A Jurassic oceanic core complex in the high-pressure Monviso ophiolite (western Alps, NW Italy)

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ABSTRACT

The eclogite-facies Monviso ophiolite in the western Alps displays a complex record of Jurassic rift-drift, subduction zone, and Cenozoic collision tectonics in its evolutionary history. Serpentinized lherzolites intruded by 163 ± 2 Ma gabbros are exposed in the footwall of a thick shear zone (Baracun shear zone) and are overlain by basaltic lava flows and synextensional sedimentary rocks in the hanging wall. Mylonitic serpentinites with sheared ophicarbonate veins and talc-and-chlorite schist rocks within the Baracun shear zone represent a rock assemblage that formed from seawater-derived hydrothermal fluids percolating through it during intra-oceanic extensional exhumation. A Lower Cretaceous calc-schist, marble, and quartz-schist metasedimentary assemblage unconformably overlies the footwall and hanging-wall units, representing a postextensional sequence. The Monviso ophiolite, Baracun shear zone, and the associated structures and mineral phases represent core complex formation in an embryonic ocean (i.e., the Ligurian-Piedmont Ocean). The heterogeneous lithostratigraphy and the structural architecture of the Monviso ophiolite documented here are the products of rift-drift processes that were subsequently overprinted by subduction zone tectonics, and they may also be recognized in other (ultra)high-pressure belts worldwide.

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INTRODUCTION

Submersible surveys, geophysical studies, and deep ocean drilling projects during the last two decades have provided new insights into the mode and nature of magmatic, tectonic, and hydrothermal processes that occur along slow- to ultraslow-spreading ridges (e.g., Cannat, 1993; Tucholke et al., 1998; Dilek, 2002; Karson et al., 2006). These studies have revealed the occurrence on the seafloor of oceanic detachment faults and associated shear zones with deformed mafic-ultramafic rocks. Detachment faults along nonvolcanic rifted margins and in young oceanic lithosphere accommodate high-magnitude extension, causing the exhumation of lower-crustal gabbros and upper-mantle peridotites on the seafloor, forming oceanic core complexes (Cannat et al., 2006; Karson et al., 2006; Smith et al., 2014). These rocks display mineral assemblages and structural fabrics developed during the interplay of ductile and brittle deformation episodes, fluid-rock interactions, and metasomatism associated with their exhumation (Boschi et al., 2006).

Recognition of detachment faults and core complex structures in fragments of ancient oceanic lithosphere is often difficult because of the multistage, intense deformation and metamorphism they experienced during subduction and subsequent continental collision–related exhumation. Yet, slivers of mafic-ultramafic rock assemblages in collision zones have been widely used in numerous studies to document the occurrence of remnants of oceanic basins and to reconstruct their paleogeographies in the geological past (Decandia and Elter, 1972; Lagabrielle, 1994; Dilek and Thy, 1998; Manatschal et al., 2011; Balestro et al., 2014; Dilek and Furnes, 2014). However, results of such reconstructions may lead to misleading interpretations for the tectonic settings of the investigated ophiolites and for the extent of the inferred ocean basins in which they formed, if the primary seafloor structures of these ophiolites go undetected.

In this paper, we document the internal structure of the eclogite-facies Monviso ophiolite in the western Alps (Fig. 1), and we show that despite the overprint of high-pressure subduction-zone metamorphism and deformation of its lithological units, this ophiolite displays a well-preserved record of the intra-oceanic extensional tectonics that affected it during the opening of the Ligurian-Piedmont Ocean. We further discuss the crustal architecture and the occurrence of a talc-and-chlorite schist shear zone (i.e., Baracun shear zone of Balestro et al., 2015) in Monviso, which represent evidence of Jurassic oceanic core complex development, documented for the first time in the eclogitized ophiolite units in the western Alps.

REGIONAL GEOLOGY OF THE WESTERN ALPS AND THE MONVISO OPHIOLITE

The western Alps (Fig. 1A) evolved between the colliding Adria microplate and the European plate during the late Eocene–early Oligocene. Eastward subduction of the Ligurian-Piedmont oceanic lithosphere during the Early Cretaceous–middle Eocene resulted in ophiolite emplacement (Rosenbaum and Lister, 2005, and reference therein), underthrusting of the European continental margin beneath Adria (Platt et al., 1989), and tectonic imbrication along WNW-vergent thrust faults (Ricou and Siddans, 1986). In the central part of the belt, eclogite-facies ophiolite units (e.g., Zermatt-Saas zone Auctorum) and blueschist-facies metasedimentary units (Combin zone and "Schistes Lustrés" Auctorum) are tectonically sandwiched between European and Adriatic continental margin units (Fig. 1A; Dal Piaz et al., 2003).

