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# SOME GARNETS, PYROXENES, AND AMPHIBOLES FROM NEPHELINE GNEISSES IN GHANA

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## ABSTRACT

Nepheline gneisses, predominantly leucocratic, but grading into mafic and feldspar-poor varieties, occur in a thin layer in the Dahomeyan shield of southeastern Ghana. Two garnets, one pyroxene, and three amphiboles were separated for chemical analyses and optical determinations from three specimens of nepheline gneiss. Optical data of two additional pyroxenes are given.

Garnets are andradite-rich grossularite, and occur only in the mafic and feldspar-poor nepheline gneisses. Aegirine-augites in the leucocratic nepheline gneisses contain up to 0.63 $Fe^{3+}$ ions per formula unit, but in the mafic and feldspar-poor gneisses the aegirine-augites are closer to soda augite (0.298 $Fe^{3+}$ ions per formula unit). On the basis of optical properties the amphiboles appear to range in a continuous series from hastingsite to iron-rich alkaline amphibole. Zoned amphiboles invariably have hastingsite cores and alkaline amphibole rims. An unzoned alkaline amphibole, optically similar to the rims of the zoned amphiboles, was analyzed. This amphibole is optically and chemically distinctive, having normal-symmetric orientation of the optic plane ($Y{:}c=9°$), dark olive-green ($\gamma$) to dark greenish-blue ($\beta$) pleochroism, two aluminum atoms in tetrahedral positions, a $Ca/Na+K$ ratio of 0.44, and a high $Fe^{3+}/Fe^{2+}$ ratio.

Textures indicate the zoned amphiboles result from the reaction:

$$\text{calcite}+\text{nepheline}+\text{aegirine-augite}+\text{hastingsite}\rightarrow\text{grandite}+\text{iron-rich alkaline amphibole}+CO_2.$$

## INTRODUCTION

In connection with geological field investigations for the Ghana Geological Survey in 1963, 1964, and 1965, specimens of nepheline gneiss were collected for petrographical and geochemical study from a thin layer (10–20 m) of alkalic gneiss in the southeastern corner of Ghana. These alkalic rocks crop out for more than 60 km along strike near the towns of Somanya, Kpong, and Pore in the western portion of the Accra Plains. Geologically, they occur with Precambrian schists, gneisses, and amphibolites of the Dahomeyan shield (Fig. 1). The purpose of this report is to present optical and chemical data of the garnets, pyroxenes, and amphiboles in the nepheline gneiss, and to discuss some of the aspects of the genesis of these minerals.

## GEOLOGY

The unit of alkalic gneiss includes a variety of moderately to strongly foliated nepheline-bearing gneisses, and silica-saturated and over-

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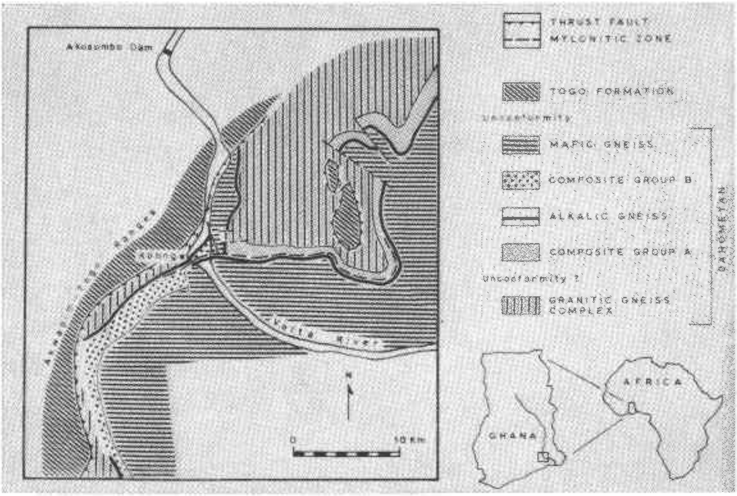

FIG. 1. Geologic map showing general field relations of the nepheline gneiss in southeastern Ghana.

