroded its general outline is that of a porphyritic crystal of quartz, and the extinction is always in accordance with this form. Fig. 13 represents some of these, as observed in several different sections. The quartz is always clear and colorless, and it contains no inclosures except lines of fluid cavities, which sometimes run uninterruptedly from one individual over into and through another.

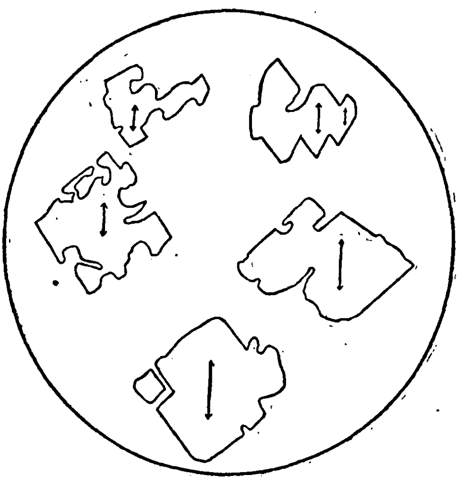


FIG. 13.—Corroded quartz crystals in red quartzite on contact with granular red rock.

The feldspathic base in which these quartzes lie fills the interstices: sometimes as mere threads between neighboring quartzes; sometimes in larger masses, when it possesses traces of twinning striations; sometimes as granophyric intergrowths with quartz in the angles between larger grains of this mineral; and frequently as embayments within the border of the eroded quartz grains; but it is never found in crystals, as in the red rock. In all cases the feldspar is much decomposed and reddened, and it always incloses all of the other constituents.

[1] From the field notes.

Rosettes of chlorite occupy some of the angles between the quartz, and occasionally large chloritized pieces of biotite inclose many grains of this mineral. An infrequent grain of magnetite, brown masses of rutile in the chlorite, numerous crystals of what is taken to be zircon, and a few crystals of apatite complete the list of components forming the matrix of the rock.

The little elongated spots scattered through this matrix are masses of chlorite, composed of green fibers well crystallized or of brown earthy amorphous material in which traces of a chloritic nature can frequently be detected. In both cases the chlorite appears to have resulted from the alteration of biotite, which, like the chloritized biotite in the other portions of the rock mass, inclosed many different grains of quartz during its crystallization.

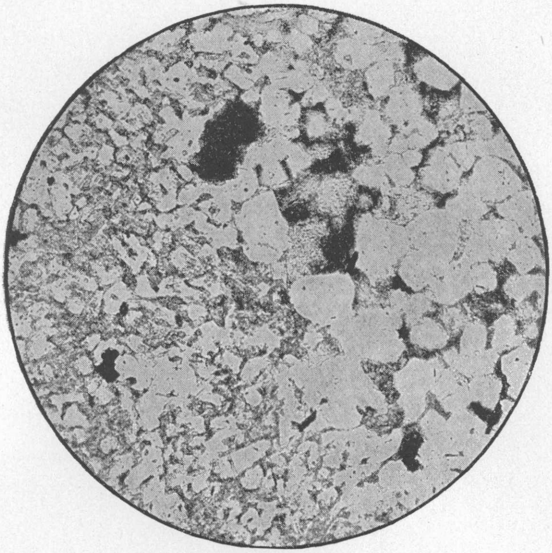
In the mottled rocks, spotted with large green spots the constituents are the same as those in the red quartzites, with the addition of sericite. The red groundmass of these rocks is composed of a globulitic red feldspar surrounding grains of limpid quartz, in which are numerous liquid inclusions bounded by the planes of negative crystals. The quartz, as before, is often bounded by crystal planes, and, when corroded, is often penetrated by embayments of the matrix. The sericite occurs as little slender needles cutting through the feldspathic groundmass. The other constituents present the same features as are observed in the red quartzites described above.

The green mottlings are composed almost entirely of quartz and sericite. The quartz is in large interlacing grains, between which no lines of demarkation can be detected in natural light, so limpid and uniform in character are the different pieces. Between crossed nicols this almost uniformly appearing field breaks up into a number of different areas which interlock with each other by very irregular sutures. In a single instance (No. 11317) one of the quartz grains retained a trace of its enlargement.

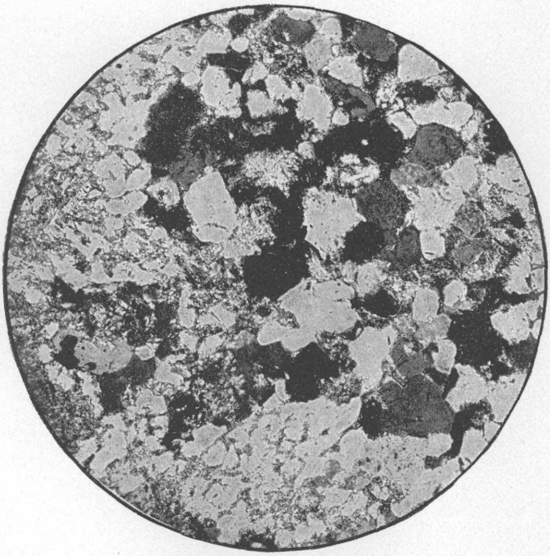
The sericite is present in large quantity. It occurs as fan-shaped radial groups of very light green fibers, between some of the quartz grains, and also as inclusions penetrating these in every direction in such a manner that a single large grain of quartz appears as if made up of many smaller ones. In polarized light, however, several of the small areas are found to extinguish together, so that they may be regarded as parts of a single grain. The light green fibers of sericite are very slightly pleochroic, being light green when their long axes are parallel to the vibration plane of the nicol, and almost colorless in other positions. They are insoluble in acids, and may thus be distinguished from chlorite, which they much resemble in ordinary light. Between crossed nicols they polarize in bright blue, yellow and crimson tints of a high order, and extinguish parallel to the long axes of the fibers. A silvery luster is also pronounced in every group of fibers examined, and other properties of sericite were recognized. It was impossible to de-

EXPLANATION OF PLATE XIII.

XIII. a and b. Thin section of mottled red quartzite (No. 11323) from the inner contact zone. The left half of the figure shows part of one of the green spots. In this are interlocking quartz grains cut by spicules and flakes of sericite. In natural light the structure of the spot appears to be granophyric, but in polarized light the quartz is seen to be an aggregate of grains. There is no interstitial substance between the grains, except in some places a very thin seam of feldspathic material. The structure of the red groundmass in which the spots lie is shown on the right of the figure. Here there is much more interstitial substance than in the spot, and the quartzes have quite a well-defined porphyritic outline. The interstitial material in both the spot and the groundmass is almost entirely feldspar. Now and then a flake of chlorite or a grain of magnetite is present, but these are rare. Magnified 80 diameters. a is in natural light, and b in polarized light.



a. MOTTLED RED QUARTZITE, POLARIZED LIGHT.



b. MOTTLED RED QUARTZITE, NATURAL LIGHT.

termine the position of the optical axes in any single instance, and attempts to separate the mineral for analysis failed. From the chemical composition of the mottlings, however, it is believed that there can be no doubt of the true nature of the mineral. It is often intergrown with chlorite, when existing between the grains of quartz, and often forms intergrowths with the latter mineral, resembling the intergrowths of quartz and feldspar known as granophyre.

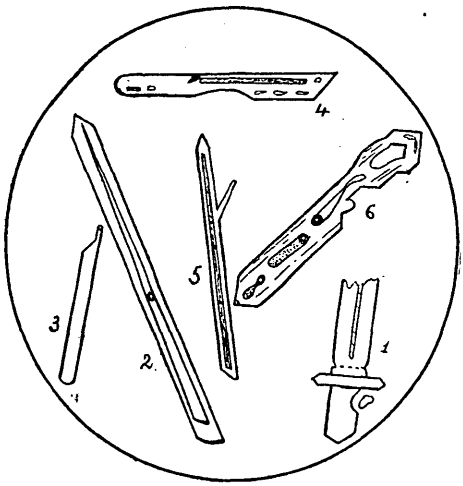


FIG. 14.—Characteristic forms of zircon crystals occurring in the mottled rocks.

Zircon crystals are even more common in the mottlings than they are in the body of the rock. They possess a long acicular form, sometimes doubly terminated, sometimes with a single termination. They extinguish parallel to their long axes, have a rhombic cross-section, a very high index of refraction, show brilliant interference colors in polarized light, sometimes show traces of zonal growth, and nearly always contain inclusions with immovable bubbles. A few characteristic forms are shown in Fig. 14. Most of these were observed in the spots and the groundmass of the mottled rocks, although similar forms were also found in the unmottled red quartzites. Fig. 15 represents a crystal extending through one quartz grain and projecting at both ends into two others. The figures of Pl. XIII illustrate the appearance of groundmass and mottling in one of these mottled quartzites (No. 11323).

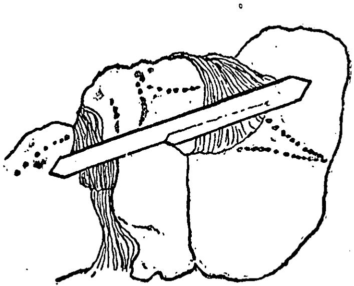


FIG. 15.—Zircon crystal extending through portions of three quartz grains.

