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Geology of the Monte Banchetta – Punta Rognosa area (Troncea valley, Western Alps)

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ABSTRACT

The map 'Geology of the Monte Banchetta – Punta Rognosa area (Troncea valley, Western Alps)' details the lithostratigraphy and structural setting of a key sector in the Alpine chain, characterized by close associations of continental and oceanic basements, and meta-sediments. The mapped Monte Banchetta – Punta Rognosa unit (BRU), tectonically juxtaposed to different metaophiolitic units, comprises the Punta Rognosa succession, made of serpentinized mantle overlain by Middle-Upper? Jurassic polymictic meta-breccia, with oceanic and continental clasts, and metasandstone, and the Monte Banchetta succession, consisting of continental crust and Lower–Upper? Jurassic carbonate-bearing quartzite, micaschist and polymictic meta-breccia. These two successions share the uppermost stratigraphic levels consisting of post-rift Upper Jurassic-Cretaceous carbonate-micaschists. The deciphered stratigraphic architecture indicates that the lower succession of the BRU represents portions of continental crust and exhumed mantle reworked and emplaced before deposition of post-rift sediments.

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1 Introduction

The present configuration of the Alps is the result of late Mesozoic to Cenozoic orogenic processes related to the collision of Europe and Adria plates that lead to the closure of their interposed Liguria-Piemonte ocean (a branch of the Alpine Tethys) opened in early-middle Jurassic (e.g. Elter, 1971; Lemoine, 1971; Dal Piaz, 1974, 2010 and references therein; Lemoine et al., 1986; Lemoine & Trümpy, 1987; De Wever & Baumgartner, 1995; Froitzheim & Manatschal, 1996). The alpine collisional belt is then made of lithological associations recording pre-orogenic segments of continental crust and their own pre-rift deposits, ophiolites, and Jurassic to Cretaceous syn-to-post rift and syn-orogenic sedimentary sequences.

Field mapping based on stratigraphic and sedimentological analyses, supported by petrological studies, is the starting point to define if the present juxtaposition of the pre-orogenic continental crustal, mantle and sediments in the Alpine belt is due to subduction and/or exhumation tectonics, rift-related extension or sedimentary mélanges (e.g. Beltrando et al., 2014 and references therein for detailed review). This gives the basis to define the architecture of the pre-orogenic paleogeography (from proximal-distal marginal to oceanic domain) involved in the Alpine Orogeny. Numerous researches are devoted to better improve the knowledge of the Alpine pre-orogenic paleogeography in terms of structural domains and dominant processes (e.g. Mohn et al., 2010, 2014; Masini et al., 2013; Beltrando et al., 2014; Decarlis et al., 2015) because the pre-orogenic setting may have played a fundamental control in the earliest stages of the continental collision (Mohn et al., 2010, 2014; Beltrando et al., 2014).

Whilst the pre-orogenic relationships are best recognizable in those sectors that escaped the pervasive Alpine deformation (such as the Central Alps), they are very difficult to decipher in the Alpine axial sector. In this sector, the Tertiary orogenic-related tectono-metamorphic evolution (e.g. Dal Piaz et al., 2001; Beltrando et al., 2010a; Dal Piaz, 2010; Villa et al., 2014) may have modified and/or reworked primary stratigraphic relationships between syn-to-post rift sediments and adjacent continental crust or ophiolites.

In the general framework of these alpine studies, the present paper details the lithostratigraphy and structural setting of a poorly investigated area in the core of Alpine axial sector, i.e. the Monte Banchetta – Punta Rognosa area (located south-east of Sestriere in the Western Italian Alps, along the drainage divide separating the Troncea and Chisonetto valleys, Figure 1a), where slivers of continental basements, meta-ophiolites and meta-sediments are in close association.

The complexity of this area has been already recognized in the past (Servizio Geologico d'Italia, 1911;

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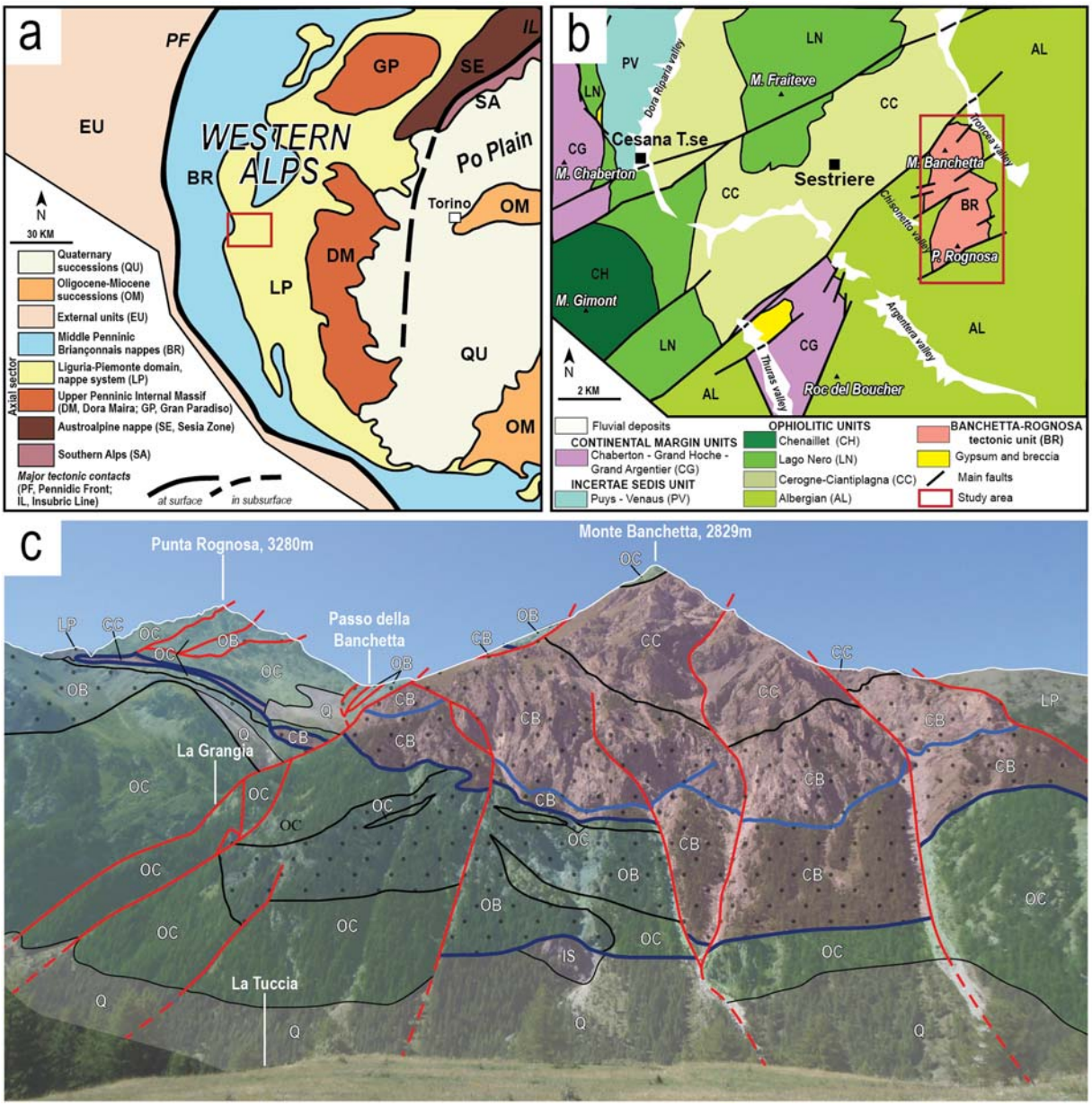

Figure 1. (a) tectonic sketch map of the Western Alps. Red box is the location of Figure 1(b). (b) tectonic sketch map of the investigated region (from Corno et al., 2019; Servizio Geologico d'Italia, 2020). (c) line drawing on photograph of the Monte Banchetta east face and Punta Rognosa north-east face. Acronyms are: CB – continental basement rocks, CC – continental metasedimentary cover, OB – serpentinized mantle, OC – oceanic metasedimentary cover, LP – Liguria-PiemonteTectonic Units, IS – La Tuccia *Incertae Sedis* and Q-undifferentiated Quaternary deposits. The legend of the lines drawn in the picture is reported in the Main Map.

