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Geochemical approach to characterization and source identification of the protoliths of metasedimentary rocks: an example from the southern Alps

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ABSTRACT. — We compare here the geochemical characters of metasediments from two main units of the Southern Alps (Serie dei Laghi and Orobic basement). Concerning the protoliths of the paragneisses from Serie dei Laghi, the Th/Sc vs Zr/Sc correlations indicate that they are mainly controlled by the composition of their sources (likely diorites to granodiorites); their REE patterns are well comparable to the average composition of continental arc wackes. The suggested environment is a dissected continental arc on an active margin. For the Serie dei Laghi metapelites (Scisti dei Laghi) the large compositional variations and the wide spread in some parameters (Th 5-15 ppm, Th/U 1.4-4.8, Th/Sc 0.35-0.92, La/Th 3.3-7.8, REE_{tot} 149-248) suggest mixing in different proportions of sediments from geochemically «undifferentiated» and from differentiated igneous sources, with a variable contribution of recycled sediments enriched in heavy minerals. The metasediments from the Orobic basement have a more pelitic character and show the influence of old upper crustal materials (Th/U= 3.6-6.7). Their main geochemical characters are compatible with a passive margin environment.

RIASSUNTO. — Vengono messi a confronto i caratteri geochimici dei metasedimenti di due delle unità del basamento delle Alpi Meridionali (Serie dei Laghi e Basamento Orobico). Per quanto riguarda i protoliti dei paragneiss della Serie dei Laghi (Cenerigneiss e Gneiss Minuti), le correlazioni fra Th/Sc e Zr/Sc indicano che essi sono controllati essenzialmente dalla composizione delle sorgenti (probabilmente da dioriti a granodioriti); i pattern delle terre rare sono comparabili con la media di grovacche di arco continentale. Ciò suggerisce un ambiente di arco magmatico profondamente eroso su margine continentale attivo. Per le metapeliti della Serie dei Laghi (Scisti dei Laghi) l'ampio range di variazione di alcuni elementi e parametri (Th 5-15 ppm, Th/U 1,4-4,8, Th/Sc 0,35-0,92, La/Th 3,3-7,8, REE_{tot} 149-248) suggeriscono una mescolanza in varie proporzioni fra sedimenti da sorgenti «geochimicamente indifferenziate» e da rocce ignee differenziate, con contributo variabile di sedimenti riciclati arricchiti in minerali pesanti. I metasedimenti del basamento Orobico hanno carattere più pelitico e mostrano una maggior influenza di materiali derivati da crosta continentale antica (Th/U= 3,6-6,7). I caratteri geochimici generali sono compatibili con un ambiente di margine passivo.

KEY WORDS: *geochemical approach, source, metasediments, Serie dei Laghi, Orobic basement*

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INTRODUCTION

Geochemical approaches to constraining possible sources of sedimentary rocks are frequently used by sedimentologists studying turbidite sequences from different tectonic environments. Different geochemical characters may provide insight into the processes affecting the sediments (like sorting or weathering) and into the nature of their source rocks; the identification of certain components may also have tectonic implications.

In this paper we compare the composition of the Orobic basement metasediments, already considered in a previous paper (Caironi *et al.*, 2002), to that of the Serie dei Laghi metasediments, in order to determine the nature of these two portions of the Southern Alps Basement. This comparison is important for the understanding of the possible correlation between these units and the reconstruction of the pre-Variscan environment. We use major, trace and RE elements analyses, that we recently performed on representative samples of the different rock types (selected among a much larger data base of analyses) during a research program aimed at the geochemical characterization of the Southern Alps crust; the data are published in Caironi *et al.* (2002) and Boriani *et al.* (2003); the data used here are reported in Table 1*.

GEOLOGICAL FRAMEWORK

The Southern Alps domain is divided, from west to east, in: Ivrea Verbano Zone (IVZ), Serie dei Laghi (SDL), Val Colla Zone and Orobic Basement (OB). The rocks taken into consideration in this paper belong to the Serie dei Laghi and Orobic basement (Fig. 1a, b*).

