ART. VI.—*A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites;* by W. S. BAYLEY.

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(I.) INTRODUCTORY.

ONE of the most striking features in the geology of Pigeon Point,* Minnesota, is the occurrence there of a bright red rock along the borders of the large mass of olivine-gabbro, which forms the main portion of the point. This rock is best seen along the south or Lake Superior side of the point near its eastern extremity, where its brilliant color when moistened by the water, forms a beautiful contrast to the dark gray of the gabbro with which it is in contact.

The first mention of the rock was made by Dr. Norwood,† Assistant U. S. Geologist, in 1851, who described it as a reddish colored syenitic rock, containing but a small amount of quartz. About thirty years later Professor N. H. Winchell, of the Minnesota State Survey, saw a red rock‡ associated with gabbro near the extremity of Pigeon Point, and a rock§ red with orthoclase, from its north shore about a mile from its eastern extremity, which latter 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,‖ who regards it as an altered phase of some eruptive, the original nature of which he is unable to decide from the single section at his command. Professor R. D. Irving¶ in 1881, described a red rock from Brick Island, one of the smaller of the Lucille group of islands, about a mile south of Pigeon Point. He says: "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." On Pigeon Point also Professor Irving found a red rock which "resembles in every particular the rock from Brick Island."

Similar red rocks have been observed by several geologists at various other places in the Lake Superior region, but no careful study has been made of any one of them.

* For exact location see this Journal. June, 1888, p. 388.

† Report of a Geological Survey of Wisconsin, Iowa and Minnesota. By D. D. Owen, U. S. Geologist, Philad., 1852, p. 399.

‡ Geol. and Nat. Hist. Survey of Minnesota for 1880, p. 70.

§ Ib. for 1881, p. 57.

‖ Geol. and Nat. Hist. Survey of Minnesota, Bulletin 2. Preliminary Description of the Peridotytes, Gabbros, Diabases, etc., of Minnesota, 1887, p. 81.

¶ Copper Bearing Rocks, etc. Monog. V., U. S. G. S., 1883, p. 369.

(II.) Macroscopical and Microscopical.

The red rock of Pigeon Point presents several phases differing in some respects from one another. In its most typical aspect it is a brick-red, fine grained, drusy rock, speckled with little spots of a dark green color. Scattered through the prevailing red feldspar are small grains of white quartz, which sometimes present well-defined crystal outlines. The feldspar itself is occasionally observed with a well marked cleavage and rarely with a crystal outline. Usually it has no distinctive morphological characteristics. In some cases a small quantity of a light colored feldspar can be detected intermingled with the red variety. The green spots consist of little plates of chloritized mica.

Under the microscope the coarser grained of these non-porphyritic varieties 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, magnetite, hematite and apatite.

The feldspars embrace a striated plagioclase, twinned according to the Carlsbad law, and in one instance according to the Manebach law, and a second, less well individualized feldspar, which is younger than the plagioclase, but slightly older than the accompanying quartz. It surrounds the plagioclase and is intergrown with the quartz in micro-pegmatitic and granophyric forms. Both the plagioclase and the granophyre feldspar are colored by numerous little plates of hematite, the plagioclase, however, containing fewer of these than the granophyre variety. When the latter occurs with its own outlines, as it occasionally does, it appears to be unstriated, though frequently in Carlsbad twins. After hematite, apatite, leucoxene, and little plates of muscovite or kaolin, are the most common inclusions of both varieties of feldspar. In no case could crystals be found fresh enough to yield measurements of sufficient accuracy to determine their true nature.

The quartz is in irregular areas filling in the interstices between the other constituents, and is also intergrown with red feldspar as has already been described. It contains numerous fluid cavities with little dancing bubbles, and also inclusions of a dust-like substance and little areas of red feldspar.

