The paragenesis of kyanite-amphibolites.

(With Plate XX.)

By C. E. TILLEY, Ph.D., B.Sc.

With chemical analyses by H. C. G. VINCENT, M.A.

Department of Mineralogy and Petrology, University of Cambridge.

[Read June 24, 1937.]

IN an earlier paper [1] the writer has discussed the paragenesis kyanite-omphacite as observed in certain eclogites. The fate of this association under conditions of retrograde metamorphism has led to a consideration of rocks showing the paragenesis amphibole-kyanite, a point which is briefly taken up in the present communication. Rocks containing this latter assemblage include two groups, the one better known, of sedimentary origin, the other essentially igneous in origin.

(*a*) *Para-rocks.*

Here are included members of the para-amphibolites, biotite-hornblende-schists, and hornblende-*Garbenschiefer* derived from sediments of the character of calcareous and dolomitic shales. The best-known examples come from the Alps—particularly the Triassic and pre-Triassic sediments on the south side of the St. Gotthard massif.

Kyanite in these rocks may appear as an essential or accessory constituent and is found often in juxtaposition with the large porphyroblasts of hornblende which characterize the *Garbenschiefer*. Reference may be made to rocks of this type from the *Quartenschiefer* of the Lukmanier region [2], and some members of the pre-Triassic Tremola series are described by Hezner [3] as containing kyanite. The *Garbenschiefer* of the Tremola series, though they have suffered a soda metasomatism under the influence of Hercynian granitic intrusions, acquired their present crystalloblastic development under the influence of the Alpine folding.

Under the names para-amphibole-gneiss and para-amphibolite Rosenbusch [4] has described felspar-rich rocks from the Schwarzwald containing kyanite with kelyphitic rings of spinel with shells of bytownite and labradorite. These rocks are recognized as metamorphosed calcareous sediments, but the amphibole content of the members containing kyanite is so low that the rocks scarcely come within the scope of the present discussion (cf. also Erdmannsdörffer's revised descriptions [5]). Rocks with the assemblage hornblende-kyanite might be expected in the Dalradian Ben Lawers schist within the kyanite zone, but such assemblages have not so far been recorded from these or related Scottish rocks.

(b) *Kyanite-amphibolites of igneous origin.*

The literature contains little reference to kyanite-amphibolites of igneous origin. Kyanite-eclogites in process of amphibolitization would be expected to develop in an intermediate stage as kyanite-bearing amphibolized eclogites, but there is little note of such rocks in descriptions of transformed eclogites. In fact, the fate of kyanite in such eclogites deserves closer study than has been given to it.

Brière [6], in discussing the eclogites of France, refers briefly to the transformation kyanite undergoes in the process of development of garnet-amphibolite. She notes that kyanite is sheathed by a kelyphite of fine fibres of indeterminate character, which, however, appears to be heterogeneous, and believes that a part of this kelyphite is made up of basic plagioclase. The ultimate transformation of a kyanite-eclogite into a garnet-amphibolite of similar bulk composition is described in the case of an eclogite from Puy Ferrières, France [6, p. 127].

Patton [7] describes an eclogite from Einsiedl, north of Marienbad, Bohemia, in which the kyanite is associated with hornblende forming a kelyphitic shell around garnet. He notes, however, that the kyanite does not occur in intimate association with the omphacite of this eclogite. Ippen [8] records kyanite-amphibolites in an eclogite region at Oplotnitz in the Bachergebirge, Yugoslavia, but no detailed reference is made to their field associations. In discussing a garnet-amphibolite of igneous origin from the island of Shikoku, Suzuki [9] mentions a type rich in kyanite associated with it. These examples are mentioned to indicate the paucity of data that are available on the paragenesis under discussion.

Brière's analyses make it clear that the ultimate fate of some kyanite-eclogites is their conversion to kyanite-free amphibolites, and it is apparent that the disappearance of kyanite is accompanied by the entry of an aluminous mineral which may, according to conditions, be anorthite (in plagioclase), zoisite, or clinozoisite. Thus, where there is no change in bulk composition, the normal type of kyanite-eclogites would be expected to give place eventually to amphibolites in which kyanite has disappeared in the manner indicated. This follows from my previous discussion of the composition of kyanite-eclogites and the knowledge of the range of composition of amphibolite hornblendes (text-fig. 3).

