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Highly aluminous hornblende-cummingtonite coronas in gabbronorites of the southern amphibolite belt, Kohistan

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ABSTRACT: *The gabbronorites of the Chilas complex and southern amphibolite belt locally contain thin (< 0.2 mm) amphibole coronas around pyroxene. These consist of an inner shell of fibrous, colourless to pale cummingtonite, and an outer shell of bluish green alumino-tschermakite, with or without a discrete growth of epidote + vermicular quartz on the edges of the plagioclase. The coronas represent the initial stage of amphibolite facies metamorphism which prevailed in the southern part of the Kohistan arc during mid Cretaceous. The tschermakite, with 19.2% Al_2O_3, is one of the most aluminous calcic amphiboles thus far reported. The primary amphibole in the gabbronorites is brown ferroan pargasite containing much higher Ti and K than the coronitic tschermakite.*

INTRODUCTION

Gabbronorites are perhaps the most abundant rock-type in southern half of the Kohistan magmatic arc. The Chilas complex, forming the back-bone of the arc, is principally made up of these rocks, with subordinate orthopyroxene-quartz diorites, dunite, pyroxenites, troctolites, anorthosite, and pyroxene/hornblende pegmatites (Jan et al., 1984; Khan et al., 1989). The southern amphibolite belt, which consists of a variety of lithologies, also contains small masses of similar gabbronorites, especially in the Indus valley to the north of Patan and Swat valley to the south of Fetehpur (Jan, 1988; Treloar et al., 1990).

The Kohistan gabbronorites are generally medium-grained and foliated. They consist essentially of calcic plagioclase (commonly labradorite), pink to green pleochroic orthopyroxene, and green pleochroic Ca-rich clinopyroxene. Quartz, Fe-Ti oxides and apatite, with or without brown horblende, reddish biotite and perthite occur as accessories. Whilst the Chilas complex is locally amphibolitized, the gabbronorites in the southern amphibolite belt occur as relict masses in sheared amphibolites which contain abundant green to bluish green hornblende (for petrography, see Jan, 1979a; Treloar et al., 1990). The gabbronorites locally contain hydrous coronas along the plagioclase-pyroxene contacts. In this paper a preliminary account of these coronas from the southern amphibolite belt is presented. Detailed mineral chemistry is planned for a future publication.

PETROGRAPHY OF THE CORONAS

Jan (1979b) observed that pyroxenes in the gabbronorites of the Chilas complex are at places surrounded by coronas consisting of a colourless amphibole envelope on the interior and a bluish green amphibole envelope on the exterior, with or without epidote + quartz. They were thought to have developed due to a reaction between plagioclase and pyroxene. Subsequent studies show that such coronas also occur in the gabbronorite relics in the southern amphibolite belt. A somewhat similar paragenesis has been described by Watters (1959) in an "igneous" amphibolite from Ringaringa, New Zealand, where cummingtonite cores are sharply surrounded by hornblende. In Tozinka gabbro, Central Bohemia, amphibole coronas replacing orthopyroxene are anologous to those of Kohistan. According to Vejnar (1972), the hypersthene in these is marginally replaced by cummingtonite with a narrow rim of bluish green tschermakitic hornblende. There are hornblende and hastingsite in the host rock to the coronas.

The Kohistan coronas are invariably thin; generally ≤ 0.05 mm, but rarely reaching 0.2 mm where plenty of amphibole replaces orthopyroxene. They are better developed around orthopyroxene and consist of an in-

TABLE 1. MICROPROBE ANALYSES OF AMPHIBOLES AND EPIDOTE

Oxides	1	2	3	4
SiO_2	39.47	38.55	50.96	37.98
TiO_2	1.94	0.02	0.01	0.06
Al_2O_3	14.74	19.19	3.55	26.19
Cr_2O_3	0.05	0.01	0.04	0.03
Fe_2O_3	1.07	5.10	2.73	8.60
FeO	16.56	12.02	21.09	-
MnO	0.20	0.27	0.63	0.11
MgO	7.90	6.80	15.94	0.06
CaO	11.71	11.11	1.20	24.26
Na_2O	1.16	1.32	0.23	0.01
K_2O	2.55	1.16	0.07	0.01
TOTAL	97.35	95.55	96.45	97.31

Cations*	1	2	3	4
Si	6.041	5.865	7.571	2.999
Al^{iv}	1.959	2.135	0.429	0.001
Al^{vi}	0.701	1.307	0.193	2.437
Ti	0.223	0.002	0.001	0.004
Cr	0.006	0.001	0.005	0.002
Fe^{3+}	0.123	0.584	0.305	0.511
Fe^{2+}	2.120	1.529	2.60	-
Mn	0.026	0.035	0.079	0.008
Mg	1.802	1.542	3.529	0.007
Ca	1.920	1.811	0.191	2.053
Na	0.344	0.389	0.066	-
K	0.498	0.225	0.012	-
A-site	0.762	0.425	-	-

* Number of cations based on 23(O) in amphiboles and 12.5(O) in epidote.

