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Coexisting hornblende and cummingtonite from the Khetri copper belt, Rajasthan, India

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SUMMARY. Coexisting hornblende and cummingtonite in an amphibolite near Peliwali have been analysed. The rock formed by Fe–Mg addition and Ca removal from pre-existing amphibole quartzites within the altered wall rocks surrounding sulphide lodes. The amphibole compositions are controlled by the bulk composition of the rock. The $Mg/(Mg+Fe^{2+})$ ratio of the hornblende (0·66) is only slightly higher than that of the cummingtonite (0·64).

THE compositions of coexisting hornblende and cummingtonite are of mineralogical interest because they give an insight into the miscibility gap, the internal chemistry, and the formation of phases of similar structure in a multicomponent system. Those aspects that have been initially studied by Eskola (1950), Shido (1958), Watters (1959), and Vernon (1962) have been greatly elaborated by Klein (1968), Robinson and Jaffe (1969), Kisch and Warnaars (1969), and Robinson *et al.* (1969). However, the relationships of cummingtonite and hornblende are so complex and varied that another occurrence is worth recording.

In the northern part of the Khetri copper belt, Rajasthan, near the old Peliwali mines, hornblende–cummingtonite amphibolites form a minor zone in the altered wall rocks rich in anthophyllite, cummingtonite, cordierite, almandine, biotite, chlorite, and quartz, surrounding the pyrite–pyrrhotine–chalcopyrite-rich sulphide lodes. Studies by Das Gupta (1964, 1967) on the wall rock alteration show that anthophyllite–cummingtonite-bearing rocks have been formed by metasomatic Fe–Mg addition and Ca removal in pre-existing quartzites, amphibole quartzites (possibly metamorphosed greywackes), and schistose rocks belonging to the Alwar and Ajabgarh Series of the Precambrian Delhi System of Heron (1922). The geology of this belt has been described in detail by Das Gupta (1965), who reported the occurrence of hornblende–cummingtonite amphibolites for the first time from this area (Das Gupta, 1962). While anthophyllite–cummingtonite-bearing rocks occur in amphibole quartzites in various parts of the belt, cummingtonite coexisting with hornblende has so far been recorded mainly from the subsurface cores. The amphibolites described in this account occur near the faulted contact of garnet–chlorite schists of the Ajabgarh Series with amphibole quartzites of the Alwar Series.

The amphibole quartzites unaffected by metasomatism are made of layers of quartz and plagioclase (An_{5-20}), alternating with hornblende (γ 1·685±0·003), chlorite, and biotite. Magnetite is uniformly disseminated in both the layers. Chlorite, which is a retrograde mineral, is present with or without epidote. The proportion of plagioclase is highly variable and is absent in some of the amphibole quartzites. An average amphibole quartzite has about 40 % hornblende, 15 % albite–oligoclase, 40 % quartz, 3 % chlorite–biotite and epidote, and 2 % magnetite.

The hornblende–cummingtonite amphibolites have fresh, subprismatic to xenoblastic hornblende (α pale brown, β yellowish brown, γ green 1·675±0·003, γ: [001] 21°, D 3·20, *a* 9·82 Å±0·02, *b* 18·07 Å±0·02, *c* 5·30 Å±0·02, β 105° 26′, Z = 2), sheaf-like radiating aggregates of cummingtonite or idiomorphic cummingtonite (γ 1·665±0·003, γ: [001] 20°, D 3·22, *a* 9·48 Å±0·05, *b* 18·19 Å±0·05, *c* 5·31 Å±0·05, β 102° 30′, Z = 2), and interstitial xenoblastic aggregates of plagioclase and quartz; locally the latter minerals are segregated in layers. The accessory minerals include biotite, chlorite, magnetite, apatite, sphene, and zircon; sometimes with a little pyrite, pyrrhotine, and chalcopyrite. The amphiboles also occur as long prisms in the groundmass of plagioclase and quartz. Although both amphiboles are intergrown parallel to their elongation, irregular patchy growth of cummingtonite in hornblende is most common. Hornblende is also marginally rimmed by cummingtonite. Cummingtonite with the *a* axis parallel to the *c* axis of hornblende giving (001) of cummingtonite parallel to (100) of hornblende also occurs. In addition there are discrete green hornblende and colourless cummingtonite grains without any intergrowth. Cummingtonite displays simple multiple twinning on (100). Both the amphiboles contain inclusions of quartz, magnetite, and sulphides; some coarse grains of amphiboles charged with these inclusions show sieve texture. Zircon occurring in amphibole is surrounded by pleochroic haloes; that in the hornblende can be altered to an isotropic yellowish metamict mass.