saturated alkalic gneisses. Most of the rocks are leucocratic nepheline gneiss, consisting predominantly of albite, microcline, and nepheline, and containing small amounts of iron-rich biotite, aegirine-augite, and alkaline amphibole. The leucocratic nepheline gneisses grade into mafic varieties. Rare feldspar-poor nepheline gneisses (ijolitic) occur locally. The mafic and feldspar-poor nepheline gneisses commonly carry garnet along with significant amounts of pyroxene and hastingsitic amphibole. Calcite is common in minor amounts. Silica-saturated syenitic gneisses occur throughout the unit, but oversaturated peralkaline types are rare. Field relations, petrography, and geochemistry of the alkalic gneisses indicate that they are isochemically metamorphosed alkaline igneous rocks (Holm, 1969). Rocks contiguous to the alkalic gneisses are mica schists and epidote amphibolites (Composite Groups A and B, Fig. 1), mafic gneisses (hornblende, oligoclase-andesine, epidote with or without garnet, salite, quartz, scapolite), and granitic gneisses.

## MATERIALS AND PROCEDURES

Three specimens of nepheline gneiss were selected for mineral separations: (1) leucocratic nepheline gneiss, specimen 107; (2) mafic nepheline gneiss, specimen 99; and (3) feldspar-poor nepheline gneiss, specimen 30A. Splits of these specimens are on file at the Ghana Geological Survey. Modes are given in Table 1; chemical analyses will be published elsewhere. Garnet, pyroxene, and amphibole samples of greater than 98 percent purity were obtained by a combination of magnetic separation and centrifuging with methylene iodide and Clerici solution. The amphiboles and pyroxene were analyzed by wet chemical methods by H. B. Wiik. The garnet analyses were made by the author with an atomic

TABLE 1. MODES OF NEPHELINE GNEISSES

| Mineral | 30A | 99 | 107 |
|---|---|---|---|
| Nepheline | 33 | 3 | 25 |
| Plagioclase | 1 | 51 | 37 |
| Microcline | 1 | 18 | 28 |
| Biotite | - | - | 4 |
| Pyroxene | 2 | - | - |
| Amphibole | 52 | 29 | 5 |
| Garnet | 1 | 5 | - |
| Calcite | 3 | tr | tr |
| Sphene | 4 | 2 | tr |
| Apatite | 2 | tr | tr |
| Opaque | tr | tr | tr |
| Color index | 59 | 36 | 9 |
| An-content of plagioclase | 11 | 17 | 0 |

absorption spectrophotometer. Refractive indices were measured in immersion oils using a spindle stage and a sodium D-line filter; after matching, the oils were checked in an Abby refractometer equipped with a high-index prism. Optic axial angles were measured directly in thin sections with a 4-axis universal stage.

## MINERALOGY

*Garnets.* Garnets occur only in the mafic and feldspar-poor nepheline gneisses, where they range between 1 and 10 modal percent. In hand specimens, the garnets are dark brownish red, but in thin sections they are orange. Where zoning is optically observable, rims are darker than cores. Some garnets are slightly to moderately flattened in the foliation and they range up to 1 cm in longest diameter. Table 2 shows the instrumental chemical analyses of two garnet samples and the molecular proportions of the garnet end-members. Both garnets are andradite-rich grossularite (grandite). Garnet 30A has a fairly high melanite content; a similar garnet has been reported from nepheline-bearing rocks in Ontario (Adams and Harrington, 1896).

TABLE 2. COMPOSITION OF GARNETS

| | Weight Per cent | | | Component Per cent | |
|---|---|---|---|---|---|
| | 1 | 2 | | 1 | 2 |
| $SiO_2$ | n.d. | n.d. | Andradite*** | 37 | 14 |
| $TiO_2$ | 1.35 | 0.48 | Grossularite | 51 | 63 |
| $Al_2O_3$ | 14.8 | 19.5 | Spessartine | 4 | 4 |
| $Fe_2O_3$ | 14.9* | 13.2* | Almandine | 7 | 18 |
| FeO | 13.4** | 11.8** | Pyrope | 1 | 1 |
| MnO | 1.74 | 2.0 | | | |
| MgO | 0.28 | 0.21 | | | |
| CaO | 30.6 | 27.5 | | | |

*Total iron as $Fe_2O_3$.

