

Trace element and isotope geochemistry of gabbro-derived and felsic granulites from the Northern Apennines (Italy): evidence for assimilation/fractional crystallization in the lower crust

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The Late Cretaceous sedimentary melanges from the External Liguride Units of the Northern Apennines include large slide blocks of mantle peridotites, MOR-basalts and lower and upper continental crust rocks representative of a continent-ocean transition between the Internal Liguride oceanic domain (Late Jurassic Western Tethys) and the thinned continental margin of the Adria plate (Marroni *et al.*, 1998). The slide-blocks of lower continental crust consist of gabbro-derived and felsic granulites, which locally preserve primary contacts. The gabbro-derived granulites show variable degree of recrystallisation related to the granulite-facies re-equilibration. However, rocks which preserve a gabbroic fabric are found locally. The most frequent rock-types are olivine-bearing gabbro-norites and Fe-Ti-oxide-bearing gabbro-norites; troctolites and anorthosites are also present. The felsic granulites include quartzo-feldspathic granulites and rare quartz-poor to quartz-free rocks. The gabbroic protoliths of the granulites were emplaced at about 290 Ma at deep crustal levels, where they underwent slow cooling and recrystallization under granulite-facies conditions ($P = 0.7-0.8$ GPa, $T = 800-900^{\circ}\text{C}$). They were exhumed to upper levels, in association with the felsic granulites, in late Triassic-middle Jurassic times (Marroni *et al.*, 1998).

Permian gabbroic rocks with granulite-facies metamorphic overprint are widespread in the Western Alps, in the remnants of the Adria plate margin. These gabbroic complexes are ascribed to the extensional tectonics which postdate the Variscan orogeny. In particular, striking similarities between the gabbro-derived granulites from Northern Apennines and the Ivrea Mafic Body (Pin, 1990) can be shown, i.e. similar ages of emplacement, close paragenetic and compositional resemblances and

comparable retrograde metamorphic evolution.

This work shows a geochemical investigation of gabbro-derived and felsic granulites from the Northern Apennines, in order to unravel (i) the affinity of the parental liquids of the gabbroic protoliths, (ii) the role of fractional crystallization and crustal assimilation in the igneous differentiation process, (iii) the nature of the mantle source. Trace element and Sr-Nd isotopic analyses have been performed on selected granulite samples, and clinopyroxene and plagioclase cores from undeformed gabbro-derived granulites were analysed for trace elements by ion microprobe.

Relics of igneous textures, mineral and bulk-rock compositional variations indicate a comagmatic origin for the gabbro-derived granulites. They can be generally recognized as cumulitic rocks with negligible amounts of residual trapped liquid, on the basis of low $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios (Kempton and Harmon, 1992) and overall low contents of incompatible trace elements. The mg# value ranges from 80 to 52, and points to negative correlations with TiO_2 (up to 5 %) and MnO, thus indicating a tholeiitic differentiation trend. Major element variations are consistent with a process of fractional crystallization of plagioclase + olivine as liquidus phases, followed by plagioclase + clinopyroxene + orthopyroxene. In addition, petrographic relations in undeformed gabbroic rocks suggest the growth of Al-spinel and Fe-Ti-oxides as intercumulus igneous minerals.

The range of incompatible trace element ratios ($\text{Zr}/\text{Y} = 0.7-2.9$, $\text{Y}/\text{Nb} \leq 9$, $\text{Zr}/\text{Nb} \leq 10$) encompasses that of subalkaline basaltic liquids. The REE distribution (Fig. 1) is characterized by: (i) slightly LREE-enriched patterns showing decreasing Eu positive anomaly with increasing absolute REE

abundances; (ii) *LREE*-depleted pattern with *MREE* enrichment which reflect relatively high amphibole amounts. The samples with the highest mg# have a marked positive Eu anomaly, which is coupled with spikes at Sr and Ba in the chondrite-normalized patterns of incompatible elements. The gabbro-derived granulites with the lowest mg# are characterized by positive Ba and negative Zr anomalies. The comparatively high Nb values (3–14 ppm) rule out island-arc tholeiites as parental magmas of the gabbro-derived granulites, thus favouring the hypothesis of within-plate tholeiites.

