The Monviso ophiolitic Massif (Western Alps), a section through a serpentinite subduction channel

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Abstract: The exhumation of subducted lithosphere requires a mechanically weak zone at the interface between the subduction plane and the rigid overlying mantle peridotites with a viscosity greater than 10^{20} Pa.s. At shallow depths (<40-50km) blueschists are exhumed in the accretionary wedge along the interface between the subducting plate and the overriding plate (Platt, 1993). At greater depth, serpentinites plays the role of a mechanically weak layer in cool continental subduction and acts as a lubricant, producing a return flow for the exhumation of eclogitic rocks. The close association of serpentinites and eclogites in the Monviso massif (Western Alps) allow the discussion of the concept of a subduction serpentinite channel. We propose that the Monviso ophiolitic massif corresponds to a section of a 50 km long serpentinite channel along which eclogitic blocks were exhumed between 60 and 45 Ma and ended when the European continental margin was involved in the southeast dipping subduction zone.

Table of Contents

Introduction

High pressure (HP) to ultra high pressure (UHP) rocks in modern orogenic belts have been interpreted as part of subducted oceanic or continental plates (Ernst 1999, Eide and Liou 2000, Guillot et al. 2003). The exhumation of subducted lithosphere requires a mechanically weak zone at the interface between the subduction plane and the rigid overlying mantle peridotites with a viscosity greater than 10^{20} Pa.s (Hirth and Kohlstedt 2003). At shallow depths (<40-50 km) blueschists are exhumed in the accretionary wedge along the interface between the subducting plate and the overriding plate (Platt 1993). Hydrated sediments at the base of the accretionary wedge can develop a corner flow due to their low viscosity ($<10^{19}$ Pa.s; Cloos and Schreeve 1988), which facilitates the exhumation of blueschists during active subduction of the oceanic plate (Platt 1986). This is the case for the Franciscan complex in California (Platt 1986, Cloos and Schreve 1988), the northern Carribean complex in Cuba and the Dominican Republic (Goncalvez et al. 2000, Garcia-Casco et al. 2002) and the External Piemont zone (Schistes Lustrés units) in the Western Alps (Schwartz 2001, Agard et al. 2002).

At greater depth, an accretionary wedge is pinched out and the abundance of sediments significantly decreases, yet the exhumation of eclogitic rocks is rapid (Duchêne et al. 1997). Therefore, a different mechanism is necessary for the exhumation of eclogitic rocks. Proposed processes for the exhumation of HP to UHP rocks vary depending on the tectonic settings. They may be classified into three end-members: (1) Partial melt provides a low viscosity layer in high temperature continental subduction, such as western Norway (Labrousse et al. 2002) and Dabie Shan in China (Hacker et al. 2000); (2) Serpentinites and/or phengite-bearing rocks play the role of mechanically weak layer in cool continental subduction, such as the Tso Morari in Himalaya and Dora Maira in the Alps (Guillot et al. 2001, de Sigoyer et al. 2004; Chopin and Schertl 1999), their exhumation likely assisted by the low density of eclogitized continental rocks (Chemenda et al. 1996), or (3) exhumation involves eclogitized oceanic or arc-related mafic rocks, a phenomenon only documented in few places, such as the Alpine belt of Cuba (Zaza zone) (Auzende et al. 2002, Garcia-Casco et al. 2002) and the Kohistan arc in Pakistan (Le Fort et al. 1997). Rare occurrences of eclogitized mafic rocks are not surprising considering the high density of eclogitized mafic rocks (3500 $kg.m^{-3}$) compared to the mantle peridotites (3300 $kg.m^{-3}$). The negative density difference requires boundary forces to compensate the gravity force.

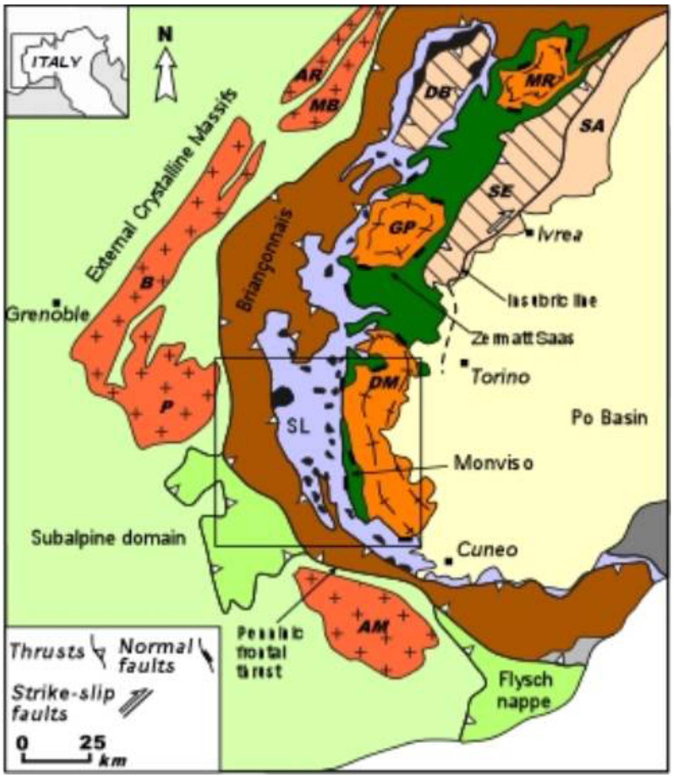
Eclogites are commonly accompanied by serpentinites. Some serpentinites are considered to have been exposed on the oceanic floor before the subduction (Scambelluri et al. 1995, Li et al. 2004). The second type of serpentinite is hydrated peridotites at the base of mantle wedges (Guillot et al. 2000, 2001). These serpentinites may replace the role of hydrated sediments at greater depths and act as the lubricant and producing a return flow for the exhumation of eclogitic rocks. This proposal is supported by the systematic occurrence of serpentinites spatially associated with eclogitic rocks derived from oceanic crust in the Alps (Hermann et al. 2000, Schwartz et al. 2000, Li et al. 2004), in Cuba (Auzende et al. 2002, Garcia-Casco et al. 2002) and in Kohistan (Le Fort et al. 1997).

