LITHOSTRATIGRAPHY AND STRUCTURE OF THE LAGO NERO UNIT (CHENAILLET MASSIF, WESTERN ALPS): COMPARISON WITH INTERNAL LIGURIDE UNITS OF NORTHERN APENNINES

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ABSTRACT

In the Western Alps, the Schistes Lustrés includes ophiolitic units that, even if affected by HP metamorphism, are relatively poorly deformed. Among them, the Lago Nero unit displays a thick and well-developed sedimentary cover, that allows a comparison with the analogue successions of the Northern Apennines. This sedimentary cover includes hemipelagic deposits, represented by Radiolarite, Metalimestone and Replatte Fms., showing a transition to turbiditic (Gondran Flysch) and mass-gravity deposits (Rocher Renard complex). This succession, characterized by a coarsening upward trend, records the approaching of an oceanic floor section to the accretionary wedge. In this picture, the Rocher Renard complex can be regarded as a formation related to a frontal erosion of the accretionary wedge, whereas the Gondran Flysch is interpreted as a turbidite deposits supplied by the continental margin of the Europe plate. The following deformation history includes four deformation phases. Whereas the first phase D1 was achieved during the coherent underplating in the alpine subduction zone, the D2, D3 and D4 phases was developed under retrograde metamorphic conditions during the progressive exhumation of the Lago Nero unit.

All the collected data suggest that the succession of the Lago Nero unit can be correlated with those of the Internal Liguride units where the same sequence of hemipelagic to turbiditic and mass-gravity deposits has been recognized since long time by several authors.

INTRODUCTION

In the Western Alps, the Jurassic ophiolites and the related sedimentary cover are preserved as strongly deformed and metamorphosed sequences in the Schistes Lustrés complex. These sequences are interpreted as fragments of the Ligure-Piemontese oceanic basin originated during the Jurassic between the Europe and Adria continental margins. This basin has been completely closed during the intraoceanic subduction and the subsequent continental collision in the Late Cretaceous – Early Tertiary. Previous studies of alpine ophiolites have ben focused on the primary lithostratigraphic and petrological features of the igneous sequences in order to outline the spreading processes in the Ligure-Piemontese oceanic basin. These studies were based on comparisons with the very low-grade metamorphic ophiolites of the Northern Apennines, that expose well preserved sequences where the primary features can be fully observed. However, not all of the sedimentary covers of the ophiolites sequences, exposed in the Western alps, have been studied in detail and some localities that display interesting features, still remain poorly known. In the Western Alps, the Schistes Lustrés includes also ophiolitic units that, even if affected by HP metamorphism, are relatively poorly deformed. Among them, the Lago Nero unit (Monginevro area, Fig. 1) displays a thick and well-developed sedimentary cover, that allows a comparison with the analogues successions from the Northern Apennines. In this paper we present the result of lithostratigraphy and structural analyses of the Lago Nero unit to reconstruct the primary features of its sedimentary cover. A comparison with the ophiolite sedimentary covers from the Internal Liguride ophiolites of the Northern Apennines is also presented.

GEOLOGICAL SETTING

The ophiolites from the Western Alps are regarded as remnants of the Ligure-Piemontese oceanic basin that opened in the Middle to Late Jurassic between the Europe and Adria plates after the Triassic-Early Jurassic rifting processes (Lemoine and Trumpy, 1987; Dewey et al., 1989; Bortolotti et al., 1991; Stampfli et al., 1998; Wortmann et al., 2001; Stamplfli and Borel, 2002). From Late Cretaceous, the oblique convergence between Europe and Adria led to the intraoceanic subduction of the Ligure-Piemontese lithosphere followed during the Eocene by the continental collision. The complex structural pattern of the Western Alps ophiolitic units resulted from the deformations achieved during both intraoceanic and continental collision events.

In the Western Alps, remnants of the Ligure-Piemontese ocean are still preserved in the Schistes Lustrés complex, also known as Piemontese units, that includes also slices derived from the thinned continental margin of the Europe plate (Prepiemontese domain). The Schistes Lustrés complex overlay directly the Internal Crystallin Massifs (Mt. Rosa, Gran Paradiso, Dora Maira) whereas to the West it is separated from the Briançonnais units by the Penninc front (Fig. 1).

According to their stratigraphic patterns and metamorphic overprint, the Piemontese units can be divided in two main groups (Dal Piaz, 1974; Polino et al., 1990; Deville et al., 1992; Lagabrielle, 1994; Oberhänsli, 1994; Dal Piaz et al., 2001).

The first group is characterized by ultramafic bodies with subordinate basalts and gabbros, enclosed in a thick metasedimentary covers mainly represented by calcschistes. In this group, that includes the Tsaté, the Charbonnel and the Mirabouc-Bouchet units, the orogenic metamorphism is gen-

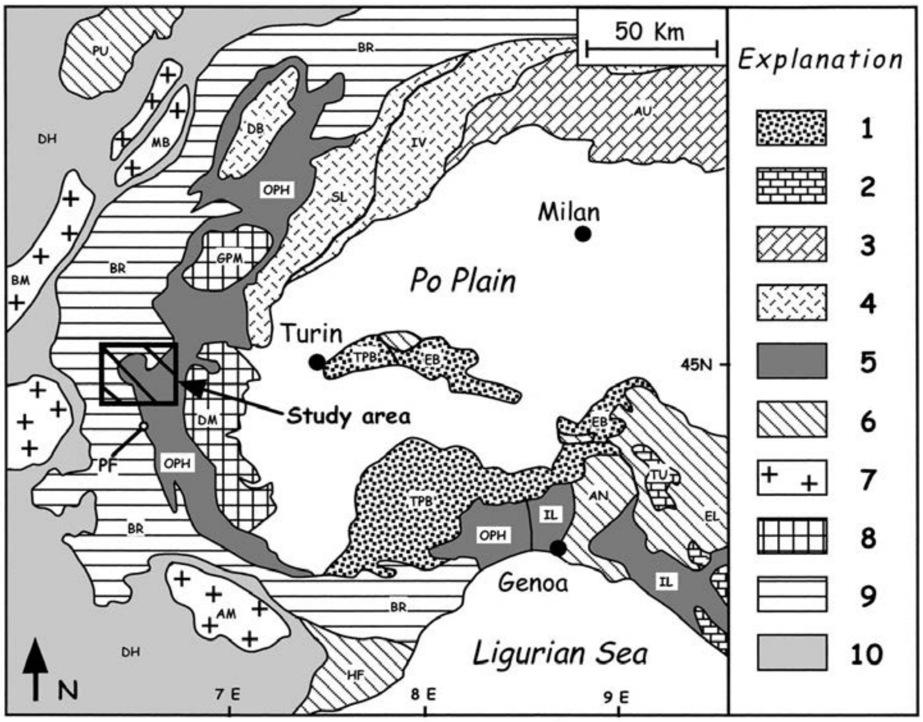

Fig. 1 - Tectonic sketch map of the Western Alps and Northern Apennines. 1: Post-orogenic sedimentary sequences of the Tertiary Piedmonte (TPB) and Epiligurian (EB) Basins; 2: Canetolo and Tuscan units (TU); 3: South Alpine cover units (AU); 4: Australpine basement units [Sesia-Lanzo Zone (SL), Ivrea Zone (IV) and Dent Blanche (DB)]; 5: Alpine and Apennines Ophiolitic units [Internal Liguride (IL), Sestri-Voltaggio, Voltri Group, Piemontese units (OPH)]; 6: Helminthoid flysch and associated sedimentary complexes [External Liguride (EL), Mt. Antola (AN), Autapie and S. Remo-M. Saccarello (HF), Prealpine (PU) units]; 7: Internal Crystalline massifs of the Western Alps [Dora Maira (DM) and Gran Paradiso (GPM)]; 8: External crystalline massifs of the Western Alps [Argentera (AM), Belledonne (BM) e Mont Blanche (MB)]; 9: Briançonnais and Lower Penninic units (BR); 10: Dauphinois-Helvetic units (DH). The Penninic Front (PF) is indicated.

erally referred to blue and green-schists facies conditions.

