

*The mineral paragenesis and metamorphic status
of garnet-hornblende-pyroxene-scapolite gneiss
from Ghana (Gold Coast).*

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Summary. The main minerals (garnet, pyroxene, hornblende, and scapolite) in certain Dahomeyan (Archaean) garnet-hornblende-pyroxene-scapolite gneisses from Ghana have been separated and analysed. Both the garnet and the pyroxene show marked eclogitic affinities, and the rocks are considered to occupy a transitional position between the amphibolite and eclogite facies. The scapolite is a sulphatic variety containing more than 4 % SO₃ and is believed to be a product of autometasomatism. A revised scheme for the distribution of mineral facies within the temperature-pressure field of metamorphism is proposed.

PART I. PARAGENETICAL MINERALOGY.

By O. von Knorring.

THE rocks with which the present paper deals belong to a great belt of basic Archaean (Dahomeyan) gneisses, from 2 miles up to 15 miles or so in width, that extends across the south-eastern corner of Ghana, from the coast-line east of Accra, through the area of the Shai Hills, and across the Volta River into the adjacent territory of Togoland (see map, fig. 1). This belt consists predominantly of very uniform, coarse, sometimes massive, but usually well-foliated garnetiferous hornblende gneisses and granulites with distinctive pale-coloured feldspathic bands (Junner and Bates, 1945, pp. 1-23), but also includes, according to Junner (*op. cit.*, p. 7), pyroxene-gneisses and eclogites, at least in the coastal section to the south.

The rocks have not yet been studied in detail and little is known concerning the variety and distribution of petrographical types. It has now been recognized, however, as a result of our own recent investigations, that pyroxene- and scapolite-bearing varieties are rather well developed in the area of the Shai Hills, particularly in the inselberg Mampong at the south-eastern extremity of the region, and may, in view of the uniform character of the metamorphism, eventually prove

to have a much wider regional distribution. These types are of considerable interest, moreover, in that they contain a sulphate-rich carbonate-scapolite in stable paragenetical association with a suite of minerals including typical members of both the amphibolite and eclogite facies. A rather detailed mineralogical and mineral-chemical study has therefore

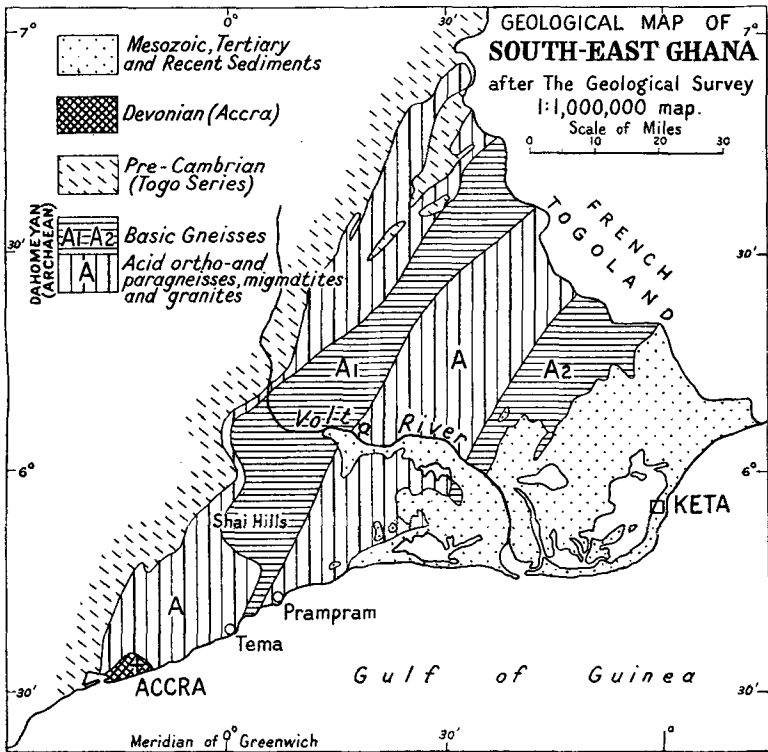


FIG. 1.

been carried out in order to assess the possible significance of the paragenesis in relation to the general scheme of metamorphic facies classification.

Character of the rocks.