The Serie dei Laghi, tectonically bounded by the Cossato-Mergozzo-Brissago Line (W) and the Val Colla Line (E), comprises two main subunits: the Strona Ceneri Zone, to the NW, and the Scisti dei Laghi, to the SE. Both contain large orthogneiss lenses (Ordovician granitoids; Boriani *et al.*, 1982-83). The transition between the two subunits occurs through the Strona Ceneri Border Zone (Giobbi Origoni *et al.*, 1997), a continuous horizon of banded amphibolites, interlayered with minor schists and paragneisses, containing metaultramafite, metagabbro and garnet-amphibolite lenses. The whole Serie dei Laghi was metamorphosed under amphibolite facies conditions during Variscan times (320-340 Ma, Boriani and Villa, 1997) and only locally reequilibrated under greenschist facies conditions (Boriani *et al.*, 1990). For further details on the geology and metamorphic evolution see Boriani *et al.* (2003) and Boriani and Giobbi Origoni (this volume).

The Orobic basement is located south of the Periadriatic Lineament between Lago di Como and the Adamello massif; to the south it overrides the Permo-Mesozoic volcano-sedimentary cover along the Orobic Line. The basement mainly consists of pelitic to psammitic metasediments; metabasites are rarer and orthogneisses are less abundant than in the Serie dei Laghi. The basement is divided into «Gneiss di Morbegno» and «Scisti di Edolo» (which include the «Filladi di Ambria» of the 1:100.000 Geological Map of Italy). An Ordovician – Silurian sedimentation age for the protoliths of the Scisti di Edolo was proposed by Gansser and Pantic (1988) on the basis of palynological data. The main metamorphism in the central and western areas is under lower amphibolite facies conditions (Spalla and Gosso, 1997 with references therein), whereas in the easternmost part a greenschist facies overprint is recognized (Cassinis *et al.*, 1986; Gosso *et al.*, 1997). The main metamorphic phase is Variscan (350-330 Ma: Bocchio *et al.*, 1981; Mottana *et al.*, 1985). For further details see Colombo and Tunesi (1999) and Spalla *et al.* (2002).

* This item is available as electronic supplementary material on the Periodico di Mineralogia web site at <http://tetide.geo.uniroma1.it/riviste/permin/permin.html>

LITHOLOGY

Serie dei Laghi

The considered samples are micaschists from the «Scisti dei Laghi» and gneisses (Cenerigneiss and Gneiss Minuti) from the «Strona Ceneri Zone».

In the micaschists the most widespread mineral composition is quartz + white mica + biotite + plagioclase (An_{20}). Porphyroblasts of garnet, kyanite and staurolite are locally very abundant.

The Gneiss Minuti are fine-grained gneisses with preserved sedimentary structures, such as grain size sorting and compositional layering. Their composition is quartz + plagioclase + biotite + white mica ± garnet, kyanite, staurolite. They contain zoned Ca-silicate nodules (characterized, from core to rim, by garnet-, diopside-, hornblende- and biotite-rich shells), interpreted as original dolomitic concretions (Boriani *et al.*, 1977). The Cenerigneisses are medium- to very coarse-grained gneisses, consisting of quartz + biotite + plagioclase + K-feldspar ± white mica. They contain more or less rounded pebbles of quartz and mafic foliated rocks, as well as small Al-rich lumps (with muscovite + garnet ± kyanite) and the same Ca-silicate nodules as the Gneiss Minuti.

This shared character, the intercalations between the two rock types in the transition zone from Gneiss Minuti to Cenerigneiss, the similar typologic characters of their detrital zircon populations (Caironi, 1995), and a similar major and minor element composition (not showing trends compatible with magmatic differentiation; Boriani *et al.*, 1997; Pinarelli *et al.*, 2004) suggest a sedimentary origin of both rocks. Based on field relations and textural considerations, Boriani *et al.* (1997) interpreted Cenerigneisses as a mass-flow turbidite and Gneiss Minuti as well sorted deposits from turbidity currents.

Orobic basement

The considered samples belong to the units «Gneiss di Morbegno», «Scisti di Edolo» and to the micaschists from the eastern shore of Lago di Como (Dervio Olgiasca Zone = «DOZ», as defined by El Tahlawi, 1965).

