NEPHELINE CONTRASTS

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At the International Geological Congress in South Africa Dr. J. Morozewicz presented a paper, restating his view that the mineral nepheline has a constant composition whatever the rock in which it is formed. During the discussion Bowen pointed out objections to this view,[1] basing them largely upon the wide range of composition of nephelines crystallizing from synthetic melts, but Doctor Morozewicz, granting that fact, nevertheless stoutly maintained his position that natural nepheline, when fresh, has the fixed composition represented by the formula $K_2Al_2Si_3O_{10} \cdot 4Na_2Al_2Si_2O_8$.[2]

After the Congress Bowen made a journey through parts of Central and East Africa where many nepheline-bearing rocks were observed and collected. It will be recalled that volcanic activity has prevailed from Tertiary to recent times in association with those remarkable features of the African continent known as rift valleys. In or about the Eastern or Great Rift, volcanic rocks are particularly abundant and are found with few interruptions throughout its extent from Nyasaland on the south to the Red Sea on the north. The lavas are uniformly soda-rich. In the region of the Western Rift volcanism is not so prominently displayed, indeed it is confined to the area adjacent to Lake Kivu and to minor areas extending northward to the eastern slopes of Ruwenzori, constituting in all but a small proportion of the total extent of the rift. The rocks of these areas are uniformly potash-rich.

If nephelines are responsive in composition to the magmas from which they form, those occurring in the potash-rich rocks of the one region should differ in a definite manner from those occurring in the soda-rich rocks of the other region. A chemical study of the nepheline was planned to test this relation. In the meantime the commonly accepted view that natural nephelines vary in composition received its strongest support through the excellent studies of Bannister and Hey upon superior materials and their correlation of physical properties with chemical composition.[3] The nephelines studied by them were for the most part formed in vugs and cavities of volcanic rocks and their inclusions. We know little of the exact nature of the solutions from which they formed and the question of the factors controlling the variability of composition of such nephelines must remain unsolved. Moreover, there is reason to believe

[1] *Compte Rendu of the XV Session, Int. Geol. Congress, South Africa*, p. 199, **1929.**

[2] See especially *Travaux du Service Géologique de Pologne*, vol. **2**, livraison 3, p. 314, 1929.

[3] Bannister, F. A., and Hey, M. A., *Mineral. Mag.*, vol. **22**, pp. 569–608, 1931.

that the nephelines of many other rocks have been introduced hydrothermally[4] and for these again we may not expect any close correlation between the nephelines and the rocks in which they occur. There seems, therefore, adequate reason for presenting the results of a study of the composition of phenocrysts of nepheline formed by direct crystallization from the molten magmas represented by the lavas of these contrasted African regions.

Nepheline from Phonolite

Phenocrysts of nepheline in a phonolite occurring as a lava flow at a point 53 miles from Nairobi on the Nairobi-Nyeri road in Kenya were separated from the other materials of the rock and studied chemically and optically. The phonolite itself is a dark grey rock containing, in an aphanitic groundmass, equant phenocrysts of nepheline about 3 mm. in diameter and tabular phenocrysts of anorthoclase of like maximum dimensions. The groundmass consists of alkali feldspar, nepheline and analcite, together with two amphiboles, a little acmitic pyroxene and rare calcite. Of the two amphiboles, the one is pleochroic in pale tones of yellow to wine-red with high extinctions and may be termed katophorite; the other is deep wine-red to nearly black, presumably cossyrite. The chemical composition of the rock is given in Table 1 under 1. It is phonolite of the Kapiti type of Gregory, which Campbell Smith regards as not essentially different from his kenytes.[5]

The nepheline phenocrysts are for the most part fresh and glassy. They are uniaxial and negative, $\omega = 1.535$, $\epsilon = 1.531$, and thus correspond with the low-index nephelines described by Campbell Smith from rocks of the same group.[6] The nepheline of the phenocrysts was separated for analysis by hand picking and its composition is given in Table 1 under 1(*a*).

Nepheline from Melilite-Leucite-Nephelinite

Nepheline phenocrysts in a nephelinite occurring as a lava flow near Burunga in the volcanic area north of Lake Kivu, Belgian Congo, were separated from the rock for chemical and optical study. The rock is a black aphanite whose only phenocrysts are nepheline. Under the microscope the groundmass is seen to be made up of nepheline, leucite, melilite, pyroxene, magnetite (titaniferous) and rare olivine. The specimen from which the nepheline was separated was not itself analyzed because the groundmass shows some alteration. Instead there was selected for analysis a fresh specimen of a nearby flow showing essentially the same microscopic characters, except that a few phenocrysts of melilite occur with

[4] Cross and Larsen, *U.S. Geol. Survey*, Bull. **843**, p. 28.

[5] Campbell Smith, W., *Q. J. Geol. Soc.*, vol. **87**, p. 239, 1931.

[6] *Op. cit.*, p. 245.

those of nepheline. The chemical composition of this rock is given in Table 1 under 2.

