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The pre-Namurian basement of the Ligurian Alps: a review of the lithostratigraphy, pre-Alpine metamorphic evolution, and regional comparisons

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ABSTRACT. — The Pre-Namurian basement of the Ligurian Alps (southern External Pennides) records evidence of poly-orogenic pre-Variscan (Ordovician), Variscan and Alpine evolution. In the Briançonnais domain, bimodal volcanism (tholeiitic to transitional basalts and acidic calc-alkaline volcanites) of Cambro-Ordovician age (~500 Ma) possibly suggesting a continental rift phase is associated with pelitic and psammitic sedimentary rocks and to large volumes of turbiditic (?) metarenites. The sequence was intruded by Early Ordovician, S-type granitoids and later metamorphosed from high-pressure amphibolite up to eclogite-facies conditions. The cogenetic or exotic nature of the eclogites, which are associated with migmatites and evolved through granulite facies conditions, is doubtful. Later, the metamorphic sequence was intruded by large granitic bodies (from monzogranites and granites to granodiorites, in the 470-460 Ma time span), and by rare gabbros and basic to intermediate dykes. Large metarhyolite bodies are likely coeval with the intrusive events. Finally, medium to low P, amphibolite facies, Variscan (327 Ma) metamorphism and with km-scale megafolding affected all the metamorphic and magmatic sequences. A small basement slice, considered of pre-Piedmont provenance, with Alpine high-pressure overprint, preserves sequences of metarhyolites, metaconglomerates, metapelites (garnet micaschists), garnet–bearing marbles with minor metabasalts and serpentine schists. The geodynamic pattern is compared with other neighbouring Palaeozoic terranes.

RIASSUNTO. — Nel dominio Brianzonese, una attività effusiva bimodale (basalti tholeiitici transizionali, vulcanite acide calc-alcaline di età Cambro-Ordoviciana -ca 500 Ma) evidenza di un rift continentale, è associata con sedimenti pelitici e psammitici e conspicui volumi di metareniti. La sequenza è intrusa da granitoidi di tipo S, ordoviciano inferiori, successivamente metamorfosati in facies anfibolitica di alta pressione fino ad eclogitica. Per le eclogiti, associate a migmatiti, è in discussione una origine cogenetica o esotica. Successivamente, la sequenza metamorfica è stata intrusa da grandi corpi granitoidi (da monzograniti e graniti fino a granodioriti, nell'intervallo 470-460 Ma) e da rari gabbri e filoni basici e intermedi.

Infine una sovrimpronta varisica (327 Ma) in facies anfibolitica di media fino a bassa P si è sovrimposta alle sequenze metamorfiche e magmatiche.

Una piccola unità di basamento, considerata di pertinenza pre-Piemontese, presenta una sequenza di metarioliti intercalata a metaconglomerati, metapeliti (micascisti a granato) e lenti carbonatiche con subordinati metabasalti. Una ulteriore sequenza è

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rappresentata da marmi a granato intercalati con micascisti a granato, con lenti di metabasalto e possibilmente serpentinoscisti.

KEY WORDS: *Ligurian Briançonnais, Migmatite-Eclogite complex, Gneiss-Amphibolite complex, U/Pb radiometric dating*

INTRODUCTION

In the southern part of the external Pennides, the pre-Namurian basement of the Ligurian Alps occurs as scattered slices in the Alpine framework of the Briançonnais and pre-Piedmont domains. These domains were part of the European continental margin of the Jurassic ocean (Fig. 1A). Like other Alpine and peri-Mediterranean basements, it records evidence of poly-orogenic pre-Variscan (Ordovician), Variscan and Alpine evolution.

During the latest phases of the Alpine collisional event, the basement as well as its Permo-Carboniferous and Mesozoic cover, affected by a metamorphic overprint under high pressure subduction-related gradients, were thrust outward upon the external zones (now located southward or south-westward), then backfolded and finally deformed by the latest folding and brittle events. The different Alpine tectonic units in a continent-continent collisional setting attained the metamorphic peak during Lower to Middle Eocene age (Cabella *et al.*, 1991). Blueschist facies conditions (up to Jd+Nam+Lws+Pmp[2] assemblages in the Bagnaschino Unit, more diffusely Nam+Lws+Ab+Pmp±Chl±Aeg-Jd Cpx) were attained in the innermost units, progressively decreasing towards the outer sectors, where anchimetamorphic conditions were not exceeded. Decompressional conditions, together with deformation of decreasing intensity, developed through the subsequent phases (Vanossi *et al.*, 1986; Cortesogno *et al.*, 1993; Desmons *et al.*, 1999 a, 1999b). The basement slices outcrop in the innermost tectonic units (Fig. 1B) where remnants of their stratigraphic relationships with the Permo-Carboniferous and Mesozoic Briançonnais or Pre-Piedmont covers are commonly preserved.