**Total iron as FeO.

***Includes Ti: about 1.6 atomic % in 30A and 0.6% in 99.

1. Garnet 30A. Atomic absorption analysis by R. Holm.

2. Garnet 99. Atomic absorption analysis by R. Holm.

*Pyroxenes.* Pyroxenes are found throughout the nepheline gneisses, ranging up to 15 modal percent. The pyroxenes are aegirine-augites that contain varying amounts of the acmite molecule in host rocks of different bulk compositions. Aegirine-augites in the leucocratic nepheline gneisses are richest in acmite, whereas those in the mafic and feldspar-poor nepheline gneisses tend to be poorer in acmite. On the basis of optical properties there appears to be a complete compositional gradation between the pyroxenes present. Many pyroxenes in the nepheline gneisses are zoned, with the rims invariably richer in $Fe^{3+}$. In hand specimens, the pyroxenes range from black to medium green and in many of the leucocratic gneisses they have prismatic forms and define a lineation.

Given in Table 3 are chemical and optical data of an unzoned pyroxene from a feldspar-poor nepheline gneiss (sample 30A). Table 3 also contains optical data of unanalyzed aegirine-augites from two specimens of leucocratic nepheline gneiss (specimens 185 and 84); these data closely fit determination curves (Deer, Howie, and Zussman, 1963), and the number of $Fe^{3+}$ ions per formula unit, as read from the curves, are given.

TABLE 3. COMPOSITION AND OPTICAL DATA OF AEGIRINE-AUGITES

| Weight Per cent | | Cations Per 6 Oxygens | | | Component Per cent | |
|---|---|---|---|---|---|---|
| | 1 | | 1 | | | 1 |
| $SiO_2$ | 48.26 | Si | 1.817 | 2.000 | Acmite | 30.9 |
| $TiO_2$ | 1.05 | Al | 0.183 | | Mg-Tschermak | 9.5 |
| $Al_2O_3$ | 8.92 | Al | 0.213 | 1.043 | Ca-Tschermak | 9.8 |
| $Fe_2O_3$ | 10.51 | Fe''' | 0.298 | | Hedenbergite | 19.3 |
| FeO | 5.46 | Ti | 0.029 | | Diopside | 24.3 |
| MnO | 0.34 | Mg | 0.320 | | Wollastonite | 5.9 |
| MgO | 5.70 | Fe'' | 0.172 | | | |
| CaO | 15.32 | Mn | 0.011 | | | |
| $Na_2O$ | 3.94 | Ca | 0.618 | 0.910 | | |
| $K_2O$ | 0.08 | Na | 0.288 | | | |
| $H_2O+$ | 0.00 | K | 0.004 | | | |
| $H_2O-$ | 0.00 | | | | | |
| Total | 99.58 | | | | | |

Optical Data

| | 1 | 2 | 3 |
|---|---|---|---|
| α | 1.720 (deep green) | 1.737 (pale green) | 1.742 (med. green) |
| β | 1.730 (deep green) | 1.759 (pale green) | 1.772 (med. green) |
| γ | 1.744 (med. yell-gr) | 1.775 (pale yellow) | 1.790 (yellow-gr) |
| γ-α | 0.024 | 0.038 | 0.048 |
| $2V_\alpha$ | 102° | 78° | 75° |
| X:c | (-)27° | (-)4° | (-)2° |
| $Fe^{+3}$ ions per formula unit | | 0.54* | 0.63* |

***Read from curves, Deer, Howie, and Zussman, 1963, p. 87.**

1. **Aegirine-augite 30A, from feldspar-poor nepheline gneiss, Wet chemical analysis by H. B. Wiik.**
2. **Aegirine-augite 185, from leucocratic nepheline gneiss.**
3. **Aegirine-augite 84, from leucocratic nepheline gneiss.**

