LEUCITE AND PSEUDOLEUCITE

N. L. Bowen and R. B. Ellestad,
*Geophysical Laboratory, Carnegie Institution of
Washington and University of Minnesota*

The Pseudoleucite Problem

The lavas of the volcanic area immediately to the north of Lake Kivu in Central Africa present an interesting variety of leucite-bearing types. The leucite occurs in some examples as phenocrysts showing the characteristic form and in others as one of the minerals of the groundmass. Usually the leucite has persisted as such but in some of the lavas of Mt. Mikeno phenocrysts of that mineral are peripherally changed to pseudoleucite, an intergrowth of orthoclase and nepheline. This change in the leucite is one that has long been recognized by petrologists, and observed in rocks from a number of localities. The formation of the soda-rich mineral nepheline as one of the products of the change has raised the question of the composition of the original leucite. Knight (1906) has suggested that the leucite had a notable content of Na_2O replacing K_2O and that by simple breakdown of this soda-bearing variety of leucite, consequent upon falling temperature, an intergrowth of orthoclase and nepheline was formed, the supposed metasilicate solid solution thus giving rise to a polysilicate and an orthosilicate. No less an authority on leucitic rocks than our late colleague, Henry S. Washington, leaned strongly to that view.

With this question in mind it was decided that the nature of the leucite in typical examples of these rocks should be determined, not only in rocks showing phenocrysts partly changed to pseudoleucite but also in those with leucite as a groundmass mineral.

Leucitophyre and its Leucite Phenocrysts

Among the specimens collected on Mt. Mikeno there are many of lavas carrying leucite phenocrysts. In one of these, a leucitophyre, these phenocrysts, greyish when freshly broken, have diameters up to 5 mm. and are surrounded by a white rim. There are phenocrysts of augite and of magnetite and the groundmass, which is very fine grained, contains these two minerals in considerable amounts but is largely made up of leucocratic minerals, a mixture of nepheline and soda-orthoclase without leucite. The white rims of the leucite phenocrysts are found to be made up of fibrous orthoclase intergrown with another mineral of slightly higher refringence which is presumably nepheline. The rim is therefore typical pseudoleucite.

TABLE 1. ANALYSES OF LEUCITIC ROCKS

	I	II	III		I(a)	I(b)	II(a)	II(b)
SiO_2	47.94	43.16	55.4	or	35.0	—	15.6	—
Al_2O_3	16.24	13.46	23.3	ab	4.7	21.1	1.6	8.6
Fe_2O_3	3.19	2.44 ⎫	0.5	an	1.7	1.7	18.6	18.6
FeO	5.54	11.35 ⎭		lc	—	27.5	—	12.2
MgO	3.06	8.42	0.0	ne	23.0	14.1	9.7	5.8
CaO	7.09	11.08	1.1					
Na_2O	5.71	2.28	1.8	di	21.4	21.4	27.3	27.3
K_2O	5.91	2.65	18.3	wo	0.6	0.6	—	—
H_2O+	0.48	0.13 ⎫	0.2	ol	—	—	14.4	14.4
H_2O-	0.21	0.03 ⎭		mt	4.6	4.6	3.5	3.5
TiO_2	3.07	4.20	0.2	il	5.9	5.9	8.1	8.1
P_2O_5	0.82	0.45		ap	2.0	2.0	1.0	1.0
Cl	0.18	—						
MnO	0.18	0.21						
	99.62	99.86	100.8					

I. Leucitophyre, Mt. Mikeno, Belgian Congo. R. B. Ellestad analyst.
II. Leucite theralite, Nyamlagira volcano, Belgian Congo. A. Willman analyst.
III. Leucite out of leucite theralite II. R. B. Ellestad analyst.
I(a). Norm of I.
I(b). Alternative recalculation of I.
II(a). Norm of II.
II(b). Alternative recalculation of II.

The chemical composition of the rock is given in Table 1 together with the norm. There is no leucite in the norm, a condition which arises from the fundamental assumption underlying the calculation, whereby silica is assigned preferably to the potash-alumina silicate. Moreover there is 23 per cent nepheline in the norm. An alternative recalculation, also given in Table 1, in which all the K_2O is assigned to leucite gives some 27 per cent leucite, 14 per cent nepheline and of course no orthoclase. The proportions of the modal salic constituents are intermediate between those of the norm and those of this alternative recalculation. The rock may be called leucitophyre although it is transitional towards leucitite.

