

NEPHELINE—K—FELDSPAR INTERGROWTH FROM KAMINAK LAKE, NORTHWEST TERRITORIES

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ABSTRACT

Results of electron probe micro-analysis of vermiform nepheline—K-feldspar intergrowth in alkalic rocks from Kaminak Lake, N.W.T., indicate chemical equivalence of the intergrowth to leucite containing 39 weight per cent soda-leucite. Mechanisms of origin are discussed, and formation by cotectic crystallization of nepheline and K-feldspar is suggested.

INTRODUCTION

During reconnaissance mapping west of Hudson Bay in 1930, D. F. Kidd of the Geological Survey of Canada discovered an outcrop of nepheline-bearing rocks at the northeast shore of Kaminak Lake (Weeks 1933, p. 72). In his unpublished manuscript report, Kidd (1930) made note of abundant vermiform intergrowth between nepheline and K-feldspar, observed in thin sections of these rocks. It is now known that this outcrop is at one end of an alkalic pluton $4\frac{1}{2}$ miles long and $1\frac{1}{4}$ miles wide (Davidson 1968, 1970). The vermiform intergrowth is a major constituent of rocks whose composition is midway between ijolite and nepheline syenite. This paper presents the results of microanalytical work done on the intergrowth, and discusses possible mechanisms for its origin.

GEOLOGIC SETTING

Figure 1 is a generalized geologic map of the area surrounding the pluton of alkalic rocks. The pluton is located along an intrusive contact between a massive, homogeneous hornblende tonalite pluton and older, probably Archean, deformed volcanic rocks of low regional metamorphic grade. Fenites, laced with syenite dikes, are developed in both country rock types adjacent to the alkalic pluton. North-trending diabase dikes cut the alkalic pluton and surrounding rocks, but five miles to the northwest dikes of the same swarm are truncated by sediments of the Hurwitz Group of Aphebian age (Bell 1968). Deformation and mild metamorphism of the Hurwitz Group are attributed to Hudsonian orogeny, whose effects increase in intensity north of Quartzite Lake

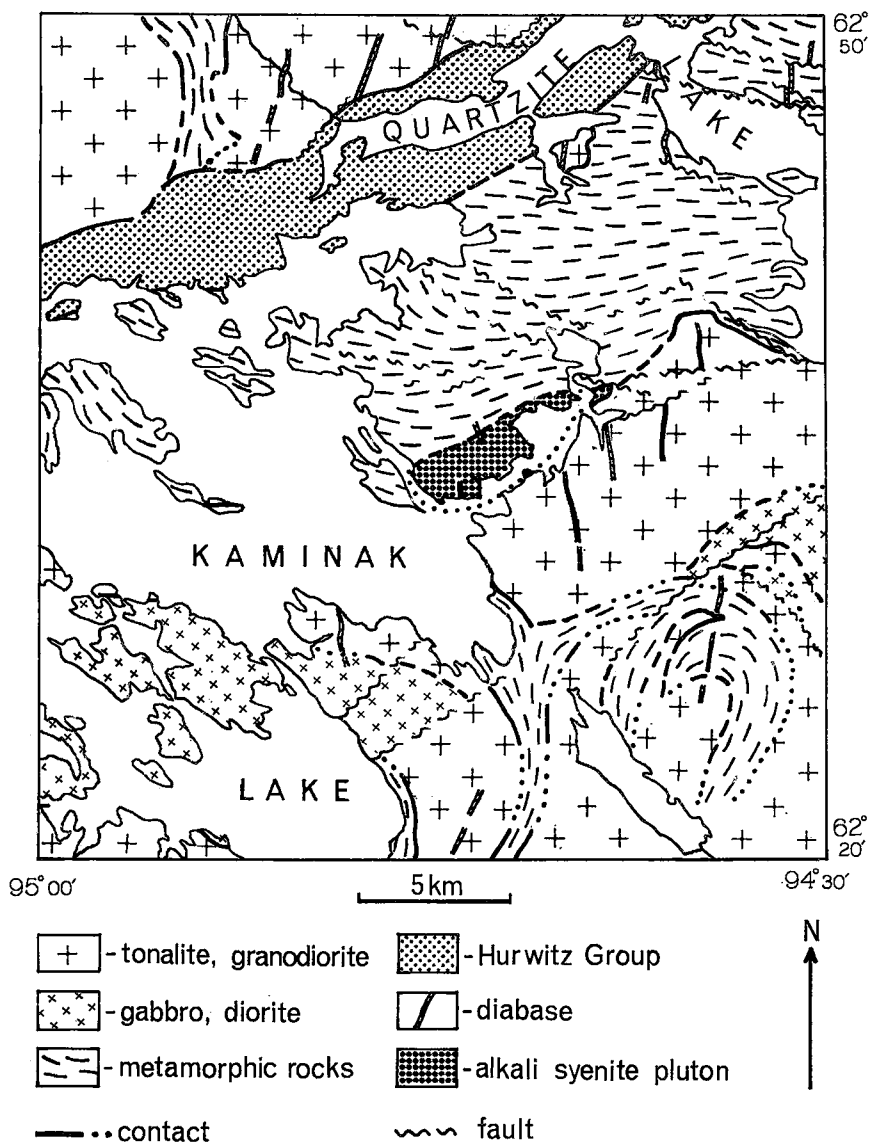


FIG. 1. Geology of the region surrounding the Kaminak Lake alkalic pluton.