On the basis of its chemistry, pyroxene 30A is an aegirine-augite close to soda ferri-augite. The molecular proportions of acmite, diopside, and hedenbergite in this pyroxene are very similar to those of pyroxenes in ijolites of the alkaline igneous complexes of eastern Uganda (Tyler and King, 1967). Pyroxene 30A is also chemically similar to pyroxenes from some crystalline schists and it plots within the field of metamorphic pyroxenes on an Na-$Fe^{2+}$-Mg diagram (Yagi, 1966). Optical properties indicate that the pyroxenes from the two leucocratic nepheline gneisses (specimens 185 and 84) are rich in aegirine. The pyroxene compositions appear to be controlled mainly by bulk rock compositions.

*Amphiboles.* Amphiboles range up to 10 modal percent with biotite and aegirine-rich pyroxene in the leucocratic nepheline gneisses, and may be as much as 55 percent in the mafic and feldspar-poor nepheline gneisses where they occur with grandite and aegirine-augites closer to soda augite. The amphiboles are black in hand specimens and may form a lineation. Hastingsite (as defined by Leake, 1968) and iron-rich alkaline amphibole are the only types present. The leucocratic nepheline gneisses contain amphiboles richest in Na and $Fe^{3+}$.

Optical properties of the hastingsites are similar to those reported in the standard reference books. On the other hand, optical properties of the alkaline amphiboles are not those of any common types: $2V_\alpha$ ranges up to 83°, O.A.P. $\perp(010)$, $Z=b$, $Y{:}c=9°–13°$, $\gamma-\alpha=0.013–0.015$, $\gamma$ ranges up to 1.728, $\alpha=$yellowish, $\beta=$dark bluish green to dark greenish blue, $\gamma=$dark olive green. Only four other described amphiboles with similar properties are known to the author: (1) the original hastingsite from Hastings County, Ontario (Adams and Harrington, 1896; Graham, 1909, later described the optic orientation); (2) an amphibole from the Almunge syenite (Quensel, 1914; Rosenbusch had apparently already discovered the orientation of this amphibole); and (3 and 4) amphiboles from the Mbozi igneous complex in southwest Tanzania and the Darkainle complex in the Somali Republic (Brock, Gellatly, and von Knorring, 1964). In all occurrences the host rocks are nepheline syenites or nepheline gneisses.

On the basis of optical properties, the amphiboles in the nepheline gneisses in Ghana appear to form a continuous series between hastingsite and the alkaline amphiboles present. Optical properties ranging between those of hastingsite and those of the alkaline amphiboles can be found in unzoned crystals in different rock specimens. The apparent compositional gradation is best shown, however, by continuous change of optical properties in zoned crystals where the cores invariably are hastingsite and the rims consist of alkaline amphibole. The most rigorous optical demonstration of the nature of the zoning, and thereby, the compositional changes involved, is the change in $2V$ and optic orientation. Hastingsite cores are parallel-symmetric and $2V_\alpha$ may be as large as 40°; toward the

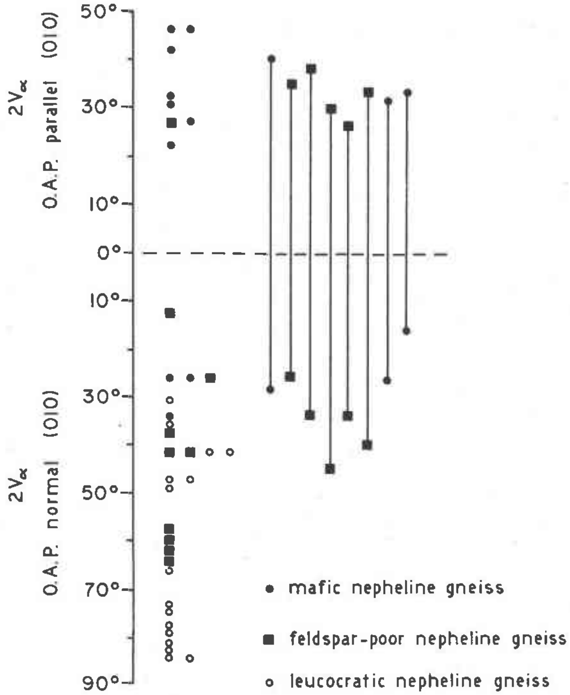

FIG. 2. Optic axial angles measured in amphiboles in 23 specimens of nepheline gneiss. Symbols indicate data from different types of host rocks. Tie lines connect cores and rims of zoned crystals, all cores have parallel-symmetric orientation.