Franchi, 1929; Caron, 1971; Fioraso, 2009) and clearly emerged during the geological mapping for the Foglio Geologico 171 Cesana Torinese (Servizio Geologico d'Italia, 2020). In this latter map, the composite Monte Banchetta – Punta Rognosa tectonic unit (BRU hereafter) has been distinguished from adjacent metaophiolitic Liguria-Piemonte units (Figure 1a,b). The BRU consists of two successions (reported as complexes in Servizio Geologico d'Italia, 2020), i.e. the Punta Rognosa succession, made of serpentinite and Jurassic to Cretaceous mainly pelagic metasediments (Corno et al., 2019), and the Monte Banchetta succession characterized by continental basement with its own carbonate cover and Jurassic to Cretaceous mainly pelagic metasediments (Figure 1c).

Based on accurate field studies supported by petrological and petrographic analyses, the main purposes of the 'Geology of the Monte Banchetta – Punta Rognosa area (Troncea valley, Western Alps)' (see enclosed Main Map) are to propose a much more detailed geological map of this area than previously documented, and to illustrate new details on the lithostratigraphy of the continental and oceanic related rock successions despite late overprinting deformation. Therefore, the map gives significant contributions to interpret pre-orogenic relationship between continental and oceanic successions, today outcropping in the highly imbricated tectonic setting of the Alpine axial belt.

2. Regional geological setting

The axial belt of the Western Alps, bounded by the Penninic Front and the Insubric Line, includes units of different metamorphic facies and grade that on the basis of their lithological assemblages are ascribed to the Mesozoic Alpine Tethys (Liguria-Piemonte ocean) or its adjacent rifted European and Adriatic continental margins (e.g. Lemoine & Trümpy, 1987; Dal Piaz, 2010; Mohn et al., 2010; Beltrando et al., 2010b; Piana et al., 2017 and references therein).

In the Western Alps, the Liguria-Piemonte oceanic domain is recorded by (meta-)ophiolite-bearing units, widespread exposed. This domain identifies an ocean basin resulting from slow – to ultraslow spreading and exhumation of lithospheric mantle that underwent low degrees of partial melting (Lemoine et al., 1987; Michard et al., 1996; Lavier & Manatschal, 2006; Manatschal & Müntener, 2009; Manatschal et al., 2011; Vissers et al., 2013; Saccani et al., 2015; Balestro et al., 2019).

The oceanic units of the Western Alps are usually subdivided on the basis of their Alpine metamorphism (Balestro et al., 2019 and references therein). Units with metamorphic peak at blueschist – or blueschist-eclogite-facies transition (or Combin zone) consist of serpentinized metaperidotites, metagabbros and metabasaltic lavas, discontinuously capped by metabreccias with mafic–ultramafic rock clasts, Upper Jurassic quartzites *(radiolarian cherts*), marbles and carbonate-micaschists with black shales spanning Late Jurassic-Cretaceous in age (e.g. Lagabrielle et al., 1984; Lemoine & Tricart, 1986; De Wever et al., 1987; Lagabrielle & Polino, 1985; Tricart & Lemoine, 1991; Deville et al., 1992; Tricart & Schwartz, 2006; De Graciansky et al., 2011 and references therein).

The eclogite-facies metaophiolites (or Zermatt-Saas zone), resting at lower structural levels, are made of serpentinite, metagabbros, metabasalts and a metasedimentary sequence of Upper Jurassic carbonate-micaschists and metabreccias, rare quartzites and marbles, and Lower Cretaceous carbonate-micaschists (e.g. Philippot, 1990; Groppo & Castelli, 2010; Angiboust et al., 2012; Balestro et al., 2014). In addition, at the uppermost structural levels, the Chenaillet ophiolite is lacking an Alpine metamorphic overprint and consists of serpentinized peridotites intruded by gabbroic bodies and covered by basaltic lavas (e.g. Lemoine, 1971; Mevel et al., 1978; Bertrand et al., 1987; Caby, 1995; Chalot-Prat, 2005; Manatschal et al., 2011).

In the considered sector of the Western Alps (upper Susa and Chisone valleys; Figure 1a,b), several ophiolite-bearing units were distinguished and mapped (Polino et al., 2002; Servizio Geologico d'Italia, 2002). The lawsonite-blueschist Lago Nero unit consists of a metaophiolitic basement sequence overlain by a metasedimentary cover characterized by intercalations of continental and ophiolitic detritus at several stratigraphic levels (Polino & Lemoine, 1984; Burroni et al., 2003). The lawsonite-blueschist Albergian and epidote-blueschist Cerogne-Ciantiplagna (Caron, 1977; Polino et al., 2002) units consist of thick sequences of post-rift carbonate metasediments embedding bodies of metaophiolites and of their sedimentary cover (quartzites and marbles). In the same sector, the evolution of a rifted continental margin is recorded by the Chaberton-Grand Hoche-Grand Argentier unit (Figure 1b), juxtaposed to different Liguria-Piemonte units and interpreted as either European (Pre-Piedmont or external Piedmont domain in literature, e.g. Lemoine, 1971; Lemoine et al., 1978; Pinto et al., 2015) or Adriatic (see Polinoet al., 1983). The stratigraphy of this unit (Polinoet al., 1983, 2002; Servizio Geologico d'Italia, 2002, 2020) is characterized by Norian dolostones (reaching a thickness on the order of 700-800 m) and Rhaetian-Hettangian carbonate schists unconformably overlain by a Lower-Middle Jurassic succession of prevailing carbonate schists and phyllites with breccias of Triassic calcareous-dolostone and continental basement rocks. Then, up-section a quartz-rich level has been correlated with radiolarian cherts (Late Jurassic); the top of this unit is represented by Upper Jurassic (?) – Cretaceous carbonate schist with black-shales.

In the area between the Troncea and Chisonetto valleys (Figure 1b), the BRU is tectonically bounded by metaophiolite-bearing units (Cerogne-Ciantiplagna and Albergian units) and its lithostratigraphic features and structural evolution will be described in details in the following sections.

3. Methods

The Main Map covers an area of about 10 km^2 at an altitude between 1800 and 3280 m a.s.l and the map scale is 1: 6500 (even if the complexity of the area imposed a few auxiliary maps and more detailed investigations in some areas). Lithological and structural data were stored in a GIS database using the UMT WGS84 reference system, and all topographic elements (contour lines, hydrography, buildings and roads) have been derived from the vector map 'Carta Tecnica Regionale Vettoriale at 1: 10,000 scale of the Regione Piemonte (vector_10 series, Edition 1991–2005)'.