Brief mention of a kyanite-amphibole paragenesis has been made by Clough in the Glenelg Memoir (Geol. Surv. Scotland, 1-inch Sheet 71) in the section devoted to the eclogites of the Glenelg region [10, p. 35]. There is noted the occurrence of a garnetiferous hornblende-schist with kyanite near an exposure of an eclogite ½ mile north of the Ordnance Station on Beinn a Chapuill. Clough also mentions that 'a mineral which resembles kyanite occurs in smaller quantity in the massive rock [eclogite] also'. Alderman [11], who recently discussed in detail the eclogites of the Glenelg area, analysed an amphibolized eclogite and an amphibole from a garnet-amphibolite from the actual exposure referred to by Clough. His material contained, however, no kyanite. The writer has since that time collected a suite of rocks from this locality and obtained an interesting group of kyanite-bearing amphibolites which come now for description.

Clough's exposure is an eclogite mass enclosed in the Lewisian gneiss. The massive eclogite is largely transformed and is represented by lenticles and bands of the unaltered rock surrounded by its amphibolized products. These hornblendic derivatives show a range of composition varying from amphibolized eclogite to hornblende-schist. Attention here is directed to the eclogite itself, the amphibolized eclogite, and the garnet-amphibolite which in places carries kyanite as Clough first recognized.

The unaltered eclogite is a medium-grained rock composed essentially of omphacite, garnet, and accessory rutile. The grain-size of both constituents averages 1–2 mm., but the garnet occurs also as larger grains up to 10 mm. in diameter. The garnet of this rock has been analysed by Pollard [10, p. 34] and corresponds to $Ca_{19.3}Fe_{37.4}Mn_{1.5}Mg_{41.8}$. Incipient amphibolization is developed even in the least-altered specimens, the amphibole first appearing at the contact of the garnet and omphacite.

The derived amphibolized eclogite analysed by Alderman is composed of hornblende, omphacite, and epidote, with residua of garnet, and also contains accessory plagioclase and rutile. The garnet-amphibolite stage, where plagioclase is more abundant, is recorded by Alderman, who has analysed the predominant hornblende of one of these rocks.

Now, some of these eclogite bands and lenticles are traversed by white streaks built up essentially of acid plagioclase with minor quartz but containing characteristically small prisms of kyanite. These streaks may appear as thin threads isolated in the rock or packed closely together in a subparallel arrangement. They have developed during a period when the eclogite was subject to deformation and have all the appearance of arising as a result of shearing at high temperature accompanied by introduction of material (pl. XX, fig. 1). The kyanite belongs only to these streaks and does not appear in the omphacite-garnet assemblage, i.e. kyanite is not an original feature of the eclogite, but has developed at a later date. The effects of stress are often revealed in the garnets by the presence of a parallel system of fractures which may be alined (*a*) parallel to the streaks, or (*b*) to narrow zones of amphibolization of the rock which are sometimes of earlier date than the streaks.[1]

The streaks as mentioned above are composed of albite, oligoclase $\pm$ quartz, forming a fine granular growth with occasionally larger oligoclase crystals showing vermiform inclusions of quartz. Kyanite is interspersed in this aggregate in the form of prisms ranging in length from 0·1 to 0·5 mm. Scattered brown biotite flakes may be present, and there are clots of green granular hornblende after pyroxene. In one eclogite sliced the streaks show predominant plagioclase with some quartz, and contain kyanite together with clinozoisite. It is clear from the relations of these two minerals that kyanite may eventually disappear and its place be taken by clinozoisite. The kyanite becomes mantled by the epidote and is often relegated to a minute core.

To pass now to the rocks in immediate association with the eclo-

[1] Hezner (Tschermak's Min. Petr. Mitt., 1903, vol. 22, p. 463) reports kyanite as occurring only in a brecciated variety of eclogite forming blocks in the Schutthalde at Burgstein, Oetztal—the kyanite developing as light blue veins penetrating the sections. In a slice collection of eclogites from this region I find, however, that kyanite is by no means limited to this type of association. The available slides from Burgstein, Sulztal, and Sölden show kyanite interspersed with omphacite and garnet as in the normal type of kyanite-eclogite. The rock from Sölden is an amphibolized eclogite in which the kyanite is giving place to clinozoisite via a minutely crystalline kelyphite similar to that described by Brière from the eclogite of St. Philbert de Grandlieu [6, p. 139].

gite. They comprise, as already noted, amphibolized eclogites, garnet-amphibolites, and hornblende-schists. That these rocks are ultimately derived from the eclogite seems clear. The garnets of these amphibolites are of the same type as those of the eclogites as indicated by their identical refraction, and residual pyroxene can be found enclosed within the garnets when omphacite has disappeared from the body of the rock. The garnet-amphibolites contain plagioclase or epidote, or both, and scapolite is often a minor constituent. Some of these types contain significant amounts of kyanite. It is these types that come now for description.