rims, $2V_\alpha$ continuously decreases, passes through 0°, and opens up to as large as 45° with the optic plane in the normal-symmetric orientation. The largest span of $2V_\alpha$ measured in a zoned crystal was 75°. In many zoned crystals the absorption color changes are so slight and gradual that the zoning is not readily apparent until the mineral is seen between crossed nicols with the gypsum plate inserted. Optic axial angle data of zoned and unzoned amphiboles in 23 specimens of nepheline gneiss are shown in Figure 2.

To investigate the chemistry of this series, amphiboles with different optical properties were separated for analysis from three specimens of nepheline gneiss: (1) hastingsite (parallel-symmetric, $2V_\alpha = 42°$, $46°$) from a mafic gneiss (specimen 99); (2) a zoned amphibole (parallel-symmetric in the core with $2V_\alpha = 35°$ and normal-symmetric on the rim with $2V_\alpha = 25°$) from a feldspar-poor gneiss (specimen 30A); and (3) an alkaline amphibole (normal-symmetric, $2V_\alpha = 80°$, $81°$, $83°$) from a leucocratic gneiss (specimen 107). The wet chemical analyses and optical data

TABLE 4. COMPOSITION AND OPTICAL DATA OF AMPHIBOLES

| Weight Per cent | | | | Cations Per 24 (O, OH) | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | 1 | 2 | 3 | |
| $SiO_2$ | 35.52 | 37.02 | 37.58 | Si | 5.598 | 5.826 | 5.911 | Z |
| $TiO_2$ | 1.79 | 1.64 | 1.66 | Al | 2.402 | 2.174 | 2.089 | |
| $Al_2O_3$ | 19.57 | 17.29 | 15.11 | Al | 1.232 | 1.034 | 0.713 | Y |
| $Fe_2O_3$ | 6.51 | 7.79 | 20.75 | Fe''' | 0.770 | 0.922 | 2.456 | |
| FeO | 18.45 | 14.94 | 9.25 | Ti | 0.212 | 0.194 | 0.195 | |
| MnO | 0.51 | 0.53 | 1.06 | Mg | 0.638 | 1.217 | 0.248 | |
| MgO | 2.72 | 5.19 | 1.06 | Fe'' | 2.431 | 1.966 | 1.217 | |
| CaO | 9.27 | 9.46 | 5.53 | Mn | 0.067 | 0.070 | 0.141 | |
| $Na_2O$ | 2.84 | 3.38 | 5.10 | Ca | 1.565 | 1.595 | 0.932 | X |
| $K_2O$ | 2.58 | 2.40 | 2.80 | Na | 0.868 | 1.030 | 1.554 | |
| $H_2O$ | 0.72 | 0.31 | 0.58 | K | 0.518 | 0.480 | 0.562 | |
| $H_2O$ | 0.00 | 0.00 | 0.00 | OH | 0.756 | 0.326 | 0.606 | |
| Total | 100.48 | 99.95 | 100.48 | X | 2.951 | 3.105 | 3.048 | |
| | | | | Y | 5.350 | 5.403 | 4.970 | |
| | | | | Z | 8.000 | 8.000 | 8.000 | |

Optical Data*

| | 1 | 2(core) | 2(rim) | 3 |
|---|---|---|---|---|
| α | 1.696 | n.d. | n.d. | 1.714 |
| β | 1.711 | 1.708 | 1.711 | 1.723 |
| γ | 1.714 | 1.710 | 1.713 | 1.728 |
| γ-α | 0.018 | | | 0.014 |
| Orientation | Y = b | Y = b | Z = b | Z = b |
| | O.A.P.=(010) | O.A.P.=(010) | O.A.P.⊥(010) | O.A.P.⊥(010) |
| Z:c | 13° | n.d. | | |
| Y:c | | | n.d. | 9° |
| $2V_\alpha$ | 42°, 46° | 35° | 25° | 80°, 81°, 83° |
| Dispersion | r > v | r > v | r>> v | r>> v |
| α | yellowish | | | yellowish |
| β | dark olive green | | | dark greenish blue |
| γ | dark bluish green | | | dark olive green |

*Refractive indices are ±0.003.