The second group, including the Zermatt-Saas Fee, Rocciavré and Monviso units, is made up by large and strongly deformed ophiolitic sequences and minor metasedimentary covers, mainly represented by quartzites and calcschists. These ophiolites are affected by an high- to ultra-high-pressure facies metamorphic overprint.

In addition, the ophiolites from Chenaillet unit, where an orogenic very low-grade metamorphism has been detected, are located close to Penninic front.

The Lago Nero unit belonging to the “second group” of the Schistes Lustrés complex, occur structurally below the Chenaillet unit. In the investigated area, these units occur in a tectonic domain bounded northward and southward by a couple of east-west trending strike-slip faults. In this tectonic domain, the Lago Nero unit is thrust by the Chenaillet unit and, in turn, it overlains the Lac des Cordes unit. All these units belong to the Piemontese domain (Barfety et al., 1995) and they are thrust onto the Gondran unit of the Prepiemontese domain.

LITHOSTRATIGRAPHIC FEATURES OF THE LAGO NERO UNIT

The Lago Nero unit is characterized by the presence of a metamorphosed Jurassic ophiolitic basement, associated to a thick metasedimentary cover. The basement crops out in the eastern region of the study area, around the Cesana Torinese village (Fig. 2). On the contrary, the metasedimentary cover of the Lago Nero unit, generally reported as “Chabrière series” (Lemoine et al., 1970), widely crops out in the whole investigated area.

The Jurassic ophiolitic sequence is represented by metaserpentinites cross-cut by rodingitized gabbroic dikes (Bertrand et al., 1982; Bertrand et al., 1984). The metaserpentinites are regarded as metamorphosed lherzolites representative of the oceanic mantle. At the top of the metaserpentinites few meters of metaophicalcites occur (Fig. 3). The metaophicalcites include two end-members; the first consists of metaserpentinites cross-cut by a net of carbonatic veins (ophicalcite de type 1 by Barfety et al., 1995) whereas the second is made up by a metabreccia where serpentinitic clasts are embedded in a calcareous matrix (ophicalcite de type 2 by Barfety et al., 1995).

In addition, a polymict metabreccia, consisting of clasts derived from both continental and oceanic source areas, occurs at the top of the metaophicalcites (Fig. 3). The lithic fragments consist of granitoids and minor basalts but, fragments of biotite-bearing granitoids have also been found by Polino and Lemoine (1984). At the top of the polymict metabreccia, as well as of the metaophicalcites, a very thin level of metabasalts, still showing pillow-lava and pillow-breccia textures is exposed.

The metabasalts or the metaophicalcites are topped by the Radiolarite Fm. consisting of a few meters of metacherts alternanting with very thin layers of schists (Fig. 3). The Radiolarite Fm. is assigned to upper Oxfordian/lower Kimmeridgian by Radiolarian assemblages (Schaff et al., 1985 and quoted references). A well exposed transition from basalt flows to Radiolarite Fm. can be observed at Mt. Cruzore (Polino, 1984); the reconstructed sequence includes metabasalts with pillow-lava texture followed by a few meters of metabreccia consisting of pillow-lava fragments and thin intercalations of metacherts. This level is, in turn, topped by the lower part of the Radiolarite Fm. showing in turn thin intercalations of ophiolitic debris.

The Radiolarite Fm. is topped by the Metalimestone Fm., consisting of an alternance of thick cherty metalimestone beds with thin schist layers (Fig. 3). In the lower part of the Metalimestone Fm., the metacherts layers are quite common. In some areas, the metalimestones overlays directly the ophiolitic basement, without occurrence of the Radiolarite Fm..

The Metalimestone Fm. shows a gradual transition to the Replatte Fm., which consists of an alternance of thick schist layers and thin metalimestone beds (Fig. 3).

The previously described sedimentary succession has been correlated since long time with the Chert (Bathonian-