The pyroxene- and scapolite-bearing rocks of the Shai Hills are mineralogical variants of the common garnetiferous hornblende gneisses from which they cannot readily be distinguished in hand specimens. Whereas pyroxene is widely distributed and must be regarded as a

normal constituent of the Dahomeyan garnetiferous hornblende gneisses, it would appear that scapolite is probably restricted in its occurrence, and may be confined to definite horizons and specific areas. The most typical scapolite-bearing rocks so far identified are those from the inselberg Mampong, at the south-eastern extremity of the Shai Hills, but insufficient work has been carried out to justify any definite statement about the regional distribution of the mineral.

As in the case of the normal garnetiferous hornblende gneisses, the scapolite-bearing rocks are usually highly foliated and present a characteristic streaky or finely striped appearance due to the lenticular or rodded development of the various constituents. Garnets are abundant, both as tiny crystals scattered throughout the body of the rock and as larger porphyroblasts, which in extreme cases may attain a diameter of several inches. Normal gneissic banding is not developed, but small-scale compositional banding due to the segregation of garnet-rich and pyroxene-rich layers is sometimes seen, as in the analysed scapolite-rich rock from Mampong. Light-coloured felspathic bands are developed locally and may in individual cases attain a thickness of a foot or more. In addition, tiny veinlets of oligoclase, containing megascopically visible scapolite, occasionally intersect the foliation of the rocks.

Under the microscope the rocks are seen to consist of a coarsely granoblastic aggregate of garnet, hornblende, pyroxene, scapolite, oligoclase, and quartz as major constituents, together with accessory rutile and apatite, a little magnetite and ilmenite, and some secondary epidote and calcite (fig. 2). The *garnet* is pinkish in colour and is usually xenoblastic in habit. Rarely, idioblastic boundaries are developed against oligoclase. Inclusions of quartz and rutile are common, but kelyphitic rims and other evidences of reaction are conspicuously lacking. Certain of the garnets from the Mampong area show a rather unusual type of orientated intergrowth in which extremely fine rods of some anisotropic mineral are arranged in a triangular pattern similar to the exsolution intergrowth of ilmenite in magnetite (fig. 3); the identity of the intergrown mineral has not yet been established. The *clinopyroxene* is a pale greenish non-pleochroic variety which in its general appearance is similar to diopside-hedenbergite. It may also contain inclusions of quartz and magnetite and, in certain cases, shows incipient uralitization. *Hornblende* is the predominant dark mineral and the most prominent constituent of the rocks. It shows a straw-yellow-dark-green-brownish-green pleochroism, but is not distinguished by any special peculiarities in

thin section. On the other hand, the *scapolite* instantly attracts attention by its high refringence and birefringence and by its local abundance. The mineral occurs throughout the body of the rocks and, in addition, is often concentrated in veinlets and bands. In its present setting the scapolite is not an alteration product of plagioclase or any other mineral but is a stable primary constituent of the rock, in full equilibrium with



FIG. 2.

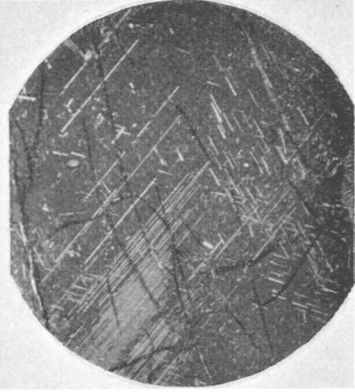


FIG. 3.

FIG. 2 (*left*). A scapolite-rich variety of the garnet-pyroxene-hornblende-scapolite gneiss. Most of the white mineral is scapolite. $\times 15$.

FIG. 3 (*right*). Lamellar and rod-like intergrowth in garnet. Crossed nicols. $\times 28$.

the accompanying minerals. It is significant in this connexion that porphyroblasts of scapolite are occasionally developed in a matrix of quartz and oligoclase. *Rutile* is typomorphic and is present in the form of dark brown, irregular, elongated, and boomerang-shaped grains. Its occurrence is particularly significant as rutile is generally regarded as a characteristic constituent of basic rocks belonging to the eclogite and granulite facies.

Two of the scapolite-bearing gneisses have been analysed and the results are set out in table I.

The rock from Mampong (anal. 1) represents a basic segregation band with approximately 20% of scapolite: that from the 'Shai Hills' (anal. 2) may be taken as fairly representative of the formation as a whole and is an otherwise normal garnet-hornblende-pyroxene gneiss, but contains approximately 2% of scapolite.