The «Gneiss di Morbegno» unit includes micaschists, paragneisses and quartz-rich paragneisses, consisting of muscovite + biotite + quartz + plagioclase ± garnet in variable proportions; staurolite is also present in the more pelitic levels. A common feature is the occurrence of oligoclase «nodules» (poikiloblasts), whose dimensions vary from 2-3 mm in the more pelitic intercalations up to 12-15 mm in the more arenaceous layers. The «Scisti di Edolo» unit includes micaschists and minor intercalations of fine-grained paragneisses, and phyllonites. They mainly consist of muscovite + quartz + plagioclase ± biotite ± chlorite ± garnet ± staurolite. The samples of the Dervio Olgiasca Zone are mainly biotite micaschists also containing sillimanite and poikiloblastic andalusite.

RESULTS AND DISCUSSION

The considered samples have been plotted (Fig. 2) in the classification diagram for clastic rocks (Herron, 1988). The Gneiss Minuti and the Scisti dei Laghi samples plot either in the field of shales, or in that of wackes, thus reflecting limited variations in the quartz / mica ratio in the individual samples; all the Cenerigneiss samples plot in the field of wackes, with log SiO_2/Al_2O_3 clustering around 0.65. The samples from the Orobic metasediments plot in the field of shales, with the exception of three quartz-rich paragneisses from the Morbegno unit, which plot near or within the field of litharenites (hence referred to as «litharenites»).

The major element data are not very relevant to provenance identification, since their variations are mainly linked to the relative contents of micas, feldspars and quartz in the individual samples (negative correlations of MgO, Fe_2O_{3tot}, TiO_2, K_2O with log SiO_2/Al_2O_3).

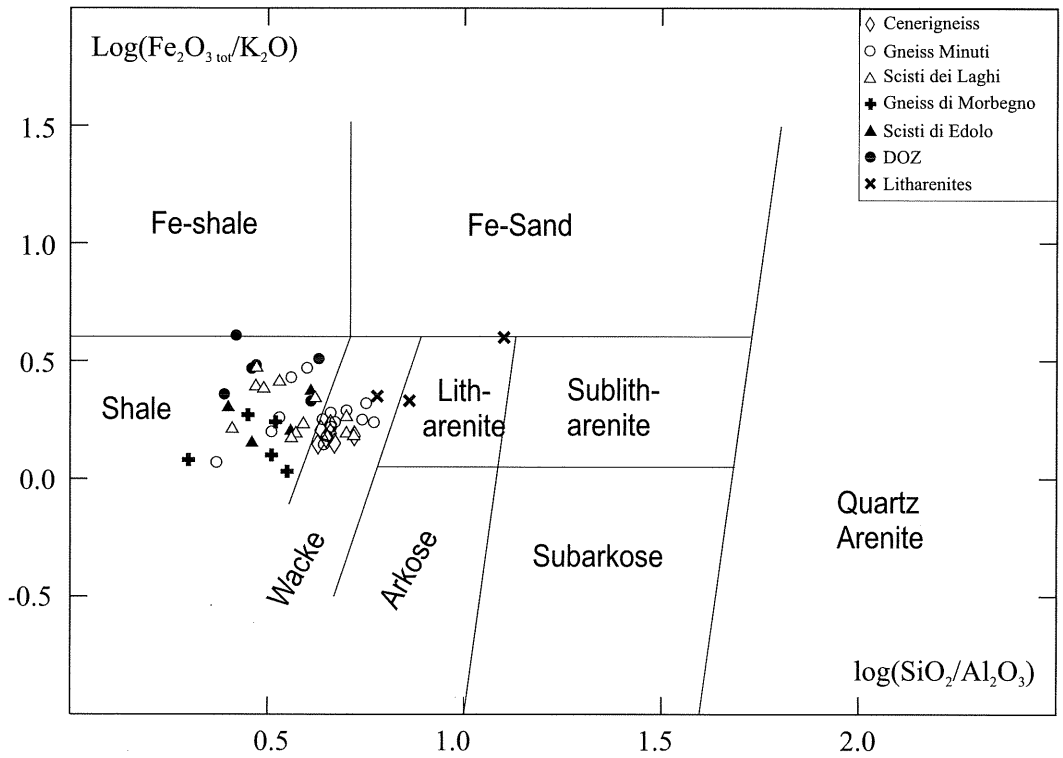

Fig. 2 – The Serie dei Laghi and Orobic basement metasediments in the classification diagram for clastic rocks (Herron, 1988). White symbols: Serie dei Laghi; black symbols: Orobic basement.