The aim of this paper is to describe the occurrence of serpentinites and eclogites in the Monviso massif (Western Alps), the origin of serpentinites, and the geometry and mechanisms for the exhumation of the eclogitized oceanic crust during active subduction.

Geological setting

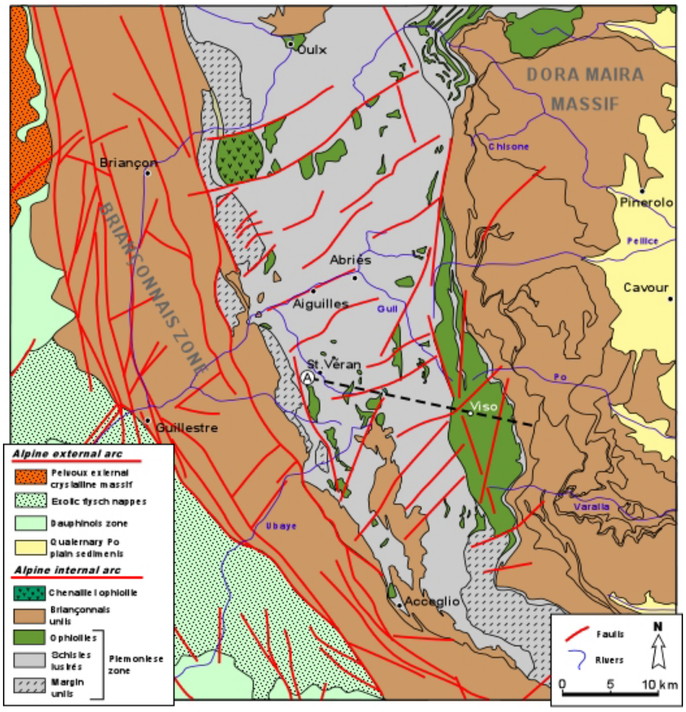
The southern part of the Piemont zone of the Western Alps (Figure 1) consists of three major tectono-metamorphic units (Figure 2) coming from the Piedmont-Liguria domain of the Western Tethys that was actively spreading during the Upper Jurassic period (e.g. Lombardo et al 2002 for review) and closed in the Late Cretaceous to Early Tertiary (e.g. Agard et al. 2002, Schettino and Scotese 2002). The uppermost unit (Chenaillet massif) consists of a weakly metamorphosed ophiolite obducted onto the European continental margin (Mével et al. 1978). The intermediate unit corresponds to the External Piedmont zone, namely the Schistes Lustrés units (Deville et al., 1992). It consists of metric to kilometric lenses of ophiolitic blocks embedded in dominant Jurassic to Lower Cretaceous clastic metasedimentary rocks (Lagabrielle et al. 1984, Lemoine et al. 1987). They were metamorphosed to blueschist facies conditions during the period from 75 to 40 Ma (Deville 1986, Schwartz 2001, Agard et al. 2002, Schettino and Scotese 2002) and are commonly considered an accretionary wedge that was later tilted during the Alpine collision (Tricart et al., 2004). The maximum thickness of the wedge during its deposition was calculated to be between 40 and 65 km, dependent on pressure estimates used for the blueschists (Schwartz et al. 2001, Agard et al. 2002). The maximum thickness of 65 km is probably overestimated as it is essentially based on the poorly constrained thermodynamic data of phengite (Vidal et al. 2001).

Figure 1. Map of the Western Alps



Map of the Western Alps showing the main tectonic units, modified after Polino et al. (1990). AM: Argentera-Mercantour, AR: Aiguilles Rouges, B: Belledonne, DB: Dent-Blanche, DM: Dora Maira, GP: Gran Paradiso, MB: Mont-Blanc, MR: Monte Rosa, P: Pelvoux, SA: South Alps, SE: Sezia, SL: Schistes Lustrés.

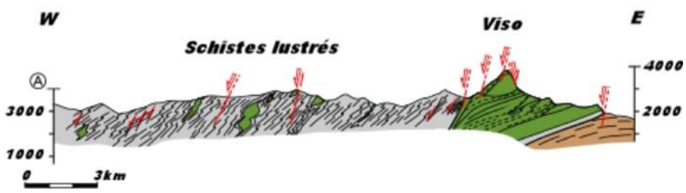
Figure 2. Detailed geological map



Detailed geological map of the studied area showing the relationships between the Monviso ophiolite and surrounding units (after Schwartz 2000).

The Monviso ophiolitic massif, 35 km NS and 35 km EW, forms the structural base of the unit (Figure 3) and is separated from the blueschist 'Schistes Lustrés' by a ductile normal fault within the western serpentinite unit (Traversetta unit) (Ballèvre et al. 1990) and to the east from the continental Sampeyre and Dronero units of the Dora Maira massif by a second normal ductile fault (Blake and Jayko 1990).