The chlorite owes its origin principally to a formerly existing biotite. It occurs both in little radiating spherulites crowded close together, and in plates enclosing quartz and feldspar. Calcite, rutile and leucoxene are its most common inclusions, while the little pleochroic halos* (Höfe) characteristic of this mineral when derived from biotite, are not rare.

* For the discussion concerning the nature of these halos, see Neues Jahrb. f. Min., etc., 1888, i, p. 165.

Associated with the chlorite is oftentimes a very light green fibrous mineral, which from its bright polarization colors is probably to be referred to sericite. Rutile forms quite a prominent constituent in some specimens. It is found in irregular masses of a dark brown color, and also in long rod-like forms, in both cases intermingled with leucoxene and frequently with chlorite.

A second phase of the red rock resembles quartz-porphyry. Well terminated quartz crystals and occasional brick-red and greenish-white feldspars are scattered through a very fine grained groundmass of a dark red or purplish color. This variety is characterized under the microscope by the beauty of its granophyre structure. All gradations between the granular structure just described, and the typical porphyritic structure have been examined, and in all there is more or less of the true granophyre. In the most typical porphyritic varieties the porphyritic crystals are both quartz and feldspar. In the less perfectly developed phases the quartz occurs in round, elliptical and even crescent-shaped areas, and includes in many places portions of the groundmass. This quartz is perfectly clear and is free from inclusions other than the little fluid cavities with movable bubbles (see fig. 1.)

A very few irregularly outlined feldspar areas represent the porphyritic crystals of this mineral in their earliest stages of development. They are now so altered as to prevent the identification of their species.

Other areas which appear in the hand specimen as crystals are seen under the microscope to be composed of granophyre substance in which the feldspathic portion is very highly colored by little plates of hematite.

The groundmass, in which these crystals are imbedded, consists of quartz and highly altered feldspathic substance in granophyric intergrowths. This is in part sometimes replaced by coarser areas in which the two minerals form a micropegmatite. The fine granophyre is found more particularly around the distorted and corroded porphyritic quartzes, and in the undeveloped feldspars mentioned above. It radiates from all porphyritic quartzes forming 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 crystals.

Chlorite, iron hydroxides, leucoxene, and tiny flakes of a dark brown biotite are the accessory constituents of the groundmass. Calcite is quite abundant as an alteration product of some of the fibres intergrown with the quartz, and also in the little cavities contained in the rock. Green alteration-products are also common. Fig. 1 is an ideal representation of the most characteristic peculiarities of the groundmass and its porphyritic ingredients as exhibited by several thin sections.

The microscopical characteristics of both the porphyritic and the granular varieties of this 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, all gradations between the two types can be recognized. Their mineralogical composition is the same, and, as will be shown later, their chemical composition is identical. There can be little doubt that the porphyritic variety is a true eruptive rock. It presents all the features of Rosenbusch's* "Vogesen granophyres." Since the granular varieties are so similar to this, it is also probable that these also are eruptive. No trace of fragmental structure could be detected in any one of them, nor is there any field evidence that they are altered fragmentals. All the field relations seem to point to the *original* character of the rocks. They occur in dykes and veins intersecting other rocks, and the contact between them and the quartzites which they cut, is sometimes clearly seen. It must be confessed, however, that without microscopical and chemical evidence of the identity of these rocks with the quartz-porphyry their true nature would be difficult to discover from the field relations alone. A more careful examination of the structure of the point than has thus far been possible, will probably reveal facts which will place beyond doubt the conclusions reached by the microscopical examination.

1.

The quartz-porphyries are very similar in macroscopic and microscopic appearance to the Keweenawan quartz-porphyries described in Irving,† as flows in the copper-bearing rocks on both sides of Lake Superior. The granular red rock approaches more nearly this author's augite-syenites, though the best developed and most characteristic augite-syenites are more nearly allied to the third phase of the red rock. The rock of Brick Island, which is classed by Irving among the augite-syenites agrees in most of its minute features with the rock described above as the most prevalent type of the red rock on Pigeon Point, as Irving‡ himself states.