The *REE* pattern of clinopyroxene is nearly flat for *LREE*, slightly *HREE*-depleted and with a significant positive Eu anomaly ($\text{Eu}/\text{Eu}^* \sim 2$). Clinopyroxene is also characterized by relatively low Zr, V and Sc contents. Plagioclase has lower *REE* content than clinopyroxene and its pattern is characterized by a steady decrease from *LREE* to *HREE* and marked positive anomaly ($\text{Eu}/\text{Eu}^* \sim 15$); Sr is extremely enriched relative to *REE*. Similar clinopyroxene and plagioclase trace element compositions were observed in the Mafic Body of the Ivrea Zone (Mazzucchelli *et al.*, 1992) and interpreted as due to mixing of mantle-derived liquids with crustal melts deriving from anatexis of granulite-facies metasediments.

Quartzo-feldspathic granulites consist mainly of mesoperthitic to perthitic feldspar, quartz and garnet, and display close petrographic, mineralogical and geochemical similarities to the granulite-facies leucocratic rocks outcropping in the Ivrea zone (e.g. Sinigoi *et al.*, 1994). Their *REE* pattern (Fig. 2) is characterized by a marked *LREE* enrichment ($\text{La}_N/\text{Sm}_N \sim 5$) and nearly flat *HREE*; they exhibit no or slightly positive Eu anomaly. Chondrite normalization of incompatible trace elements reveals an extreme LILE enrichment, with high Ba/K ratios, and Nb and Ti depletion.

The Sr isotopic ratios of the gabbro-derived granulites recalculated for the age of emplacement (290 Ma) ranges between 0.70305 and 0.70774, whereas $\epsilon_{\text{Nd}}(290 \text{ Ma})$ vary between +6.7 and -4.5. Preliminary data performed on a sample of felsic granulite yield age-corrected $^{87}\text{Sr}/^{86}\text{Sr} = 0.71071$ and $^{143}\text{Nd}/^{144}\text{Nd} = 0.51185$ ($\epsilon_{\text{Nd}} = -8.0$), falling in the range of the Ivrea felsic granulites (Pin, 1990). The Nd and Sr isotopic data form a hyperbolic array, in which the gabbro-derived granulites with the highest mg# have the highest Nd and the lowest Sr isotopic ratios. This suggests mixing or AFC process involving a mafic magma derived from a depleted mantle source and a crustal end-member moderately enriched in radiogenic Sr and characterized by low $^{143}\text{Nd}/^{144}\text{Nd}$.

The involvement of a crustal component in the petrogenesis of the gabbro-derived granulites fits also well with (i) the finding of primary contacts with felsic granulites; (ii) the extensive crystallization of orthopyroxene and the occurrence of intercumulus Al-spinel; (iii) the trace element composition of clinopyroxene and plagioclase.

The AFC modelling on the basis of isotopic compositions shows that the gabbro-derived granulites may have originated through a process involving a primary tholeiitic magma derived from a depleted mantle source and a crustal end-member moderately enriched in radiogenic Sr and characterized by low $^{143}\text{Nd}/^{144}\text{Nd}$. The crustal component is represented by the wall-rocks of the mafic intrusion, i.e. the felsic granulites, whereas the isotopic features of the mantle component are consistent with those of mantle peridotites from both External and Internal Liguride Units recalculated at 290 Ma. Recent trace element and isotopic investigations indicate that the External Liguride peridotites represent a relatively fertile, undepleted mantle, whereas the Internal Ligurides ultramafics are residual after the extraction of MOR-type liquids and likely upwelled and melted during Permian times (Rampone, *et al.*, 1996). The Internal Liguride peridotites are therefore plausible candidates as the mantle source for the mafic end-member of the AFC process, in agreement with their Lower Permian age of depletion. We propose that, at Early Permian times, an isotopically homogeneous MORB-type mantle was subjected to significant melt extraction. The mantle-derived liquids possibly intruded the lower crust, thus triggering an AFC process which finally gave rise to the gabbro-derived granulites.

References

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