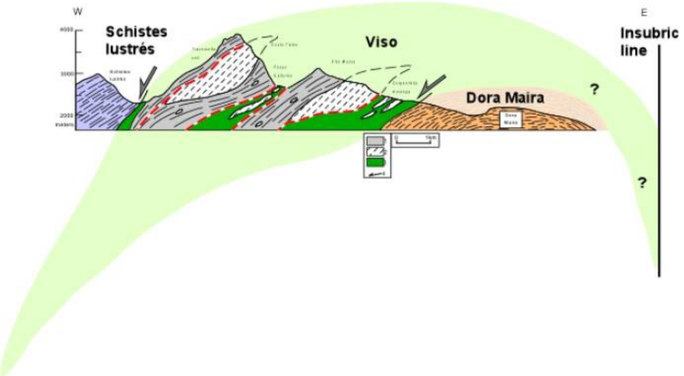
Figure 3. Vertical x-sections



Schematic vertical sections across the studied area from the Briançonnais to the Dora Maira (after Schwartz 2000).

Geophysical data shows the root of this massif at a depth of about 10 km (Schwartz 2001, Paul et al. 2001, Fig. 4). The root of this unit in the eastern part is buried below the Tertiary sediments of Po Plain. However, northward along the Gran Paradiso or Monte Rosa transects, the ophiolitic unit has a vertical extension along the Insubric line (Escher et al., 1997). The evidence suggests that the Monviso unit likely extends vertically east of the Dora Maira massif (Fig. 4).

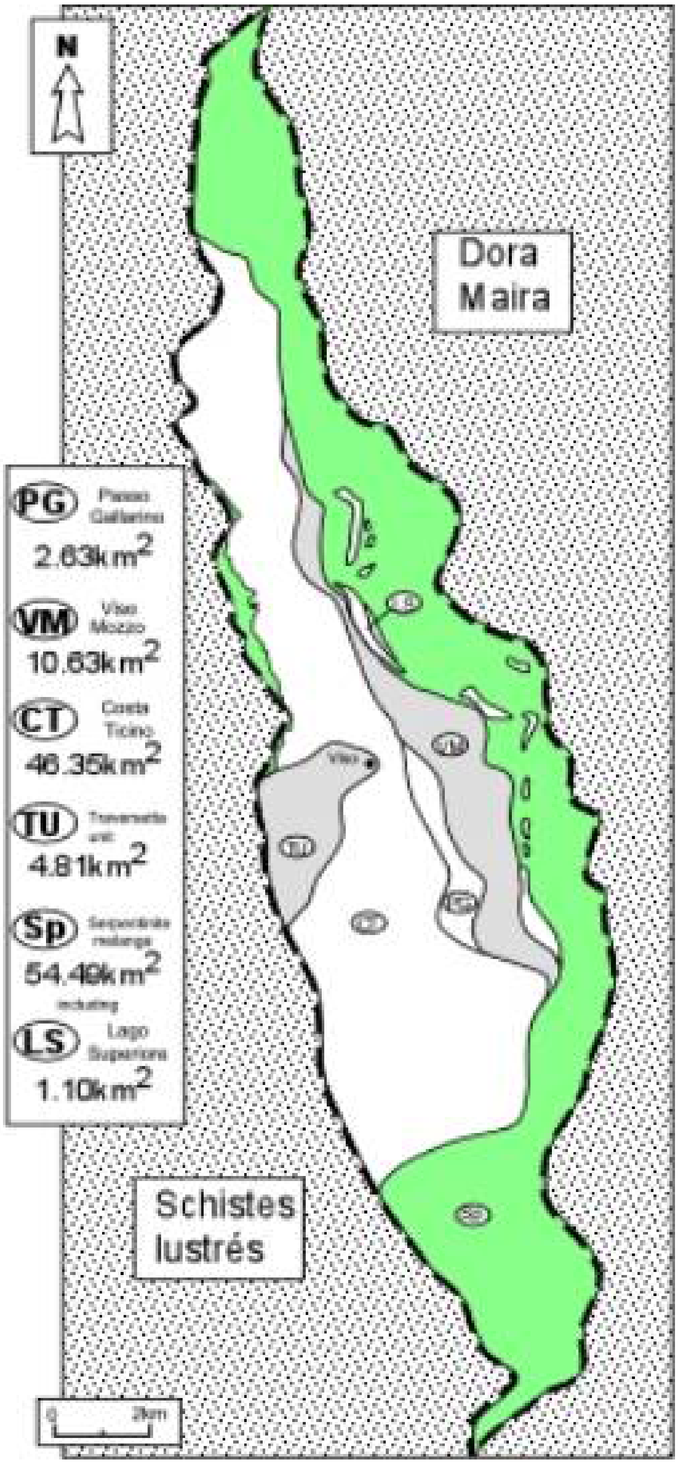
Figure 4. Monviso x-section



Cross section of the Monviso ophiolite showing the different units with eclogitic lenses embedded within the serpentinite. The tectonic contact between the different units correspond to normal shear zones under greenschist facies conditions. 1: Greenschist foliated metabasalts (prasinites); 2: eclogitic lenses composed of undifferentiated metagabbros, massive metabasalts and pillow lavas; 3 serpentinites. The shaded envelop corresponds to the geometry of the Monviso unit rooted below the Schistes Lustrés (Paul et al. 2001) and possibly rooted east of the Dora Maira massif, along the Insubric line.