(Fig. 1). South of this lake the Hudsonian overprint is slight; Hudsonian deformation in the pre-Hurwitz rocks seems to be confined to fracturing and shearing, with only minor accompanying mineral alteration. Consequently, most of the alkalic rocks are remarkably fresh.

ROCKS OF THE ALKALIC PLUTON

Two series of rock types comprise the bulk of the alkalic pluton. The earlier, ijolite series is composed predominantly of nepheline and aegirine-augite, with smaller amounts of melanite, magnetite, biotite, and apatite in various proportions. There is a complete gradation from nepheline-bearing pyroxenite through ijolite and melanite ijolite to a leucocratic rock composed chiefly of nepheline and nepheline—K-feldspar intergrowth with minor aegirine-augite and melanite. The intergrowth-bearing rocks are similar to some examples of borolanite and ledmorite described by Shand (1910) and Tilley (1958a) from Scotland, except that they very rarely contain K-feldspar other than that present in the intergrowth. Most rocks of the ijolite series are medium to very coarse grained. Many outcrops display a crude, steeply dipping compositional layering sub-parallel to the outer contacts of the pluton. Most rocks contain minor amounts of secondary biotite and cancrinite. Alteration is severe in some places and has given rise to fine- to medium-grained, dull-looking rocks containing albite, biotite, muscovite, cancrinite, grossularite, vesuvianite, clinozoisite, and calcite, commonly arranged so as to preserve the original ijolite texture.

In general, the pyroxene-rich members of the ijolite series are concentrated in the southern part of the pluton; ijolites and leucocratic members underlie the central and southwestern parts. Rocks of the later, syenite series form a lens along the northwest side and at the northeast end of the pluton, and also occur as dikes cutting ijolitic rocks. Coarse-grained leucosyenite is the predominant member of this series. Less common are varieties containing different amounts of nepheline, melanite, biotite (lepidomelane), cancrinite, vishnevite (sulphate cancrinite with measured cell dimensions a : 12.75 Å, c : 5.22 Å), calcite, and sphene, with accessory apatite, magnetite, and pyrite. In all these rocks K-feldspar is the dominant mineral.

In addition to these two main rock series, dikes of grey, green, and brown, fine-grained rocks cut the ijolitic rocks, but apparently not the syenites. Lenses and dikes of carbonatite containing various amounts of acmite, arfvedsonite, biotite, K-feldspar, apatite, pyrite, and magnetite occur within or cut all other rock types, including the marginal fenites.

THE NEPHELINE—K-FELDSPAR INTERGROWTH

The intergrowth is composed of threads or rods of nepheline in a K-feldspar matrix. X-ray powder diffraction photographs confirm the identities of the two intergrowth phases. Occurrence of the intergrowth

is almost entirely restricted to the more leucocratic members of the ijolite series. Where constituting only a few per cent of the rock, the intergrowth is invariably interstitial to euhedral and subhedral grains of the other minerals. Where a major constituent, it forms a matrix of anhedral grains surrounding euhedra or subhedra of the other minerals (Fig. 2A). Veins of intergrowth up to 5 cm wide cut across layered ijolites in a few places. The occurrence together of nepheline, intergrowth, and K-feldspar as separate grains has only been observed in narrow pegmatitic lenses in some ijolites, and in a few syenitic dikelets that cut across layered ijolites. In these occurrences, radiating masses of intergrowth commonly project from the margins towards the centres of the K-feldspar-bearing layers or dikelets. Thin sections show that grains of intergrowth have equally sharp contacts with K-feldspar and nepheline grains, and also that K-feldspar and nepheline grains are not necessarily separated by intergrowth. Neither the nepheline syenites of the main body of the syenite series nor of the larger dikes cutting ijolites have been found to contain intergrowth.

Distinct domains are present within the intergrowth, with nepheline rods and feldspar matrix showing individually different, uniform extinction in each domain. Nepheline rods commonly range from about 5 microns thick to considerably less than one micron, and the finest intergrowths cannot be resolved with the petrographic microscope. In general, but not invariably, the coarser intergrowths are adjacent to euhedral grains of nepheline, aegirine-augite, and melanite. Outward from these grains the intergrowth becomes progressively finer, with nepheline threads radiating outwards in each domain, giving a pinnate structure as shown in Fig. 2B. Where intergrowths radiating out from different centres meet, it is not unusual to find irregular patches of fine, equant microcline and nepheline grains together with vishnevite. Optical, hence crystallographic, continuity is rarely observed between nepheline grains and nepheline in the surrounding intergrowth. In some rocks, nepheline crystals appear rounded or corroded adjacent to intergrowth. Figures 2C and 2D are plane- and cross-polarized photomicrographs respectively of the field outlined by the rectangle in Fig. 2A, and show the contact detail between nepheline and intergrowth; alteration within the nepheline is cancrinite. In Fig. 2D, parts of three intergrowth domains are readily apparent. The nepheline in each domain is in different crystallographic orientation, and none of it has the same orientation as the neighbouring nepheline grain (at extinction).

