SUBDUCTION AND EXHUMATION OF HP LIGURIAN-PIEDMONTESE OPHIOLITES: AN INTEGRATED APPROACH FROM FIELD TO NUMERICAL MODELS

CRISTINA MALATESTA
Dip.Te.Ris., Università di Genova, Corso Europa 26, 16132 Genova

INTRODUCTION

Active convergent plate margins are the sites of major geologic processes, such as consumption of oceanic lithosphere, formation of continental crust, earthquakes, volcanic activity and mountain building. For this reason, the dynamics occurring in these sites attracted the interest of a wide part of the geological community.

Among the most debated topics, the subduction of oceanic lithosphere and continental crust, together with the exhumation and emplacement of high-pressure (HP) and ultra-high pressure (UHP) rocks in mountain chains, have an important role.

The study of HP and UHP rocks, recording past subduction to depths exceeding 100 km, gave important contributions on the knowledge of the dynamics acting at convergent margins. A relevant break-through the common thinking of subduction zones has been provided coupling field-based structural and petrologic analysis of natural HP- to UHP-terrains with recent numerical models (*e.g.* Burov *et al.*, 2001; Gerya *et al.*, 2002; Gorczyk *et al.*, 2007; Yamato *et al.*, 2007; Warren *et al.*, 2008; Faccenda *et al.*, 2008; Faccenda *et al.*, 2009; Roda *et al.*, 2010). A good chance to study the exhumation of subducted oceanic lithosphere is represented by the HP Ligurian-Piedmontese ophiolite units, outcropping at the eastern border of the Ligurian Alps (Western Alps); such HP ophiolites represent remnants of the oceanic lithosphere forming the Mesozoic Ligurian Tethys; this ocean separated Europe from Adria and was involved in the subduction and continental collision that finally led to its closure. Although the HP Ligurian-Piedmontese ophiolites were deeply investigated in the past, studies directly focused on the mechanism that allowed the rise from high depths of subducted rocks are still few.

The aim of this work is thus to provide new information about the exhumation mechanisms that acted in the evolution of the Ligurian-Piedmontese units; in particular, I coupled field-, petrographic- and petrologic-evidences with 2D numerical models to propose a subduction/exhumation evolutionary model.

The study was conducted in two main stages. The first stage was addressed to the structural and petrologic study of rocks that record HP conditions; I selected eclogite and blueschist-facies metagabbro bodies outcropping in the Palmaro-Caffarella Unit and in the eastern sector of the Voltri Unit and I defined their tectono-metamorphic history. The obtained P-T paths and peak P-T conditions were then added to the already existing estimates of the Palmaro-Caffarella and Voltri units.

The second stage of the work was dedicated to 2D numerical simulations reproducing intraoceanic subduction within a narrow intercontinental oceanic basin, like that of the Ligurian Tethys.

TECTONO-METAMORPHIC EVOLUTION OF THE STUDY AREA

The analyzed metagabbro bodies are part of a heterogeneous area where highly deformed serpentinite and metasediment tectonically host lenses of subcontinental lithospheric mantle, metagabbro, metabasite and metasediment of continental margin derivation.

All the studied outcrops experienced a strong strain partitioning; deformation is most pervasive in the country-rock (serpentinite or metasediment) where it acted from relatively high-pressure conditions till shallow levels (greenschist conditions); in the metagabbro bodies deformation is localized at the boundaries with the country-rock whereas the core is almost undeformed and locally preserves the igneous gabbroic texture.

In the metagabbro lenses a strong greenschist deformation is well developed only in metasediment-wrapped bodies. Such last feature suggests that the country-rock lithology may control the way in which the wrapped metagabbro reacts to the imposed stress.