1. Host rock potassian ferroan pargasite.
2. Corona alumino-tschermakite.
3. Corona cummingtonite.
4. Corona epidote (Ps = 17.3).

ner shell of a colourless amphibole and an outer shell of a bluish green amphibole, which may be separated from the plagioclase by a discrete corona of epidote + vermicular quartz. Bluish green amphibole, with or without epidote + quartz, may also grow around clinopyroxene and opaque oxide. The colourless amphibole is fibrous, better developed crystals are multiply twinned, and it displays inclined extinction. Some grains are charged with dusty magnetite, but others have few inclusions. The bluish green amphibole, separated sharply from the colourless one, is generally devoid of opaque dust. Photomicrographs of the coronas are displayed in Figure 1.

Preliminary microprobe data were collected on a gabbronite from the amphibolite belt to the north of Patan. The host rock contains brown pargasite. The colourless amphibole in the coronas is cummingtonite, whereas the bluish green amphibole is tschermakite. There are two possibilities for the growth of the two-amphibole coronas. During incipient hydration under amphibolite facies conditions, the orthopyroxene was marginally converted to cummingtonite (+ magnetite) which reacted subsequently with the plagioclase to produce the tschermakite. Alternatively, orthopyroxene and plagioclase reaction led to simultaneous growth of the two amphiboles. Textural details are insufficient, but the latter possibility is here preferred. If so, then a reaction of the following kind was responsible for their growth:

labradorite + orthopyroxene(En_{60}) = tschermakite + cummingtonite(+Fe-oxide).

MINERAL CHEMISTRY

Amphiboles were analysed in the host rock and a corona, together with epidote, with a Jeol superprobe JCX 733, using wavelength dispersive system. Suitable minerals and synthetic oxides were used as standards. Total iron was determined as FeO. For epidote, it was taken as Fe_2O_3. Recasting into FeO and Fe_2O_3 in the amphibole analyses was carried out on the basis of 23 oxygens in the following manner.

In cummingtonite, the recalculation was carried out so as to make the total number of cations in T + C + B = 15.00, with vacant A site. The allotment of K to B site is