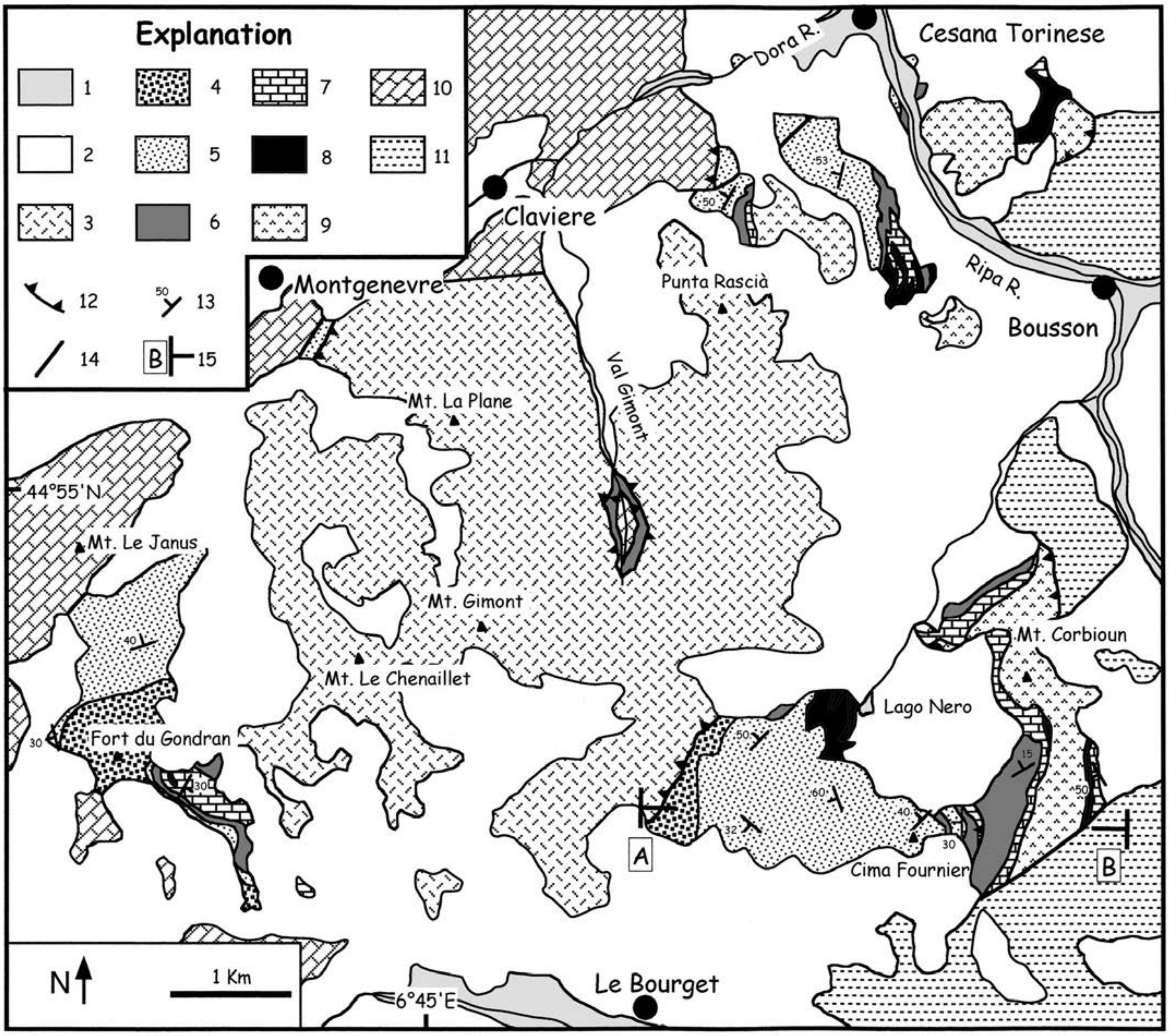

Fig. 2 - Geological map of the study area. 1. Quaternary alluvial deposits; 2. Quaternary glacial derived deposits; 3. Chenaillet unit; Lagonero unit: 4. Rocher Renard Complex; 5. Gondran Flysch; 6. Replatte Formation; 7. Metalimestone Formation; 8. Metabasalts, Polymict Breccia and Metaradiolarites; 9. Ultramafic basement; 10. Chaberton unit; 11. Lac des Cordes unit; 12. Thrust; 13. D2 phase foliation; 14. fault; 15. Location of the cross section represented in Fig. 7.

Tithonian; Chiari et al., 2000), Calpionella Limestone (Berriasian-Valanginian; Perilli and Nannini, 1997) and Palombini Shale (Valanginian-Santonian; Marroni and Perilli, 1990) that represents the sedimentary cover of the Jurassic ophiolite sequence in the Internal Liguride units from the Northern Apennines (Polino, 1984; Tricart et al., 1985; Lemoine and Tricart, 1986).

The Replatte Fm. is followed by the Gondran Flysch, which is made up by an alternance of calcschists and metasandstones (Fig. 3). At Cima Fournier the stratigraphic transition from Replatte Fm. to Gondran Flysch is marked by the presence of grey to black schists (Black Shales by Barfety et al., 1995), whose thickness is about 20 meters. The Gondran Flysch is mainly represented by thin-bedded turbidites with minor occurrence of thick and coarse grained terrigenous metasandstones. Arenites indicate an arkosic composition (Fig. 4a) mainly characterized by quartz and feldspar and minor lithic fragments. The rock fragments mainly derive from granitoids and carbonatic rocks; low grade metamorphic and acidic volcanic rock fragments can be also recognized. Some carbonatic rock fragments are characterized by relics of sedimentary textures, as for instance, the oolitic-grainstones, that indicate a carbonatic shelf successions as source area (Fig. 4b). The presence of diagenetic features in these carbonatic fragments such as veins inside the fragment, pore flling cement and angular shape indicate the non-coeval and extrabasinal origin of these fragments probably from Triassic-Jurassic carbonatic platform. Even if no fossil has been found, the Gondran Flysch is generally referred to a Late Cretaceous age (Polino and Lemoine, 1984; Barfety et al., 1995).

Associated to those formations a sedimentary complex, hereafter referred as Rocher Renard complex, occur. This complex has been partially mapped in “Black Shale Fm.” (Barfety et al., 1995) but also described as “dissociated facies” of the Replatte Fm. by Lemoine and Tricart (1986). The glacial deposits prevents to determine the stratigraphic relationships between the Rocher Renard complex and the others

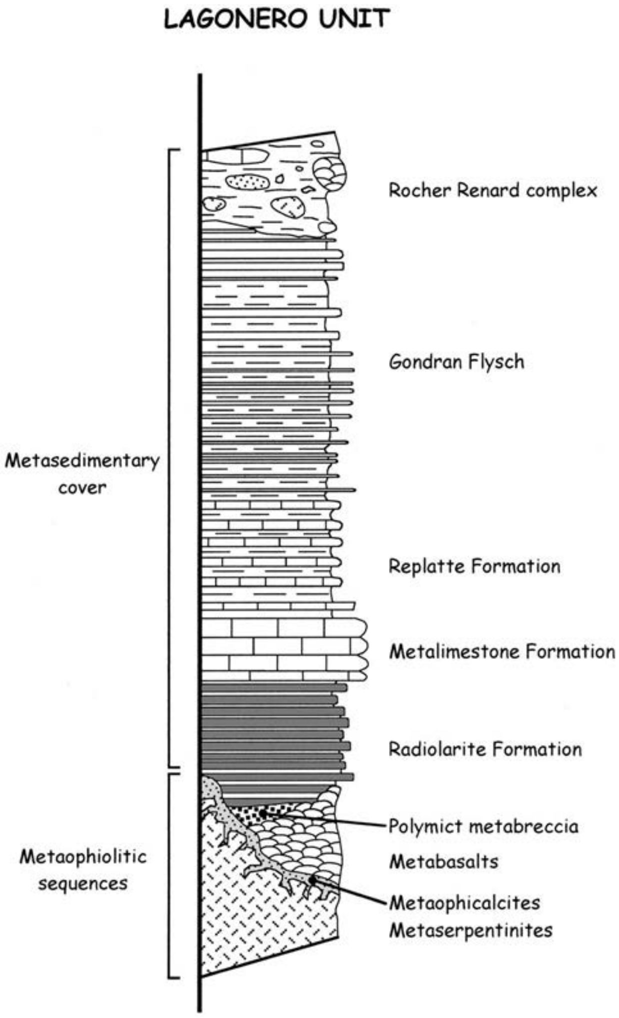

Fig. 3 - Proposed reconstruction of the Lagonero unit succession.

formations of the Lago Nero unit. The Rocher Renard complex is mainly represented by homogeneus dark schists, which locally can include several blocks. The Rocher Renard outcrop is characterized by the presence of blocks derived from an ophiolitic sequence and related sedimentary cover similar to that of the Lago Nero unit (Fig. 4c). The ophiolitic blocks are mainly represented by metabasalts, metaophicalcites but metaserpentinites and metagabbros have been also recognized. In a decametric block, located in the lower part of the outcrop, the stratigraphic relationships between metaophicalcites and metabasalts are still preserved. The blocks derived from the ophiolitic sedimentary cover are mainly represented by metalimestones, probably derived from the Replatte and the Metalimestone Fms., but a small block of metacherts have been also observed. Blocks derived from continental crust are lacking at all. No data about the age are available.

DEFORMATION HISTORY

The Lago Nero unit is characterized by a deformation history consisting of four folding phases, hereafter referred as D1, D2, D3 and D4, followed by a brittle tectonics event (not described in this paper). The structural analysis has been performed on the whole sequence, from metaserpentinites to Rocher Renard complex.

D1 Phase

The structural elements related to the D1 phase are largely transposed by the later deformation phases. The D1 phase is mainly represented by a foliation preserved as relics in the hinge of the F2 folds. This foliation is characterized by a L1 mineralogical lineation evidenced by white mica recrystallization. Also the rare rootless, similar folds with angular hinges can be regarded as belonging to D1 phase, but the trend and the facing of these structures remain undetermined.