The structural architecture and geological setting are illustrated in six cross sections and in a tectonic sketch map, where geological interpretation and generalization of outcrops and structures are provided. Overprinting relationships of structural elements (from outcrop to thin-section scale) and their relative metamorphic conditions have been considered for the identification of deformation phases (labeled D with

subscript numbers on the basis of their chronological order). Symbols used for structural elements are S for schistosity, A for folds axis and L for stretching lineation.

The most penetrative schistosity at the outcrop scale is S2, which represented during the geological mapping the main foliation for the identification and correlation of tectonic features at map scale. Structural elements (S, A and L) are plotted in eighteen equal-area lower hemisphere stereographic projections, referred to ten sub-areas. Six geological cross sections, variably oriented, were drawn to illustrate the most significant structural features of the mapped area.

Minerals abbreviations in the map and in the figures of the following text are from Whitney & Evans (2010), integrated with the acronym Wm used for white mica.

No paleontological data exist for the successions exposed in the mapped area. Therefore, the ages of the distinguished lithologies are inferred by published papers and/or geological maps (e.g. Caron, 1971; Barfety et al. 1995; Polino et al., 2002; Mohn et al., 2010; Piana et al., 2017 and references therein) or on the basis of their stratigraphic positions.

4. Lithostratigraphy of the Monte Banchetta – Punta Rognosa area

4.1. The Monte Banchetta – Punta Rognosa tectonic unit

4.1.1. The Punta Rognosa succession (Liguria-Piemonte oceanic domain)

The Punta Rognosa succession consists of oceanic basement and its own stratigraphic cover (Corno et al., 2019).

The serpentinized mantle (OCs), locally preserving pyroxene relics (cm in size) of the original peridotite, grades upwards to meta-ophicarbonate rocks (OCof) characterized by serpentinite fragments (up to 50 cm) within a matrix of serpentine + chlorite + amphibole and displaying an irregular network of calcite veins.

Serpentinite and meta-ophicarbonate rocks are often directly overlain by a polymictic meta-breccia (OCbr), reaching a thickness up to 30 m, characterized by clasts of oceanic and continental origin. The matrix of the meta-breccia is made of carbonate+ chlorite + Ca-amphibole and widespread fine-grained Fe-oxides, and the embedded clasts and blocks (Figure 2a,b) consist of serpentinite and meta-ophicarbonate rocks (of), micaschist and gneiss (co), and dolostone and dolomitic breccia (bl^1). Locally (e.g. gorge north of La Grangia, Monte Banchetta eastern side), blocks of dolostone (bl^1) lie directly on the serpentinized mantle. On the western side of Monte Banchetta (east of the upper chairlift departure station) the polymictic meta-breccia contains a metric block of meta-gabbro (g), characterized by large pseudomorphs after magmatic plagioclase consisting of epidote + white mica + albite and a recrystallized fine-grained matrix made of omphacite ± aegirine augite + Mg-chlorite + epidote + phengite (Corno et al., 2019). Up section, the polymictic metabreccia grades into a fine-grained impure marble (~10 m thick) defining then a broad fining upward sequence. The observed stratigraphic relationships suggest a Middle to Late Jurassic age for the polymictic meta-breccia.

Laterally discontinuous bodies of metasandstone (OCq; Figure 2c), up to 15 m thick and 50-60 m long, are usually observed on the top of the polymictic meta-breccia or locally directly above serpentinite and meta-ophicarbonate rocks. This lithology consists of quartz + phengite + muscovite + chlorite + Fe-oxides aggregates (up to cm in size), and has a few (<50 cm thick) green to blueish metabasic levels made of chlorite + glaucophane ± detrital allanite. In its uppermost part, the metasandstone contains bodies of dolostone and dolomitic breccias (bl^2), centimetric (Figure 2c) to plurimetric in size. The supposed age of the metasandstone is Middle to Upper Jurassic.

Serpentinized mantle and the overlying sediments are unconformable covered by ophiolite-bearing carbonate-micaschist (csO; Figure 2d) of Upper Jurassic-Cretaceous age. It consists of carbonates + quartz + muscovite + phengite + chlorite, and preserve pseudomorphs after lawsonite. The csO presents intercalations of black and green schists with garnet + stilpnomelane + opaque minerals + Mn and Fe carbonate minerals.

The carbonate-micaschists embed isolated sheared bodies of serpentinite (s) and metabasite (m; Figure 2d) from metric to pluri-decametric in size (eastern side of M. Banchetta, just above the valley floor in front of Seytes village). The metabasite is made of glaucophane + tremolite ± aegirine-augite + chlorite + epidote + rutile + phengite + muscovite + pumpellyite assemblage.

As observed south of Passo della Banchetta, the carbonate-micaschist (csO) overlays blocks of dolomitic breccia (bl^1), up to hectometric in size, resting directly on the serpentinized mantle.

4.1.2. The Monte Banchetta succession (European continental margin)

Two main associations of continental basement rocks, here considered as Paleozoic in age, have been identified.

Dark gray gneiss and with minor occurrence of micaschists (CBpm; Figure 3a) crop out south of La Grangia (in the southern-central sector of the map). These rocks consist of quartz + muscovite + phengite + paragonite + jadeite + chloritoid + chlorite + allanite assemblages, and at the outcrop scale they have several

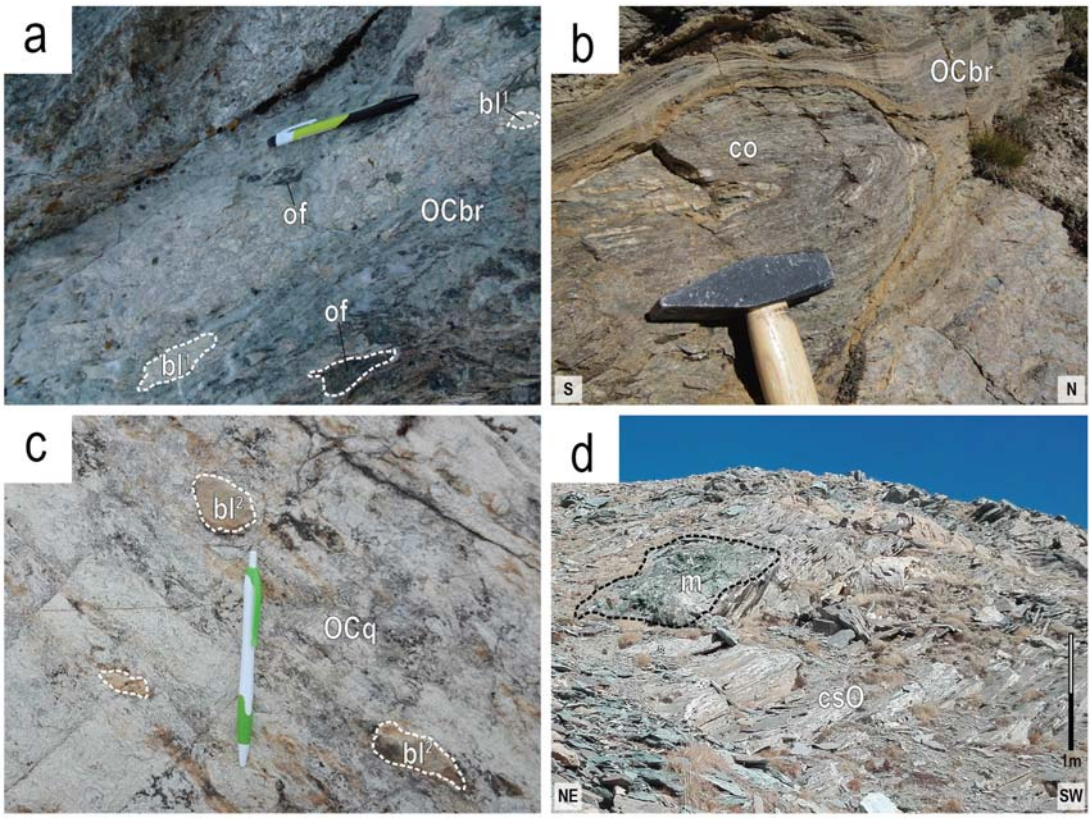

Figure 2. Representative lithologies of the Punta Rognosa succession: (a) clasts of meta-ophicarbonate rock (of) and dolostone (bl^1) in the polymictic meta-breccia (OCbr; Monte Banchetta south-western side, 2400 m); (b) continental clast (co – gneissic micaschist) in the polymictic meta-breccia (OCbr; Monte Banchetta summit, 2823 m); (c) dolomitic clasts (bl^2) in the upper part of a discontinuous body of metasandstone (OCq; south-east of Passo della Banchetta, 2710 m); (d) metabasite (m) in carbonate-micaschist (csO; south-west of Monte Banchetta, 2750 m).

intercalations (thickness < 1-2 m) of graphite bearing dark schist, marble and metabasite.

