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ART. XLVI.—*Missourite, a new Leucite Rock from the High-wood Mountains of Montana*; by WALTER H. WEED and LOUIS V. PIRSSON.\*

THE Highwoods form one of the isolated mountain groups of central Montana which rise like islands from the great treeless plains stretching eastward from the slopes of the Rocky Mountain Cordillera, and forming the great basin of the Missouri River. They consist of a group of extinct, greatly eroded volcanoes, and the elevations which now compose the area are formed chiefly of tuffs, breccias, and lava flows resting on Cretaceous sediments, together with intruded stocks or cores of massive granular rocks which represent the former centers of volcanic activity and from which great numbers of dikes radiate outward in all directions.†

In the preparation of a report on the geology of this mountain group it has been found that the body of granular rock forming the core at one of the denuded volcanic centers is composed of a new rock type whose petrologic character is of exceptional interest. As the type, moreover, proves to be of great importance to systematic petrography, it has been thought best to present a brief account of the rock and its mode of occurrence, a more detailed description and the discussion of its geological and petrographical relations being reserved for the report in preparation.

\*By authority of the Director of the U. S. Geological Survey. Field geology and collection of material by W. H. W.; microscopical petrography by L. V. P.

† A sketch of the geological features of the region, with a geological map, has already been published by the authors. Bull. Geol. Soc. America, vol. vi, p. 389, 1895.

The stock or core is situated at the head of Shonkin Creek, a large stream draining the northern part of the mountains. The headwaters of this stream have cut deeply trenched channels through the mountains and have exposed the granular rock. The region, although mountainous, is almost devoid of timber. Smooth grassy slopes with occasional low rock exposures generally prevail.

*Geological occurrence.*—The new rock type described forms a stock of granular rock intrusive in Cretaceous shales and in the fragmental volcanic material which overlies them, both being highly altered near the contact with the igneous mass. These enclosing rocks are cut by a multitude of dikes, radiating from the core as a center and forming the most conspicuous feature of the surrounding country.

The igneous rock forming the stock constitutes an irregular mass  $2\frac{1}{2}$  miles long and in places half as wide. Where covered by the sedimentary strata, the structure simulates that of a laccolith, but careful study showed that the intrusion is not of this character. The igneous rock was in part intruded between the sedimentary rocks and the volcanic breccias which overlaid them, and in part injected along the bedding planes of the sedimentary strata at the edges of the stock. At the south end of the core a coarse agglomerate of massive rock represents the filling of a vent of a volcanic throat, the material of the blocks and cement varying greatly in granularity but consisting essentially of the same type composing the main body of the core.

Constituting beyond all doubt a geological unit, the rock mass of this volcanic stock varies considerably both in coarseness of grain and in the proportion of its constituent minerals. The specimen selected for description and analysis represented the coarsest grained and freshest variety observed.

The rock seldom forms conspicuous exposures; near the contact it is sometimes weathered into castellated masses and pinnacles, but the usual outcrop is low and hidden by the debris blocks into which the rock ordinarily weathers. Platy parting was observed near the contact, but elsewhere the fracture is massive and determined by shrinkage planes.

*Megascopic characters.*—Seen in the outcrop, the rock appears dark gray, coarse grained, and resembles many basic massive rocks in appearance. In the specimen it is seen to be coarsely and evenly granular and to be composed of light and dark constituents, the proportion by bulk being about two of the light to three of the dark minerals. The separation by the heavy fluids shows, however, that by weight the white mineral forms only one-fifth to one quarter of the whole. The distinction in color is strongly marked and gives the rock a mottled mosaic-like appearance.

Upon examination the dark constituents may be distinguished as chiefly a greenish black augite in columnar masses and aggregates which are never idiomorphic, together with an occasional speck of a bronzy brown biotite of ill-defined outline or a grain of a deep yellow olivine. Filling the interspaces between these dark minerals in formless masses is a very pale greenish gray substance which is leucite. The average size of crystal grain varies from 2 to 5<sup>mm</sup>, so that the rock is of quite coarse granular structure, and it resembles most strikingly in fact many coarse-grained gabbros.

*Microscopic characters.*—The thin section under the microscope shows the minerals present to be *apatite*, *iron ore*, *olivine*, *augite*, *biotite*, *leucite*, and some zeolitic products.

The *apatite* and *iron ore*, which are present rather rarely in moderate-sized grains, show nothing of especial interest beyond that they are found enclosed in the other minerals, and the biotite frequently encloses the iron ore.