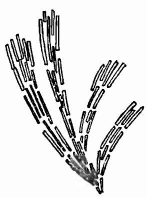
* Die Steiger Schiefer. etc. Strassburg, 1876.

† Copper-Bearing Rocks, p. 95.

‡ L. c., p. 369.

The third variety was noticed more particularly at the contact with an olivine gabbro, which occurs on the point in larger masses. As the red rock approaches the gabbro it is clearly seen to be affected by the latter in such a way as might be expected if both rocks were in a pasty condition at the same time, or if one had been intruded in or next to the other under enormous pressure. The red rock becomes darker as it approaches the gabbro. The green spots, which are scattered over the red groundmass, become more prominent. They are larger in size and more abundant in number than in the two varieties above described, and in some cases are united into red-like bodies and arborescent forms (fig. 2). A light colored feldspar is also much more frequently discernible in this variety.

2.



Still closer to the gabbro a rock is observed which is very dark in color, and can be distinguished from the gabbro only by the possession of a reddish feldspar among its components. The darkest of these rocks resembles very closely the orthoclase gabbros* of Irving, which are supposed by Dr. Wadsworth† to be but altered forms of olivine-gabbro. A discussion of this point can not be entered upon in this place, but it is hoped soon to obtain results from the work now being carried on, which will determine whether or not the orthoclase gabbros may have been derived by the action of an acid magma upon a basic gabbro with which they are always associated.

The lighter colored of these intermediate rocks (as we shall call them for the sake of brevity) when examined under the microscope are found to differ but little from the red rocks described above. They contain a larger amount of plagioclase (oligoclase ?), of chlorite, and of biotite, and much more magnetite and apatite than do the latter, but otherwise resemble them very closely. Micropegmatite is more frequent than is the granophyre intergrowth of quartz and feldspar, and it is especially to be remarked that in almost every case examined the extinctions of the little quartzes are in the direction of their longer axes. The most noticeable fact in relation to them is the freshness of their plagioclase, which is usually in large tabular or lath-shaped crystals.

When examined carefully and compared with sections of Irving's augite-syenites they are seen to bear a strong resemblance to some of these—a resemblance so strong that pictures‡ representing the augite-syenites might as well be used to illustrate the appearance of the Pigeon Point rocks under the microscope.

* Copper-Bearing Rocks, p. 50.
† L. c., p. 54. Cf. also Herrick et al., American Geologist, June, 1888, p. 340.
‡ Copper-Bearing rocks, p. 112, and figs. 1, 2, 3, 4, Pl. XIV.

After a careful microscopic examination of every one of the thin sections of rocks described by Irving as augite-syenites and a comparison of these with the typical red rock of Pigeon Point and its associated intermediate varieties, the conclusion is established beyond doubt that some of the former are in every respect similar to the typical red rock of the point, while the others are as certainly identical in all essential particulars with those varieties which have been called its intermediate varieties.

(III.) Chemical and General.

From a mere microscopical examination of different sections of the various phases of the red rock on Pigeon Point, one would naturally be lead to regard them as portions of the same magma which had crystallized under different conditions, and then had undergone more or less decomposition. They both possess the same mineralogical composition and present gradation in structure from the granular to the porphyritic, with granophyric groundmass.

In order to obtain more positive evidence on this question, analyses of the quartz-porphyry and also of the granular rock were made by Mr. W. F. Hillebrand in the laboratory of the U. S. Geological Survey, with these results:

I. Analysis of the powder of seven of the freshest specimens of the granular rock.

II. Analysis of the powder of three of the quartz-porphyries.

III. Analyses of the granite from Bejby, Sweden; containing red orthoclase, gray and brownish gray quartz, black mica, and a few flakes of a golden yellow mica.*

	I.	II.	III.
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
BaO	·15	·12	----
MgO	·58	·42	----
K_2O	4·97	4·33	4·96
Na_2O	3·44	3·47	3·21
Li_2O	tr.	tr.	----
H_2O	1·21	·86	1·22
P_2O_5	·20	·06	----
Cl	tr.	tr.	----
	100·37	99·93	100·48
Sp. Gr.	2·620	2·565	

* Gerhard: Neues Jahrb. f. Min., etc., 1887, ii, p. 271.

