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Nepheline as a Metasomatic Product

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Abstract

Petrographic observations on nepheline syenites from the Eastern Ghat province of India indicate that alkali-exchange reactions wherein potassium replaces sodium in a silica-deficient environment may convert plagioclase to perthite plus nepheline. A pervasive vapor phase is postulated as the vehicle for diffusion of alkali ions along temperature and/or pressure gradients, K moving down (and Na up) any temperature gradients.

Introduction

Nepheline, an important undersaturated mineral, has hitherto been ascribed to magmatic melts. However, in recent times a metasomatic origin has been postulated (Gummer and Burr, 1946; Tilley, 1957; Gittins, 1961; Appleyard, 1967; Duffin, 1964; Narayana Kutty *et al,* 1969; Henderson and Gibb, 1972). Such metasomatic origin has been attributed to the action of alkali fluids or to plagioclase transformation by solid-state reaction.

Present Work

Janardan Rao and Murthy (1970), while studying nepheline syenites in the Eastern Ghat province of India between Vinayakapuram and Kunavaram (81° 5′–81° 17′ 30″ E—17° 20′ 30″–17° 37′ 10″ N) observed petrographic features which indicate that nepheline may form by transformation from plagioclase. The 'unexpected results' reported by Duffin (1964), and similar experiments carried out by Narayana Kutty *et al* (1969) on conversion of plagioclase to nepheline by cation exchange reaction in sodium chloride solutions, further support the observed phenomenon in the present petrographic studies.

Feldspar—Nepheline Association

Nepheline in the Eastern Ghat syenites is closely associated with plagioclase and microcline-perthite whereas direct relationship with hornblende or biotite is absent or relatively rare. Megascopically, nepheline occurs as elongated or well developed grains along the foliation planes of the syenite gneiss. The close association of nepheline with feldspars may have a direct bearing on its genesis.

Thin sections of the Eastern Ghat nepheline syenites show that nepheline, plagioclase and microcline-perthite are closely associated and characterized by the following textural features.

1. The plagioclase is of three varieties based on the anorthite content. The oldest plagioclase (An_{20-28}) is often corroded, engulfed, or cross-cut by a texturally younger plagioclase having a composition essentially of pure albite or in the range of An_{14-16}.
2. Isolated relics of plagioclase in microcline-perthite show optical continuity between them.
3. Highly corroded plagioclase grains along the boundaries of microcline-perthite show optical continuity with the plagioclase blebs in the perthite (Figs. 1, 2.)
4. There is continuity of the twin lamellae of relict plagioclase grains with grid twinning in microcline–perthite (Fig. 2).
5. The *patch* and the *ribbon* types of nepheline recognized by Appleyard (1969) in Ontario also occur in our area. Rounded, residual patches of plagioclase or perthite are often found within the large grains of 'patch' nepheline (Fig. 3) showing optical continuity with the surrounding grains. 'Ribbon' nepheline is invariably found along the intergranular boundaries.
6. Large nepheline grains associated with plagioclase show diffuse borders at their contacts. Such plagioclase grains show a skeletal form as though being encroached upon by nepheline (Fig. 3).
7. Nepheline grains occurring along plagioclase or perthite borders show optical continuity

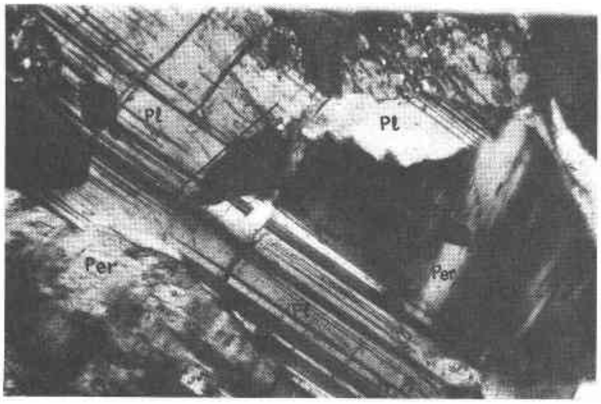

FIG. 1. Microclinization of plagioclase (An_{24}). Note the highly corroded plagioclase (Pl) along the contact of perthite (Per). Also one face of the perthite is parallel to the twinning of plagioclase and other faces and subboundaries (marked by a line) are parallel to the microfractures and dust lines that are nearly perpendicular to the plagioclase twinning. Nepheline occurs along the borders of the plagioclase (Pl) (crossed nicols, × 40).

FIG. 3. Plagioclase and 'patch' nepheline relationship. Nepheline (Ne) boundaries show diffuse borders (**d**) along the contact of plagioclase (Pl). The indistinct cleavage and cracks in nepheline (Ne) are parallel to the twinning in plagioclase (marked by a line). The perthite blebs in nepheline are optically continuous with the outside perthite grains (crossed nicols, × 40).

with one set of twin lamellae in plagioclase and corresponding grid twin in microcline–perthite (Fig. 4).