The fact that the leucite is only peripherally changed to pseudoleucite suggests that the intervention of the liquid magma was necessary to the action and that the liquid contributed the soda necessary to the production of nepheline. However, this is not altogether conclusive and it is desirable that the character of the leucite phenocrysts should be determined.

In this case it was not considered necessary to analyze the leucite. Excellent material, all but free from inclusions of any kind, was obtained by picking out selected phenocrysts, and the purity of the leucite was determined by measuring the melting temperature. This can be done on a much smaller amount of material than that necessary for chemical analysis. With the aid of this unusually pure sample of the phenocrysts
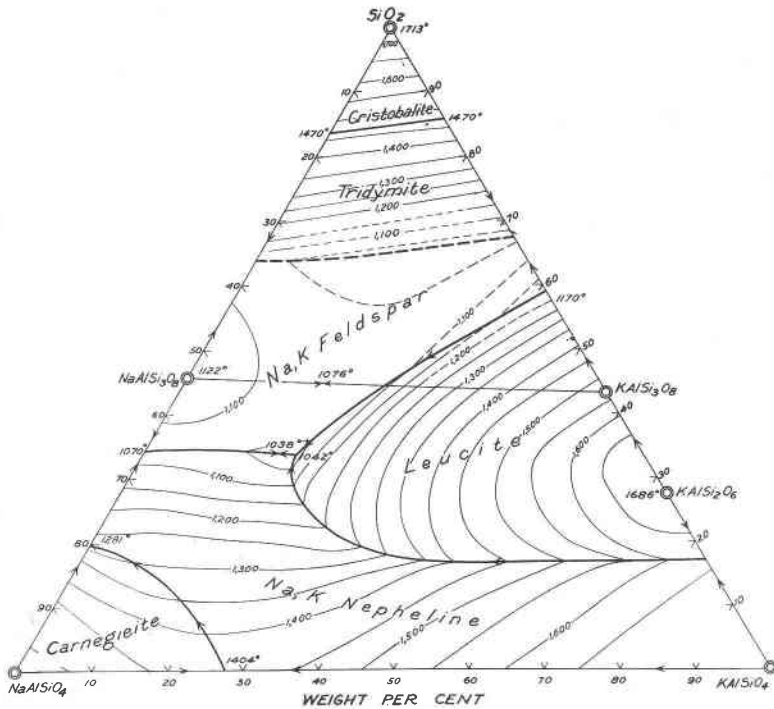

FIG. 1. Equilibrium diagram of the ternary system, $NaAlSiO_4$–$KAlSiO_4$–SiO_2
(after Schairer and Bowen.)

it was possible to prove that the leucite can contain no more than a small amount of Na_2O. The crystals are not pure $KAlSi_2O_6$ and therefore show a melting interval rather than a melting point, but the temperature of completion of melting was found to be 1660°, only 26° lower than that of pure $KAlSi_2O_6$. From the equilibrium diagram of the system, $KAlSiO_4$–$NaAlSiO_4$–SiO_2, as determined by Schairer and Bowen (1935) and given in Figure 1, it is possible to state that the leucite can contain no more than 1–1.5 per cent Na_2O replacing K_2O.

The temperature of completion of melting of a leucite having a content of Na_2O corresponding with that ordinarily contained in pseudoleu-

cite (6–7 per cent), if such a leucite exists, would be about 1350°, or some 300° lower, as shown by the same diagram.