After an inspection of these figures there can be no reasonable doubt that the two rocks from Pigeon Point are parts of the same mass. The very slight differences in amount noted in the case of the silica, alumina and potash are not greater than are frequently found in different portions of the same hand specimen of most rocks. The slight difference in specific gravity are what might be expected from a study of the structure of the rocks.

Unfortunately no complete analyses of Irving's Keweenawan quartz-porphyries are given by that geologist, but a few silica determinations have been recorded, which are of interest in showing the close agreement, in this respect, between these rocks of undoubted eruptive origin and the Pigeon Point rock. The percentages of silica in three Minnesota quartz-porphyries* are respectively 71·10, 73·87 and 76·83; thus differing but slightly from the 74 per cent. of the Pigeon Point rock.

In consideration of the large amount of sodium indicated in analysis I, it was thought interesting to separate the feldspar from one of the freshest of the red rocks and subject it to a chemical examination. This was done in the usual way, and it was found that the greater portion fell when the specific gravity of the solution used was 2·577. This was analyzed by Mr. Whitfield of the U. S. Geological Survey with the following result:

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Ign
65·00	18·22	2·64	1·06	0·06	4·18	8·40	·46=100·12

When examined under the microscope the powder of this mineral is seen to be free from quartz and quite homogeneous, although slightly altered and filled with little plates of hematite. Its optical constants could not be accurately determined, but from the figures given above there can be but little doubt that the feldspar is an anorthoclase.†

If this be true the rock would fall into the quartz-keratophyre group as defined by Rosenbusch.‡ Its microscopical characteristics correspond to those of the quartz-keratophyres, as described by Gümbel and Lossen, and the composition of its feldspar is that of an anorthoclase.

Many of the quartz-porphyries of the Keweenawan series, as well as some of the augite-syenites will probably be found to belong to this same class of rocks—a class which up to the present time has not been known to have a representative on this side of the Atlantic.

One of the most interesting points in the study of the red rocks of Pigeon Point, has reference to the origin of those

* Copper-Bearing Rocks, pp. 108, 109, 100, 441.

† Anorthoclase separated from a liparite of Pantelleria, has a composition (according to Förstner, Zeitschr. f. Kryst., 1883, p. 125) as follows: SiO_2=66·06, Al_2O_3 19·24, Fe_2O_3 0·54, CaO 1·11, MgO 0·11, K_2O 5·45, Na_2O 7·63.

‡ Rosenbusch: Mikroskopische Physiographie, 1887, ii, pp. 434–442.

phases which are found upon the contact with olivine-gabbro. As has already been stated, the macroscopical and microscopical characteristics of these rocks are such as would lead to the supposition that they were produced by the mutual interfusion of the basic and acid rocks at their points of contact. The field relations of the three rocks leave no doubt as to the fact that the intermediate rock is the result of contact action. That this action took place at some distance below the surface is proved by the perfect crystallization of the constituents of the intermediate rock. That it was not confined to the effect of solutions passing from the gabbro to the keratophyre, or the reverse, is shown by the perfect freshness of the plagioclase, and its well-defined crystal outlines in both rocks.

The best place upon the point at which to study these rocks is on its south side, near its eastern extremity. Here the space between the fresh olivine gabbro and the typical quartz-keratophyre is occupied by a series of rocks which exhibit in the field a gradual transition between the heavy, dark basic rock, and the light red keratophyre.

Analyses and specific gravity determinations of several of these intermediate products substantiate the conclusions arrived at above.