Some of the rocks contain only scattered garnets, but others represent coarse-grained types very rich in garnet. The constituents include, in addition to garnet, green hornblende, kyanite, andesine (zoned), both α- and β-zoisite, some scapolite confined often to definite bands, and rutile. Plagioclase varies much in amount and shows usually strong inverse zoning, oligoclase in the core with an andesine forming a shell. The extent of the zoning is, however, very variable. The scapolite is a dipyre ($Ma_{50}Me_{50}$).

In hand-specimens kyanite is by no means conspicuous, but careful scrutiny with a lens reveals white to very pale bluish streaks traversing the rock. These on microscopic examination are seen to be built essentially of kyanite. Examination shows that the kyanite occurs in the following associations:

1. In narrow streaks or clots elongated parallel to the foliation—the kyanite building subidioblastic prisms elongated parallel to the *c*-axis, and forming often the only mineral of the streak, which may be followed through the slice for six or more millimetres, though the width is usually under ½ mm. The streaks are packed between a foliated aggregate of green hornblende which contains, especially near the streaks themselves, sparing little inclusions of kyanite (pl. xx, fig. 2).

2. As isolated crystals in a plagioclase-hornblende ground.

3. Associated with garnet. This is a less common association, but the occurrences are significant.

The garnets in these rocks are characteristically xenoblastic, and are clearly residual and in process of conversion to hornblende as chief degradation product. Some of the larger garnets of these rocks are traversed by narrow veins of hornblende containing minute prisms of kyanite, while other garnets in process of destruction appear to give place to hornblende together with larger crystals of kyanite both types of associations presenting a picture of the transformation that the garnets of these rocks may undergo (text-fig. 2 and pl. xx, figs. 3 and 5).

To throw further light upon the problems presented by these rocks, analyses have been made of the least-altered type of eclogite in which only incipient amphibole development is present, the rock being

TABLE I.

	1.	2.	3.	4.	5.
SiO_2	48·74	45·66	45·23	47·50	47·00
TiO_2	0·86	1·13	0·59	1·03	1·00
Al_2O_3 ...	15·41	14·09	24·76	17·14	17·61
Fe_2O_3 ...	1·81	2·65	1·87	2·00	2·25
FeO... ...	8·81	10·87	7·64	6·04	6·78
MnO	0·15	0·17	0·09	—	—
MgO	10·71	11·23	7·67	10·37	8·78
CaO	10·68	12·18	9·18	13·61	14·90
Na_2O... ...	2·06	1·24	2·27	1·42	1·14
K_2O	0·35	nil	0·83	0·23	0·21
H_2O+ ...	0·41	0·34	0·24	0·19	0·40
H_2O- ...	0·13	0·04	0·09	0·02	
P_2O_5 ...	—	—	—	0·14	0·40
CO_2	—	0·19	—	—	—
	100·12	99·79	100·46	99·69	100·47
Sp. gr. ...	3·26	—	3·10	3·36	3·01

1. Eclogite, ½ mile slightly E. of N. of Ordnance Station, Beinn a Chapuill, Glenelg. Analyst, H. C. G. Vincent.
2. Amphibolized eclogite, same locality. Analyst, A. R. Alderman [11, p. 507].
3. Kyanite-garnet-amphibolite, same locality. Analyst, H. C. G. Vincent.
4. Kyanite-eclogite, Puy Ferrières, France. Brière [6, p. 168].
5. Garnet-amphibolite, same locality. Brière [6, p. 127].

essentially composed of omphacite, garnet, and rutile, with accessory amphibole derived in the manner already indicated (analysis 1, table I). This rock is identical with the specimen collected by Clough from this locality (Geol. Survey slice 8449), and from which presumably the garnet was analysed by Pollard (Clough [10, p. 34]). Analysis 2, table I, represents the composition of an amphibolized eclogite collected by Alderman from the same rock exposure. It shows a striking resemblance to that of the eclogite. The third analysis is that of a kyanite-garnet-amphibolite also collected from the same outcrop. This rock is comparable with the specimen (Geol. Survey slice 8448) referred to by Clough. Its chief distinguishing feature is the high content of alumina. Analyses 4–5 are of an eclogite and its associated sheath of amphibolite from Puy Ferrières. This latter example suffices to show that the transformation of eclogite into amphibolite may be accomplished without notable changes in bulk chemical composition.