Along the eastern slope of the Monte Banchetta (Figure 1c), the continental basement outcrops are widely represented by white-greyish micaschists (CBm; Figure 3b) made of quartz + muscovite + phengite + paragonite + chlorite + albite + epidote ± glaucophane, and containing levels, up to plurimetric in size, of fine-grained gneiss (gn), glaucophane + chloritoid-bearing micaschist (cld; Figure 3b), and white quartzite (mq). In the southern part of the map, south-west of La Grangia, a pluridecametric glaucophane + garnet meta-diorite (md), preserving magmatic K-feldspar, has been observed embedded within the micaschist.

The basement rocks are unconformable overlain by siliciclastic deposits (CBq; Figure 3c,d), reaching maximum thickness of about ten meters. These are quartzite and quartz metaconglomerate (locally characterized by mm to cm-sized clasts of pink quartz) upward passing to massive phengite-bearing quartzite. These deposits are correlated with the Upper Permian (?) to Lower Triassic quartzitic deposits extensively occurring through the Western Alps.

Up section, a Middle to Upper Triassic dolomitic sequence, reaching a thickness up to 200 m, consists of well-stratified dolostone (locally exposed west of La Tuccia) overlain by clast-supported monomictic meta-breccia (CBd; Figure 3d). The dolomitic meta-breccia is made of poly-dolomitic clasts (up to dm in size) within a dolomitic matrix. Locally, discontinuous plurimetric-thick levels of black shale, carbonate schist and phyllite occur through the sequence.

The dolomitic sequence is unconformable overlain by a detrital sequence (up to 200 m thick) including carbonate-bearing quartzite (CBsq), black micaschist (CBbs) and polymictic meta-breccia (Cbdq).

The lower part of the detrital sequence consists of carbonate-bearing quartzite (CBsq), composed of quartz + muscovite + phengite and variable amount of calcite and ankerite. Up section it passes to a black micaschist (CBbs) consisting of graphite + muscovite + phengite + chlorite + calcite + dolomite + quartz and has pseudomorphs after lawsonite. This black micaschist is interleaved with polymictic meta-breccia (Cbdq; Figure 3e) and seems to embed a few portions of this lithology. The polymictic meta-breccia is composed of dolostone and quartzite clasts (Figure 3f) in a carbonate matrix containing minor fuchsite, talc and detrital K-feldspar. In the uppermost part of the polymictic meta-breccia (exposed on the western side of Monte Banchetta, north of the upper chairlift

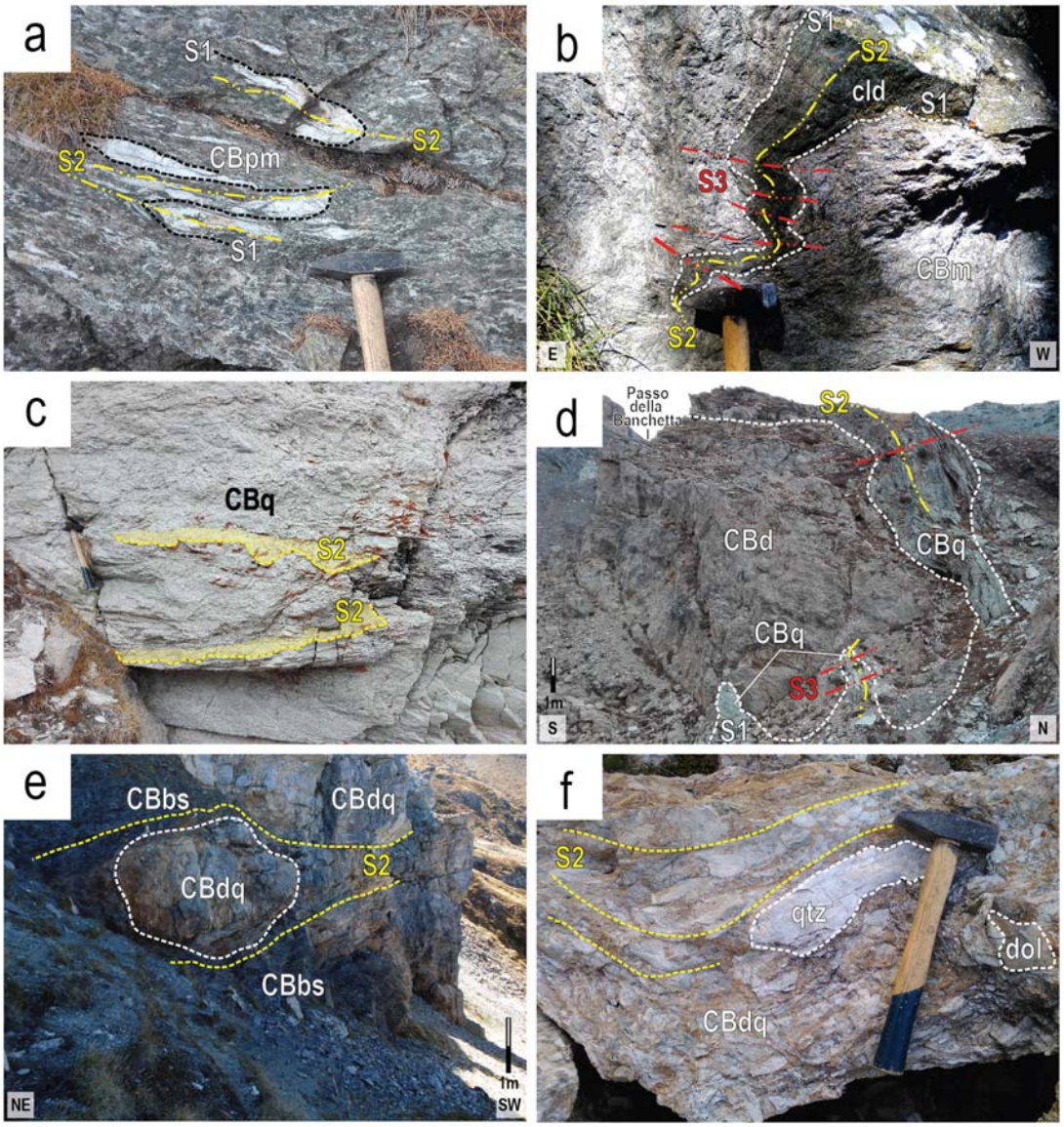

Figure 3. Representative lithologies of the Monte Banchetta succession: (a) polydeformed Jd-bearing gneiss (CBpm; south of La Grangia, 2300 m); (b) Gln + Cld-bearing micaschist level (cld) folded together with micaschist (CBm), D3 folds (with incipient S3 axial plane schistosity) overprint a D2 fold hinge (Monte Banchetta eastern side, 2020 m); (c) white-greenish Phe-bearing quartzite (CBq; west of Passo della Banchetta, 2400 m); (d) Phengite-bearing quartzite (CBq) folded together with dolomitic meta-breccia (CBd), a major overturned D2 fold is overprinted by minor D3 folds (east of Passo della Banchetta, 2400 m); (e) heteropic relationship between black micaschist (CBbm) and meta-breccia with dolostone and quartzite clast (CBdq; south-west of Clot della Mutta, 2450 m); (f) detail of dolostone (dol) and quartzite (qtz) clasts within clast-supported carbonate meta-breccia (CBdq; north of Monte Banchetta, 2400 m).

departure station), a level of impure quartzite (qr) contains dolostone clasts up to decimetric in size.