As the mottled quartzites weather they become nodular. The red portion between the mottlings weathers more quickly than the green material of the mottlings, so that the latter are left as elevations on a depressed surface. The final result of the weathering is a mass of round marble-like bodies in a loose sandy matrix, which falls apart when disturbed, leaving the more durable mottlings as a pile of little spheres. A cross-section of one of the spheres, examined under the microscope, presents the characteristic appearance of the green mottlings in the fresh mottled red quartzite. The sericite is not quite so prominent a feature in the weathered rock as it is in the fresh one, but the quartz has all of the same peculiarities.

In discussing the origin of these rocks it is important to recall the principal features of their structure, viz, the porphyritic appearance of the quartz grains in the red groundmass, the globulitic character of the feldspar, the long acicular crystals of zircon, extending sometimes from one grain of quartz over another, and the irregular dissemination of the sericite throughout all of the quartz of the spots.

The corrosion of the quartz grains and the embayments of feldspathic substances in them would seem to indicate that the matrix of the rock had once existed as a molten magma that had eaten into the quartz crystals that lay immersed in it. The existence of sericite fibers in the quartz and the presence of well formed zircon crystals running from one quartz grain into another prove that the original material of the fragmental rocks entirely recrystallized during the process which resulted in the formation of the new rocks. This recrystallization may have taken place either through the aid of material derived from the red rock or through the influence of solutions emanating from it.

The origin of the green mottlings is difficult to determine. The quartz of these, like the quartz of the red groundmass, is sometimes in apparent porphyritic crystals, with an extinction parallel to the long axes of their vertical sections. More frequently, however, it is in grains united by irregular sutures, very like the quartz in some of the less altered rocks. In all the quartz, whether it be porphyritic or corroded, sericite is abundant, and is so arranged that its position can be ascribed only to an original crystallization. It seems necessary, in order to account for the structure of these mottlings, to assume that their material has crystallized in situ. The existence of an enlargement on one of the quartz grains referred to above would, however, seem to oppose the notion that this crystallization took place from a molten magma. It appears more probable that the crystallization of the material now forming the mottlings was in consequence of the continuation of a process like that which gave rise to the rocks in the outer contact zone. As the result of the solvent action of heated water under pressure, in most cases the outer envelopes, and in many cases the entire nuclei of the quartz grains were dissolved and the quartz substance was again deposited. In the redeposition, however, sericite separated contemporaneously with the quartz, and was included within the crystals of this substance as they grew. In this case we would expect to find the quartz possessing the appearance of the mineral when in the form of the well-known secondary quartz. And this, indeed, we do find, as reference to the figure illustrating the structure of one of these mottlings (Pl. XIII, Figs. 1 and 2) will show. The individual quartzes interlock with each other in the most intricate fashion, the sinuosities resembling the outlines of aggregated blebs of this mineral, which have been secondarily developed by the decomposition of silicates. It is possible, then, that the red groundmass of these rocks has recrystallized with the addition of feldspathic substance from the red rock, while the green mottlings are the recrystallized residues of the original quartzites that have not been penetrated by the red magma.

Analyses of the mottlings and of the red groundmass of one of these rocks show that they differ but slightly in composition, and that the red groundmass contains a little more of the constituents of the red rock than does the material of the mottlings. Neither differs materially from unaltered quartzites, except in the proportion of ferrous and ferric iron, of lime, and of soda present. The greater amount of alumina in the red groundmass as compared with that in the mottling, and the increase in the amounts of lime and soda may be attributed to the absorption of the red-rock magna by the quartzite, and it is in all probability due to this addition of extraneous substance that the peculiar structure of this groundmass is found. The portions of the rock represented by the mottlings were not so thoroughly saturated with this substance, and consequently upon their recrystallization they have yielded different minerals.

The figures in column XXI were obtained by Mr. W. F. Hillebrand from the red groundmass of the rock represented in Pl. IV (p. 28), and those in column XXII by the same gentleman from the green mottlings of the same rock (No. 11317).

	XXI.	XXII.
SiO_2	76·57	77·70
TiO_2	·42	·30
Al_2O_3	9·21	7·67
Fe_2O_3	1·67	3·55
FeO	3·94	3·29
MnO	·05	·04
CaO	·73	·26
SrO	Trace.	(?)
MgO	1·51	1·83
K_2O	1·02	1·04
Na_2O	3·07	1·96
Li_2O	Trace.	Trace.
H_2O	1·89	2·36
P_2O_5	Trace.	....
	100·08	10·000

The composition of the mottlings, as indicated by the above analysis, seems to be a little unusual, when it is remembered that the principal components of this portion of the rock are quartz and sericite. The rock from which the material for the analyses was obtained is the most coarsely mottled one that was at hand at the time when the analyses were made. On the second visit to the point, however, a much more coarsely mottled variety was collected. This was crushed, and from the broken pieces enough of the green material was selected for another analysis. To prevent the possibility of the admixture of portions of the red ground mass with the green material, the pieces of the latter were broken into still smaller fragments, and from these the most homogeneous looking were picked. An analysis of these was made by Mr. L. G. Eakins. His results are given in column XXIII.

	XXIII.	XXIV.
SiO_2	83·27	83·69
TiO_2	trace.	trace.
Al_2O_3	7·81	7·50
Fe_2O_3	1·99	1·81
FeO	1·81	·38
MnO	....	trace.
CaO	·20	·39
MgO	1·59	·35
K_2O	1·11	2·61
Na_2O	·19	2·46
H_2O	2·32	·72
Total	100·29	99·91

A study of the figures here given indicates the correctness of the hypothesis outlined above. It will be noticed that the mottling contains, in addition to the quartz, but a little alumina, iron, magnesia, potash, and water. The small amount of chlorite present in the mottling would account for some of the alumina, iron, magnesia, and water, leaving the potash and the remainder of the iron and alumina, and possibly some of the water to be accounted for by the brightly polarizing green mica. As these are the constituents composing sericite, and since the properties of the green mica are not unlike those of this mineral, there can be little doubt that the light green fibers in the mottlings, and in certain portions of the other mottled rocks are fibers of sericite. If, further, the composition of these mottlings be compared with the composition XXIV of one of the most brilliantly red vitreous quartzites (No. 11425) obtained from an inclusion in the contact belt in the western portion of the point, it will be found that the two rocks differ principally in the percentages of the constituents of the red rock that are present in them. The amounts of silica and alumina in each are about the same, but the amounts of potash and soda in the two are quite different. The last two substances are the most characteristic components of the red rock, and they are present in the altered red quartzite in nearly the same relative proportions as those in which they exist in the red rock. If the mottlings represent very nearly the constitution of the quartzite when unaffected by the addition of foreign material, the red quartzite undoubtedly represents a mingling of the quartzite with the rich feldspathic magma of the red rock.

THE INCLUSIONS IN THE GABBRO AND THE RED ROCK.

The effect of the gabbro and of the red rock upon the quartzites and slates can be studied directly in the inclusions. These, as has been stated, are slates and quartzites in the red rock, and quartzites and quartz pebbles in the gabbro.

The inclusions in the red rock present all the features of the contact rocks in one or the other of the three contact zones. Altered slate fragments consist of quartz, feldspar, chlorite, and sericite, with a little magnetite and rutile. Around these are zones of spotted slates, where the spots are little crystals of feldspar, including within themselves all the constituents of the slates. Sometimes these crystals are composed principally of granophyre substance, and sometimes they are more compact and possess occasional traces of twinning striations. The red rock surrounding the inclusions is very like the red rock near the contact with slates.

The quartzite pieces in the red rock have undergone the same changes that have been undergone by the quartzites on the contact with the red rock. Certain of them are reddened and mottled, others are spotted like the spotted red quartzites, while still others seem to be but very slightly altered. As the slates and quartzites which are now found as inclusions were probably once like the corresponding rocks outside of the contact belt, it is natural to regard the changes that have been induced in them as due to the action of the rock in which they are imbedded. This rock, to judge from its general nature, must once have existed as a plastic mass under great pressure. When in this condition it was intruded into the quartzites and slates, penetrating them as veins and dikes, and breaking from them fragments which it afterwards dissolved. Under the influence of heat and pressure those portions of the fragments that resisted solution longest were permeated by the material of the red rock; they became softened and thus subject to the rearrangement of the chemical molecules in such a manner as to yield stable compounds, and in this way may have resulted the mottled slates and the red quartzites with their sericitic and chloritic ingredients. Other portions of the fragments were, perhaps, not impregnated with the material of the red rock, but were saturated with solutions emanating from the surrounding rock. These portions would have crystallized without the addition of new substances, and may have given rise to the fragments resembling the altered slates and mottled quartzites.

The red quartzitic inclusions spotted with circular green areas are so thoroughly intermingled with the material of the rock in which they are imbedded that no definite conclusion as to the origin of the spots can be reached. The red portion of these inclusions, like the substance of the red quartzites, appears to be a mixture of the quartzite and the red rock. If so, the mottlings may represent the portions of the original fragment which escaped solution, but in which certain changes, amounting in most cases to an entire recrystallization, were effected. If the supposed enlargement of a quartz grain, observed in the mottling of one of these rocks, is really such, then at least a portion of the original quartzite has in one case entirely escaped change. The zircon crystals in other portions of the mottling and the bunches of sericite scattered through the quartz are, however, abundant proof that in the greater part of the mottling as well as in the groundmass of the rock a complete rearrangement of the constituents has taken place.

Inclusions in the olivine gabbro have been subjected to changes a little different in character from those that have taken place in the fragments imbedded in the red rock. The fragments of slate in the former differ from those in the latter in the development of small plates of biotite throughout their mass, but more particularly on their edges. The quartzites present much the same features as the slightly mottled quartzites in the red rock, but the phases representing the final stages of alteration in the latter case are absent. In their place are certain rocks differing from the mottled rocks in the possession of a great deal of brown mica, which crystallized between and around the quartz grains, including many of them in a single one of its flakes. Around the edges of these fragments are also developed little, brightly polarizing, almost colorless grains of augite.

