

POTASH ANALCIME AND PSEUDOLEUCITE FROM THE HIGHWOOD MOUNTAINS OF MONTANA

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INTRODUCTION

This paper is based on a field and laboratory study of the igneous rocks of the Highwood Mountains, Montana, carried on by E. S. Larsen, C. S. Hurlbut, Jr., C. H. Burgess, D. T. Griggs, B. F. Buie, and N. A. Haskell, and we have used freely the collections, field and laboratory notes, and other data of our coworkers. We are indebted to them for permitting us to make use of their material and for helpful co-operation in every way. The work was carried on as a project financed by the Shaler Memorial Fund, and we are grateful to the Department of Geology, Harvard University, for generous support from that fund.

In the field numerous collections were made of the rocks of the area, and specimens were collected from the contact-zone and the centers of many of the dikes and laccoliths in order to study the effect of chilling and slow cooling. Several hundred thin sections from carefully collected specimens were examined.

The potash-rich rocks of the Highwood Mountains are distributed over an area more than twenty-five miles across. In the central part there is a pile of volcanic rocks over a thousand feet thick, also a number of stocks and many smaller intrusives. The Cretaceous sediments about the volcanic rocks are intruded by many dikes, sills, and laccoliths.

The volcanic rocks are nearly all dark basaltic rocks consisting of about one half of phenocrysts distributed through a groundmass whose texture ranges from very fine to rather coarse, for volcanic rocks. The chief phenocrysts are pyroxene, olivine, and leucite, analcime or pseudoleucite or their alteration products. Some rocks have phenocrysts of biotite or of a barium sanidine with as much as 5 per cent of BaO. The groundmasses of the rocks are made up of the same minerals as the phenocrysts, but sanidine and biotite are much more abundant. Plagioclase is lacking in the greater part of the rocks but is present in a few. Of the eighty thin sections of volcanic rocks studied, the following percentages of rock types were found:

Rock Types	Percentages
Basalts with fresh leucite.....	5
Basalts with clear analcime.....	24

Basalts with secondary cloudy isotropic alteration products from leucite or analcime	29
Basalts with natrolite and other zeolites from leucite or analcime.....	10
Basalts with pseudoleucite.....	18
Basalts with feldspar as the felsic mineral.....	7
Mafic phonolites.....	3
Other types.....	4

The dike rocks are in great part very similar to the volcanic rocks but some are phonolites, syenites, and alnoites. The central portions of the dikes are rather coarse grained, and among the basaltic rocks few contain fresh leucite or analcime, and most have pseudoleucite. The stocks are in large part shonkinites, with smaller amounts of nepheline syenites, syenites, monzonites, and very rare granite. The laccoliths are chiefly shonkinites with the central parts of nepheline or sodalite syenites.

POTASH ANALCIME

Many of the fresh lavas and a few of the dikes contain abundant phenocrysts of a clear glassy potash analcime which has the form and appearance of leucite, but lacks twinning and has an index of refraction of 1.493. This analcime is present in rocks that are much like those that contain leucite, except for the higher content of soda and water in the analcime rocks. The analcime is clear in the freshest rocks, but in most specimens it is traversed by cracks along which the analcime is cloudy from alteration, and some of the analcime is completely altered to the cloudy material. The analcime occurs chiefly as phenocrysts but in part also in the groundmass. On its borders it shows a small reaction rim that is made up chiefly of orthoclase. This analcime has all the appearance under the microscope of being a fresh primary mineral and it is found only in the freshest rocks—rocks in which the olivine and other minerals show little alteration and which show no zeolites.

An analysis of a sample of this analcime is shown in Table 1, column 1. Analcime formed at low temperatures is in all cases low in potash, and from our knowledge of the isomorphism of Na and K and from the fact that the atomic radii of Na (0.95) and K (1.33) are very different we should expect little isomorphic replacement of one by the other. At high temperatures we find that K and Na can replace each other to a much greater extent, as in the sanidines. The analcime of the Highwood lavas was probably formed at a high temperature, and this tends to confirm the evidence from the thin sections that these clear analcime phenocrysts are primary.