The analysis of the kyanite-garnet-amphibolite raises immediately, therefore, the problem of the origin of the high alumina content, and

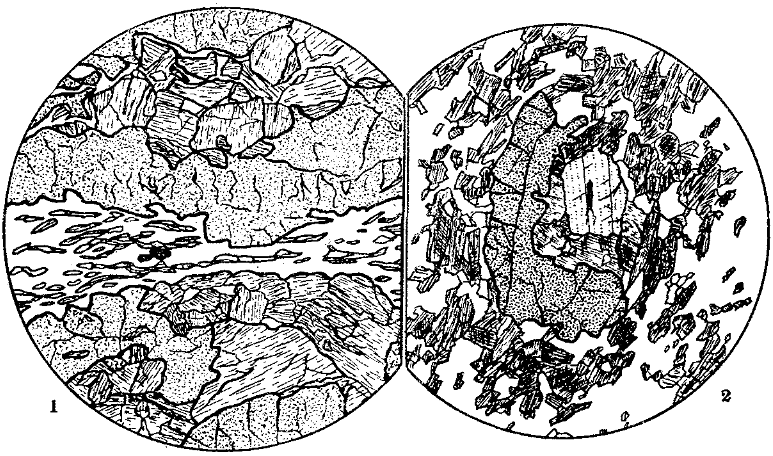


FIG. 1. Eclogite, 530 yards SSE. of Totaig, Loch Duich. The eclogite composed of omphacite and garnet is traversed by a quartz-kyanite streak containing accessory orthoclase (west to east). This streak is built, in the continuation of its course, essentially of orthoclase and kyanite with minor quartz. $\times 20$.

FIG. 2. Kyanite-garnet-amphibolite, $\frac{1}{4}$ mile N. of Ordnance Station, Beinn a Chapuill, Glenelg. Residual garnet partly enwrapping hornblende and kyanite. The ground consists of hornblende, plagioclase, zoisite. $\times 20$.

further discussion of the analyses is required. The analysis of the Glenelg eclogite is that of a normal type, and it falls in its appropriate place among pyroxene-eclogites without excess alumina (text-fig. 3).

The appearance of streaks and venules, composed of oligoclase $\pm$ quartz and containing significant kyanite, can legitimately be interpreted as resulting from migration of material during the shearing the eclogites have suffered. The occurrence of streaked eclogites of this character is not limited to this locality in the Glenelg area. A somewhat similar eclogite is recorded from a point approximately $\frac{1}{4}$ mile north of Cnoc Mòr (NE. of Glenelg). Here the streaks consist essentially of oligoclase $\pm$ quartz together with prisms of clinozoisite. Kyanite occurs sparingly in these streaks, which may be bordered by mylonitized quartz. Here the kyanite is being mantled and replaced by threads of sericite.

Eclogites from two other localities may be mentioned: (1) ½ mile slightly E. of N. of the NE. end of Lochan na Beinne Faide (9323). (2) 530 yards SSE. of Totaig Pier, Loch Duich (9183). Both these rocks are contained in the Geological Survey collections, and I am indebted to the Director for permission to make reference to them. The former

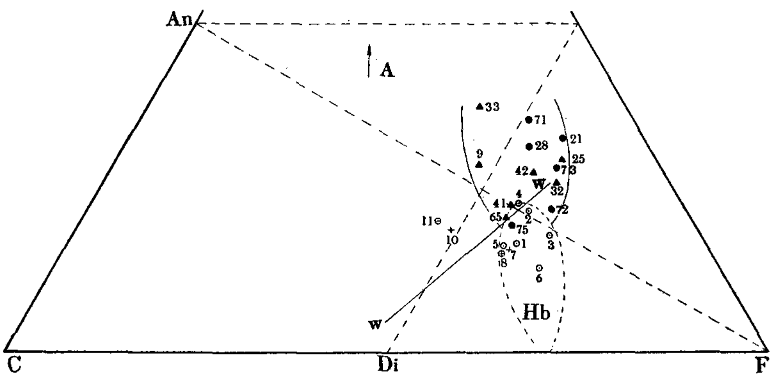


Fig. 3. Plot of analyses referred to in the text.

A-F-C. diagram, cf. fig. 2, Min. Mag., 1936, vol. 24, p. 247. W–W pyroxene–garnet conjugation line.

Hornblendes 1–6 (centred circles); see table IV, p. 566.

Eclogites and amphibolites 7–11 (crosses and encircled crosses respectively); see table I, p. 560, analyses 1–5.

Kyanite-amphibolite, Glenelg, 9 (black triangle).