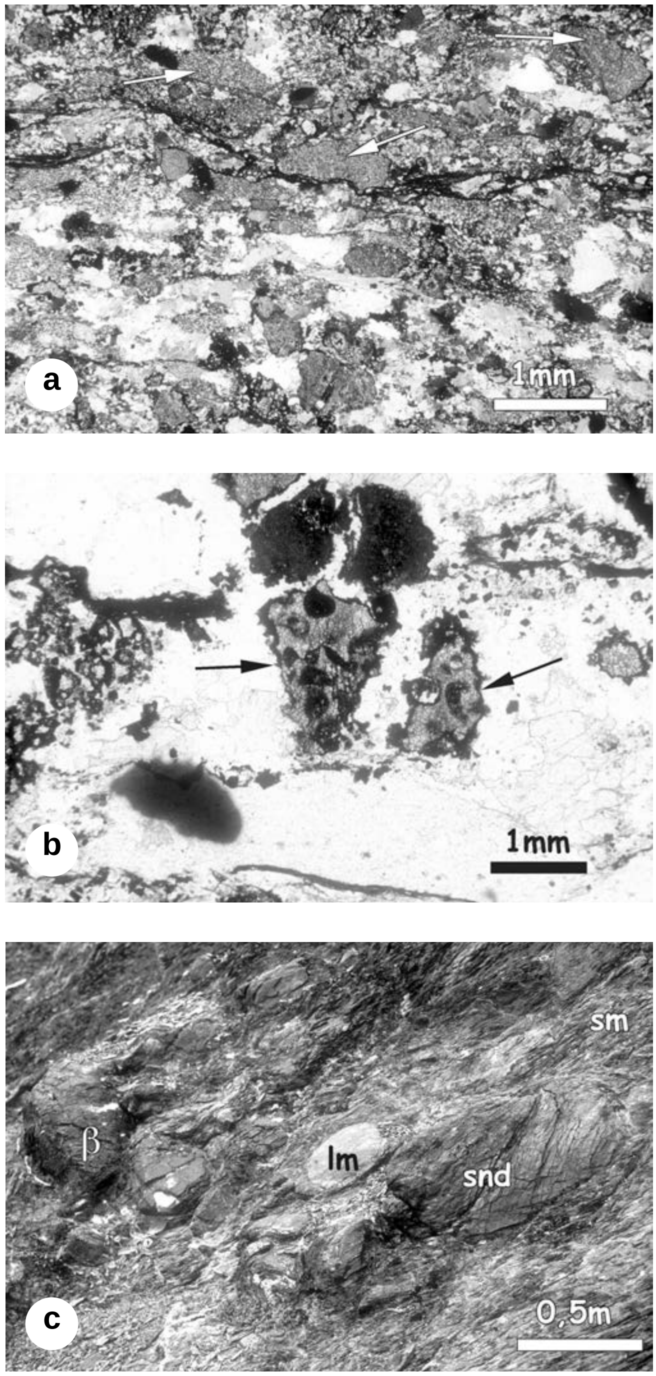

Fig. 4 - a) photomicrograph of coarse grained arenites from Gondran Flysch showing a mixed silicilastic-carbonatic composition. The whithe arrows indicate micritic carbonatic fragments; b) photomicrograph of coarse grained arenites from Gondran Flysch, the black arrows indicate a carbonatic rock fragment represented by a peloidic grainstones; c) Rocher Renard Complex: pebbly mudstone, consisting of reworked cobbles, boulders and pebbles of calciluthites (lm), basalts (β) and sandstones (snd) in a shaly matrix (sm).

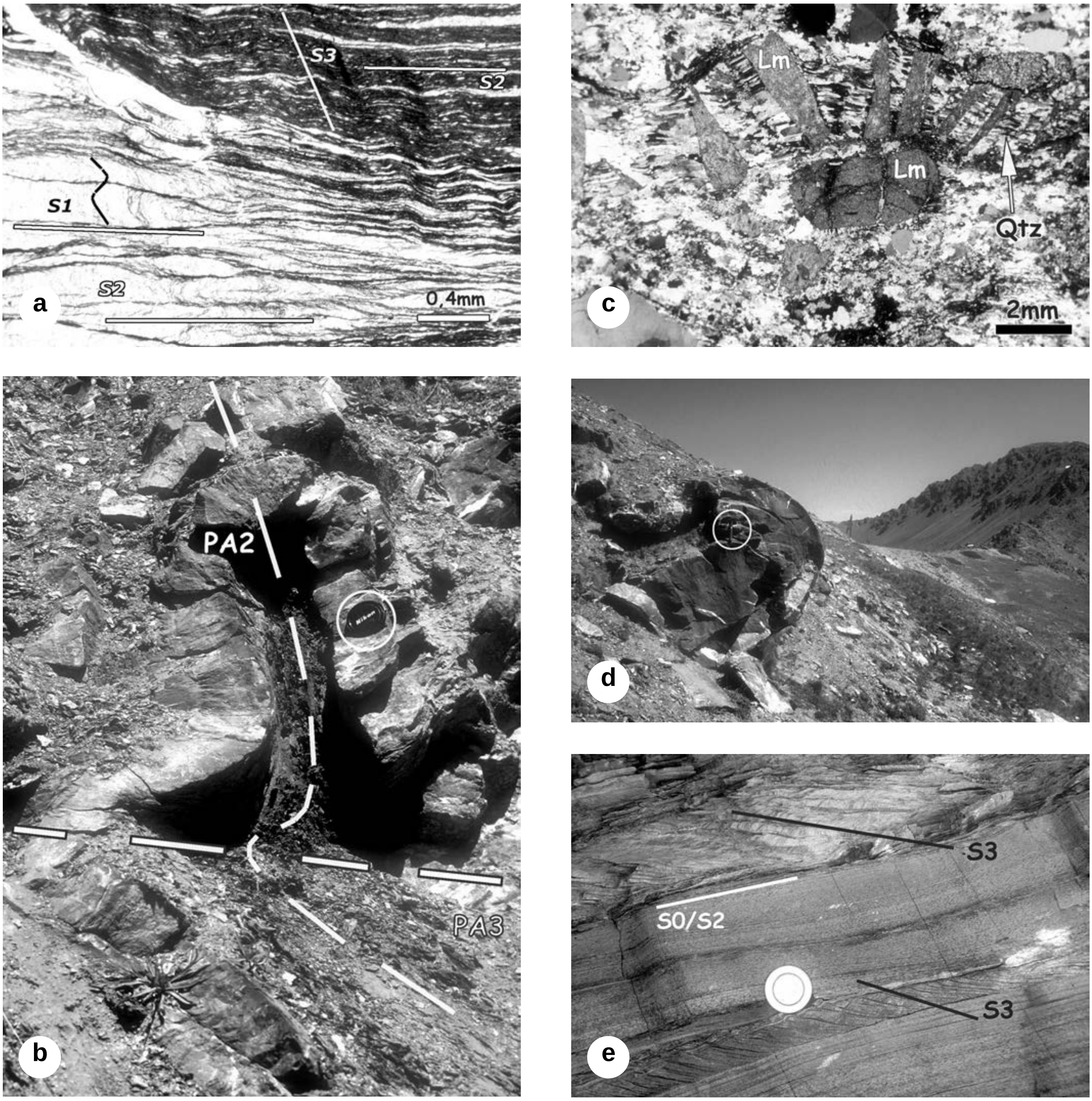

Fig. 5 – a) photomicrograph of D2 phase hinge zone with associate axial plane foliation (S2). Relics of S1 foliation and D3 phase related crenulation cleavage (S3) are also indicated; b) Isoclinal F2 fold deformed by a F3 fold in the Replatte Formation, the related axial planes PA2 and PA3 are indicated; 52mm lens cap for scale; c) Quartz fibers (Qtz) growth between microboudinaged carbonatic fragments (Lm); d) D3 phase related metric fold developed in the Replatte Formation; hammer for scale; e) Relationships between D3 phase-related crenulation cleavage (S3) and composite S0 and D2 phase-related foliation (S0/S2) at the boundary between the Radiolarite Formation and the Metalimestone Formation.