TABLE 1. ANALYSES OF ANALCIME AND PSEUDOLEUCITE

	1	2	3	4	5	6
SiO ₂	51.41	54.90	49.87	42.43	64.39	56.9
TiO ₂	none			none	0.09	0.1
Al ₂ O ₃	23.03	23.30	22.55	30.11	18.81	22.6
Fe ₂ O ₃	1.35	tr	1.51	0.06	0.91	0.6
FeO						
MnO	none					
MgO	0.43	0.70	1.28	none	none	none
CaO	1.19	1.90	2.62	3.24	0.39	1.3
Na ₂ O	8.48	10.40	10.92	9.61	0.98	3.9
K ₂ O	4.48	1.60	2.66	4.97	13.71	10.8
H ₂ O—	0.28	7.50	11.05	9.67	0.45	3.5
H ₂ O+	9.32					
SO ₃		none	tr			
Cl		none	none			
BaO					none	none
SrO					none	none
	99.97	100.30	102.46	100.09	99.73	99.7

1. Analcime. Phenocrysts from an analcime basalt (FBH 169) from the west end of the ridge that is east of the Geyser-Geraldine road and west of Round Butte. F. A. Gonyer, analyst.
- 2 and 3. Analcime, believed by Lindgren to be primary. From a dike in the Highwood Mountains. Analyses by W. H. Melville.
4. Part of pseudoleucite soluble in acid. From headed dike along Geraldine-Geyser road. F. A. Gonyer, analyst.
5. Part of pseudoleucite insoluble in acid. Same pseudoleucite as 4.
6. Whole pseudoleucite crystals. Same pseudoleucite as 4 and 5.

PSEUDOLEUCITE

Description

Most of the pseudoleucite in the rocks of the Highwood Mountains is made up of a mixture of orthoclase and a cloudy, amorphous material. In some of the lavas, especially where altered, and in a very few of the other rocks, natrolite or analcime takes the place of the amorphous material and locally calcite and other alteration products are present. The orthoclase has low indices of refraction ($\alpha=1.518$, $\beta=1.523$, $\gamma=1.525$) and is low in sodium and barium. The clouded amorphous material has the composition of nepheline with water. It is crossed by cracks and has an index of refraction of 1.500. The pseudoleucite phenocrysts range in size from a few millimeters to ten millimeters or more across.

A representative sample, using whole crystals of the pseudoleucite, was picked out from the pseudoleucite-rich rock in the upper part of the

headed dike and the extraneous material was carefully removed. A two-gram portion of this pseudoleucite was treated with acid by F. A. Gonyer and 66.0 per cent was insoluble. The insoluble fraction was examined under the microscope and was found to be at least 98% feldspar, and the chief impurity was undissolved amorphous material. Both the feldspar and the solution containing the dissolved fraction were analyzed according to standard analytical methods with the results shown in Table 1, columns 4, 5, and 6.

The feldspar of the pseudoleucite is a rather pure potash feldspar. The amorphous material yields approximately the formula $2(\text{Na}_2, \text{K}_2, \text{Ca})\text{O} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot 4\text{H}_2\text{O}$, which is near that of thomsonite, and it might be considered an amorphous thomsonite. No nepheline was found in the pseudoleucite of the Highwood Mountains, but the amorphous material has about the composition of nepheline with water added, and it was probably derived from the hydration of nepheline.

The feldspar of some of the pseudoleucites is in matted, submicroscopic fibers and in others it is in grains a millimeter or more across. In the fine-textured varieties the feldspar grows in from the boundaries of the leucite crystal, and the amorphous material is concentrated in the central part.

There is a strong tendency for the pseudoleucite to be fine grained in rocks that have fine grained groundmasses and coarse textured in rocks that have coarse-textured groundmasses. This is well shown in the many pairs of specimens from the borders and central parts of dikes. In the laccoliths the chilled borders have pseudoleucite phenocrysts with submicroscopic orthoclase; and, as the rock becomes more coarsely grained away from the contact, the pseudoleucite becomes coarser; and, finally, in the main shonkinite it grades into granular material of the shonkinite. In places in the stocks, dikes, and laccoliths all stages in the recrystallization of the pseudoleucite can be seen from very finely crystalline, with sharp outline, to coarse grained rounded patches in which the individual orthoclase crystals merge with those of the groundmass. Here the chief difference between the pseudoleucite and the groundmass is in the lack of femic minerals in the former. Finally, all evidence of the pseudoleucite is lost and the rocks are ordinary granular rocks.