Para-amphibolites and hornblende-*Garbenschiefer*, south side of St. Gotthard, 21–75 (black dots, without kyanite; black triangles, with kyanite); see Niggli [2, p. 162] analyses identically numbered.

rock (Geol. Survey slice 9323) is an amphibolized eclogite with streaks of oligoclase comparatively rich in parallel orientated kyanite prisms. In parts of the streaks kyanite is replaced by clinozoisite and may form cores to these crystals. It is probable that these examples could be multiplied were a detailed search made for them. An eclogite (M. 361) from Totaig contains nests and narrow streaks of quartz or quartz and orthoclase, and in the Survey rock (9183) streaks of this character contain orientated kyanite prisms (fig. 1). These streaks are bordered by a garnet rim. In the nature of the felspar, the unaltered character of the eclogite—the absence of amphibolization in the vicinity of the streaks, these rocks come to differ notably from those just discussed.

Now it is possible that streaks of this character are more comparable with the quartz (muscovite) kyanite nests that appear as a common feature of the eclogites of the Bavarian Fichtelgebirge, with this difference, however, that in the latter examples kyanite is also a conspicuous mineral in the omphacite-garnet ground of the rock. There is nothing to suggest that this orthoclase represents injected material

TABLE II.

	1.	2.	3.	4.	5.
SiO_2 ...	45·23	46·45	48·78	47·26	45·54
TiO_2 ...	0·59	1·19	0·37	0·38	1·06
Al_2O_3 ...	24·76	21·30	22·07	22·80	23·39
Fe_2O_3 ...	1·87	0·81	1·92	2·21	1·98
FeO ...	7·64	9·57	7·73	5·41	6·98
MnO ...	0·09	trace	trace	0·31	0·27
MgO ...	7·67	7·90	5·22	7·76	4·60
CaO ...	9·18	9·83	9·67	10·93	11·82
Na_2O ...	2·27	2·14	1·81	1·72	2·50
K_2O ...	0·83	0·34	1·17	0·29	0·44
H_2O+ ...	0·24	1·02	1·68	0·90	0·72
H_2O- ...	0·09	0·14	—	0·11	0·62
P_2O_5 ...	—	0·02	0·44	0·06	0·13
CO_2 ...	—	—	—	0·10	—
	100·46	100·75*	100·86	100·24	100·05

* Including NiO 0·04.

Norm of (1)

Orthoclase ...	5·00
Albite	19·39
Anorthite ...	45·59
Corundum ...	3·26
Hypersthene ...	2·32
Olivine ...	20·48
Magnetite ...	2·78
Ilmenite ...	1·22

Normative plagioclase An_{70}.
II 5.4.4–5.

1. Kyanite-garnet-amphibolite, ½ mile slightly E. of N. of Ordnance Station, Beinn a Chapuill, Glenelg. [11.]
2. Gabbro, St. Louis Co., Minnesota. Washington's Tables, 1917, p. 532.
3. Gabbro, near Abu Uruf, Kordofan. Ibid., p. 544.
4. Eucrite, Ring dike, Centre 3, Ardnamurchan. Mem. Geol. Surv. Scotland (Ardnamurchan), 1930, p. 85.
5. Dolerite, Coire Buidhe, Mull. Washington's Tables, 1917, p. 538.

from the surrounding Lewisian gneiss, and it may well be that the potash-felspar represents an original constituent of the eclogite segregated as an accessory mineral of the eclogite facies. Oligoclase, however, is not a typical mineral of this facies and the evidence is very clear that it has developed at a later stage in the history of the rock. If it is derived by internal differentiation in metamorphism its source must be the sodic omphacite which in retrograde metamorphism is known to give rise to sodic plagioclase.

The analysis of our kyanite-amphibolite can now be examined and compared with those of genuine igneous rocks. In table II this analysis is set down with analyses of igneous rocks most closely comparable. The composition is unusual inasmuch as the analysis shows a figure of 3·26 % corundum in the norm which corresponds more nearly with those of igneous rocks of the type of anorthositic gabbros or allivalites. Most analyses with comparable alumina show, however, considerably higher lime percentages. If this amphibolite were derived from a variant of the eclogite it seems clear that this variant must have been a kyanite-bearing one (Tilley [1]). No such eclogites from the Glenelg region have been revealed by the detailed studies of Alderman, nor in the eclogite exposure north of Beinn a Chapuill has kyanite been recognized as an original constituent with omphacite.