An accurate petrologic and petrographic study of selected metagabbro bodies (Granara, Mt Pesucco, and Cima di Mezzo outcrops) provided further information about the metamorphic evolution of both the Palmaro-Caffarella and the eastern sector of the Voltri Unit. In order to obtain the metamorphic peak conditions and the P-T paths recorded by each metagabbro lens, as well as to avoid any influence from the rock composition, P-T pseudosections were produced and calculated for a fixed bulk-rock composition, using the programs collection PERPLE_X. The metagabbro lenses in this area show variable metamorphic peak conditions: in particular, the Granara outcrop (Palmaro-Caffarella Unit) records the lower metamorphic peak conditions of about 10-15 kbar and 450-500°C. The metagabbro bodies selected inside the Voltri Unit display values that vary from 21 kbar and 450-490°C of Cima di Mezzo outcrop to 22-28 kbar and 460-500°C of Mt Pesucco outcrop. A clockwise P-T path was inferred for at least the Granara and Mt Pesucco outcrops and an almost isothermal, slightly cooling decompression trajectory characterizes all the analyzed outcrops.

Both the field and petrographic evidences deriving from this work and the data obtained from literature indicate that in the Palmaro-Caffarella and Voltri units the different lithologies were sheared together within a serpentinite/metasediments matrix and that now the main regional schistosity controls their contacts; the different metamorphic peak conditions recorded by the rock bodies indicate that they reached variable depths along the subducting slab and that they were probably coupled during exhumation. Finally, all these evidences suggest that the Palmaro-Caffarella and Voltri Units could represent a tectonic serpentinite mélange.

RESULTS OF THE 2D NUMERICAL MODELS

Features with a general validity for several worldwide intraoceanic subduction settings can be extrapolated from the 2D numerical models produced in this work. The simulations are based on the modified code I2VIS (Gerya & Yuen, 2003); the code combines the conservative finite differences method and a non-diffusive marker-in-cell technique to simulate multiphase flow. The models reproduce the processes occurring after subduction beginning at a weak zone in the oceanic mantle. The oceanic basin is 600 km-wide and is floored by a non-layered oceanic lithosphere and by a sedimentary cover.

In every run model, a serpentinite channel forms between the subducting slab and the overriding plate. The most important parameters influencing the geometry of the channel are the serpentinite rheology, the initial slab dip, the structure, and the age of the oceanic lithosphere. Convergence rates and distances of the subduction zone from the continental margins play a minor role. Planar and wedge channels are promoted using a power-law rheology of serpentinite whereas serpentinite deforming in a Newtonian way involves formation of planar and “hourglass” channels.

Moreover, mixing and exhumation mechanisms inside the serpentinite channel are strongly controlled by the serpentinite rheology. In fact, a Newtonian rheology promotes the mixing of slab slices and sediments together with the mantle wedge serpentinites. Slab serpentinites and mantle-wedge serpentinites can be therefore closely associated in a serpentinite mélange. Exhumation of slab slices, sediments or mantle wedge serpentinites occurs even from high depths (exceeding 70 km).

Conversely, using a serpentinite power-law rheology a top serpentinite layer forms after hydration of a restricted area of the mantle wedge; in this case slices detached from the subducting lithosphere are continuously accreted at the base of the channel; sediments stagnate at the top of the channel and are incorporated within it only during continental subduction.

Serpentine rheology generally poorly affects the volcanic activity resulting from the melting of slab or mantle wedge. However, a Newtonian rheology produces a minor extension of the volcanic arc; steep and fast slabs are responsible for younger volcanism and young oceanic lithosphere produces an early volcanic activity.

AN EVOLUTIONARY MODEL FOR THE SUBDUCTION AND THE EXHUMATION OF THE HP LIGURIAN-PIEDMONTESE OPHIOLITES

This work provides new data that increase the knowledge of the tectono-metamorphic evolution of the HP Ligurian-Piedmontese ophiolites. Coupling the data derived from the petrographic and petrologic overview of the study area with the results of 2D numerical simulations, I propose an exhumation mechanism of the HP ophiolites outcropping in Liguria. Among all the run numerical models, I choose the one that best represents the subduction/exhumation dynamics experienced by the Ligurian ophiolites (Fig. 1).