1. Amphibole 99 (hastingsite), wet chemical analysis by H. B. Wiik.
2. Amphibole 30A (zoned from hastingsite to alkaline amphibole), wet chemical analysis by H. B. Wiik.
3. Amphibole 107 (alkaline amphibole), wet chemical analysis by H. B. Wiik.

are given in Table 4. The zoned amphibole was selected for analysis to provide a representative from near the middle of the series; no unzoned specimens near $2V_\alpha = 0°$ could be found, and it is thought that this analysis provides an average composition for this part of the series. The hastingsite from specimen 99 is similar to many reported in the literature (Leake, 1968). The alkaline amphibole from specimen 107, however, is rare, and the only known amphibole similar in composition is the Mbozi amphibole (Brock, Gellatly, and von Knorring, 1964). The distinctive chemical features of these alkaline amphiboles are: (1) two aluminum atoms in tetrahedral positions; (2) Ca/Na+K ratio of about 0.5; and (3) high $Fe^{3+}/Fe^{2+}$ ratios.

The chemical variations between the analyzed amphiboles from Ghana are shown graphically in Figure 3. The total iron and magnesium in

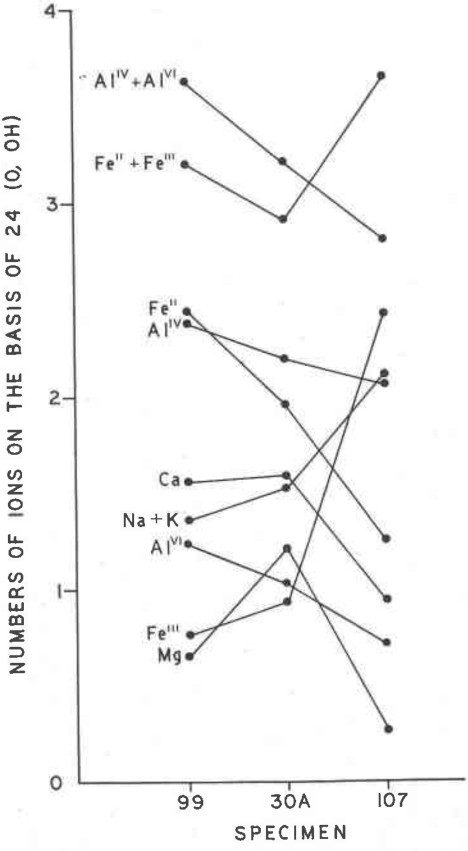

FIG. 3. Chemical variations of the analyzed amphiboles from the nepheline gneisses.

amphibole 30A reflect the host rock composition. The continuous changes in optical properties of the amphiboles are related to these chemical changes. It appears that increases in the Fe/Mg, $Fe^{3+}/Al^{VI}$, and $Fe^{3+}/Fe^{2+}$ ratios in the parallel-symmetric hastingsites causes the $2V_\alpha$ to continuously decrease, pass through 0°, and open up with the optic plane in the normal-symmetric orientation (Billings, 1928; Murgoci, 1906). Although limited, the chemical and optical data suggest that a continuous series may exist between the calciferous hastingsitic amphiboles and alkaline amphiboles of the type found in Ghana.