The presence of kyanite as a subsequently developed mineral in oligoclase streaks and veins in the usual type of eclogite makes evident that migration of material is involved and it is pertinent to inquire whether the origin of the kyanite in the amphibolites is not part of the same story. Indeed the mode of development of the kyanite in these rocks—already described—the streaked aggregates of closely packed kyanites extending over a length of six or more millimetres—renders the above inference very probable, and it is of interest to note in this connexion that analyses of the eclogite and kyanite-amphibolite differ principally in their percentages of alumina. In view of the known capacity of kyanite substance to migrate during stress metamorphism, and the evidence already presented, it is difficult to refute a belief that the origin of the kyanite in these amphibolites is to be traced to migration and segregation during the conversion of the eclogite to the amphibolite stage.

The break-down of garnet with formation of amphibole together with kyanite must involve migration of material, for the proportion of kyanite is much greater than could possibly be derived from a chemically closed system; moreover, the garnet has a much greater FeO/MgO ratio than the associated amphibole.

Finally, the evidence of eventual replacement of kyanite by clinozoisite—whether in the eclogites or derived amphibolites—may serve to warn us that in other Glenelg occurrences clinozoisite (especially as a constituent of quartz-oligoclase veins or streaks) may similarly have arisen on the ruins of former kyanite.

The occurrence of the kyanite-amphibole paragenesis in these rocks provides, however—apart from the problem of ultimate genesis—an opportunity of determining how the aluminous environment has controlled the content of aluminium in the constitution of the amphibole. An analysis of the hornblende of the rock analysed has therefore been made.

The amphibole was separated from the other constituents except zoisite by means of heavy liquids, methylene iodide and bromoform mixtures proving suitable liquids. Zoisite was ultimately separated from the amphibole by repeated treatment of the powder in a Hallimond electromagnetic separator. Microscopic examination of the resultant powder showed only hornblende grains, but a few of these

TABLE III. Hornblende from kyanite-garnet-amphibolite, Glenelg.

			Metal atoms to 24(O,OH).		
SiO_2 ...	...	42·28	6·13		8·00
Al_2O_3	...	17·24	2·94	1·87 / 1·07	
TiO_2...	...	0·66	0·08		
Fe_2O_3	...	2·68	0·29		
FeO ...	...	9·34	1·12		5·16
MnO...	...	0·12	0·01		
MgO...	...	11·91	2·59		
CaO ...	...	11·06	1·72		
Na_2O	...	1·73	0·47		2·35
K_2O ...	...	0·81	0·16		
H_2O+	...	2·05	1·98		1·98
H_2O-	...	0·08			
		99·96			
Sp. gr.	...	3·20	α 1·648, γ 1·672, $2V_\alpha$ 84°, $c:\gamma = 19°$.		

contained minute needles of kyanite which defied complete separation by the above means. The very small amount of this kyanite was determined by treatment of a weighed quantity of the hornblende powder with hydrofluoric acid *in the cold*. Complete decomposition of the hornblende with kyanite remaining unattacked was obtained. The gelatinous silica was removed by digestion of the washed residue with HCl. The residual material—kyanite showing no signs of chemical attack—was weighed. This residue constituted 0·47 % of the powder and its component oxides were deducted from the analyses of the hornblende fraction. The final analysis thus obtained is given in table III. As was to be expected the hornblende shows a high alumina figure. Comparable alumina percentages are found in certain basaltic and barkevikitic amphiboles of alkali igneous rocks and still higher figures are known from metamorphic rocks. Some of these amphibole analyses are set down in table IV. Here are listed two amphiboles showing 22·73 % and 22·62 % Al_2O_3, the former from a hornblende-*Garbenschiefer* of the Tremola series referred to at the beginning of this paper, the latter from a Hessian basalt (inclusion in).

Hornblende 5 is of interest as it is reported as occurring associated with corundum—in the serpentine belt of Corundum Hill, North Carolina. Hornblende 3 with 18·52 % is reported by Sahlstein as developed by reaction between pyroxene and garnet in a Greenland eclogite.[1]

TABLE IV. Analyses of hornblendes.

	1.	2.	3.	4.	5.	6.
SiO_2	42·28	42·73	41·06	40·09	45·14	42·17
TiO_2	0·66	1·37	0·24	1·17	—	1·00
Al_2O_3 ...	17·24	22·73	18·52	22·62	17·59	13·46
Fe_2O_3 ...	2·68	3·17	4·67	2·44	—	5·92
FeO	9·34	7·62	7·81	9·05	3·45	7·82
MnO ...	0·12	—	0·25	—	—	0·15
MgO	11·91	8·59	15·31	12·40	16·69	14·46
CaO	11·06	9·64	9·92	10·49	12·51	11·76
Na_2O ...	1·73	2·18	1·24	1·17	2·25	0·68
K_2O	0·81	0·98	0·34	0·65	0·36	0·80
H_2O+ ...	2·05	0·97	0·11	0·24	1·34	1·53
H_2O- ...	0·08	0·06	0·46			—
	99·96	100·04	99·93	100·53*	100·33†	99·75

* Including P_2O_5 0·21. † Including Cr_2O_3 0·79, NiO 0·21.

