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*AN ANALCITE-BASALT FROM
COLORADO*

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AN ANALCITE-BASALT FROM COLORADO.¹

THE discovery that analcite plays the rôle of an important primary constituent of certain igneous rocks must be regarded as one of the most interesting developments of recent petrographical investigations; and I, for one, am inclined to believe that Pirsson has not gone too far in his general conclusions, published in this JOURNAL a year ago,² that analcite is an essential, primary component of many rocks now assigned to the monchiquites, a rock group described some years ago by Hunter and Rosenbusch. As each definitely proven instance of primary analcite in igneous rocks must for some time to come be of value in establishing its true rank as a rock constituent, the following description is offered, although some important details of occurrence cannot be given.

The rock in question was found by myself in 1893, while engaged in the geological survey of the Pike's Peak quadrangle. The exact locality, which may be identified by reference to the published map of that area,³ is in the small park called "The Basin," twelve miles nearly west of Cripple Creek. Near the southern end of The Basin, and on its western side, at the end of a little ridge between two branches of High Creek, there is an outcrop of black basaltic rock directly on the line where a great complex of andesitic and basaltic breccia and agglomerate rests on the Dakota Cretaceous sandstone. This volcanic series extends far to the westward, between South Park and the Arkansas River, but only a few tongues and remnants now exist to the eastward of The Basin. The outcrop mentioned was regarded

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²"The Monchiquites or Analcite Group of Igneous Rocks," by L. V. PIRSSON. JOUR. GEOL., Vol. IV, 1896, pp. 679-690.

³Geological Atlas of the United States, Pike's Peak Folio (No. 7), Washington, 1894.

at the time of discovery as indicating a short dike parallel to the ridge, but no contact was seen, owing to detritus. Although the rock had a somewhat unusual habit, it was not supposed to be materially different from many other basaltic dikes which had been observed cutting the fragmental series referred to. It turns out on examination, however, that this rock of The Basin is an analcite-basalt, quite unlike any other rock collected in the entire district.

The rock is dark and very fresh looking, with many small crystals of augite and olivine, and a white mineral occurring in roundish grains, all these averaging about 1^{mm} in size. A few augite prisms are larger, and terminations exhibiting the usual pinacoidal twinning were seen. The white mineral, by its rounded grains and the absence of cleavage, presents the only marked deviation from the normal habit of the neighboring plagioclase-basalts. A black, aphanitic groundmass holds the phenocrysts.

Under the microscope augite, olivine, and magnetite possess a development common in basalts. Augite of pale, yellowish green color, and very faint pleochroism, occurs in phenocrysts, which are usually almost free from inclusions, but a few aggregates of similarly colored grains are full of irregular or sack-shaped glass inclusions. There is commonly a narrow outer zone to the purer augite, in which inclusions of glass and magnetite are seen, and the substance of this outer rim has a faint purplish tinge, like that of the smaller groundmass grains. An analysis of the pure augite is given below.

Olivine appears in moderate abundance, of usual habit, and is the only mineral showing any sign of alteration. Perhaps half of the olivine is serpentinized with pale brown biotite leaves inclosed in the serpentine of the most altered grains, as an apparent secondary product. Primary dark, reddish brown biotite also appears very sparingly. Magnetite and apatite have the customary development.

A considerable part of the rock is colorless and isotropic in polarized light; a much smaller part is colorless but doubly refracting, and is mainly assignable to three species of feldspar.

The isotropic constituent embraces most of what is megascopically visible, and also much more, in small grains, which, with corresponding ones of augite, magnetite, and feldspar, make up the groundmass. There is, in fact, a regular gradation between large and small isotropic grains. No crystal form was observed for the isotropic substance, but neither does it appear in any way to play the rôle of a glassy base. It seems throughout to be an irregularly granular mineral constituent, of the isometric system.

The larger grains are almost wholly free from inclusions, and while probably the last substance to crystallize the isotropic mineral has in its growth pushed back the smaller grains of augite and magnetite so that they often form a distinct zone about it. This phenomenon seems clear evidence of a crystallizing force. The smaller grains mingle with augite, magnetite, and feldspar.