While reviewing the literature on nepheline—K-feldspar intergrowths, the author was impressed by the similarity of the intergrowth described above to some published descriptions and photomicrographs of textures

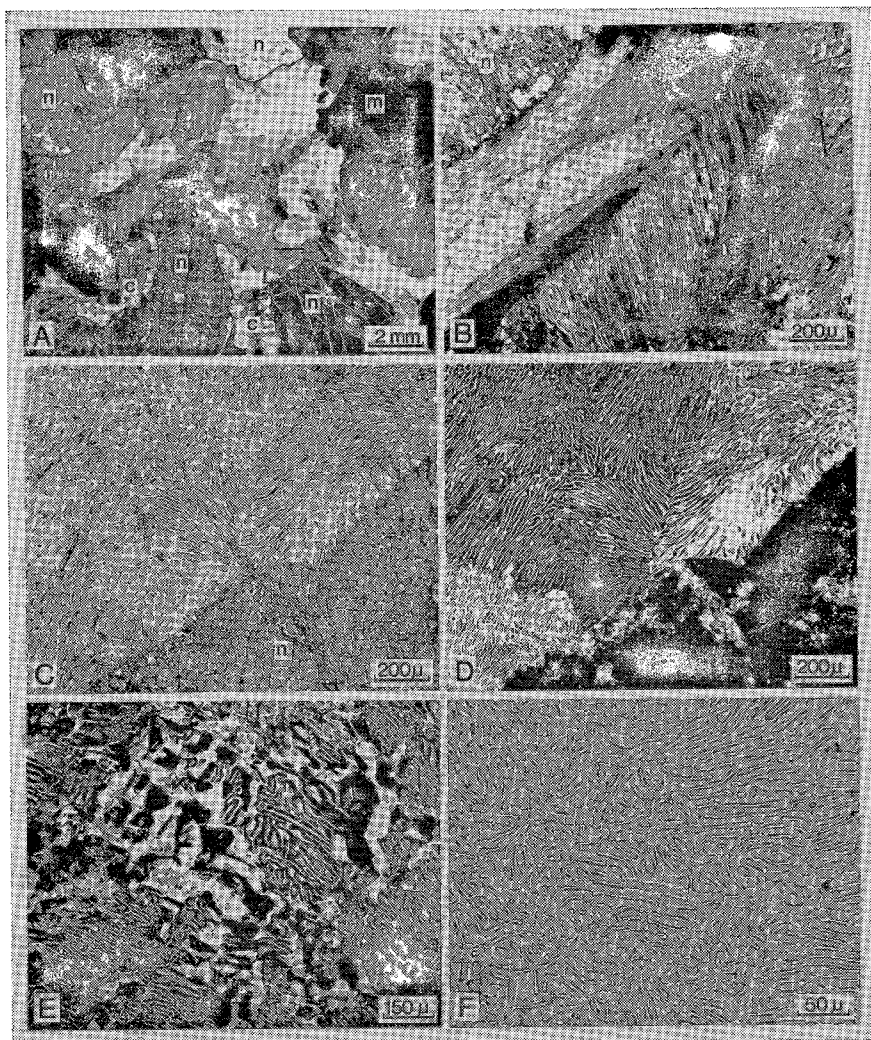


FIG. 2. Photomicrographs of the nepheline—K-feldspar intergrowth. A: intergrowth forms matrix to nepheline (n) and melanite (m); cancrinite (c) is derived from nepheline; crossed nicols. B: pinnate structure in intergrowth; crossed nicols. C and D: detail of contact between nepheline and intergrowth in area outline in A, plane light and crossed nicols respectively. E: detail of intergrowth with nepheline at extinction; crossed nicols. F: detail of intergrowth, plane light.

in pseudoleucites. Figure 2E is a photomicrograph of intergrowth from the Kaminak Lake alkalic pluton that is almost identical to a photomicrograph presented by Fudali (1963, Plate 2, Fig. 4) of nepheline—K-feldspar intergrowth in a pseudoleucite phenocryst from a phonolite

dike in the Bearpaw Mountains of Montana. It was therefore decided to attempt analysis of the intergrowth as a whole and of its component phases to determine where it lies with respect to published analyses of pseudoleucite and other pertinent data plotted on the ternary diagram nepheline—kalsilite—silica.

ANALYSIS OF THE INTERGROWTH

The two intergrowth phases have a remarkably consistent modal ratio. Point counts were made by placing a transparent 1/10th inch grid over each of eleven enlarged photomicrographs, such as Fig. 2F, of the intergrowth from different rocks. About 1,000 points were counted for each photograph. Values obtained for nepheline content range from 34.5 to 40.3 area per cent. The mean value, converted to weight per cent, for nepheline is 37.7, standard deviation 1.56.

