THE POSSIBLE ORIGINS OF AMPHIBOLITES IN AN AREA OF HIGH METAMORPHIC GRADE

By

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Abstract — The origins of amphibolites occurring in high grade metamorphic gneisses on Langøy, North Norway, are discussed in light of results of a general survey recently published by WALKER et al. (1960). Mainly on the basis of some trace element data it is possible to separate between two groups of the amphibolites. It is likely that this separation reflects a difference in origin.

Introduction.

The distinction between ortho-amphibolites (i.e. amphibolites formed from igneous rocks), and para-amphibolites (i.e. amphibolites formed from sedimentary rocks) is of concern to petrologists working in many metamorphic areas. The general problem has recently been discussed by WALKER, JOPLIN, LOVERING, and GREEN (1960) who placed special emphasis on rocks from the Precambrian of North-Western Queensland, Australia. They tried to find criteria via six different approaches (field, texture, mineralogy, major elements, minor elements, rock magnetism). None of the methods was successfully employed to determine the origin of all of the amphibolites examined. Their conclusions may be summarized:

(1) Metamorphosed basic magmatic rocks and lime-magnesia sediments, which are essentially unaffected by metasomatism, have some diagnostic features, in particular their trace element content.

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(2) Predominantly metasomatic rocks tend to converge towards an amphibolitic type with properties that do not indicate its origin. For such rocks no method has been found more successful than careful field examination.

HEIER (1960) in a discussion of the origin of some amphibolites occurring with other metamorphic rocks on the island of Langøy in North Norway concluded that some of these amphibolites probably were original lime-magnesia sediments, whereas others were basic magmatic rocks. However, the basis for the conclusion was weak so it is interesting to try to use some of the criteria recommended by WALKER et al. (1960).

Field occurrence.

Of the multitude of rock types on Langøy a series of veined and banded gneisses is most common. The metamorphic grade ranges from amphibolite to granulite facies. Metamorphic rocks of a recognizable sedimentary origin occur at intervals within the gneisses, and the gneisses are assumed to be for the most part high grade metamorphic equivalents of geosynclinal sediments, lavas, tuffs, etc. Amphibolites have three modes of occurrence within these rocks:
(1) As bands alternating with acid rocks in the gneisses (nos. 3, 4, 7, 8, 9),
(2) associated with graphite schists (5, 6) (the latter are everywhere between massive amphibolites), and
(3) associated with metalimestone (marble) (1, 2) in such a manner as to suggest a genetic relationship.

The amphibolites associated with metasedimentary rocks are of a more massive appearance than those which occur as dark bands in the quartzo-feldspathic gneisses. However, the rocks of the two occurrences are mineralogically similar. Chemical analyses (major elements), and modes of the nine amphibolites considered in this paper are given in Table 1. Numbers 1, 2, 3, 4, and 7 are from the amphibolite facies area; numbers 5, 6, 8 and 9 are from the granulite facies area. This accounts for the mineralogical differences.

The appearance of these amphibolites in the field gives little evidence of their origin. The close association between nos. 1 and 2 with impure limestones may indicate them to have originally been lime-magnesia sediments, or metasomatic rocks (skarns). The field

Table 1.

Chemical analyses and mode of amphibolites from Langøy.

	1 13/56	2 33/55	3 29/55	4 3/56b	5 81/56	6 77/56	7 147/56	8 150/56	9 151/56
SiO_2	45.6	48.7	45.9	46.87	42.5	46.2	49.45	51.37	49.20
TiO_2	1.17	1.17	2.17	1.81	1.67	1.50	0.72	1.11	1.16
Al_2O_3	15.2	17.7	12.8	16.75	11.2	13.6	17.13	14.94	15.02
Fe_2O_3	3.97	5.32	7.62	4.45	7.15	4.98	2.87	0.92	1.19
FeO	8.65	5.50	10.25	9.29	11.82	8.65	7.15	8.36	9.08
MnO	0.21	0.13	0.22	0.15	0.18	0.22	0.14	0.14	0.22
MgO	8.79	5.80	5.97	5.55	7.46	6.63	7.24	11.08	10.26
CaO	11.89	7.70	10.07	7.69	12.73	11.75	9.64	7.71	8.52
Na_2O	2.60	4.50	2.84	3.55	3.11	4.07	3.48	1.41	2.37
K_2O	0.45	2.02	0.67	2.26	0.67	0.87	0.89	1.99	1.58
H_2O −				0.17			0.15	0.13	0.13
H_2O +				0.99			0.99	0.46	0.42
P_2O_5				0.70			0.11	0.79	0.70
Quartz	4	—	2	—	—	—	1	5	—
Plag.	33	62	43	45	35	32	42	39	46
(An in plag)	(54)	(43)	(42)	(30)	(30)	(30)	(33)	(53)	(50)
Hyperst.	—	—	—	—	—	1	—	20	20
Augite	1	9	14	—	15	6	—	11	6
Hbl.	61	10	31	33	42	60	53	tr.	9
Biotite	—	16	—	18	2	tr.	3	23	16
Titanite	tr.	—	—	—	—	—	1	—	—
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	1	tr.	1
Ore	1	3	10	4	6	1	1	2	2

