

ART. XXXIV.—*A Sodalite-Syenite and other Rocks from Montana*; by WALDEMAR LINDGREN, with *Analyses* by W. H. MELVILLE.

AMONG the collections in the U. S. National Museum there is a suite of specimens, principally of eruptive rocks, collected in the northern part of Montana, by Dr. C. A. White and Mr. J. B. Marcou during the summer of 1883. The principal localities where the collections were made are the Moccasin Mountains, the Bear Paw Mountains, and Square Butte, near the Highwood Mountains. Rocks from these places have not been previously examined, as far as I know, and it is only proposed in this paper to describe in detail one which appears of particular interest; the general character of the collection, however, may be briefly noted. All of the igneous rocks collected appear to belong to the class of post-Cretaceous intrusive rocks which has such a wide distribution in the Rocky Mountains and which range from the most acid to the most

basic composition. Dr. C. A. White has had the kindness to furnish me with information regarding the occurrence in the field of the rocks and all the statements in the following pages in reference to this are from his unpublished notes.

The Moccasin Mountains form an isolated group about seventy miles southeast from Fort Benton on the eastern side of Judith river. They consist, according to Dr. White, of a central core of eruptive masses, probably laccolitic in character, surrounded by a ring of upturned sediments ranging from the Cretaceous to the Carboniferous. The rocks from the central core appear to belong only to one type. They are light colored, gray or yellowish porphyritic rocks with large phenocrysts of sanidine and soda-lime-feldspar, and smaller ones of brown hornblende; a greenish augite is occasionally seen. The groundmass is always holocrystalline of more or less fine grain and consisting of unstriated feldspar and quartz which sometimes are intergrown in such manner that each quartz grain contains numerous smaller feldspar grains of irregular optical orientation.*

These intrusive rocks from the Moccasin Mountains appear almost identical with the laccolitic masses in the Carboniferous of the Little Belt Mountains and the dikes in the Cretaceous east of Cadottes pass which I have described in previous papers under the name of dacites and diorites.†

Again, very similar rocks have been described in detail by Mr. Whitman Cross from Leadville and other localities in Colorado, and by Mr. Iddings from the Yellowstone Park region. It is apparent that this type of porphyritic intrusive rock is of wide-spread occurrence in the Rocky Mountains; the name of porphyrite or quartz-porphyrite‡ is now usually applied to them.

The Bear Paw Mountains are situated sixty miles northeast of Fort Benton and rise about 2500 feet above the surrounding plains. According to Dr. White, they are largely made up of igneous rocks intruded in Cretaceous strata. The specimens which are taken in the broad valley of Eagle creek at the south base of the mountains, mostly from dikes or dike-like masses, show a very different type from the one just described.

Prevailing is a dark fine-grained porphyritic rock with phenocrysts of greenish idiomorphic augite up to three milli-

* The name of *micro-poikilitic* has recently been suggested by Mr. Iddings for this structure.

† 10th Census, vol. xv, pp. 720 and 731. Eruptive rocks from Montana; Proc. Cal. Acad. Sci., series II, vol. iii, p. 39.

‡ The definition of porphyrite as applied to this type of rocks is given by Mr. Iddings in his paper on "The Eruptive Rocks of Electric Peak and Sepulchre Mountain." 12th Ann. Rep. U. S. Geol. Survey, p. 582.

meters long and flakes of a brown, slightly pleochroic mica with very small axial angle. The groundmass consists mostly of lath-shaped plagioclase crystals together with augite and mica. In some specimens with phenocrysts of olivine and augite the groundmass is glassy and contains no feldspar; this rock approaches closely to certain limburgites. The general appearance of the Bear Paw series and the absence of phenocrysts of feldspar in it points to its connection with the group which Rosenbusch has called the lamprophyric dike rocks.