The original basic igneous character of the rocks is clearly indicated by these analyses, which are comparable with those of certain gabbros

TABLE I

	1.	2.	3.	4.	Norm. of 1.	Norm. of 2.
SiO ₂	42.12	50.00	43.32	49.68	or 1.7	or 1.7
TiO ₂	0.89	1.00	0.80	0.23	ab 13.6	ab 37.8
Al ₂ O ₃	18.95	19.53	18.22	20.86	an 38.4	an 32.5
Fe ₂ O ₃	4.36	2.85	5.84	1.02	ne 5.4	di 8.1
FeO	9.50	5.55	6.26	5.52	di 10.5	hy 0.2
MnO	0.20	0.07	0.09	—	ol 19.5	ol 11.6
MgO	7.63	5.59	8.42	6.50	mt 6.3	mt 4.2
CaO	11.26	9.28	11.48	10.77	il 1.7	il 1.9
Na ₂ O	2.76	4.48	2.34	3.46	ap 0.3	ap 0.7
K ₂ O	0.28	0.32	0.18	1.38	cc 1.4	cc 0.5
H ₂ O +	0.84	0.64	1.91	0.53	$\frac{sal}{fem} = 1.5$	$\frac{sal}{fem} = 2.7$
H ₂ O -	0.02	0.00	0.28	—		
P ₂ O ₅	0.09	0.32	0.09	0.00		
CO ₂	0.60	0.20	0.19	—		
SO ₃	0.86	0.09	—	0.26†		
Total	100.36	99.92	99.42	100.21		

† S.

1. Garnet-hornblende-pyroxene-scapolite gneiss from Mampong, Ghana. Anal. M. H. Kerr. F and Cl, tr.
2. Garnet-hornblende-pyroxene-scapolite gneiss from Shai Hills, Ghana. Anal. M. H. Kerr. F and Cl, tr.
3. Kyanite-eclogite from Roberts-Victor mine, Kimberley. Anal. J. Parry. (Analyses of rocks and minerals, Geol. Surv. Mem., no. 32, p. 187, Union of South Africa, 1938.)
4. Garnet-pyroxene-labradorite from Sebo, Norway (Eskola, 1921, p. 92).

and basalts, and more particularly with eclogite rocks from various localities (Eskola, 1921, p. 92; Alderman, 1936, p. 488). The petrographical uniformity of the formation and the complete absence of relict sedimentary banding are also indicative of an original igneous character, but, as the rocks have been entirely reconstituted under conditions of deep-seated metamorphism, and have lost all trace of original structures, it is impossible to specify whether they were of volcanic or intrusive origin.

Mineral chemistry.

The main mineral constituents (garnet, pyroxene, hornblende, and scapolite) in the gneiss from Mampong (anal. 1, table I) were separated by means of Clerici solution and a magnetic separator, and pure samples for analysis were finally prepared by hand-picking under a binocular microscope. The analyses, together with the optical data, are shown in tables II-IV, below.

The analysed minerals all show peculiarities of composition that are

TABLE II. Chemical composition of garnets from the Mampong gneiss compared with those of garnets from some eclogites.

	1.	2.	3.	4.	5.
SiO ₂ . . .	39.50	38.73	39.76	40.3	40.30
TiO ₂ . . .	0.16	0.34	—	tr.	tr.
Al ₂ O ₃ . . .	21.53	19.76	22.04	21.6	21.86
Cr ₂ O ₃ . . .	tr.	—	—	—	—
Fe ₂ O ₃ . . .	1.05	5.45	1.37	1.3	2.16
FeO . . .	20.91	19.31	18.06	18.0	19.08
MnO . . .	0.66	—	—	0.7	0.69
MgO . . .	7.85	8.92	8.92	11.2	11.28
CaO . . .	8.34	7.87	10.42	7.2	5.22
Total	100.00	100.38	100.57	100.3	100.59
Sp. Gr. . . .	3.93	—	—	3.74	3.88
<i>n</i>	1.773 ± 0.002	—	—	1.756	1.766
<i>a</i> , Å.	11.59 ± 0.05	—	—	—	—

Atomic ratios to 96 oxygen, anal. 1: Mg_{7.2}Fe_{10.7}²⁺Mn_{0.3}Ca_{5.5}Al_{15.5}Fe_{0.5}³⁺Si_{24.1}O₉₆.

1. Garnet from garnet-pyroxene-hornblende-scapolite gneiss, Mampong, Ghana. Anal. O. von Knorring.
2. Garnet from eclogite, Schutthalde, Tyrol (Alderman, 1936, p. 499).
3. Garnet from eclogite, Saint-Philbert de Grandlieu (Alderman, 1936, p. 499).
4. Garnet from eclogite, Beinn à Chapuill, Glenelg (Alderman, 1936, p. 498).
5. Garnet from eclogite, Silden, Norway (Eskola, 1921, p. 38).

highly significant in relation to the metamorphic status and character of the rocks.