A slice of pre-Namurian basement (T. Visone Unit), was tectonically associated, during the Alpine tectono-metamorphic phases, with the meta-ophiolites of the Jurassic Piedmont–Ligurian basin. In the hypothesized eastward-verging subduction (Vanossi *et al.*, 1986) and oblique collision (Cortesogno and Haccard, 1986), the involvement with the oceanic crust in the subducted slab, which reached an eclogite-bearing blueschist-facies, Early-Alpine peak (Omp+Grt+Nam+Rt±Czo; Desmons *et al.*, 1999b), suggests a more internal paleogeographical origin.

The present work aims at synthesising the pre-Namurian evolution recorded in the Ligurian Alps and at proposing paleogeodynamic interpretations with particular concern to the regional framework. In this perspective, the Alpine tectonic and metamorphic overprint will not be discussed.

THE PRE-NAMURIAN BASEMENT OF THE BRIANÇON-PREPIEDMONT DOMAINS IN THE LIGURIAN ALPS

On the basis of the nature of the basement protoliths and of their metamorphic evolution, the following lithologic complexes have been distinguished (Cortesogno *et al.*, 1993; Desmons *et al.*, 1999c).

I) Lithologic complexes showing polyphase (or polymetamorphic) evolution, through two tectono-metamorphic cycles (M_1 and M_2): IA) a Migmatite–Eclogite complex (Savona–Calizzano Unit); IB) a Gneiss–Amphibolite complex (Savona-Calizzano, Pallare, Arenzano and Bagnaschino Units).

II) Lithologic complexes of meta-intrusives, post-dating S_1, and affected by the S_2 pre-Alpine schistosity. IIA) Metagranitoids and associated dykes (Savona-Calizzano, Nucetto, Costa Dardella, Lisio Units) intruding IB

[2] abbreviations after Kretz (1983), with the exception of Nam: sodic amphibole

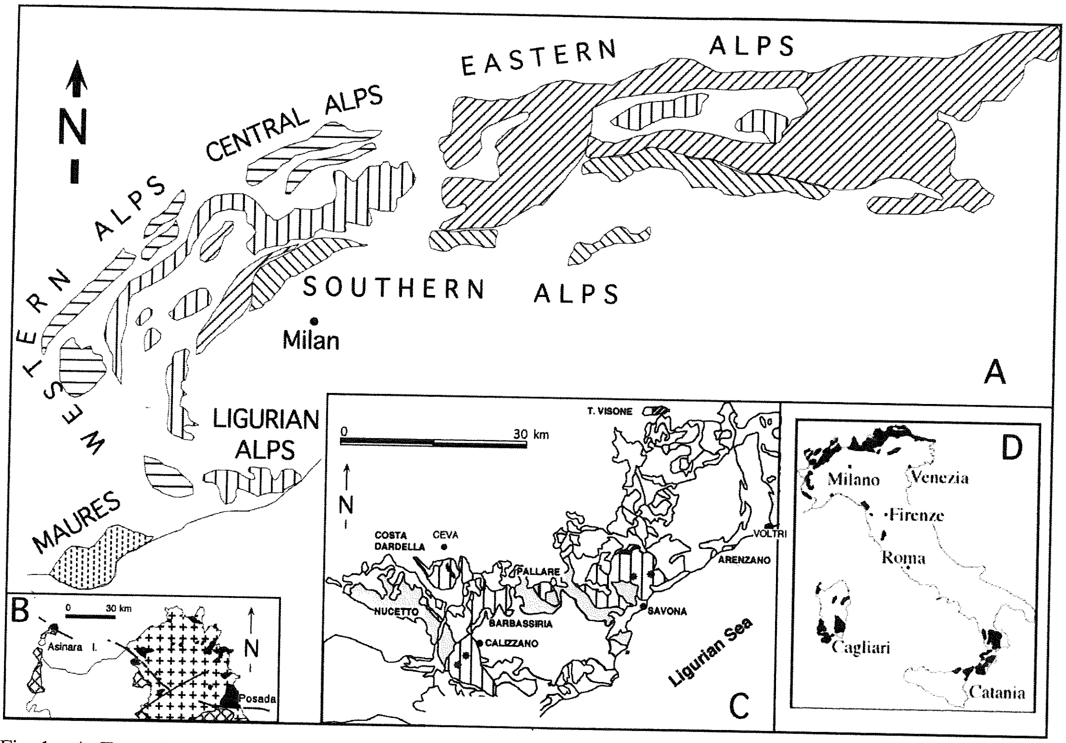


Fig. 1 – A: Tectonic scheme of the Alps. Vertical hatches: Internal Pennidic domain. Horizontal hatches: External domain. Left-to-right oblique hatches: South Alpine domain. Right-to-left oblique hatches: Australpine domain. B: Northern Sardinia. Trace of the Posada – Asinara line; hatched pattern: internal zone of the Variscan belt; black: high grade, eclogite bearing complex; cross pattern: Late Variscan granitoids; white: post-Variscan covers. C: Ligurian Alps. Hatched pattern: Calizzano – Savona Unit; oblique hatch: T. Visone Unit; black: Bagnaschino Unit. D: Paleozoic basement occurrence in Italy.

complex; IIB) Metagabbros intruding complex IA, and basic to intermediate dykes within both IA and B (Savona–Calizzano Unit).