Two thin sections containing intergrowth were prepared and coated with carbon film for analysis using a Materials Analysis Company electron microprobe. Analyses were made by Dr. A. G. Plant of the Geological Survey of Canada in close co-operation with the author. Chemically analyzed orthoclase and albite, and synthetic plagioclases of various compositions were used as standards. For analysis of the individual intergrowth phases, an electron beam diameter of 1 to 2 microns was used; for analysis of fine-grained intergrowth as a unit, the beam diameter was increased to 10 microns. Instrument conditions (20 kilovolts and 0.03 micro-amps specimen current) were kept below the level at which volatilization of alkali could be detected. 25 spot analyses were made of both nepheline and feldspar in intergrowths coarser than 4 microns, and 30 analyses of fine-grained intergrowth were with the wide beam. 20 spot analyses were made of nepheline in non-intergrowth grains in order to compare its composition with that of intergrowth nepheline. Also for comparison, one thin section of nepheline syenite that does not contain intergrowth was prepared for analysis of nepheline and K-feldspar; 15 spot analyses were made of each phase. Precision of the determined contents of K_2O and SiO_2 is approximately 2 per cent of the amounts reported. Precision ranges from 5 per cent for low values of Na_2O to 3 per cent for values in excess of 10 weight per cent. Results for CaO were obtained by wavelength scanning and comparison of peak heights with those of low-calcium standards; precision for CaO is about 10 per cent. K, Na, Si, and Ca were the only elements determined by analysis. Checks were made for Fe, Sr, and Ba, and showed negligible contents of these elements in all phases.

Tables 1 and 2 list the results of the individual phase analyses in

TABLE 1. PARTIAL ELECTRON PROBE MICROANALYSES OF NEPHELINE FROM KAMINAK LAKE ALKALIC PLUTON IN WEIGHT PER CENT

	Intergrowth nepheline from ijolite series	Non-intergrowth nepheline from ijolite series	Non-intergrowth nepheline from syenite series
SiO ₂	<i>42.3 ± 0.85</i> (40.0 ± 1.0)	<i>42.3 ± 0.85</i> (41.1 ± 1.0)	<i>41.6 ± 0.85</i> (40.3 ± 1.0)
Al ₂ O ₃	34.0 ± 0.9	34.8 ± 0.9	34.3 ± 0.9
CaO	<0.1	<0.5	<0.1
Na ₂ O	<i>15.5 ± 0.5</i>	<i>16.4 ± 0.5</i>	<i>16.1 ± 0.5</i>
K ₂ O	<i>7.8 ± 0.15</i>	<i>7.2 ± 0.15</i>	<i>7.2 ± 0.15</i>
Total	99.7 ± 2.4	100.7 ± 2.4	99.2 ± 2.4
Ne	71.3	74.6	74.4
Ks	26.4	24.2	24.3
Q	2.3	1.2	1.3

Note: Figures in italics are analyzed, figures in plain type are calculated.

TABLE 2. PARTIAL ELECTRON PROBE MICROANALYSES OF K-FELDSPAR FROM KAMINAK LAKE ALKALIC PLUTON IN WEIGHT PER CENT

	Intergrowth K-feldspar from ijolite series	Non-intergrowth K-feldspar from syenite series
SiO ₂	64.8 ± 1.5	64.6 ± 1.5
Al ₂ O ₃	18.4 ± 0.4	18.3 ± 0.4
CaO	<0.05	<0.05
Na ₂ O	<i>0.8 ± 0.05</i>	<i>0.9 ± 0.05</i>
K ₂ O	<i>15.7 ± 0.3</i>	<i>15.5 ± 0.3</i>
Total	99.7 ± 2.25	99.3 ± 2.25
Or	93.2	92.3
Ab	6.8	7.7

Note: Figures in italics are analyzed, figures in plain type are calculated.

weight per cent of the oxides. Italicized figures were obtained by analysis, and those in ordinary type were calculated from the analyzed Na and K contents according to stoichiometric proportions in the phases concerned. Si was analyzed for in nepheline because this mineral commonly contains more than stoichiometric SiO₂, presumably on account of lattice vacancies in the cation sites (Hamilton & MacKenzie 1960, p. 56); both analyzed and stoichiometric SiO₂ contents are given for nepheline in Table 1. Nepheline—kalsilite—quartz ratios are given for nepheline, and orthoclase—albite ratios for K-feldspar. The analyses indicate a slight

difference in composition between intergrowth and non-intergrowth nepheline in the same ijolitic rocks, that K-feldspar in the nepheline syenite is virtually the same as the intergrowth feldspar in the ijolitic rocks, and that non-intergrowth nepheline in the ijolitic rocks compares more closely to nepheline in the syenite than to intergrowth nepheline.

TABLE 3. ANALYTICAL DATA FOR NEPHELINE—K-FELDSPAR
INTERGROWTH IN WEIGHT PER CENT

	Partial electron probe microanalysis of intergrowth	Analysis calculated as leucite from the determined contents of Na ₂ O and K ₂ O	Analysis calculated from mode and analyzed composition of component phases
SiO ₂	<i>56.9 ± 1.14</i>	56.9 ± 1.5	56.5
Al ₂ O ₃	—	24.2 ± 0.6	24.4
Na ₂ O	<i>6.0 ± 0.24</i>	<i>6.0 ± 0.24</i>	6.3
K ₂ O	<i>13.2 ± 0.26</i>	<i>13.2 ± 0.26</i>	12.8
Total	76.1 ± 1.64	100.3 ± 2.1	100.0

Note: Figures in italics are analyzed, figures in plain type are calculated.