8. There is incipient growth of nepheline parallel to the twin planes of plagioclase (Fig. 5).
9. The relative paucity of albite blebs around nepheline inclusions (Fig. 6).
10. Streaks marked by alteration products in nepheline show a striking parallelism to one of the trends of albite blebs in the host perthite (Fig. 6).
11. Nepheline grain boundaries are often subparallel to cleavages, microfractures, or lattice strains in the host perthite (Fig. 2).

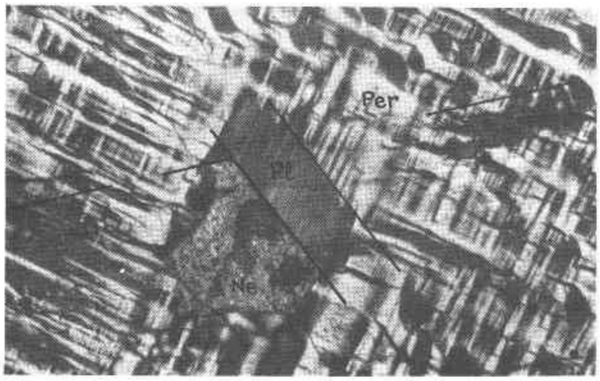

FIG. 2. Plagioclase (Pl)-microcline-perthite (Per)-nepheline (Ne) relationship. Note the optical continuity between the plagioclase blebs in perthite, and one set of twinning in plagioclase. Also, plagioclase twinning is parallel to one set of grid-twinning in microcline and the faces of nepheline. Further, nepheline grain boundaries (marked by lines) follow the edges of corroded plagioclase, trends of blebs of plagioclase, and opaque dust lines in perthite (crossed nicols, × 40).

Model of the Replacement Process for the Formation of Nepheline

Henderson and Gibb (1972), while describing plagioclase–nepheline replacement textures similar to those described by Tilley (1957), conclude

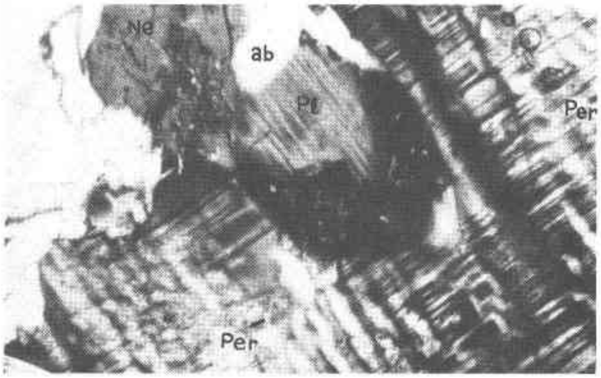

FIG. 4. Plagioclase (Pl)-microcline-perthite (Per)-nepheline (Ne) relationship. Nepheline (extinction position) is optically continuous with one set of plagioclase twinning and with microcline in the perthite. Late albite (**ab**) is seen along the boundaries of plagioclase. Further, the nepheline-plagioclase relationship suggests that plagioclase is remnant (crossed nicols, × 40).

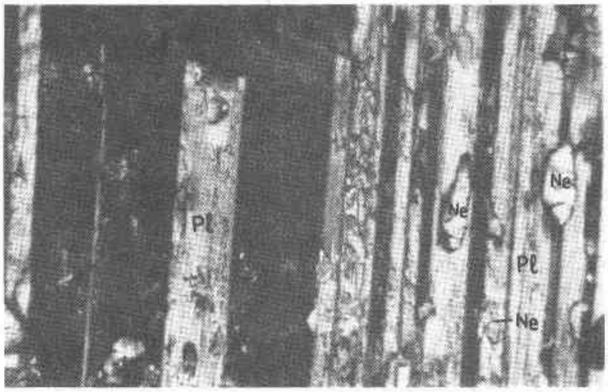

FIG. 5. Development of nepheline (Ne) parallel to the twinning in plagioclase (Pl) (crossed nicols, × 40).

that "the replacement of plagioclase by nepheline may indicate that the plagioclase is in fact being resorbed and immediately replaced by nepheline." They point out that the alkali feldspar (orthoclase) shows no direct textural relations with the plagioclase and nepheline and hence recognize only the replacement of plagioclase by nepheline.