The *olivine* is extremely fresh, unaltered in any way, and resembles the olivine of fresh gabbros. It contains great numbers of very fine glass and iron ore enclosures. It never shows any crystal faces, but is in rounded, formless, anhedral grains which are frequently enclosed in biotite and augite.

The *augite* is of a pale green color with a tone of brown; it is very fresh and clear, contains enclosures of ore and specks of biotite and is entirely allotriomorphic, though the orientation of the ore grains is at times zonal, thus indicating crystal planes. It has an excellent cleavage and twinning bands pass through it in places; it does not show any pleochroism.

The *biotite* is strongly pleochroic between a deep umber brown and a pale yellow brown; it is also entirely allotriomorphic though apt to surround the other minerals in bands, especially the olivine and iron ore. It is particularly characteristic in such cases that it then passes from brown into an olivine green variety which has a mottled, somewhat stringy, fibrous appearance. It appears in these cases as if the brown variety had suffered from some magmatic process; it does not seem to be due to any ordinary process of weathering.

*Leucite.*—The leucite appears also like the other minerals in formless masses filling the interspaces between other minerals. It is perfectly clear and free from all inclusions, except now and then a grain of the ferromagnesian minerals. Between crossed nicols it shows most beautifully the cross-banded twinning structure so characteristic of leucite. It is in general perfectly clear, limpid and fresh, though in some areas, in delicate fringes along cracks and on the borders of grains, a low birefracton shows that processes of zeolitization have commenced. This will be described more in detail later.

As the presence of actual leucite itself has never before been demonstrated, so far as we know, in a granular plutonic rock, it became a matter of importance to prove its identification beyond all doubt.

For this purpose a considerable portion of the rock was crushed, sifted, washed, and treated with the potassium mercuric iodide solution. Immediately all of the ferro-magnesian minerals sank, leaving the white component floating. On then lowering the specific gravity by dilution, nothing except an occasional grain fell until 2.465 was reached, when a very little of the white powder came down. This under the microscope proved to consist of isotropic grains with attached particles of pyroxene and biotite which had evidently increased their specific gravity. This behavior of the rock powder in the heavy solution proves the absence of all feldspars and nephelite, thus confirming the microscopic examination. On now lowering the specific gravity of the liquid to 2.405, the great bulk of the white component came down, leaving a small portion floating. The average specific gravity of this material may be taken as 2.44. Examined under the microscope it was found to be a very pure product, consisting of clear isotropic grains which here and there showed a faint birefracton. An analysis of it (by L. V. Pirsson) gave the following results:

			Molecular ratios.
SiO <sub>2</sub> .....	54.46	.907	.907 = 4.12 = 4.
Al <sub>2</sub> O <sub>3</sub> .....	22.24	.216	.220 = 1      = 1
Fe <sub>2</sub> O <sub>3</sub> .....	.68	.004	
MgO .....	trace	----	.213 = .97 = 1
CaO .....	.10	.002	
K <sub>2</sub> O .....	18.86	.200	
Na <sub>2</sub> O .....	.70	.011	
H <sub>2</sub> O .....	2.29	----	
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99.33			

The formula is therefore  $\text{KAl}(\text{SiO}_3)_2$  and the mineral is consequently leucite. There appears to be a very slight deficiency of alkalis, and this may be due in part to replacement by water, whose presence is undoubtedly due to processes of zeolitization which are commencing and which may be in part the cause of the faint birefracton noticed above. The small amount of soda shows the leucite to be a very pure potash compound. So far as we know, this is the first analysis of a leucite from other than an Italian locality, with the exception of that given by Steinecke\* of the mineral from Choi in Persia.

\* Jüngere Eruptivgesteine aus Persien, Inaug. diss., Halle, 1887, p. 12.

*Zeolitization and a probable new zeolite.*—The small portion of powder which was left floating in the heavy solution after the precipitation of the leucite at 2·405 was found to come down gradually as the specific gravity was lowered. At 2·357 much had already fallen. At 2·30 a small portion was still floating, and this was then thrown down and analyzed, in the hope of learning what the character of the zeolitization mentioned above had been. Examined under the microscope it was found to consist of isotropic grains, presumably analcite, mingled with a substance of low birefracton. The amount of material was less than ·4 gram, and of this one-tenth gram was taken for the determination of water.

