

On the metamorphic facies of the Dahomeyan gneiss in the western Accra Plains, Ghana

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SUMMARY. In the Dahomeyan of the western Accra Plains mafic gneisses, amphibolites, and ortho-amphibolite dykes in granitic gneiss occur. During the latest recrystallization, metamorphic conditions ranged (north to south) from oligoclase-epidote amphibolite subfacies through andesine-epidote amphibolite subfacies to at least the medium or upper part of the amphibolite facies. Chemical analyses of hornblende, garnet, and clinopyroxene from two mafic gneiss specimens supplement data from the Mampong specimen (Knorring and Kennedy, 1958) and indicate that mineral compositions are largely controlled by rock compositions.

THE Accra Plains of south-eastern Ghana are predominantly underlain by Precambrian schists and gneisses of the Dahomeyan (Junner and Bates, 1945). In the western portion of the plains the Dahomeyan consists of two broad belts (2 to 25 km wide) of north-east trending gneisses, heterogeneous granitic gneisses on the north-west and mafic gneisses on the south-east (fig. 1). The mafic gneisses are of a general basaltic chemistry, ranging in normative composition from basanite to tholeiite and including hawaiite (Holm, 1969). Separating these belts in the area studied in the present investigation is a fairly narrow group (up to 4 km wide) of interlayered amphibolites, schists, and gneisses of various types. The Dahomeyan is separated from the Togo Formation on the west by a major thrust fault.

About 10 km south of the area studied are the Shai Hills, a group of inselbergs within the belt of mafic gneiss. On the basis of the petrography and mineral chemistry of mafic gneiss from the Shai Hills (Mampong specimen) Knorring and Kennedy (1958) proposed that the rocks should be classified in a metamorphic facies transitional between the amphibolite and eclogite facies. This proposal was based on the association of the typical amphibolite minerals hornblende and plagioclase with garnet and pyroxene that they consider to be of eclogitic type. Fairly high pyrope and grossular contents in the garnet and a presumed jadeite content of about 10 % in the pyroxene were thought to be distinctive enough to propose this facies scheme. Because the mafic gneisses throughout the area mapped, as well as those further along the belt to the north-east (pers. comm., John Crook), are petrographically similar to those in the Shai Hills, it is possible that Knorring and Kennedy's facies assignment could be applicable to the entire belt.

In order to evaluate more critically the conditions of metamorphism in the area under investigation, the mineralogy of two additional specimens of mafic gneiss was studied in detail. The purpose of this report is to describe briefly the petrography and

geology of the gneisses in the western Accra Plains and to supplement the information from the Mampong specimen with new mineralogical data as bases for metamorphic facies assignment. Plagioclase compositions reported on fig. 1 are averages of determinations by the *x*-normal method of 4 to 8 grains in each thin section using the curve in Deer *et al.* (1963*b*, p. 138).