The Monviso ophiolite is exposed in the southern part of the western Alps (Fig. 1), where it rests tectonically on the Dora Maira unit, which was part of the European continental margin (Dal Piaz et al., 2003), and below the Queyras Schistes Lustrés unit, which consists of carbonaceous metasedimentary rocks with meta-ophiolite bodies (Lombardo et al., 1978; Tricart and Lemoine, 1991). The Monviso ophiolite includes lherzolitic mantle rocks intruded

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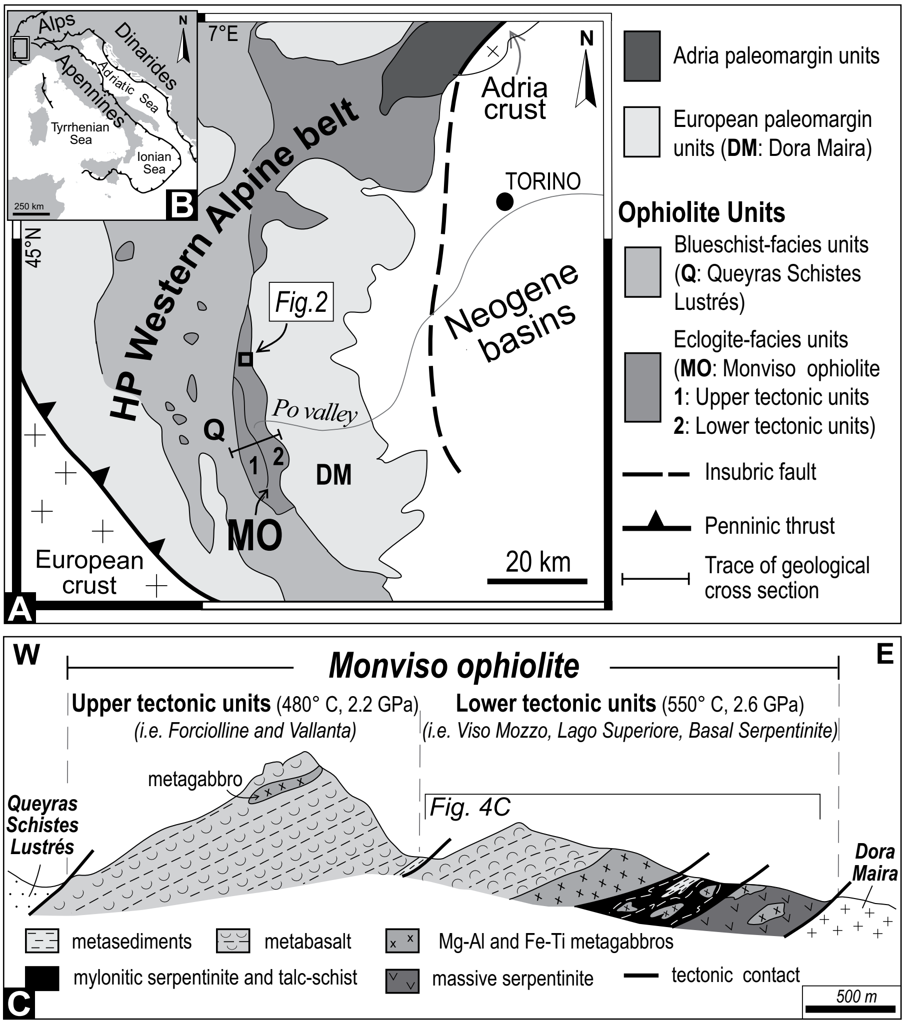

Figure 1. (A) Simplified tectonic map of the western Alps. HP—high pressure. (B) Location of map in A. (C) Representative structural cross section of the Monviso (modified from Angiboust et al., 2011; Balestro et al., 2013).

by Middle–Upper Jurassic metagabbros (163 ± 2 Ma; Rubatto and Hermann, 2003). Both the metaperidotites and metagabbros are overlain by tholeiitic metabasaltic lavas and an Upper Jurassic–Lower Cretaceous metasedimentary sequence along major tectonic contacts (Angiboust et al., 2011; Balestro et al., 2013, and reference therein; Fig. 1C). As a result, the Monviso ophiolite consists of a pile of superposed tectonic units (Fig. 1C), heterogeneously affected by high-pressure metamorphism (T = 550 °C and P = 2.6 GPa for the Basal Serpentinite, Lago Superiore, and Viso Mozzo lower units; T = 480 °C and P = 2.2 GPa for the Forciolline and Vallanta upper units; Angiboust et al., 2012), formed during three main phases of deformation-metamorphism (Balestro et al., 2015): (1) Paleocene to middle Eocene contractional deformation (D_1), and eclogite-facies metamorphism at an E-dipping subduction zone, during which S_1 foliation was developed; (2) late Eocene–early Oligocene continental collision stage, which caused W-vergent thrusting (D_2) and blueschist- to greenschist-facies metamorphic reequilibration, producing S_2 foliation and F_2 folds; and (3) middle Oligocene–Miocene crustal exhumation (D_3), uplift, and doming of the Dora Maira unit and westward tilting of the Monviso ophiolite.

Next, we describe the lower part of the Monviso ophiolite, corresponding to the Basal Serpentinite, Lago Superiore, and Viso Mozzo units, which display the same peak pressure-temperature conditions of metamorphism.