TABLE 1. CHEMICAL COMPOSITION OF NEPHELINE-BEARING ROCKS AND OF THEIR NEPHELINE PHENOCRYSTS

	1	1(*a*)	1(*b*)	2	2(*a*)	2(*b*)
SiO_2	54.81	46.41	*773*	37.70	40.74	*679*
Al_2O_3	19.10	31.07	*305*	13.83	33.39	*328*
Fe_2O_3	1.57	0.78	*005*	4.27	0.83	*005*
FeO	3.52			7.09		
MgO	0.96	0.11	*003*	5.41	0.25	*006*
CaO	1.81	0.87	*016*	15.02	0.91	*016*
Na_2O	6.88	15.67	*253*	4.50	12.53	*202*
K_2O	5.41	3.81	*040*	4.92	11.13	118
H_2O+	3.63	0.97		1.22	0.23	
H_2O-	0.57	0.17		0.61	0.06	
CO_2	0.14			0.12		
TiO_2	0.82			3.18	0.11	
P_2O_5	0.22			1.86		
MnO	0.27			0.26	tr.	
	99.71	99.86		99.99	100.18	
or	31.7			—		
ab	35.6			—		
an	5.3			2.8		
lc	—			22.7		
ne	12.2			20.7		
di	1.6			14.2		
ol	4.5			8.1		
cs	—			12.7		
mt	2.3			6.3		
il	1.5			6.1		
ap	0.3			4.4		

1. Phonolite, 53 miles from Nairobi on Nairobi-Nyeri road, Kenya (with norm below). A. Willman, analyst.

1(*a*). Nepheline from phonolite 1. R. B. Ellestad, analyst.

1(*b*). Molecular ratios of 1(*a*).

2. Melilite-leucite nephelinite, Ngoma crater, L. Kivu, Belgian Congo (with norm below). R. B. Ellestad, analyst.

2(*a*). Nepheline from nephelinite closely related to and associated with nephelinite 2. R. B. Ellestad, analyst.

2(*b*). Molecular ratios of 2(*a*).

The nepheline phenocrysts of these nephelinites are fresh and glassy and form equant grains about 3 mm. in diameter. They are uniaxial and negative with $\omega = 1.544$, $\epsilon = 1.540$. The groundmass of the rock is so heavily charged with fine magnetite that it proved possible to separate phenocrysts and groundmass magnetically. The nepheline so separated was analyzed and its composition is given in Table 1 under 2(*a*).

The Optical Properties of the Nephelines

Corresponding with the relations found by Bannister and Hey, the nepheline which is low in K_2O, that from the phonolite, is also low in refractive index and the nepheline which is rich in K_2O, that from the nephelinite, is high in refractive index. But although the latter is the richest in K_2O of all analyzed nephelines, it does not have the highest refactive index. So also in the Bannister and Hey plot, although the general tendency is plain, in detail there is a staggering of the points whose significance has not yet been made out.

The Composition of Nepheline

Bannister and Hey reached the conclusion that the contents of the unit cell of nepheline may be written $Si_{16-n}\,Al_n\,(Na, K, \frac{1}{2}\,Ca)_nO_{32}$. They find also that nepheline is built upon a tridymite scaffolding with Al substituting for Si, and Na or K or $\frac{1}{2}$Ca going into open spaces of the structure to satisfy valency requirements. Nepheline thus has the same relation to tridymite as carnegieite has to cristobalite, according to the conclusion of Barth and Posnjak.[7] This work represents a signal advance in our knowledge of the intimate structure of nepheline. When the composition of nepheline is regarded from the point of view of one interested in phase equilibrium precisely the same conclusion is reached as to the bulk composition. Thus it has been concluded that nepheline is made up of pure soda nepheline with the kaliophilite molecule and two plagioclase molecules, albite and anorthite, in solid solution.[8] The composition of these constituents may be written respectively $Na_8Al_8Si_8O_{32}$, $K_8Al_8Si_8O_{32}$, $Na_4Al_4Si_{12}O_{32}$, and $Ca_4Al_8Si_8O_{32}$, whereupon it is seen at a glance that all the requirements of the Bannister and Hey formula for the unit cell are met. One interested in phase equilibrium may therefore be pardoned if he continues to speak of nepheline as a solid solution of these constituents, just as in the case of liquid solutions one speaks of solutions of sodium chloride, even although an intimate study of the solution reveals that chlorine ion and sodium ion are present in the solution. In phase equilibrium studies one is interested in the phase which separates when saturation is reached. In the solution of sodium chloride, so-called, that phase is sodium chloride. In the solid solution, nepheline, albite or anorthite, or a mix-crystal of them, are the phases which separate when their (solid)

[7] *Zeit. Krist.*, vol. **81**, pp. 376–385, 1932.
[8] Bowen, N. L., *Am. Jour. Sci.*, vol. **43**, pp. 127–130, 1917.

solubility is exceeded. Therefore, for phase equilibrium purposes it is convenient and consistent to speak of albite or anorthite being in solid solution in nepheline. In an example as complicated as that of nepheline, where reciprocal salt pair relations are involved, it might be adequate for some nephelines to speak of orthoclase as occurring in solid solution, but the compounds chosen above are of general applicability and are therefore to be preferred.