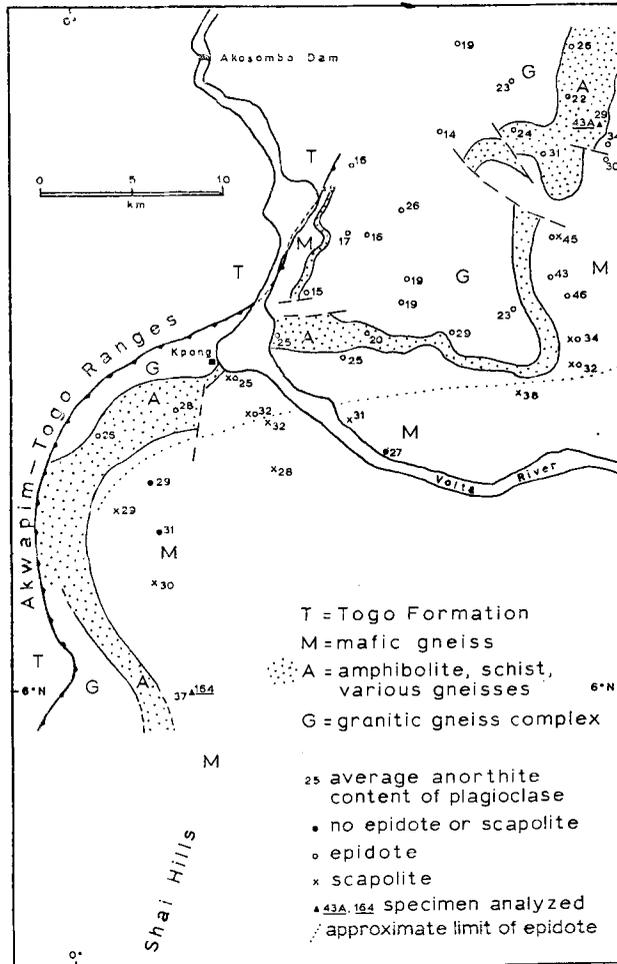


FIG. 1. Geological map of the western Accra Plains, Ghana.

Geology and petrography. Throughout that part of the belt studied the mafic gneisses are remarkably uniform in mineralogy, texture, and structure. Locally, different rock types occur, including the occurrence of mica schists and protoclastic websterite, norite, and two-pyroxene quartz diorite intrusions; discussion of these rocks is excluded.

Mafic gneisses typically consist of oligoclase-andesine, green hornblende, sahlite, and garnet, with or without quartz and epidote (pistacite) or calcic scapolite or both. Few specimens lack garnet, and clinopyroxene is rarely absent. Quartz is common, but it is absent (both modal and normative) in some specimens. Most modal plagioclase compositions are in the range An_{22} to An_{38} , the smaller values of anorthite content generally being found in the north-western part of the belt where the plagioclase typically occurs in textural equilibrium with epidote. Bulk rock compositions are variable, with normative plagioclase ranging from andesine to bytownite. The general distribution of modal epidote as a main assemblage mineral is shown on fig. 1. Although absent in some specimens, calcic scapolite occurs throughout the region (up to 10 modal %), invariably in textural equilibrium with the other minerals present as a main assemblage phase (Knorring and Kennedy, 1958). Ubiquitous accessory minerals are sphene, apatite, rutile, magnetite, and ilmenite. The mafic gneisses typically are finely foliated, consisting of alternating light and dark bands a few mm in thickness.

Interlayered with the mafic gneisses along the north-western margin of the belt are epidote amphibolites, mica schists, and various types of quartzo-feldspathic and alkalic gneisses. The mafic gneisses decrease in abundance toward the north-west, and where they are subordinate the rocks are mapped as an interlayered group of schists, gneisses, and amphibolites (fig. 1). Petrographically, the mafic gneisses in this narrow belt are similar to those in the major belt, and the only significant difference is the volume % of the minerals; hornblende is more abundant and garnet and clinopyroxene are less abundant. Mineralogically, the epidote amphibolites are distinctive and uniform throughout this narrow belt, consisting of green hornblende, oligoclase-andesine, epidote, and quartz; in addition, pink garnet occurs locally, but sahlite was found in only two specimens. Plagioclase is An_{17} to An_{37} , but calcic oligoclase is usual. Accessory minerals are biotite, apatite, sphene, rutile, and ilmenite. Plagioclase and epidote are in textural equilibrium in all specimens examined. Most of the other schists and gneisses in this narrow belt are strongly weathered, and those examined microscopically lack assemblages diagnostic for facies classification.