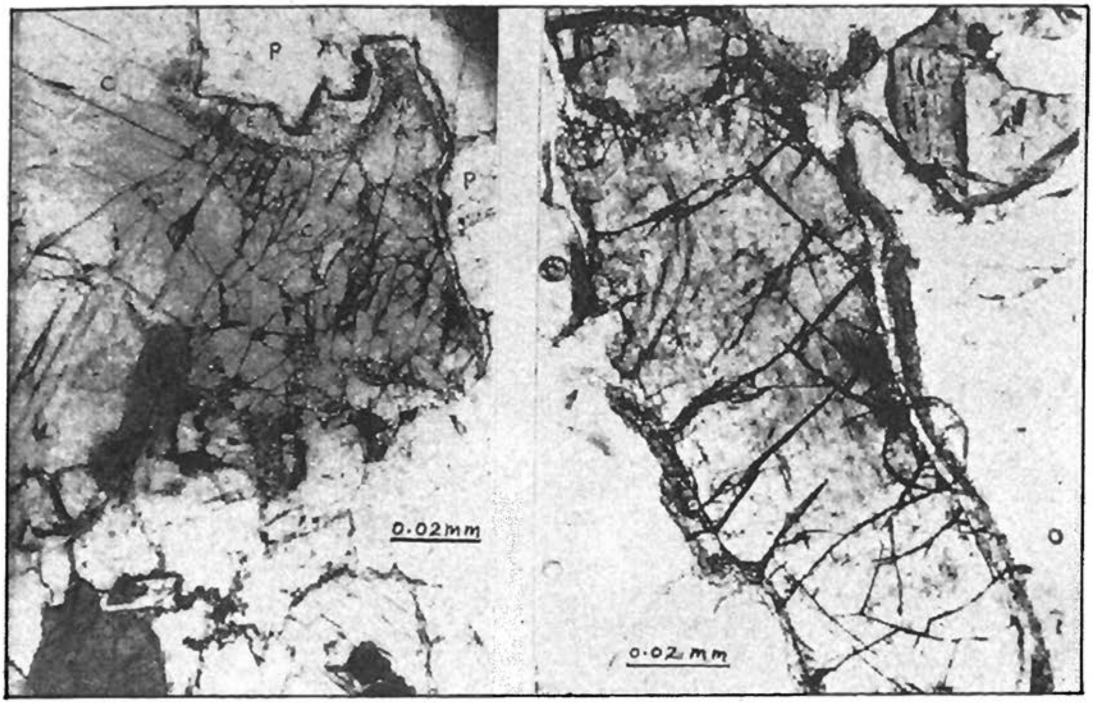

Fig.1. Photomicrographs showing reaction relations between calcic plagioclase and pyroxenes in the meta-gabbronorite relics in the southern amphibolite belt of the Kohistan island arc. Plane polarised light.
Left shows the development of green calcic amphibole (A) commonly sieved with quartz granules on the margin of clinopyroxene (C), and clear epidote (E) + vermicular quartz neighbouring calcic plagioclase. The immediate margin of the plagioclase is altered to cloudy (?) epidote. Lower left is host rock hornblende and lower right opaque oxide.
Right shows an orthopyroxene crystal surrounded by a corona consisting of colourless cummingtonite on the interior and bluish green tschermakite on the exterior. White areas are plagioclase and grain in the top right is host rock hornblende.

debatable (Robinson et al., 1982), but the amount of K is too small to make a substantial difference in the proportion of other cations. In the case of the calcic amphiboles, iron was split such that T + C = 13.00, assuming no Fe, Mn, Mg in B position, all Ca in B, and K in A site (Robinson et al., 1982; Rock & Leake, 1984).

The cummingtonite analyses are not unusual in any way and can be compared with those listed in Deer et al. (1963). The two analyses performed during this work are fairly close in composition. According to IMA nomenclature (Leake, 1978), the analyses of hornblende in the corona classify as alumino-tschermakite and those in the host rock as potassian ferroan pargasite (Table 1). The latter contain a considerable amount of Ti, have higher K and lower Al, especially Al^{vi}, when compared with the corona calcic amphibole. Increase in Ti, alkalies and A site occupancy have been related to increasing temperature by several authors (Zakrutkin and Grigorenko, 1967; Kostyuk and Sobolev, 1969; Raase, 1974; Spear, 1981). The pargasite is similar to that reported in the gabbronorite of the Chilas complex (Jan and Howie, 1982).

The corona hornblende is one of the most aluminous Ca-amphiboles so far reported. Like other alumino-tschermakites, it is typically impoverished in Ti. Leake (1965, 1971) predicted that in natural calcic amphiboles the amount of $Al^{vi} \leq 0.6\ Al^{iv} + 0.25$ (subsequently modified to $0.7\ Al^{iv} + 0.25$ by Doolan et al., 1978). Note that the Al^{vi} content of the corona hornblende is only slightly lower than the maximum permissible value. Along with high Al^{vi}, this also contains 0.19 atoms of Na in M4 site, suggesting a fair amount of glaucophane substitution, pointing to formation under higher pressure conditions than the host rock hornblende.

DISCUSSION

Gabbronorites in the Chilas complex and southern amphibolite belt contain small amounts of a brown pargasitic amphibole. This amphibole, characterized by high TiO_2 and alkalis may be igneous or grown during granulite facies reequilibration of the rocks. Some of the gabbronorites, especially those occurring as relics in the amphibolite to the north of Patan, also contain two-amphibole coronas around orthopyroxene. These coronas are thin (< 0.2 mm) and consist of an inner shell of colourless to pale cummingtonite and an outer shell of bluish green hornblende, with or without a discrete rim of epidote + vermicular quartz. The corona hornblende is very rich in Al_2O_3 (19.2%) and classifies as alumino-tschermakite.

The coronas are a product of a reaction between calcic plagioclase and orthopyroxene. They represent incipient stages of amphibolitisation which remained restricted to grain boundaries due to an inadequate supply of water and lack of shearing in the rocks. In the surrounding rocks, which are sheared and thoroughly hydrated amphibolites, the corona amphibole pair is substituted by a hornblende less aluminous than that of the corona (Jan and Howie, 1982; Bard, 1983; Treloar et al., 1990). It is thought here that the coronas grew during regional metamorphism which affected much of the southern amphibolite belt and parts of the Chilas complex. This metamorphism, accompanying shearing in the southern Kohistan, has a minimum age of 83 Ma (Treloar et al., 1990).

The corona assemblage suggests amphibolite facies metamorphic conditions. The high Al^{vi} and some glaucophane substitution in the tschermakite point to high pressure conditions. These conclusions are in agreement with the temperature estimates of 550 to 650°C and pressures as high as 8 to 10 kbar suggested for the metamorphism in the southern amphibolite belt (Bard, 1983; Jan, 1988; Treloar et al., 1990).

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