The first column in Table 3 gives the results of wide beam microprobe analysis of fine-grained intergrowth. From the figures thus obtained for Na₂O and K₂O, stoichiometric proportions of Al₂O₃ and SiO₂ were calculated according to the molecular formula of leucite, (K, Na)AlSi₂O₆, and are given in the second column of Table 3. The third column gives an analysis of the intergrowth calculated from the modal proportion of the two phases using the intergrowth phase compositions calculated from the analyses in Tables 1 and 2. This treatment serves to check the analytical data and illustrates that the intergrowth as a unit has almost exactly the composition of sodian leucite, whose calculated weight ratio of leucite to soda-leucite is 61:39.

Figure 3, the ternary composition diagram nepheline—kalsilite—quartz, shows that the point representing the intergrowth lies on the leucite—soda-leucite composition line. A tie-line through this point joins points representing the component phases nepheline and K-feldspar. On this diagram, for comparison, are also plotted:

1) Eight analyzed pseudoleucites, seven of which are phenocrysts with trapezohedral form from tinguaita dikes; point 5 is an analysis of the 'white spots' in borolanite from Scotland (Shand 1939). For only one pseudoleucite, point 8, have the component nepheline and feldspar phases been analyzed (Zies & Chayes 1960).

2) One analysis of potash-analcite, the most potassic so far recorded (Larsen & Buie 1938).

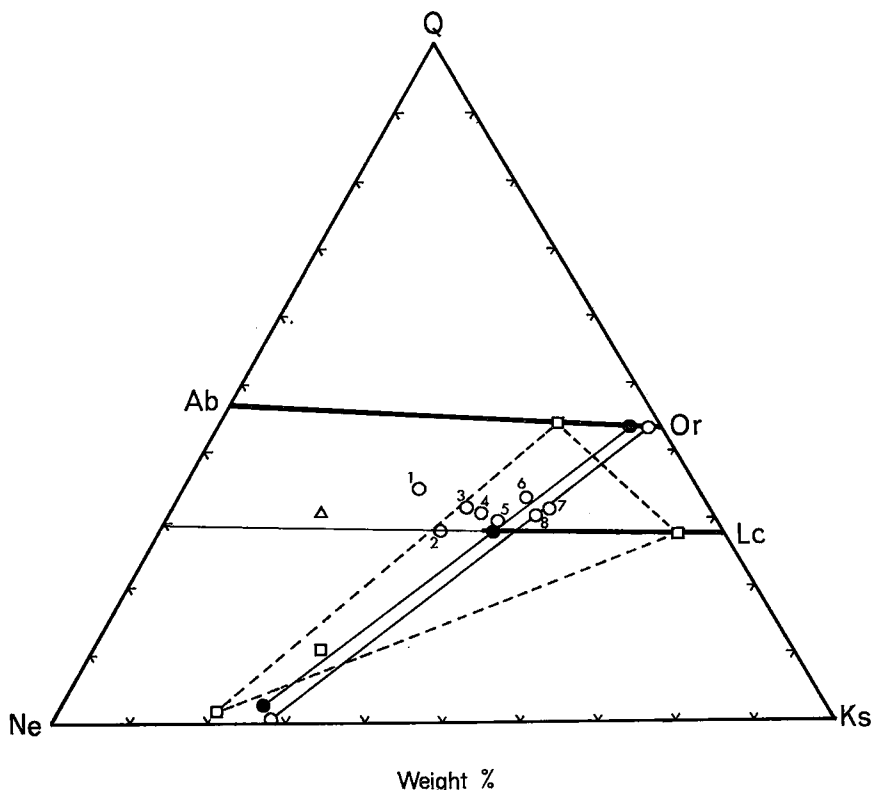


FIG. 3. Nepheline-kalsilite-quartz ternary diagram showing compositions of the intergrowth and its component phases (●). For comparison are also plotted: pseudoleucite analyses (○), 1—Knight (1906); 2—Williams (1890); 3 and 4—Sukheswala & Sethna (1967); 5—Shand (1939); 6—Larsen & Buie (1938); 7—Fudali (1963); 8—Zies & Chayes (1960), including analysed nepheline and feldspar phases; potash analcite (Δ), Larsen & Buie (1938); leucite nepheline dolerite and its contained, coexisting nepheline, leucite, and feldspar (□), Tilley (1958*b*).

3) The mineral triplet nepheline—leucite—feldspar found co-existing in a dike in Germany, together with the point representing the host rock (Tilley 1958*b*).

DISCUSSION

Any suggested origin for the nepheline—K-feldspar intergrowth must account for the facts that the two component phases are in constant proportion and that the intergrowth's composition corresponds to a 61:39 weight per cent solid solution of leucite and soda-leucite. The principal ways in which such an intergrowth could have formed are outlined and discussed below.