STRUCTURE OF THE BARACUN SHEAR ZONE

The Baracun shear zone within the Monviso ophiolite is best exposed at Colle del Baracun (Figs. 1A and 2), where it is marked by up to tens-of-meters-thick talc-and-chlorite schist rocks, separating metaperidotites and 163 ± 2 Ma metagabbros (Rubatto and Hermann, 2003) in the footwall from metabasalt and calc-schist with ophiolite-derived detrital intercalations in the hanging wall (Figs. 2, 3A, and 3B). Both the hanging-wall and footwall assemblages and the Baracun shear zone (Figs. 2 and 3A–G) are unconformably overlain by a Lower Cretaceous (Lagabrielle, 1994) metasedimentary sequence (i.e., postextensional succession), which is metamorphosed along with the rest of the assemblage (i.e., high-pressure eclogitic-facies metamorphism).

Footwall and Hanging-Wall Units of the Baracun Shear Zone

Lithological units in the footwall of the Baracun shear zone include massive serpentinite with poorly preserved relics of the original mineral phases and textures. Metagabbroic intrusions are meters to tens of meters thick and are composed mainly of Mg-Al metagabbro characterized by the occurrence of Cr-omphacite. Less common Fe-Ti metagabbro intrusions occur as meters-thick dikes and contain eclogitic assemblages of garnet-omphacite-rutile. At the contacts with their host metaperidotites, all metagabbro intrusions are extensively rodingitized. The massive serpentinite immediately beneath the Baracun shear zone includes 50-cm- to 1-m-thick mylonitic serpentinite with sheared ophicarbonate veins (Fig. 3H). These carbonate-rich veins, which also crosscut the talc-and-chlorite schist of the Baracun shear zone (Figs. 3H–3I), are overprinted by S_1 foliation and F_2 folds, constraining the timing of hydrothermal activities to a pre–eclogitic-facies metamorphic stage.

The hanging-wall units above the Baracun shear zone consist mainly of calc-schist and metabasaltic rocks. The calc-schist defines a wedge-shaped stratigraphic unit, increasing in thickness from several meters to ~70 m away from the Baracun shear zone (Figs. 2 and 3B). The calc-schist mainly consists of carbonates, quartz, and white mica, with subordinate textural relics of lawsonite, and it hosts lenticular intercalations, up to meters thick, of clast- to matrix-supported metabreccia with clasts of gabbroic material (Fig. 3B), which is laterally gradational into a metasandstone unit (Balestro et al., 2014). To the south (Fig. 2), the hanging-wall succession consists mainly of metabasalt that preserves relics of brecciated structures, and it is characterized by alternating greenish/yellowish levels, composed of albite, epidote, and clinozoisite, and dark-green levels of Na-Ca amphibole, garnet, and chlorite. These are in

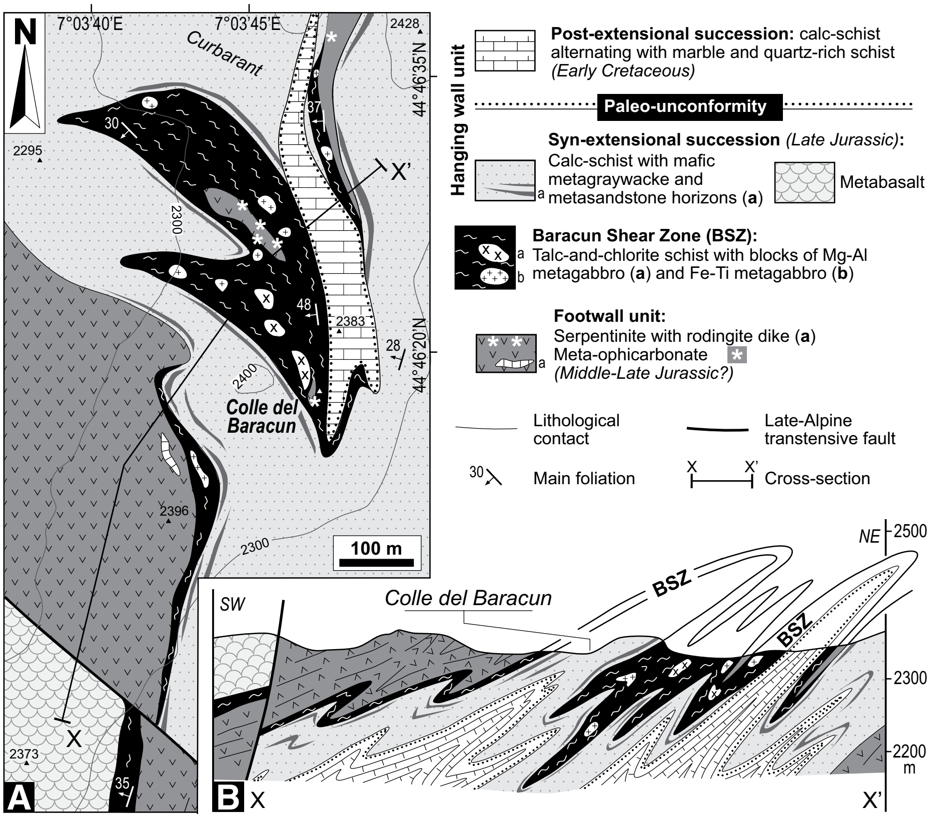

Figure 2. (A) Geological map of the Colle del Baracun section, and (B) cross section depicting the geometry of the Baracun shear zone (BSZ).

tectonic contact with calc-schists along a late-Alpine, NW-SE–striking transtensional fault, which juxtaposes the overturned and upright limbs of a D_2 macroscale fold.