In the central part of the massif, the Monviso massif is comprised of six distinct west-dipping tectono-metamorphic units of metabasalts or metagabbroic lenses, each of which is separated by west dipping normal shear zones in the serpentinite matrix (Fig. 4 and Fig. 5). Each unit records different eclogitic facies metamorphic conditions between 1.2 and 2.6 GPa and retrogression under similar blueschist facies conditions of about 0.7 GPa and 420°C (Lombardo et al. 1978, Philippot 1990, Blake et al. 1995, Schwartz et al. 2000, Lombardo et al. 2002) (Fig. 6 and Fig. 7).

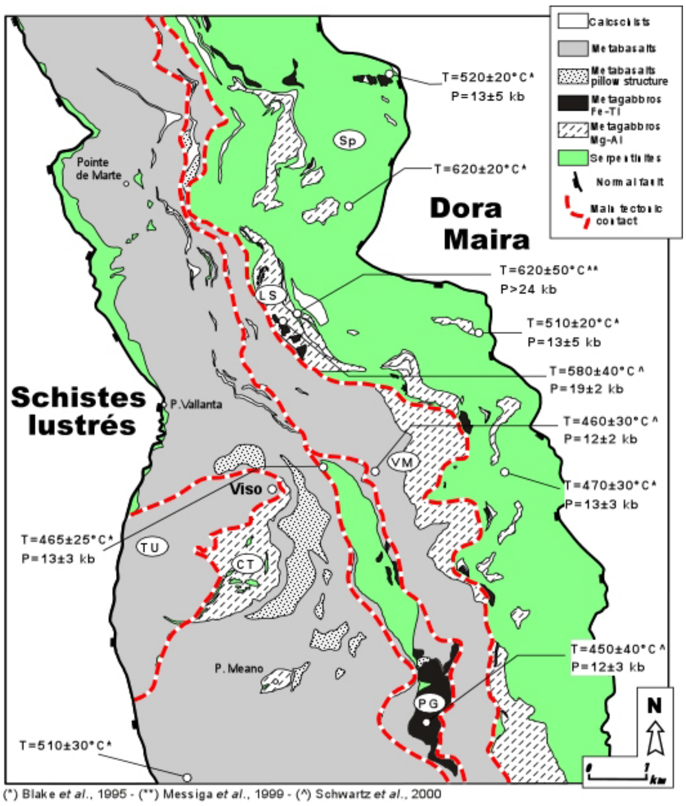
Figure 5. Monviso map



Schematic geological map of the Monviso unit after Blake et al. (1995) and Schwartz et al. (2001) showing the relationships of main tectonic units. The boundaries are estimated by image analysis. Notice that the serpentines (SP) represent about 50% of the total surface area and caps (OR overlies) all the eclogitic units. CT: Costa Ticino, LS: Lago Superiere. PG: Passo Gallarino, VM: Viso Mozzo.

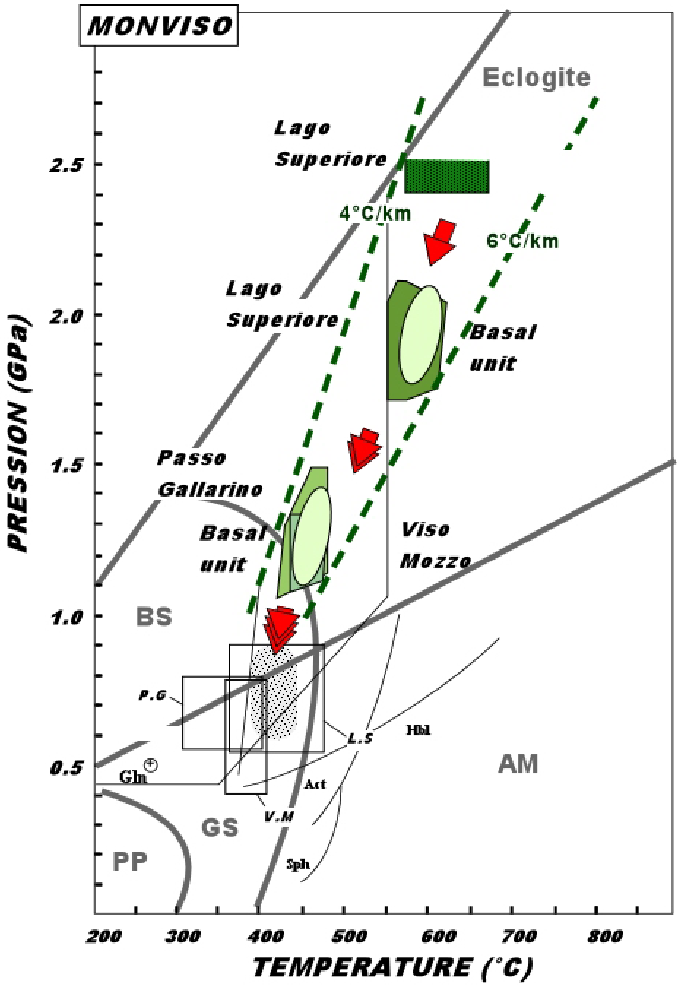
The age of the eclogitization varies. The Lago Superior unit yielded a Sm-Nd isochron age of 61 ± 10 Ma from garnet + omphacite (Cliff et al. 1998), a Lu-Hf isochron age of 49 ± 1 (Duchêne et al. 1997), and a U-Pb zircon age of 45 ± 1 Ma by Rubatto and Hermann (2003). These ages are comparable to an Ar-Ar age of 50 ± 1 Ma (Monié and Philippot 1989). The exhumation rate of the unit was estimated by Schwartz et al (2000) as fast at the beginning (1 cm.yr-1) and slower at the blueschist to greenschist-facies transition (1 mm.yr-1).