The intergrowth could have formed from a pre-existing, homogeneous,

solid phase, *without* change in bulk chemical composition, either by exsolution or by sub-solidus breakdown. Formation by exsolution can be discounted on the grounds that nepheline and K-feldspar are not mutually soluble under any known conditions. The only phase with the right original composition to give the observed proportions of nepheline and K-feldspar by sub-solidus breakdown is sodian leucite. It is known that the stability field of leucite in the system kalsilite—quartz—water decreases with increase in water vapour pressure (Goranson 1938; Tuttle & Bowen 1958). Fudali (1963) has shown that this is also true in the system nepheline—kalsilite—quartz—water, and has also demonstrated that the amount of soda-leucite ($\text{NaAlSi}_2\text{O}_6$) that can be held in leucite solid solution decreases from 40 weight per cent at 1 atmosphere under dry conditions to 28 weight per cent at 1,000 bars water pressure. The Na content of leucite is presumably further inhibited at higher water pressures. Recent work by Lindsley (1967), however, has shown that the leucite stability field is not reduced at high pressures under dry conditions, but the effect of high pressures where $P_{\text{H}_2\text{O}} < P_{\text{total}}$ on the Na content of leucite is not at present known.

Fudali has demonstrated convincingly that pseudoleucite phenocrysts from the Bearpaw Mountains are in fact derived from sodian leucites with near maximum soda-leucite content. Some of the other pseudoleucite analyses plotted in Fig. 3 contain a greater proportion of Na than would be permitted even by maximum solid solution, unless there exist as yet unrecognized conditions under which solid solution is extended. Most authors agree that some form of chemical change is involved in the production of these pseudoleucites. Nearly all pseudoleucites are characterized by trapezohedral crystal form. The fact that the chemically similar Kaminak Lake intergrowth is invariably anhedral does not by itself negate a leucite origin, because it can be argued that if leucite was a late crystallizing phase, its crystal growth would presumably have been restricted by the presence of earlier formed minerals.

If it is assumed that $P_{\text{H}_2\text{O}}$ approximately equalled P_{total} during crystallization of the intergrowth-bearing rocks, it seems unlikely that the Kaminak Lake alkalic rocks crystallized at the extremely low pressure required for formation of leucite as sodic as 39 weight per cent soda-leucite (Fig. 3). In this regard, it is worth noting that intergrowth-bearing members of the Kaminak Lake ijolite series will plot fairly close to the leucite—nepheline dolerite described by Tilley (1958a), data for which are reproduced in Fig. 3. The magma of this rock, presumably crystallizing under hypabyssal conditions, that is, at relatively low pressure, precipitated leucite with less than 10 weight per cent soda-leucite in solid solution.

If the Kaminak Lake intergrowth formed from sodian leucite that had

crystallized at, say, 1 or 2kb, from experimental work to date it must be assumed that $P_{\text{H}_2\text{O}}$ was much less than P_{total} . Such an assumption is perhaps supported by the fact that the primary minerals in the intergrowth-bearing rocks are non-hydrous, except for the sporadic occurrence of biotite. Under relatively dry conditions, therefore, the intergrowth could have formed from sodian leucite by sub-solidus breakdown, provided that it is only $P_{\text{H}_2\text{O}}$ that notably reduces the Na content of leucite. However, early crystallization of non-hydrous phases will lead to concentration of water in the remaining melt, with consequent build-up of water pressure; this will have the effect of reducing the leucite stability field and the extent of solid solution. Unless, therefore, the ijolite series magma was practically devoid of water, leucite as sodic as 39 weight per cent probably could not form, and certainly not as a late crystallizing phase. In addition, the postulation of water-poor magma of the required composition introduces the problem of very high magma temperatures (Lindsley 1967).

The intergrowth could have formed from a pre-existing, homogeneous, solid phase, *with* change in bulk chemical composition, either by sub-solidus replacement of a stable phase, by sub-solidus breakdown of an unstable phase, or by reaction with a fluid phase. It seems unlikely that replacement of K-feldspar by nepheline, of nepheline by K-feldspar, or of some unknown phase by both nepheline and feldspar would give rise to an intergrowth of the consistency observed. Rather, such evidence as cores of unreplaced material, irregular composition and texture, and preferred replacement along grain boundaries might be expected. Sub-solidus breakdown with chemical change allows suggestion that the original phase was soda-poor leucite or potassic analcite, but again it is hard to see why such a mechanism would lead to so consistent an intergrowth as is found, regardless of total rock composition. Formation by reaction with a fluid phase involves two alternatives: sub-solidus reaction with a pervasive, presumably aqueous fluid, or reaction of an early crystallized phase with remaining melt. It is unlikely that the first alternative would produce so chemically and texturally consistent a product throughout such a large volume of the alkalic pluton; besides, hydrous rather than anhydrous products would be expected, as in most pseudoleucites. The second alternative introduces the well-known pseudo-leucite reaction of Bowen (1928), in which early-formed leucite reacts with magma to form nepheline and K-feldspar. This mechanism does not require that the original leucite be particularly sodic (Bowen & Ellestad 1937). It is possible that the Kaminak Lake intergrowth represents the condition discussed by Bowen (1928, p. 254) in which "there is a further outgrowth of the orthoclase and nephelinite beyond the limits of the