Most rocks in the belt of granitic gneiss are orthogneisses, and although quartz monzonite is the most abundant, compositions range from granite to quartz diorite. Paragneiss and mica schist are subordinate, and ortho-amphibolites occur locally, apparently as dykes. The ortho-amphibolites, the metaquartz diorites, and some of the paragneisses contain diagnostic assemblages and because these rocks occur throughout the belt the metamorphic facies of the non-diagnostic orthogneisses can be inferred. The ortho-amphibolites consist of green hornblende, oligoclase, epidote, and quartz, with or without garnet, and in the diagnostic paragneisses coexisting oligoclase and epidote occur with quartz and hornblende or biotite or both. Metaquartz diorites contain oligoclase, epidote, biotite, and quartz with subordinate hornblende and microcline.

Some of the mafic gneisses and amphibolites are coarse granoblastic aggregates of the phases described, but others contain evidence of at least two stages of metamorphic recrystallization separated by a stage of strong cataclastic deformation. Some

of the rocks are recrystallized mylonitic gneisses derived from pre-existing coarse-grained rocks. Minerals relict from the earlier stage of recrystallization are the same as those stable during the latest, indicating that both stages were under similar metamorphic conditions. The mafic gneisses commonly contain porphyroclasts of hornblende and clinopyroxene set in finer grained mosaics of plagioclase, scapolite, and quartz. Fragments of broken garnet porphyroblasts, as well as small pieces of pyroxene and hornblende sheared off porphyroclasts, are strung out along the foliation.

TABLE I. *Chemical analyses and modes of mafic gneiss specimens*

| | 1 | 2 | 3 | | 4 | 5 | 6 |
|--------------------------------|--------|--------|--------|---------------|----|----|---|
| SiO ₂ | 46.64 | 49.63 | 42.12 | plagioclase | 28 | 27 | p |
| TiO ₂ | 1.78 | 1.72 | 0.89 | scapolite | — | 5 | p |
| Al ₂ O ₃ | 15.49 | 16.82 | 18.95 | hornblende | 40 | 22 | p |
| Fe ₂ O ₃ | 6.29 | 2.69 | 4.36 | clinopyroxene | 7 | 17 | p |
| FeO | 10.42 | 8.53 | 9.50 | garnet | 18 | 24 | p |
| MnO | 0.18 | 0.15 | 0.20 | quartz | 3 | — | p |
| MgO | 6.25 | 5.66 | 7.63 | sphene | tr | 5 | — |
| CaO | 10.15 | 10.79 | 11.26 | rutile | tr | — | p |
| Na ₂ O | 2.64 | 2.72 | 2.76 | opaque | 4 | tr | p |
| K ₂ O | 0.02 | 0.19 | 0.28 | | | | |
| P ₂ O ₅ | 0.18 | 0.27 | 0.09 | | | | |
| CO ₂ | 0.12 | 0.21 | 0.60 | | | | |
| H ₂ O+ | 0.25 | 0.78 | 0.84 | | | | |
| H ₂ O— | 0.09 | 0.42 | 0.02 | | | | |
| Total | 100.41 | 100.16 | 100.36 | | | | |

1. Chemical analysis of specimen 43A. Anal. Tadashi Asari.
2. Chemical analysis of specimen 164. Anal. Tadashi Asari.
3. Chemical analysis of Mampong specimen, Knorring and Kennedy, 1958, p. 850.
4. Mode of specimen 43A.
5. Mode of specimen 164.
6. Minerals present (p) in Mampong specimen.

See table III for molecular norms.

Some amphibolites contain mechanically rounded grains of hornblende and epidote set in a matrix of newly recrystallized hornblende, epidote, and plagioclase. Although some of the deformed hornblende and pyroxene grains exhibit residual strain, many have recrystallized to polygonal aggregates, and the rocks in general appear to have been annealed during the latest stage of recrystallization. This latest recrystallization probably occurred during the reactivation of the Dahomeyan in the late Precambrian to early Paleozoic (Kennedy, 1964; Grant, 1969).

The locations of two mafic gneiss specimens selected for detailed study are shown on fig. 1. The chemical analyses and modes of these specimens are given in table I along with the data of the Mampong specimen for comparison.