Occurrence

Somewhat more than half the leucite and analcime of the rocks of the area have been replaced by pseudoleucite. In the lavas some of these minerals have been replaced by a cloudy amorphous material that resembles the amorphous part of the pseudoleucite. A small proportion of the rocks still contains leucite or analcime. Pseudoleucite is abundant

in the dikes and lava flows. It is present in the chilled borders of the laccoliths and stocks and can be recognized in some of the coarse grained rocks of the stocks. Some of the best pseudoleucite (analyses 4-6) comes from the headed dike and can be collected from the cuts along the road from Geraldine to Geyser, about 8 miles southwest of Geraldine.

In many of the rocks the leucite or analcime has been completely converted to pseudoleucite, but in some this conversion has taken place only slightly along the margins, leaving most of the crystals as fresh leucite or analcime, or as the cloudy amorphous alteration product. All stages in the conversion have been found. There is little relation between coarseness of texture of the rocks and the extent to which pseudoleucite has replaced the leucite or analcime, as these minerals with little replacement appear to be at least as common in the granular rocks of the stocks as in the dikes and lava flows. In the dikes whose chilled borders and central parts were both studied, the leucite and analcime of the central parts in which the groundmass and the pseudoleucite are relatively coarse grained, show nearly the same amount of replacement by pseudoleucite as do the chilled borders in which the groundmasses and the pseudoleucite are submicroscopic in texture. Where the border of the dike carries leucite or analcime with narrow borders of pseudoleucite, the central part also carries these minerals with a border of pseudoleucite that is of about the same width as or a little broader than that of the contact rock.

Pseudoleucite was found chiefly in the phenocrysts of the porphyritic rocks, but it was found also in the groundmasses of some of them. It is not present in most of the granular rocks, as in the slow crystallization of such rocks it is commonly lost in the course of crystallization. Many, if not most, of the shonkinites and nepheline syenites originally had pseudoleucite, which has become a part of the granular rock. All stages in this recrystallization have been seen from pseudoleucite with submicroscopic texture, to that with granular texture such that the pseudoleucite can be distinguished only as rounded patches that lack dark minerals, and finally to granular rocks. All the stages have been found in sections from the chilled borders to the centers of some of the dikes and laccoliths.

A very curious occurrence of pseudoleucite, and one difficult to explain, is as large scattered leucitohedrons in a contact metamorphosed sandstone next to the headed dike on the small saddle east of the gulch, three-quarters of a mile east of the Geraldine-Geyser road. At this locality there is no visible sharp contact between the fergusonite of the headed dike and the overlying sandstone. In passing from the typical igneous rock to the sandstone the matrix first becomes a feldspathic rock, with some

interstitial quartz, then a quartzite with interstitial orthoclase and some biotite, and about 12 millimeters from the contact it is a hardened sandstone, and beyond that it is but slightly metamorphosed. In passing into the sandstone the pseudoleucite becomes gradually somewhat smaller, fewer in number and less regularly distributed. These well formed pseudoleucite leucitohedrons, as large as 5 millimeters across, are present as much as 10 millimeters from the contact where they are imbedded in a matrix that is made up chiefly of quartz grains with some interstitial orthoclase and a little biotite.

Time of Formation

The following facts point strongly to the conclusion that the pseudoleucite was formed for the most part after the magmas reached their present positions—after the intrusion of the dikes, sills, and stocks, but before complete crystallization of the rocks.

1. In rocks with fine grained groundmasses, such as the chilled borders of dikes, the pseudoleucite is made up of a very finely crystalline aggregate. The pseudomorphs are in well formed leucitohedrons that are sharply separated from the groundmass so that on weathering well formed pseudomorphs can be broken out, while in rocks with coarse grained groundmasses, such as the centers of dikes, the aggregates that make up the pseudoleucite are correspondingly coarsely crystalline.

