

Ti-rich amphibole of igneous origin in MOR-type gabbroic rocks (Northern Apennine ophiolites, Italy): an ion microprobe study

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Two major hypotheses have been formulated for the origin of Ti-rich amphibole in MOR-type gabbroic rocks (e.g. Otten, 1984). In the first, amphibole derives from an igneous trapped liquid. This hypothesis implies that the parental magma had a relatively high volatile content, thus contrasting with the nearly anhydrous nature of MORB. The second hypothesis assumes a metamorphic origin, i.e. amphibole was originated by solid state reactions of igneous minerals with volatile-rich seawater-derived fluids.

In the gabbroic rocks from Northern Apennine ophiolites, Ti-rich amphibole occurs both with igneous and metamorphic texture. The gabbroic rocks were formed by low-pressure fractional crystallization of N-MORB type liquids in a slow-spreading ridge system (Tiepolo *et al.*, 1997). Accessory Ti-rich amphibole with igneous texture is found as the last crystallizing mineral, in interstices between plagioclase and clinopyroxene and as rim around Fe-Ti-oxides. Moreover, Ti-rich amphibole occurs as a major mineral in the most evolved, volumetrically subordinate, intrusive lithologies (albitites). These rocks consist of albitic plagioclase and Ti-rich amphibole (up to 30 % by volume), both showing euhedral to subhedral habitus, plus accessory Fe-Ti-oxides, apatite and zircon.

This work aims to unravel the origin of Ti-rich amphibole with igneous texture. Amphibole from Mg- and Fe-rich gabbroic rocks, as well as from albitite, has been analysed for major elements by electron microprobe, and for halogen (F, Cl and H) and trace elements (*REE*, Y, Sr, Zr, Cr, V, Sc, Ti, Ba, K, Nb) by ion microprobe.

Results

According to the classification of Leake *et al.* (1997), amphibole from gabbroic rocks is titanian pargasite. The Mg# value ($Mg/(Mg+Fe^*)$) ranges from 0.78 to

0.70 and from 0.61 to 0.53 in Mg- and Fe-rich rocks, respectively. Amphibole from albitites is edenite (Mg# = 0.5) and has lower Ti contents than that from gabbroic rocks (about 0.15 apfu and 0.4 apfu, respectively). As a whole, Mn increases with decreasing Mg#, whereas Al and Ca decrease; K is invariably negligible.

Both Ti-pargasite and edenite contain significant F (up to 0.5 wt.%), relatively low H and negligible Cl (<0.03 wt.%), thus indicating a significant oxygen component ($O^{2-} = 0.4-0.8$ apfu). Calculation of structural formulae shows that Na at the M4 site and octahedral Al are low, whereas Fe^{2+} at the M4 site is significant.

The chondrite-normalized *REE* pattern of Ti-pargasite is characterized by *LREE* depletion ($La_N/Sm_N = 0.2-0.4$), nearly flat *HREE* and variable negative Eu anomaly ($Eu/Eu^* = 0.4-0.8$). Total *REE* contents are highly variable, with *HREE* ranging from 20 to 120 times chondrite. In the incompatible trace element pattern (Fig. 1), Ti-pargasite shows a marked depletion of Ba, K and Sr relative to *LREE*. Nb, Zr and Ti are slightly depleted to slightly enriched relative to neighbouring *REE*. Nb and Zr show great variations (about one order of magnitude), whereas Ba, K, Sr and Ti encompass a narrow compositional range. As a whole, the variations in incompatible trace element contents do not correlate with the Mg# value.

Edenite has distinctive trace element compositions. It has higher *REE* and Y, and lower Sr, Ti, V, and Ba than Ti-pargasite. Edenite also differs in the more marked negative Sr, Zr and Eu negative anomalies.

Discussion

The halogen compositions of both Ti-pargasite and edenite can be obtained through a Rayleigh fractional crystallization model, starting from N-MORB compositions, with a high crystallization degree

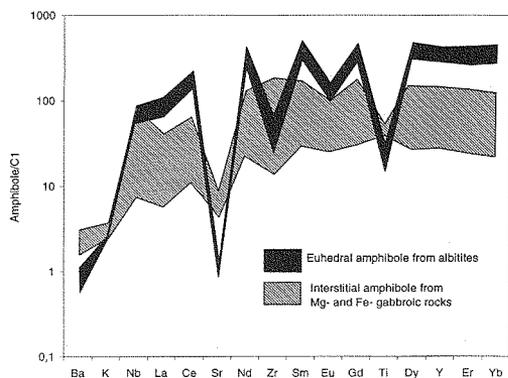


FIG. 1. Incompatible trace elements in igneous amphibole from gabbroic rocks and albitites of Northern Apennine ophiolites; normalization to CI chondrite.

(96%) of anhydrous minerals. In the calculation, we have assumed that the primitive N-MORB had F = 135 ppm, H = 280 ppm, Cl = 30 ppm (McDonough, 1996, GERM web site), and that amphibole/liquid partition coefficients for F, H₂O and Cl are equal to 2.0, 0.2 and 0.2, respectively (Tiepolo, unpublished PhD thesis). Therefore, amphibole could have been formed in response to an extreme fractional crystallization process.

The igneous origin is consistent with the overall high incompatible trace element contents. Compared with tholeiitic liquids, hydrothermal vent fluids from present-day oceanic basins are extremely depleted in incompatible trace elements (e.g. Campbell *et al.*, 1988). Moreover, amphiboles have low Cl, K, Ba and Sr concentrations, in agreement with the formation from N-MORB derived liquids.

In gabbroic rocks, Ti-pargasite could be the final result of closed system crystallization of liquid trapped between cumulus minerals. The variations in incompatible trace elements can thus reflect an incomplete process of subsolidus re-equilibration between originally highly-enriched amphibole and cumulus minerals. Ti-pargasite Mg# values would be mainly controlled by the compositions of mafic cumulus minerals, because of the relatively high diffusion rate of Mg and Fe²⁺. Alternatively, the compositional variations might reflect a process of mixing between trapped liquids and highly-evolved

percolating liquids, similar to those which gave rise to the albitites.

Trace element edenite compositions suggest their derivation from liquids more evolved than those which formed Ti-pargasite. The lower values of Sr, Eu/Eu*, Ti, V, and Zr/Zr*, as well as the higher REE and Y contents, could be due to fractionation of plagioclase, Fe-Ti-oxides and zircon. The Ba decrease relative to Ti-pargasite can be ascribed to the high Ba concentration in the coexisting plagioclase, which is favoured by the high albite component. A straightforward comparison between edenite and Ti-pargasite could, however, be incorrect. Major element compositions (low Ti content and edenite substitution) indicate that amphibole crystallization in albitites occurred at lower temperature than in gabbroic rocks. In albitites, moreover, edenite may be considered as a cumulus mineral and it does not coexist with other Mg-Fe-bearing silicates. Likely, amphibole/liquid partition coefficients were different in the two systems, and the subsolidus re-equilibration process in the albitites was negligible.

Despite the uncertainties in the mechanisms of amphibole formation, the data from this study strongly support the occurrence of Ti-rich igneous amphibole in MORB-type gabbroic rocks. Although Ti-pargasite of metamorphic origin does exist in MORB-type gabbroic rocks (e.g. Ito and Anderson, 1983), it could derive from subsolidus re-equilibration or recrystallization of igneous Ti-pargasite. The formation of accessory metamorphic Ti-pargasite in high-grade ductile shear zones, therefore, does not necessarily imply the infiltration of seawater-derived fluids.

References

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