The uppermost lithostratigraphic levels of the Monte Banchetta succession consist of a carbonate-micaschist (csC), laterally passing to that (CsO) resting on the Punta Rognosa succession.

4.2. Liguria-Piemonte tectonic units

The BRU is tectonically bounded by the Albergian Unit (LPa) to the south and the Cerogne-Ciantiplagna Unit (LPcc) to the north. These units consist of Cretaceous carbonate-micaschist made of carbonate minerals + quartz + white mica + chlorite + graphite, embedding locally pluri-decimetric meta-ophiolitic bodies (not reported in the map).

4.3. *La Tuccia* Incertae sedis *tectonic unit*

On the eastern side of Monte Banchetta, just above the valley floor close to La Tuccia, the Punta Rognosa succession is tectonically juxtaposed to a pluri-decametric body of mica-bearing dolomitic marble and clast-supported dolomitic meta-breccia. Due to the complicate tectonic relationships with neighboring rocks, these dolomitic rocks are referred to as an *Incertae Sedis* unit. A Triassic age can be supposed for these dolomitic rocks.

5. Structural evolution of the Banchetta – Rognosa tectonic unit

Structural and petrographic data reveal for the Monte Banchetta and the Punta Rognosa successions a common structural evolution consisting of three tectono-metamorphic deformation phases, labeled from D1 to D3, and a late D4 deformation phase.

The D1 is the first tectono-metamorphic deformation phase observed. At the outcrop scale, the S1 is well recognizable only in quartzitic and dolomitic rocks (see cross-section F-F' in the map), while at the microscale it is usually preserved as microlithons and/or intrafolial folds. The S1, resulting parallel to the original compositional banding of the rocks (Figures 3b,d), is characterized by assemblages developed at the transition between lawsonite – and epidote – blueschist facies conditions (Corno et al., 2019): this is constrained by omphacite + zoisite + glaucophane + rutile paragenesis in the basic system, quartz + phengite + chloritoid + jadeite + rutile paragenesis in the quartz-feldspatic system and quartz + phengite + chloritoid + glaucophane + graphite + rutile paragenesis in the pelitic system. A pre-D1 metamorphic event has been only locally recorded by growth of lawsonite, now completely pseudomorphosed, in carbonate-micaschist mapped as csC and CBbs of the Monte Banchetta succession and csO of the Punta Rognosa succession respectively (Corno et al., 2019). The D2 tectono-metamorphic deformation phase led to the development of tight to isoclinal folds, from outcrop to thin section scale (Figure 3b,d and Figure 4a), whose axial plain schistosity (S2) is usually the most penetrative planar fabrics in the field. The S2, developed under epidote-blueschist facies conditions, is characterized by glaucophane + epidote + phengite paragenesis in the basic system (Figure 4b), and quartz + phengite + paragonite + chloritoid paragenesis in the pelitic system. At the map scale, the S2 generally dips to the W-NW and contains a L2 stretching lineation marked by alignment of phengite, glaucophane and chloritoid. At the outcrop scale, the L2 has been observed to be sub-parallel to A2 fold axis, highlighting non-cylindrical folding during D2 deformation (see cross-section D-D'). A2 fold axes are NE-SW trending.

Major tectonic contacts between the Monte Banchetta and the Punta Rognosa successions, as well as their minor intra-succession tectonic contacts, were deformed since the earliest deformation phases (D1-D2). The D3 tectono-metamorphic deformation

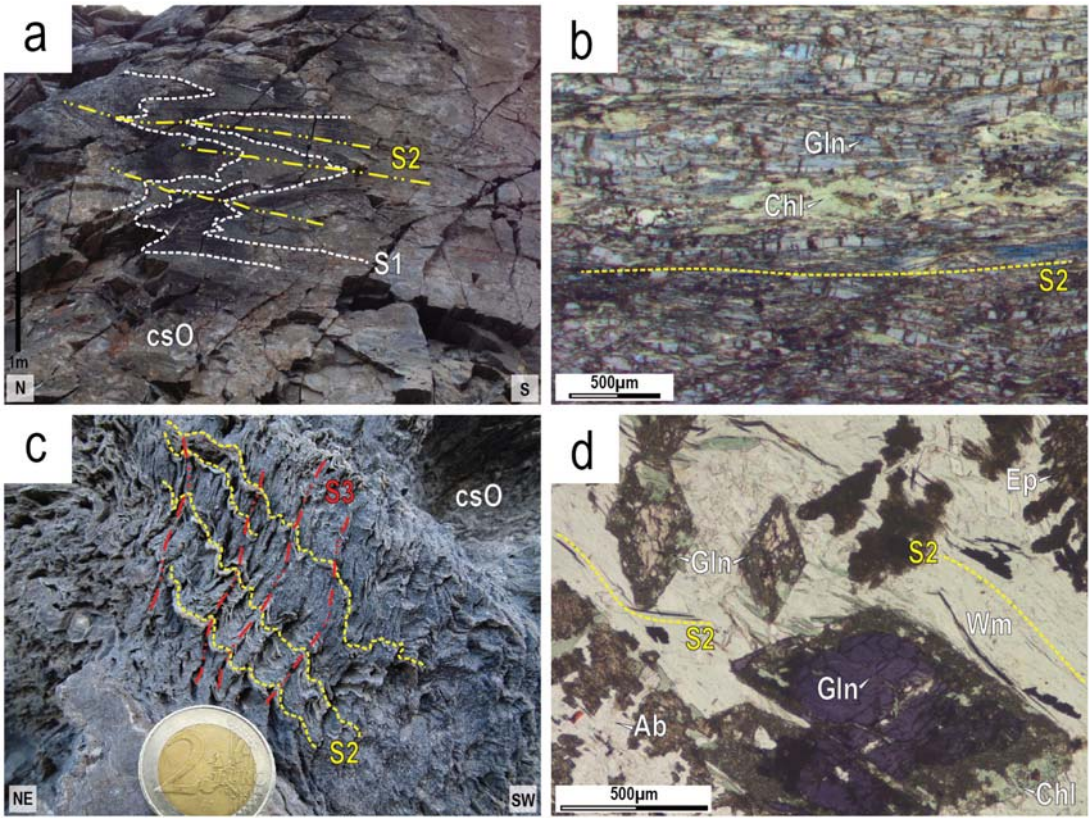

Figure 4. Representative meso – and microstructures: (a) D2 folds with S2 axial plane foliation in carbonate-micaschist (csO; west of Clot della Mutta, 2400 m); (b) metabasite embedded in the micaschist (CBpm) of the Monte Banchetta succession, displaying S2 pervasive foliation defined by Gln partially replaced by Chl (Plane Polarized Light, PPL); (c) S3 crenulation cleavage growing in carbonate-micaschist (csO) of the Punta Rognosa succession (west of Clot della Mutta, 2350 m); (d) photomicrograph from a level of Gln + Cld micaschist with D2-Gln crystals partially (right) and completely (upper left) replaced by D3 Chl + Ab. Note that Wm + Ep grow both in D2 mineral assemblage and recrystallize during the D3 phase (PPL).