All the contacts between the different lithologies tend to be parallel to the major planar fabric S_2, which developed as axial planar schistosity linked to plurikilometric folds. Locally this schistosity is folded by open, pre-Alpine folds (F_3), not associated with penetrative schistosity. In the Savona–Calizzano Unit, the basement and its Upper Palaeozoic covers were intruded by granodiorites (300.5±1.8 Ma, Cortesogno *et al.*, in prep.) and rare andesite dykes.

The T. Visone Unit is represented by volcano-sedimentary sequences likely preserving evidence of pre-Alpine metamorphic overprint, and by ruditic, arenitic to pelitic meta-sedimentary rocks and minor marbles, associated with metarhyolites, subordinate metabasites, and serpentinite slices.

THE PROTOLITH NATURE AND THEIR PRE-NAMURIAN METAMORPHIC EVOLUTION

IA) The Migmatite–Eclogite complex (Savona–Calizzano Unit) is represented by hectometric migmatite lenses with embedded metric to one hundred metre thick eclogite bodies. Eclogites show tholeiitic and, in part, transitional, within-plate, affinity (Fig. 2). They

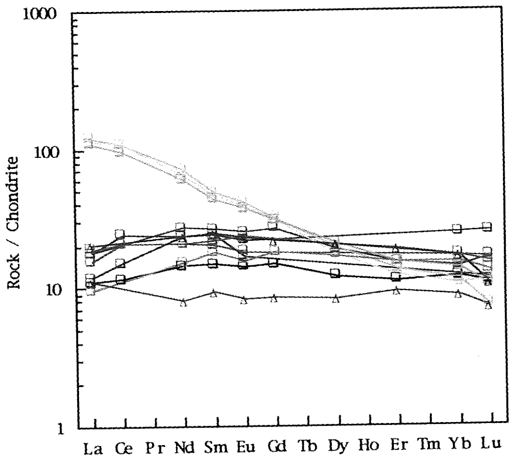


Fig. 2 – Chondrite-normalized (Nakamura, 1974) REE patterns of eclogites (squares) and amphibolites (triangles).

preserve mineral and textural relics of the polyphase pre- and syn-kinematic crystallisation of garnet with decussate to nematoblastic omphacite ($Jd_{30-47}Aeg_{0-15}$) and subcalcic amphibole associated with zoisite + rutile ± quartz ± white mica ± biotite in the S_1 schistosity (Plate 1A).

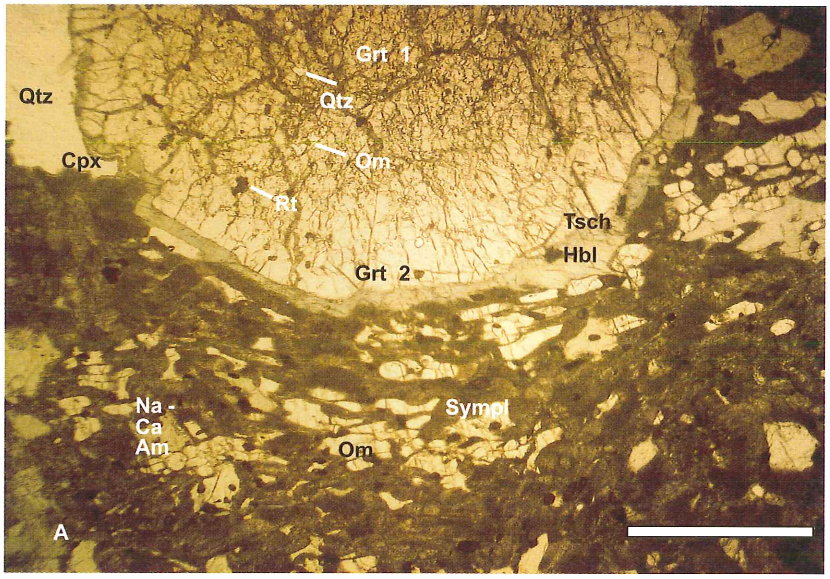
The garnet ($Alm_{30-56}Prp_{2-37}Grs_{14-50}Sps_{0-7}Adr_{0-10}$) is characterized by apparent zoning with important pyrope increase from the pre-kinematic, poikiloblastic core to the post-kinematic, inclusion-free rim, where grossular content and, to a minor extent, almandine decrease (Fig. 3A). In the garnet core, inclusions are omphacite ($Jd_{26-36}Aeg_{7-16}$), subcalcic amphibole (taramite-katophorite), quartz, zoisite, rutile, phengite (Cortesogno *et al.*, 1997; Desmons *et al.*, 1999a). A decompressional evolution without evidence of penetrative schistosity controls the breakdown of omphacite to symplectitic diopside and/or pargasitic hornblende+plagioclase (An_{10-35}). Higher anorthite contents are related at the microscale to the zoisite re-equilibration to clinozoisite.