Mineralogy. Amphibole, garnet, and pyroxene were separated for analysis from mafic gneiss specimens 43A and 164. They were judged to be greater than 99 % pure.

The amphiboles (table II) appear to be common hornblende and can be classified as ferroan pargasite (Leake, 1968). Although primary amphiboles from certain types

of eclogites are similar to the hornblendes from the mafic gneiss (Mottana and Edgar, 1969), similar hornblendes also are known from mafic rocks in many localities where recrystallization occurred in the epidote amphibolite, amphibolite, or granulite facies (Leake, 1968). It appears that hornblendes of the type in the mafic gneiss in Ghana are widespread in metamorphic terrains and are not completely diagnostic for facies classification. Their titanium contents are, however, high for metamorphic hornblendes, but the significance of this is not entirely clear. It is known that the

TABLE II. *Chemical data of analysed amphiboles, garnets, and pyroxenes*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
|--------------------------------|-------|-------|--------|-------|--------|--------|------|-------|-------|-------------------|-------|-------|
| SiO ₂ | n.d. | n.d. | 41.86 | n.d. | 38.16 | 39.50 | n.d. | 50.09 | 49.60 | Si | 5.883 | 1.878 |
| TiO ₂ | 2.13 | 2.04 | 1.90 | 0.02 | 0.08 | 0.16 | 0.52 | 0.49 | 0.62 | Al ^{iv} | 0.117 | 0.122 |
| Al ₂ O ₃ | 13.5 | 14.9 | 14.31 | 22.9 | 21.75 | 21.53 | 4.8 | 5.40 | 6.12 | Al ^{vi} | 3.835 | 0.116 |
| Fe ₂ O ₃ | 4.29 | 3.94 | 4.29 | 2.31 | 1.60 | 1.05 | 3.60 | 3.04 | 3.80 | Fe ⁱⁱⁱ | 0.186 | 0.086 |
| FeO | 12.10 | 10.74 | 8.79 | 23.02 | 21.29 | 20.91 | 6.86 | 6.41 | 5.86 | Ti | 0.009 | 0.014 |
| MnO | 0.09 | 0.07 | 0.10 | 1.16 | 0.48 | 0.66 | 0.12 | 0.06 | 0.10 | Mg | 1.275 | 0.639 |
| MgO | 12.7 | 12.9 | 12.58 | 5.2 | 5.55 | 7.85 | 13.7 | 11.43 | 11.26 | Fe ⁱⁱ | 2.745 | 0.201 |
| CaO | 11.2 | 11.4 | 11.14 | 8.7 | 11.49 | 8.34 | 20.6 | 21.94 | 20.58 | Mn | 0.062 | 0.002 |
| Na ₂ O | 2.13 | 1.98 | 2.47 | n.d. | 0.15 | n.d. | 1.20 | 0.15 | 1.68 | Ca | 1.898 | 0.882 |
| K ₂ O | 0.24 | 0.82 | 0.63 | n.d. | 0.05 | n.d. | 0.02 | 0.02 | 0.05 | Na | 0.010 | 0.010 |
| H ₂ O+ | 2.06 | 1.74 | 1.84 | — | — | — | — | 0.42 | 0.25 | K | — | 0.002 |
| H ₂ O- | 0.35 | 0.23 | 0.08 | — | — | — | — | 0.16 | 0.05 | | | |
| Total | — | — | 100.06 | — | 100.60 | 100.00 | — | 99.45 | 99.97 | | | |