Figure 6. Monviso central map



Geological map of the central part of the Monviso, after Schwartz et al. (2001). The P-T estimates on the eclogite facies conditions are from Blake et al. (1995), Messiga et al. (1999) and Schwartz et al. (2000).

Figure 7. PT paths



P-T paths of eclogitic units in Monviso, showing that different units show similar retrogression paths under blueschist facies conditions. Note that the P-T paths yield geothermal gradients of 4 to 6°/km, typical of subduction zone conditions.

The basal serpentinite unit is 400 meters in thickness. The serpentinites have a lherzolitic protolith with only minor harzburgite and dunite, and are cut by sheared dykes of rodingitized gabbro and basalt. The serpentinite layer commonly contains metric to hectometric lenses of foliated eclogitic gabbro, ferrogabbro and metamorphosed plagiogranite. These lenses are tectonically incorporated as a tectonic melange and they show widely varied metamorphic conditions, from 1.3 GPa and 470 °C to 2.0 GPa and 575° C (Blake et al. 1995, Schwartz et al. 2000, Castelli et al. 2002). Considering its geometry, this basal serpentinite unit likely had an initial size of about 50 km x 10 km (Fig. 4).

The Lago Superiore unit is a discontinuous layer of intensely deformed and recrystallized metagabbros with local occurrences of chromian omphacite (smaragdite gabbro). The metagabbros host small bodies of ultramafic cumulates and hydrated mantle peridotites (Messiga et al. 1999). This unit recorded the highest pressure and temperature conditions of 2.4 GPa and 620 ± 50°C in Cr-rich magnesiochloritoid-bearing eclogites.

The Viso Mozzo unit consists of greenschists and banded glaucophane-epidote metabasalts with local preservation of pillow lava structures (Lombardo et al. 2002). Metric eclogitic lenses are embedded in the strongly foliated metabasalts, recording pressure–temperature conditions of 1.2 ± 0.2 GPa and 460 ± 30°C (Schwartz et al. 2000). In the upper part of the unit outcrops thin layers of carbonate micaschists (Schistes Lustrés) interbedded with the metabasites.

The Passo Gallarino unit is a 100 m thick layer of eclogite and omphacite-bearing metagabbro (1.3 ± 0.3 GPa, 450 ± 40°C) hosted in sheared serpentinites associated with quartzite and mica schist. This unit is characterized by intense syn-eclogitic shearing (Lardeaux et al. 1986) superimposed by flattening under blueschist facies conditions (Schwartz et al. 2000).

The Costa Ticino unit is the thickest unit (~1.2 km) and composed from the base to the top of basalt breccia, pillow lavas, metagabbro and slices of serpentinites that have been metamorphosed under blueschist facies conditions (~0.7 GPa, ~420°C) (Lombardo et al. 1978).

The Vallanta unit structurally overlies the Costa Ticino unit. It is also an eclogitic unit that consists of fine-grained metabasalts, carbonate-bearing mica schists and serpentinites. Metamorphic conditions are not available for this unit.

Origin of the Monviso ophiolitic massif

The Monviso ophiolitic massif is characterized by the alternation of tectonic units dominated by thick metabasalts with N-MORB geochemical signatures and Mg- and Fe-rich tholeitic metagabbros (Lombardo et al. 1978, MONVISO 1980). The basal serpentinite-rich unit appears to have originated from lherzolite overlain by a thin sedimentary sequence (Lemoine 1980). The assemblage of basalt-rich and basalt–poor units is similar to the lithology of low spreading oceanic lithosphere, such as the Mid Atlantic Ridge and the Indian ocean (Lagabrielle and Cannat 1990, Mevel 2003). This appears to be supported by dO^{18} values between 3.0 to 5.3 ‰ and NaCl equivalent salt contents of 17 to 21 wt% for the Monviso omphacite (Nadeau et al. 1993), and typical of a HT oceanic hydrothermal signature?? (Philippot et al. 1998). dO^{18} and salinity can support either hydration in the mantle wedge at high temperature or on the ocean floor. It rejects hydration at low temperatures on the ocean floor because low temperature hydration yields high dO^{18} values.

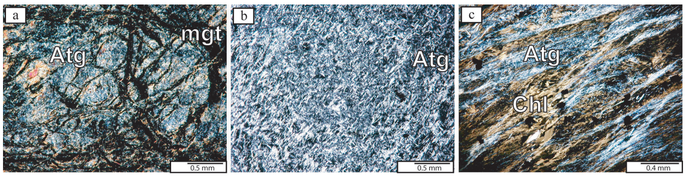
These units are interpreted as fragments of the Piedmont domain of the Western Tethys ocean during the Upper Jurassic and subucted during the Paleocene-Eocene. Recent U-Pb zircon ages show that magmatic activity occurred between 163 ± 2 Ma and 152 ± 2 Ma (Rubatto and Hermann 2003, Lombardo et al. 2002). Lombardo et al. (2002) noted this short duration of igneous activity in the Monviso massif and also a short time span (from ca 170 to ca 150 Ma) for the entire Piedmont-Liguria Tethys and suggested an embryonic ocean (max 380 km; Piccard et al. 2001, Schettino and Scotese 2002) rather than a mature, slow spreading, Atlantic-type ocean model (Lagabrielle and Cannat 1990). Blake et al. (1995) and Schwartz et al. (2001) suggested that part of the serpentintes represent hydrated peridotites at the base of mantle wedge, as observed in the Himalaya (Guillot et al. 2001). This is supported by the bulk composition of serpentinites, which show refractory character, similar to those from the Himalayas (our unpublished data).