Orthopyroxene (Mg/Mg+Fe=0.6-0.7; CaO=0.6-0.7 wt.; Al_2O_3=2.3 – 3.0 wt.), in part originated from the biotite breakdown, is rarely found in diopside-bearing symplectites, or as large poikiloblasts in Fe- and Mg-rich, Ca-poor bands. A re-equilibration towards the amphibolite facies (Mg- or tschermakitic hornblende + plagioclase (An_{25-35}) ± clinozoisite ± titanite) occurred during the M_2 phase.

The refractory component of migmatites is characterized by the polyphase growth of biotite + sillimanite ± plagioclase (An_{25}) ± K-feldspar ± garnet ($Alm_{43-50}Prp_{37-44}Grs_{0-4}Sps_{2-5}Adr_{19-22}$) followed by static, post-S_2, recrystallisation of biotite, muscovite, cordierite (?) with andalusite megablasts. Impregnations and dykelets of granite composition, affected by S_2, represent the neosome.

IB) The protoliths of the Gneiss–Amphibolite complex correspond to a volcano-sedimentary sequence of arenites, mostly greywacke (paragneisses) and of pelites (micaschists and Al-silicate-rich paragneisses) associated with tholeiitic basalts (amphibolites) and calc-alkalic rhyolites and dacites (Fig. 4, field 1). The acidic metavolcanites yields U/Pb igneous zircon ages as old as 506.9±4.7 Ma (Cortesogno *et al.*, in prep.). Large meta-intrusive bodies (from granodiorite and granite protoliths, Fig. 4, field 2) and haplo-granitic dykes intruding the siliciclastic sequence are affected by M_1 and M_2. The U/Pb igneous zircon ages are as old as 494+5, -3 Ma (Cortesogno *et al.*, in prep.). Serpentinized ultramafite lenses occur locally in the paragneisses.

In amphibolites, garnet ($Alm_{47-68}Prp_{0-15}Grs_{17-37}Sps_{2-14}Adr_{0-8}$) or ferrian diopside can occur associated with polyphase (pre- to post-kinematic with respect to S_2) green hornblende (Mg- or tschermakitic hornblende) + plagioclase (An_{30-35}) + rutile ± titanite ± clinozoisite ± quartz assemblages (Plate1B). Textural relics of an earlier S_1 foliation, transposed to the S_2, are preserved. Garnet is commonly zoned, showing almandine and spessartine decrease and grossular increase from the pre-S_2 core to the syn-kinematic rim (Fig. 3B). Rutile has commonly been



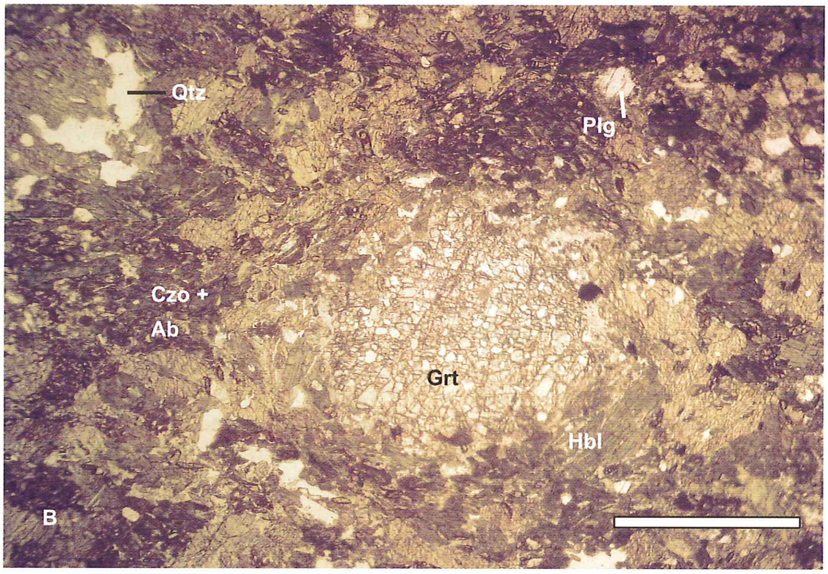


Plate 1A – Transmitted light microphotograph. Bar scale = 1 mm. Partially retrogressed eclogite. Large zoned garnet with quartz, rutile, omphacite, Na-amphibole inclusions and rimmed by tschermakitic hornblende. Omphacite (elongated, lobate grains largely replaced by Di+Ab symplectites), apatite (white, elongated grains) and Na-Ca amphibole (grayish grains, in part surrounded by hornblende) lie on the S_1 schistosity. Top left: quartz with Ca-clinopyroxene rim. 1B. Transmitted light microphotograph. Bar scale = 1 mm. Pre- to(?) syn-kinematic garnet porphyroblast wrapped by post-kinematic (with respect to S_2) hornblende + saussurritic (Czo+Ab dark aggregates) plagioclase + quartz + titanite + magnetite assemblage. Saussurite and garnet fracturing are due to the Alpine overprint.