In thin section, the relics of the D1 phase are common (Fig. 5a). In the schists and calcschists, the F2 hinge zones preserve evidences of the S1 foliation, which can be defined as a continuous schistosity. In these lithologies the S1 foliation is characterized by growth of quartz, calcite, white mica and chlorite. In the Mt. Cruzore metabasalts, relics of Na-amphibole have been observed. In the same outcrop, a metamorphic assemblages made by chlorite, lawsonite, Na-amphibole, Na-pyroxene and phengite has been described by Kohen and Vuagnat (1970). Also in the polymict breccias relics of lawsonite transposed by the S2 foliation have been observed. These assemblages imply a P-T conditions of 6-8 Kbar and 300-350°C (Yardley, 1989; Pognante, 1991). This is consistent with the previous data from Queyras units (Ballèvre et al., 1990)

D2 Phase

The D2 phase is characterized by isoclinal, strongly non cylindrical and recumbent F2 folds. The F2 folds (Fig. 5b), belonging to the classes 2 and 3 of the Ramsay classification (1967) and they are characterized by tickened hinges and thinned limbs, generally marked by boudinage and pinch-and-swell structures. According to the F2 folds geometry the A2 axes trend is scattered, but a N30ºE cluster can be recognized (Fig. 6). The L2 mineralogical lineation is represented by chlorite and white mica, whereas the stretching lineations, mainly observed in the Replatte Fm., are represented by boudinaged millimetric pyrite grains with oriented growth of quartz fibers. Both mineralogical and stretching lineations display a preferred orientation showing a N40ºE trend, subparallel to the A2 axes (Fig. 6). This evidence suggests that the F2 folds can be regarded as sheat folds with fold axes subparallel to the mineralogical/stretching lineations. The westward facing of the D2 phase has been determinated by the analysis of the megastructures, as for instance the structure of Cima Fournier (Fig. 7).

The F2 folds are characterized by an S2 axial plane foliation (Fig. 6), that is found as a well developed anisotropy in all the metasedimentary lithologies. In thin section, the F2 folds hinge zone of schists and calcschists is characterized by a S2 spaced foliation that can be classified as a crenulation cleavage (Fig. 5a). Following the Passchier and Trouw classification (1996), the shape of the cleavage domains is smooth, they hold about 30% of the rock and the transition to the microlithons is discrete. In the cleavage domains the growth of white mica, quartz, calcite, chlorite, oxides and stilpnomelane has been observed. In the limbs of F2 folds a composite foliation derived by the superposition of the S1 and S2 foliations is detected. In the metalimestones this continuous foliation S1+S2 is classificable as schistosity whereas in the others metasedimentary rocks it occur as slaty cleavage. In the metasandstones the D2 phase is characterized also by the development of microstructures, as, for instance, the pressure shadows characterized by the growth of calcite and quartz fibers developed between microboudinaged carbonatic fragments (Fig. 5c). In the metaophiolites the S1+S2 composite foliation has been observed, in the pillow-breccia basalts. This continuous foliation is characterized by the development of metamorphic assemblages referable to a low-grade greenschist facies (Ballèvre et al., 1990). These assemblages are made by chlorite, albite, epidote, quartz, white mica and stilpnomelano, moreover a widespread instability of the plagioclases have been also observed. This assemblage implies a pressure of about 4 Kbar and a temperature of 300-400°C (Yardley, 1989; Pognante, 1991).

D3 Phase

The D3 phase is characterized by asymmetric F3 folds, with an approximately parallel geometry and rounded hinges (Fig. 5d). The F3 folds belong to 1B and 1C classes of the Ramsay classification (1967). On the fold limbs quartz or calcite fibers and slickensides are quite common, according to a flexural slip folding mechanism. The A3 axes are characterized by a N40ºE main trend (Fig. 6) as suggest-