V and Sc also show negative correlations with log SiO_2/Al_2O_3 (Fig. 3) and positive ones with MgO (not shown), suggesting that they are mainly related to biotite abundance. Ni varies more irregularly, probably due to variable retention by absorption on the clay fraction (Bhatia and Crook, 1986). La, U and Th are not well correlated, particularly in the Scisti dei Laghi samples. Zr and Hf increase with increasing log SiO_2/Al_2O_3 in most samples, indicating that zircon is probably linked to the coarser-grained, quartz-rich fraction. The opposite behaviour, although with some scatter, is shown by the Morbegno and DOZ samples, suggesting variable contributions of sediments from zircon-rich source rocks (possibly felsic rocks) to the clay fraction.

As already underlined by Boriani *et al.* (1997) and Pinarelli *et al.* (2004), the Cenerigneisses have homogeneous major and trace element compositions, roughly corresponding to tonalites-granodiorites, but without typical magmatic differentiation trends. Indeed in the Th/Sc vs Zr/Sc diagram (Fig. 4) the samples considered here plot on a trend subparallel to the reference magmatic trend given by average Phanerozoic Basalts, Andesites and Granites (Condie, 1993), in an interval corresponding to intermediate igneous rocks. After McLennan *et al.* (1993), such behaviour suggests a provenance control on the sediment composition and is typical of turbidite sands from active margins. The Gneiss Minuti samples define a less steep alignment (Fig. 4) starting near the representative point of