While no crystal form has been observed, rings or wreaths of small inclusions were noticed in a few grains, and these so strongly suggested leucite that until the chemical analysis was made I felt quite sure that the rock must be a leucite-basalt. A smoky tinge is present in a very few grains, and in one the coloring matter is arranged in zones, clearly suggesting a regular crystal form. Irregular fractures traverse the substance, and its index of refraction is less than that of the Canada balsam, as indicated by Becke's method.

The feldspathic constituent appears in small, irregular, clear particles, some of which have most characteristic microcline structure, with an extinction of 15° ; others can only be considered as sanidine, with Carlsbad twinning in some grains; and the remainder is a plagioclase rich in soda, with very delicate albitic twinning. Its angle of extinction is always small. There is possibly some nepheline associated with the feldspar.

The purity, freshness and abundance of the isotropic mineral invited the attempt to determine its composition by isolation and analysis. This was done by Dr. W. F. Hillebrand, and the result is given in column I of the table below. Under I^a is given the molecular ratio deduced from the analysis. The

amount and composition of the portion of the rock soluble in hydrochloric acid is shown in column II. The augite was, in the main, so free from inclusions that an analysis was made by Dr. Hillebrand for comparison with other rock augites. The material was isolated by the Thoulet solution, and was found to be very pure on microscopical examination. III is the analysis of the augite.

	I	Ia	II	III
SiO ₂	51.24	854	21.97	49.26
TiO ₂				1.53
Al ₂ O ₃	24.00	235	9.94 ³	6.01
Fe ₂ O ₃	1.20 ⁴		3.71 ⁴	3.31
FeO				4.23
CaO	1.62	29	1.95	21.79
SrO	.06		.08	.06
BaO			?	?
MgO	.33	8	2.87	12.40
K ₂ O	1.25	13	.56	.41
Na ₂ O	11.61	187	4.04	.79
H ₂ O	.62 ¹		3.91 ⁵	
H ₂ O	8.47 ²	470		
P ₂ O ₅				
SO ₃	none			
Cl	trace		.05	
	100.40		49.08	99.79

¹ Over H₂SO₄.

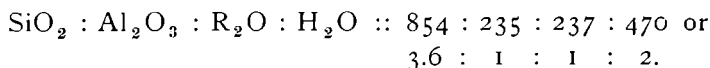
³ Includes P₂O₅.

⁵ Assumed from rock analysis.

² Remainder of water.

⁴ Total iron as Fe₂O₃.

The isotropic mineral could not be secured entirely free from attached or included particles of doubly refracting substances. But these made up a small part of the material subjected to analysis. After treatment with hydrochloric acid there remained an insoluble residue, amounting to 4.22 per cent. of the substance taken, and this was found on microscopical examination to consist of augite and feldspar. From the molecular ratio the following proportion may be derived:



In this result CaO and MgO are united with the alkalis and iron

is neglected. This ratio is exactly that of analcite except for the silica. It cannot be assumed that the material isolated was pure, and small amounts of various substances no doubt went into solution. But we can reasonably consider it demonstrated that the isotropic substance acting like a mineral constituent has practically the composition of analcite. I can see no reason for doubting this identification.

The analysis of the soluble portion of the rock leads to practically the same result as that of the isolated analcite. By deducting olivine, apatite, and magnetite, there remains a residue having about the ratio 1 : 1 for Al_2O_3 to alkalis. Silica is again low. If nepheline were present in the rock the low silica of both analyses might be explained. It is possibly there in some small amount but probably not in sufficient quantity to entirely explain the figures of the analyses.

The augite proves to be quite high in alumina and to have more titanitic acid than would be inferred from the pale violet tinge it exhibits. It is thoroughly normal augite.

An analysis of the rock of The Basin was also made by Dr. Hillebrand, and it is given in column IV of the following table, in which analyses of several allied rocks are introduced for purposes of comparison. Of the other analyses, V is of a rock from Shelburne Point, Vermont, described by J. F. Kemp and V. F. Marsters,¹ with other dikes of the Lake Champlain region. In the original description Kemp published another analysis of this rock, the accuracy of which he was afterward led to question, and the analysis here quoted, made by H. T. Vulté, was published by Pirsson, at Kemp's request, in his cited discussion of the monchiquite group. VI is of one of the original monchiquites from Brazil, by M. Hunter.² The relation between the analcite-basalt and the other basalts of the region is illustrated by analysis VII, by W. F. Hillebrand, of a normal plagioclase-basalt occurring in Saddle Mountain, a few miles northwest of The Basin.