evidence gives no clues as to the origin of the amphibolites in the gneisses (nos. 3, 4, 7, 8, 9). Such amphibolitic bands are commonly assumed to be original basic magmatic rocks, e.g., metamorphosed basalts, or their derivatives. However, they also may be metamorphosed limemagnesia sediments or markedly metasomatized products of either category. Nos. 3 and 4, although not clearly associated with metalimestones (marble) occur within an anticlinorium of metasedimentary rocks (together with no. 2). A sedimentary origin is feasible on the basis of their stratigraphic positions. As will be shown later their sedimentary origin, or at least the similarity between the rocks nos. 1—4, is supported by some of the chemical data.

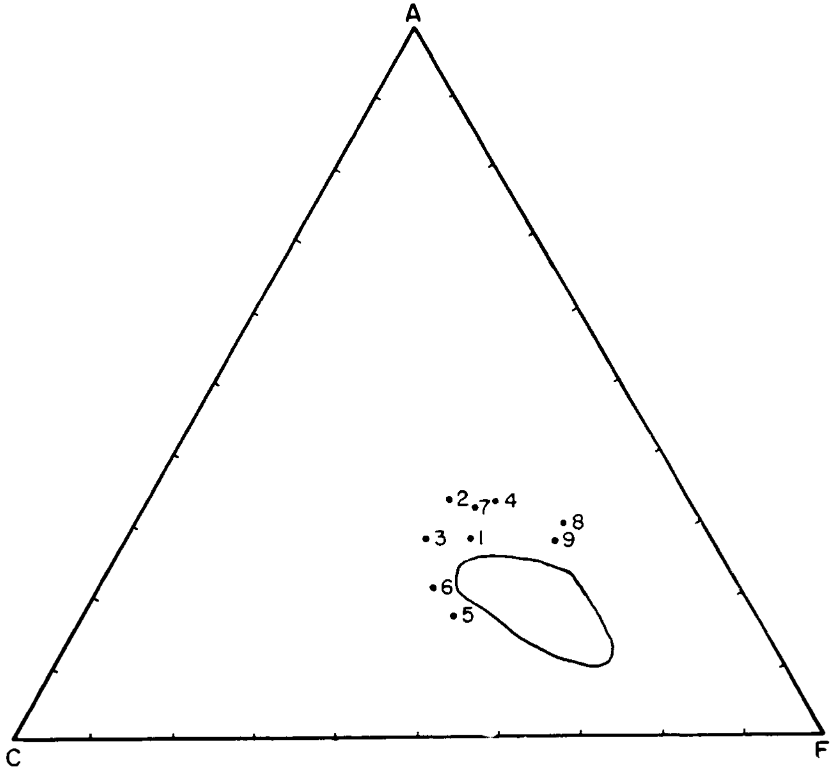

Fig. 1. Amphibolites from Langøy plotted on a modified A C F diagram. A = Al_2O_3 — (Na_2O + K_2O), C = CaO (corrected for P_2O_5), F = MgO + total Fe (as FeO, excluding iron allotted to mt. and il). The basic igneous rock analyses of Walker et al (1960) fall within the delineated field.

The origin of the amphibolites associated with graphite schists (nos. 5, 6) is also unknown. Their occurrence in a sedimentary sequence could suggest that they are original lime-magnesia sediments. However, close association between black shales and basaltic volcanism is known from many orogenic areas. Pyrrhotite mineralization is characteristic of the amphibolites near the graphite bands. Heier (1960) assumed this mineralization to be caused by a metamorphic activation of sulphur which originally occurred within the carbonaceous sediments. Simultaneous influx of the most sulphophile elements, i.e., Cu, Fe, Co, and Ni might be expected. Although Walker et al. (1960) suggested these elements to be among the best indicators of amphibolite origin, this is obviously not valid for the amphibolites nos. 5 and 6.