Shear Zone Rocks and their Mineralogy

Decimeter- to several-meter-wide blocks of Mg-Al and Fe-Ti metagabbros are embedded in a talc-and-chlorite schist matrix within the Baracun shear zone (Figs. 3A–3B). These blocks are lithologically similar to the metagabbro intrusions in the footwall metaperidotites. Importantly, there is no material within the Baracun shear zone that was derived from the postextensional Lower Cretaceous metasedimentary succession or metabasaltic rocks. Metagabbro blocks are draped by a clast-supported, several-decimeter-thick mafic metabreccia (Figs. 3O–3P). Clasts and the matrix in this metabreccia are also made of metagabbros as in the blocks, and the entire metabreccia horizon and the gabbroic blocks are foliated (S_1) and folded (F_2; Fig. 3P; Balestro et al., 2015). These structural relationships clearly constrain the brecciation process as having occurred before the D_1 deformation stage (i.e., before eclogitic-facies metamorphic stage).

Rocks within the Baracun shear zone show different chlorite-, talc-, and amphibole-rich domains (Figs. 3L–3M), which are deformed by F_2 folds (see Figs. 3M–3N). Chlorite-rich domains consist of chlorite, magnetite, pistacite, and accessory apatite, magnetite, allanite, and zircon. Talc-rich domains are composed of talc and fine-grained magnetite, whereas amphibole-rich domains include fine-grained, light-green amphibole and minor chlorite. Calcite locally occurs between these different domains. Our electron microprobe (EMP) mineral chemistry analyses have shown that (1) talc is characterized by a negligible substitution of Mg by Fe (X_{Fe} = [0.04–0.09]), (2) chlorite has a penninite (i.e., Mg-rich solid solution between serpentine and amesite) composition (X_{Mg} = [0.88–0.95]), (3) amphibole generally belongs to the tremolite-actinolite series, and (4) talc and chlorite are characterized by high Cr and Ni concentrations. The highest concentrations of Cr and Ni (Cr_2O_3 = 0.23 wt% and NiO = 0.32 wt% in talc; Cr_2O_3 = 1.75 wt% and NiO = 0.33 wt% in chlorite) occur in the core of zoned, coarse-grained talc and chlorite grains and, particularly, within pre-D_1 talc and chlorite lamellae included in apatite grains. Talc and chlorite also have a relatively high chlorine content (up to 900 ppm and 500 ppm, respectively).

Unconformable Sealing of the Baracun Shear Zone

The Baracun shear zone and related hanging-wall and footwall units are unconformably overlain by alternating, centimeter- to decimeter-thick layers of calc-schist, marble, and quartz-schist, devoid of any ophiolite-derived detrital material (Figs. 3A–3G). The age of these metasedimentary rocks, which thus represent a postextensional succession (i.e., postrift), was constrained as the Early Cretaceous by Lagabrielle (1994) based on a correlation with other sections of the western Alps, and comparison with the unmetamorphosed stratigraphic succession in the Northern Apennines (e.g., Decandia and Elter, 1972). The basal contact between this succession and both the underlying calc-schist alternating with ophiolite-derived horizons of the hanging wall (i.e., Curbarant and east of Colle del Baracun), and the talc-and-chlorite schist of the Baracun shear zone (Colle del Baracun and south of Curbarant) is sharp (Figs. 3C–3E and 3G) and corresponds to a depositional surface as inferred from the lack of any mylonitic structure associated with it (Fig. 3F). Furthermore, field observations clearly show that this unconformable contact is folded together with the Baracun shear zone structural architecture (including hanging-wall and footwall units) due to the superposition of D_1 and D_2 stages (Fig. 2). Collectively, these structural data constrain the slip and faulting activities along the Baracun shear zone to the pre–Early Cretaceous.