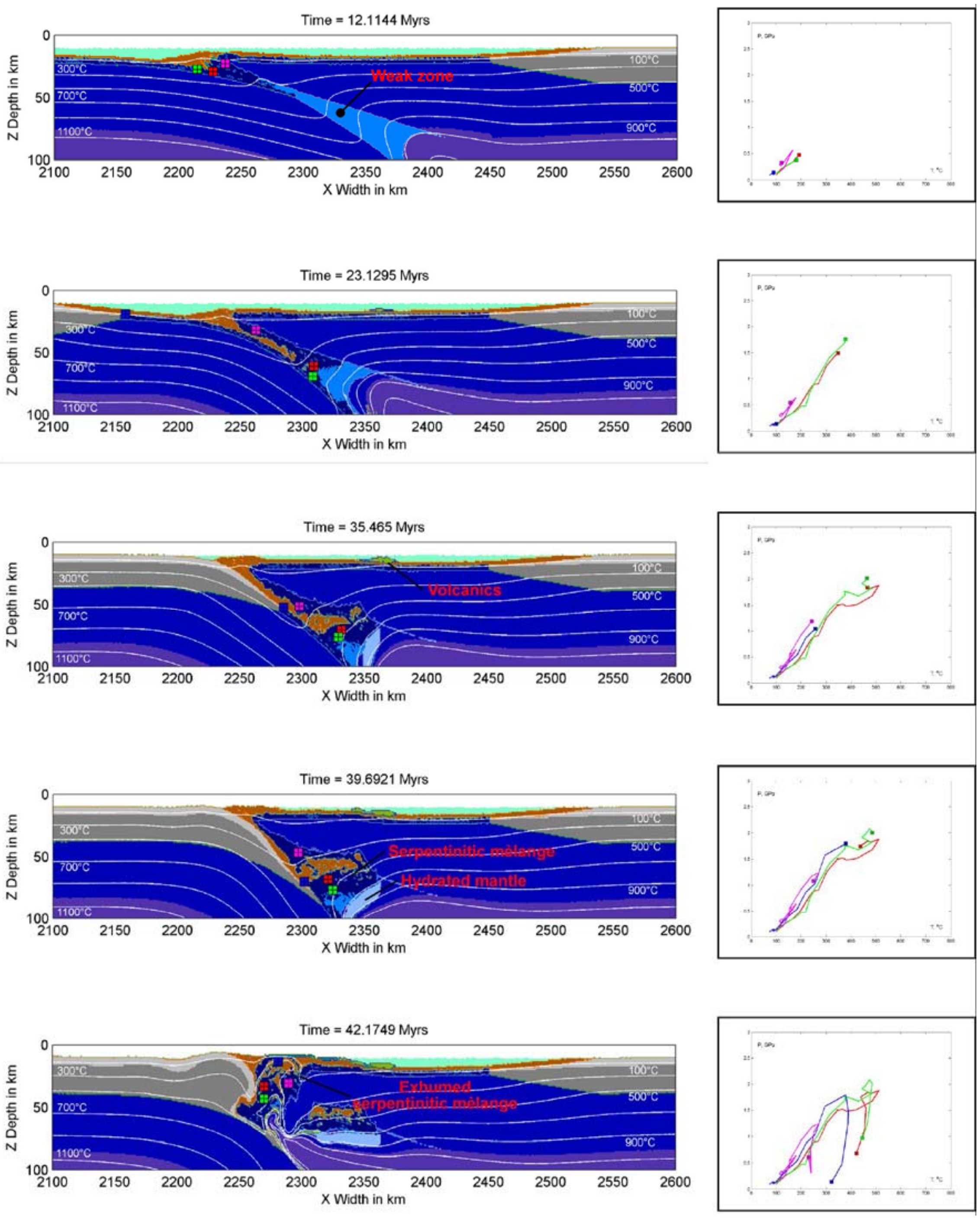

Fig. 1 - Frames of the selected numerical model representing subduction and exhumation dynamics in an intercontinental oceanic basin. The squares depict two metagabbro lenses (red and green squares), a metasediment block (blue square) and a serpentinite body (pink square). On the left, their paths in 2D dimensions are represented; the right boxes depict their trajectories in the P-T space.

This model fits several features observed in the study area: selected rock bodies in the model and the "natural" outcropping rocks show comparable P-T metamorphic evolutions and similar exhumation velocities; moreover, the ages of peak metamorphism can be compared with a good confidence. The selected numerical simulation considers a Newtonian rheology of the serpentinites, a convergence rate of 1 cm/yr, an initial slab dip of about 15°, and a distance of the subduction zone from the continental margin of 250 km.