The suite of specimens collected at Square Butte is of particular interest. Square Butte, which really forms the eastern end of the Highwood Mountains, is situated thirty miles southeast of Fort Benton and eighteen miles nearly due east of Highwood Peak. The rocks from this locality show a close relationship with those from the main group of the Highwood Mountains, and it may perhaps not be amiss to refer briefly to the character and rock types of the latter.*

The Highwood Mountains with their sharp and jagged peaks and ridges stand in isolated grandeur on the monotonous plains twenty miles south of Fort Benton on the Missouri river. They form an oblong group twenty miles from north to south and thirty miles from east to west and their highest peaks rise 3600 feet above the surrounding Cretaceous plateau which here consists of the nearly horizontal black shales of the Fort Benton group. The mass of the mountains is made up of a network of dikes and probably also of laccolitic masses between which are included contact metamorphosed and disturbed remnants of sediments none of which are believed to be older than the Cretaceous. Above the Fort Benton group once rested the whole thickness of the Montana and Laramie formations or at least 8000 feet of sediments. Volcanic activity began at this point at or after the close of the Cretaceous period. Great quantities of igneous rocks were forced into the sediments and on the surface the eruption was probably connected with the phenomena of a subaerial volcano. Subsequent erosion has removed nearly the whole thickness of the softer Laramie rocks, exposing the harder core of the ancient volcano and the abyssal rocks solidified under a pressure of many thousand feet of superincumbent sediments.

The Highwood Mountains are very similar in structure to the Crazy Mountains, also in Montana, recently described by

* The general geology of the Highwood Mountains has been described by Prof. W. M. Davis in 10th Census, vol. xv, p. 697, and the petrography by W. Lindgren, *loc cit.*, p. 729. See also, "Eruptive Rocks from Montana," by W. Lindgren. Proc. Calif. Acad. Sci., series II, vol. iii, p. 40.

Mr. J. E. Wolff,* but the petrographical character of the two volcanic districts is somewhat different.

The intrusive rocks of the Highwood Mountains are in general basic in composition and holocrystalline in structure. There are a few coarsely granular rocks, principally dikes of augite syenites, but a much more common type of rock is of a porphyritic structure and closely allied to the trachytes.†

Augite-trachytes are frequent, usually containing two generations both of the orthoclase and the augite. The latter is characterized by a deep green color and evidently contains an admixture of the aegirine molecule. The quantity of augite in these rocks is sometimes very large, and they grade over into basaltic rocks with orthoclase, plagioclase, olivine and augite.

Attention should be called to the great similarity of these rocks with the peculiar intrusive and extrusive masses recently described by Mr. Iddings from the Crandall basin and the Absaroka range in the National Park region.‡

Another interesting type in the Highwood Mountains is that of the analcite-basalts which, with holocrystalline porphyritic structure, consist of augite, olivine, brown mica and analcite. The latter mineral here appears under conditions strongly suggesting a primary origin.

Square Butte and vicinity was not visited by me in 1883, and I am again indebted to Dr. C. A. White for notes regarding it. As already mentioned, it forms the extreme eastern part of the Highwood Mountains with which it is connected by several lower buttes and ridges. The elevation of the flat top, about three-quarters of a mile in diameter, is 5600 feet above sea level according to the maps of the Northern Transcontinental Survey (Fort Benton sheet, U. S. Geol. Survey). The Butte is composed of a light gray eruptive rock with very distinct lamination. In the elevated table land surrounding its base are found several horizontal sheets of a dark gray or black volcanic rock interbedded with black Cretaceous shale belonging to the Fort Benton group. There are three distinct sheets of this dark rock, each about eight feet thick and separated by beds of shale of about the same thickness. Surrounding Square Butte there are numerous dikes apparently radiating from the central mass.

The dark volcanic sheets are represented in the collection by three types. Unfortunately, most of them are very much decomposed. The first is porphyritic and contains as phenocrysts augite of the Highwood type, olivine, usually brown

* Bull. Geol. Soc. Amer., vol. iii, p. 445.

† This term is here used without restriction to surface flows.

‡ The Origin of Igneous Rocks, by J. P. Iddings. Phil. Soc., Washington, D. C., vol. xii, p. 169.

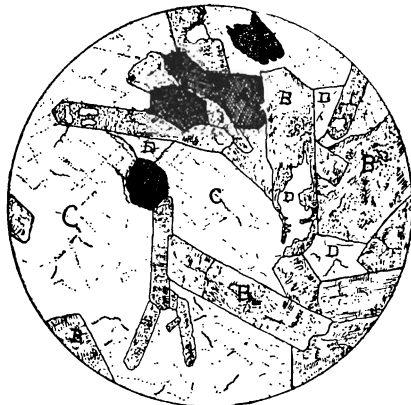
mica, and lastly white isometric crystals up to two millimeters in diameter. The original character of these white crystals cannot be made out as they are completely converted into secondary aggregates. The groundmass, which is quite fine-grained, contains much augite, besides other indeterminable minerals.