The first stages in the alteration of the quartzite fragments by the gabbro are similar in most respects to the corresponding stages in the alteration of the same rocks by the red rock. The natural conclusion from these facts would be that in both cases the same processes had acted to produce the same effects. From rocks as different in chemical composition as the olivine-gabbro and the red rock, solutions may have emanated which contained only traces of the constituents of the rocks. By the action of these solutions upon the material of the quartzites the same results would be produced. In the third stage, however, where material from the including rock was intermingled with that of the quartzite, a different product would be expected, and a different product has been found.

The effect of the solution of fragments of quartzite and slate on the two inclosing rocks has also given rise to new products, which, however, are as different as the two inclosing rocks themselves. The solution of slate fragments in the red rock has resulted in the formation of a dark, granular, crystalline rock, in which sericite and chlorite have been developed, but which otherwise is not unlike the typical red rock. Quartzite fragments upon dissolving added nothing new to the red rock, as the chemical composition of both is nearly the same.

The olivine-gabbro is quite different from the fragmental rocks, both in the constituents contained in it and in the proportions of those which are common to both. The solution of slate and quartzite fragments in this, therefore, changed the composition of the magma in the vicinity of the dissolved fragments, and a product resulted upon cooling that is different in composition and structure from either one of the two rocks by whose intermingling it resulted, but is not so different from the rock on the contact of the gabbro and the red rock.

Several thin sections across the contact between the gabbro and a quartzite inclusion reveal interesting relations existing between the two rocks. The quartzite is altered in a manner corresponding to that characteristic of other quartzite inclusions. The same new minerals are found in it, and in addition it contains flakes of biotite. The gabbro has suffered changes that are undoubtedly due to the solution of a portion of the inclusion. Quartz occurs in it in irregular and club-shaped masses. Olivine and augite have been changed to uralite, and a large quantity of strongly pleochroic brown biotite has been developed. The characteristic features of this product are not very different from those on the contact of the red porphyritic rock and the gabbro, at the foot of the quartz-porphyry bluff, west of the Little Portage. The red rock at this place includes pieces broken from the gabbro. It contains flakes of brown biotite and a few grains of colorless augite. In the included gabbro a great deal of strongly pleochroic brown biotite has been developed, as has also uralite and quartz. Many of the specimens which have been described as altered gabbros possess the same characteristic minerals. Therefore it is but natural to assume that these owe their origin in most cases to the effect of the material of the red rock upon that of the gabbro. Since the composition of the red rock is practically the same as that of the feldspathic quartzite, the results of the mingling of their material with the magma of the gabbro should in both cases be the same. Around the quartzite inclusion, between it and the gabbro is a rim in which there is a great deal of red feldspar. This is in rudely outlined crystals, in granophyric intergrowths with quartz, and in micropegmatite. With it is more or less quartz in club-shaped masses, and a great deal of pale hornblende and chlorite that has been derived from biotite. Magnetite and ilmenite, in grains and long rods, a little leucoxene, and a few crystals of apatite are the only other constituents found.

The mineralogical composition of the material forming the rim and its structure are both like the corresponding features of the lighter colored of the intermediate rocks on the contact of the gabbro and the red rock. It has been shown that the intermediate rock was produced by the intermixture of the magmas of the red rock and the gabbro. It has also been repeatedly stated that the quartzites differ from the red rock but slightly in composition. It is therefore to be expected that the result of the fusion of quartzite inclusions by the gabbro would be the same as that produced by the fusion of the gabbro and the red rock.

In other cases the same kind of a rim surrounds what appear to be pebbles of white quartz. These apparent pebbles are corroded and are fringed with a bright red border, in which the microscope detects numerous small colorless grains and crystals of augite. In addition to the augite are the usual constituents of the red rock or of the lighter colored of the intermediate rocks.

In certain areas the rock cementing fragments of slate and quartzite is not the gabbro proper, but is rather like that phase of the intermediate rock in which the arborescent groups of hornblende occur. This cementing material may be due either to the solution of some of the fragments in the gabbro, or it may have had the same origin as the intermediate rocks on the contact of the gabbro and the red rock. In either case it afterwards acted as an eruptive, breaking off pieces from the fragmental rocks and altering them in the same manner as did the gabbro and the red rock.

The most striking feature in connection with the quartzite inclusions in this rock is the existence of a red rim around the inclusion, between this and the inclosing rock. Under the microscope the substance of this rim has very much the same appearance as the granular red rock. It consists of red feldspar and quartz, much micropegmatite, and a very little chlorite. The sharp contrast in color and structure between this material and that of the surrounding rock, and its well defined position as a fringe around the quartzite fragment seem to prove its origin to have been due to the fusion of the exterior portion of the inclusion.

COMPARISON WITH OTHER CONTACT ROCKS.

It has already been stated incidentally that the contact phenomena just described differ in many respects from those which have been observed at other places. In the usual case of the alteration of sedimentary by intrusive (plutonic) rocks, the latter appear to have acted through their mass and not through their material, for, with the exception of the loss of organic matter and water and the addition of volatile substances like boric acid, the sedimentary rocks retain the same composition after alteration as they possessed prior to it.[1] The rock resulting from their alteration differs according to the nature of the sedimentaries, and is independent of that of the metamorphosing agent, whether this be an acid granite or a basic gabbro. The character of the changes which take place in the fragmental beds is too well known to need description in this place. Prof. Rosenbusch has given an excellent review of the literature of the subject in his "Mikroskopische Physiographie der massigen Gesteine," and since the publication of this book a few other petrographers[2] have reviewed the work in special phases of the subject.

The changes that have taken place in the Pigeon point rocks are attended in some instances by changes in chemical composition, although the larger portion of the contact rocks differ but very slightly in composition from the original quartzites. In the latter case the change is analogous to the alteration effected in sedimentary rocks by intrusives. In the former case there has been an impregnation of the quartzites by the material of the red rock. Alteration of the latter kind has been noted in recent years in one or two localities where sandstone and gneisses are in contact with granite and gabbro. Barrois[3] describes an instance

[1] Cf. Rosenbusch: Mikroskopische Physiographie, 1887, vol. II, p. 44.
[2] Cf. C. Greim: Neues Jahrb. f. Miner., etc., 1888, I, p. 1.
[3] Ann. Soc. Geol. du Nord, 1884, vol. 11, p. 103, and vol. 12, p. 1.

of the alteration of Lower Silurian sandstone by granite at Guéméné, Morbihan, and Rostrenen, Côtes-du-Nord, France. This contact differs from those to which allusion has been made above, in the fact that the sandstones have been impregnated by the material of the granite, and have thus had new minerals developed in them. At the same time a recrystallization of the quartz has taken place whereby the grains of this mineral have assumed a round or hexagonal form and have included within themselves small flakes of biotite. The changes which have been effected here are due to the intrusion of small veins of granite into the spaces between the grains of the sandstone. Barrois was able to trace these veins, as they break up into smaller and smaller veins until they finally become too small to be observed with the microscope. Nothing analogous to this has been observed in the Pigeon point rocks. Veins of the red rock penetrate the quartzites and slates, but they can not be followed into smaller and smaller veins. Moreover, the changes which have taken place in these rocks differ materially from those which have been observed in the French sandstones. In the latter biotite, sillimanite, cordierite and more or less muscovite in large plates have been developed, while in the Pigeon point rocks the only new minerals observed are sericite and chlorite in sheaf-like bundles. Moreover, there is nothing in the French rocks which resembles in the least the mottlings in the Minnesota quartzites. The only similarity between the two occurrences is in the crystallization of the quartz grains. Barrois, who has examined thin sections of some of the Pigeon point rocks, observes in a letter to the writer that the characteristics of the Minnesota contact rocks are entirely different from those of the French rocks, and suggests that the differences may be due to the differences in the composition of the rocks effecting the metamorphism. Very recently Lacroix[1] has discovered the same kind of action at a granite contact in the Loire Inférieure, France, and a result which is ascribed to a similar cause at Pierrepont, N. Y. In these cases the surrounding rocks are pyroxene-scapolite-gneisses into which the granite has penetrated. Lévy[2] and Lehmann[3] had already described the impregnation of gneisses by granite in the years 1879 and 1884, respectively. Lacroix[4] further mentions the injection of gabbro into the gneiss of Pallet, Loire Inférieure, and the formation of a contact rock differing from the two rocks by whose combination it resulted.

A third class of contact phenomena, differing essentially from those above mentioned, has been observed on the contact of quartzites with basalt and other effusive rocks. Here the interstitial substance of the quartzite (or sandstone) has been so changed as to produce a glass, in which as a matrix, are scattered various porphyritic crystals and devitrification products. This glassy interstitial substance, according to Zir-

[1] Bull. Soc. France d. Miner. 1889, vol. 12, pp. 117 and 275.
[2] Bull. Soc. Geol. d. Fr. 1879, vol. 7, p. 861.
[3] Untersuchung über die Entstehung der altkrystallinischen Schiefer-gesteine, etc. Bonn, 1884.
[4] Loc. cit., p. 247.

kel,[1] Hussak [2] and Stecher,[3] is due to the fusion of certain portions of the altered rocks without the addition of basalt material. Very close to the contact, however, some of the eruptive material is found to have penetrated a short distance into the quartzite and tc have left its impress in the numerous microlites of augite and grains of magnetite that occur here.[4] This accumulation of augite and magnetite on the borders of the quartzite is an indication that the latter rock acted as a filter,[5] allowing some of the material of the basalt to enter it and arresting the balance at the threshold. Pieces of quartzite and sandstone that occur as inclusions in the basalt are frequently surrounded by a rim of augite that has been developed by interaction of the basalt magma upon the material of the inclusion.[6]

As the contact on Pigeon point resembles in some respects that of intrusive rocks, so does it also resemble in some other respects the contact between quartzites and effusives. The development of augite around the edges of inclusions has been referred to as characteristic of quartz pebbles and quartzite fragments in the gabbro. The filtering action observed in the basalt contacts has also its analogue in the Pigeon point contact. In this place the rocks nearest the red rock have become impregnated with red feldspathic substance, while those in the next outer zone have obtained almost nothing from the metamorphosing agent.