Microstructural study of the serpentinite

The serpentinites represent about 40% of the Monviso ophiolitic massif (e.g., Lagabrielle 1987, Blake et al. 1995, Schwartz et al. 2001) (Fig. 5). Serpentinites are particularly well exposed in the Lago Superiore, Passo Gallarino and Viso Mozzo units. The intimate association of serpentinites with the eclogites from cm to cartographic scale suggest that they shared similar metamorphic evolution. The orientation and the sense of shear observed in the serpentinite matrix are similar to those observed in the surrounding metabasites: top to the west under greenschist facies metamorphic conditions (Schwartz et al. 2000, 2001).

The serpentinites observed in the Monviso unit are mostly hydrated close to 100% and few samples show relict diopside grains which are highly chloritized and deformed. Serpentinites show penetrative foliation with locally pseudomorphic textures. Pseudomorphic structures are observed with relict magnetites that still underline early mesh boundaries whereas former pyroxenes (bastites) correspond to magnetite-free areas (Fig. 8). The core of meshes or bastites recrystallized at high grade with interpenetrative serpentine blades (Fig. 8). Textural evidences coupled to a micro-Raman spectroscopic study show that antigorite is the main variety, as expected from its stability under high pressures (Auzende et al. 2005). Antigorite grains show no apparent compositional variation with low Al2O3 and Fe2O3 (<2 wt%). Lizardite and chrysotile form secondary veins during retrogression.

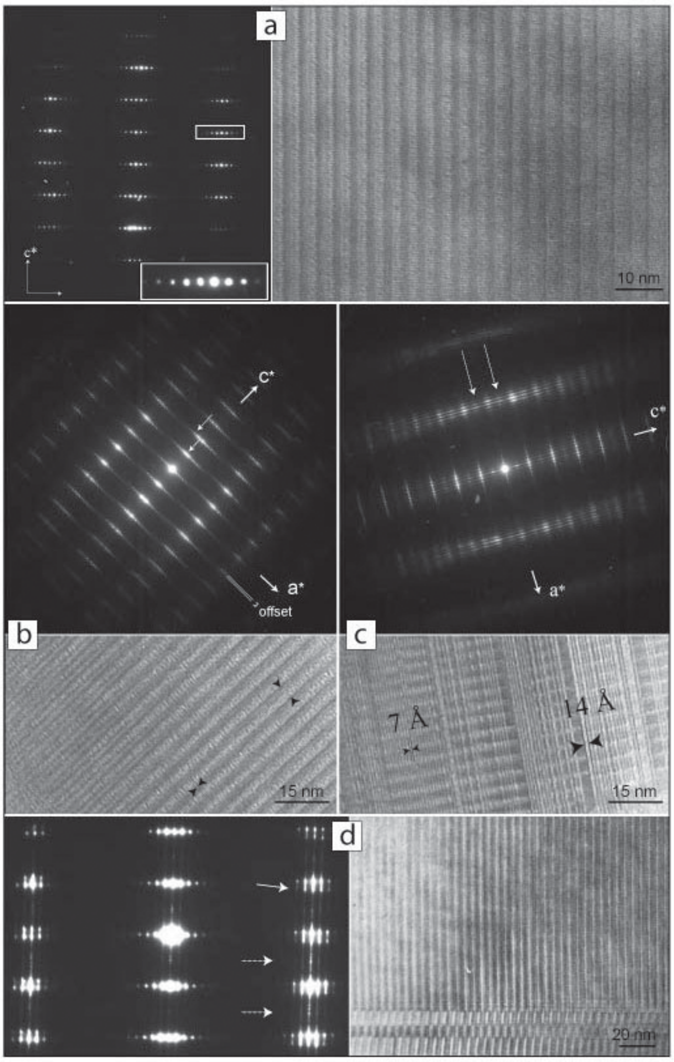
Figure 8. Photo micrographs



Photomicrographs of serpentinites from Monviso under cross-polarized light after Auzende et al. (2005). a) Interpenetrative antigorite surrounded by fine grained magnetite that outlines the pseudomorph of olivine (Sample 624-2: Viso Mozzo), b) Typical antigorite interpenetrative texture in metabasalt? (Sample 623-3: Lago Superiore), c) Sheared serpentinite where antigorite and chlorite (Chl) define the foliation and post-kinematic chlorite crystals cut the foliation (Sample 625-6: Lago Superiore).

The Microstructure of antigorite was investigated by electron imaging coupled to SAED with a transmission electron microscope (Auzende et al. 2005). The results show that antigorite crystals display similar texture and compositions. However, all studied SAED patterns show sharp modulation diffraction spots without streaking in the a* direction (Fig. 9). The evidence suggests intracrystalline polysomatic regularity in Monviso samples with the constant A dimension (modulation wavelength). This regularity is also apparent on TEM images, showing a highly ordered structure along a. Nevertheless, while the modulation length is constant in each crystal, this dimension significantly varies from one antigorite grain to one another within the same TEM preparation.