2. Pseudoleucite is present in the groundmasses of some of the dikes and lavas.

3. The pseudoleucite phenocrysts are commonly as large and abundant in the chilled borders of the dikes as in the centers, but in some dikes pseudoleucite is present in the groundmass of the main part of the dikes but is lacking or in very small grains in the chilled borders.

Origin

The leucite has not all been replaced by pseudoleucite in the Highwood rocks, and there seems to be no relation between the texture of the rocks and the extent to which the leucite has been replaced. Some of the coarsely granular rocks carry leucite with only slight replacement along the margins, and unreplaced leucite is about as common and abundant in the stocks as in the lavas and dikes.

In the chilled borders of the thirteen dikes studied, the leucite is replaced to nearly the same extent as in the centers of the corresponding dikes, although the intergrowths making up the pseudoleucite are much finer textured in the chilled borders than in the centers.

Schairer and Bowen (1935) believe that pseudoleucite is formed by the reaction of the residual liquid on leucite crystals, as is indicated by

the equilibrium diagram shown in Fig. 1, and they call this reaction the pseudoleucite reaction. However, the facts stated in the preceding paragraph show that in the Highwood Mountains magma the pseudoleucite reaction took place even when the rocks were rapidly cooled and that the leucite remaining in some of the rocks cannot be explained as due to failure of the pseudoleucite reaction to go to completion, but rather to the chemical composition of the liquid phase or of the leucite crystals. The presence of typical pseudoleucite in leucitohedrons five millimeters across in the metamorphosed sandstone as much as ten centimeters from the headed dike is difficult to explain by the "pseudoleucite reaction."

Rittmann (1933, p. 43) concluded that the pseudoleucite of Vesuvius was formed by "autopneumatometamorphism." In the Highwood rocks the cloudy isotropic material of the pseudoleucite may have been formed from nepheline, leucite or analcime by such a process, or by some hydrothermal process or even by weathering, but the orthoclase and original nepheline must have been magmatic.

Knight (1906) concluded that leucite crystallized in the intratelluric stage as soda leucite and that, after the entire magma had solidified, the soda leucite changed to pseudoleucite. In the Highwood Mountains most of the leucite formed in the intratelluric stage but, as shown above, the change to pseudoleucite took place during the solidification of the groundmass. Most of our observations could be explained by assuming that the leucite crystallized with variable amounts of soda leucite in solid solution, with some zoned crystals richer in soda in their outer parts, and that the soda leucite unmixed to nepheline and orthoclase, but the potash leucite did not. Any unmixing must have taken place before the rock was completely crystalline and the resulting pseudoleucite was recrystallized and coarsened in texture where the rock cooled slowly. In this later stage there was certainly some reaction, as the coarse pseudoleucite merges with the matrix and even the least replaced leucites show a lacework border of orthoclase replacement.

It is also possible that the "pseudoleucite" is derived from the unmixing of potash analcime.

Some of the evidence favoring the postulate that pseudoleucite is formed by inversion and not by magmatic reaction is:

1. Well formed crystal pseudomorphs of pseudoleucite with sharp boundaries against the groundmass are characteristic of the rapidly cooled rocks.

2. The extent to which the pseudoleucite has been formed does not depend on the rate of cooling, as many of the rocks with fresh leucite crystals are from coarse grained stocks and in the dikes pseudoleucite

has been formed to about the same extent in the very fine grained chilled borders as in the coarse grained centers.

3. In some of the lavas and near the contacts of some of the dikes the groundmass is submicroscopic in texture and the cooling must have been