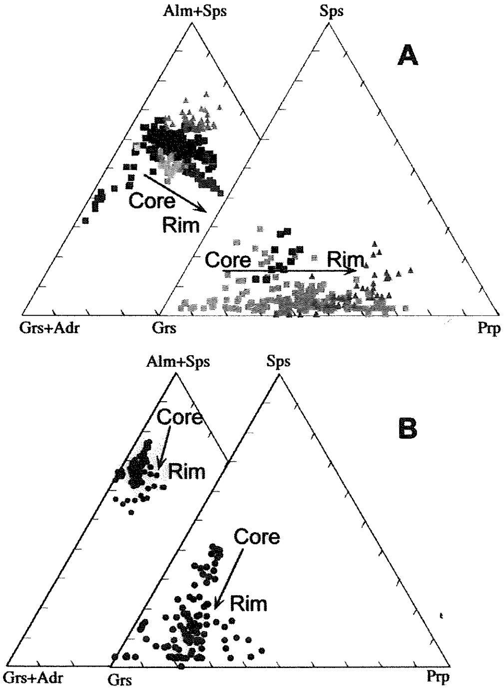


Fig. 3 – Mineral chemistry and core-rim trends of garnets from eclogites (A) and amphibolites (B).

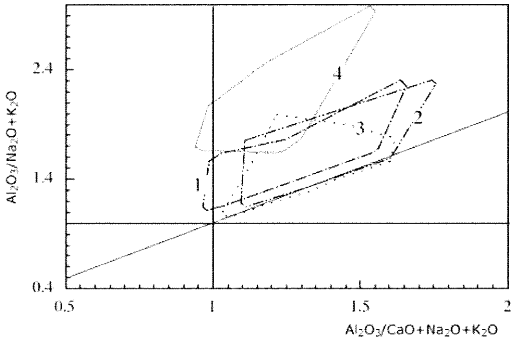


Fig. 4 – A/CNK vs. A/NK for Ligurian Alps granitoids. Dashed – dotted line, field 1: metavolcanites in the complex IB; dashed – dotted line, field 2: metagranitoids in the complex IB; dotted line, field 3: metagranitoids from complex IIA; dotted line, field 4: late orogenic, Carboniferous granitoids. Fields 1-3 fall within the *continental collision granitoids* and field 4 in the *continental arc granites* of Maniar and Piccoli (1989).

overgrown by titanite. The S_2 is followed by the retrograde garnet breakdown to plagioclase + biotite + actinolitic hornblende + magnetite + cordierite (?), by the diopside retrogression to actinolitic hornblende, and by re-equilibration of the plagioclase down to An_{25}. In Al-rich paragneisses and micaschists, garnet ($Alm_{62-83}Prp_{4-11}Grs_{5-27}Sps_{1-4}Adr_{0-1.5}$), kyanite, staurolite±sillimanite, can occur associated with the widespread plagioclase + quartz + biotite + muscovite + rutile assemblages. Textural evidence supports the pre- and syn-kinematic coexistence of sillimanite, kyanite, garnet and staurolite throughout the D_1, followed by their post-D_2 breakdown. In the orthogneisses (metagranites and metarhyolites), granoblastic K-feldspar is in equilibrium with biotite, muscovite and ribbon quartz along the S_1. Locally, garnet-rich amphibolites preserve hornblende + plagioclase symplectites, which evidence an origin from retrogressed eclogites. It seems likely that this eclogite facies event was restricted to part of the Gneiss–Amphibolite complex, suggesting a metamorphic zoning.

Evidence of a metamorphic zoning within the Gneiss–Amphibolite complex is supported by coexistence or lack of Sil with Ky and St, and by the andalusite growth in Ky-Sil-St-free metapelites during the shallow level intrusion of granites in the time span between D_1 and D_2.

IIA) Metagranites and associated dykes (peraluminous monzogranites and rare granodiorites, Fig. 4, field 3) intruded the Gneiss–Amphibolite complex. Igneous U/Pb zircon ages are: 473±1 Ma in the Ellera monzogranites and granites; 468±1 Ma in the Sanda granodiorites and granites; 459.4±2.9 Ma in the Calizzano monzogranites and granites (Cortesogno *et al.*, in prep.). Thermally induced recrystallisation in the host paragneisses is recorded by metre-thick hornfelses with fine-grained granoblastic garnet, staurolite, biotite and plagioclase. In the metagranites, biotite, muscovite, plagioclase (An_{20-25}), and, locally, fibrolite lie in the S_2 schistosity. K-feldspar shows brittle behaviour with fractures filled by quartz and plagioclase. A Variscan age at 327 Ma has been obtained from metamorphic biotite (Del Moro *et al.*, 1982).