In the first place, the composition of the *garnet* (table II) is unusual in that both Mg and Ca are relatively high, indicating a lime-bearing pyrope-almandine with some 26 % of pyrope and approximately 20 % of grossular. Garnets of this type, in which there has been appreciable substitution of Fe by Mg and Ca, are not formed under the normal metamorphic conditions of the amphibolite facies, but are, on the other hand, typically developed in eclogites, granulites, and related high pressure rocks.

The composition of the *clinopyroxene* (table III) is also indicative of high-pressure conditions as the Al₂O₃ and Na₂O content is that of an omphacitic variety of diopside-hedenbergite with approximately 10 % of jadeite component. The jadeite component is admittedly considerably lower than in true omphacites, but the mineral is nevertheless clearly related in composition to the eclogitic pyroxenes.

A similar tendency is perhaps also apparent in the case of the *hornblende* (table IV) which compares closely in composition with hornblendes from garnet-amphibolites of eclogitic derivation. Hastingsitic amphiboles of this type are, however, more widely distributed and are consequently less significant in regard to metamorphic facies.

TABLE III. Chemical composition of pyroxene from the Mampong gneiss compared with those of pyroxenes from some eclogites.

	1.	2.	3.	4.
SiO ₂	49.60	48.11	55.56	53.48
TiO ₂	0.62	0.97	0.15	1.04
Al ₂ O ₃	6.12	7.55	7.17	9.52
Fe ₂ O ₃	3.80	8.18	2.82	3.00
FeO	5.86	5.38	2.06	5.84
MnO	0.10	—	0.05	—
MgO	11.26	12.97	11.32	6.34
CaO	20.58	15.10	16.85	14.87
Na ₂ O	1.68	1.60	3.92	3.97
K ₂ O	0.05	0.30	0.57	0.63
H ₂ O+	0.25	—	0.08	0.73
H ₂ O-	0.05	—	—	—
Total	99.97	100.16	100.55	99.42
Sp. Gr.	3.35	—	3.33	3.31
α	1.689	—	—	—
β	1.699	—	1.683	1.700
γ	1.718	—	—	—
2V _γ	64°	—	67°	—

Atomic ratios to 48 oxygen (anal. 1): $C_{6.6}Na_{1.0}Mg_{5.0}Fe_{1.5}^{2+}(Fe^{3+}Ti,Al)_{2.0}Al_{1.2}Si_{14.8}O_{48}$.

1. Pyroxene from garnet-pyroxene-hornblende-scapolite gneiss, Mampong, Gold Coast (Ghana). Anal. O. von Knorring.
2. Pyroxene from labradorite rock Alvaerstrømmen, Norway (Eskola, 1921, pp. 91-92).
3. Pyroxene from eclogite, Silden, Norway (Eskola, 1921, p. 38).
4. Pyroxene from eclogite, Glønelg (Alderman, 1936, p. 494).

Finally, the *scapolite* (table IV) is particularly interesting in that the content of SO₃ is higher than in any scapolite so far analysed. At the same time, Cl is virtually absent although the majority of rock-forming scapolites are Cl- and CO₂-bearing varieties. Few complete analyses are available for comparison, but the mineral is seen to compare most closely with scapolites in ejectamenta from the Laacher See and in skarn rocks from Laurinkari in Finland. It may be emphasized that the scapolite from the Shai Hills is not a secondary product replacing some existing mineral such as plagioclase but is a primary constituent of the paragenesis, and is in completely stable equilibrium with the associated minerals.

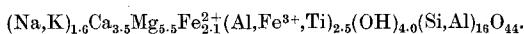
Discussion of results.

The chemical and mineralogical examination of the basic gneisses from the Shai Hills leads to the conclusion that the rocks must have formed under metamorphic conditions transitional between those of the

TABLE IV. Chemical composition of hornblende from the Mampong gneiss compared with those of some other hornblendes of eclogitic origin; and composition of scapolite from the Mampong gneiss compared with some other sulphatic scapolites.