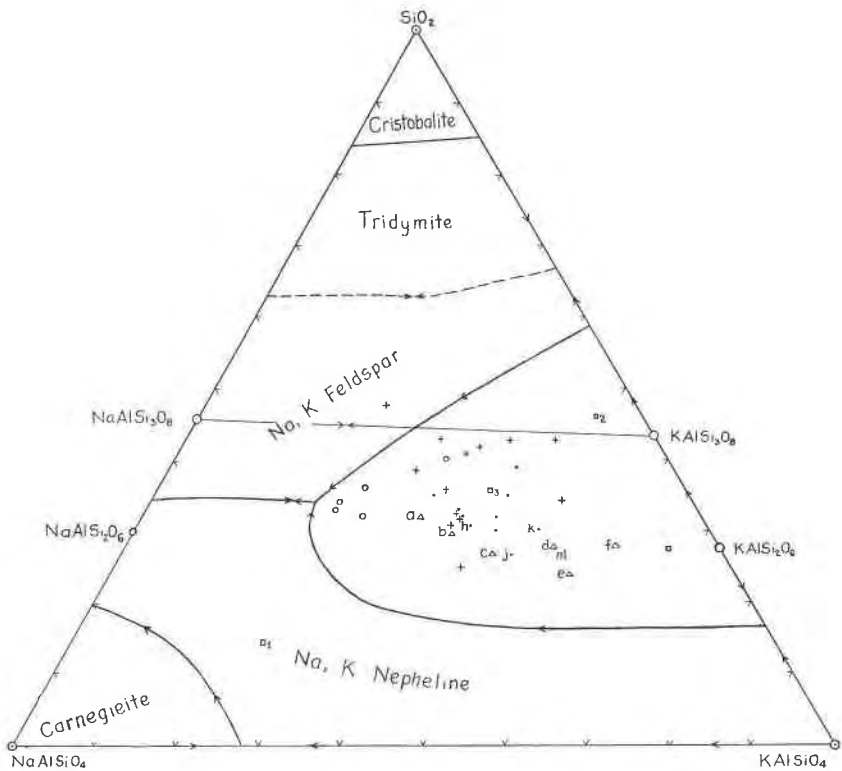


FIG. 1. Equilibrium diagram of the ternary system, $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2$ (after Schairer and Bowen.), on which the compositions of some Highwood rocks have been plotted.

Dots —Rocks containing pseudoleucite.

Triangles—Rocks containing leucite.

Circles —Rocks containing analcime.

Crosses —Other rock types.

Squares —Pseudoleucite. 1. soluble component; 2. insoluble; 3. soluble and insoluble components.

very rapid, yet in crystals 10 millimeters across the replacement to pseudoleucite is complete. The magmatic reaction on leucite crystals could hardly have been so rapid, requiring, as it does, diffusion both through the leucite crystal and the interstitial liquid. In most of the

rocks the pseudoleucite reaction took place after the magma reached its present position.

Bowen and Ellestad (1937) believe that no soda-rich leucite exists. If such a leucite crystallized from the Highwood magmas, the evidence indicates that unmixing was so rapid that any soda-rich leucite that crystallized from a magma would break down on cooling.

On a preceding page we have shown that analcime with about 4.5 per cent of K_2O is a common phenocryst in the basaltic rocks of the Highwood Mountains. It seems not improbable that an analcime with even more K_2O than $4\frac{1}{2}$ per cent crystallized from some of the basalts and that such analcime rapidly inverted on cooling to "pseudoleucite." The crystal habit of pseudoleucite would be the same whether it was derived from leucite or analcime. Except for the water in the analcime, the chemical compositions of soda leucite and potash analcime would be much the same. The pseudoleucite analysis shown in column 6 of Table 1 yields about the same molecular ratio $(Na, K)_2O$ to Al_2O_3 as leucite or analcime, but it has a little higher SiO_2 content. It has more potash than soda and hence is nearer to leucite than to analcime.

The Highwood rocks offer a favorable opportunity to apply the equilibrium diagram of Schairer and Bowen (1935) for the system nepheline-kaliophilite-silica to a group of rocks, since, except for the barium in the sanidine, the salic part of the rocks can be expressed in terms of these three components. The primary felsic minerals of the rocks are barium sanidine, leucite, nepheline, and perhaps analcime. The normative salic components are therefore plotted on the diagram in Fig. 1. Some of the soda in the normative minerals is in the pyroxene of the mode and some of the potash in the normative minerals is in the biotite of the mode. The six rocks that carry some leucite that has not been replaced by pseudoleucite all fall near the join between leucite and soda leucite. One has as much as four per cent less SiO_2 than the leucites.