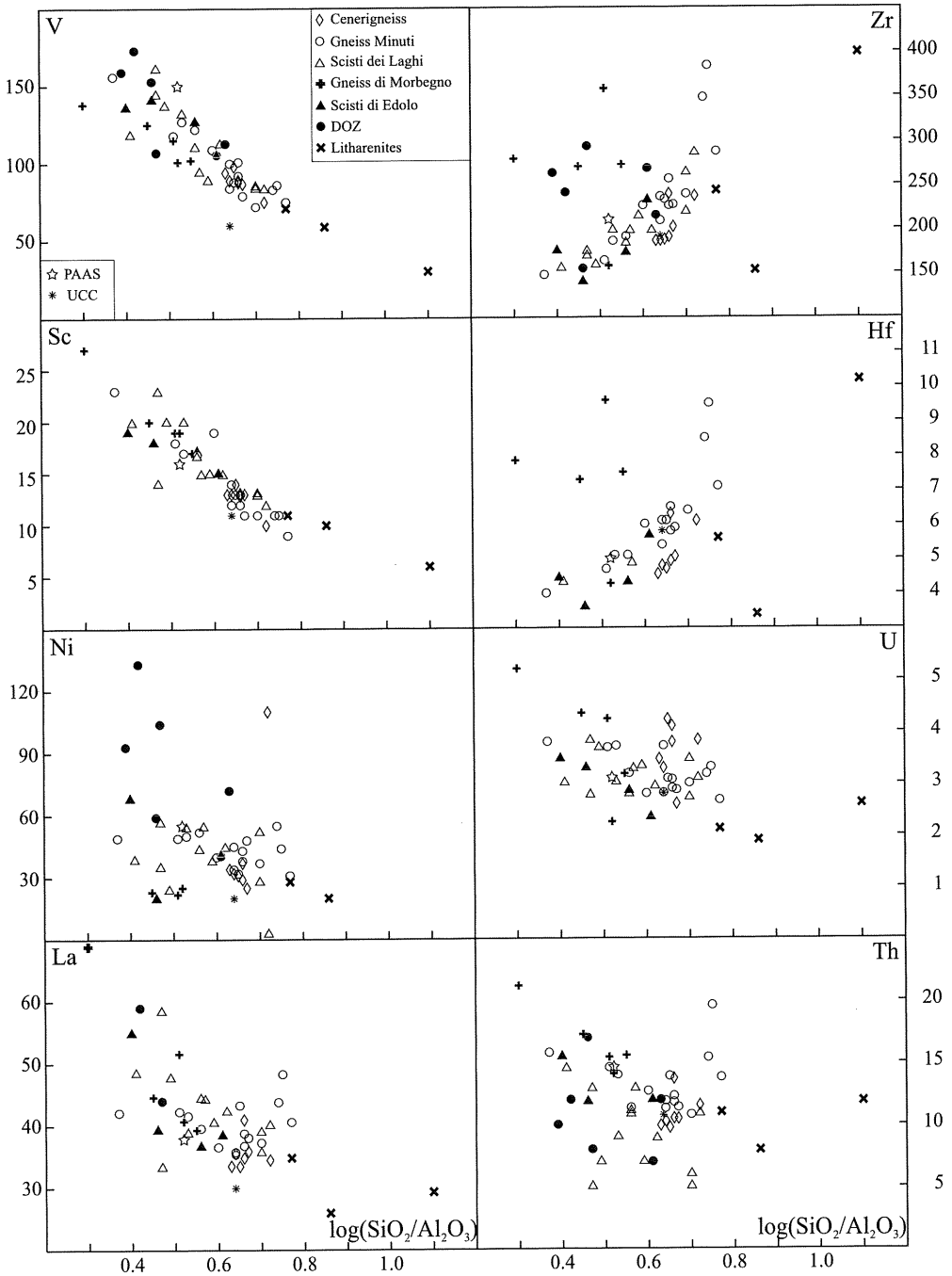

Fig. 3 – Selected trace element vs log SiO_2/Al_2O_3 diagrams for the Serie dei Laghi and Orobic basement metasediments. Symbols as in Fig. 2.