1. Hornblende, from kyanite-garnet-amphibolite, Glenelg. Analyst, H. C. G. Vincent.
2. Hornblende, from hornblende-*Garbenschiefer*, Airolo, Tessin. L. Hezner [3, p. 157].
3. Hornblende, from eclogite, Hurry Inlet, Greenland. T. G. Sahlstein [12, p. 22].
4. Hornblende, inclusion in basalt, Seigertshausen, north Hesse. C. Trenzen [13, p. 37].
5. Hornblende, associated with corundum, serpentine contact, Corundum Hill, North Carolina. C. Doelter [14, p. 617].
6. Hornblende, from garnet-amphibolite (of eclogite origin), locality of 1. A. R. Alderman [11, p. 519].

The compositions of these amphiboles together with others from eclogites and garnet-amphibolites are graphically represented in the plot of text-fig. 3 (p. 562). This plot contains also the co-ordinates for the rocks analysed, together with those of a group of hornblende-*Garbenschiefer* and amphibolites ± kyanite. The field demarcated in the upper portion of the figure is characteristically that of sedimentary rocks—in the central region of the field bounded by dolomite-

[1] This analysis it should be noted when calculated to the amphibole structural formula yields the abnormally high figure of 6·1 for the 'Y' group (Mg,Fe'',Fe''',Al,Ti...).

muscovite-chlorite (quartz) as could be expressed in this A-F-C diagram. The analysis of the kyanite-amphibolite falls above the join Anorthite-F—appropriately within the region bounded by the four chief phases building the rock, whereas the majority of basic igneous rocks of the composition of eclogites including kyanite-bearing types fall below it.

Appendix.—In my account of kyanite-eclogites [1, p. 430] reference was made to the reported occurrence of sillimanite-bearing kyanite-eclogites from Tanganyika. Since that account was written I have, through the courtesy of Dr. A. W. Rogers and Mr. A. F. Williams, had opportunity of examining some of the original material from the Mabuki mine, Tanganyika. This examination has shown that in the rocks in question the only aluminium silicate mineral present is kyanite occurring in part as elongated prismatic crystals which in appropriate sections show almost zero extinction.

References.

1. C. E. Tilley, Min. Mag., 1936, vol. 24, p. 422.
2. P. Niggli, Schweiz. Min. Petr. Mitt., 1929, vol. 9, p. 160.
3. L. Hezner, Neues Jahrb. Min., 1908, Beil.-Bd. 27, p. 157.
4. Osann-Rosenbusch, Elemente der Gesteinslehre, 1923, pp. 673, 709.
5. O. H. Erdmannsdörffer, Sitz.-ber. Heidelberg. Akad. Math.-nat. Kl., 1936, Abh. 10, pp. 1–12.
6. Y. Brière, Bull. Soc. Franç. Min., 1920, vol. 43, p. 72. [M.A. 1–163.]
7. H. B. Patton, Tschermak's Min. Petr. Mitt., 1887, vol. 9, p. 134.
8. J. A. Ippen, Mitt. Naturwiss. Ver. Steiermark, 1893, p. 12.
9. J. Suzuki, Journ. Fac. Sci. Hokkaido Imp. Univ., Ser. IV, 1930, vol. I, no. 1, p. 51. [M.A. 4–402.]
10. C. T. Clough, Mem. Geol. Surv. Scotland (Glenelg), 1910, p. 35.
11. A. R. Alderman, Quart. Journ. Geol. Soc. London, 1936, vol. 92, p. 488.
12. Th. G. Sahlstein, Medd. om Grønland, 1935, vol. 95, no. 5, p. 22.
13. C. Trenzen, Neues Jahrb. Min., 1902, vol. ii, p. 37.
14. C. Doelter, Handbuch der Mineralchemie, 1914, vol. 2, pt. 1, p. 617.

EXPLANATION OF PLATE XX.

Kyanite-garnet-amphibolites and eclogite from Glenelg, Inverness-shire.

