Age and petrogenesis of the Sondalo gabbroic complex (Central Alps, Northern Italy): implications for the origin of post-Variscan magmatism

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The Late Carboniferous-Early Permian gabbroic complexes of the Alpine belt are commonly ascribed to the extensional tectonics which postdate the Variscan orogeny (Dal Piaz, 1993). The best examples are provided by the Main Gabbro from the Ivrea-Verbano Zone (Quick *et al.*, 1994) and by the Malenco Gabbro (Hermann *et al.*, 1997). However, both Main and Malenco Gabbro have a widespread granulite-facies metamorphic overprint, which does not allow a complete petrological characterization of their igneous features. Very little is known about the Sondalo gabbroic complex of the Languard-Campo nappe (Austroalpine nappe system of Central Alps), although it is volumetrically important (it occupies an area of about 40 km^2) and almost devoid of metamorphic recrystallization. There are no recent studies on its petrogenesis and a determination of the intrusion age is lacking, despite geochronological determinations on adjacent granitoid masses suggesting that the Sondalo gabbroic complex was emplaced in Permian times (Del Moro and Notarpietro, 1987).

The Sondalo gabbroic complex is a stock intrusive into high-grade metapelites of the Languard-Campo nappe (Austroalpine nappe system of the Central Alps). The pluton broadly consists of norites and minor troctolites at the core, and diorites and subordinate granodiorites at the rim. The pluton frequently contains xenoliths of granulite-facies restitic rocks and is crosscut by muscovite-bearing pegmatitic to aplitic dykes. This work aims to verify whether the Sondalo gabbroic complex is related to the Alpine gabbroic complexes which postdate the Variscan orogeny. For this purpose, we carried out a petrological study (petrography, major and trace element mineral chemistry, and Nd-Sr-O isotopic compositions) of the troctolite/norite association, thus unraveling the intrusion age, the affinity of the parental liquids and the role of crustal contamination. Combining the data presented with the literature information on the Late Carboniferous-Early Permian gabbroic complexes from the Alpine belt, we give some insights into the origin of the post-Variscan magmatism.

Troctolitic rocks commonly consist of euhedral to subhedral plagioclase and olivine (Fo = 73–78 mol %), and minor poikilitic clinopyroxene. The variation trend of anorthite content of plagioclase versus the forsterite content of olivine differs from that of arc-related troctolitic rocks (Beard, 1986) and is similar to that of troctolitic rocks from slow spreading-ridges. Noritic rocks are usually composed of euhedral to subhedral plagioclase and orthopyroxene, and minor poikilitic clinopyroxene. Moreover, noritic rocks may contain relatively high percentages of interstial ilmenite and biotite. Both troctolitic and noritic rocks have up to 15 % of titanian pargasite, which occurs as discontinuous rims around mafic minerals or as poikilitic grains. Pyroxenes and Ti-pargasite from troctolitic rocks have higher Mg, Al and Cr than those from noritic rocks, whereas plagioclase does not show systematic compositional variations (An about 65 mol %).

Plagioclase, pyroxene and Ti-pargasite were analysed for *REE* and selected trace elements by ion microprobe. Plagioclase shows a regular decrease from *LREE* to *HREE* and a marked positive Eu anomaly. Orthopyroxene contains low *REE*, with a steady increase from *LREE* to *HREE*. Clinopyroxene has depleted *LREE*, negative Eu anomaly and slightly depleted to almost flat *HREE*. The *REE* pattern of titanian pargasite mimics that of the associated clinopyroxene, but at higher abundance levels. Chondrite normalization of incompatible trace elements in Ti-pargasite reveals that K, Ba and Sr (LILE) are slightly depleted relative to *LREE*, and Nb is commonly enriched relative to K and Ba. The trace element compositions of parental liquids,

calculated using experimentally determined crystal/liquid partition coefficients to mineral compositions, suggest that parental liquids of both troctolites and norites were slightly *LREE*-enriched. Calculations also indicate that the parental liquids were K-depleted, with relatively low K/Ba ratios and no Nb trough. As a whole, trace element mineral compositions indicate that the parental liquids of the Sondalo gabbroic rocks had tholeiitic affinity, and differed from normal MORB in the slightly higher LILE and *LREE* abundances.

A troctolitic and a noritic rock give Sm/Nd mineral isochron ages of 299 ± 9 Ma and 275 ± 8 Ma (N = 4, MSWD = 0.02, N =3, MSWD = 0.02 respectively), considered to date the emplacement of the gabbroic rocks. Amphibole-plagioclase Rb-Sr isochron ages are 266 ± 10 Ma and 267 ± 13 Ma for the same samples, and they are interpreted to represent cooling ages. They are concordant with Rb-Sr muscovite ages for the granitoid masses adjacent to the Sondalo gabbroic complex, which range from 259 Ma to 282 Ma (Del Moro and Notarpietro, 1987). Initial Nd-Sr-O isotopic compositions indicate that a substantial crustal contribution was involved in the petrogenesis of the noritic rocks, which have low initial ε_{Nd} and high $\delta^{18}O^{Px}$ (+7.8) compared with the troctolitic rocks (+4.2 and +6.3, respectively). We thus suggest that the troctolitic/noritic rock association formed by concomitant fractional crystallization (olivine + plagioclase → orthopyroxene) and crustal assimilation. An AFC-type process is also consistent with the trace element mineral variations, because minerals from noritic rocks have higher LILE and *LREE* than those from troctolitic rocks.

It is unclear whether a crustal component was involved in the petrogenesis of the least differentiated, troctolitic rocks. If the parental liquids of troctolitic rocks had already been evolved through an AFC-type process, the mantle-derived melts could derive from a depleted source (N-MORB-type). This hypothesis is supported by the overall low forsterite contents in olivine and by the Sr negative anomaly in the incompatible trace element pattern of calculated parental liquid compositions, which suggests that the analysed troctolitic rocks had already undergone significant fractionation. Further, the somewhat elevated $\delta^{18}O^{Px}$ in the troctolitic rock (+ 6.4) indicates that initial ε_{Nd} (+4.2) of these rocks are lower than their mantle source. If a major crustal component was not involved, the parental liquids could have been derived from a plume-type mantle source (P-MORB-type, like HIMU), or from a contaminated mantle source recording the modifications from preceding Variscan subduction.

The post-Variscan gabbroic complexes of the Alpine belt cover a narrow interval for the intrusion ages, mainly comprised between 300 and 275 Ma. All these gabbroic intrusions are characterized by the extensive occurrence of cumulus orthopyroxene and by the absence of anorthite-rich plagioclase. Petrographic data and isotopic compositions suggest that they can be ascribed to the intrusion of MORB-type melts at different crustal levels. Most likely, the lithosphere thinning associated with the post-Variscan extension resulted in the partial melting of uprising astenospheric mantle, thus giving rise to MORB-type melts. Under- and intra-plating of these melts would promote anatexis and formation of hybrid contaminated magmas, thus giving rise to the gabbroic complexes.

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