	1.	2.	3.	4.	5.	6.	7.
SiO ₂	41.86	42.17	46.68	42.28	47.52	46.25	46.59
TiO ₂	1.90	1.00	0.35	0.66	none	—	—
Al ₂ O ₃	14.31	13.46	14.37	17.24	25.21	26.50	26.33
Fe ₂ O ₃	4.29	5.92	4.00	2.68	—	—	—
FeO	8.79	7.82	8.29	9.34	0.30	0.13	1.31
MnO	0.10	0.15	—	0.12	0.02	—	—
MgO	12.58	14.46	11.71	11.91	0.14	0.17	0.52
CaO	11.14	11.76	10.32	11.06	15.48	16.03	15.70
Na ₂ O	2.47	0.68	2.41	1.73	4.52	3.96	3.68
K ₂ O	0.63	0.80	0.54	0.81	0.10	0.57	1.11
H ₂ O+	1.84	1.53	1.06	2.05	0.22	1.16	0.80
H ₂ O-	0.08	—	0.23	0.08	0.08	—	—
P ₂ O ₅	—	—	—	—	0.03	—	—
CO ₂	—	—	—	—	2.16	3.12	3.52
F	n.d.	—	—	—	none	—	—
Cl	0.07	—	—	—	0.06	0.72	tr.
SO ₃	—	—	—	—	4.17	1.41	2.06
Total	100.06	99.75	99.96	99.96	100.01	100.02	101.62
Sp. gr.	3.22	3.13	—	3.20	2.72	2.71	2.75
α	1.659 ± 0.001	—	—	1.648	ω 1.587 ± 0.001	1.580	1.5872
β	1.673 ± 0.001	1.65	—	—	ϵ 1.564 ± 0.001	1.553	1.5595
γ	1.678 ± 0.001	—	—	1.672	—	—	—
2V _{α}	75°	—	—	84°	—	—	—
c:γ	13°	26°	—	19°	—	—	—

Atomic ratios to 48 (O,OH) (anal. 1):



1. Hornblende from garnet-pyroxene-hornblende-scapolite gneiss, Mampong, Ghana. Anal. O. von Knorring.
2. Hornblende from garnet-amphibolite, Beinn à Chapuill, Glenelg (Alderman, 1936, p. 519).
3. Hornblende from Umhausen (Alderman, 1936, p. 520).
4. Hornblende from kyanite-garnet-amphibolite, Glenelg (Tilley, 1937, p. 566).
5. Scapolite from garnet-pyroxene-hornblende-scapolite gneiss, Mampong, Ghana. Anal. O. von Knorring.
6. Scapolite from Laurinkari, Finland (Borgström, 1913).
7. Scapolite from Laacher See (Niggli, 1926).

amphibolite and eclogite facies. This is seen in the association of the typical amphibolite minerals, hornblende and plagioclase, with garnets and pyroxenes of distinctive eclogitic type. A somewhat similar paragenesis, in which, however, hornblende and plagioclase are associated with *normal* types of almandine and diopside, has been recognized by Korzhinsky (Korzhinsky, 1937, p. 393), and is referred by Turner (Turner and Verhoogen, 1951, p. 458) to an almandine-diopside-horn-

blende subfacies, which he regards as transitional between the amphibolite and granulite facies. In view of the marked differences in the chemistry of the equivalent minerals it is not possible, however, to assign the rocks of the Shai Hills to this subfacies, and they are consequently regarded as possessing a different status in metamorphism.

It is proposed, therefore, to recognize two mineralogically similar amphibolite parageneses, characterized by the association garnet-pyroxene-hornblende, and represented by the almandine-diopside-hornblende subfacies on the one hand, and the gneisses of the Shai Hills on the other. These are considered to be transitional to the granulite and eclogite facies respectively, and are distinguishable only on the basis of mineral chemistry. In both instances, moreover, affinities with the higher metamorphic facies are emphasized by the presence of rutile as a characteristic accessory mineral.

Amphibolitized eclogites, possessing mineralogical characters similar to those of the Shai Hills gneisses, are by no means uncommon as products of retrograde metamorphism, but differ fundamentally in origin from the rocks in question, which are progressive types that have just failed to attain the full status of eclogites.