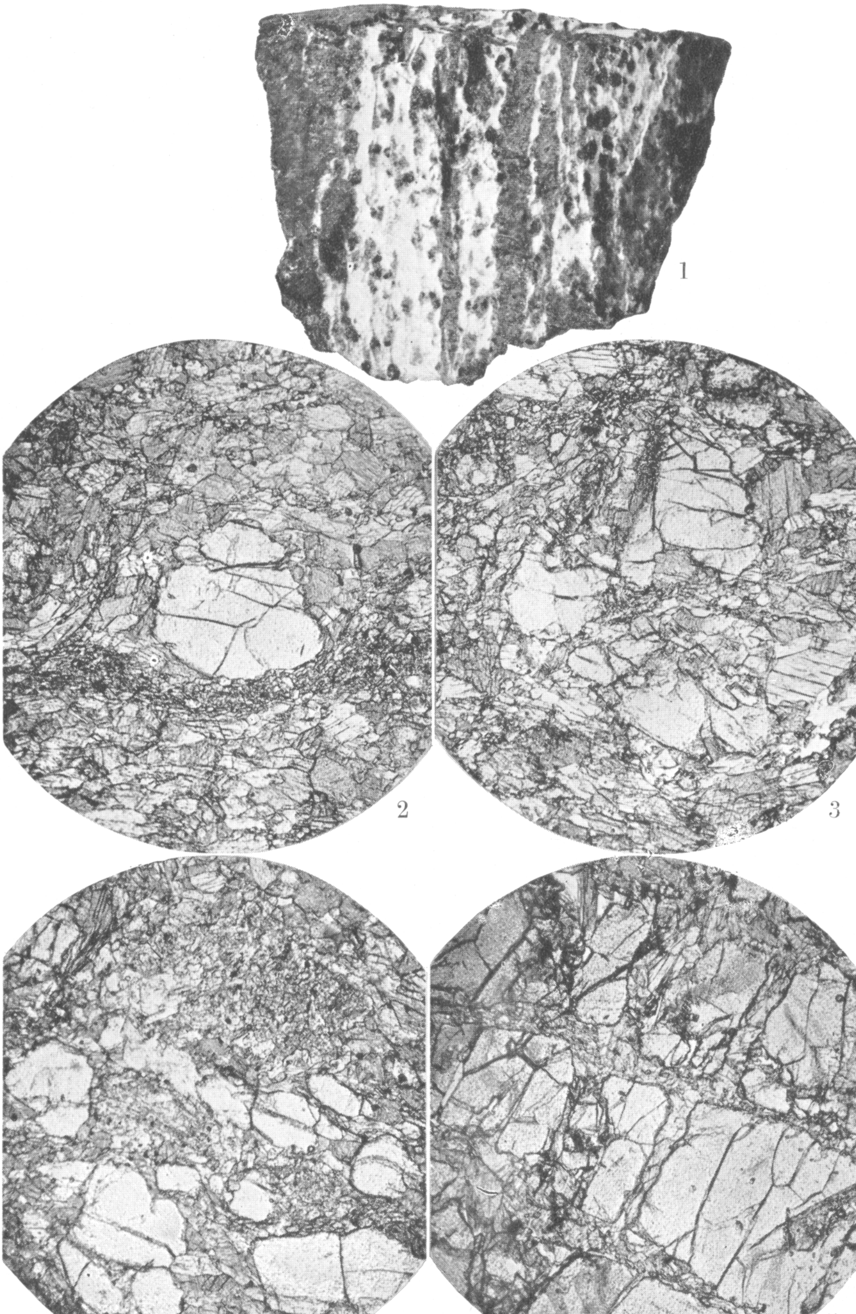
FIG. 1. Eclogite, ½ mile north of Ordnance Station, Beinn a Chapuill, Glenelg. The rock is veined by fine-grained oligoclase-kyanite streaks. In this example the streaks are more strongly developed than usual. Dark spots in the white streaks are garnets isolated from the main body of the eclogite. × ⅜.

FIG. 2. Kyanite-garnet-amphibolite, same locality. Streaked aggregates of kyanite form a darker coloured band below the central garnet. Kyanite is present as isolated crystals in the hornblende ground. × 20.

FIG. 3. Kyanite-garnet-amphibolite, same locality. Residua of garnet and abundant kyanite. The dark zones traversing the garnet of the upper centre and top right consist of fine hornblende with numerous kyanite prisms. × 20.

FIG. 4. Kyanite-garnet-amphibolite, same locality. Residua of garnet and abundant kyanite in the form of closely packed aggregates (left centre and in the upper half of the photograph). × 20.

FIG. 5. Kyanite-garnet-amphibolite, same locality. Garnet in process of replacement by hornblende with numerous fine crystals of kyanite. The latter are well seen in the fractures directed across the photograph from left to right. × 20.



C. E. TILLEY : KYANITE-AMPHIBOLITES