Since the composition of this leucite is such that it could not give typical pseudoleucite by simple transformation it is necessary to suppose that reaction with liquid magma was essential. That such reaction could give the observed result is indicated by experimental results which reveal the nature of the reaction.
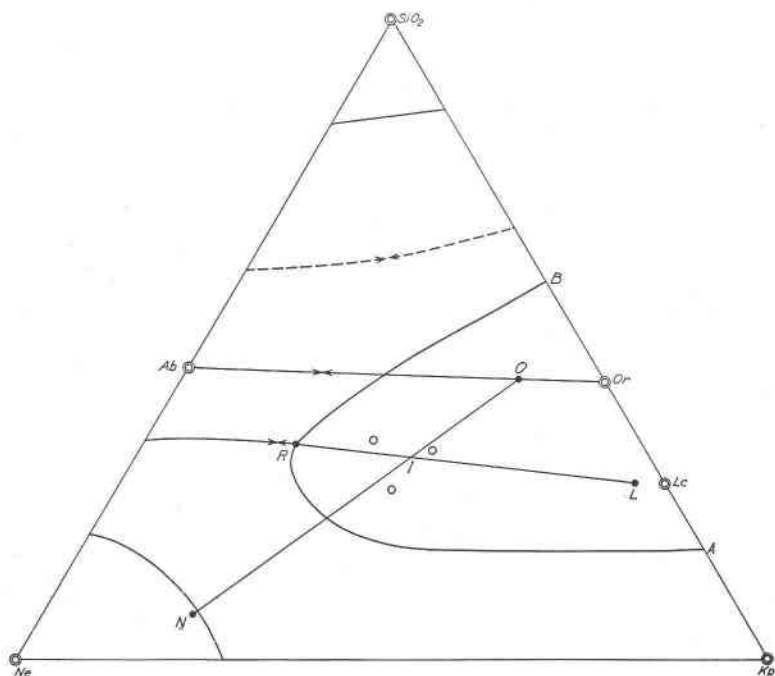

Fig. 2. Diagram to illustrate formation of pseudoleucite. Hollow circles—three analyzed pseudoleucites (neglecting minor oxides). Solid circles—composition of reacting phases.

In order to illustrate this fact we have plotted upon the ternary equilibrium diagram, Figure 2, the compositions of three analyzed pseudoleucites as given by Knight (1906). Examination of this diagram shows that if a leucite of the composition L (corresponding with that of the usual leucite) reacts with liquid of composition R (that of the pseudoleucite reaction point) it could give a solid product corresponding closely with the analyzed pseudoleucites, since their composition lies close to the line RL. Moreover it shows that this solid product could be made up of orthoclase of composition O and nepheline of composition N, and the line

NO likewise passes close to the points indicating the compositions of the analyzed pseudoleucites.

In the ideal case where all the compositions involved could be represented in the diagram of the ternary system the actual quantitative relations of the phases could be stated. Thus liquid and leucite in the proportions given by the lengths *LI* and *IR* would react to give orthoclase and nepheline in proportions corresponding to the lengths *NI* and *IO*. In other words, two parts (by weight) of liquid (*R*) react with one part leucite (*L*) to give a solid product consisting of two parts orthoclase (*O*) and one part nepheline (*N*). In order to reach these figures it has been necessary, of course, to assign definite compositions to the orthoclase, the nepheline and the leucite but the assumed compositions are probably not far from the true values. In the ternary system the composition of all these phases in equilibrium with liquid at the pseudoleucite reaction points is necessarily fixed but it has not yet been possible to determine the composition of the solid phases experimentally.

It should be pointed out that some variation in the bulk composition of pseudoleucite might be expected even if the phases concerned were all of compositions such that they could be accurately represented in the ternary diagram. The variation will arise from the fact that the cooling liquid, changing in composition by subtraction of leucite and therefore moving in the leucite field, will not ordinarily reach the boundaries of that field exactly at the point *R* but will first encounter either the curve *BR*, in which case some of the leucite will be transformed to orthoclase only, or else the curve *AR*, in which case some nepheline will be formed. The pseudoleucite as finally formed at *R* may therefore contain an excess of either orthoclase or nepheline. The composition of pseuodoleucite may show further variation in view of the fact that in the natural magmas compositions do not lie in the ternary system. It is not to be expected that pseudoleucite compositions should always coincide with the point *I*. Rather is it that there should be a tendency to cluster around that point and this there seems to be.

GROUNDMASS LEUCITE

The considerations brought out thus far tend to show that the phenocrystic leucites which have been transformed to pseudoleucite in many rocks have probably been close to theoretical leucite in composition and not notably soda rich. At the same time it should be pointed out that the general relations in the equilibrium diagram to which repeated reference is made in this paper make it clear that phenocrystic leucites are those that are the most likely to show high K_2O content, since the high temperatures lie towards the composition of the pure potash compound.