This contact then possesses some of the characteristics of the contacts between quartzites and flow-rocks, and some of those of contacts between sedimentaries and plutonic rocks. It resembles most closely the contact described by Barrois, in which are comprehended the characteristics of both classes of contact phenomena. The Pigeon point contact differs from Barrois's contact in the smaller amount of new minerals developed, and in the character of these.

Further, if the red rock is a product of the contact action between the gabbro and the quartzites, then the Pigeon point occurrence represents the first instance of the formation of a massive crystalline rock from a fragmental rock through *contact* metamorphism.

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[1] Neues Jahrb. für Min., etc. 1872, pp. 7-12.

[2] Tschermaks mineral und petrog. Mittheil, 1883, vol. 5, p. 530.

[3] Ibid., 1887, vol. IX. pp. 159, 160.

[4] Zirkel: Petrographie, II, p. 577.

[5] Stecher: op. cit., p. 159.

[6] Möhl: Neues Jahrb. für Miner., etc., 1874, p. 799. Trippe: Zeitschr. d. deutsch. geol. Geselsch., 1878, p. 155. v. Chrustschoff: Bull. Soc. Min. d. Fr., 1885, vol. VIII, p. 62, and Tschermaks Mineral u. petrog. Mittheil., 1882, vol. IV, p. 485.

CHAPTER VIII.

ORIGIN OF THE RED ROCK.

From a perusal of the preceding pages it is evident that the relations of the gabbro and the red rock to each other and to the members of the contact belt are so complicated that it can not be determined positively whether the gabbro is the cause of the contact phenomena and the red rock a product of its action, or the latter an original irruptive and the agent producing the metamorphism. Isolated facts bearing upon the solution of the question have been referred to in the chapters on the red rock and the contact belt, and arguments to be drawn from them have been stated in brief. In the present chapter are collected statements of all the facts which may serve to throw any light upon the origin of the red rock, and a discussion of their bearing is given at some length.

At first glance it would appear that the evidence is strongly in favor of the red rock as the active agent producing the contact phenomena. It is found in largest quantity where the contact belt is widest, and is absent from those places in which there are no indications of a metamorphic action in the slates and quartzites. When present it sends out apophyses into the gabbro on the one side of it, and into the outer members of the contact belt on the other side. It is almost identical in chemical and mineralogical composition with some of Irving's[1] augite-syenites, of which the rock on Little Brick island is a typical example. Its structure is holocrystalline like that of an undoubted irruptive, or is porphyritic like that of an eruptive rock. It resembles undoubted eruptives like the quartz-porphyries of Irving[2] or the granophyres of Rosenbusch.[3]

Moreover, the gaboro has produced no very great alteration in the surrounding sedimentary beds in those localities where no traces of the occurrence of the red rock can be found. It has not affected the bedded rocks on the north shore of Pigeon point with the possible exception of a single instance, in which slight alteration in quartzite is accompanied by a small dike of the red rock, nor are immense dikes of similar rock known to have produced any change in the Animikie slates and quartzites at other points along the north shore of Lake Superior.

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[1] Copper-Bearing Rocks, pp. 112–125.

[2] Loc. cit., pp. 95-111.

[3] Die Steiger-Schiefer und ihre Contact Zone an den Granititen von Barr-Andlau und Hohwald 1877.

If, however, we examine these facts critically, it will be found that none of them exclude the possibility of a secondary origin for the red rock or of the active agency of the gabbro in promoting the metamorphism of the clastic beds.

The existence of the red rock in veins in the gabbro and in dikes and veins in the contiguous slates and quartzites proves merely that it once existed in a plastic condition, and not even necessarily in a molten state, since the material of a very well-marked bright red dike has been discovered under the microscope to consist of clastic material which has undergone quite a great deal of alteration, but in which the clastic structure can still be detected. The structure of the main mass of red rock, however, indicates that it did once exist as a molten magma or in such other condition as would allow of its complete crystallization, unless we assume, with Wadsworth[1] and Judd,[2] that the porphyritic and granophyric structures may arise from secondary causes. However, the nature of the alteration which has been effected in the contact rocks immediately beyond the red rock—their impregnation by the material of this—is further evidence that the red rock was once in a liquid state.

If, then, we assume the original molten or liquid condition of the red rock all of its present characteristics are explained, whether its origin be regarded as igneous or whether it be considered as a final product of contact action. In either case its most characteristic features would be those of a plutonic rock, since the conditions under which it solidified are those which give rise to the distinctive features of plutonic rocks. The porphyritic structure noted in a few places must be due to local conditions that prevailed only at a few localities. Under this assumption are explained the intrusion of the red rock into the slates, the crumpling of the latter, and the alterations effected in those near the sides of dikes of the former.

The microscopical and macroscopical structure of the rock and its geological features, then, have no bearing upon the source of the material of which it is composed, other than to show the conditions prevalent at the time of the rock's solidification. The similarity in chemical composition between the Pigeon point red rock and the rock on Little Brick island and its similarity in mineral composition with undoubted flow rocks in various portions of the Lake Superior region, are likewise of no value in deciding as to the source of its material; for it is a well-known fact that rocks of the same composition may have originated in very different ways. For instance, rocks as different in structure

[1] Geol. and Nat. Hist. Survey of Minn., Bull. No. 2, pp. 12 and 68.

[2] Quart. Jour. Geol. Soc., London, May, 1889, pp. 175, 178.

and origin as granite, gneiss, and liparite are shown by Roth[1] to be almost identical in composition. The question of the origin of the rock under consideration must therefore be decided upon field evidence rather than upon the evidence obtained by means of the microscope.

In a former paper[2] on the origin of the red rock, it was stated that the field relations seemed to point to an independent origin for it, and that "a more careful examination of the structure of the point would probably reveal facts which would place beyond doubt the conclusion reached by the microscopical examination (viz, that the red rock is an independent eruptive). Since the article in question was written another visit to the point has been made, but contrary to expectation the study of the relations of the rocks tends rather to the conclusion that the red rock is a product of contact action.

The distribution of the red rock, its occurrence only between the gabbro and the altered quartzites, is the strongest argument in favor of its secondary origin. A glance at the map (Pls. XIV, XV, and XVI) will show that the red rock occurs only at those places where the gabbro and the members of the contact belt in the quartzite approach each other. At no other places is it found, except in the form of dikes, which are directly connected with the larger masses of the rock. It will also be noticed that the gabbro and the altered quartzites are sometimes in direct contact without the presence near them of any of the red rock.

The existence of the rock between the gabbro and the members of the contact belt only indicates a close relationship between the three rocks. If it could be shown that the contact rocks of the quartzite owe their origin to the existence of gabbro near them, it would follow as a most natural probability that the red rock is likewise of contact origin. Whenever it is present, there is on its one side the gabbro, and on the other side are two or more members of the quartzite contact belt. Its position is that of a member of the contact belt. It follows the sinuosities of the gabbro, as no irruptive rock would be likely to do, and is wider or narrower, according as the contact belt in the quartzite beyond it exhibits contact phenomena in greater or less degree. Where this contact action has been most intense there is found the greatest amount of red rock; where the action has been less, the amount of the red rock

[1] Chemische und allgemeine Geologie, Bd. II, pp. 66-67:

	SiO_2.	Al_2O_3.	Fe_2O_3.	(Fe. Mn)O.	MgO.	CaO.	Na_2O.	K_2O.
a....	75.06	11.70	1.04	1.57	.19	1.01	2.56	6.25
b....	75.90	12.95	....	1.31	.16	1.48	2.39	5.12
c....	75.65	11.52	2.37	....	Trace.	.76	2.91	5.93

a. Granite, from Pyterlaks, Finland.
b. Gneiss, from Crodo, Antigoriothal, Piedmont.
c. Liparite, from Hot Springs Hill, Nevada.

[2] Am. Jour. Sci., vol. 37, 1889, p. 57.

decreases until finally none is present. All this is also what would be expected if the red rock were regarded as an independent irruptive and the cause of the alteration of the quartzite. However, when the red rock is wholly absent contact action is yet often marked. One, or even more, of the contact zones may be present, but that which indicates the most intense action, viz, the zone of the spotted red quartzites, has disappeared. It is, then, plain that the red rock as an independent irruptive is inadequate to explain the whole of the quartzite contact belt.