IIB) Olivine-clinopyroxene-bearing metagabbros were emplaced as small (tens to hundreds metre wide?) bodies within the Migmatite–Eclogite complex, whereas sub-alkalic basic and intermediate dykes intruded either the Migmatite–Eclogite and Gneiss–Amphibolite complexes. During the D_2 event, heterogeneous strain partitioning in the gabbros, evidenced by discrete metre to centimetre-thick? shear zones surrounding lenses of undeformed rock, has been associated with plagioclase (An_{25}) + hornblende assemblages. Rare garnet also occurs in basic dykes.

On the whole, in the Ligurian Briançonnais basement, the Variscan metamorphism affects medium- to high-grade metamorphic rocks and their acid-basic intrusions; as a consequence, decompressional patterns are evidenced. Volcanic and sedimentary rocks affected by prograde Variscan overprint, generally under greenschist facies conditions, only occur as reworked clasts in the Late Carboniferous deposits.

In the T. Visone basement two different lithostratigraphic sequences are considered. In the topographically lower sequence, hundred-metres thick metarhyolites are interbedded with siliciclastic metasedimentary rocks (quartz metaconglomerates, garnet micaschists and micaceous quartz-schists including lenses of calcareous to dolomitic marbles). Garnet-clinozoisite-two mica marbles in dm-thick bands interbedded with garnet micaschists represent the geometrically overlying sequence. The whole metasedimentary sequence is characterized by relatively abundant tourmaline. Dm to dam-thick boudins of tholeiitic metabasites occur within metavolcanites and metasediments. Mineral and textural relics of a pre-Alpine metamorphic event take to infer these sequences as pre-Namurian basements. Decametre-thick serpentine-schists and chlorite-tremolite-diopside marbles, from ophicalcite protoliths, occur within the garnet-marble and garnet–micaschist sequences, suggesting an origin from a reworked ophiolite sequence. However, an Alpine tectonic involvement of the ultramafic rocks cannot be excluded. Biotite and muscovite in the orthogneisses and garnet, zoisite, biotite and muscovite in the metasedimentary rocks are considered to record a pre-Alpine metamorphic history. In metabasic rocks, pre-Alpine textural features and possibly garnet relics survive the Alpine overprint.

P-T-t EVOLUTION

In the Migmatite–Eclogite complex the polyphase re-equilibration of metabasites to eclogite during the M_1 metamorphic peak yields, on the basis of garnet–omphacite and garnet-phengite geothermobarometers, temperatures as high as 760°C for a minimum pressure of 1.7 GPa, suggesting subduction under a relatively high thermal gradient. Eclogites were likely associated with metasedimentary rocks that underwent partial melting during a nearly-adiabatic decompression path towards granulite-facies conditions. The high thermal regime was associated with the intrusion of basic magmas (IIB complex).

In the Gneiss–Amphibolite complex, plagioclase-hornblende and garnet–hornblende exchange thermometry yields temperatures of 600-650°C for pressures $\approx$ 0.6 GPa, consistent with the Ky-Sil-St assemblage in micaschists (Fig. 5). However, metastable equilibrium conditions between the pre- to syn-kinematic garnet, and plagioclase+hornblende, largely re-equilibrated post-kinematic to the D_2 phase, should be assumed. On the other hand, the local occurrence of eclogite relics in amphibolites favours the hypothesis that portions of the IB complex were involved in subduction up to eclogite-facies conditions. The mineral assemblages in the associated metasedimentary rocks suggest lower P-T conditions compared with those of the IA eclogites.

In the IB complex the timing of the M_1 event is constrained between the age of the metarhyolites (506.9±4.7 Ma) and the emplacement of the IIA) granitoids (473±1

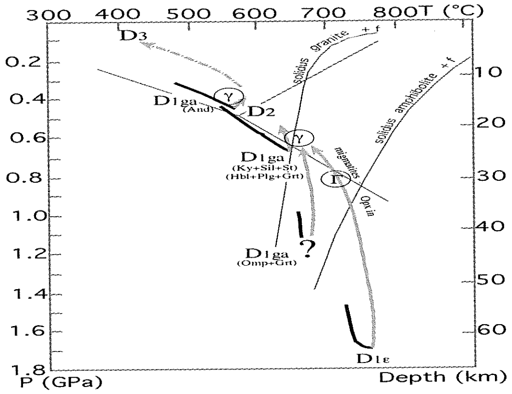


Fig. 5 – P-T-t metamorphic paths for the Pennidic pre-Namurian basement in the Ligurian Alps. D_{1ga}: main pre-Variscan schistogenous event in the Gneiss–Amphibolite complex.? D_{1E}: main pre-Variscan schistogenous event in eclogites of the Migmatite-Eclogite complex. D_2: main Variscan schistogenous event associated with plurikilometric folds, dated at 327 Ma. D_3: Late Variscan folding phase. Γ: Gabbro intrusions. γ: Granite intrusions, dated in the range 473-459 Ma. Black full lines: prograde paths. Gray full lines: exhumation paths. Gray dashed-dotted line: Variscan exhumation path.