The question whether leucite notably rich in soda can form from any liquid is not decided by such considerations, nor is it decided by the experimental work, for as we have noted, little was accomplished in that work in the way of determining the exact composition of solid phases. It is still possible to suppose, therefore, that in some leucitic rocks with considerable soda content, the groundmass leucites might contain notable amounts of soda. For this reason a rock containing leucites in the groundmass has been examined in some detail, a leucite theralite from the crater of Nyamlagira being chosen.

LEUCITE THERALITE AND ITS LEUCITE

The inner walls of the crater of the active volcano, Nyamlagira, are made up of a rock which is parted into layers a foot or somewhat less in thickness. This effect is apparently due to jointing; otherwise the rock is of very massive appearance and there is no clear evidence of separation into distinct flows. The rock is coarser in grain than the lava flows of the area and may be tentatively regarded as the remnant of a plug or neck, some of which has been removed by explosion. Similar rocks are found as bombs on the slopes of the volcano.

The rock has abundant large titanaugites, less abundant olivines and titaniferous magnetite, in a groundmass rather indefinitely marked off, since the minerals of the groundmass attain nearly the same dimensions. These minerals are principally plagioclase, pyroxene and leucite. The plagioclase is strongly zoned and passes more or less continuously, but with some oscillation, from basic bytownite to a broad outer border which has distinctly lower indices than balsam and must be in part anorthoclase. The latter mineral shares with the leucite or at least with the outer borders of leucite an interstitial relation to the other minerals. There are also some grains probably to be referred to nepheline, some magnetite, apatite and rare biotite.

The chemical composition of this leucite theralite is given in Table 1 together with the norm. There is no normative leucite, the undersilicated character of the rock finding its expression in normative nepheline, in addition to olivine. An alternative recalculation in which all the K_2O is assigned to leucite, also given in Table 1, shows some 12 per cent leucite and, of course, no orthoclase. It also shows altogether too much albite. In the proportions of salic minerals the actual mode of the rock is intermediate between the norm and this alternative recalculation. An older analysis of a leucite theralite bomb from Nyamlagira is given by Finckh (1912). The analysis (by Hauser) seems to be of inferior grade. The rock is described as rich in leucite yet the norm, calculated by Washington (1917), shows only a fraction of a per cent of nepheline and no leucite.

The given value of Fe_2O_3 is too high and that of MgO too low, for the mineral assemblage present. Indeed the rock appears to be sensibly identical with that here described and analyzed.

The nature of the leucite is our immediate concern. It was not possible to get a clean enough separation of leucite to permit determination of its character by the melting-point method. A quantity sufficient for chemical analysis was therefore separated. Only a small sample was available, and it contained small amounts of the associated minerals, principally feldspar, nevertheless the analysis, given in Table 1, leaves no question as to the nature of the leucite. There is but 1.8 per cent Na_2O altogether, and some of this is in the associated feldspar. The leucite can contain no more than the 1–1.5 per cent Na_2O ordinarily found in that mineral. It is plain, then, that groundmass leucite has no notable tendency towards a higher soda content than has phenocrystic leucite, which is that usually analyzed.

These determinations upon leucites of contrasted occurrence may be accepted as showing, with little possibility of doubt, that leucite never has a high content of soda; in other words that, in leucite, potash is replaceable by soda only to a very limited degree, and that, for development of pseudoleucite, reaction with liquid magma is essential.

The broader implications of the pseudoleucite reaction have been discussed at some length elsewhere by Bowen (1928). Suffice it to say here since leucite can separate not only from undersilicated magmas but also from certain types of oversilicated magmas, and since the local accumulation and subsequent transformation by pseudoleucite reaction may give rise to a nepheline-bearing rock, we have in these relations the possibility of the development of a nepheline rock as a crystallization differentiate of an oversilicated magma.

REFERENCES

BOWEN, N. L. (1928): *The Evolution of the Igneous Rocks*—Princeton. 253–7.

FINCKH, L. (1912): *Wiss. Ergebn. deutsch. Zentral-Afrika Exped.* 1907–8 *des Herzogs zu Mecklenburg*, **1,** 19.

KNIGHT, C. W. (1906): *Amer. Jour. Sci.*, **21,** 252.

SCHAIRER, J. F., and BOWEN, N. L. (1935): *Trans. 16th Ann. Meeting Amer. Geophysical Union*, 326.

WASHINGTON, H. S. (1917): *U. S. Geol. Surv. Prof. Paper* **99,** 603.