¹ The trap dikes of the Lake Champlain region. Bull. 107, U. S. G. S., 1893 p. 32

² Über Monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Elæolithsyenite, Tschermak's Min. und petr. Mitth. Vol. XI, 1890, p. 445.

TABLE OF ROCK ANALYSES.

	IV.	V.	VI.	VII.
	Analcite-basalt, The Basin, Colo. W. F. Hillebrand.	Monchiquite, Shelburne Point, Vt. H. T. Vulté.	Monchiquite, Brazil. M. Hunter.	Plagioclase-basalt, Saddle Mt., Colo. W. F. Hillebrand.
SiO ₂	45.59	45.58	46.48	48.76
TiO ₂	1.32	undet.	.99	1.65
ZrO ₂	.03	....	....	none
Al ₂ O ₃	12.98	15.87	16.16	15.89
Fe ₂ O ₃	4.97	4.65	6.17	6.04
FeO	4.70	6.37	6.09	4.56
MnO	.14	trace	....	.13
CaO	11.09	9.91	7.35	8.15
SrO	.12	....	....	.06
BaO	.13	....	....	.17
MgO	8.36	8.32	4.02	5.98
K ₂ O	1.04	1.61	3.08	2.93
Na ₂ O	4.53	3.42	5.85	3.43
Li ₂ O	trace	....	....	none
H ₂ O	.51	} 3.14	} 4.27	{ .40
H ₂ O	3.40				{ 1.48
P ₂ O ₅	.91	....	....	.60
Cl	.05	....	....	....
CO ₂	....	....	.45	....
S	....	....	....	....
	99.87	98.87	100.91	100.23

Were the greater part of the water in the analcrite-basalt deducted, and the remainder recalculated to 100, the analysis IV might stand for an ordinary nepheline-tephrite. It is lower in alumina than many analyses of basalt, but if TiO₂, P₂O₅, and MgO were accurately estimated in all such rocks the alumina would often fall 2 or 3 per cent. below the published figures. The magma of this basalt was relatively quite rich in soda with low silica and much water. The formation of analcrite in the final stages of consolidation of such a magma seems to me much more natural than that glass should be the result, provided only that the conditions were in general favorable to crystallization. As the rock probably occurs in a dike and in a region where there are many dikes of holocrystalline plagioclase-basalt, the presumption must be that the conditions were favorable to crystallization.

The monchiquite of Shelburne Point agrees very closely in composition with this analcite-basalt. Its high alumina would no doubt be materially reduced if TiO_2 and P_2O_5 were deducted. Of this particular rock Kemp quotes Professor Rosenbusch, to whom it had been shown, as saying that it is a "true monchiquite of typical habit."¹ From a microscopical examination of a specimen of this rock which is in the reference collection of the Geological Survey it is plain that there is a great difference in the development of the two rocks. In the Shelburne Point rock there is a cloudy gray base of indistinct radially fibrous structure and of weak double refraction. It is neither glass nor normal analcite at present, whatever it may have been originally. It is clear from the analysis, however, that the rock of Shelburne Point and that of The Basin resulted from magmas of almost identical composition.

The original monchiquite (analysis VI) varies somewhat from the others, being higher in alumina, iron and alkalis and lower in lime and manganese. Its alumina must contain considerable phosphoric acid. Its isotropic base, interpreted by Hunter and Rosenbusch as glass, has been shown by Pirsson's recalculation of Hunter's analysis to have practically the composition of analcite.

The plagioclase-basalt of Saddle Mountain is so near to the monchiquite of analysis VI in chemical composition that if its magma had contained 2 per cent. more water it might in all probability have yielded a monchiquite. As many normal basaltic dikes occur near The Basin it seems reasonable to assume that the analcite-basalt magma contained more water at eruption than did those of the plagioclase-basalt dikes.