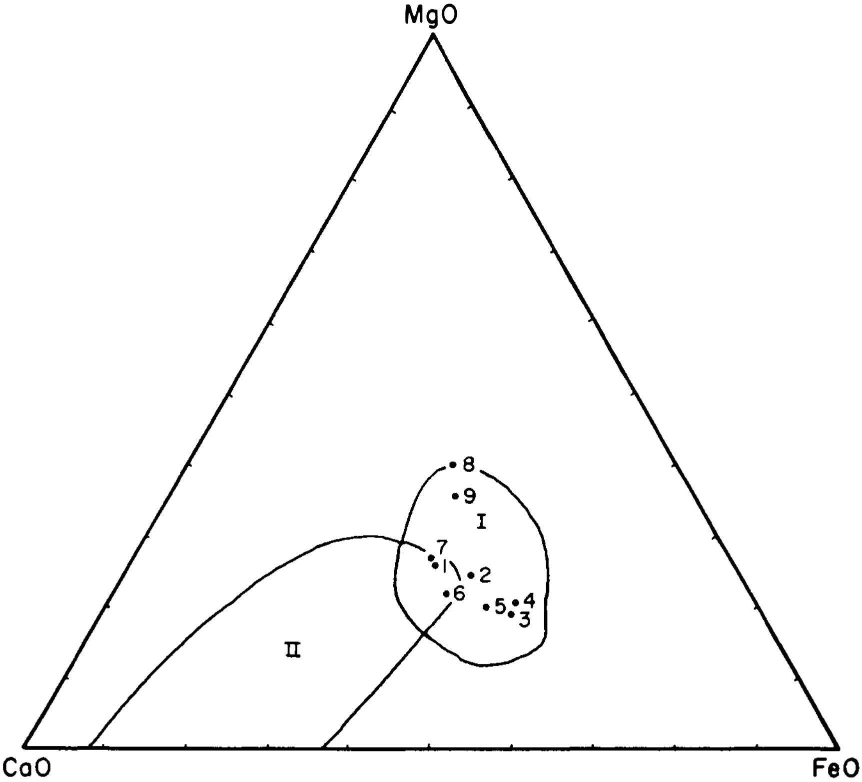

Fig. 2. Amphibolites from Langøy plotted on a MgO — CaO — FeO (wt. per cent, total Fe as FeO) diagram. I. igneous field; II. sedimentary field (from Walker et al, 1960).

Mineralogy.

The modes of the nine rocks examined are given in Table 1. The mineralogical variation are dependent upon variations in chemical composition and upon metamorphic grade. In no case can they be shown to be related to differences in original geneses of the parental rocks of the amphibolites.

Chemistry.

In general it should be possible to separate chemically between para- and ortho-amphibolites that have developed through a metamorphic process with no metasomatism. In Figs. 1 and 2 the Langøy amphibolites are plotted on the triangular diagrams used by WALKER et al. (1960).

Table 2.

Trace elements (p.p.m.) in amphibolites from Langøy.

	1	2	3	4	5	6	7	8	9
Ga	20	22	33	18	21	25.5	21	17	19
Ti	7000	7000	13000	10900	10000	9000	4300	6700	7000
Cr	(23)	28	—	45	135	172	113	800	570
V	290	125	500	140	275	225	1022	107	110
Li	8	19	12	18	6.5	3.9	14	10	10
Ni	76	65	26	41	230	135	136	336	280
Co	62	39	74	48	70	49	144	53	47
Cu	63	8	167	34	300	52	40	24	14
Sr	160	600	155	385	130	260	285	380	500
Pb		14		tr.			12	tr.	tr.
Ba	180	450	150	500	150	200	155	868	775
Rb	14	134	12	120	14	15	30	183	95

Table 3.

Comparison between the adopted concentrations of Co, Cr, Cu, and Ni in G—1 and W—1 by Heier (1960) and those determined by Walker et al, (1960).