MONVISO OPHIOLITE AND THE BARACUN SHEAR ZONE AS A JURASSIC OCEANIC CORE COMPLEX

We interpret the Monviso ophiolite and the Baracun shear zone as an oceanic core complex, and we discuss here several independent lines of evidence for its origin (Fig. 4). In our model, the lherzolitic peridotites in the footwall of the Baracun shear zone represent an exhumed lithospheric mantle. They were intruded by gabbroic dikes and plutons, the magmas of which were produced by decompressional melting of the asthenosphere during its slow upwelling. Basaltic lavas and the Upper Jurassic clastic rocks in the hanging wall represent a synextensional (i.e., synrift) sequence resting on the peridotites and gabbros. These processes are reminiscent of those that produce oceanic core complexes, in which deformed older rocks are tectonically overlain along detachment faults by relatively unde-

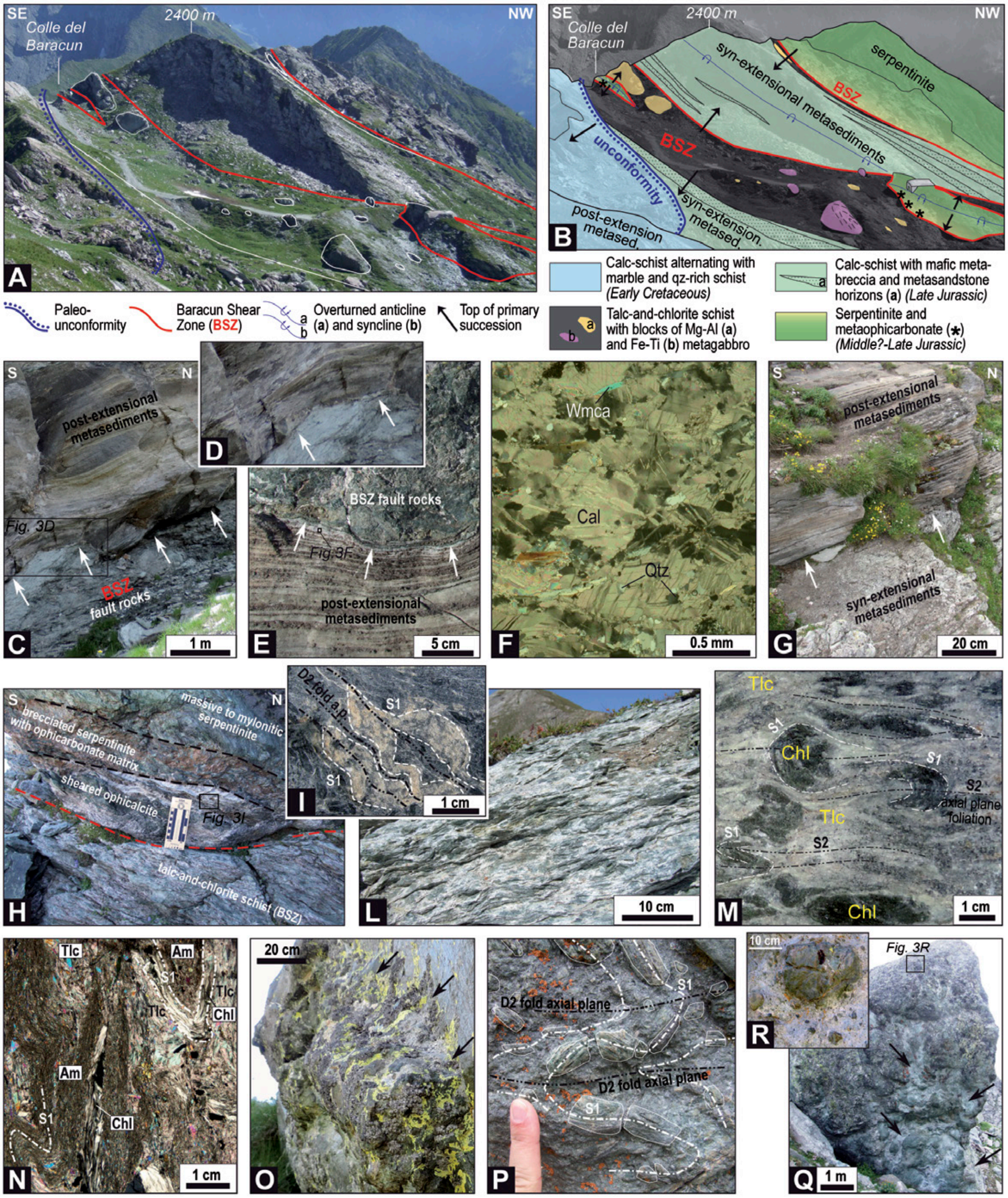

Figure 3. (A) Panoramic view, and (B) line drawing of the Baracun shear zone (BSZ), showing postextensional sedimentary sequence resting unconformably on the talc-and-chlorite schist of the Baracun shear zone, and serpentinite and synextensional sequence. (C, D, E) Views of the postextensional sequence unconformably resting on the Baracun shear zone. Note that in Figure 3E, the sequence is overturned. (F) Photomicrograph of a marble layer occurring in the Lower Cretaceous metasedimentary succession, a few centimeters above the contact with the talc-and-chlorite schist of the Baracun shear zone. The marble is poorly foliated, and calcite crystals show a weakly deformed granoblastic texture. Key to lettering: Wmca—white mica, Cal—calcite, Qtz—quartz. (G) Postextensional metasedimentary rocks unconformably overlying the synextensional metasedimentary units. (H) Close-up view of the overturned tectonic contact between the massive serpentinite in the footwall and the Baracun shear zone. Note