Ma). All the complexes were affected by amphibolite facies re-equilibration during M_2, in turn followed by a decompressional evolution. This is evidenced by the post-kinematic growth of andalusite within melasomes in migmatites, whereas in metabasites garnet broke down to plagioclase, biotite, hornblende ± cordierite (?) and actinolitic hornblende replaced diopside and Mg-hornblende. Finally, greenschist facies conditions were attained during a third pre-Alpine deformation phase, which is characterized by actinolite + chlorite along axial planes of open folds.

DISCUSSION, REGIONAL COMPARISON AND GEODYNAMIC INFERENCES

The Early Ordovician magmatism

Bimodal effusive activity (tholeiitic and transitional basalts, acidic calc-alkalic volcanites) occurred at the Cambrian–Ordovician transition (~500 Ma), and was associated with pelitic and pelitic-psammitic sedimentation. The huge volumes of metarenites, mostly graywackes, might indicate the evolution towards turbiditic deposits, where small mantle-derived ultramafic bodies (olistoliths) were involved with the volcano-sedimentary products. Also during Early Ordovician (~494 Ma), peraluminous S-type granitoid bodies intruded the volcano-sedimentary sequence. No evidence is recorded for metamorphic events earlier than the Ordovician granite intrusion, with the exception of monomineralic biotite selvedges, interbedded with the metagranitoids, interpreted as products of local anatexis (Cortesogno, 1986).

The sequence may indicate a continental rift phase, at the threshold of ocean floor spreading, characterized by flysch deposition likely fed by dismantlement of an arc. A similar geotectonic environment has been proposed for the Aiguilles Rouges amphibolites in the Helvetic Western Alps (von Raumer *et al.*, 1990). Basic volcanites, often showing MORB and also alkalic affinity, are commonly associated with acidic volcanics («Leptyno-amphibolitic» complexes), and sometimes with ultramafic rocks, between the Upper Cambrian and the Lower Ordovician, rarely earlier; they occur in the western Pennidic and Helvetic Alps, but also in the Vanoise and in the Internal French Alps, and are widespread in most of the pre-Variscan terranes from Spain to the Bohemian massif (see e.g. Paquette *et al.*, 1985; Santallier *et al.*, 1988; Briand *et al.*, 1995; Bellot *et al.*, 2003).

In the western South Alpine basement the «Leptyno-amphibolitic» group has been interpreted as derived from a back arc, bimodal volcanism associated with turbiditic sedimentation, with incorporation of ophiolitic materials (Giobbi *et al.*, 2003). On the whole, the inferred extensional setting of the Cambrian–Ordovician alkalic to subalkalic magmatism evolving up to ocean basins is consistent with the Lower Ordovician drift of Avalonia terranes from Gondwana (Stampfli *et al.*, 2002; von Raumer *et al.*, 2003).

The pre-Variscan metamorphic event

The metamorphic event affecting the volcano-sedimentary sequences and the Early Ordovician granite intrusions can be placed in the time span between about 490 Ma and the age (~473 Ma) obtained for the post-metamorphic Early to Middle Ordovician granitoid intrusions. In the Gneiss-Amphibolite complex, the different peak metamorphic conditions (low to high amphibolite up to medium-T eclogite facies) likely represent different steps of a subduction event. As it is unlikely to correlate the gradients within the Gneiss-Amphibolite with those of the Migmatite–Eclogite complex, owing to the present lack of radiometric dating, two separate subduction events could correspond to the development of different subduction surfaces within the same collision, or pertain to different collisions. In this case, the M_1 event in complexes IA and IB would have been diachronous.

A trace of a metamorphic event at 470-500 Ma is recorded in the Eastern Alps (Frisch *et al.*, 1990; Sassi et al, 1987; Matte, 1991). Eclogite or high-pressure granulite relics are widespread in several Palaeozoic units as the «Leptyno-Amphibolite» complexes, in the eastern Austrides, Calabria (Miller and Thöni, 1997; Fornelli *et al.*, 2002; Grassner and Schenk, 2001). In Sardinia, high- and medium-T pre-Variscan eclogites occur respectively northward and southward of the Posada line (Cortesogno *et al.*, 2000).