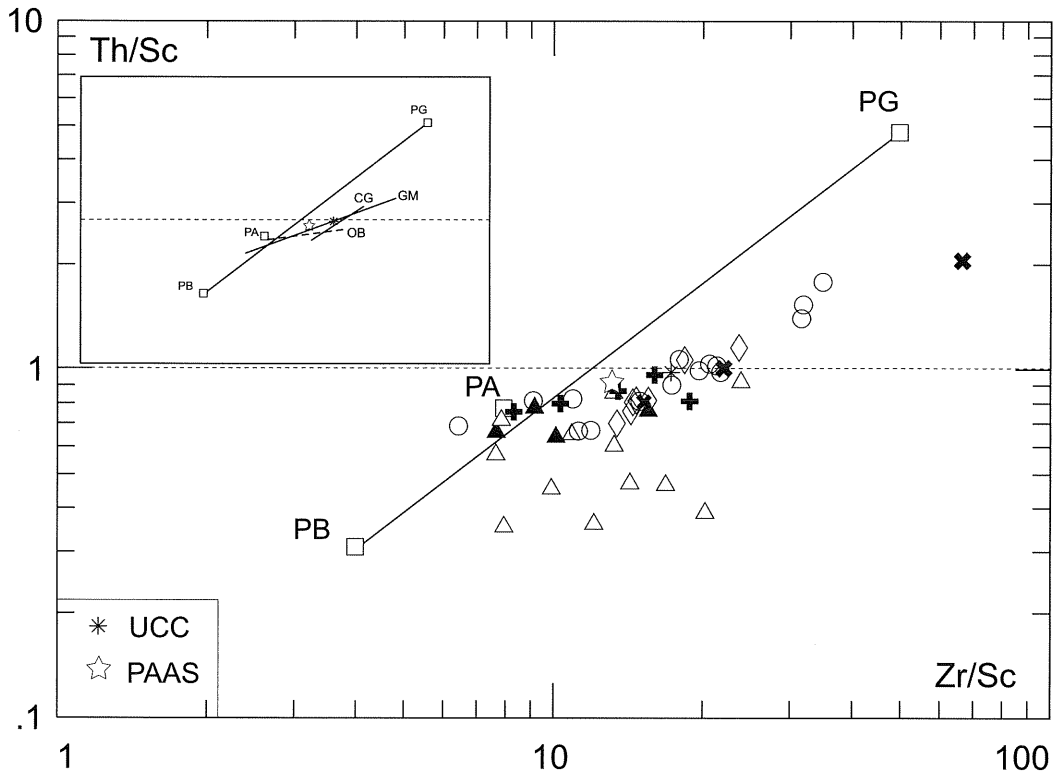

Fig. 4 – The Serie dei Laghi and Orobic basement metasediments in the Th/Sc vs Zr/Sc diagram (McLennan *et al.*, 1993). Average values of Phanerozoic Basalts (PB), Andesites (PA) and Granites (PG) after Condie (1993); of Upper Continental Crust (UCC) and Post Archean Australian Shales (PAAS) after Taylor and McLennan (1985). Inset: trends defined by the different groups of samples: CG = Cenerigneiss; GM = Gneiss Minuti; OB = Orobic basement. Symbols as in Fig. 2.

Phanerozoic andesites and approximately passing through the composition of PAAS and of the Upper Continental Crust (Taylor and McLennan, 1985). Zr/Sc increases more rapidly than Th/Sc and at pace with increasing SiO_2/Al_2O_3. This behaviour suggests mixing in variable proportions between a clay-rich sediment poor in Zr and rich in Sc and Al (from intermediate to mafic rocks) and a quartz-rich sediment rich in Zr and Th and poor in Sc (likely recycled sediments enriched in heavy minerals). Also the slightly higher Th/U and lower La/Th of the Gneiss Minuti with respect to the Cenerigneiss (Table 1*) suggest a larger contribution of sediments derived from older «granitic» or (meta)sedimentary rocks (Bhatia and Taylor, 1981). Similar indications were obtained from the study of detrital zircon populations (Caironi, 1995): in the Gneiss Minuti very abraded subrounded crystals (recycled) prevail over slightly abraded crystals derived from diorites-tonalites; in the Cenerigneiss, on the contrary, slightly abraded crystals from tonalites-granodiorites dominate the detrital zircon population.

Both paragneiss types have Rb/Sr generally less than 0.9 (Table 1*) probably reflecting a low degree of chemical alteration of feldspars during sedimentary processes. This may be an indication of proximity of the sediments to their source area. The chondrite-normalized REE patterns are always PAAS-type (Fig. 5a),

with overall enrichment, variable fractionation, small negative Eu anomaly and nearly flat HREE. With respect to PAAS, Gneiss Minuti are slightly enriched, whereas Cenerigneisses show a very small depletion in LREE. These patterns resemble those of «Active Continental Margin» wackes (Bhatia, 1985). We attribute this behaviour to the large contribution of sediments derived from magmatic rocks of calcalkaline affinity.

The Scisti dei Laghi samples differ from the Strona Ceneri paragneisses mostly for their scattered distribution in the Th/Sc vs Zr/Sc diagram (Fig. 4), where they mainly plot below the Strona Ceneri paragneisses and the reference magmatic trend. The samples with lower Th/Sc (0.35-0.47) are also characterized by low Th/U ratios (1.45-2.98; Table 1*), low Th and U contents (Fig. 3) and slightly less enriched REE patterns (Fig. 5b). These characters are considered by McLennan *et al.* (1993) as indicative of «geochemically depleted» sources, such as mantle-derived volcanic rocks that have not undergone