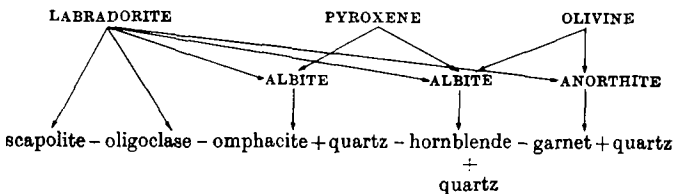
The presence of scapolite in certain of the gneisses also presents features of considerable interest as the mineral has not formed through any contact action but appears to be a normal product of the main regional metamorphism. This is important in view of the fact that scapolitization is generally regarded as an essentially metasomatic process associated with the introduction of fugitive constituents such as H_2O , CO_2 , Cl, and SO_3 . So far as chlorine is concerned, an external source must usually be postulated, and Buddington (1939, p. 267), for example, attributes the formation of the chlorine-bearing scapolite in the metagabbros and basic gneisses of the north-western Adirondacks to metamorphic processes connected with the intrusion of granite magmas. In the Cloncurry district of north-western Queensland, moreover, the process has operated on a regional scale (Edwards and Baker, 1953, pp. 1-33), and the widespread development of scapolite-diopside granulites is there related to regional scapolitization connected with the albitization of calcareous shales. The source of the emanations is unknown, but the metasomatism appears to have been contemporaneous with regional metamorphism, and the scapolite is predominantly a Cl-bearing dipyre.

An extraneous source for the fugitive constituents is not always necessary, however, and, in particular, CO_2 - and SO_3 -bearing scapolites,

such as those from the Shai Hills, may well have formed through internal reactions of pre-existing minerals containing CO_2 and S (Ramberg, 1952, p. 268). This may apply also to certain scapolite-bearing amphibolites and pyroxene-gneisses from south-eastern Finland that have been described by Parras (1941, p. 493), and are considered to have originated under conditions of high-grade regional metamorphism allied to those of the granulite facies. The scapolite from this area has not been analysed, but on the basis of its optical properties it appears to be an almost pure meionite. It is interesting, therefore, that Sundius (1918, p. 104) has recognized two types of scapolite in the scapolite-amphibolites of Northern Sweden: soda-rich Cl-bearing scapolites formed through pneumatolytic action; and lime-rich CO_2 -bearing scapolites formed during contact or deep-seated regional metamorphism *without* addition of extraneous fugitive constituents.

The scapolite of the Shai Hills falls within the second category and is considered to have formed through some process of autometasomatism involving the interaction of sulphide and other minerals present in the original rock. Geological observations indicate, moreover, that there is a rather constant occurrence of scapolite in association with eclogites and related rocks, and it is probable that the process of autometasomatism is dependent on the high temperatures and particularly on the high pressures involved.

There can be little doubt that the garnet-hornblende-pyroxene-scapolite gneisses of the Shai Hills represent original basic igneous rocks that have attained their present condition as a result of regional metamorphism under the influence of intense stress and high temperature. Assuming that the original rocks consisted mainly of olivine, pyroxene, and labradorite, as indicated by the norm, the following transformation process can be envisaged:



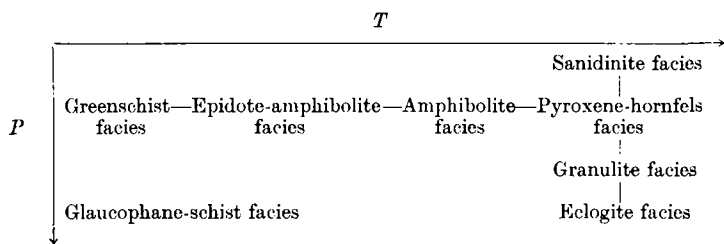
This is closely related to the 'eclogite reaction' and serves to emphasize the restricted stability of both albite and anorthite under the pressure-temperature conditions involved.

PART II. THE DISTRIBUTION OF MINERAL FACIES WITHIN THE PRESSURE-TEMPERATURE FIELD OF METAMORPHISM.

By W. Q. Kennedy.

THE evidence provided by the foregoing detailed mineralogical and mineral-chemical study of garnet-hornblende-pyroxene-scapolite gneiss from Ghana leads to certain interesting conclusions regarding the inter-relationship of mineral facies within the pressure-temperature field of metamorphism.

It is the aim of facies petrology to subdivide the pressure-temperature field of metamorphism in terms of the stability fields of individual mineral facies, and a *formalized* scheme, originally proposed by Eskola (Eskola, 1920), and subsequently adopted by other writers (e.g. Turner and Verhoogen, 1951, p. 433) is shown below:



Each facies covers the stability range of a certain group of associated minerals, but within the general scheme there is variation in the stability fields of individual minerals or mineral components. The behaviour of the end components of the plagioclase feldspar series, albite and anorthite, is particularly instructive in this connexion as it is possible to group the various facies on the basis of the stability, partial stability, and instability of albite and anorthite respectively. Thus, in the granulite facies albite is stable, and albite-bearing plagioclases can exist. In the eclogite facies, on the other hand, albite is completely unstable and is represented by the jadeite component of the pyroxene. Again, in the glaucophane-schists and in the garnet-hornblende-pyroxene-scapolite gneiss from Ghana, a partial stability of albite can be recognized as its constituents appear partly in the feldspar and partly in the ferromagnesian mineral. Similarly, anorthite is stable in the granulite facies, where it appears in plagioclase feldspar, but is completely unstable in the eclogite facies. The stability relationships of albite and anorthite in the various metamorphic facies are summarized in table V.