We may, then, express the composition of the two nephelines with which we are here concerned as follows:

	Nepheline from Phonolite	Nepheline from Nephelinite
Ne	61.8	57.0
Kp	12.9	37.6
An	4.5	4.4
Ab	20.8	1.0

In the recalculation of the nepheline analyses, ferric oxide, magnesia and water have been neglected, as presumably not present in the nephelines themselves. The analyses are readily transformed into the molecules tabulated because there is a substantially exact 1:1 ratio between the Al_2O_3 and bases. In some of the analyses made by Hey there is notable departure from this ratio, and therefore from correspondence with the formula for the unit cell as given by Bannister and Hey. It is not clear from their discussion what disposition of atoms is to be made in their structure to satisfy these departures from the 1:1 ratio, if the departures are indeed real and not due to analytical error or to alteration of the mineral. However this may be, the question does not arise in connection with the two nephelines here analyzed.

In consonance with its formation from a sodic magma rich in the polysilicate molecules of the alkalic feldspars, the nepheline of the phonolite is among the most siliceous (rich in the albite molecule) of analyzed nephelines. It is likewise rich in the nepheline molecule as compared with the kaliophilite molecule. On the other hand, the nepheline of the very basic leucite-bearing nephelinite is richer in the kaliophilite molecule than any nepheline hitherto analyzed, even than the so-called pseudonepheline of Vesuvius, and at the same time contains little if any silica in excess of the orthosilicate ratio, corresponding to only 1 per cent of the albite molecule, an amount within the limits of analytical error. The control of the composition of these phenocrysts by the magmas from which they formed is so clear that it need not be further discussed. In Fig. 1[9] the composition of the nepheline is plotted (lacking the anorthite

[9] The equilibrium diagram of the system, $NaAlSiO_4$-$KAlSiO_4$-SiO_2, as determined by Schairer and Bowen: *Trans. Am. Geophysical Union*, pp. 325–328, **1935.**

content) and also the alkali-alumina-silica content of the rocks when these are recalculated into the standard minerals of the norm. The relation between the composition of the phenocrysts and that of the magma is thus graphically brought out.

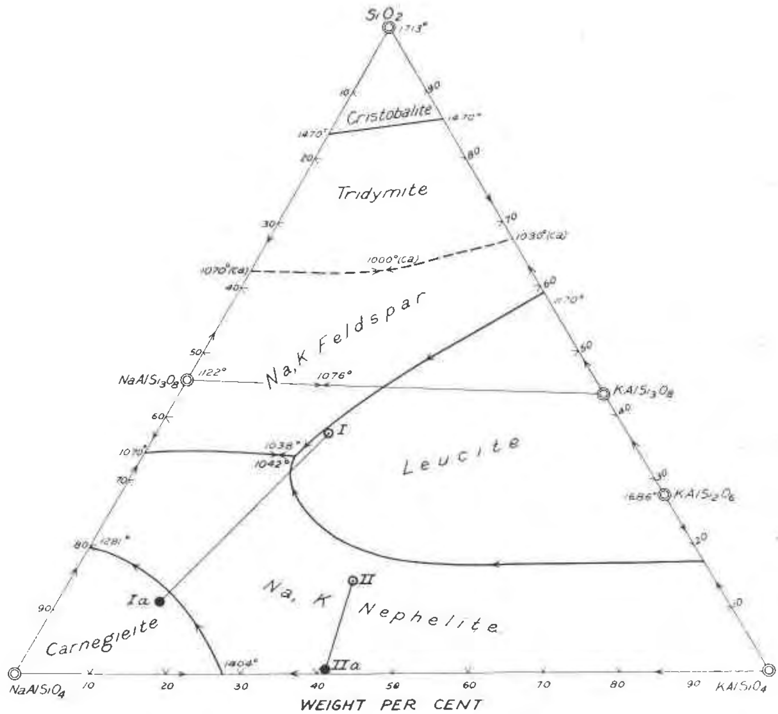

FIG. 1. Equilibrium diagram of the system, $NaAlSiO_4$-$KAlSiO_4$-SiO_2, (after Schairer and Bowen). The numbered points indicate the salic normative composition (exclusive of an) of the two analyzed rocks and of their nepheline phenocrysts, and the numbers correspond with those used in Table 1.

SUMMARY

In order to determine the relationship between nepheline phenocrysts and the magma from which they separate, the chemical composition has been determined of nepheline from a soda-rich rock, phonolite, typical of the East African Rift, and of nepheline from a potash-rich rock, melilite-leucite nephelinite, typical of the Central African Rift. The results are given in Table 1, together with the composition of the rocks. The two nephelines are respectively soda-rich and potash-rich and thus emphasize the variability of the composition of nepheline and its control by the magma from which they form, a relation brought out graphically in Fig. 1.