Tectonophysics 568–569 (2012) 102–123

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

The exhumation of high pressure ophiolites (Voltri Massif, Western Alps): Insights from structural and petrologic data on metagabbro bodies

C. Malatesta *, L. Crispini, L. Federico, G. Capponi, M. Scambelluri

Dipartimento per lo Studio del Territorio e delle sue Risorse, Università degli studi di Genova, corso Europa 26, 16132, Genoa, Italy

ARTICLE INFO

Article history:
Received 28 February 2011
Received in revised form 23 August 2011
Accepted 28 August 2011
Available online 8 October 2011

Keywords:
HP–LT metamorphism
Exhumation
Subduction channel
Tectonic mélange
Voltri Massif
Western Alps

ABSTRACT

Serpentinites can enhance the exhumation of HP-rocks by lowering the bulk density of subducted material and by establishing a low-viscosity channel between the lower and upper plates; this mechanism has been proposed for a 100 m-scale tectonic mélange outcropping inside the Voltri Massif (Ligurian–Piemontese Units, Western Alps, Italy). We want to test if the mechanism of the subduction channel is feasible at a larger scale, i.e. for the km-scale Voltri Massif, that consists of metaophiolites recording blueschist to eclogite facies peak conditions.

We identified a study area in the eastern part of the massif made of highly sheared serpentinite which hosts lenses of metagabbros; a strong strain partitioning between host-rock and the lenses and between core and rims of the lenses occurs.

We coupled P–T pseudosections, garnet–omphacite geothermometry and petrographic observations and we obtained clockwise P–T paths with almost isothermal decompression trajectory. The analyzed blueschist lens recrystallized at peak conditions of 10–15 kbar and 450–500 °C; the eclogitic ones reached peak metamorphic conditions ranging from about 21 kbar and 450–490 °C to 22–28 kbar and 460–500 °C; the studied bodies thus recorded different metamorphic peaks acquired at slightly different T conditions.

Comparing our results with literature data, a large scatter in the metamorphic peak conditions is displayed, with peak temperatures up to 650 °C and pressures ranging from 18 to 25 kbar.

(1) The presence of poorly deformed lenses (from m- to km-scale) of heterogeneous lithologies inside highly sheared serpentinite and metasediments country-rocks, (2) the strong strain partitioning and (3) the heterogeneous metamorphic peak conditions of the different lenses allow us to suggest that the Voltri Massif matches the requirements of a tectonic mélange; in particular the eastern sector may thus represent a "fossil" serpentinite-subduction channel, comparable to the small-scale one already described in the western sector of the Voltri Massif.

1. Introduction

The exhumation of high-pressure (HP) and ultra high-pressure (UHP) rocks is presently subject of tectonic and petrologic debates. Different models have been proposed so far to explain uprise of such rocks from depths greater than 100–120 km (Compagnoni and Rolfo, 2003; Guillot et al., 2004; Pilchin, 2005 and references therein) and their emplacement at crustal levels in orogenic belts. Such models have been derived from field and petrological studies (Duchêne et al., 1997; Engi et al., 2001; Hermann et al., 2000; Pilchin, 2005; Platt, 1993) as well as from analog and numerical models (Chemenda et al., 1996; Cloos, 1982; Gerya et al., 2002; Roda et al., 2010). Models invoke several mechanisms such as:

(I) channel flow Cloos (1982);
(II) corner flow (Platt, 1993);
(III) thrusting towards the foreland followed by erosion (Chopin, 1987; Guillot et al., 2009; Steck et al., 1998);
(IV) extensional collapse of orogens (Dewey et al., 1993; Guillot et al., 2009);
(V) buoyancy uplift driven by erosion and tectonic processes (Chemenda et al., 1996; Guillot et al., 2009);
(VI) compression of a soft zone between two rigid blocks (Guillot et al., 2009; Thompson et al., 1997);
(VII) extension associated with a decoupling fault (Guillot et al., 2009; Jolivet et al., 2003; Sedlock, 1999);
(VIII) the serpentinite channel (Gerya et al., 2002; Guillot et al., 2001); and
(IX) the extrusion wedge (Ring et al., 2007).