TABLE V. Stability relationships of albite and anorthite in metamorphic facies (+ indicates stable, - unstable, and +- partially stable).

Facies.	Albite.	Anorthite.
Greenschist	+	-
Epidote-amphibolite	Lower	-
	Upper	+-
Amphibolite	+	+
Pyroxene hornfels	+	+
Sanidinite	+	+
Granulite	+	+
Eclogite	-	-
Glaucophane schist	+-	-
Ghana gneiss	+-	+-

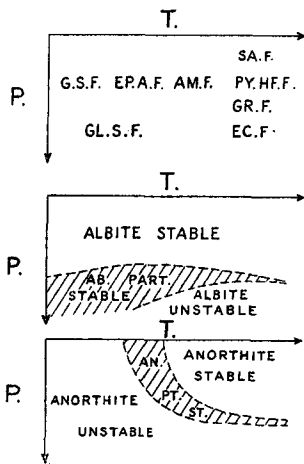


FIG. 4.

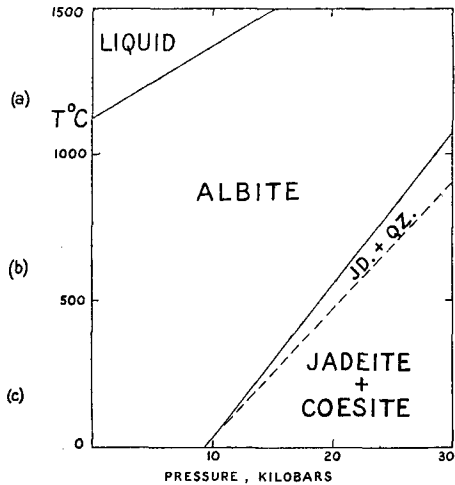


FIG. 5.

FIG. 4 (left). Stability fields of albite and anorthite in relation to metamorphic facies: (a) formalized scheme of facies distribution according to Eskola and others; SA.F. (Sanidinite facies), G.S.F. (greenschist facies), EP.A.F. (epidote-amphibolite facies), AM.F. (amphibolite facies), PY.HF.F. (pyroxene-hornfels facies), GR.F. (granulite facies), EC.F. (eclogite facies), GL.S.F. (glaucophane-schist facies); (b) and (c) stability fields of albite and anorthite plotted on basis of scheme (a).

FIG. 5 (right). Theoretical temperature-pressure relationships for the reaction albite = jadeite + quartz. According to Robertson, Birch, and MacDonald (1957).

It is possible to transfer these relationships to Eskola's formalized scheme of facies distribution and so to subdivide the pressure-temperature field of metamorphism on the basis of the stability behaviour of albite and anorthite; this is shown on fig. 4.

The most striking and significant feature is the very direct relationship between pressure and the stability field of albite. Under the influence of pressure, albite is converted into jadeite plus quartz, the jadeite normally entering into the ferromagnesian mineral. Eskola's facies scheme is, however, a formalized one, but could be rendered

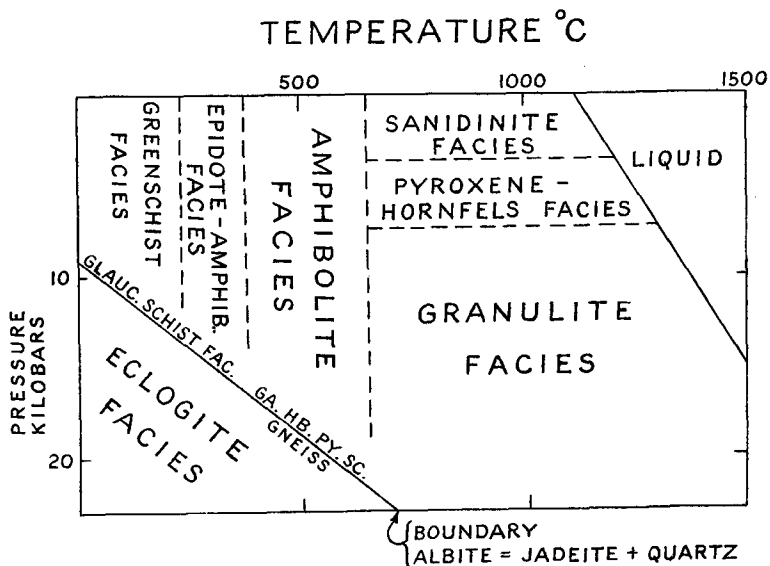


FIG. 6. Proposed scheme of facies distribution within the temperature-pressure field of metamorphism.