The analysis (by L. V. Pirsson) gave the following results:

			Ratios.	A.	B.
SiO <sub>2</sub> .....	50·18	·836	·836	4	3·46
Al <sub>2</sub> O <sub>3</sub> .....	25·07	·243	·243	1·16	1
Fe <sub>2</sub> O <sub>3</sub> .....	trace	----			
CaO .....	1·70	·030	·224	1·06	·93
Na <sub>2</sub> O .....	6·53	·105			
K <sub>2</sub> O .....	8·36	·088			
H <sub>2</sub> O .....	9·02	·501	·501	2·39	2·06
Total	100·86				

The substance dissolved readily in acid with separation of gelatinous silica. The ordinary analytical errors are of course somewhat magnified by the small quantities operated upon, but as great care was taken it is not believed they are sufficient to affect the ratios. In the first column under A one-quarter of the silica is taken as unity, under B the alumina is taken as unity. It will be seen that the ratio of the protoxides to the sesquioxide to the water is 1:1:2, as demanded by the analcite formula, but that there is a deficiency of silica. The microscope having already shown that two substances are present, one of them isotropic and most probably analcite, if we consider the soda present as forming that mineral and deduct sufficient silica, water and alumina to make with it analcite, the remainder reduced to 100 becomes:

	Found.	Ratios.		Calculated.		
SiO <sub>2</sub> .....	45·85	·764	·764	3·01	3	44·6
Al <sub>2</sub> O <sub>3</sub> .....	26·07	·253	·253	1	1	25·6
CaO .....	3·12	·056	·218	·86	1	3·4
K <sub>2</sub> O .....	15·35	·162				
H <sub>2</sub> O .....	9·61	·534				
	100·00					100·0

This yields approximately the formula  $(K_2Ca)Al_2Si_3O_{10} \cdot 2H_2O$ , which is exactly that of a natrolite  $Na_2Al_2Si_3O_{10} \cdot 2H_2O$ , in which potash and lime have replaced soda. The ratio of  $CaO : K_2O$  is 1:2.91 or almost exactly 1:3, and the theoretical composition of such a compound  $(K_2Ca)Al_2Si_3O_{10} \cdot 8H_2O$  is given above in the column to the right, and it can be seen that the agreement with the amounts obtained is moderately close. If, on the other hand, we assume that the potash yielded by the analysis belongs to leucite and consider it the isometric mineral, then the soda and lime would belong to a mesolite-like mineral, but in that case the agreement of the ratios is very poor and the water entirely too high. The material also floated at a specific gravity of 2.30 and was thrown down below this, which should have excluded leucite, if present in the proportion the amount of potash would indicate. It is reasonable to suppose also that the zeolitization of leucite would yield a potassic compound and not a sodium one. Taking into consideration the mathematical chances against the improbability of the above ratios being accidental and the natural chemical possibility of a potash molecule similar to natrolite, it is not unreasonable to infer that we have a potash zeolite of the natrolite type in this rock.

In thin section this zeolite is seen as small feathery particles of low birefracton running in narrow bands around the leucites and along fractures; it evidently attacks the mineral from the outer surfaces. In places where it has grown into considerable areas, the areas, while they extinguish as units, are seen to be composed of a curious grouping of two substances in winding, interlaced, vermicular forms almost exactly like micrographic intergrowths of quartz and feldspar, but excessively fine. Of these two substances one is birefractive, the other isotropic, and from what has already been said it seems probable that they are a mixture of the potash zeolite with analcite.

Occasional separate isotropic grains also occur, which do not show the cross-banded twinning of the leucite, and these are supposed to be also of analcite.

*Chemical composition.*—A mass analysis of the rock has been made for the U. S. Geological Survey laboratory by Mr. E. B. Hurlburt of the Sheffield Scientific School, which gave the following results (average of two):