	W—1				G—1			
	Co ppm	Cr ppm	Cu ppm	Ni ppm	Co ppm	Cr ppm	Cu ppm	Ni ppm
Walker et al	50	108	114	69	2	16	13	2
Heier	49	130	110	90	4	20	11	(5)

On Fig. 1 all the amphibolites fall outside the field containing the plots of basic magmatic rocks of WALKER et al. (1960). They found the plots of their amphibolites of sedimentary origin to be widely scattered, also occurring within the "magmatic" field, and that no particular sedimentary field could be delineated. As metasomatic alteration of rocks greatly affects their position in the ACF diagram the chemical interpretation is more complicated than suggested by Fig. 1. This is especially true because the concentration of the alkali elements affects the position of the plots, and the alkali elements are generally regarded as among the most mobile elements during metamorphism.

Fig. 2. shows plots of the Langøy amphibolites on a MgO-CaO-FeO diagram. A small overlap exists between the magmatic and sedimentary field. All the plotted points fall within the magmatic field, and only one of the amphibolites (no. 1) of those that are most likely to be of sedimentary origin plots within the overlap area.

Thus it may be seen that the major elements are of little value so far as ascertaining the origin of these amphibolites.

Trace element distribution.

A number of trace elements were determined in the Langøy rocks, Table 2. Walker et al. (1960) used logarithmic plots of Ni-Co, Ni-Cu, and Cr-Cu to distinguish between ortho- and para-amphibolites. Similar plots of the Langøy rocks are shown on Figs. 3, 4, and 5.

Walker et al. (1960) and Heier (1960) both used optical spectrographic methods for the determinations of the trace elements. Heier (1960) used G-1 and W-1 as external standards and Walker et al. (1960) checked the accuracy of their method by determining Cr, Co, Cu and Ni in both G-1 and W-1. The concentrations of these elements in the two rocks as they were adopted by Heier and determined by Walker et al. are compared in Table 3.

Figs. 3, 4, and 5 show that the amphibolites nos. 1—4, which occur within an area characterized by recognizable metasediments, form a distinct group, but only one (no. 4) plots in the "sedimentary field" in all diagrams. However, if the value of 69 p.p.m. Ni in W-1 (determined by Walker et al, 1960) was used by Heier (1960) the other rocks in this group would have plot within the "sedimentary field" in Figs. 3 and 4 (except no. 3 in Fig. 4). Thus the trace element data may support a sedimentary origin for the amphibolites 1—4.

The origin of the other amphibolites is less certain. It seems that they are either magmatic, or very strongly metasomatized rocks.

The use of Cu as a base in Figs. 4 and 5 is somewhat unfortunate. Heier (1960) discussed the behaviour of Cu in rocks during metamorphism, and gave evidence that Cu present as sulphides (the bulk of the Cu in basic rocks) is easily activated during metamorphism. Thus the Cu content of high grade metamorphic basic rocks is likely to be of little real significance in these studies.

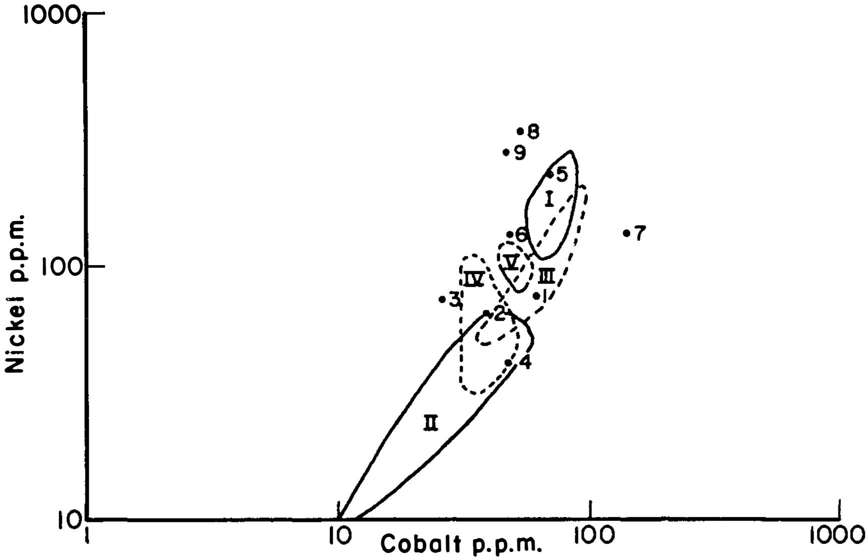

Fig. 3. Plots of Ni *vs.* Co in the Langøy rocks (logarithmic scale). I. unaltered and slightly altered basic magmatic rocks. II. para-amphibolites of low to moderate grade alteration, including metasomatism. III. metamorphosed basic magmatic rocks (metadolerites and metabasalts). IV. ortho-amphibolites, intensely metasomatized. V. para-amphibolites, intensely metasomatized.