In the present work the authors have taken into cognizance the association of three minerals, *viz* plagioclase, microcline–perthite, and nepheline. Microclinization of plagioclase is indicated by the observed facts described under the textural criteria. In this connection, it is pertinent to note that the granitic rocks of the Precambrian shield areas of the world invariably show certain mineral transformations of which microclinization of plagioclase is one of the most important and commonly accepted

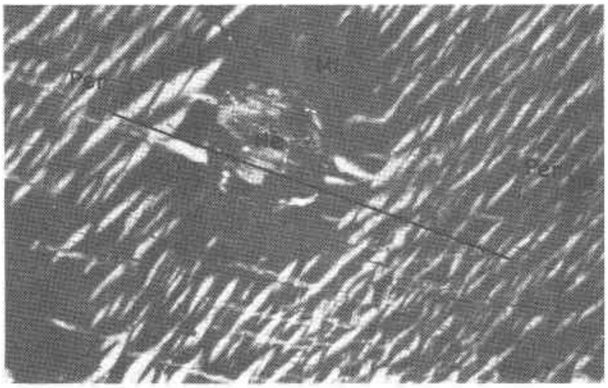

FIG. 6. Nepheline (Ne) in perthite (Per). Note the streaks marked by alteration product in nepheline showing a striking parallelism to the trend of one set of albite blebs in the perthite (marked by a line). Further, there is relative paucity of albite blebs around nepheline in perthite (Per) (crossed nicols, × 40).

phenomena (Cheng, 1943; Harry, 1953; Marmo, 1971). The experimental proof for such phenomena has been reported by Wyart and Sabatier (1956), Orville (1953), and Anantha Iyer *et al* (1970) by cation exchange reaction in the molten alkali halide.

The textural features observed by the writers in the Eastern Ghat syenites suggest that nepheline merely represents one of the important products in the replacement of parts of plagioclase by K-feldspar in a silica-deficient environment. The reaction, as envisaged by the authors, involves an ion exchange origin by the substitution of sodium by potassium, as follows:

$$\underbrace{3(NaAlSi_3O_8)\cdot(CaAlSi_2O_8)}_{\text{Plagioclase }(An_{25})} + 2K^+$$

$$\rightarrow \underbrace{2(KAlSi_3O_8)\cdot(NaAlSi_3O_8)}_{\text{Perthite}} + \underbrace{2(NaAlSiO_4)}_{\text{Nepheline}} + Ca\uparrow$$

The kind of alkali ion exchange reaction involved in the process has received powerful experimental support from Orville (1958, 1961, 1963). The conversion of natural potash feldspar into soda feldspar and vice versa over a considerable range of pressure and temperature in the presence of alkali chloride water solution was found to be a relatively easy process. It was merely an ion exchange reaction involving the exchange of K and Na between all the alkali compounds taking part in the reaction. Further, a continuous reciprocal transfer of alkalies between two portions of a rock mass could occur, if (1) a temperature gradient exists between the parts of the rock mass in question, (2) two alkali feldspars are present in both parts of the rock, and (3) a pervasive vapor phase is present through which alkali ions in solution may diffuse. Reaction between the vapor phase and two feldspar phases produces a higher proportion of K relative to Na in the vapor phase in the high temperature portion of the rock mass than in the low temperature portion. Diffusion of alkali ions will take place along the concentration gradients thereby established, with K moving to the low temperature rock and Na to the high temperature rock.

The experimental results of Duffin (1964) and Narayana Kutty *et al* (1969) suggest that nepheline could form from plagioclase by the solid state reaction:

$$\underbrace{NaCa_2Al_5Si_7O_{24}}_{\text{Plagioclase}} + 4NaCl$$

$$= \underbrace{Na_5Al_5Si_7O_{24}}_{\text{Nepheline}} + 2CaCl_2$$

According to them, this reaction results in a nepheline with an Si:Al ratio of 1.4 and with a lower sodium content than indicated by the simple formula $NaAlSiO_4$. The occurrence of nepheline containing an excess of silica over that required by the simple formula and the variation in Si:Al ratio up to 1.4 is known (Mason, 1966). Further, during the exchange of cations of unequal charges the rearrangement of the silicate structure occurs in preference to substitution or depletion of Al^{3+} or Si^{4+}. Based on such results it is concluded that such cation exchange reactions may occur in nature to produce nepheline.

Conclusions

Nepheline may develop in syenites concurrently with replacement of plagioclase by K-feldspar in a silica deficient environment. The process presumably involves an alkali exchange reaction with potassium replacing sodium in parts of plagioclase crystals that are then converted to perthite. During this process other parts of the plagioclase crystals undergo a rearrangement of structure to form nepheline during the exchange of cations of unequal charges.

A pervasive vapor phase may be the vehicle for diffusion of the alkali ions along temperature or pressure gradients during the exchange reactions. The alkalies necessary for the metasomatic reactions could be provided by the silicate phases present in the rock mass.

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