	I.	II.	III.	IV.	Ia.
SiO <sub>2</sub> .....	46·06	47·28	46·73	44·35	·767
Al <sub>2</sub> O <sub>3</sub> .....	10·01	11·56	10·05	10·20	·097
Fe <sub>2</sub> O <sub>3</sub> .....	3·17	3·52	3·53	13·50	·020
FeO .....	5·61	5·71	8·20		·078
MgO .....	14·74	13·17	9·68	12·31	·391
CaO .....	10·55	9·20	13·22	11·47	·188
Na <sub>2</sub> O .....	1·31	2·73	1·81	3·37	·021
K <sub>2</sub> O .....	5·14	2·17	3·76	4·42	·054
H <sub>2</sub> O .....	1·44	2·96	1·24	?	·080
TiO <sub>2</sub> .....	·73	·88	·78	?	·009
P <sub>2</sub> O <sub>5</sub> .....	·21	·59	1·51	?	
MnO .....	trace.	·13	·28	----	
BaO .....	·32	?	?	?	
SrO .....	·20	?	?	?	
SO <sub>3</sub> .....	·05	----	none.	----	
Cl .....	·03	·18	·18	----	
	<hr/>	<hr/>	<hr/>	<hr/>	
	99·57	100·08	100·97	99·62	
Cl = O	·01	·04	·04		
	<hr/>	<hr/>	<hr/>	<hr/>	
	99·56	100·04	100·93		

- I. Missourite, head of Shonkin Creek, Highwood Mountains, Montana. E. B. Hurlburt, analyst.  
 II. Leucite absarokite (Hague, this Jour. vol. xxxviii, p. 43, 1889. Iddings, Jour. Geol., vol. iii, p. 938, 1895. J. E. Whitfield, analyst.  
 III. Shonkinite, Square Butte, Highwood Mountains (Bull. Geol. Soc. Amer., vol. vi, p. 414, 1895). L. V. Pirsson, analyst.  
 IV. Leucite basalt, Bongsberg by Pelm Eifel (Hussak 77 Bd Sitzb. K. Akad. Wiss. Wien I Abt. 1878). E. Hussak, analyst.  
 Ia. Molecular ratios of No. I.

This analysis brings out strongly the leading characteristics of the rock, its very high lime, iron and magnesia, which have compelled the formation of such quantities of pyroxene and olivine; the predominance of potash over soda, which with the low silica have conditioned the formation of the leucite, and which explains also why no feldspars have formed.

The endeavor to compare this rock chemically with the effusive leucite basalts, of which it forms the plutonic representative, has not been entirely satisfactory owing to the lack of accurate and complete analyses of them. A number of analyses exist but are deficient in important determinations, and in some cases it is clear, from what is stated concerning the mineralogical composition, that the separation of the magnesia and alumina is inaccurate, the magnesia being in part thrown down with the

alumina. This is unfortunately an all too common error in rock analyses. One of the best is shown in the above table in No. IV, and it will be seen that the agreement is good in the essential details. In No. II is given one of the absarokites of Iddings, with which the missourite, from a chemical point of view, seems to be closely related. In No. III is shown the composition of the shonkinite from the same mountain group. With the same amount of silica in each, the lower alkalis of the shonkinite have permitted orthoclase to form as the dominant white mineral, while their higher amount in the missourite has produced leucite in its place. In the shonkinite the excess of the alumina over the alkalis has gone into the augite and biotite, and the same is undoubtedly true in the missourite. Taking into consideration the ratios shown by the analysis, the separations by the heavy liquid and the study of the section, the rock has approximately the following mineralogical composition:

Iron ore.....	5
Augite .....	50
Olivine .....	15
Biotite .....	6
Leucite .....	16
Analcite .....	4
Zeolites .....	4
	<hr/>
	100

*Structure.*—The structure is purely granitoid, but is not hypidiomorphic since no mineral shows any crystal planes, but all are wholly allotriomorphic. The iron ore, apatite and olivine commenced forming before the other minerals, but are in rounded anhedral grains; the augite and leucite were crystallizing contemporaneously, as shown by the fact that each encloses grains of the other. In plain light the rock section appears precisely like those of many coarse-grained, massive gabbros, and it is not until the nicols are crossed that it is perceived that the colorless areas are not composed of striated plagioclase but of isotropic leucite.

The relations of the minerals are shown in the accompanying figure.

*Classification.*—It is clear from what has been said in the foregoing that this rock is a new type, and it fills a place which has hitherto been vacant in all systems of rock classification in which either the texture, structure and granularity of rocks or their geological mode of occurrence is taken into account. It is the massive, granular, plutonic representative of the leucite basalts and bears the same relation to them that gabbro bears to

the ordinary plagioclase basalts or granite to rhyolite. It is closely related to theralite, shonkinite, and ijolite, but cannot be classed under any of these types and must therefore be dis-



Micro-drawing of Missouriite  $\times 6$ ; P = pyroxene, O = olivine, b = biotite  
L = leucite.

tinguished by a special name of its own. We have therefore called it *missourite* from the Missouri River, the most prominent and best known geographical object in the region where it occurs.

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