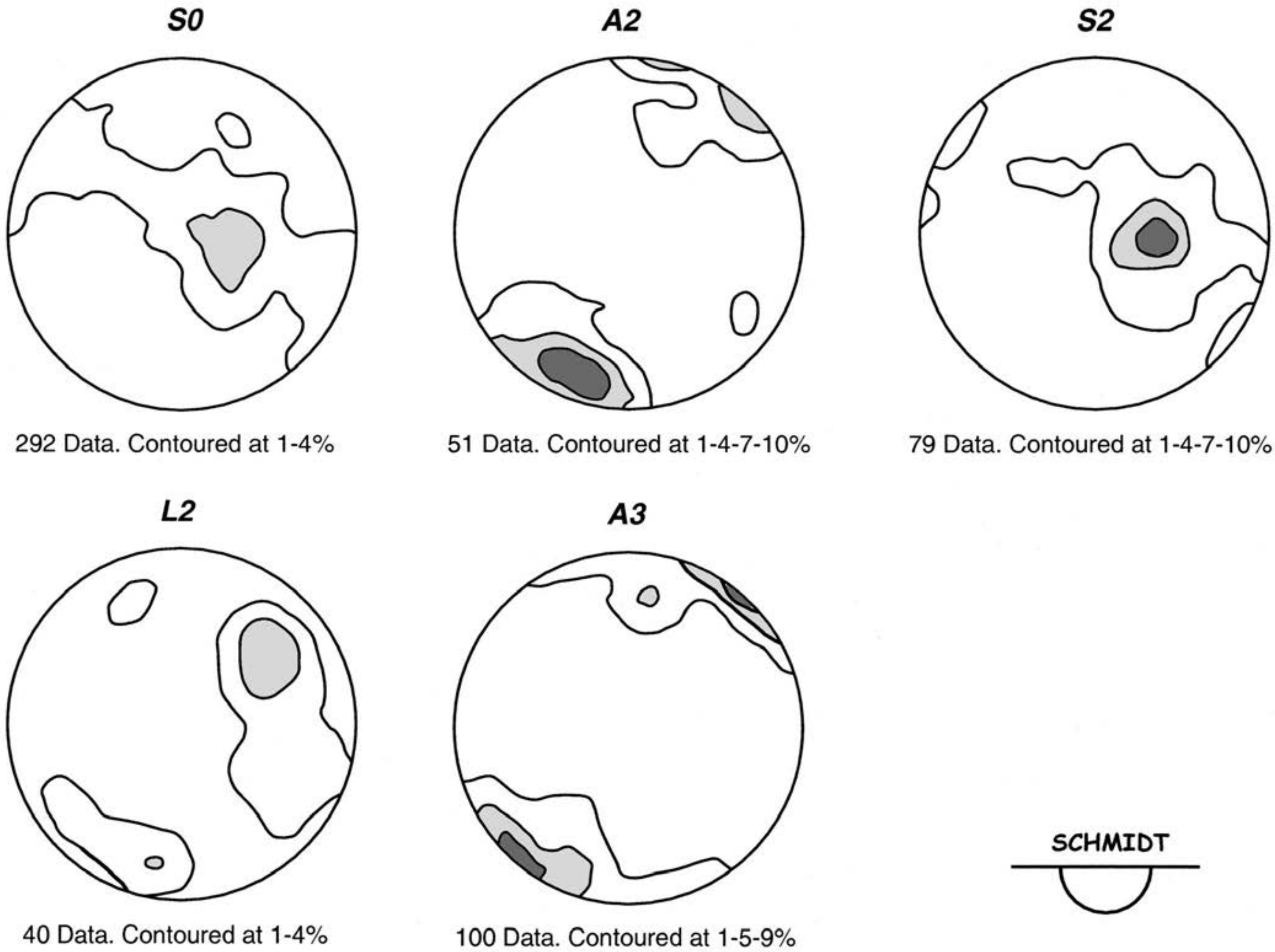

Fig. 6 - Equal-area, lower hemisphere stereographic representation of D1, D2 and D3 structural data. S0: bedding planes; A2: D2 phase axes; S2: D2 phase foliations; L2: D2 phase mineral lineations; A3: D3 phase axes.

ed also by the stereographic projection of the S0 bedding and the S2 foliation (Fig. 6). The PA3 axial planes are generally subhorizontal. The S3 foliation is well developed only in the F3 hinge zone found in the schists, calcschists and metaradiolarites (Fig. 5e). According to the Ramsay's classification (1967), the F2/F3 superposition produce a type 3 interference pattern (Fig. 5b). For the D3 phase an eastward facing has been determinated by the analysis of the megastructures of the Lago Nero unit, as for instance in the Cima Fournier area (Fig. 7).

The S3 foliation is a crenulation cleavage. Following the Passchier and Trouw classification (1996), the shape of the cleavage domains is smooth. They hold about 20-30% of the rock and the transition to the microlithons is gradational or discrete. In the cleavage domains the growth of white mica, chlorite, oxides and calcite have been observed.

In the metabasalts from the Lago Nero unit the D3 phase is characterized by the static growth of metamorphic assemblages made up by chlorite, prehnite and pumpellyite (Bertrand et al., 1984; Barfety et al., 1995). This assemblage implies P/T conditions of about 2-4 Kbar and 200-300°C (Yardley, 1989; Pognante, 1991). The widespread presence of calcite twins referable to the type 2 and 3 of the Burkhard classification (1993) is coherent with this temperature range.

D4 Phase

The D4 phase is characterized by the development of open, concentric folds with rounded hinges. Kink-folds have been also observed. The A4 axes display a main N-S trend whereas the PA4 axial planes are subvertical. In the schists a weak S4 foliation has been rarely observed. This spaced foliation is definible as a crenulation cleavage with gradational transition among microlithons. No mineral recrystallization related to the D4 phase have been observed.

DISCUSSION

According to the geodynamic scenario proposed for the western Tethys (e.g. Le Pichon et al., 1988; Dewey et al., 1989; Bortolotti et al., 1991; Stampfli et al., 1998; Wortmann et al., 2001; Stamplfli and Borel, 2002), the deformation phases recognized in the Lago Nero unit can be related to the tectonic evolution connected with the convergence phases affecting the Ligure-Piemontese oceanic basin from mid-Cretaceous up to Late Eocene.

Recent kinematic models proposed for the Alps (Lagabrielle, 1987; Polino et al., 1990; Stampfli and Marthaler, 1990; Stampfli et al., 1998) suggest the development of an accretionary wedge starting from mid-Cretaceous in the oceanic domain. This hypothesis is supported by sedimentologic, stratigraphic and structural data and by comparison with modern and ancient examples. According to the occurrence of HP/LT metamorphism, the Lago Nero unit can be regarded as a fragment of the oceanic lithosphere involved in the subduction of the Ligure-Piemontese oceanic basin.

In subduction zones, sediments are incorporated at the toe of the accretionary wedge by the process known as "offscraping" or they are underthrust beneath the accretionary wedge and later underplated, showing coherent or diffusive styles (Moore and Sample, 1986, and references therein). The deformation history of these units can provide important insights for the distinction between these two accretionary mechanisms, i.e. offscraping vs. underplating (Moore and Sample, 1986, and references therein).

The well preserved sedimentary sequences and the features of the D1 deformation, such as finite strain, rootless folds and schistosity, strongly support the interpretation of the Lago Nero unit as coherently underplated unit at the base of the accretionary wedge during subduction phases as suggested, for instance, by comparison with examples from Kodiak Island (Sample and Fisher, 1986; Sample and Moore, 1987).

The structures belonging to the D1 phase generated during the underplating in response to non-coaxial deformation along the decollement zone separating the lower oceanic plate from the overlying accretionary wedge. The occurrence of the D1 phase associated with HP/LT metamorphism is coherent with an underplating depth ranging about from 20 to 25 km.

The occurrence of mantle ultramafics indicate an involvement of the whole oceanic sequence in the underplating processes according to proposed coherent style. This process has been probably driven by the stratigraphy of the ophiolite sequence, that displays suitable discontinuities able to allow the detachment of a whole section of the oceanic lithosphere from mantle to sedimentary cover (e.g. Polino and Lemoine, 1984).

According to the available radiometric age, the HP-LT metamorphic events in the ophiolitic units are regarded as Early-Middle Eocene in age (Dal Piaz et al., 2001 and quoted references). This age can be extended also to the D1 phase recognized in the Lago Nero unit.

As observed in many examples of coherently underplated units (Moore and Allwardt, 1980; Fisher and Byrne, 1987; Sample and Moore, 1987; Goodge, 1989; George, 1990; Marroni and Pandolfi, 1996), also in the Lago Nero unit, the D1 phase is followed by less intense deformation phases, i.e, D2 and D3 phases, related to post-underplating deformation. Both the D2 and D3 phases can be regarded as developed during a retrograde deformation history that marks the transition from the deeper structural level reached during the

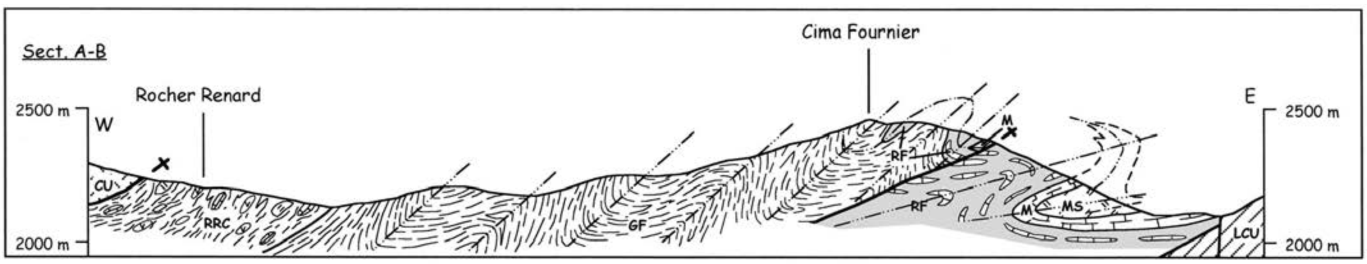

Fig. 7 - Geological cross section of the Cima Fournier area. CU: Chenaillet unit; Lagonero unit: RRC Rocher Renard complex; GF: Gondran Flysch; RF: Replatte Fm.; M: Metalimestone Formation; MS: Metaserpentinites. Location of the cross section is indicated in Fig.2.