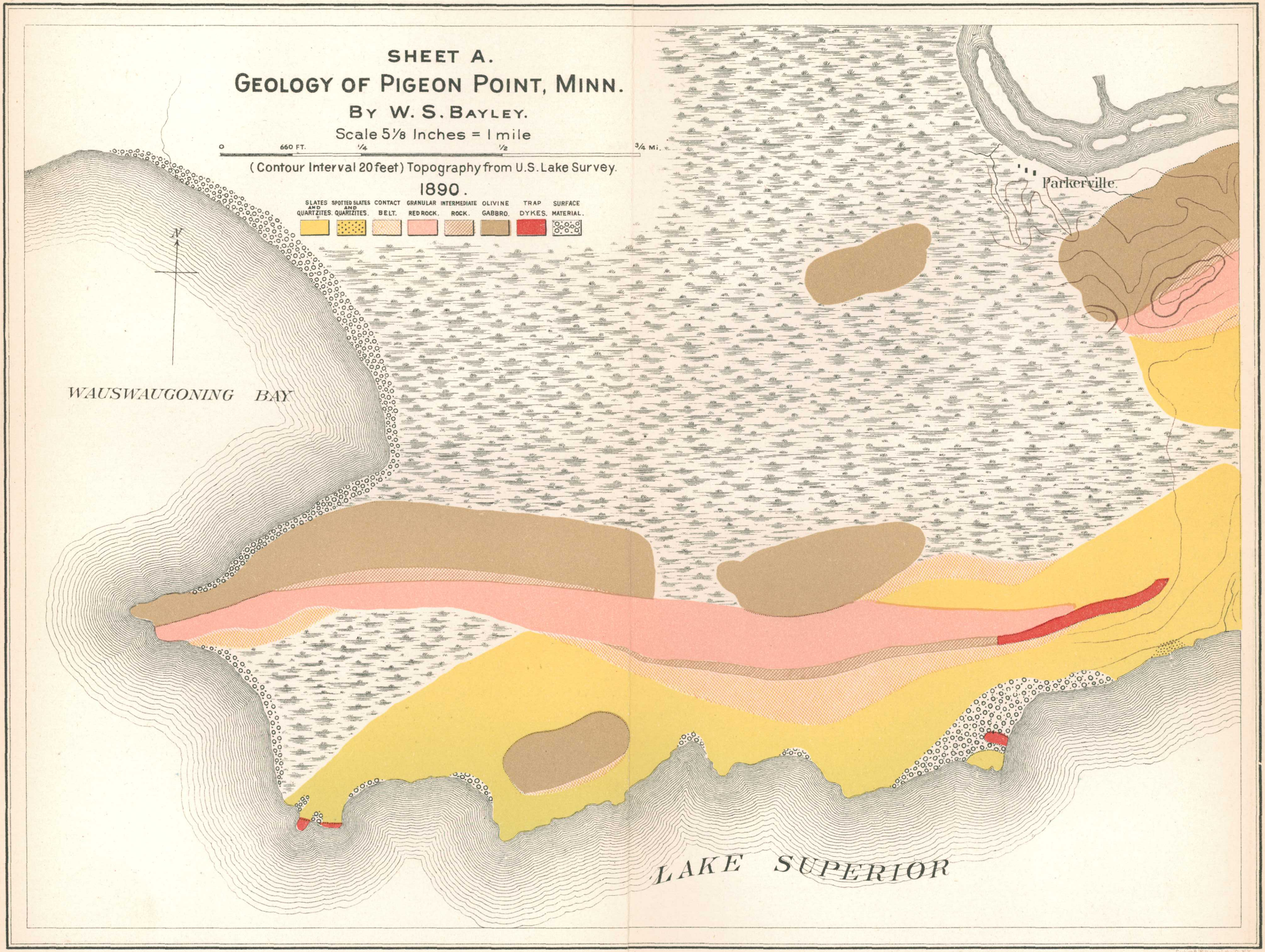
The existence of the red rock at points where contact phenomena in the quartzite are observed is not confined to the Pigeon point locality. At a few other places where such phenomena are known to occur, viz, on the islands east of the point, there is also present a red rock in the same relative position as that of the rock on the point. The localities on Spar, Jarvis, and Victoria islands[1] have already been referred to. Here are masses of gabbro which present many of the features of the Pigeon point gabbro. Around their borders is a series of contact rocks, and between these and the gabbro is a mass of the red rock. This red rock is exactly like the red rock on the point in every particular. If an independent irruptive, its position, always between the gabbro and the contact rocks, needs explanation; if a product of contact action, the explanation is given.

These phenomena of distribution are such as would be expected were the gabbro the cause of the existence of both the red rock and the quartzite contact zone. If the red rock is a result of contact action we would expect to find it between the gabbro and the outer members of the contact belt—in greatest quantity where the other contact effects are best exhibited, and in small quantity where the other contact products are scant in amount. Where the effect of the metamorphosing rock upon the quartzites is very slight the red rock should be absent.

Since the distribution of the red rock with respect to the gabbro and the altered quartzites is such as to indicate the probable correctness of the view that it is a final product of the action of the former rock upon the latter, there remain to be considered the great differences in the intensity of the effects of the action of the gabbro as evinced by the varying amounts of the contact rocks on its periphery.

If the gabbro is the cause of the contact effects, the difference in the intensity of its action may easily be accounted for upon the supposition that a great mass of the eruptive immediately underlies those portions of the contact belt in which the greatest alteration has been produced and the greatest quantity of the red rock is present, or that just at these places were situated the orifices through which the rock was extruded. When the contact products are not abundant the gabbro may

[1] E. D. Ingall: Report on Mines and Mining on Lake Superior, Part H. of Ann. Rept. Geol. and Nat. Hist. Survey of Canada, 1887, pp. 41-46 and 115-116.


SHEET A.
GEOLOGY OF PIGEON POINT, MINN.
BY W. S. BAYLEY.
Scale 5 1/8 Inches = 1 mile
0
660 FT.
1/4
1/2
3/4 Mi.
(Contour Interval 20 feet) Topography from U.S. Lake Survey.
1890.
SLATES AND QUARTZITES.
SPOTTED SLATES AND QUARTZITES.
CONTACT BELT.
GRANULAR RED ROCK.
INTERMEDIATE ROCK.
OLIVINE GABBRO.
TRAP DYKES.
SURFACE MATERIAL.
N
WAUSWAUGONING BAY
Parkerville.
LAKE SUPERIOR

extend to no great depth. It may here have intruded itself between the sedimentary beds and cooled rapidly, so that its action upon the latter was not appreciable. At the contact of the gabbro with the slates and quartzites on the north side of the point, where no contact phenomena are to be found, the junction between the latter rocks and the gabbro is visible. The appearance here suggests the contact of a flow upon the eroded side or top of a bed of slates, or is such as would be produced by the lateral flow of an irruptive between, and then obliquely across bedded rocks. Other contacts of the gabbro with the slightly altered slates and quartzites indicate the same relation between the different rocks. The apparent nonexistence of altered slates and quartzites on the sides of the great gabbro dikes so abundant along the north shore of Lake Superior may be accounted for by the differences in the geological character of the gabbro masses. Along the north shore of the lake the dikes always have the features of simple dikes, while on Pigeon point and on the islands to the east the gabbro possesses other characteristics which cause its masses to resemble those of bosses.

The production of contact phenomena in the quartzite by the gabbro alone is well shown at the falls of Pigeon river. At this place the gabbro has intruded the slates and has broken from them fragments which it has altered much in the same way as slates have been altered by the granite of the Andlau region described by Rosenbusch[1] and others. Since there is not the least indication of the presence of the red rock in the vicinity of the falls of Pigeon river, it is plain that the effects noted in the slates have been produced by the gabbro. As on Pigeon point, this gabbro is not in the form of a simple dike, but is rather like that of a dike from which the orifice-filling material has escaped and insinuated itself between the beds of the surrounding fragmental rocks.[2] This intrusion of the dike material between the layers of the surrounding rocks is probably due to the enormous pressure under which the rock existed at the depth at which the contact effects were produced. Whether the rock mass possessed the shape of a dike or not, the conditions under which it solidified were more nearly like those which obtain during the solidification of plutonic rocks.

More direct evidence of the action of the gabbro upon the quartzite is found in the inclusions of the latter in the former. It will be remembered that the alteration of the fragments in the gabbro is in general similar to that of quartzite fragments in the red rock. In the latter in certain places the quartz fragments are surrounded by a rim of red material, which, under the microscope, presents all the appearances of the red rock, except in the presence of green flecks of chlorite. Quartzite fragments in the gabbro are bordered by a rim which is

[1] Mikroskopische Physiographie, II Aufl., pp. 47-54.