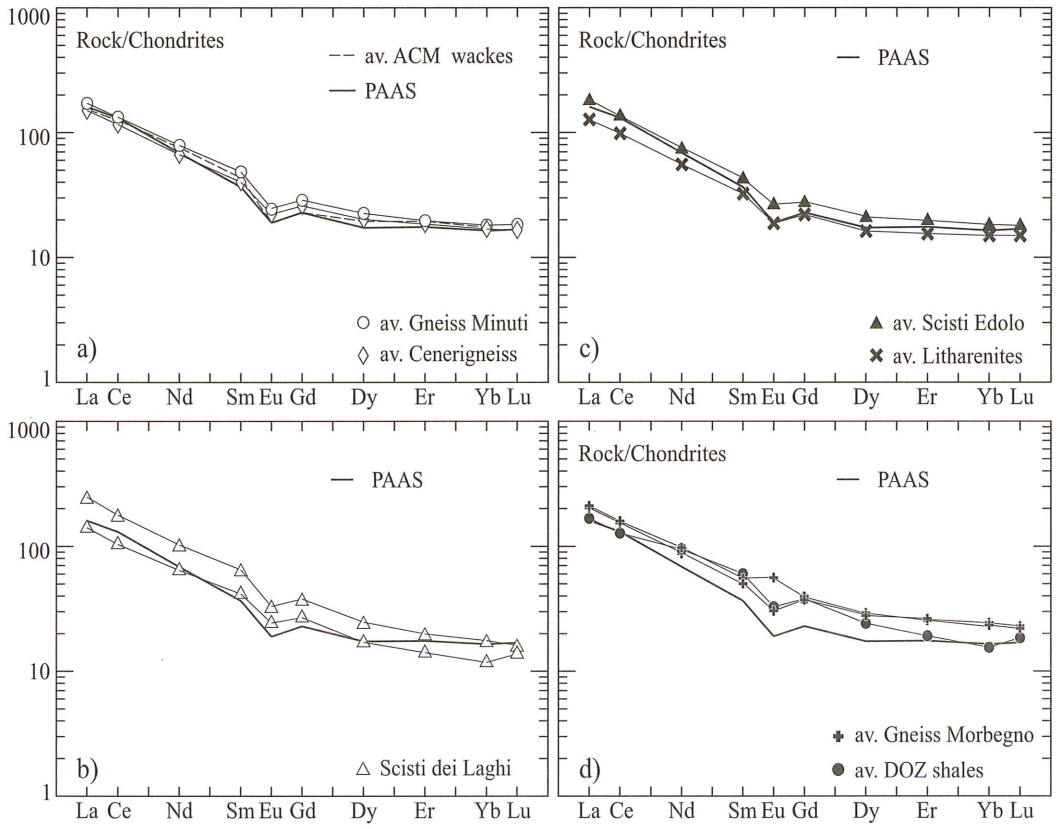

Fig. 5 – Chondrite-normalized REE patterns compared to the pattern of Post Archean Australian Shales (PAAS) after Taylor and McLennan (1985). Normalization values after McDonough and Sun (1995). Also reported for comparison in a) the pattern of average Active Continental Margin (ACM) wackes after Bathia (1985). In b) for the Scisti dei Laghi we reported the least enriched and most enriched sample (respectively GBL12 and GAZ06) to evidence the progressive variation. In d) the Gneiss di Morbegno averages are separately calculated for samples with or without negative Eu anomaly.

significant intracrustal differentiation with plagioclase separation. However, the negative Eu anomaly (Fig. 5b), together with the progressive overall enrichment in REE of the samples as they approach the reference magmatic trend in the Th/Sc vs Zr/Sc diagram, suggest increasing contribution of differentiated, acidic magmatic rocks. A small contribution of recycled materials enriched in heavy minerals may be envisaged for those samples with high Zr/Sc ratio, which also show higher SiO_2/Al_2O_3 (Table 1*).

Compared with the Serie dei Laghi rocks in the Th/Sc vs Zr/Sc diagram (Fig. 4), the samples from the Orobic basement metasediments (excluded the DOZ samples, whose Sc contents were not available) define a nearly subhorizontal trend, approximately between the representative points of Phanerozoic andesites (Condie, 1993) and of the Upper Continental Crust (Taylor and McLennan, 1985). The Th/Sc ratio approaches 1 as Zr/Sc rapidly increases, without a clear correlation with the SiO_2/Al_2O_3 ratio. After McLennan *et al.* (1993) this behaviour suggests that the composition of the protoliths is mainly controlled by sedimentary processes. Also the high Th/U ratios (3.6-6.3; Table 1*) reflect the influence of recycled materials. The occurrence, in the Morbegno and Edolo samples, of very abraded detrital zircons, sometimes with recognizable typologies corresponding to zircons from granitic rocks, and the very negative εNd values recently determined in these rocks (Bergomi, 2004) indicate an important contribution from an old upper crustal source.