Figure 9. Electron micrographs



Electron micrographs and SAED patterns of antigorite crystals from Monviso oriented along [010] direction (after Auzende et al. 2005). a) Highly ordered structure along a* and c*, b) Offset structure. The offset is the deviation between the alignment of satellites around a (h00) sublattice spot and that of the neighbouring (h00) group (Passo Gallarino, 624-7), c) Stacking variations, alternating 1- and 2-layer polytypes. The dashed arrows in the SAED pattern point at the intensity reinforcement due to the double periodicity along c*. Besides the polytypic variations, the pattern shows diffuse streaks which affect the lattice and modulation spots along c*, indicating the loss of periodicity due to planar faults (Passo Gallarino, 624-7), d) Streaking along c* indicates stacking disorder. The white arrow shows spot rotation due to twinning and dotted white arrows indicate supplementary diffraction spots with 14.6 Å periodicity showing 2-layer polytypism (Monviso, Lago Superiore, 623-3).

The modulation wavelength is commonly expressed by the m-value, as the number of tetrahedra in one modulation. According to our data from SAED patterns of the 96 antigorite crystals oriented along [010], antigorites from Monviso have m-values varying between 16 and 20 (41 to 52 Å), with a dominance of crystals with m = 18 (46 Å) and 19 (49 Å) (Fig. 9). The average m-values for the three units are close considering their standard deviation.

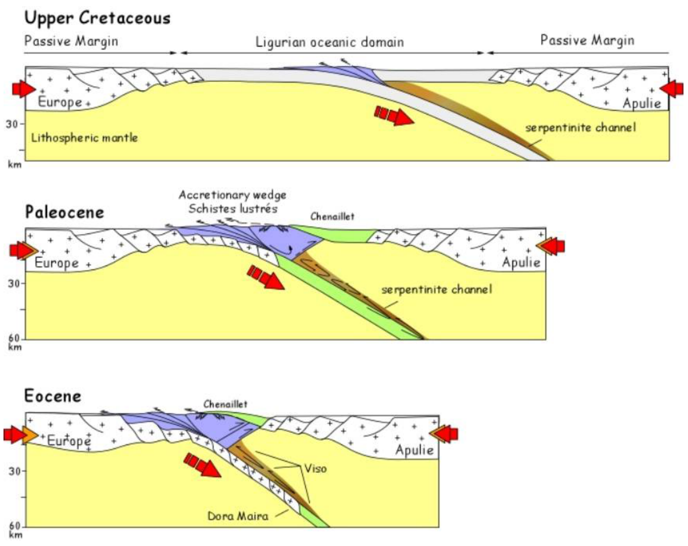
+ (exhumation timing) Timing and mechanism of exhumation

As previously mentioned, the Monviso unit is generally considered as a fragment of the Upper Jurassic Tethyan oceanic lithosphere, subducted at the Paleocene-Eocene boundary (Lagabrielle and Cannat 1990). However, the eclogites show metamorphic pressures varying from 1.2 GPa to 2.4 GPa and independent of the size of blocks from decimetres to kilometres (Messiga et al. 1999, Schwartz et al. 2000, Castelli et al. 2002). This suggests that the Monviso massif does not represent a continuous fragment of the Tethyan lithosphere. Instead, it is an assemblage of tectonically juxtaposed slices that were subducted to different depths. Furthermore, PT conditions of different units do not show any logical arrangement (Fig. 6), suggesting that this tectonic juxtaposition was unlikely to have taken place during the exhumation. Finally, the basal unit records variable P-T conditions from a minimum of 1.3 GPa and 470 °C to 2.0 GPa and 575°C (Blake et al. 1995, Schwartz et al. 2000, Castelli et al. 2002). The evidence collectively suggests that the Monviso is a tectono-metamorphic melange with variable eclogitic blocks in a serpentinite matrix. Our proposed interpretation is supported by numerical modelling by Gerya et al. (2002) and Stöckert and Gerya (2005) which showed that a subduction channel with low viscosity (~ 10^{19} Pa.s) favoured the formation of a large melange. If the Monviso massif represents the exhumed part of a subduction channel, the varied ages of eclogites between 61 ± 10 Ma and 45 ± 1 Ma may be related to the different blocking temperatures of isotope systems. This is a long standing problem in metamorphic rocks (Monié and Chopin 1991, Arnaud and Kelley 1995, Rubatto and Hermann 2003). Alternatively, these ages may signify different events in the serpentinized channel. This may be supported by the fact that these ages do not overlap each other. Thus, we favour the latter interpretation. In this case, it gives a duration for operation of the serpentinized channel of 5 to 15 Ma.

The exhumation of rocks requires a mechanically weak zone at the interface between the subducting plate and overlying mantle peridotites (Cloos 1982, Closs and Schreeve 1989, Platt 1993, Allemand and Lardeaux 1997). At the depths greater than 40-50 km, hydrated peridotites can play the role of the lubricant (Hermann et al. 2000, Guillot et al. 2000, Gerya et al. 2002). The exhumation of dense eclogitic blocks (>3500 kg.m3) in a buoyant serpentinite matrix (<2700 kg.m3) requires a dynamic return flow (corner flow). Assuming a Newtonian rheology of serpentinites in subduction conditions (Gerya and Stöckert 2002, Auzende et al. 2005), the velocity and the size of the exhumed eclogitic blocks are controlled by Stoke's law (Cloos 1982). In our previous paper (Schwartz et al. 2001) we have numerically evaluated the possibility that the eclogitic blocks similar to those in the Monviso can be exhumed in a low viscosity channel (Fig. 10). The exhumation of decimetric to kilometric eclogitic blocks at a velocity of one cm/yr requires the low viscosity channel of about 10 km width and a minimum viscosity of 10^{20} Pa.s. The viscosity is similar to the result obtained by Guillot et al. (2001) and Stöckert and Gerya (2005). The viscosity imposes that the channel is composed of partially (up to 50%) hydrated peridotites.