The second type is similar to the "analcite-basalts," but the specimens are not fresh and the white mineral is again completely decomposed. This type is more coarsely crystalline and not so pronouncedly porphyritic.

The third type is coarsely granular and in composition approaches the *thermalite* described by Mr. J. E. Wolff from Martindale near the Crazy Mountains.

The main mass of Square Butte is represented by a light yellowish grey, rather coarse grained granular rock of miarolitic appearance (No. 28705, U. S. National Museum, Summit Square Butte). Macroscopically it consists of grains and broad lath-shaped crystals of feldspar, often five millimeters long, black glistening hornblende prisms reaching three millimeters in length, and sodalite which appears as small grains of a pale brownish color. Under the microscope the rock is shown to be hypidiomorphic granular and the following constituents are noted in their order of formation: *apatite*, *hornblende*, *orthoclase* (with some *plagioclase*), *sodalite*, and *analcite*.

Fig. 1.



Sodalite-syenite magnified 7 diameters. A hornblende, B orthoclase, C sodalite, D analcite.

The predominant constituent is orthoclase, occurring both as irregular grains and lath-shaped crystals; individuals partly or wholly imbedded in sodalite show terminal faces. Many of

the grains are very clear, but the larger part are somewhat clouded, not, however, by decomposition and the formation of muscovite and kaolin, but principally by irregular and elongated gas inclusions together with others of indeterminable character. Small crystals of apatite, as well as green and brown hornblende microlites, are noticed in the feldspars. A triclinic feldspar with very fine twinning lamellæ in only one direction occurs in intimate, almost micropertthitic intergrowth with many of the orthoclase grains. This triclinic feldspar which usually is more pellucid than the orthoclase has every appearance of being albite.

Many of the feldspar grains are corroded in a peculiar manner as shown on the figures and are filled with faintly doubly refracting analcite. The same corrosion has been observed in an augite-syenite from the Little Belt Mountains,* although the enclosed mineral was not then recognized as analcite; a comparison with the Square Butte rock shows beyond doubt the identity of the two minerals. It has also been noted by J. Francis Williams in similar rocks.† This analcite is doubtless derived from the albite. It is a curious fact that although there is abundant sodalite present in the rock it should have remained fresh and undecomposed while the albite was attacked. There are no other zeolites or products of decomposition and it appears as if this conversion into analcite would have taken place very soon after the solidification of the rock. It certainly cannot here be regarded as a product of ordinary decomposition. Prof. Brögger‡ and other authors have shown that analcite, in general, is the earliest of all the zeolites and that it must have been formed at a relatively high temperature, that is, perhaps between 200° and 400°. Friedel and Sarasin§ for instance obtained analcite by heating the constituents of *albite* with water to 400°.

In order to test the character of the feldspars, fragments were introduced into a Thoulet solution. The feldspars began to sink at sp. gr. 2.57 and continued to fall until a sp. gr. of 2.45 was attained. Two portions were subjected to partial analysis:

Sp. gr. 2.57	Sp. gr. 2.55
Na ₂ O 6.08	3.88
K ₂ O 8.91	11.03

It is evident that the first portion is orthoclase with a strong admixture of albite and equally so that the second is a nearly

* Eruptive Rocks from Montana, loc. cit., p. 46.

† Ark. Geol. Survey, 1890, vol. ii, p. 79.

‡ Zeitschrift f. Kryst. u. Miner., xvi, p. 169.

§ Compt. rend. 1883, xcvi, 290.

pure orthoclase. The analcite which penetrates the feldspars is the cause of the lowering of the specific gravity; a mechanical separation of the two minerals is hardly practicable.