The exhumation of continental rocks is buoyancy-driven and it is relatively fast at mantle depths (≥cm/yr) (Rubatto and Hermann, 2001); according to Chemenda et al. (1996) and Agard et al. (2009), uprise of continental rocks takes place as a first approximation through extrusion and can be enhanced by breakoff of the slab. Differently, the ocean-floor

* Corresponding author. Tel.: +39 010 353 8280.
E-mail address: cristina.malatesta@unige.it (C. Malatesta).

0040-1951/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2011.08.024

sediments and the oceanic lithosphere record lower exhumation velocities (on the order of mm/yr) (Agard et al., 2009). High-density blueschist and mafic eclogites are mostly associated with serpentinites and/or with a muddy/shaly mechanically weak matrix (Agard et al., 2009; Hermann et al., 2000; Schwartz et al., 2001), suggesting a different driving force for their exhumation.

Gerya et al. (2002) and Stöckhert and Gerya (2005) simulated various subduction processes using numerical models: they have suggested that the influx into the mantle wedge of fluids released from the subducting slab can enhance formation of a serpentinitic layer. Before collision, circulation and exhumation of slices from the slab are provided by forced return flow inside such a low viscosity channel. Therefore the development of a serpentinite channel implies decoupling between the exhumed slices and the rest of the slab. Consequently, peculiar structural relations with the surrounding matrix, variable P–T paths and diachronous metamorphic evolutions are expected to be observed in the exhumed slices (e.g. Gerya et al., 2002).

Several Phanerozoic ophiolite massifs have been related to the "serpentinite channel" exhumation mechanism (Guillot et al., 2009; Schwartz et al., 2007). These HP–LT units are mostly exposed in the internal part of an orogen and are dominated by highly sheared serpentinite containing metabasite bodies. The bodies are weakly deformed and record different P–T conditions.

Two referenced examples from the Western Alps are represented by the Monviso Massif and the Cascine Parasi mélange from the Voltri Massif (Federico et al., 2007; Guillot et al., 2009; Schwartz et al., 2007). The Monviso Massif is made of kilometric blocks mostly composed of serpentinite hosting metric to a 100 m-size lenses of metagabbro and metabasalts. Each block in the Monviso Massif records different P–T conditions: therefore it can be considered as a dismembered ophiolitic sequence and a deep tectonic mélange (Guillot et al., 2009).

The Voltri Massif consists of two major tectono-metamorphic units mainly composed of meta-ophiolites and metasediments. In this Massif, Federico et al. (2007) described a 100 m-sized serpentinite-hosted tectonic mélange (Cascine Parasi mélange) that consists of 1 to 10 m-sized lenses of metabasalts, metagabbros and metasediments in a foliated serpentine–chlorite–actinolite matrix. The blocks equilibrated at different diachronous HP metamorphic peak conditions. According to Federico et al. (2007), such lenses were tectonically incorporated within the ductile ultramafic matrix during forced return flow in a subduction channel.

The Cascine Parasi mélange represents a small volume in the Voltri Massif and it is now a general interest to test if this process worked over a larger scale, involving larger bodies of HP rocks within serpentinites, i.e. the whole Voltri Massif.

In this paper we focus on the structural and metamorphic architectures of the eastern part of the Voltri Massif on the basis of new detailed field mapping and petrologic studies.

This sector of the Voltri Massif lacks detailed petrological study coupled with structural analyses, historically focused either on the western (Vara area) or central (Rossiglione surroundings) portions of the massif (see Messiga and Scambelluri, 1991; Messiga et al., 1983; Vignaroli et al., 2005, 2010).

The aim of this paper is to discuss the possible interpretation of the whole Voltri Massif as a large-scale tectonic mélange, where slices and boudins of different rocks and with different peak metamorphic assemblages are enclosed in a serpentinite and/or metasedimentary matrix that shares corresponding parts of the entire structural history.

Finally we analyze the possible exhumation mechanisms that affected this area of the Western Alps.