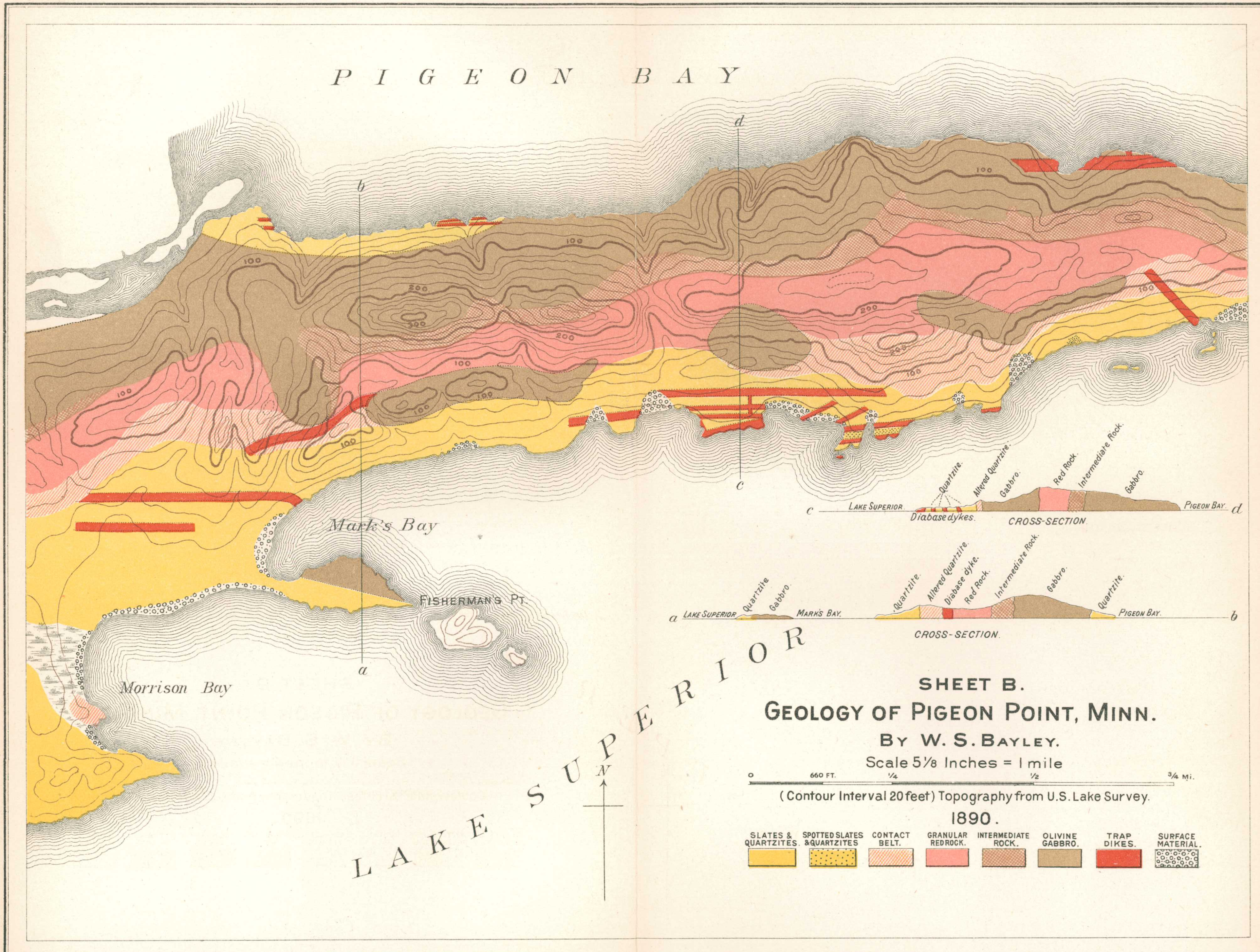
[2] Cf. N. H. Winchell: Ninth Ann. Rept. Geol. and Nat. Hist. Survey of Minnesota, p. 63, Nos. 261 and 263.

exactly like the material of the red rock. At a point on the southern shore, in the eastern portion of the peninsula, about $\frac{1}{4}$ mile from the end of the point (Pl. XVI), the rock cementing quartzite and slate fragments is similar to one of the rocks intermediate between the gabbro and the red rock, and whose formation is supposed to be due to the interfusion of these two rocks. The origin of the cementing material of this breccia may be the direct solution of fragments in the gabbro. Most striking instances of the occurrence of red rims around inclusions are found in this breccia. One of the fragments embedded in the intermediate rock is a large rhomboidal block of pink quartzite, about 7 feet long and 4 feet wide. Surrounding this, between it and the including rock, is a bright red border $2\frac{1}{2}$ or 3 inches wide. In the field this border looks as if it were a small dike of the red rock which had been formed by the filling of a crack produced by the shrinking of the fragment from the rock in which it is embedded. That this is not the case is shown by the fact that there can nowhere be seen any connection between the rim and the mass of the red rock. The structure of the border is likewise different from that of most dikes. The red feldspathic material has a granophyric structure in which the fan-like groups of feldspar and quartz extend perpendicularly from the bounding planes of the inclusion. Since the rim is probably the result of the fusion of portions of the quartzite by the surrounding rock, and its structure and composition are identical with those of the red rock, it may fairly be concluded, in the absence of any evidence to the contrary, that the red rock itself has been produced by the fusion of quartzites by the gabbro—that it is a product of the action of the gabbro upon the slates and quartzites, melting the latter and thus producing a magma from which the red rock solidified. Under the influence of great pressure this magma has acted to a certain extent as an irruptive, intruding and altering the fragmental rocks at a distance from the gabbro. Finally, solidifying slowly, it has for the most part crystallized with the structure of a plutonic mass, but with occasional effusive phases.

The idea that an eruptive rock may originate from a clastic one by fusion is by no means a novelty in geological literature. The well known metamorphic[1] view of the origin of granite supposes the fusion of sedimentary beds by the rise of the isogeotherms. The only instance known to the writer in which it has been shown conclusively that sedimentary rocks have been fused and have afterwards acted as eruptives, is the one described by Reusch[2] in Bømmeløen, Norway, where granite conglomerates have been fused by dynamometamorphism and have afterwards acted as eruptives, intruding eruptive, and clastic rocks in the form of dikes.

[1] Cf. LeConte: Elements of Geology, 1879, p. 219. J. D. Dana: Manual of Geology, 3rd ed., pp. 754–762. Von Gümbel: Grundzüge der Geologie, p. 382.

[2] Bømmeløen og Karmøen med omgivelser geologisk beskrevne. Kristiania, 1888.


PIGEON BAY
LAKE SUPERIOR
Mark's Bay
Fisherman's Pt.
Morrison Bay
SHEET B.
GEOLOGY OF PIGEON POINT, MINN.
By W. S. Bayley.
Scale 5 1/8 Inches = 1 mile
0 660 FT. 1/4 1/2 3/4 Mi.
(Contour Interval 20 feet) Topography from U.S. Lake Survey.
1890.
SLATES & QUARTZITES.
SPOTTED SLATES & QUARTZITES
CONTACT BELT.
GRANULAR RED ROCK.
INTERMEDIATE ROCK.
OLIVINE GABBRO.
TRAP DIKES.
SURFACE MATERIAL.
CROSS-SECTION.
Lake Superior
Quartzite.
Altered Quartzite.
Gabbro.
Red Rock.
Intermediate Rock.
Diabase dykes.
Pigeon Bay.
Mark's Bay.
Diabase dyke.
100
200
300
N
a
b
c
d
Sackett & Wilhelms Litho Co. N.Y.

The fusion of clastic rocks by basalt has been referred to in the preceding chapter. In this case the molten material, thus produced without the addition of any material from the metamorphosing agent, cooled under the conditions which give rise to the structures characteristic of effusive rocks. It failed to act as the magma of an eruptive, only because it was under insufficient pressure. On Pigeon point the rocks were under great pressure, so that, if a magma was produced by the fusion of the slates and quartzites by the gabbro, this magma must have acted like the magma of any other rock under similar conditions. Except in respect to this feature, the formation of the red rock of Pigeon point presents a complete analogy with the formation of glassy rocks at basalt contacts. It was produced without the addition to it of any substance from the gabbro, as is shown by the very small amounts of the characteristic gabbro constituents (calcium and magnesium) in its composition, except on its immediate contact with the latter rock, where the intermediate phases occur. The new rock produced at the basalt contact, however, remained in its original position. It cooled there quickly under slight pressure, and as a consequence formed a glass. The magma of the Pigeon point rock, on the contrary, formed under the influence of considerable pressure, shifted its position, was thrust into the surrounding rocks in the form of dikes, was forced between the grains of quartz in the quartzites, and finally cooled, yielding a rock with the holocrystalline or the porphyritic structure according to the conditions which prevailed at different places.