1. Amphibole from specimen 43A. Atomic absorption analysis by R. Holm. Ferric and ferrous iron and water by T. Asari. α 1.658 (yellowish), β 1.670 (dark olive green), γ 1.677 (dark green), γ : [001] 12°, 2V _{α} 72°.
2. Amphibole from specimen 164. Atomic absorption analysis by R. Holm. Ferric and ferrous iron and water by T. Asari. α 1.658 (yellowish), β 1.669 (dark olive green), γ 1.676 (dark green), γ : [001] 13°, 2V _{α} 81°.
3. Amphibole from Mampong specimen, Knorring and Kennedy, 1958, p. 853.
4. Garnet from specimen 43A. Atomic absorption analysis by R. Holm. Ferric and ferrous iron by T. Asari. Mol. %: andradite 7, grossular 18, spessartine 2, almandine 52, and pyrope 20.
5. Garnet from specimen 164. Chemical analysis by T. Asari. Mol. %: andr. 4.9, gr. 26.9, sp. 1.0, alm. 45.9, py. 21.3.
6. Garnet from Mampong specimen, Knorring and Kennedy, 1958, p. 851. Mol. %: andr. 4.0, gr. 19.1, sp. 1.4, alm. 45.2, py. 30.3.
7. Clinopyroxene from specimen 43A. Atomic absorption analysis by R. Holm. Ferric and ferrous iron by T. Asari. α 1.690 (pale green), β 1.699 (pale yellowish green), γ 1.717 (pale green), γ : [001] 40°, 2V _{γ} 59°.
8. Clinopyroxene from specimen 164. Chemical analysis by T. Asari. α 1.691 (pale green), β 1.700 (pale yellowish green), γ 1.719 (pale green), γ : [001] 41°, 2V _{γ} 62°. Mol. % acmite 1.4, jadeite 0.0, diopside 61.3, hedenbergite 23.3, Tschermak 14.0.
9. Clinopyroxene from Mampong specimen, Knorring and Kennedy, 1958, p. 852. Mol. %: ac. 10.5, jd. 1.8, di. 54.4, hd. 18.5, Ts. 14.8.
10. Chemical analysis of garnet 164 calculated on the basis of 24 oxygen.
11. Chemical analysis of pyroxene 164 calculated on the basis of 6 oxygen.

titanium content of hornblende increases with progressive metamorphism (Engel and Engel, 1962), but it is impossible to correlate specific titanium contents with temperature because of such variables as bulk rock composition, modal hornblende, and the presence of other titanium-bearing phases. Not enough data are available in this study to draw firm conclusions from the titanium contents of the hornblendes, although it seems that fairly high crystallization temperatures are indicated. The amount of octahedral aluminum in relation to the silicon in the Mampong hornblende does

not point toward an unusually high pressure of metamorphism (Leake, 1965), particularly in view of the relatively high alumina content of the rock.

In table II are chemical analyses of the garnets. Although very similar garnets are known from eclogites near the type locality in the Saualpe region, Austria, (Angel, 1957) the garnet compositions on their own are not diagnostic for facies classification; this has been emphasized by many authors. On fig. 2 the garnets plot in the area where garnets from eclogites, granulites, and amphibolites overlap in composition.

The pyroxene from the Mampong specimen was considered an omphacitic variety of diopside-hedenbergite by Knorring and Kennedy (1958), and has been classified as an omphacite by Deer *et al.* (1963a). In dealing with pure pyroxene end-members, however, considerable uncertainty exists as to the classification of this pyroxene as omphacite. Even if all of the sodium atoms were assigned to the jadeite molecule, this pyroxene would still be much lower in jadeite than most eclogitic pyroxenes. If, however, the sodium is assigned preferentially to acmite along with the available Fe^{3+} the jadeite component is less than 2%. Following Clark and Papike (1968), these pyroxenes (table II) can be classified as aluminous diopside-hedenbergites ($\text{Na}/(\text{Na}+\text{Ca}) = 0.10$ in 43A, 0.01 in 164, 0.13 in Mampong specimen). On the Ca-Mg-Fe diagram (Polderwaard and Hess, 1951) the pyroxenes are sahlite (164, Mampong specimen) and diopsidic augite (43A). Furthermore, the jadeite/Tschermak's-molecule ratios of these pyroxenes are significantly lower than is normal in eclogitic pyroxenes, thus indicating that pressure was not unusually high in relation to temperature during the metamorphism (White, 1964).