the progressive transition from massive serpentinite to pervasively sheared talc-and-chlorite schist. (I) Close-up of the sheared ophicalcite of Figure 3H, showing a carbonate vein overprinted by S_1 foliation (dashed white line) and deformed by D_2 folds (dashed black line). (L) Structural fabric in the talc-and-chlorite schist matrix of the Baracun shear zone. (M) Rootless D_2 fold hinges in chlorite-rich (Chl) domains of the talc-and-chlorite schist overprinting the early S_1 foliation (dashed white lines). S_2 axial plane foliation (dashed black lines) occur in talc-rich (Tlc) domains (hand sample). (N) Photomicrograph of talc- and-chlorite schist in the Baracun shear zone, showing amphibole- (Am), chlorite- (Chl), and talc-rich (Tlc) domains folded by tight to isoclinal D_2 folds; note the folded S_1 foliation (dashed white lines). (O) Close-up of a Fe-Ti metagabbro block within the Baracun shear zone; arrows point to a clast-supported mafic metabreccia including gabbroic clasts of the same composition. (P) Close-up view of the mafic metabreccia of Figure 3O. Note that centimeter-sized, irregularly shaped clasts preserve an earlier foliation (S_1) deformed by D_2 folds. (Q) A Mg-Al metagabbro block in the Baracun shear zone, enveloped by the talc-and-chlorite schist matrix (arrows). (R) The talc-and-chlorite matrix includes gabbroic clasts wrenched by faulting along the Baracun shear zone.

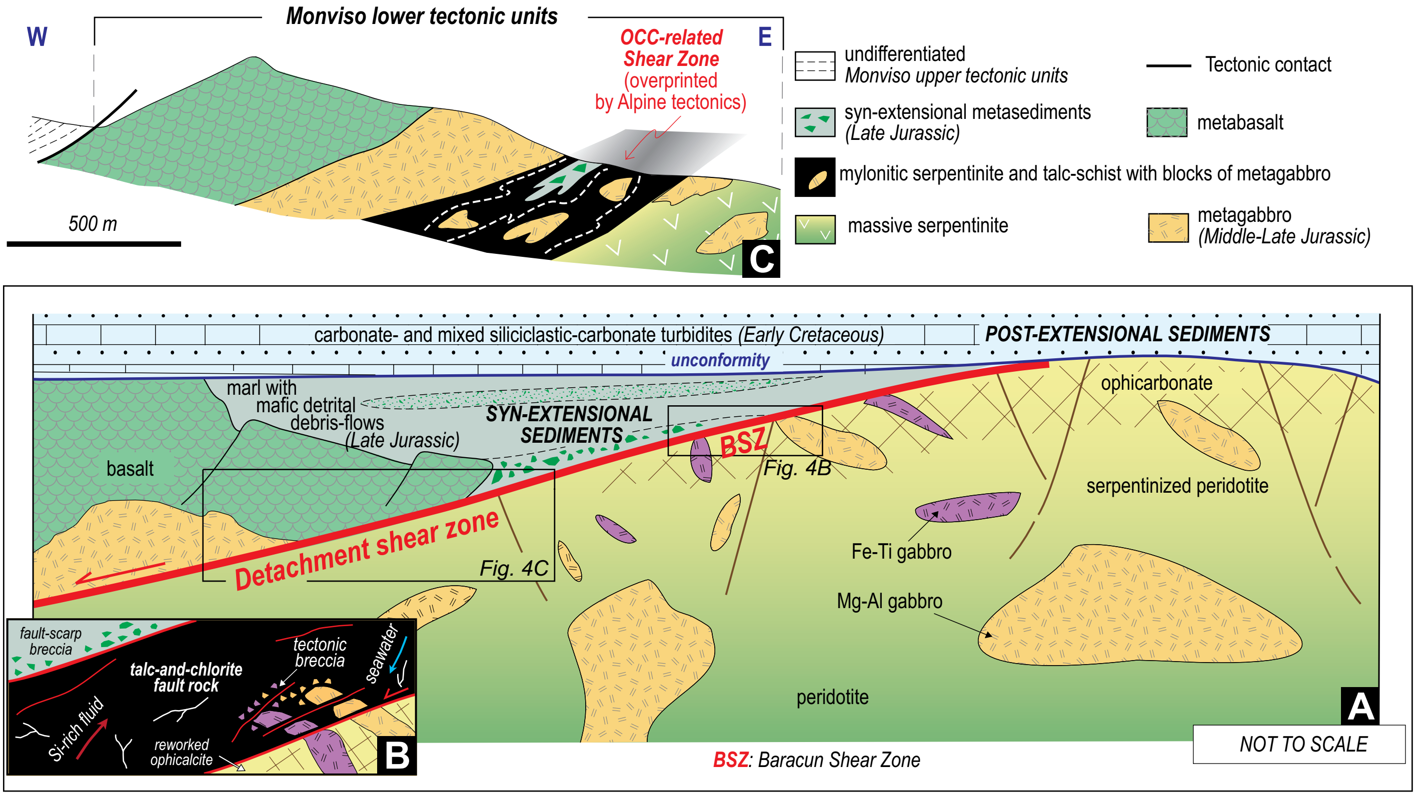

Figure 4. (A) Interpretive cross section for the development of the oceanic core complex (OCC), Baracun shear zone and syn- and postextensional sequences in the Monviso ophiolite. (B) Close-up of the Baracun shear zone, depicting the inferred tectonic and hydrothermal processes. (C) Close-up of the representative cross section of Figure 1C, depicting at a regional scale the prolongation of the Baracun shear zone within the Monviso ophiolite lower tectonic units.