2. Geological background

The Voltri Massif is located at the transition from the Alps to the Apennines, in the southeastern termination of the Western Alps and it is part of the Penninic ophiolites; it is constituted by metamorphic rocks derived from the Jurassic Ligurian–Piemontese ocean, which separated the European and Apulian microplates (Piccardo, 1984; Vanossi et al., 1984), slices of subcontinental lithospheric mantle, and minor slices of rocks derived from the paleo-European continental margin.

The Voltri Massif rocks underwent a multistage metamorphic evolution with blueschist- to eclogite facies peak metamorphism (Cimmino et al., 1979; Cortesogno et al., 1977; Federico et al., 2005; Messiga and Scambelluri, 1991) and variable retrogression overprints.

Hereafter we will resume the main geological and petrologic knowledge about the Voltri Massif and we will adopt the outline by Capponi and Crispini (2008b) for the description of the eastern sector of the Voltri Massif. After these Authors, this area is composed of two main tectono-metamorphic units recording different peak metamorphic conditions but with a common exhumation history: i) the blueschist facies Palmaro–Caffarella Unit (Cabella et al., 1994; Cortesogno et al., 1979), formed by metamorphic slices of ophiolites and ii) the eclogite facies Voltri Unit, which encompasses slices of different paleogeographic origins, including meta-ophiolites, metasediments and subcontinental lithosphere mantle that share a corresponding multistage petrologic–structural evolution.

2.1. Voltri Unit and Palmaro–Caffarella Unit

In both the Voltri and the Palmaro–Caffarella units (Fig. 1), the metaophiolites largely consist of serpentinites enclosing metagabbro bodies and lenses of metabasalt and minor metarodingite. Serpentinites are the dominant lithology and locally they also form lenses inside metasediments, where they are wrapped by chlorite–amphibole–talc schists (Crispini, 1996; Hoogerduijn Strating, 1991). Metagabbros outcrop as 10 to 100 m-sized bodies, elongated along the regional foliation, mostly enclosed in larger volumes of serpentinites and/or metasediments (Capponi et al., 2008a; Cortesogno et al., 1975; Hoogerduijn Strating, 1991). Deformation partitioning inside metagabbro bodies allows the preservation of texture related to the magmatic or to the LP–HT (low pressure–high temperature) oceanic stage; the deformation is localized at the contact with the host-rock or in shear zones (Liou et al., 1998; Messiga et al., 1995).

Undifferentiated metabasites occur in serpentinites as strongly foliated plurimetric isolated bodies along the regional foliation or as intercalations in metasediments and they represent the least abundant lithology.

Metasediments represent the metamorphosed sedimentary cover of the Ligurian–Piemontese ophiolitic basement; ocean-derived metasediments are quartzschists, calcschists and micaschists and are locally associated to metabasites and marbles (Chiesa et al., 1976; Cortesogno et al., 1979).

In the Voltri Unit the metasediments represent to a lesser extent also metamorphosed slices of the thinned European continental crust (Capponi, 1987; Messiga et al., 1983; Vanossi et al., 1984). Another peculiar feature of the Voltri Unit is the occurrence of portions of subcontinental mantle, that became exposed on the seafloor during opening of the Ligurian Tethys; they occur as m- to km-scale peridotite with minor amount of associated metagabbros and metarodingites (Erro–Tobbio Unit Auct.; Borghini et al., 2007; Ernst, 1981; Hoogerduijn Strating et al., 1993; Messiga and Piccardo, 1974; Piccardo, 1984; Scambelluri et al., 1995). Peridotite bodies show a variable degree of serpentinization that, in most cases, did not fully overprint the pre-Alpine mantle structures and mineral assemblages (Borghini et al., 2007; Piccardo and Vissers, 2007; Piccardo et al., 2009; Rampone et al., 2005; Scambelluri et al., 1997; Vissers et al., 1991). Peridotites are surrounded by strongly foliated serpentinites and a gradual transition between them occurs (Hoogerduijn Strating, 1991; Scambelluri et al., 1995; Hermann et al., 2000; Capponi and Crispini, 2008a); at places contacts are re-worked by faults as a result of the ductility contrast between the two rock types. The high strain partitioning between serpentinite mylonites (high-strain domain) and the low serpentinized peridotites (low-strain domains) during syn-tectonic subduction