The leucite basalt of Pirsson (1905, pp. 168-170) represented by point *a* is altered and of doubtful significance. It was placed among the altered rocks by Washington (1917, p. 921). The other leucite rock rich in soda (*b*) is a leucite shonkinite in which nearly all the original leucite has been replaced by pseudoleucite. The point *c* represents a granular rock from North Peak that contains 35 per cent of leucite that has a little cloudy alteration product and a very little replacement about the periphery by orthoclase. It also contains about 10 per cent of interstitial barium sanidine. The points *d* and *e* represent two analyses of a leucite shonkinite from Shonkin Creek that have from 16 to 50 per cent of leucite and little other felsic minerals. The point *f* represents a leucite basalt from the Bearpaw Mountains. Considering only the rocks that are

clearly leucite rocks, the range in soda content is from 17 to 44 per cent of soda leucite.

The eight analyzed rocks, in which there is pseudoleucite, or good evidence that leucite or analcime first crystallized and was later replaced by orthoclase and nepheline, fall in about the same area of the diagram as do the leucite bearing rocks. They show some less range in the relative proportions of soda and potash, and two of them are richer in silica than are the leucite rocks.

The five rocks that contain analcime that is thought to be primary tend to be slightly higher in silica than the leucite and pseudoleucite rocks. Four of them are richer in soda than the leucite rocks and the other one has a soda content within the range of the leucite and pseudoleucite rocks.

Some of the rocks that show no direct evidence of leucite, analcime, or pseudoleucite fall in or near the field of the leucite and pseudoleucite rocks. Most of these rocks came from the Shonkin Sag and Square Butte laccoliths and in their crystallization leucite probably separated in the early stages and was later so completely reworked that the rocks are now granular nepheline syenites and related rocks. Another part of the rocks that show no evidence of leucite or pseudoleucite, are syenitic rocks and fall near the orthoclase-albite join. There is nothing in these rocks or their field relations to indicate that leucite or analcime formed during their crystallization.

With the exception of the older quartz latites, which are separated from the younger rocks of the leucite basalt-shonkinite series by an interval of erosion, nearly all the rocks of the Highwood Mountains fall in the leucite field of Schairer and Bowen (1935). The rare quartz syenites are exceptions to this rule.

Assuming that the feldspar and feldspathoid content are those calculated from the norm; that the orthoclase and nepheline in equilibrium with the liquid at the triple point (leucite-orthoclase-nepheline) have the compositions of the insoluble and soluble parts of the pseudoleucite, respectively, as given in Table 1; and that crystallization took place according to the diagram (Fig. 1), most of the leucite- and pseudoleucite-bearing rocks of the Highwood Mountains fall within the triangle nepheline-leucite-orthoclase and in the leucite field. For most of these rocks, leucite would crystallize first, then leucite and nepheline together and finally, at the triple point, nepheline and feldspar would crystallize and leucite be reacted on. Some of the rocks are well within the nepheline-leucite-orthoclase composition triangle, and for these the liquid would be used up before all the leucite was worked over and the resulting rock would be a mixture of orthoclase, nepheline, and leucite. About half of

the rocks fall near the orthoclase-nepheline join, and for these the leucite should be used up at about the same time as the liquid. Three of the pseudoleucite rocks that are rich in silica would crystallize leucite first, then orthoclase with reaction on leucite, then orthoclase and nepheline with reaction on leucite, and finally orthoclase and nepheline after the leucite was completely resorbed.

In this and the following discussion the change in composition during crystallization of the three solid-solution phases is not taken into consideration and equilibrium is assumed.

The pseudoleucite rocks near the orthoclase-nepheline join, and the rock *b* in which most of the original leucite has been replaced by pseudoleucite, followed very nearly the course of crystallization outlined above except that biotite appears to have taken some part in the crystallization.