formed, younger syntectonic sediments and basaltic lava flows (e.g., for ancient orogenic belts—Miranda and Dilek, 2010; Manatschal et al., 2011; e.g., for present-day oceanic settings—Cann et al., 1997; Tucholke et al., 1998; Cannat et al., 2006; Smith et al., 2014).

Baracun Shear Zone—A Low-Angle Extensional Detachment Fault

The architecture of the Baracun shear zone, the nature of the contacts with hanging-wall and footwall rocks, and the types of fault rocks suggest a simple-shear mode for the kinematics of extension along this originally low-angle shear zone. We interpret the Baracun shear zone (up to tens of meters thick and several hundreds of meters long in outcrop) as the northern segment of a major shear zone, which is tens of kilometers in length and tens to hundreds of meters in thickness (i.e., the Lago Superiore shear zone of Balestro et al., 2013; lower shear zone of Angiboust et al., 2011). This major shear zone is reminiscent of, both in length and thickness, detachment faults associated with modern oceanic core complexes, which range from a few kilometers up to tens of kilometers in length and up to hundreds of meters in thickness (e.g., Karson et al., 2006; Smith et al., 2014). Our major shear zone, which was intensely folded and thickened during subduction and collisional stages (Fig. 4C), characterizes the lower tectonic units of the Monviso ophiolite that were affected by the same peak metamorphic pressure-temperature conditions (Angiboust et al., 2012). It occurs in the same structural position along its N-S strike, and it separates mafic-ultramafic rock units (i.e., serpentinite, metagabbros, and meta-ophicarbonate of the Basal Serpentinite unit) in the footwall from different assemblages of metabasalts, metagabbros, and metasedimentary rocks (i.e., the Viso Mozzo unit) in its hanging wall (Fig. 4C).

Metamorphic Mineralogy of the Baracun Shear Zone Rocks as a Result of Hydrothermal Metasomatism

We posit that the talc-and-chlorite schist within the Baracun shear zone originally formed metasomatically as a result of rock-fluid interactions between gabbros, serpentinite, and seawater-derived hydrothermal fluids along an oceanic core complex–related detachment fault. We remark that the Lower Cretaceous postextensional sequence sealing the Baracun shear zone and the hanging-wall and footwall units do not display any structural or textural evidence of metasomatic processes and mineral assemblages, as would be expected if faulting occurred during subduction and/or the collisional Alpine-related stages.

The texture and composition of the talc-and-chlorite schist within the Baracun shear zone are quite similar to those observed in hydrothermally metasomatized oceanic rocks along the detachment fault zone in the Atlantis Massif core complex at the Mid-Atlantic Ridge (Mével, 2003; Boschi et al., 2006; Miranda and Dilek, 2010). Amphibole and chlorite in these rocks were produced from a gabbroic source, whereas talc was produced from serpentinite. The existence of Cl-bearing minerals in the Baracun shear zone rocks indicates the occurrence of seawater-derived hydrothermal fluids percolating along and/or across the shear zone. As documented from the Atlantis Massif and other oceanic core complexes (Boschi et al., 2006), silica-enriched hydrothermal fluids, produced from gabbro-seawater interactions, reacted with serpentinites, leading to talc formation.

Although talc and chlorite recrystallized during Alpine metamorphism, we can still distinguish them due to their high Ni and Cr concentrations in the cores of zoned, coarse-grained crystals and, particularly, within talc and chlorite lamellae included in apatite grains. Apatite, along with other accessory minerals such as magnetite and zircon, represents a pre-Alpine mineral phase, reworked from peridotites and gabbros. Its occurrence constrains the timing of crystallization of talc and chlorite inclusions to a pre-D_1 stage. These high Ni and Cr concentrations are compositionally similar to those of chlorite and talc documented from detachment zone fault rocks in both modern (Boschi et al., 2006) and ancient (Manatschal et al., 2011) oceanic core complexes.