IV. Olivine gabbro, analysed by Mr. Hillebrand.
V. Intermediate rock (No. 11211) near the gabbro.
VI. Intermediate rock (No. 11209) midway between the red rock and the gabbro.
VII. Intermediate rock (No. 11210) near the keratophyre, analyzed by Mr. Hillebrand.
VIII. Quartz-keratophyre, as given on p. 59

	IV.	V.	VI.	VII.	VIII.
SiO_2	49·88	50·69	57·88	57·98	72·42
TiO_2	1·19	----	----	1·75	·40
Al_2O_3	18·55	----	----	13·58	13·04
Fe_2O_3	2·06	----	----	3·11	·68
FeO	8·37	----	----	8·68	2·49
MnO	·09	----	----	·13	·09
CaO	9·72	7·94	4·68	2·01	·66
SrO	*tr.*	----	----	*tr.*	----
BaO	·02	----	----	·04	·15
MgO	5·77	----	----	2·87	·58
K_2O	·68	----	----	3·44	4·97
Na_2O	2·59	----	----	3·56	3·44
Li_2O	----	----	----	*tr.*	*tr.*
H_2O	1·04	----	----	2·47	1·21
P_2O_5	·16	----	----	·29	·20
Cl	*tr.*	----	----	----	----
	100·12			99·91	100·33
Sp. Gr.	2·923		2·741		2·620

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. We can hardly imagine the conditions under which a rock of the composition of the gabbro (IV) could be changed into a rock of the composition of the intermediate rock (VII), by means of solutions* emanating from the keratophyre, unless these solutions contained in them the materials of the keratophyre in about the proportions in which they are present in that rock, a supposition which is not at all probable.

It would seem, then, that we are justified in regarding the intermediate rock as due to the fusion and recrystallization of the materials of both the keratophyre and the gabbro, in consequence of the irruption of one of these rocks into the other at some considerable depth below the surface of the earth, where the conditions were such as to produce a rock with the characteristics of a plutonic rock. In other words the intermediate rock is the result of deep seated contact action.

Analyses of Irving's augite-syenites are not given, so that a comparison of their composition with that of the intermediate rock (No. 11,209) cannot be made. Their thin sections, however, as has already been stated, exhibit a very close similarity to many of those of the contact rocks. Further, those with these characteristics are always, so far as could be determined, in close association with gabbro, and in many cases are also very near a more acid red rock resembling the quartz-keratophyre in one of its phases.

The augite-syenites of Irving, then, may be divided into two classes, those which are like the quartz-keratophyre, described above, and those which are similar to the contact rock. In neither case are they altered eruptives, in the sense that they owe their present characteristics to the alteration of a more basic eruptive. They have both resulted from the solidification of a molten magma.

Of course it is not affirmed that no alteration has taken place in any of the augite syenites, for such is not the case. Some of them have suffered the kaolinization of their feldspar, and the chloritization of their augite and mica, with the production of secondary silica. Their most characteristic properties, however, are not due to this alteration, but are due to the chemical composition of the magma by whose cooling they were formed.

* Cf. American Geologist, June, 1888, p. 343. Messrs. Herrick, Clarke and Deming: Some American Norites and Gabbros.

(IV.) Conclusions.

The red rock on Pigeon Point is not an altered gabbro nor an altered sedimentary rock, but is the result of the solidification of a magma, which under certain conditions gave rise to a rock with the characteristics of a granophyre. These two rocks contain a sodium-potassium feldspar, and thus should be classed among the quartz-keratophyres.

Upon the contact of the quartz-keratophyre with an olivine-gabbro is a series of rocks, which possess a composition intermediate between those of the keratophyre and the gabbro. They may be regarded as the result of contact action at great depths

Irving's augite-syenites are similar to the Pigeon Point quartz-keratophyre, in some instances, and in others are like the intermediate rocks. They are neither altered gabbros nor altered forms of a previously existing augite-syenite.

Geological Laboratory of Colby University, June 25, 1888.