The hornblende occurs as slender black prisms bordered by αP and $\alpha P\infty$; terminal faces are not seen. It is idiomorphic both against the orthoclase and the sodalite. The color in thin section is a very dark brown, so dark in fact that in slides of ordinary thickness many crystals are only faintly translucent. The pleochroism is very strong; the rays vibrating parallel to *c* and *b* are both very strongly absorbed, producing a dark brown color, while those vibrating parallel to the axis of maximum elasticity are less absorbed with a yellowish brown color, sometimes showing a tinge in green. The axis of minimum elasticity is inclined to the principal axis at an angle not exceeding 13° . In some places the brown hornblende is undergoing a peripheral conversion into a green modification with an extinction up to 25° .* The specific gravity of the hornblende was found to be 3.437. From the characteristics mentioned above the identity with Prof. Brögger's barkevikite† seemed highly probable and to confirm this a quantity was isolated and analyzed.

	I. Square Butte.	II. Barkevik. Analyzed by G. Flink.
H ₂ O (above 100°)	0.24	
SiO ₂	38.41	42.46§
Al ₂ O ₃	17.65†	11.45
Fe ₂ O ₃	3.75	6.18
FeO	21.75	19.93
NiO	trace	
MnO	0.15	0.75
CaO	10.52	10.24
MgO	2.54	1.11
Na ₂ O	2.95	6.08
K ₂ O	1.95	1.44
	<hr/> 99.91	<hr/> 99.64

The mineral differs from barkevikite, an analysis of which is given under II, in containing somewhat less silica and alka-

* The conversion of brown compact hornblende into a green fibrous modification was first observed by Mr. G. F. Becker, in his "Geology of the Comstock Lode," Monogr. III, U. S. G. S., p. 36, Washington, 1882. The same change has been noted by Mr. F. Becke and Prof. G. H. Williams, Bull. 28, U. S. Geol. Survey, p. 45.

† Z. f. Kryst., u. Min., xvi, p. 412.

‡ The titanate in (I) is contained in the alumina. The rock carries 0.29 per cent TiO₂ and contains 23 per cent hornblende; hence, there being no other titanium minerals present, the TiO₂ in the hornblende may be calculated at 1.26 per cent which would reduce the alumina to 16.39 per cent.

§ With some TiO₂.

lies, while the alumina is higher. The low percentage of CaO and MgO and the high amount of FeO show, however, that it is very closely related to it. In the absence of any crystallographic orientation the only way of distinguishing it from arfvedsonite is by its color and streak. I believe this is the first time that barkevikite has been identified in the United States. The hornblende in the *pulaskite*,* described by J. Francis Williams, also a syenitic rock, is probably closely related to barkevikite, but no analysis was made of it.

The sodalite forms irregular grains and partly developed crystals; it is allotriomorphic against the feldspar, but usually idiomorphic whenever bordering on the analcite. It sometimes fills triangular interstices between the lath-shaped feldspars. The period of its consolidation seems here to be decidedly later than that of the feldspar. The cleavage parallel to $\alpha 0$ is well indicated by the arrangement of very numerous inclusions in part of gas, in part of liquid with very large air bubbles; frequently these inclusions have the form of the enclosing minerals. Small moving bubbles do not often occur. The sodalite is perfectly isotropic and very fresh. Only very locally may a corrosion and decomposition into analcite be observed, such as shown on the large sodalite grain in figure 2.

Fig. 2.



Sodalite-syenite. Magnified 25 diam. A hornblende, B orthoclase, C sodalite, D analcite.

A little chlorite or serpentine is sometimes infiltrated from the hornblende. The sodalite is somewhat unequally distributed through the rock; the figures are taken from places where it

* Geol. Survey of Arkansas, Ann. Rep., 1890, vol. ii, p. 64.

is especially abundant and give a rather exaggerated idea of the quantity of this mineral.