phase overprints previous D1 and D2 planar and linear tectonic features. It is characterized by meso – to large-scale folds with generally sub-horizontal ENE-WSW trending A3 axes and axial planes dipping towards SSE at high angle (see cross-section C-C'''). Locally, the D3 develops an incipient S3 crenulation cleavage in the micaschist and carbonate-micaschist (Figure 4c) defined by chlorite ± stilpnomelane occurrence. The D3 is associated with blastesis typical of greenschist facies conditions, replacing D2 mineral assemblages (Figure 4d): muscovite + tremolite + chlorite + albite + stilpnomelane ± epidote in the basic system and of quartz + muscovite + chlorite + albite in the pelitic system. The late D4 deformation phase is responsible for gentle km-scale folding recognizable at the map scale, characterized by N-S trending axes and high-angle dipping axial planes. During D4, major and minor tectonic contacts often show evidences of S-SW extensional reactivation.

The post-D4 faulting is characterized by three major systems oriented ENE-WSW, N-S and NNW-SSE, all revealing often close relationship with morphology. The most relevant systems are ENE-WSW trending right-lateral strike-slip faults and two of these faults separate the BRU to the north and south from the adjacent ophiolitic units. The N-S and NNW-SSE trending systems are high-angle normal to transtensional faults.

6. Conclusions

The 1:6500 scale map 'Geology of the Monte Banchetta – Punta Rognosa area (Troncea valley, Western Alps)' is the result of new, extensive and detailed lithostratigraphic and structural field studies supported by petrographic analyses.

The geology of the mapped area is characterized by the complex juxtaposition of different lithological associations ascribed to the Punta Rognosa succession of oceanic origin and to the Monte Banchetta succession of (European) continental margin origin.

Serpentinite of the Punta Rognosa succession is covered by meta-ophicarbonate rocks followed up section by polymictic metabreccia with continental and oceanic-derived clasts and by siliciclastic deposits (quartz-rich sands). This lithostratigraphy suggests that the BRU includes a segment of exhumed mantle adjacent to continental crust source areas.

In the Monte Banchetta succession, pre-rift rocks (continental basement with dolostone) are covered by syn-rift middle-late Jurassic (?) polymictic metabreccias whose fuchsite (chrome mica) in the matrix can be interpreted as signature of deposition in sectors proximal to areas floored by mantle exhumation (where pervasive Cr-enriched fluids derive from chromite related to exhumed serpentinites or Mg-Cr gabbros).

The Monte Banchetta and the Punta Rognosa successions share the upper stratigraphic levels consisting of late Jurassic?-Cretaceous post-rift deposits (carbonate-micaschist), distinguished in the map taking into account their deposition on continental or oceanic substratum.

On the basis of these considerations, the BRU can be inferred as a lithospheric portion where thinned continental crust was adjacent to exhumed mantle, both covered by the same post-rift sediments. This setting can be referred to a distal continental margin that underwent rift-related hyperextension: hence, the BRU represents a remnant of the pre-orogenic setting preserved in the axial sector of the Alpine chain. However, alternative possible processes (syn-orogenic mélanges, possibly reworked) should not be excluded.

The two continental and oceanic successions included in the BRU recorded a common orogenic tectono-metamorphic evolution at least since the D1 deformation phase, therefore from HP/LT to greenschist facies conditions, during which the primary contacts were variably reworked. According to the available literature, the HP-LT D1 and D2 phases can be related to the Eocene subduction history (Dal Piaz et al., 2001; Beltrando et al., 2010a and references therein).

The post-D4 brittle deformation is represented by a fault network characterized by ENE-WSW right-lateral strike-slip faults and N-S and NNW-SSE high-angle normal to transtensional faults that contribute to the shaping of the present-day landscape.

In conclusion, the results of this study place emphasis on the role exerted by hyperextension in the development of the pre-collisional Alpine paleogeography, later involved and modified by the complex tectono-metamorphic orogenic evolution. Furthermore, this study confirms that relationships among the different paleo-structural domains must be constrained by accurate field mapping including stratigraphic and sedimentological analyses, and reconstruction of the structural evolution of the different rock volumes supported by petrological studies.

Software

The geological map was digitalized using ESRI ArcGIS v. 10.3, its final layout has been edited using Adobe Illustrator®. Structural data have been projected with the software StereoNet®. The cross sections presented in the geological map and the photographs were edited with Adobe Illustrator®.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [AC], upon reasonable request.

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References

Angiboust, S., Langdon, R., Agard, P., Waters, D., & Chopin, C. (2012). Eclogitization of the Monviso ophiolite (W. Alps) and implications on subduction dynamics. *Journal of Metamorphic Geology*, *30*(1), 37–61. https://doi.org/10.1111/j.1525-1314.2011.00951.x

Balestro, G., Festa, A., & Dilek, Y. (2019). Structural architecture of the Western Alpine ophiolites, and the Jurassic seafloor spreading tectonics of the Alpine tethys. *Journal of the Geological Society*, *176*(5), 913–930. https://doi.org/10.1144/jgs2018-099

Balestro, G., Lombardo, B., Vaggelli, G., Borghi, A., Festa, A., & Gattiglio, M. (2014). Tectonostratigraphy of the northern Monviso meta-ophiolite complex (Western Alps). *Italian Journal of Geosciences*, *133*(3), 409–426. https://doi.org/10.3301/IJG.2014.13

Barfety, J. C., Lemoine, M., Graciansky, P. C. (., Tricart, P., & Mercier, D. (1995). Notice explicative, carte géologique de la France (1/50 000), feuille Briançon (823). Bureau de Recherche Géologiques et Minières, Orléans.

Beltrando, M., Compagnoni, R., & Lombardo, B. (2010a). (Ultra-) high-pressure metamorphism and orogenesis: An Alpine perspective. *Gondwana Research*, *18*(1), 147–166. https://doi.org/10.1016/j.gr.2010.01.009

Beltrando, M., Manatschal, G., Mohn, G., Dal Piaz, G. V., Vitale Brovarone, A., & Masini, E. (2014). Recognizing remnants of magma-poor rifted margins in high-pressure orogenic belts: The Alpine case study. *Earth-Science Reviews*, *131*, 88–115. https://doi.org/10.1016/j.earscirev.2014.01.001

Beltrando, M., Rubatto, D., & Manatschal, G. (2010b). From passive margins to orogens: The link between ocean-continent transition zones and (ultra) high-pressure metamorphism. *Geology*, *38*(6), 559–562. https://doi.org/10.1130/G30768.1

Bertrand, J., Dietrich, V., Nievergelt, P., & Vuagnat, M. (1987). Comparative major and trace element geochemistry of gabbroic and volcanic rock sequences, Montgenèvre ophiolite, Western Alps. *Schweiz. Mineral. Petrogr. Mitt*, *67*, 147–169.