D1 phase to the shallow structural levels where the D3 phase developed (Fig. 8). By contrast, the D4 phase can be related to a deformation history developed in the mature stage of the continental collision.

All the ophiolitic sequences involved in the subduction zone are characterized by a sedimentary cover that records depositional events occurred before the inception of the deformation history. These events was developed during the motion of oceanic lithosphere from oceanic basin to the trench setting (Schweller and Kulm, 1982). Also in the Lago Nero unit it is possible to recognize these events. They are represented by the transition from hemipelagic (Replatte Fm.) to turbidite (Gondran Flysch) deposits as well as by the transition from the latters to mass-gravity (Rocher Renard complex) deposits. These events are reflected by sharp changes in depositional processes that occurred when the section of oceanic lithosphere was approaching to the trench setting. This picture is confirmed by the difference in the source areas of the Gondran Flysch and the Rocher Renard complex. Whereas the Gondran Flysch was supplied by a faulted continental margin, the deposits as the Rocher Renard complex can be originated from the lower slope of an accretionary wedge, where ophiolites and related sedimentary covers were imbricated.

COMPARISON WITH NORTHERN APENNINES OPHIOLITIC SEQUENCES

The analogies between the ophiolitic sequences in Western Alps and Northern Apennines have been pointed out since long time (Sturani, 1973; Lombardo and Pognante, 1982; Abbate et al., 1986; Lagabrielle and Polino, 1988; Lemoine et al., 1987; Tricart and Lemoine, 1991; Lagabrielle and Lemoine, 1997).

As recognized in the Northern Apennines (Decandia and Elter, 1972; Cortesogno et al., 1975; Abbate et al., 1980; Cortesogno et al., 1987), in the Western Alps the ophiolite sequence is characterized by an oceanic basement represented by small gabbroic bodies intruded in a lherzolitic mantle, widely serpentinized (Bertrand et al., 1982; Lombardo and Pognante, 1982; Lemoine et al., 1987; Tricart and Lemoine, 1991; Lagabrielle, 1994). Both gabbros and lherzolites were exposed at the sea floor as testified by the occurrence of ophicalcites at the top of the serpentinized lherzolites. This basement is covered by a volcano-sedimentary complex consisting of massive and pillow-lava basaltic flows interfingering with ophiolitic breccias and cherts. The sedimentary cover can be found at the top of the basaltic flows and the ophiolitic breccias, as well as at the top of the basement. Several settings for the origin of this "peculiar" stratigraphy has been proposed: a transform fault setting (Lemoine, 1980; Ishiwatari, 1985), a slow-spreading ridge setting (Lagabrielle and Cannat, 1990; Lagabrielle, 1994; Lagabrielle and Lemoine, 1997) or alternatively this stratigraphy has been thought as consequence of mantle denudation by symmetric or asymmetric process of rifting (Lombardo and Pognante, 1984; Lemoine et al., 1987).

Despite the different settings proposed for its origin, the ophiolite sequence from the Lago Nero units displays the same characteristics, already suggested by the occurrence of ophicalcites and the scarceness of the basalt flows. In addition, the presence of a polymict metabreccia characterized by continental-derived clasts (Polino and Lemoine, 1984) suggests that this ophiolite sequence was very close to the continental margin or to an extensional allochtonous. This finding is not so rare in the ophiolite sequences from Ligure-Piemontese basin, as observed for instance in the Balagne nappe, Alpine Corsica (Rossi and Durand-Delga, 2002).

Analogies between the "Chabrière series" (Radiolarite, Metalimestone and Replatte Fms), which represent the lower part of the Lago Nero succession, and the Internal Liguride units (Cherts, Calpionella Limestone and Palombini Shale) have been evidenced by several Authors (Haccard and Lemoine, 1970; Tricart, 1974; De Wever and Caby, 1981; Bertrand et al., 1984; Lagabrielle et al., 1984. Lemoine and Tricart, 1986; Elter, 1993). Differently, less attention has been devoted to the upper part of the sedimentary succession, that includes the Gondran Flysch and the Rocher Renard complex.

Whereas, the Gondran Flysch is located at the top of the Replatte Fm., through a boundary regarded as stratigraphic, the setting of the Rocher Renard Complex is more difficult to define, because of the relationships with the underlying deposits are everywhere covered by glacial deposits. In the stratigraphic pattern proposed by Polino (1984) the "black shales", which are largely coincident with the

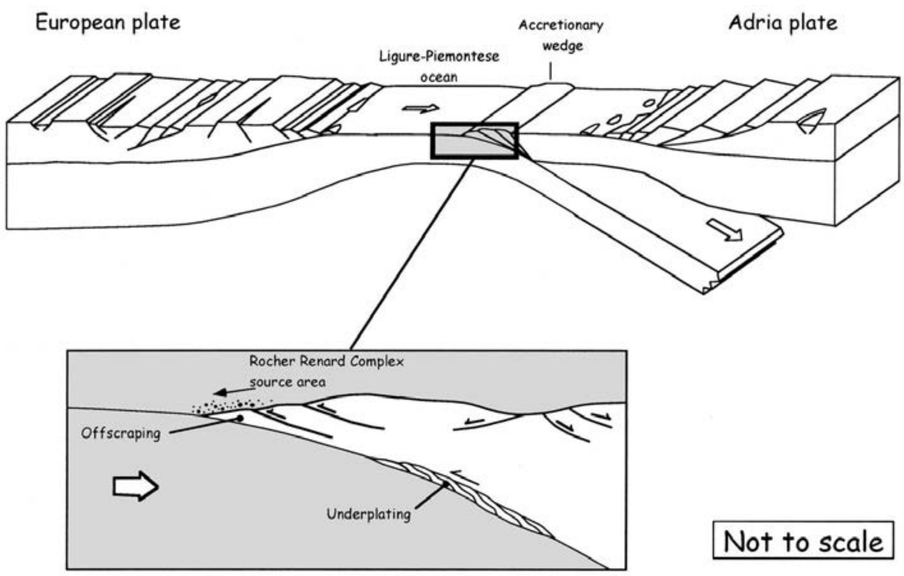

Fig. 8 – Interpretive section of the subduction zone in the Ligure-Piemontese oceanic basin during Late Cretaceous. In the close up a detail of the accretionary wedge during the sedimentation of the Rocher Renard complex is proposed.

Rocher Renard complex, holds a position located between the Replatte Fm. and the Gondran Flysch. However, the structural data allow a different interpretation where the Rocher Renard complex can be located at the highest stratigraphic position in the Lago Nero succession. The geological setting of the area between the Cabane du Douanier and the Fort du Gondran seems to be coherent with this interpretation (Fig. 7).

In this picture, the sedimentary succession of the Lago Nero unit displays a coarsening-upward trend indicated by transition from pelagic deposits (Radiolarite, Metalimestone and Replatte Fms) towards turbidites (Gondran Flysch) up to coarse-grained mass-gravity deposits characterized by the presence of ophiolitic debris (Rocher Renard complex) (Figs. 3 and 4c). The reconstruction of the upper part of the Lago Nero succession shows strong analogies with the stratigraphical setting of Internal Liguride units (Fig. 9).

