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SR, ND, AND PB ISOTOPE INVESTIGATION OF THE SERIE DEI LAGHI (SOUTHERN ALPS, ITALY): THE BEHAVIOUR OF DIFFERENT ISOTOPE SYSTEMS DURING CRUSTAL METAMORPHISM, MAGMATISM, AND DEFORMATION.

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1. Introduction

The Serie dei Laghi is part of the polymetamorphic crystalline basement of the Southern Alps, and is considered as a segment of intermediate crust juxtaposed to the Ivrea Verbano Zone – a segment of lower crust - about 270Ma ago. The Serie dei Laghi consists of amphibolite facies metasediments, metagranites, and post-metamorphic granites.

The aim of the present paper is to constrain the timing of the metamorphic and magmatic processes in the Serie dei Laghi and, at the same time, to trace the behaviour of different isotope systems during such processes.

The ideas developed in the present paper are the result of many years of geological, geochemical, and isotope work carried out on the Serie dei Laghi, and are based on both new and already published isotope data.

2. Geological setting and rocks studied

The Southern Alpine domain occurs to the south of the Canavese Line (or Insubric Line), which is part of the Periadriatic Lineament, a major fault system that separates the Europe vergent belt - the Alpine Belt sensu stricto - from the Africa vergent belt – the Southern Alpine basement.

The Southern Alpine basement is a polymetamorphic crystalline basement that includes the Ivrea Verbano Zone, an upper-amphibolite to granulite facies sequence with a large mafic body, and the Serie dei Laghi, a lower-amphibolite facies sequence hosting younger and older granites.

The contact between Ivrea-Verbano Zone and Serie dei Laghi occurs through a shear zone: the Cossato-Mergozzo-Brissago Line (CMBL).

Contrary to the other alpine complexes, the Southern Alps seem to have been only slightly affected by Alpine metamorphism. The main metamorphism in the Serie dei Laghi occurred under amphibolite facies conditions at a temperature between 540-610˚C and pressure of 6-9 kbar. According to Boriani & Villa (1997), the age of this metamorphic event is about 340 Ma, in agreement with similar data (320-350 Ma) reported by many authors in the entire Southern Alpine domain East of Serie dei Laghi.

The rocks studied are the following: 1) coarse and fine-grained *metarenites* (Strona Ceneri Zone, SCZ). 2) bimodal banded *amphibolites*, with lenses of ultramafites and retrogressed eclogites (Strona-Ceneri Border Zone, SCBZ), which occur at the base of the SCZ. 3) large lenses of metagranites-metagranodiorites (*mg*), with minor mafic terms, mainly localised within or close to the SCBZ. 4) Hbl-bearing augen gneisses (*ag*), derived by the infiltration of residual hydrous magmas into the protolith of the *amphibolites*, at the time of *mg* emplacement (Pinarelli et al., in press). 5) "Graniti dei Laghi"(*gl*): large granite plutons, accompanied by a swarm of mafic-intermediate stocks and dykes (Appinites), in a narrow belt along the CMBL.

3. Rb-Sr geochronology of metagranites and granites

Sr whole-rock isotope data of *mg* plot on an isochron at 466±5Ma. Such age value agrees with U-Pb radiometric age determinations (Köppel & Grünenfelder, 1971). Only 5 samples out of 26, the most mafic ones, plot far from the isochron. These data indicate that the Sr isotope system, at a whole-rock scale, remained closed from the time of emplacement up to now. Muscovite ages in the range of 325-311Ma, instead, approach the age of the regional metamorphism (340Ma). Biotite ages vary from 316 to 234Ma, indicating an opening of their Rb-Sr system following both the emplacement and the Carboniferous metamorphism.

As regards to *gl*, Baveno-Mottarone, Montorfano and Pella plutons plot on a Sr whole-rock isochron of 277Ma, and have biotite ages of 276-281Ma. Quarna and Roccapietra

plutons, which crop out nearer to the CMBL, also plot on the 277Ma isochron, but have biotite ages in the range of 233 - 219Ma. Most Appinites, which occur along the CMBL, scatter under the 277Ma isochron, and have biotite ages of 259-170Ma. Such results point to closed system behaviour of Sr isotopes at whole-rock scale for all the granitic plutons. Nevertheless, opening of the Sr isotope systems is increasingly evident when approaching the CMBL.