Burroni, A., Levi, N., Marroni, M., & Pandolfi, L. (2003). Lithostratigraphy and structure of the Lago Nero unit (Chenaillet massif, Western Alps): comparison with internal liguride units of northern Apennines. *Ofioliti*, *28*(1), 1–11. https://doi.org/10.4454/ofioliti.v28i1.185

Caby, R. (1995). Plastic deformation of gabbros in a slow-spreading Mesozoic ridge: Example of the montgenevre ophiolite. In R. L. M. Vissers, & A. Nicolas (Eds.), *Mantle and Lower crust exposed in oceanic ridges and in ophiolites* (pp. 123–145). Kluwer.

Caron, J. M. (1971). Contribution a l'étude lithostratigraphique et structurale de la région de sestrière (Alpes Cottiennes, italie). *Trav. Lab. Géol. Grenoble*, *21*, 45–68.

Caron, J. M. (1977). Lithostratigraphie et tectonique des Schistes lustrés dans les Alpes Cottiennes septentrionales et en Corse orientale (Vol. 48, No. 1). Persée-Portail des revues scientifiques en SHS.

Chalot-Prat, F. (2005). An undeformed ophiolite in the Alps: Field and geochemical evidences for a link between volcanism and shallow plate tectonic processes. In G. R. Foulger, J. H. Natland, D. C. Presnall, & D. L. Anderson (Eds.), *Plates, plumes & paradigms, Geol. Soc. Am., Spec. Pap.* (388, pp. 751–780). https://doi.org/10.1130/0-8137-2388-4.751

Corno, A., Mosca, P., Borghi, A., & Gattiglio, M. (2019). Lithostratigraphy and petrography of the Monte Banchetta-Punta Rognosa oceanic succession (Troncea and Chisonetto valleys, Western Alps). *Ofioliti*, *44*(2), 83–95. https://doi.org/10.4454/ofioliti.v44i2.526

Dal Piaz, G. V. (1974). Le mètamorphisme de haute et basse température dans l'évolution structurale du bassin ophiolitique alpino-appenninique. *Ière Partie. Boll. Soc. Geol. It*, *93*, 437–468. http://dx.doi.org/10.5169/seals-42202

Dal Piaz, G. V. (2010). The Italian Alps: A journey across two centuries of Alpine geology. In M. Beltrando, A. Peccerillo, M. Mattei, S. Conticelli, & C. Doglioni (Eds.), The Geology of Italy: Tectonics and life along plate margins, Journal of the Virtual Explorer (Vol. 36, pap. 8). https://doi.org/10.3809/jvirtex.2010.00234

Dal Piaz, G. V., Cortiana, G., Del Moro, A., Martin, S., Pennacchioni, G., & Tartarotti, P. (2001). Tertiary age and paleostructural inferences of the eclogitic imprint in the Austroalpine outliers and Zermatt-Saas ophiolite, Western Alps. *International Journal of Earth Sciences*, *90*(3), 668–684. https://doi.org/10.1007/s005310000177

Decarlis, A., Manatschal, G., Haupert, I., & Masini, E. (2015). The tectono-stratigraphic evolution of distal, hyper-extended magma-poor conjugate rifted margins: Examples from the Alpine Tethys and newfoundland-iberia. *Marine and Petroleum Geology*, *68*, 54–72. https://doi.org/10.1016/j.marpetgeo.2015.08.005

De Graciansky, P.-C., Roberts, D. G., & Tricart, P. (2011). *The Western Alps, from rift to passive margin to orogenic belt*. Elsevier.

Deville, E., Fudral, S., Lagabrielle, Y., Marthaler, M., & Sartori, M. (1992). From oceanic closure to continental collision: A synthesis of the 'Schistes lustrés' metamorphic complex of the Western Alps. *Geological Society of America Bulletin*, *104*(2), 127–139. https://doi.

org/10.1130/0016-7606(1992)104<0127:FOCTCC>2.3.CO;2

De Wever, P., & Baumgartner, P. O. (1995). Radiolarians from the base of the supra-ophiolitic Schistes lustrés formation in the Alps (Saint-Véran, France and Traversiera Massif, Italy). In P. O. Baumgartner, L. O'Dogerthy, S. Gorican, E. Urquhart, A. Pillevuit, & P. De Wever (Eds.), *Middle Jurassic to lower Cretaceous radiolaria of tethys: Occurrences, systematics, biochronology* (Vol. 23, pp. 725–730). Lausanne: Mém. Geol.

De Wever, P., Baumgartner, P. O., & Polino, R. (1987). Précision sur les datations de la base des Schistes lustrés post-ophiolitiques dans les Alpes cottiennes. *C.R. Acad. Sci*, *305*(2), 487–491.

Elter, G. (1971). Schistes lustrès et ophiolites de la zone piémontaise entre Orco et Doire Baltée (Alpes Graies). Hypothèses sur l'origine des ophiolites. *Géol. Alpine*, *47* (2), 147–169.

Fioraso, G. (2009). Carta Geologica della Val Troncea. CNR - Istituto di Geoscienze e Georisorse, Ente di Gestione Parco Val Troncea, Regione Piemonte. Litografia Geda–Nichelino.

Franchi, S. (1929). Sulla tettonica delle Alpi Cozie franco-italiane.

Froitzheim, N., & Manatschal, G. (1996). Kinematics of Jurassic rifting, mantle exhumation, and passive-margin formation in the Austroalpine and Penninic nappes (eastern Switzerland). *Geological Society of America Bulletin*, *108*(9), 1120–1133. https://doi.org/10.1130/0016-7606(1996)108<1120:KOJRME>2.3.CO;2

Groppo, C., & Castelli, D. (2010). Prograde P–T evolution of a lawsonite eclogite from the Monviso meta-ophiolite (Western Alps): dehydration and redox reactions during subduction of oceanic FeTi-oxide gabbro. *Journal of Petrology*, *51*(12), 2489–2514. https://doi.org/10.1093/petrology/egq065

Lagabrielle, Y., & Polino, R. (1985). Origine volcano-détritique de certaines prasinites des Schistes lustrés du Queyras (France): arguments texturaux et géochimiques. *Bulletin de la Société Géologique de France*, *4*(4), 461–471. https://doi.org/10.2113/gssgfbull.I.4.461

Lagabrielle, Y., Polino, R., Auzende, J. M., Blanchet, R., Caby, R., Fudral, S., Lemoine, M., Mevel, C., Ohnestetter, M., Robert, D., & Tricart, P. (1984). Les témoins d'une tectonique intraocéanique dans le domaine téthysien: Analyse du rapport entre les ophiolites et leur couvertures métasédimentaires dans la zone piémontaise des Alpes franco-italiennes. *Ofioliti*, *9*, 67–88.

Lavier, L., & Manatschal, G. (2006). A mechanism to thin the continental lithosphere at magma-poor margins. *Nature*, *440*(7082), 324–328. https://doi.org/10.1038/nature04608

Lemoine, M. (1971). Données nouvelles sur la série du Gondran près Briançon (Alpes cottiennes). Réflexions sur les problemes stratigraphiques et paléogéographiques de la zone piémontaise. *Géol. Alpine*, *47*(2), 181–201.

Lemoine, M., Bas, T., Arnaud-Vanneau, A., Arnaud, A., Dumont, T., Gidon, M., Bourbon, M., De Graciansky, P. C., Rudkiewicz, J. L., Mégard-Galli, J., & Tricart, P. (1986). The continental margin of the Mesozoic Tethys in the Western Alps. *Marine and Petroleum Geology*, *3*(3), 179–199. https://doi.org/10.1016/0264-8172(86)90044-9

Lemoine, M., Bourbon, M., & Tricart, P. (1978). Le Jurassique et le Crétacé prépiémontais à l'Est de Briançon (Alpes occidentales) et l'évolution de la marge européenne de la Téthys: données Nouvelles et conséquence. *C.R. Acad. Sci. Paris*, *286*, 1655–1658.