During subduction, both in the model and in the studied area, slices of the oceanic lithosphere (*e.g.* Mt Pesucco, Cima di Mezzo outcrops) and of the sedimentary cover, either oceanic or continental (*e.g.* Angassino Terma Unit), were incorporated inside the serpentinite channel (Fig. 2).

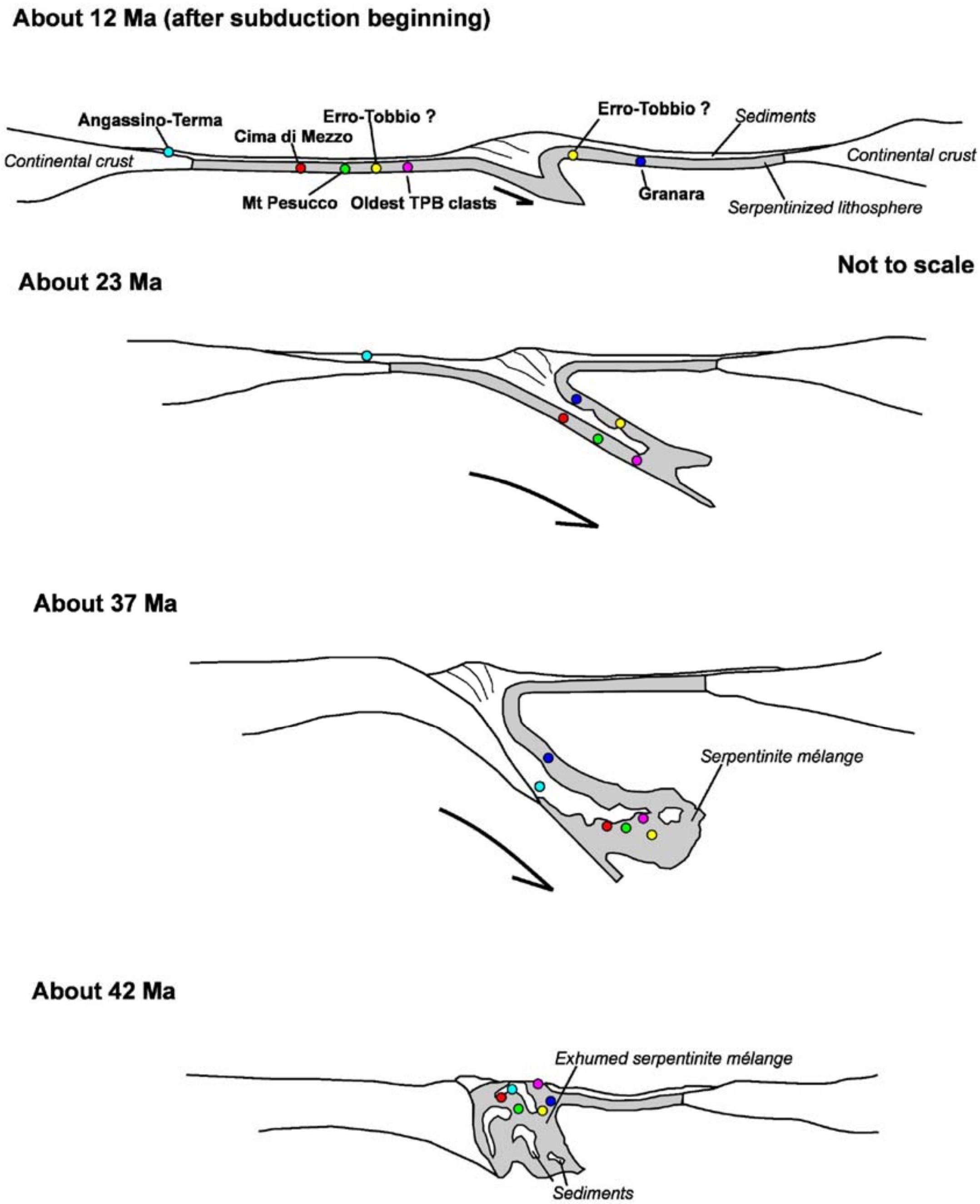

Fig. 2 - Evolutionary model of the Ligurian-Piedmontese area during subduction/exhumation processes. The former location of few outcrops (colored dots) is inferred comparing the paths of selected markers in the models with the "real" P-T paths of the outcrops.