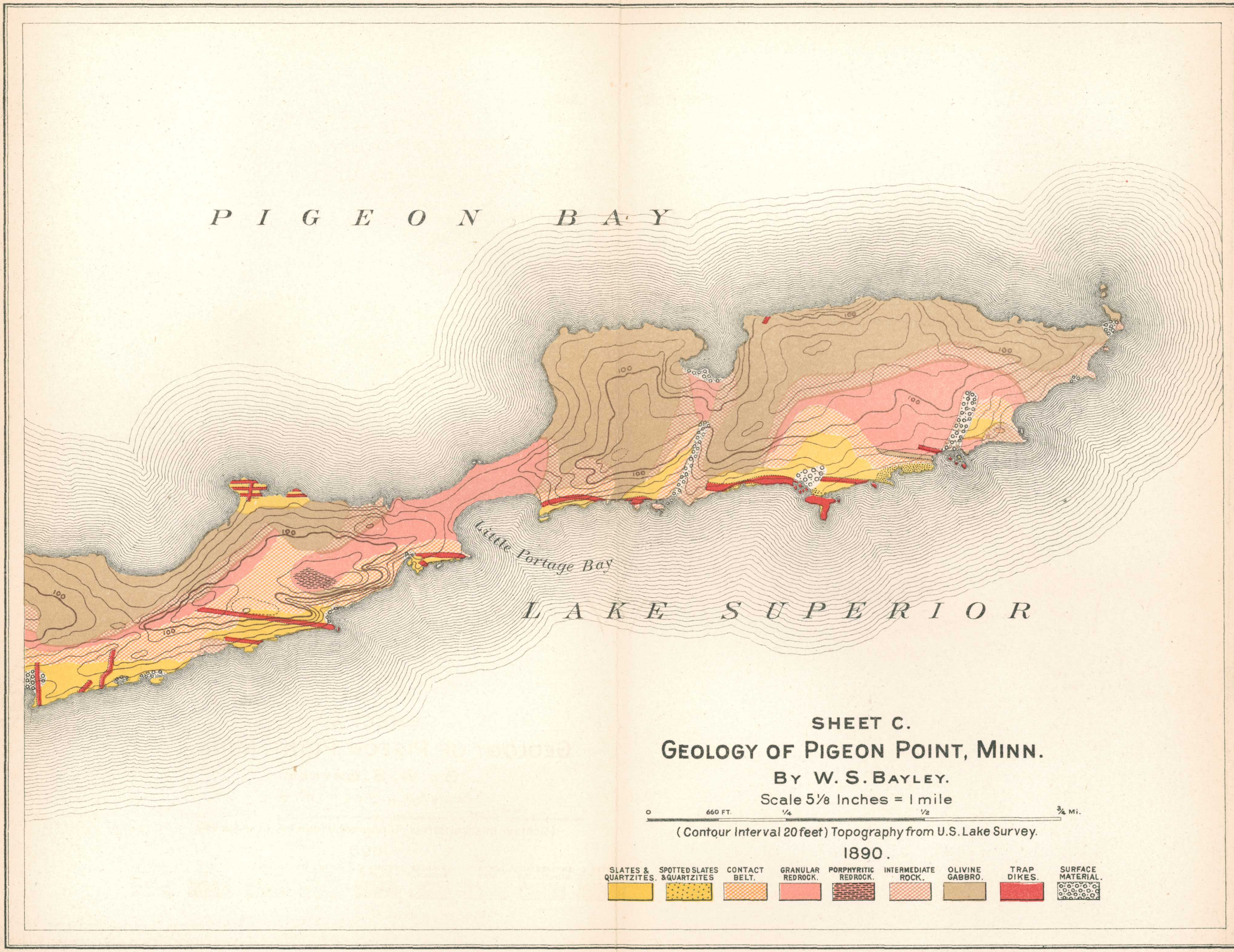
One other point remains to be discussed. If the red rock is a fused sedimentary, there should be intermediate stages in the transition from a clastic rock to a crystalline one. The red quartzites of the inner contact belt have a structure that can be explained by supposing them to be quartzites whose interstitial substance has been fused, or by regarding them as fragmental rocks into which the liquid magma of the red rock has been squeezed by pressure. In either case the apparently porphyritic and the irregularly outlined quartz grains are probably the corroded remains of the original grains of the quartzite. Other indications of a transition between the fragmental rocks and the red rock are found in the mottled rocks of the middle contact belt. Here are undoubted evidences of clastic origin on the one hand, and on the other well-outlined crystals of quartz and feldspar, indicating pyrogenous origin.

In the field there appears to be a gradual transition between the altered quartzites of the inner contact belt and the red rock. At the point on the west side of Little Portage bay there is a gradation between the typical red rock occurring at the base of the cliff, a platy red recrystallized quartzite in which are jagged and corroded quartz crystals, and ordinary spotted quartzites that are undoubtedly altered fragmentals. At many other places the same gradation is encountered. At no place is there a sharp line of contact between the red rock and the highly altered fragmentals, except where the former has cut the latter in dikes. In Fig. 1, on p. 20, where a sharp contact between altered quartzites and the red rock is pictured, the latter has broken through the rocks of the inner contact belt and has intruded those which belong to the outer zone, where the contact effects have been slight. Again, on the top of the quartz-porphyry bluff (see map) the porphyritic red rock is abundant on the west side of the cliff. As we proceed eastward, however, mottlings are discovered in it which remind one of the mottlings of the spotted quartzites. On the extreme eastern side the prevailing rock is the altered red quartzite. No line of demarkation can anywhere be discovered between the different types.

Although these gradations may not serve to prove that the quartzites by fusion gradually pass into the red rock, they afford at least a proof of the existence of transition phases between the rocks. Transitional phases would be expected, whether the red rock is a product of the fusion of the quartzites, or whether as an independent irruptive it has impregnated them and thus altered their characters; but its universal presence bears in favor of the first explanation.

To complete the chain of evidence which links the red rock with the slates and quartzites, a comparison of the composition of the former with the latter is necessary. At present it is not possible to obtain a sufficient basis for this comparison, since it is impossible to discover the mean composition of the sedimentary beds. The unaltered beds show interstratified slates and quartzites of various compositions. Some of them contain much more feldspar than any of the specimens whose analyses are given, while others are more quartzitic. The quartzites are in largest quantity, but their proportion with respect to the slates is unknown. It is evident, therefore, that no comparison that can be instituted will show accurately the relation between the composition of the red rock and the slates and quartzites.

The nearest approach to an average composition for the fragmental beds is obtained by taking a mean of the results of the analyses of the three unaltered quartzites and the slightly altered slate, given in earlier chapters of this paper. In column I is given this mean, and in column IX the figures obtained by the analysis of the powder of seven specimens of the red rock.


PIGEON BAY
Little Portage Bay
LAKE SUPERIOR
100
SHEET C.
GEOLOGY OF PIGEON POINT, MINN.
BY W. S. BAYLEY.
Scale 5⅛ Inches = 1 mile
0
660 FT.
¼
½
¾ Mi.
(Contour Interval 20 feet) Topography from U.S. Lake Survey.
1890.
SLATES & QUARTZITES.
SPOTTED SLATES & QUARTZITES
CONTACT BELT.
GRANULAR REDROCK.
PORPHYRITIC REDROCK.
INTERMEDIATE ROCK.
OLIVINE GABBRO.
TRAP DIKES.
SURFACE MATERIAL.

	IX.	I.
SiO_2	72·42	70·31
TiO_2	·40	trace.
Al_2O_3	13.04	12·81
Fe_2O_3	·68	7·26
FeO	2·49	·88
MnO	·09	....
CaO	·66	·60
SrO	trace.	....
BaO	·15	....
MgO	·58	2·03
K_2O	4·97	1·90
Na_2O	3·44	2·19
Li_2O	trace.	....
H_2O	1·21	2·22
P_2O_5	·20	....
Cl	trace.	....
	100·33	100·20

The principal differences to be noted are in the amounts of iron, magnesium, and alkalies present. But since none of the quartzites analyzed contain nearly as much feldspar as many of those on the point, it is probable that the average composition of the fragmental beds as given in column I, differs from the true average in containing much less potassium and sodium.

From the evidence at hand it would seem probable that the red rock is a product of contact action between the gabbro and the bedded rocks, rather than an independent irruptive which has altered the quartzite. No conclusive evidence bearing upon the question is available, but if the assumption of the secondary origin of the red rock is made, all the facts observed are readily explained; not a single one but is in accord with this supposition; whereas, if we assume that the red rock is the metamorphosing agent, there remain to be explained the contact phenomena around the gabbro in those places where the red rock is absent and the peculiar distribution of this rock. The view that the gabbro is the cause of the alteration of the slates and quartzites and the red rock is an independent irruptive between the former and the latter meets with the same objection as does the supposition that the red rock is the cause of the contact belt. The presence of the red rock between the gabbro and the contact rocks, and in this position when the contact phenomena in the adjacent quartzite evince intense action, is a mode of distribution for an independent irruptive rock which, to say the least, is peculiar.

Since, therefore, objections can be raised to any view that regards the red rock as an original irruptive, and since, on the other hand, every fact observed, either with reference to the gabbro or to the red rock, accords with the assumption that the latter rock is a product of contact action, and none can be found which contradict this supposition, it would seem gratuitous to regard the red rock as having originated in any way but through the fusion by the gabbro of the fragmental rocks which lie upon one side of it.

SUMMARY.

A recapitulation of the facts set forth in the present paper and of the conclusions that have been drawn from them may be of interest to those who find it inconvenient to follow the detailed description of the different rock masses and of the mutual effects which these have had on each other.

The oldest rocks on the point are the interbedded Animikie slates and indurated quartzites, which strike a little north of east and dip about 15° to the southeast. They consist of quartz grains, feldspar, and more or less green chloritic interstitial substance. The induration takes the form of the enlargement of the quartz fragments. In certain beds the quartzites contain lenticular and spherical concretions of calcite, that by alteration and replacement have given rise to epidote in grains and crystals. This change has taken place more particularly where the quartzites are penetrated by diabase dikes. The resulting rocks are characterized by round green spots which are scattered over surfaces with all the peculiarities of the surfaces of the indurated quartzites. Under the microscope the spotted rocks are found to have a groundmass exactly resembling the quartzites with enlarged quartzes. The spots consist of enlarged quartz grains, a little feldspar and tiny grains and crystals of epidote. The calcite concretions are like those so common in the sedimentary beds in the Connecticut valley and elsewhere; and the green spots have originated from these by alteration superinduced by the presence of eruptive rocks in the vicinity of the calcite-bearing beds.

The irruptive rocks cutting the fragmental beds are an olivine gabbro, diabases, and a peculiar red rock whose origin is ascribed to the action of the gabbro on the surrounding slates and quartzites. The olivine gabbro is a heavy, dark, basic rock with a porphyritic structure. The porphyritic crystals are bytownite. They are of various sizes, sometimes measuring as much as 6 inches in length. The groundmass in which they lie is composed essentially of olivine, bytownite, and augite in the order of their age. Its structure is the hypidiomorphic granular, with a tendency to the ophitic. In accordance with the general usage of American writers, and for the purpose of distinguishing it from the diabase dikes on the point, some of which are porphyritic, the rock has been called a gabbro, although perhaps its true designation, following the classification of Profs. Rosenbusch and Judd, should be diabase-porphyrite.