Lemoine, M., & Tricart, P. (1986). Les Schistes lustrés piémontais des Alpes Occidentales: Approche stratigraphique, structural et sédimentologique. *Eclogae Geol. Helv*, *79*(2), 271–294.

Lemoine, M., Tricart, P., & Boillot, G. (1987). Ultramafic and gabbroic ocean floor of the Ligurian Tethys (Alps, corsica, Apennines): in search of a genetic model. *Geology*, *15*(7), 622–625. https://doi.org/10.1130/0091-7613(1987)15<622:UAGOFO>2.0.CO;2

Lemoine, M., & Trümpy, R. (1987). Pre-oceanic rifting in the Alps. *Tectonophysics*, *133*(3-4), 305–320. https://doi.org/10.1016/0040-1951(87)90272-1

Manatschal, M., & Müntener, O. (2009). A type sequence across an ancient magma-poor ocean–continent transition: The example of the western Alpine Tethys ophiolites. *Tectonophysics*, *473*(1-2), 4–19. https://doi.org/10.1016/j.tecto.2008.07.021

Manatschal, G., Sauter, D., Karpoff, A. M., Masini, E., Mohn, G., & Lagabrielle, Y. (2011). The Chenaillet ophiolite in the French/Italian Alps: An ancient analogue for an oceanic core complex? *Lithos*, *124*(3-4), 169–184. https://doi.org/10.1016/j.lithos.2010.10.017

Masini, E., Manatschal, G., & Mohn, G. (2013). The Alpine Tethys rifted margins: Reconciling old and new ideas to understand the stratigraphic architecture of magma-poor rifted margins. *Sedimentology*, *60*(1), 174–196. https://doi.org/10.1111/sed.12017

Mevel, C., Caby, R., & Kienast, J. R. (1978). Amphibolite facies conditions in the oceanic crust: Example of amphibolitized flaser gabbro and amphibolites from the Chenaillet ophiolite massif (Hautes Alpes, France). *Earth and Planetary Science Letters*, *39*(1), 98–108. https://doi.org/10.1016/0012-821X(78)90146-2

Michard, A., Goffe, B., Chopin, C., & Henry, C. (1996). Did the Western Alps develop through an Oman-type stage? The geotectonic setting of high-pressure metamorphism in two contrasting Tethyan transects. *Eclogae Geol. Helv*, *89*(1), 43–80.

Mohn, G., Manatschal, G., Beltrando, M., & Haupert, I. (2014). The role of rift-inherited hyper-extension in alpine-type orogens. *Terra Nova*, *26*(5), 347–353. https://doi.org/10.1111/ter.12104

Mohn, G., Manatschal, G., Muntener, O., Beltrando, M., & Masini, E. (2010). Unravelling the interaction between tectonic and sedimentary processes during lithospheric thinning in the Alpine Tethys margins. *International Journal of Earth Sciences*, *99*(S1), 75–101. https://doi.org/10.1007/s00531-010-0566-6

Philippot, P. (1990). Opposite vergence of nappes and crustal extension in the French–Italian Western Alps. *Tectonics*, *9*(5), 1143–1164. https://doi.org/10.1029/TC009i005p01143

Piana, F., Fioraso, G., Irace, A., Mosca, P., D'atri, A., Barale, A., Falletti, P., Monegato, G., Morelli, M., Tallone, S., & Vigna, G. B. (2017). Geology of Piemonte region (NW Italy, Alps–Apennines interference zone). *Journal of Maps*, *13*(2), 395–405. https://doi.org/10.1080/17445647.2017.1316218

Pinto, V. H. G., Manatschal, G., Karpoff, A. M., & Viana, A. (2015). Tracing mantle-reacted fluids in magma-poor rifted margins: The example of Alpine Tethyan rifted margins. *Geochemistry, Geophysics, Geosystems*, *16*(9), 3271–3308. https://doi.org/10.1002/2015GC005830

Polino, R., Borghi, A., Carraro, F., Dela Pierre, F., Fioraso, G., & Giardino, M. (2002). Note illustrative della Carta

Geologica d'Italia alla scala 1: 50.000, F. 132-152-153 "Bardonecchia". Regione Piemonte, Direzione Regionale dei servizi Tecnici di Prevenzione. Litografia Geda, Nichelino. Torino.

Polino, R., & Lemoine, M. (1984). Détritisme mixte d'origine continentale et océanique dans les sédiments jurassico-crétacés supra-ophiolitiques de la Téthys ligure: la série du Lago Nero (Alpes Occidentales franco-italiennes). *C.R. Acad. Sci., Série*, *2*(298), 359–364.

Polino, R., Monticelli, F., & Vaccaro, D. (1983). L'unità piemontese Chaberton-Grand Hoche (Val Susa-Alpi Occidentali): evoluzione litostratigrafica, assetto strutturale e rapporti con i complessi circostanti. *Mem. Soc. Geol. It*, *26*(2), 489–498.

Saccani, E., Dilek, Y., Marroni, M., & Pandolfi, L. (2015). Continental margin ophiolites of neotethys: Remnants of ancient ocean–continent transition zone (OCTZ) lithosphere and their geochemistry, mantle sources and melt evolution patterns. *Episodes*, *38*(4), 230–249. https://doi.org/10.18814/epiiugs/2015/v38i4/82418

Servizio Geologico D'italia. (1911) Carta Geologica d'Italia alla scala 1:100.0000, F. 66 Cesana T.se. Roma.

Servizio Geologico D'italia. (2002). Carta Geologica d'Italia alla scala 1:50.0000, F. 132-152-153 Bardonecchia Regione Piemonte, Direzione Regionale dei servizi Tecnici di Prevenzione. Litografia Geda, Nichelino. Torino.

Servizio Geologico D'italia. (2020) Carta Geologica d'Italia alla scala 1:50.0000, F. 171 Cesana. http://www.isprambiente.gov.it/Media/carg/171_CESANA_TORINESE/Foglio.html

Tricart, P., & Lemoine, M. (1991). The Queyras ophiolite west of Monte Viso (Western Alps): indicator of a peculiar ocean floor in the Mesozoic tethys. *Journal of Geodynamics*, *13*(2-4), 163–181. https://doi.org/10.1016/0264-3707(91)90037-F

Tricart, P., & Schwartz, S. (2006). A north–south section across the Queyras Schistes lustrés (Piedmont zone, western Alps): Syn-collision refolding of a subduction wedge. *Eclogae Geologicae Helvetiae*, *99*(3), 429–442. https://doi.org/10.1007/s00015-006-1197-6

Villa, I. M., Bucher, S., Bousquet, R., Kleinhanns, I. C., & Schmid, S. M. (2014). Dating polygenetic metamorphic assemblages along a transect across the Western Alps. *Journal of Petrology*, *55*(4), 803–830. https://doi.org/10.1093/petrology/egu007

Vissers, R. L. M., Van Hinsbergen, D. J. J., Meijer, P. T. H., & Piccardo, G. B. (2013). Kinematics of Jurassic ultra-slow spreading in the Piemonte Ligurian ocean. *Earth and Planetary Science Letters*, *380*, 138–150. https://doi.org/10.1016/j.epsl.2013.08.033

Whitney, D. L., & Evans, B. W. (2010). Abbreviations for names of rock-forming minerals. *American Mineralogist*, *95*(1), 185–187. https://doi.org/10.2138/am.2010.3371