The leucite rocks lettered *c*, *d*, and *e* and the pseudoleucite rocks lettered *j*, *k*, and *m* followed somewhat different courses. The two rocks, *d* and *e*, are much alike and both came from the Shonkin stock, possibly from the same outcrop. They are 3-millimeter grained rocks and are made up of approximately one-third leucite, much augite, some olivine, one per cent of biotite, and a little iron ore. There is no feldspar or nepheline. The leucite is somewhat clouded, probably from weathering, and an analysis by Pirsson (1905, p. 117) showed 18.86 per cent of K_2O and 0.70 per cent of Na_2O . It is therefore a potash-rich leucite and most of the soda in the rock must be in the pyroxene. The feldspathic part of the rock therefore had the composition of leucite and its crystallization as leucite without reaction fits the equilibrium diagram.

The rock represented by the point *c* on figure 1 is of a type found in five widely scattered small intrusives. It is 3-millimeter grained and contains 20 per cent of leucite, 6 per cent of hyalophane, much pyroxene, and some olivine and ore. The leucite is somewhat clouded from alteration and has been replaced to some extent by orthoclase. The hyalophane is interstitial to the leucite and is strongly zoned. A mixture of 20 parts of leucite and 6 parts of sanidine would form leucite, then orthoclase with reaction on leucite until the whole was crystalline. The actual course of crystallization was much like that postulated from the equilibrium diagram except that much of the feldspar is interstitial and not formed by reaction.

The rock represented by point *b* is much like that of point *c* except that the former rock is a little richer in soda and its leucite has been in large part replaced by pseudoleucite. The rocks represented by points *j* and *m* are from the chilled border of the Shonkin Sag laccolith and have fine grained groundmasses while the rocks represented by points *k* and *h*

are the coarse shonkinites above the chilled border. In all of these rocks the leucite has been completely replaced by pseudoleucite or granular feldspar and nepheline (now altered). These rocks are very similar chemically to the three leucite rocks represented by *c*, *d*, *e*. Why was the leucite replaced in some of the rocks and not in others?

Figure 1 and the preceding discussion show that analcime tends to be in the rocks that are rich in soda and SiO_2 ; leucite is in the rocks with about the amount of SiO_2 to form leucite and with no more soda, molecularly, than potash; pseudoleucite is in rocks with about the same compositions as those of the leucite rocks, although some may contain a little more silica. The rocks without leucite, analcime, or pseudoleucite are for the most part high in silica.

Whether pseudoleucite is formed by unmixing of leucite or analcime or by the pseudoleucite reaction of Bowen (1928) we should expect a more consistent relation between the composition of the rock and the extent of the pseudoleucite replacement than is shown in Table 1.

SUMMARY AND CONCLUSIONS

In the potash-rich province of the Highwood Mountains of Montana, many of the extrusive rocks and some of the dike rocks contain abundant phenocrysts of a clear analcime that appears to be primary. An analysis of the analcime shows $4\frac{1}{2}$ per cent of K_2O , and this high potash content confirms the belief that the analcime is primary.

The rocks of a few of the lavas and stocks, and of a very few of the dikes contain fresh leucite. In the lavas leucite is present both as phenocrysts and in the groundmass. The leucite of the phenocrysts is intratelluric; that of the groundmass crystallized after the magma reached its present position.

Pseudoleucite is an abundant constituent of many of the igneous rocks. It is present also in the metamorphosed sandstone within 10 centimeters from the headed dike. It consists of a mixture of an orthoclase that contains little Na or Ba and an amorphous material that has about the composition of nepheline with water and is probably derived from nepheline.

The extent to which the leucite or analcime has been replaced by pseudoleucite appears to be about as great in the rocks with very fine textured groundmasses, such as the chilled borders of dikes, as in the coarse grained rocks, such as occur in the centers of dikes. The minerals that make up the pseudoleucite tend to be in fine intergrowths in rocks with fine textured groundmasses, and in coarse intergrowths in rocks with coarse textured groundmasses. In the final stage of this coarsening

of the grains of the pseudoleucite the rock becomes an ordinary grained nepheline syenite.

Most of the pseudoleucite formed after the magmas reached their present positions.

The pseudoleucite is formed by the unmixing of either soda-rich leucite or potash-rich analcime. Some of the narrow rims of orthoclase about leucite and analcime were formed by magmatic reaction, and this reaction may have gone farther in some cases.

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