The variations of major cations between the analysed garnets, clinopyroxenes, and amphiboles are shown in fig. 3. Except for minor but systematic variations discussed later the compositions of these phases appear to be more the result of original bulk rock compositions and the presence or absence of other coexisting phases of the same components than of significant differences in metamorphic temperature and pressure conditions. The mineral compositions do not indicate unusual temperature and pressure conditions of metamorphism. This is especially apparent in the compositions of the clinopyroxenes when their normative compositions are compared with the norms of the host rocks. In table III it is apparent that the pyroxene compositions are largely controlled by the bulk rock compositions. Although the host rocks contain similar amounts of sodium, the Mampong pyroxene has the most sodium and greatest silica undersaturation because the host rock is the most undersaturated, whereas the pyroxene from specimen 164 is the most silica oversaturated because its host rock contains normative quartz. A norm was not calculated for the pyroxene from specimen

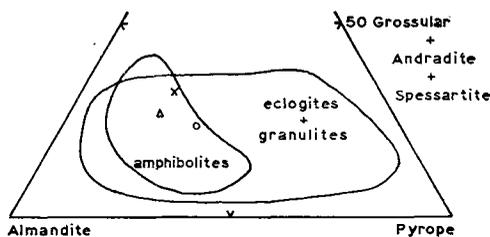


FIG. 2. Compositions of garnets in molecular per cent from the mafic gneiss compared with garnets from eclogites, granulites, and amphibolites. Garnet fields from Yoder and Tilley, 1962. Δ 43A; \times 164; \circ Mampong specimen.

43A because of incomplete analysis; however, its intermediate sodium content probably reflects its host rock, which contains neither quartz nor nepheline in the norm.

Lovering and White (1964) tentatively classified the Mampong specimen in the pyroxene granulite facies because of the unusually high S content of the scapolite.

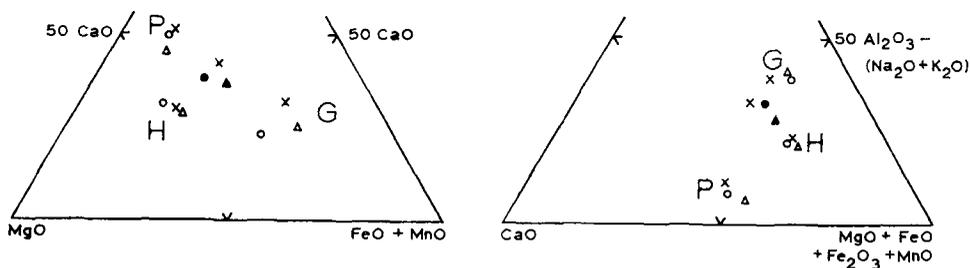


FIG. 3. Diagrams showing (left) distribution of mole per cent CaO, MgO, and FeO + MnO between the analysed hornblendes (H), garnets (G), and clinopyroxenes (P) from the mafic gneiss (symbols same as fig. 2; rock compositions with solid symbols) and (right) distribution of mole % $\text{Al}_2\text{O}_3 - (\text{Na}_2\text{O} + \text{K}_2\text{O})$, CaO, $\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3 + \text{MnO}$.