Moreover, the model highlights that even the portions of the overriding plate (potentially the Erro-Tobbio peridotite and the Palmaro-Caffarella Unit) were subducted and mixed in the serpentinite "mélange" together with slab slices and sediments.

The rise of the rocks buried inside the serpentinite channel from high depths was controlled by a combination of several factors. Buoyancy, related to the presence of low density serpentinites, is considered the main acting force during the late exhumation of the Ligurian-Piemontese HP rocks, even if early and continuous minor exhumation events occur also during progressive subduction. During the late stage of continental subduction, a serpentinite mélange thus rise upward, following a slight slab roll-back. The exhumed mélange includes slab slices, metasediment, and portions of mantle wedge that record various and diachronous metamorphic peak conditions.

The evolutionary model proposed in this study could be applied with a good confidence only to the early orogenic stages; the final exhumation stage of the Ligurian-Piedmontese ophiolites and the relative sedimentary cover was deeply affected by the complex Oligo-Miocene evolution of the Western Alps - Northern Apennines interfering area (*e.g.* Molli *et al.*, 2010).

REFERENCES

Burov, E.B., Jolivet, L., Le Pourhiet, L., Poliakov, A. (2001): A thermomechanical model of exhumation of HP and UHP methamorphic rocks in Alpine mountain belts. *Tectonophysics*, **342**, 113-136.

Faccenda, M., Burlini, L., Gerya, T.V., Mainprice, D. (2008): Fault-induced seismic anisotropy by hydration in subducting oceanic plates. *Nature*, **455**, 1097-1100.

Faccenda, M., Minelli, G., Gerya, T. (2009): Coupled and decoupled regimes of continental collision: Numerical modeling. *Earth Planet. Sci. Letters*, **278**, 337-349.

Gerya, T.V. & Yuen, D.A. (2003): Characteristics-based marker-in-cell method with conservative finite-differences schemes for modeling geological flows with strongly variable transport properties. *Phys. Earth Planet. Int.*, **140**, 295-320.

Gerya, T., Stöckhert, B., Perchuk, A.L. (2002): Exhumation of high-pressure metamorphic rocks in a subduction channel: a numerical simulation. *Tectonics*, **21**, 1-19.

Gorczyk, W., Guillot, S., Gerya, T.V., Hattori, K. (2007): Asthenospheric upwelling, oceanic slab retreat, and exhumation of UHP mantle rocks: insights from Greater Antilles. *Geophys. Res. Letters*, **34**, 1-5.

Molli, G., Crispini, L., Malusà, M., Mosca, P., Piana, F., Federico, L. (2010): Geology of the Western Alps-Northern Apennine junction area: a regional review. *In:* "The Geology of Italy: tectonics and life along plate margins", M. Beltrando, A. Peccerillo, M. Mattei, S. Conticelli, C. Doglioni, eds. *J. Virt. Expl., Electronic Ed.*, **36**.

Roda, M., Marotta, A.M., Spalla, M.I. (2010): Numerical simulations of an ocean-continent convergent system: Influence of subduction geometry and mantle wedge hydration on crustal recycling. *Geochem. Geophys. Geosyst.*, **11,** Q05008, doi:10.1029/2009GC003015.

Warren, C.J., Beaumont, C., Jamieson, R.A. (2008): Modelling tectonic styles and ultrahigh pressure (UHP) rock exhumation during the transition from oceanic subduction to continental collision. *Earth Planet. Sci. Letters*, **267**, 129-145.

Yamato, P., Agard, P., Burov, E., Le Pourhiet, L., Jolivet, L., Tiberi, C. (2007): Burial and exhumation in a subduction wedge: mutual constraints from thermo-mechanical modeling and natural P-T-t data (Sch. Lustrés, W. Alps). *J. Geophys. Res.*, **112**, 1-28.