This gabbro occupies all the higher portions of the point. It is in all probability the lower portion of a large dike whose upper part has been removed by denudation. In consequence of the depth at which that portion of the mass now exposed formerly existed, and as a result of the pressure under which the rock cooled, its magma was thrust between the interstratified layers of the slates and quartzites. Its geological relations are very similar to those of plutonic masses.

The material of the gabbro is unvarying in character, differing from the type described only where it has undergone alteration. The alteration consists principally in the change of augite and olivine to hornblende and the production of more or less biotite. It has taken place more particularly near the contact with the red rock and with the fragmentals on its southern border.

The trap dikes offer but few interesting peculiarities. They are much altered, nonolivinitic diabases, that cut the bedded rocks and the gabbro. They are occasionally porphyritic and sometimes they contain red feldspar. Usually they consist of plagioclase, uralitized augite, and chlorite, that may in some cases have been derived from olivine. They differ from the gabbro in their finer grain, their lack of fresh olivine and augite, and in their well-marked ophitic structure. Those in the gabbro are on the whole more decomposed than those in the quartzites and slates.

Between the olivine gabbro and the bedded rocks, in most places, are successively a coarse-grained red rock, containing large hornblende crystals, a fine-grained red rock, and a series of contact rocks.

The fine-grained red rock is undoubtedly younger than the gabbro. It occurs as dikes and veins cutting the fragmental rocks, and is always found as stringers in those of the contact belt. It occupies two distinct areas on the point. One of these is south of the large mass of olivine gabbro, beginning on the north side of Wauswaugoning bay, and running east to the extremity of the point. The other large area is on the southern border of a second gabbro belt, beginning at the eastern side of Wauswaugoning bay and extending east about a mile and a half. The most typical rock in both of these areas is a fine-grained granular aggregate of a soda-potash feldspar, quartz, and a little chlorite. Between some of the rudely outlined feldspar crystals is occasionally a little micropegmatite. Granophyre fringes others. In certain restricted areas the red rock is developed with a porphyritic structure. The porphyritic crystals are eroded quartzes and fairly well-defined feldspars in a groundmass made up essentially of pseudospherulites of granophyre and a few secondary constituents. The structure of this phase of the rock is like that of Rosenbusch's granophyres. It possesses the same composition as the granular red rock, and is therefore regarded as identical with it. From the nature of the feldspar contained in both phases the rock has been called a soda granite, or quartz-keratophyre, in which the keratophyre structure is developed only in a few localities.

The structure of the porphyritic red rock proves it to have solidified from a molten magma. And since the granular red rock is identical with it in composition, it is assumed that this also originally existed as a melted mass. The existence of dikes and veins of the latter, and the contortions that have been produced in the slates and quartzites where they have been intruded by the red rock, are further incontestable proof that the latter was once in a plastic condition.

The similarity in structure and mineralogical composition between this rock and the undoubted eruptives occurring as flows in the Keweenaw series would indicate a community of origin for them. The peculiar relations of the red rock to the gabbro, however, its distribution along the borders of this, and its nonexistence at other places, as well as the seeming gradual transition between it and the fragmental rocks lying along its southern edge would, on the other hand, appear to point to a contact origin, the red rock representing the most altered stages in the metamorphism of the quartzites by the gabbro.

Whether the red rock is an original eruptive, or a product of contact action, there are certain other rocks on the point which undoubtedly owe their origin to contact phenomena. Between the gabbro and the red rock is a series of dark red, coarsely crystalline rocks, through whose mass are arborescent groups of hornblende crystals. These rocks have been called intermediate rocks because their composition is intermediate between that of the basic olivine gabbro and that of the acid soda granite, varying proportionately as the distance from one or the other of the end members of the series. They are found only where the gabbro and the red rock are in contact, and around inclusions of quartz or of quartzite imbedded in the gabbro. In the latter case a rim marking the outline of the inclusion, and possessing the same character as the material of the intermediate rocks, has evidently been derived by solution of portions of the fragments in the inclosing rock. The same kind of origin is ascribed to the large masses of intermediate rock between the gabbro and the red rock. They are supposed to have originated by the interfusion of the two rocks between which they lie.

Again, between the unaltered quartzites and the red rock is another series of rocks to which a contact origin must also be assigned. As the unaltered fragmental rocks approach the red rock they first assume a red tinge and lose their vitreous luster, and then become mottled with large red and green spots. The first class consists of those rocks in which the quartz grains have corroded outlines. In addition to the quartz they contain indefinitely outlined grains of feldspar, some chlorite and an earthy substance, and in addition more or less of a brightly polarizing light green mica, which is in all probability sericite. The amount of sericite increases as the rock approaches a slate in macroscopic appearance, and hence it is regarded as the result of the alteration of the interstitial clay that once existed between the grains forming the rock.

The rocks in the next zone of this contact belt are the mottled rocks. In the case of slates these consist of the altered slates in which rudely outlined red feldspar crystals have separated. These occur wherever the slates are in direct contact with dikes or veins of the red rock, or where the slates are very near large masses of the latter. The mottled rocks are, as their name implies, those in which there is an irregular mottling, usually of green and red. The green portions have the composition and structure of slightly altered slates and quartzites; that is, they consist of corroded quartzes interlocking by irregular sutures, a little feldspar, and more or less sericite and chlorite. The red portions differ materially from the green in the very large amount of feldspar present. This feldspar is occasionally in rudely outlined crystals, but usually it occurs as a globulitic groundmass in which are sericite, chlorite, and slightly corroded quartzes with the outlines of porphyritic crystals.

The contact rocks nearest the red rock are bright red in color. They possess a vitreous luster, and are sometimes spotted with bright green spots. The red quartzites and the red portions of the spotted rocks are composed of somewhat corroded bipyramidal quartz crystals in a globulitic red feldspathic base, in which is a little chlorite, crystals of zircon, and sericite. In the green mottlings sericite is abundant in and between quartz crystals, with bypyramidal contours. Zircon crystals are quite abundant, and these extend through two or more quartzes without interruption. Feldspar is entirely absent.

From the structure of the rocks of the contact belt and from their composition, it would seem that the red quartzites have resulted from the complete crystallization of a magma produced by the fusion of the quartzites alone, or from the intermingling of this fused substance with the material of the red rock. The spots in these may represent portions of the original quartzite which has escaped entire fusion or solution. The mottled rocks beyond the red quartzites have been impregnated with some of the material of the red rock, and in consequence have suffered recrystallization in parts without complete fusion. The recrystallized portions are represented by the red mottlings. The green portions of these rocks and the mass of the less altered slates and quartzites have been changed by solutions emanating from the red rock, but which have been freed from most of their dissolved salts by filtration through those members of the contact belt that are nearest the red rock, and which would have to be passed through before the solutions reached the outer members.

If the red rock is an original eruptive, the changes which have been outlined owe their origin entirely to the presence of this rock. If the red rock is a product of contact action, it was produced by the fusion of beds of slates and quartzites and recrystallization under pressure. It then acted as an eruptive, intruding and altering the fragmental rocks in its vicinity. The composition of the red rock is such that it can in no case have received any considerable amount of material from the gabbro, near which it exists, except in the narrow belt on its northern side where the intermediate rocks are found.

Further, in a few localities where the red rock is absent, there is a series of contactrocks between the gabbro and the bedded rocks. This series is composed of altered quartzites and slates whose characteristics are the same in kind as those of the rocks at the contact with the red rock.

Since the intensity of the action around the gabbro is much less than that in the neighborhood of the red rock, or in other words, since the red rock is present only where the contact effects are most pronounced, it is concluded that this rock is only the final stage in the alteration of the slates and quartzites by the gabbro.

That this latter rock is capable of producing contact alteration in the Animikie beds with which it comes in contact, is shown by the contact rocks around the gabbro mass at the falls of Pigeon river. That similar gabbro masses in other places along the north shore of Lake Superior have not produced alteration in the surrounding fragmental beds is explained by the difference in the geological relations of these dike masses as compared with those of the boss-like dike on Pigeon point.

DESCRIPTION OF MAP. (PLATES XIV, XV, XVI.)

Geological map of Pigeon point, based upon the Lake Survey chart. The outline of the point east of Morrison's bay was mapped by pacing; that west of the bay is taken from the chart. The areal distribution of the rocks was determined by making sections across the point at intervals of 250 feet in its eastern portion and 500 feet in its western part. The rocks generally pass into one another so gradually that the mapping of their distribution must be to some extent arbitrary. In the eastern portion of the point the colors representing the different rocks and groups of rocks cover areas approximately occupied by the respective rocks. The color for the contact belt covers all of the altered quartzites and slates. No distinction has been made between those that are entirely recrystallized and those that have suffered but little change. The former always occur nearer the gabbro and the red rocks than do the latter, and the latter pass by insensible gradations into the unaltered fragmentals. In the few places where the rocks do not pass into each other, their contact is indicated by a solid line. At A in the interior of the western part of the point, and at a few other places, the gabbro occurs in knobs, when the area occupied by it is represented as sharply defined. Many of the trap dikes have been exaggerated in size, in order that they might be represented on the scale of the map, as have also the spotted-rock areas. In the western portion of the point the distribution is not as carefully worked out as it is in the eastern part, but is accurate enough to illustrate the features most prominent in the geology of the region. A large swamp occupies most of this part of the point, and in it no rock exposures were detected. A few other low areas have been covered with the color of the rock which undoubtedly underlies them. Scale: 5½ inches to the mile.

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