TABLE III. *Molecular norms of mafic gneiss specimens and their clinopyroxenes*

| | 1 | 2 | 3 | 4 | 5 |
|----|------|------|------|------|------|
| qz | — | 1.5 | — | 1.6 | — |
| or | 0.1 | 1.1 | 1.7 | 0.1 | 0.3 |
| ab | 24.2 | 24.8 | 13.6 | 1.3 | 5.5 |
| ne | — | — | 5.4 | — | 5.7 |
| an | 31.1 | 33.7 | 38.4 | 14.3 | 9.1 |
| wo | — | — | — | — | 0.5 |
| di | 14.9 | 14.4 | 10.5 | 77.7 | 73.9 |
| hy | 18.9 | 18.1 | — | 1.0 | — |
| ol | 0.8 | — | 19.5 | — | — |
| il | 2.5 | 2.4 | 1.7 | 0.7 | 0.9 |
| mt | 6.7 | 2.9 | 6.3 | 3.2 | 4.0 |

1. Specimen 43A.
2. Specimen 164.
3. Mampong specimen.
4. Clinopyroxene from specimen 164.
5. Clinopyroxene from Mampong specimen.

The significance of the high S scapolite is, however, still uncertain and in view of the abundance of the primary green hornblende in the Mampong specimen (Knorring and Kennedy, 1958) this facies classification seems to be unwarranted.

Discussion. The lack of diagnostic mineral compositions necessitates metamorphic facies assignment mainly on the basis of mineral assemblages. Diagnostic assemblages of green hornblende and plagioclase \pm epidote in the mafic gneisses, amphibolites,

and ortho-amphibolite dykes in the granitic gneiss complex place the latest metamorphic recrystallization in the amphibolite facies (Turner, 1968). On the basis of the composition of plagioclase in textural equilibrium with epidote it appears that the metamorphic grade increases from the north and north-west to the south and south-east (fig. 1). In this area the amphibolite facies can be divided into a lower-temperature oligoclase-epidote amphibolite subfacies (Ramberg, 1952; Barth, 1952) on the north and a higher-temperature andesine-epidote amphibolite subfacies (Misch, 1964) toward the south and south-east. South of the limit of primary main-assemblage epidote the rocks probably have been metamorphosed under still higher temperature conditions within the amphibolite facies. It is not entirely clear, however, whether the mafic gneisses in the southern part of the area studied (including the Shai Hills) are in the medium-temperature range of the amphibolite facies, or whether they reached the highest temperature range. In the mafic gneisses south of the epidote limit calcic scapolite is widespread as an anorthite-substitute mineral (actually labradorite or bytownite substitute) in textural equilibrium with plagioclase. Misch (1964) reported that at Nanga Parbat andesine plus calcic scapolite are common in the assemblages of the epidote amphibolite subfacies and that scapolite (but without epidote) also occurs at somewhat higher temperature ranges of the amphibolite facies; calcic scapolite, however, is not stable in the highest temperature amphibolite facies rocks where the most anorthite-rich plagioclase possible is stable. On the other hand, scapolite has been reported in metamorphic rocks of the granulite facies (Lovering and White, 1964). Presumably the stability field and upper temperature limit of calcic scapolite is variable, being controlled to a large extent by P_{CO_2} . The Ca-content of scapolite and its associated plagioclase have been shown to increase with metamorphic grade (Hietanen, 1967; Lovering and White, 1964). Judging from the scapolite (Me_{66}) and plagioclase (andesine) compositions of the Mampong specimen it appears that temperatures probably did not reach the highest part of the amphibolite facies.

Textural relations in thin sections indicate equilibrium between garnet and clinopyroxene (Knorring and Kennedy, 1958, fig. 2). On theoretical grounds Evans (1965) suggested that in rocks where the phases cannot be linked in the form of a garnet-producing reaction, the distribution coefficient $K_D = (\text{Mg:Fe in garnet})/(\text{Mg:Fe in silicate})$ increases with rising metamorphic grade and may be a reliable indicator of relative pressure-temperature conditions. Saxena (1968) demonstrated this relationship in natural garnet-clinopyroxene pairs. Systematic increase of distribution coefficients (K_D) of garnet-clinopyroxene pairs in the mafic gneiss (from north to south $K_D = 0.114$ in 43A, 0.146 in 164, and 0.195 in Mampong specimen) agrees with the conclusion based on petrographic evidence that metamorphic grade in the area studied increases from north to south.

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