On the basis of the composition of the Mbozi amphibole, Brock, Gellatly, and von Knorring (1964) proposed mboziite as a new sodic amphibole end-member. The composition of this theoretical end-member is: $Na_2CaFe_3^{2+}Fe_2^{3+}Al_2Si_6O_{22}(OH)_2$. The Mbozi amphibole approaches this end-member, as does the amphibole from specimen 107. However, the latter is even more alkaline ($Ca/Na+K=0.44$) and may be more closely related to a different, but as yet undescribed, end-member. The high tetrahedral aluminum in alkaline amphibole 107 would seem to preclude a series with any of the common soda amphiboles. With the present data, therefore, it appears that the alkaline amphiboles in Ghana are more closely related to the theoretical end-member mboziite than to any of the common alkaline amphibole end-members.

## Genetic Considerations

All specimens of nepheline gneiss show evidence of cataclasis of preexisting coarse-grained rocks and subsequent recrystallization. No primary textures or structures remain. Petrographic data of the alkalic gneisses indicate they have undergone at least two stages of metamorphic recrystallization which were separated by a period of intensive cataclasis (Holm, 1969). The latest stage of metamorphic recrystallization of the alkalic gneisses was in the epidote-amphibolite facies. This conclusion is based on the facies assignment of the contiguous epidote amphibolites and mafic gneisses as the alkalic gneisses lack diagnostic assemblages.

The garnets and amphiboles in the alkalic gneisses are stable phases of the latest recrystallization. In most mafic and feldspar-poor nepheline gneisses textures indicate that garnet grew as a reaction product between calcite, nepheline, and aegirine-augite (Fig. 4). The garnet commonly is parasitic in complex skeletal forms closely associated with these three minerals. Similar textures have been described by Misch (1964) in calc-silicate rocks where the garnet occurs as a reaction product between wollastonite and plagioclase. In some of the nepheline gneisses the garnet cores are fairly free of inclusions, but the rims are parasitic. The reaction is:

calcite + nepheline + aegirine-augite → grandite + Na + $CO_2$.

This reaction may have been the direct cause of the zoning in the amphiboles, because those with the strongest zoning are only in the rocks that contain the parasitic garnet. Textural relations indicate garnet grew fairly late in the recrystallization, thus releasing sodium from the nepheline after hastingsite had crystallized. The sodium released from nepheline was taken up in the amphibole in the later stages of its crystallization. Textures indicate that amphibole also grew at the expense of aegirine-augite (Fig. 4). The reaction is:

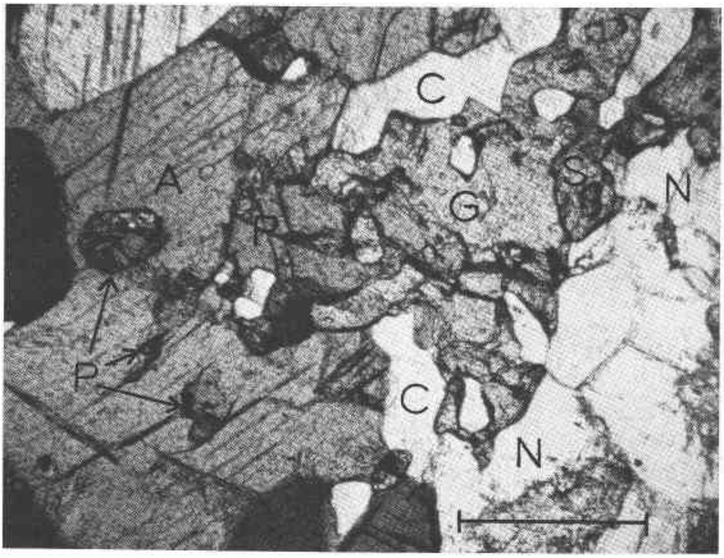

FIG. 4. Photomicrograph of feldspar-poor nepheline gneiss showing textural relations of calcite (C), nepheline (N), pyroxene (P), amphibole (A), garnet (G), and sphene (S). Length of bar is 0.25 mm.

hastingsite + Na + aegirine-augite → alkaline amphibole.

This explains why the zoning invariably is from hastingsite cores to alkaline amphibole rims. The presence of the unzoned alkaline amphiboles in apparent textural equilibrium with aegirine-rich pyroxenes in some of the leucocratic nepheline gneisses reflects the original bulk rock compositions.

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