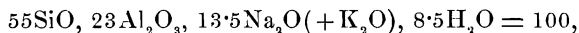
Besides the already mentioned occurrence of analcite in the feldspar it also fills interstices between the feldspar and sodalite grains in the manner shown in the figures. It is very clear and free from inclusions; a peculiarity of it is that contrary to the data usually given its refraction appears stronger than that of the feldspar and sodalite. It always shows a faint double refraction in dark gray and bluish colors and each grain usually divides into several sectors with different optical orientation. The form of the larger grains is triangular or polygonal, being molded by the crystallographic faces of the feldspar and sodalite as shown in the figure. The interpretation of this analcite offers some difficulties. It is not derived from the sodalite; there is no direct proof to show that it has been derived from nepheline; if it is an altered nepheline, then this mineral must have been formed later than the sodalite. No nepheline has been found so far, but it is by no means impossible that other parts of the eruptive mass might contain this mineral. Another possibility is that the analcite fills miarolitic cavities in the rock; it cannot then very well have been derived from any other mineral than the feldspar. The specific gravities of the sodalite and analcite were found to lie extremely close together. They both fell between 2.27 and 2.23. A special and repeated separation was made of this mixture which resulted in the two minerals being obtained in a relatively pure state. The specific gravity of the sodalite ranges from 2.27 to 2.255 while that of analcite extends from 2.26 to 2.24. The two products were then analyzed:

	III. Sodalite.	IV. Analcite.
H ₂ O (at 100°)-----	0.45	
H ₂ O (above 100°)----	3.73	(7.07)*
SiO ₂ -----	41.56	49.54
Cl -----	4.79	1.67
Al ₂ O ₃ -----	29.48	25.07
FeO -----	0.49	0.40
CaO -----	0.49	0.22
MgO -----	0.15	0.20
Na ₂ O -----	19.21	15.32
K ₂ O -----	0.91	0.89
	<hr/>	<hr/>
	101.26	100.00
Excess O -----	1.08	
	<hr/>	
	100.18	

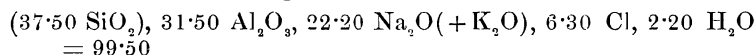
* By difference.

It is evident that both of these analyses are made of mixed material and equally plain that one of the constituents is sodalite.

In order to calculate approximately the composition of the two minerals let us assume an analcite composed as follows :

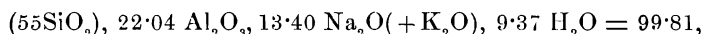


and a sodalite containing 37.5 per cent SiO_2 . From the silica contents it follows then that (III) contains 76 per cent sodalite and 24 per cent analcite. Calculating further the remaining elements and disregarding for the present the small quantities of Fe, Ca and Mg, one obtains



which, excepting the high percentage of water, is a normal sodalite.

On the other hand, assuming a sodalite composed as above and an analcite containing 55 per cent SiO_2 , it follows that (IV) contains 68 per cent analcite and 32 per cent sodalite, and that the other constituents of the analcite are



which corresponds very closely to a normal analcite. It does not seem possible to avoid the conclusion that a part of the water belongs to the sodalite. Under the microscope the sodalite appears perfectly pure and isotropic and no other zeolites such as natrolite or hydronephelite are present. If all the water belonged to the analcite it would have to contain about 15 per cent H_2O . The amount of H_2O in analcite is, however, very constant and varies only between 8 and 9 per cent. As a matter of fact, the majority of sodalite analyses do contain a small amount of water, and it has been suggested that a certain quantity of Cl may be replaced by (OH).

A quantitative separation of the rock was made and the following figures obtained for which only an approximate correctness is claimed :

66 feldspar.
23 hornblende.
8 sodalite.
3 analcite.

100

The proportion between albite and orthoclase could not be correctly ascertained on account of their very intimate intergrowth, but from the thin sections and from the separation it was estimated that the rock might contain 50 per cent ortho-

clase and 16 per cent albite. If it is further assumed, for the purposes of a calculation of the rock analysis, that the composition of the two minerals is

	Orthoclase.	Albite.
SiO	68	66
Al ₂ O ₃	21	19
Na ₂ O	11	13
K ₂ O	--	2
	<hr/>	<hr/>
	100	100

the composition of the rock may be calculated as follows:

	Horn- blende.	Ortho- clase.	Albite.	Soda- lite.	Anal- cite.	Calc. comp.	Rock analysis. V.	Difference.	VI.
H ₂ O*	----	----	----	----	----	----	0.26	----	----
H ₂ O†	0.06	----	----	0.16	0.29	0.51	1.51	+ 1.00	3.49
SiO ₂	8.83	33.00	10.88	3.00	1.65	57.36	56.45	— .91	55.76
P ₂ O ₅	----	----	----	----	----	----	0.13	----	----
Cl	----	----	----	0.48	----	0.48	0.43	— .05	----
TiO ₂	0.28	----	----	----	----	0.28	0.29	----	----
Al ₂ O ₃	3.77	9.50	3.36	2.52	0.66	19.81	20.08	+ .27	21.61
Fe ₂ O ₃	0.86	----	----	----	----	0.86	1.31	+ .45	1.65
FeO	5.00	----	----	----	----	5.00	4.39	— .61	4.09
NiO	----	----	----	----	----	----	trace	----	----
MnO	0.04	----	----	----	----	0.04	0.09	+ .05	----
CaO	2.43	----	----	----	----	2.43	2.14	— .29	2.26
MgO	0.58	----	----	----	----	0.58	0.63	+ .05	0.74
Na ₂ O	0.69	1.00	1.76	1.72	0.40	5.57	5.61	+ .04	6.94
K ₂ O	0.46	6.50	----	0.08	0.03	7.07	7.13	+ .06	5.34
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>		<hr/>
	23.00	50.00	16.00	7.96	3.03	99.99	100.45		101.88
					Excess O.		.10		
							<hr/>		
							100.35		

The complete analysis of the rock is inserted under V in the third column from the right. The analysis agrees fairly well with the calculated composition in all except SiO₂ and H₂O; the former is very uncertain on account of no complete analysis having been made of the feldspars; the latter is too low in the calculated composition and the rock evidently contains more analcite than 3 per cent. A part of that amount which is not accounted for in the calculated composition doubtless fell together with the feldspars in the separation and some per cent of analcite should be substituted in the 16 per cent of albite. This would bring the calculated analysis closer to the actual composition, as the only effect would be to lower the SiO₂ and increase the H₂O. The analysis further shows that no plagioclase except albite is contained in the rock and also that there is about 0.3 per cent of apatite present.

* At 100°.

† Above 100°.

The absence of titanite is remarkable, but as only one specimen has been examined it is not unlikely that this mineral as well as some of the rarer minerals frequently connected with such rocks may be found upon closer examinations of more abundant material.

The analysis agrees in general with that of many nepheline-syenites, but differs from them all in the fact of containing much more K_2O than Na_2O ; it has also great similarity with Prof. Brögger's augite-syenite (Laurvikite) except as to the alkalies. Most of all it resembles the nepheline-syenite from the Cape Verde Islands,* the analysis of which is copied in the right column of the table (VI). The latter, however, contains much less K_2O . From the ordinary syenite it differs in the amount of silica, as well as in the low percentage of CaO and MgO .

Only one sodalite-syenite appears to have been described previously; it occurs at Kangerdluarsuk, Greenland, and its minerals have been described in detail by Mr. Joh. Lorenzen,† but I have been unable to find an analysis of the rock. It consists of microcline, arfvedsonite and sodalite, while nepheline is only found in places.

I would finally like to call attention to the striking similarity of the analysis of this rock with those of certain leucitophyres from Rocca Monfina.‡ Under different conditions the same magma, now crystallized as a sodalite-syenite, might have produced a leucite-feldspar rock.

Résumé—The following rocks are described in this paper:

1) Porphyrites and quartz-porphyrites from the Moccasin Mountains. They are intrusive, holocrystalline rocks of post-Cretaceous age and consist of quartz, orthoclase, soda-lime feldspar and hornblende.

2) Porphyritic, dark colored post-Cretaceous dike rocks from the Bear Paw Mountains. They consist of augite, olivine, biotite and triclinic feldspar and have a general resemblance to the lamprophyric dike rocks of Prof. Rosenbusch.

3) A post-Cretaceous sodalite-syenite from Square Butte. This rock consists of hornblende, orthoclase, albite, sodalite and analcite. No nepheline is found but the interstitial analcite, of which there is 3 per cent, might possibly have been derived from such a mineral. It contains 8 per cent of sodalite.

Washington, D. C., Dec., 1892.

* C. Doelter, Die Vulcane der Cap Verden und ihre Producte; cited in Arkansas Geol. Survey, 1890, vol. ii, p. 81.

† Mineralogical Magazine, vol. v, p. 49, 1882.

‡ Analyses cited in "The Origin of Igneous Rocks," by J. P. Iddings. Phil. Soc. Washington, Bull., vol. xii, p. 199.