The Gondran Flysch shows the same stratigraphical position, similar composition and, probably, the same age of turbidite deposits from the Internal Liguride units, as, for instance, the Ronco and Canale Fms. (Pandolfi and Marroni, 1996). These turbidite deposits have been interpreted as representative of deep sea fan systems, supplied by the European margin (Pandolfi, 1997).

In turn, the analogies between the Rocher Renard complex and the formations/complexes recognizable at the top of the Internal Liguride units must be underlined (Bocco Shale, Colli/Tavarone complex, Cassingheno Fm., Lavagnola Fm.; Marroni and Meccheri, 1993; Pandolfi and Marroni, 1996; Ducci et al., 1997). All these formations consist of shales where several blocks of ophiolites and/or their sedimentary cover are enclosed (Fig. 9). Even if the age is unknown, the lithostratigraphic analogies allow us to correlate the Rocher Renard complex with the Bocco Shale and correlated deposits of the Northern Apennines.

In the Internal Liguride Units these deposits have been interpreted as related to the frontal tectonic erosion of an accretionary wedge (Marroni and Pandolfi, 2001). This process was related to the subduction of the oceanic lithosphere from Ligure-Piemontese oceanic basin, characterized by fault-bounded topographic highs inherited from the Jurassic spreading events. In this setting, the bending of the lower plate lithosphere when it approaches the trench was associated to the reactivation of the oceanic faults that produced topographic reliefs. The subduction of this oceanic crust results in the uplift and breakup of the lower slope front of the accretionary wedge whose mass failure is able to produce submarine landslides and related processes. The eroded materials were thus deposited on the faulted lower plate and, consequently, involved in the underplating processes (Marroni and Pandolfi, 2001). This process is described, with slightly different tectonic interpretation also by Lagabrielle and Polino (1988).

CONCLUSION

The deformation history of the Lago Nero unit can be compared to that of several units of the Western Alps, Northern Apennines and Alpine Corse. All these units are characterized by a first phase with deformations coeval with metamorphic climax, generally under HP/LT conditions. The first phase D1, achieved during the subduction processes, is followed by at least three phases developed under ret-

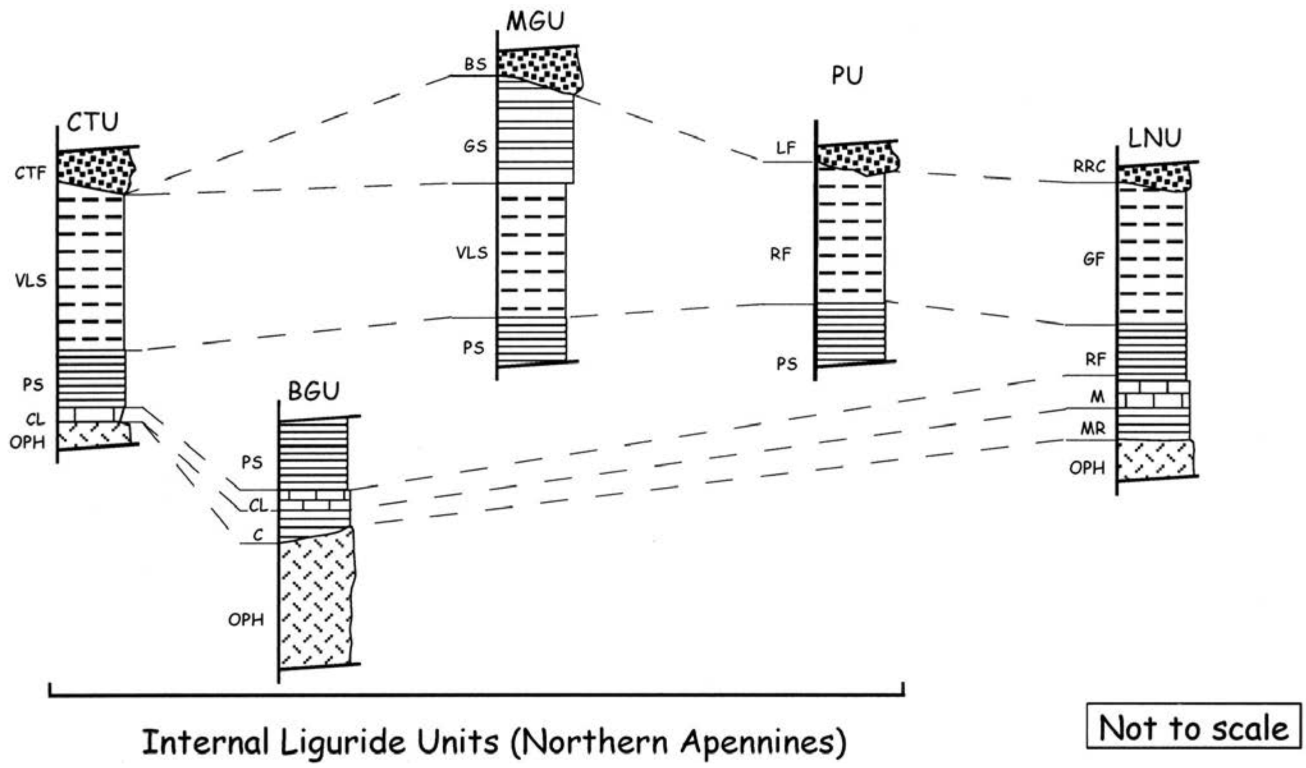

Fig. 9 - Schematic stratigraphic columns of the Internal Liguride units and of the Lago Nero unit and proposed correlations. CTU: Colli Tavarone unit; BGU: Bracco-Val Graveglia unit; MGU: Monte Gottero unit; PU: Portello unit; LNU: Lagonero unit. OPH: ophiolitic sequence; C: cherts; CL: Calpionella Limestones; PS: Palombini Shales; VLS: Val Lavagna Shales; RF: Ronco Formation; LF: Lavagnola Formation; GS: Gottero Sandstone; BS: Bocco Shale; CTF: Colli/Tavarone Formation; MR: Radiolarite Formation; M: Metalimestone Formation; RF: Replatte Formation; GF: Gondran flysch; RRC: Rocher Renard complex.

rograde metamorphic conditions. This evolution can be interpreted as resulting from a coherent underplating in the alpine accretionary wedge and later exhumation. The deformation achieved in the subduction zone was predated by sedimentary events, still detected in the ophiolite sedimentary cover of the Lago Nero unit. These successions, characterized by a coarsening upward trend, records the approaching of an oceanic floor section to the accretionary wedge. The sharp change from hemipelagic deposits, today represented by Radiolarite, Metalimestone and Replatte Fms, to turbiditic and mass-gravity deposits (Gondran Flysch and Rocher Renard complex) is coherent with this interpretation. In this picture, the Rocher Renard complex can be regarded as a formation related to a frontal erosion of the accretionary wedge, whereas the Gondran Flysch is interpreted as a deposits supplied by the faulted continental margin of the Europe plate.

This succession can be correlated with those of the Internal Liguride units where the same sequence of hemipelagic to turbiditic and mass-gravity deposits has been recognized since long time by several authors (Decandia and Elter, 1972; Marroni et al., 1992; Marroni and Pandolfi, 2001 and quoted references).

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