Mosaics of An_{50} plagioclase (γ 1·562±0·003, $2V_\gamma$ 82°) occur. Some of the plagioclase has irregular and indistinct zoning with a core of An_{25} (γ 1·550±0·003, $2V_\alpha$ 80°). Large plagioclases contain small rounded inclusions of quartz, possibly released during basification of earlier plagioclase. Plagioclase has been partly sericitized. Quartz forms granoblastic aggregates with or without plagioclase or is found as inclusions in amphiboles and plagioclase.

Brown biotite (n 1·620±0·003) occurs as tiny flakes and is randomly distributed within the amphiboles. Optically positive chlorite (β 1·625±0·005) forms tiny needles and flakes in the groundmass but mainly it occurs along the margins or cleavages of amphiboles as a retrograde mineral. Magnetite is partially altered to hematite.

The chemical compositions of the coexisting hornblende and cummingtonite are given in table I along with the bulk composition of the rock in which these two minerals are found.

Hornblende occurring in association with cummingtonite is quite different from the earlier hornblende present in the unmetasomatized amphibole quartzites. The petrography indicates that the hornblende has closely approached chemical equilibrium with the cummingtonite. The evidence for a prograde reaction includes the sodic cores of the plagioclase and the cummingtonite rim on hornblende. The metasomatic reaction is of the type hornblende+sodic plagioclase+$X \rightarrow$ less aluminous hornblende+more calcic plagioclase+cummingtonite+U . . . where X is introduced and U removed material and other phases are involved.

TABLE I. *Chemical Analyses*

	1	2	3		2a	3a
SiO_2	50·72	47·50	53·04	Si	6·96	7·56
Al_2O_3	10·08	9·58	2·25	Al^{iv}	1·04	0·38
				Al^{vi}	0·62	0·00
TiO_2	0·30	0·30	0·34	Ti	0·03	0·03
Fe_2O_3	2·16	3·12	0·42	Fe^{3+}	0·34	0·04
FeO	15·60	11·60	19·44	Fe^{2+}	1·42	2·31
MnO	0·40	0·24	0·23	Mn^{2+}	0·03	0·03
MgO	12·42	12·74	19·36	Mg	2·78	4·11
CaO	5·36	11·59	0·40	Ca	1·82	0·06
Na_2O	1·20	1·07	0·09	Na	0·30	0·02
K_2O	0·23	0·23	0·26	K	0·04	0·05
H_2O^-	0·12	0·20	0·15	OH	1·48	2·91
H_2O^+	1·40	1·51	3·06	F	0·10	0·36
F	0·36	0·22	0·80	O	22·42	20·72
Total	100·35	99·90	99·84	ΣZ	8·00	7·94
F≡O	0·15	0·09	0·34	ΣY	5·22	6·52
				ΣX	2·16	0·13
	100·20	99·81	99·50			

Analyst: N. R. Sen Gupta.

1. Amphibolite. Host rock to 2 and 3. Mode is cummingtonite 45, hornblende 38, quartz 5, plagioclase 5, chlorite–biotite 5, magnetite and sulphides 1·5, apatite, sphene, and zircon 0·5 %.
2. Hornblende. Physical constants in text.
3. Cummingtonite. Physical constants in text.

2a, 3a. Atoms calculated to 24(O,OH,F) for 2 and 3.

$Mg/(Mg+Fe^{2+})$ in both cummingtonite and hornblende varies with increase in the value of MgO/FeO in the rock.

	MgO/FeO in rock	$Mg/(Mg+Fe^{2+})$ Horn.	Cumm.
Seitsaari (1952)	0·41	0·38	0·42
Watters (1959)	0·53	0·57	0·58
Das Gupta (here)	0·80	0·66	0·64
Eskola (1950)	1·13	0·78	0·70
Vernon (1962)	1·22*	0·70	0·68

* Calculated from the mode and chemical compositions of the minerals.

The nearly identical $Mg/(Mg+Fe^{2+})$ ratios in Ca-rich and Ca-poor pairs fit the model of Chowdhury (1970). In the present hornblende Si is very high and Al^{iv} is low for amphibole-facies hornblende. This may be due to the presence of free quartz and other aluminous phases like plagioclase and biotite in association with hornblende and cummingtonite.

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