The average chondrite-normalized REE patterns of the Orobic metasediments (Fig. 5c, d) are similar to those of the Serie dei Laghi rocks, but the individual samples display large variations in REE_{tot} and LRE/HRE fractionation (Table 1*). The litharenite samples (Fig. 5c) are slightly REE depleted with respect to PAAS, in agreement with their less pelitic character; they clearly derive from sediments with a high degree of mineralogical and chemical maturity, as also indicated by their depletion in those elements that are linked to feldspars and micas (Table 1*). The average Scisti di Edolo have PAAS-type, slightly enriched REE patterns (Fig. 5c). Two Morbegno samples (separately averaged, Fig. 5d) show no or slightly positive Eu anomaly (probably related to local abundance of plagioclase, as indicated by their higher CaO, Na_2O and Sr and lower K_2O and Rb contents; Table 1*). Compared to most of the Serie dei Laghi metapelites (Scisti dei Laghi), the Morbegno and DOZ samples have higher total REE; the DOZ samples also have slightly more fractionated patterns. According to McLennan *et al.* (1990), the enrichment in LREE and total REE is a typical feature of muds derived from the erosion of a continental crust (consisting of «granitic» and metasedimentary rocks), with respect to muds deposited adjacent to juvenile volcanic arcs. The DOZ samples are also characterized by $Gd_N/Yb_N > 2$, suggesting an enrichment in monazite, which is also responsible for their higher La, Ce and La/Th values (Table 1*). Compared to PAAS, the Morbegno and DOZ samples are enriched in the intermediate REE (Fig. 5d), as it is observed in sediments related to a passive margin environment (Bhatia, 1985). With respect to the Serie dei Laghi rocks, the DOZ samples and the Morbegno samples with negative Eu anomaly have higher Rb/Sr ratios (mainly > 0.8; Table 1*), suggesting a higher degree of chemical alteration of feldspars in the protolith (Bhatia and Crook, 1986; McLennan *et al.*, 1993).

CONCLUSIONS

The geochemical characters of the Strona Ceneri paragneisses are compatible with those of turbidite sands from active margin settings, mainly derived from calcalkaline plutonic rocks and deposited not far from their source. This suggests a marginal o interarc basin, where sediments derived from a dissected continental arc are variably mixed with sediments derived from older «granitic» and sedimentary rocks (Bhatia and Taylor, 1981).

For the protoliths of the Strona Ceneri Border Zone metasediments (dividing the Strona Ceneri from the Scisti dei Laghi) Giobbi Mancini *et al.* (2003) proposed a derivation from a bimodal volcanic association (basalts – rhyolites) typical of oceanic island arcs or back arc environments. These results suggest the occurrence of an interarc basin between a volcanic arc and a continental margin.

The Scisti dei Laghi protoliths seem to consist of materials deriving from a geochemically «undifferentiated» (mantle-derived?) source mixed in different proportions with sediments from acidic igneous rocks, with variable contributions of more «mature» sediments (recycled component), such as may be observed in sediments from fore-arc basins (McLennan *et al.*, 1993). A derivation of the «undifferentiated» component from Archean rocks cannot be excluded, since the Th/Sc and Sc values of most of the samples are similar to those of Archean sedimentary rocks from volcanically active settings (McLennan and Taylor, 1991). The occurrence of remnants of an ophiolitic sequence (Giobbi Origoni *et al.*, 1997) in the Strona Ceneri Border Zone, which separates the Scisti dei Laghi from the Strona Ceneri Zone, indicates an old suture zone and suggests that these units probably belonged to different plates.

Compared with the metasediments from the Serie dei Laghi, the metasediments from the Orobic basement show a more pelitic character, with higher degree of chemical alteration of feldspars in the protoliths, suggesting a longer duration of sedimentary processes and a more distal position with respect to the source. As a whole, their characters reveal a larger contribution of materials from a continental crust containing both «granitic» and metasedimentary rocks. This component is likely to be dominant in passive, or at least non-active, margins (McLennan *et al.*, 1993). The comparison between the Orobic basement and the Serie dei Laghi metasediments indicate that they represent different geotectonic environments.

The exposed data suggest a more complex paleogeodynamic evolution of the Southern Alps than that envisaged by von Raumer *et al.* (2003), who consider the basement of the Southern Alps as entirely belonging to Gondwana until the opening of the Paleotethys.

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