The occurrence of pre-S_1 carbonate-rich fillings, both at the base of the Baracun shear zone (i.e., footwall–Baracun shear zone interface; Fig. 3I) and within the talc-and-chlorite schist rocks, also constrains the timing of the responsible metasomatic processes to an intra-oceanic faulting episode. These carbonate-rich fillings, which are homogeneously distributed both along strike and downdip of the shear zone, represent the artifacts of seafloor hydrothermal activities, as evidenced by our $\delta^{13}C$ and $\delta^{18}O$ stable isotope data. The stable isotope values range from −2.80‰ to <+1.89‰ for $\delta^{13}C_{VPDB}$ and from +11.80‰ to <+17.79‰ for $\delta^{18}O_{VSMOW}$ (where VPDB—Vienna Peedee belemnite; VSMOW—Vienna standard mean ocean water). The $\delta^{13}C_{VPDB}$ values are similar to those of marine carbonates, and the $\delta^{18}O_{VSMOW}$ values are closely comparable to those documented from ophicalcites associated with the ophiolites in the Alps, Apennines, and Pyrenees (Clerc et al., 2014). The obtained $\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VSMOW}$ values are different from those of syntectonic fluids along subduction zones (e.g., Yamaguchi et al., 2012), and they also show that the Baracun shear zone fault rocks were not involved in pervasive decarbonation processes and related open-system devolatilization.

Synextensional Sedimentary Sequence in the Baracun Shear Zone Hanging Wall

Formation of the metabreccia horizons, which drape metagabbro blocks within the Baracun shear zone, was spatially and temporally associated with extensional deformation along the shear zone. Gabbroic intrusions experienced cataclastic deformation along the tectonically active extensional Baracun shear zone. The process of formation of metabreccia horizons is comparable with those described for gabbro bodies deformed along detachment faults in the Mid-Atlantic Ridge (e.g., Boschi et al., 2006). Their brecciated products were progressively exposed in a bathymetric high on the footwall of this shear zone, providing detrital material to accommodation space in the hanging wall (Figs. 4A and 4B). Multiple occurrences of detrital intercalations in different stratigraphic positions within the synextensional sedimentary sequence in the hanging-wall block may correspond to discrete episodes of faulting and slip along the Baracun shear zone. Similar extensional breccias have been described from the Atlantis Massif core complex along the Mid-Atlantic Ridge (Karson et al., 2006). The primary depositional and extensional deformation textures of the metabreccia unit were overprinted by the S_1 foliation (Fig. 3P), which developed during the eclogite-facies metamorphism and related deformation in a subduction zone.

Postextensional Sedimentary Sequence

The Lower Cretaceous sedimentary assemblage (i.e., alternating layers of calc-schist, marble, and quartz-schist), unconformably covering the footwall–hanging-wall rock units and the Baracun shear zone, represents a postextensional succession (i.e., postrift) that was folded during the Alpine deformation phase, together with the Baracun shear zone and its hanging-wall and footwall units. Its depositional age constrains the timing of the faulting and associated shearing as the pre–Early Cretaceous (Fig. 4A). Its protolith was deposited on exhumed upper-mantle peridotites. Coeval postextensional lithologies also occur in the western Alps (e.g., Lagabrielle, 1994) and in the nonmetamorphosed successions in the central Alps and the Northern Apennines (e.g., Decandia and Elter, 1972). The Valanginian–early Aptian siliciclastic rocks interfingering with carbonate-rich turbiditic deposits in the Deep Galicia margin (Winterer et al., 1988) represent an excellent in situ analogue for the postrift succession we describe from the western Alps. These postrift sequences in the Deep Galicia margin mark the critical timing of the separation of Iberia from the Grand Banks of Canada and the formation of the oldest oceanic crust in the North Atlantic Ocean (Winterer et al., 1988).

CONCLUSIONS

This study documents, for the first time, the occurrence in the eclogitized units of the western Alps of an ancient oceanic core complex, comparable with those described from the modern Mid-Atlantic Ridge. Represented by the Monviso ophiolite, this ancient oceanic core complex reflects the rift-drift history of the Ligurian-Piedmont Ocean basin, which never reached a mature stage (see Lombardo et al., 2002).

The internal structure of the Monviso ophiolite and the Baracun shear zone displays a primary, rift-drift–related extensional tectonic architecture (Dilek and Furnes, 2014). However, the complex juxtaposition of the lithological units along and across the Baracun shear zone, the incomplete pseudostratigraphy of the Monviso ophiolite, and the existence of mafic metabreccia outcrops have led some researchers to suggest that this ophiolite represents either a fossilized subduction channel with a serpentinite matrix (Guillot et al., 2009), or a fragment of the Jurassic Piedmont oceanic lithosphere crosscut by discrete eclogite-facies shear zones (Angiboust et al., 2011). These existing models interpret the structure of the Monviso ophiolite primarily as a result of subduction zone tectonics, acquired after the development of oceanic lithosphere at a mid-ocean-ridge setting within a mature Ligurian-Piedmont Ocean. Our study has shown, however, that the Monviso ophiolite displays a well-preserved record of extensional detachment faulting that exhumed the lithospheric mantle and produced an oceanic core complex during the initial stages of the development of the Jurassic Ligurian-Piedmont Ocean. This oceanic core complex subsequently experienced a strong overprint of subduction zone and continental collision tectonics. The multiply deformed Monviso ophiolite in the western Alps indicates that incomplete and highly deformed meta-ophiolitic successions that are juxtaposed across major shear zones in high-pressure belts do not always represent the product of a subduction channel, even though that is where and how they might have come up after going down during ocean closure.

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