absolute on the basis of the stability relationships of albite and anorthite within the various facies, provided the pressure-temperature factors of the stability fields were known. No experimental data for anorthite are available, but Robertson, Birch, and MacDonald (1957, p. 115) have recently determined the stability relations of jadeite to 25 000 bars, and fig. 5 shows their theoretical temperature-pressure relations in the plane of (dry) albite compositions (op. cit., fig. 7, p. 132). This gives the position of the stability boundaries of albite against jadeite+quartz, and can be utilized as a basis for a revised scheme of facies distribution within the pressure-temperature field of metamorphism. The revised scheme suggested by the present authors is shown in fig. 6.

This scheme is tentative and no validity is claimed for the temperatures and pressures shown. It is believed, nevertheless, that the pro-

posed facies distribution scheme does, in fact, provide a closer approximation to reality, and at least serves to explain some hitherto anomalous metamorphic rock associations and relationships.

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References.

- ALDERMAN (A. R.), 1936. Eclogites in the neighbourhood of Glenelg, Inverness-shire. *Quart. Journ. Geol. Soc.*, vol. 92, p. 488.
- BORGSTRÖM (L. H.), 1913. Die Skapolithlagerstätte von Laurinkari. *Bull. Comm. Géol. Finlande*, No. 41.
- BUDDINGTON (A. F.), 1939. Adirondack igneous rocks and their metamorphism. *Geol. Soc. Amer.*, Mem. 7.
- EDWARDS (A. B.) and BAKER (G.), 1953. Scapolitization in the Cloncurry district of North-western Queensland. *Journ. Geol. Soc. Australia*, vol. 1, p. 1 [M.A. 12-421].
- ESKOLA (P.), 1920. The mineral facies of rocks. *Norsk. Geol. Tidsskr.*, vol. 6, p. 143.
- 1921. On the eclogites of Norway. *Skrifter Vidensk.-selskab. Kristiania. I. Mat.-Nat. Kl.*, no. 8 [M.A. 2-313].
- HALL (A. L.), 1938. Analyses of rocks, minerals, ores, etc., from southern Africa. *Dept. Mines, Geol. Surv. Mem.* no. 32.
- JUNNER (N. R.) and BATES (D. A.), 1945. Reports on the geology and hydrology of the coastal area east of the Akwapim range. *Gold Coast Geol. Surv. Mem.*, no. 7.
- [KORZHINSKY (D. S.)] КОРЖИНСКИЙ (Д. С.), 1937. [Dependence of mineral stability on the depth.] *Зап. Всеросс. Мин. Общ.* (Mém. Soc. Russe Min.), vol. 66, no. 2, p. 369.
- NIGGLI (P.), 1926. *Lehrbuch der Mineralogie*, vol. 2. Berlin, Borntraeger.
- PARRAS (K.), 1941. Das Gebiet der Pyroxen führenden Gesteine im westlichen Cusimaa in Südfinnland. *Geol. Rundschau (Suomi-Finnland Heft)*, Bd. 32, p. 484.
- RAMBERG (H.), 1952. The origin of metamorphic and metasomatic rocks. *Univ. Chicago Press.*
- ROBERTSON (E. C.), BIRCH (F.), and MACDONALD (G. J. F.), 1957. Experimental determination of jadeite stability relations to 25 000 bars. *Amer. Journ. Sci.*, vol. 255, p. 115.
- SUNDIUS (N.), 1918. Beiträge zur Kenntnis der Skapolithe. *Bull. Geol. Inst. Univ. Upsala*, vol. 16, p. 96.
- TILLEY (C. E.), 1937. The paragenesis of kyanite-amphibolites. *Min. Mag.*, vol. 24, p. 555.
- TURNER (F. J.) and VERHOOGEN (J.), 1951. *Igneous and Metamorphic Petrology*. New York, McGraw-Hill Book Co., Inc.