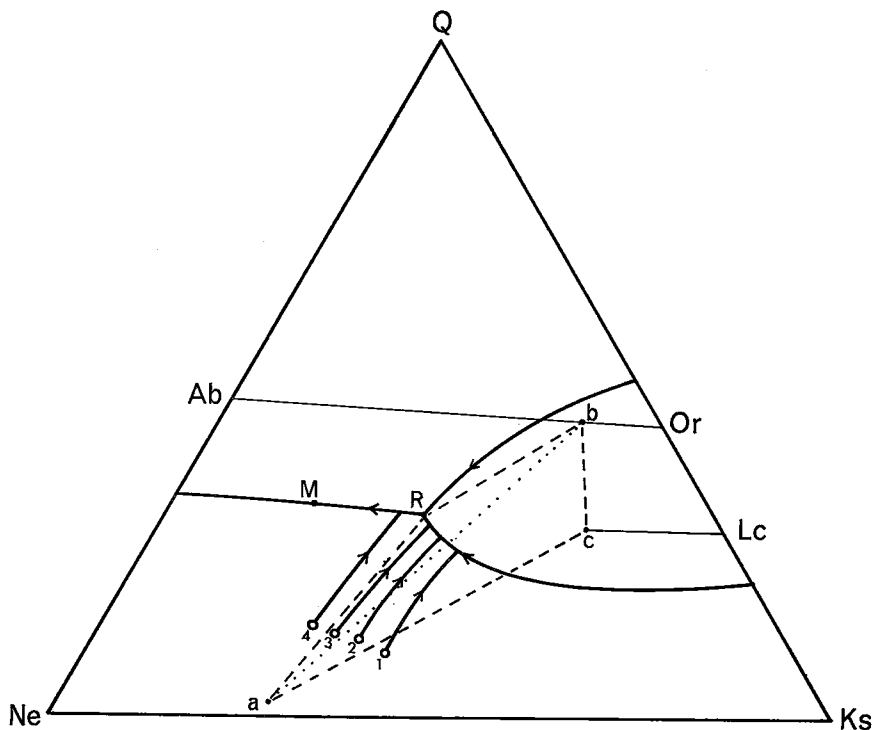


FIG. 4. Projection of the liquidus relations at 1,000 bars P_{H_2O} in the quaternary system nepheline-kalsilite-quartz-water, after Fudali (1963), showing the rock compositions that have the four different equilibrium crystallization sequences discussed in the text.

original leucite, giving indefinite patches of pseudo-leucite material." The reaction of early-formed leucite with magmatic fluid is fully discussed by Fudali (1963; see Fig. 6, p. 1112) in the light of his experimental work. In summary, Fig. 4 illustrates the different crystallization histories of melts (points 1, 2, 3, 4) lying initially in the nepheline field. Under equilibrium crystallization conditions, melt 1 yields an assemblage of nepheline and leucite; melt 2, nepheline, leucite, and K-feldspar, with part of the leucite having been re-dissolved; melt 3, nepheline and K-feldspar, with all originally precipitated leucite having been re-dissolved; melt 4, nepheline and K-feldspar, without an intervening period of leucite formation and resorption. A specific melt could follow any one of these crystallization paths, depending on the position of the field boundaries, which is governed by the operating water pressure. Also, the degree of fractionation, versus equilibrium crystallization, will govern how far along the boundary curves the melts will move, and how complete will be the resorption of early-formed leucite. It is possible

that the Kaminak Lake intergrowth was formed in place of completely resorbed leucite as in the case of melt 3, even though there is now no direct textural evidence that leucite was ever present. If some leucite remained after the disappearance of the melt, as in the case of melt 2, and if it was highly sodic, nepheline—K-feldspar intergrowth could have formed by direct sub-solidus breakdown as already described.

Consideration of melt 4 introduces another mechanism by which the intergrowth could have formed, namely, simultaneous crystallization from a liquid phase. Theoretically, having changed its composition, by precipitation of nepheline, until it reached the nepheline—K-feldspar field boundary, melt 4 should produce nepheline and K-feldspar of specific compositions and in a set proportion by cotectic crystallization. The Kaminak Lake alkalic rocks may have crystallized at a water pressure too high for an appreciably sodian leucite to have formed. Figure 5 shows, superimposed, projections of the liquidus field boundaries in the system nepheline—kalsilite—quartz—water at one atmosphere (Schairer 1957), at 1kb P_{H_2O} (Fudali 1963), and at some hypothetical higher water pressure (dashed curves) at which the leucite field is further reduced. The minimum trough between nepheline and K-feldspar is displaced towards the nepheline—kalsilite side with increase in P_{H_2O} . At some pressure greater than 1kb P_{H_2O} it must lie very close to the leucite solid solution line for compositions near the undersaturated minimum. A silicate melt crystallizing at this pressure would therefore precipitate nepheline and K-feldspar in proportion coinciding with the nepheline—K-feldspar ratio produced by sub-solidus breakdown of sodian leucite. This mechanism of cotectic crystallization can therefore explain why the point in Fig. 3 representing the Kaminak Lake intergrowth lies on the leucite composition line.