4. Sr, Nd, and Pb isotope characterisation of the Serie dei Laghi rocks

The Serie dei Laghi rocks yield distinct Sr-Nd isotope patterns in the $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ diagram: the *amphibolites* plot on the upper-left side of the diagram, in the field of depleted mantle, whereas the *metarenites* plot on the lower-right side, along with *ag*, *mg*, and *gl*. The Sr-Nd isotope ranges of the examined metasediments mainly overlap with those of other pre-Hercynian crustal sections (Ivrea Verbano Zone, Serre), whereas those of *mg* and *gl* have comparatively higher Nd isotope ratios.

On the lead/lead diagrams the Pb isotope ratios of the *amphibolites* plot in the lower crust field. The *metarenites*, instead, plot at the transition between the upper and lower crust fields. As a whole, the metasediments of Serie dei Laghi have $^{206}Pb/^{204}Pb$ slightly higher than those of Ivrea Verbano Zone and Serre, under the same $^{207}Pb/^{204}Pb$. The Pb isotope ratios of *mg* and *gl* mainly overlap those of the intruded metasediments.

5. Common Pb: a reverse approach to date a recent event

By contrast with the substantial uniformity of the present-day Pb isotope ratios, the "initial Pb isotope ratios" of *ag*, *mg* and *gl* - after correction for in situ decay since the age of their emplacement (466Ma and 280Ma, respectively) – have large variations and spread up to values as low as: $^{206}Pb/^{204}Pb$ =12.345, $^{207}Pb/^{204}Pb$ =15.259 (sample LM80-2 coming from the Lago d'Orta, near to the CMBL). Such variable initial Pb isotope ratios define, in the lead-lead diagrams, two subparallel linear arrays, one fitted by the *ag* + *mg*, the other one fitted by the *gl* (mainly Appinites, clustered near the CMBL).

Such lines could be interpreted as mixing lines between two average "granite end-members" and as many fluids that recently circulated and altered the Pb isotope systems. But the Pb isotope characteristics of these hypothetical fluids would be so extreme that cannot be traced back to any of the known crustal reservoirs.

On the other hand, if the Pb isotope ratios of *ag* and *mg* are computed for 280Ma, the obtained initial values plot on the same line defined by the *gl*. It is thus evident that such linear arrays are a numerical artifice due to the age-recalculations. But such a conclusion gives an important information: the equation of the radiogenic decay (in

the form used for the calculation of the initial isotope values) contains the following terms: the initial Pb isotope ratio, the present-day Pb isotope ratio, the U/Pb ratio (or Th/Pb), and t. For a fixed t, a progressive increase of U/Pb (Th/Pb) ratios produces progressively decreasing calculated initial Pb isotope ratios, which plot on a straight line in the Pb diagrams. The slope of such a line is a function of t, in other words it can be considered as a "negative isochron". There is therefore a value of t, between 480Ma and the present, for which the samples plot on a horizontal line in the Pb diagrams: such t represents the age at which the U/Pb ratios were modified, and the Pb isotope ratios roughly homogenised. By applying such a reverse approach to the two decay equations of uranogenic Pb, we obtained an age of 26 ± 10 (2σ), $^{206}Pb/^{204}Pb$ $=18.63\pm0.06$, and $^{207}Pb/^{204}Pb$ $=15.63\pm0.04$.

6. Conclusions

In both *mg* and *gl* the Sr isotope system remained closed at the whole rock scale from the time of their emplacement up to present. Nevertheless, an opening of the Sr isotope systems at the mineral scale is evident in an increasing way approaching the CMBL.

Moreover, also the Pb whole rock isotope systems were opened recently in the rocks near the CMBL. A "reverse approach" allowed estimating 26 ± 10Ma as the time of this opening event.

An age of 26Ma corresponds to the metamorphic peak of the Neoalpine orogenic phase in the Central Alps near the contact with the Southern domain (Deutch and Steiger, 1985; Hurford, 1986; Romer et al., 1996). In addition, the ages of movements along the Insubric Line between the Ivrea-Verbano and the Sesia-Lanzo are in the range 19-26Ma north of Lago Maggiore, and in the range 28-43Ma west of Lago Maggiore (Zingg and Hunziker, 1990; Hunziker & Hurford, 1992).

We therefore suggest that the CMBL line was somewhat reactivated during the Neoalpine phase, similarly to the Insubric line. The resulting mobilised fluids modified only slightly the Sr isotope system, while they influenced more heavily the U/Pb isotope system, which is more sensible to fluid circulation.

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