In the original description of monchiquite Messrs. Hunter and Rosenbusch call attention to the association of all the rocks of that type then known to them with *elæolite-syenite*, and express the belief that magmas of this kind must have given rise to the monchiquites together with some complementary acid rocks. The expression of this belief in the positive form of the title to

¹ Bull. 107, U. S. G. S., p. 35.

their communication—"Über Monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Elæolithsyenite"—is of course in harmony with the well-known attempts of Professor Rosenbusch to make geological occurrence the foundation stone in the classification of igneous rocks. And whether one believes or does not believe that the "dike rocks" of Rosenbusch have individually or collectively that restricted geological occurrence and that constant association indicating their origin which are assumed in the system of that master, it is of great importance to the development of petrography to know the facts. An association of rocks, the importance of which may be exaggerated from certain standpoints, should not on that account be slighted by those who occupy other points of view.

The analcite-basalt of The Basin occurs in a region where there is a great series of volcanic rocks, mainly andesitic, with basalts, trachytes, and rhyolites, all more or less prominent within five miles of The Basin. Phonolites occur in abundance at and near Cripple Creek, but there seems to be no reason for assuming any relation whatever between the magma of this analcite-basalt and that of the Cripple Creek center. As has been described¹ there are basic dikes at Cripple Creek, some of them plagioclase-basalts and some containing a scanty, colorless, residual material of indistinct character, which was interpreted as nepheline in large part, and hence these rocks were called nepheline-basalts. From the much decomposed condition of these dikes I am unable to say upon reëxamination that they may not originally have contained analcite or a glassy base, but still believe it more probable that they were nepheline rocks.

Since it is evident that the monchiquite or analcite-basalt magma contains nothing peculiar to itself except water, it is difficult to see why Rosenbusch should regard it as a differentiation product of different origin from other basaltic magmas. Nor is it plain why any significance, as to genetic relations, should be attached to the fact that the supposed glassy base of the mon-

¹Geology of the Cripple Creek District, Colorado, by WHITMAN CROSS. Sixteenth Ann. Rep. U. S. Geological Survey, 1895.

chiquites is similar to *elæolite-syenite* in composition. The residual parts of any moderately basic rock, after crystallization of the ferro-magnesian constituents, will be identical with some possible extremely feldspathic rock.

As for the question whether the colorless isotropic base of the so-called monchiquites is really glass or analcite it must be admitted that both are possible, although the former has not been proven in any special case known to me. The point raised by Pirsson, however, seems very important, namely, that as the monchiquites are supposed to be rather deep-seated dike rocks, it is much more reasonable to suppose that the residual substance would crystallize rather than form a glass. This argument has special weight where it can be shown that the residue has practically the composition of analcite, and where associated rocks of the same or more silicious composition are found to be holocrystalline.

The name analcite-basalt has been used for the rock here described because it accurately expresses its relation to allied types, because the name has priority over monchiquite through its use by Lindgren¹ for the rock of the Highwood Mountains, Montana, and further because the definition of monchiquite by Rosenbusch implies a glassy base, which is certainly a possibility, so that there may be rocks to which the name monchiquite applies in the sense originally proposed. It is probable that in many cases it cannot be demonstrated whether the colorless isotropic residual matter is glass or analcite, and where decomposed it will be clearly a matter of inference, in most instances. Criteria will doubtless be discovered by which analcite can be more readily determined than at present. The advisable course then seems to be to apply the name analcite-basalt where the determination can be rendered probable and to apply monchiquite in other cases. The fact that an analcite-basalt would have been a monchiquite if its residue had not crystallized shows the extremely close relationship of the two rocks. But it does not follow that

¹ Eruptive rocks from Montana. Proc. Cal. Acad. Sci., Ser. 2, Vol. III, 1890, pp. 39-57 (reference).

all monchiquites would have yielded analcite-basalt on crystallization, for the ratio of $\text{SiO}_2 : \text{Al}_2\text{O}_3 : \text{R}_2\text{O} : \text{H}_2\text{O}$ must probably be very nearly 4 : 1 : 1 : 2 in order that this unusual rock constituent may form. With lower silica, nepheline and analcite, or glass, would presumably result.

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