It may be argued that there is no reason why cotectic crystallization should produce a fine, vermiform intergrowth, rather than an aggregate of equant grains. Moreover, even if an intergrowth is formed, it might be expected that the early-formed and intergrowth nephelines would be in crystallographic continuity. Lack of such continuity, combined with the common observation in the Kaminak Lake rocks that the early nepheline crystals surrounded by intergrowth are rounded or corroded, leads to the suggestion that there may have been some break in the crystallization sequence. In this regard, the slight composition difference in the two nephelines (Table 1) may be significant. Although it may be, for reasons not known, that formation of intergrowth is a normal product of cotectic crystallization of nepheline and K-feldspar, it is possible that the intergrowth was produced by some form of quenching, perhaps brought about by some change in physico-chemical parameter, such as P_{H_2O} . For example, with build-up of P_{H_2O} , the liquidus surface, on which

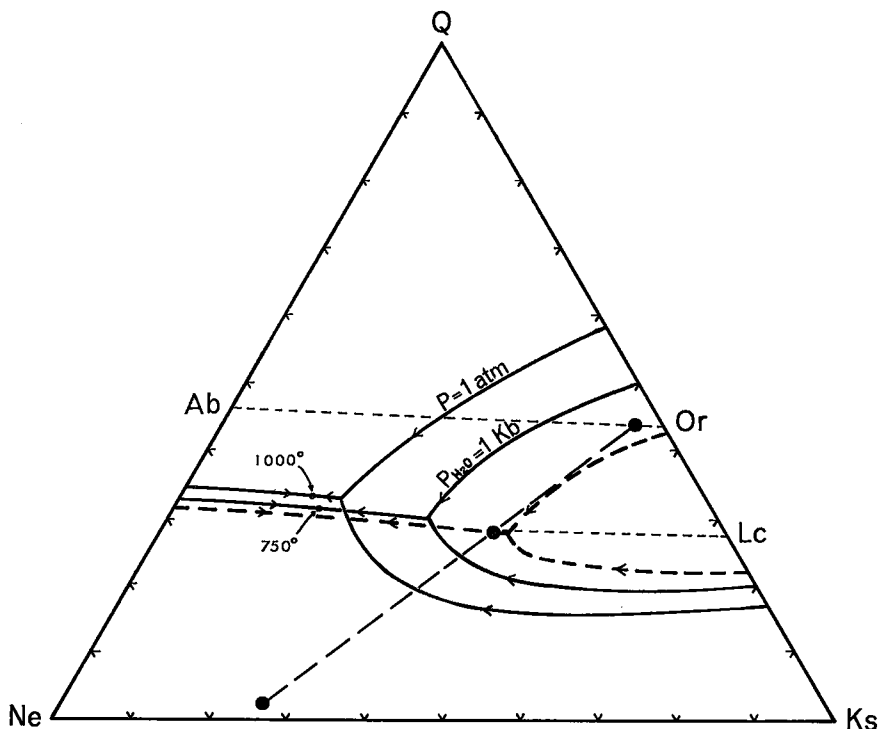


FIG. 5. Superimposed projections of liquidus relations in the quaternary system nepheline-kalsilite-quartz-water at 1 atmosphere (Schairer 1957), at 1,000 bars P_{H_2O} (Fudali 1963), and at some hypothetical pressure $>1,000$ bars P_{H_2O} (dashed curve). At the hypothetical higher pressure, nepheline and feldspar will crystallize directly from the same liquid that at lower pressure will precipitate nepheline and leucite.

the melt crystallizing nepheline lies, might recede towards the nepheline—kalsilite side faster than crystallization of nepheline can change the melt composition towards the field boundary, so that nepheline at first ceases to crystallize and then starts to re-dissolve. If at this stage there is a release in P_{H_2O} , perhaps brought about by movement of the magma with concomitant escape of water, then not only will the liquidus surface shift back towards the quartz apex, but the liquidus temperature will increase, leaving the remaining melt in a super-cooled state below the liquidus surface. Rapid crystallization of such a melt could produce a nepheline—K-feldspar intergrowth such as is found.

CONCLUSIONS

Three of the mechanisms discussed can explain the formation of the nepheline—K-feldspar intergrowth, namely (1) formation by sub-solidus breakdown of sodian leucite, (2) reaction of early-formed leucite with melt (the pseudoleucite reaction), and (3) cotectic crystallization directly

from a melt. The first two mechanisms require that leucite was formed at some stage during crystallization, and it has been argued that conditions favouring leucite formation may not have occurred in the Kaminak Lake pluton. The third mechanism can explain, without involving leucite, the textural and compositional data pertaining to the Kaminak Lake nepheline—K-feldspar intergrowths. It is possible, however, that further experimental work will reveal that leucite can crystallize, and in addition be appreciably more sodic, under conditions other than those investigated to date, so the interpretation that the Kaminak Lake intergrowths are in fact pseudoleucite cannot be discounted.

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