Eclogites from MORB metabasalts in the external massifs of the Western Alps, (~450 Ma), and coeval metagranitoids are interpreted as evidence of a Late Ordovician subduction (Paquette et al 1985). The Early-Middle Ordovician metamorphic event can be related with the subduction suturing the aborted Rheic basin between Laurussia and Hun superterrane (Stampfli *et al.*, 2002; von Raumer *et al.*, 2003). The relatively long span of time of the eclogite metamorphism (Middle-Late Ordovician to Silurian) possibly results from diachronous collisions among the different microcontinents of the Hun superterrane. In this perspective, the subduction in the Ligurian Briançonnais can represent an earlier event.

In the western Southern Alps (Strona-Ceneri Zone) no evidence arises of a pre-Variscan event prior to Ordovician granitoid intrusion (Boriani *et al.*, 1990).

The Middle-Late Ordovician magmatism

The second magmatic event in the Ligurian Briançonnais is represented by peraluminous S-type granitoids emplaced between about 473 and 459 Ma and by localised gabbros and rare basic to intermediate dykes.

S- and I-type orthogneisses (~480-450 Ma) occur in the Western external Alps and in the Vanoise (Paquette *et al.*, 1999; Guillot et al, 2002; Bertrand *et al.*, 2000). In the Eastern Alps, large plutonic masses of Late Ordovician age showing calc-alkaline affinity are interpreted as anatectic. In the western Southern Alps, Ordovician metagranitoids (~470-420 Ma) are considered as originated within convergent plate boundaries. In Sardinia, Ordovician metagranodiorites occur at Capo Spartivento, in the external zone of the Variscan chain, and granodiorite orthogneisses in the Nappe Zone (Ferrara *et al.*, 1978). The axial zone of the belt, made up of migmatites, along with its prolongation in Corsica also includes several orthogneiss bodies, generally derived from S-type granite of Early Ordovician age.

In the lack of radiometric data, a Middle–Late Ordovician age can be proposed for the peraluminous metarhyolites of the T. Visone basement, on the ground of similarities with Ordovician metarhyolites («Porphyroids») occurring in Sardinia (Oggiano, 1994; Di Pisa *et al.*, 1992), Southern Alps (Sassi *et al.*, 1987; Sassi and Zanferrari, 1989) and in Tuscany, also associated with basic volcanites. In the Southern Alps, the Ordovician metavolcanics (~480 Ma) are interpreted as product of crustal anatexis (Meli and Kloetzi 2001).

The Variscan metamorphic event

The Variscan metamorphic event (327 Ma, Del Moro *et al.*, 1982) affected all units of the

Ligurian Briançonnais basement, paralleled with a pervasive schistosity characterised by intrafolial microfolds at the microscale and by plurikilometric folds at the macroscale. The metamorphic pattern records a peak under amphibolite facies and Barrovian gradients, followed by generalised decompression.

The decompressional phase evidenced by the post-D_2 and syn-D_3 retrograde evolution is likely to be the consequence of the erosion of the Variscan orogen. The products of such erosion, deposited in Upper Carboniferous basins are represented by: a) ubiquitous, reworked quartz pebbles; b) widespread micaschists and paragneisses, rare orthogneisses and micaschists (complex IB); c) metarenites, metacherts and metarhyodacites affected by pre-Alpine greenschist facies; d) Late Variscan granitoids and volcanites (Cortesogno *et al.*, 1988; 1998). The clasts record a low-grade Variscan basement largely eroded and presently not outcropping.

The Variscan metamorphic event affected most of the Palaeozoic basement units; in the Austrides it shows low-pressure conditions, whereas in the western Central Alps, Barrovian-type gradients were dominant. In northern Sardinia, the Posada–Asinara line separates Barrovian amphibolite facies conditions to the South from a northern zone characterized by anatexis of para- and orthoderivates. In southern Sardinia, the Nappe Zone is affected by Variscan metamorphism from greenschist- to pumpellyite-bearing, subgreenschist-facies. In the Calabrian-Peloritan Units, the Variscan event attained conditions from greenschist to the upper amphibolite facies, under medium pressure gradients.

The late orogenic events

In the Ligurian basement radiometric evidence support a Permian thermal event, which can be correlated with the intrusion of Late Variscan calc-alkaline, Al-saturated, granitoid rocks (~294-300 Ma), preceding, or associated with, the late–orogenic Permo-Carboniferous effusive activity. In the Briançon Zone Houillère (Pennidic Alps) Visean-Namurian granitoids have been associated with an extensional phase preceding the post-orogenic collapse.

In the Ivrea–Verbano Zone the intrusion of the mafic Ivrea body at the base of the crust under late-orogenic extensional regime was the source of the thermal metamorphic peak of Permian age (Boriani and Villa, 1997). In the European basement units a Late Variscan thermal event, evidenced by hydrothermal activity, is locally associated with the intrusion of granitoid rocks (Bonin *et al.*, 1993; Deroin and Bonin, 2003). In Sardinia, Corsica, Maures and Provence, the intrusion of aplites, granophyres and the effusive calc-alkaline, intermediate to acid rocks were associated with the extensional–transtensional tectonics and with the collapse of the orogenic belt.

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