Our proposed interpretation is supported by the geophysical evidence for a 10 km thick hydrated peridotites layer along Pacific subduction zones (Bostock et al. 2002, Billen and Gurnis 2003, Seno and Yamasami 2003). The cross section of the Monviso (Fig. 4) suggests that the serpentinite subduction channel had a minimum thickness of 4 km. The total length of this channel is difficult to estimate, but may be 40 to 50 km long if the Monviso massif extends beneath the Dora Maira massif and has a depth of 10 km on its western part (Paul et al. 2001) (Fig. 4). The first assumption is supported by geophysical data farther north of the study area (Escher et al. 1997).

Figure 10. Schematic evolution



Schematic evolution of the Piedmont subduction zone from Upper Cretaceous to Eocene. The Schistes Lustres accretionary wedge is separated from the serpentinite channel overlying the subduction zone. Note that the serpentine channel records internal motions during the Paleocene, whereas, the initiation of the subdcution of the Continental European margin in Eocene time stopped the activity inside the subduction channel, leading to the final exhumation of the Monviso eclogitic blocks.

The length of the subduction channel is estimated using the PT conditions of eclogitic fragments in the Monviso massif. If the massif is a tectonic melange, different eclogitic blocks record the pressures of the subduction channel. The pressure difference of 1.2 GPa between the highest pressure unit (2.4 GPa, Lago Superior) and the lowest pressure unit (1.2 GPa, Passo Galarino) corresponds to a depth difference of ~ 40 km.

A question remains in respect to the relationship between the southeast dipping subduction of the European continent margin and the exhumation of the eclogitized oceanic crust (e.g. Agard et al. 2002 for a complete discussion). Polino et al. (1990) and Allemand and Lardeaux (1997) proposed that the burial and the subsequent exhumation of the oceanic plate occurred only during active subduction whereas other authors proposed that the main exhumation of the oceanic plate occurred when the buoyant continental margin subducted (Chemenda et al. 1996, Ernst 2001). In contrast, Rosenbaum and Lister (2005) proposed a collisional event at 45 Ma.

The relationship between the exhumation and continental subduction is clear north of the study area along a Gran Paradiso Zermatt-Saas transect. The HP metamorphism in Zermatt-Saas ophiolite is dated at 40.6 ± 0.6 Ma by Sm-Nd isotopes whereas the HP metamorphism of the European continent at the Gran Paradiso massif is estimated to have occurred at a 43.0 ± 0.5 Ma (Rb-Sr isochron based on microsampling). The data suggest that HP metamorphism was synchronous. Stöckhert and Gerya (2005) also show by numerical simulation that the peak of metamorphism in the Internal Alps is probably contemporaneous for continental and oceanic units, 10 to 20 Ma after the initial subduction of the European continent. In the Monviso area, the relationship between oceanic and continental subdution is not so clear. In fact, the HP metamorphism in the Monviso ophiolite occurred between 60 and 45 Ma whereas the UHP metamorphism in the nearby continental unit of Dora Maira is dated between 31 and 35 Ma (Duchêne et al. 1997, Gebauer et al. 1997, Cliff et al. 1998, Rubatto and Hermann 2001). We can assume than the subduction and subsequent exhumation of the Monviso massif occurred before the continental subduction of the Dora Maira continental massif (Fig. 10). However, a low convergence rate, about 6-8 mm.yr-1, of the Western Tethys from Late Cretaceous to Eocene (Facenna et al. 2001, Schettino and Scotese 2002) suggests a minimum of 17 Ma for the time required for the Dora Maira massif to reach the depth of 120 km for the UHP metamorphic conditions. This implies that the continental subduction initiated before 45-50 Ma in the studied area, i.e. at the time of the HP metamorphism in the Monviso unit. Thus we conclude that the exhumation of the Monviso massif is broadly contemporaneous with the continental subduction of the Dora Maira massif (Fig. 10).

Conclusion

The Monviso ophiolitic massif in the Western Alps is one of the best exposed serpenite subduction channels. As has been suggested for over 30 years, metamorphosed mafic igneous rocks in the Monviso ophiolite were originally oceanic basalts formed at a slow spreading ridge on the western Tethys ocean floor. The origin of the serpentinites remains partly unclear, but the majority of serpentinites are likely derived from oceanic lherzolites. Some refractory harzburgites at the basal unit may have derived from the mantle wedge overlying the subduction plate, as observed in the Himalaya and presently observed along Pacific subduction zones. The serpentinites are completely recrystallized under HP conditions as only the high grade antigorite specimen of serpentine is observed. The low viscosity of serpentinites favours the formation of a low viscosity subduction channel (10^{19}-10^{20} Pa.s) where cm to kilometric blocs of eclogitized oceanic crust are incorporated at different depths and exhumed together to blueschist facies conditions along a 40-50 km long subduction channel with a width of 4 to 10 km. The time difference between the different units of 5 to 15 Ma may reflect the minimum life span of serpentinite subduction channel. Finally we propose that this serpentinite subduction channel ended when continental subduction started at about 45-40 Ma.

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