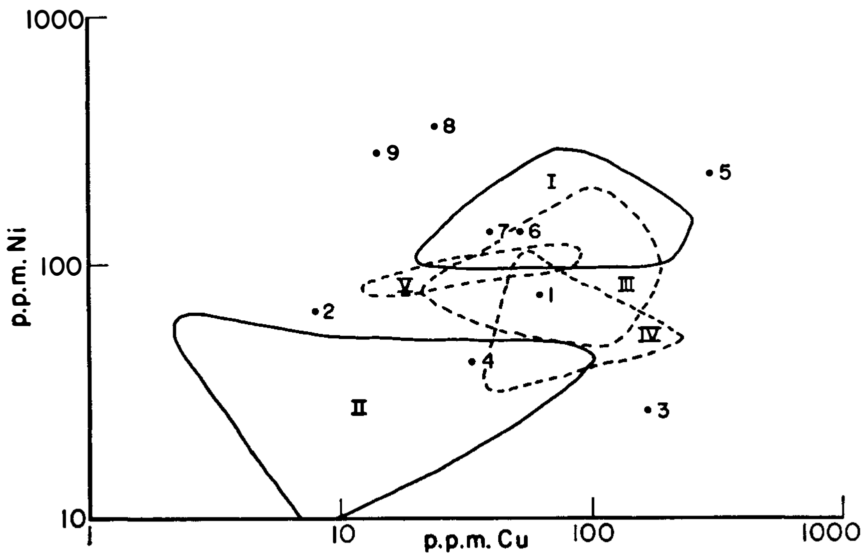

Fig. 4. Plots of Ni *vs.* Cu in the Langøy rocks (logarithmic scale). Numbering of fields as in Fig. 3.

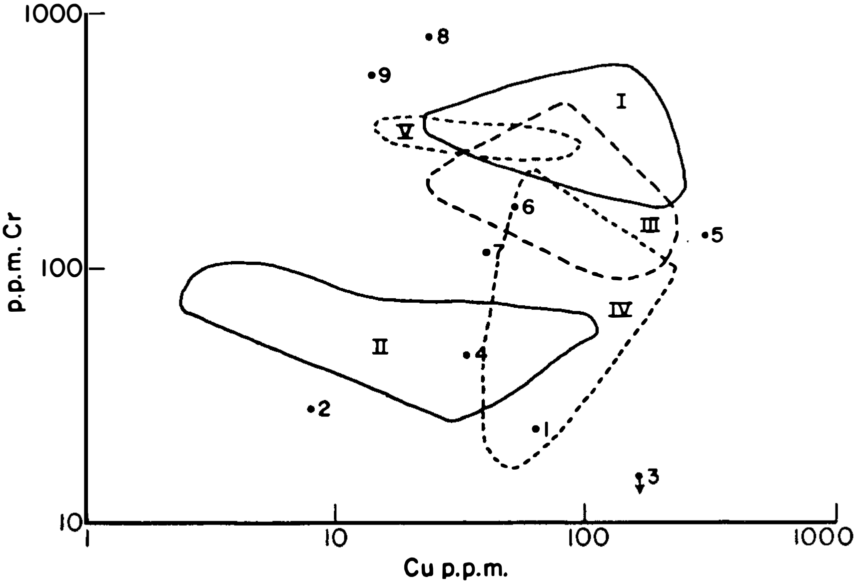

Fig. 5. Plots of Cr *vs.* Cu in the Langøy rocks (logarithmic scale). Numbering of fields as in Fig. 3.

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REFERENCES

HEIER, K. S. (1960). Petrology and geochemistry of high grade metamorphic and igneous rocks on Langøy, Northern Norway. Norg. Geol. Unders. *207*.

WALKER, K. R., JOPLIN, G. A., LOVERING, J. F., and GREEN, R. (1960). Metamorphic and metasomatic convergence of basic igneous rocks and lime-magnesia sediments of the precambrian of north-western Queensland. Jour. Geol. Soc. Australia, *6*, 149—178.

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