1661-8726/08/030579-15
DOI 10.1007/s00015-008-1302-0
Birkhäuser Verlag, Basel, 2008

Late Triassic-Early Jurassic Paleokarst from the Ligurian Alps and its geological significance (*Siderolitico Auct.*, Ligurian Briançonnais domain)

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This paper is dedicated to the memory of Prof. M. Vanossi who guided our steps through the Ligurian Alps

Key words: paleokarst, bauxite, syn-rift deposits, Early Jurassic, *Siderolitico*, Ligurian Briançonnais.
Parole chiave: paleokarst, depositi sin-rift, Giurassico Inferiore, *Siderolitico*, Brianzonese ligure.

ABSTRACT

In the Ligurian Briançonnais domain, the thick Middle Triassic carbonate-platform units, formally known as the *Costa Losera Fm*. and *S. Pietro dei Monti Dolomites*, are followed by a significant unconformity separating them from the Rio di Nava neritic limestones of Bathonian age. According to the evolution of a passive continental margin, the end of subsidence and subsequent uplift led to the progressive erosion of the Triassic carbonate platform from outer to inner units, *i.e.*, in the direction of the Ligurian Tethys. This erosion, possibly acting on a fault-controlled block system, created sedimentary sequences of differential composition, and the virtual absence of the entire Triassic complex and even the underlying Permian rocks. In the study area (and in many other locations belonging to the external Ormea unit), the so-called "briançonnais sedimentary gap" shows more than a non-depositional surface: the associated deposits (known as "*Siderolitico" Auct.*) include both red pelites between the above-mentioned units, and deep-penetrating karstic red breccia within the Ladinian carbonates. We performed detailed stratigraphic, microfacies and compositional analyses on the karsts and paleosoils associated with the unconformity in order to define their character, genesis and age. In addition, we discuss the regional context and importance of these deposits in a large-scale comparison with the classic Briançonnais domain and other locations of the Western Alpine Arch with the same unconformity. In light of these data, we propose an Upper Triassic to Early Jurassic age (until the Upper Bajocian?) for the karstic event in the Ligurian Alps.

RIASSUNTO

Nel domino Brianzonese ligure, le unità carbonatiche medio triassiche, note come *Formazione di Costa Losera* e *Dolomie di San Pietro dei Monti*, sono stratigraficamente seguite da una importante lacuna che segna il passaggio ai calcari neritici di Rio di Nava del Batoniano. Nell'ambito di una classica evoluzione di un margine continentale passivo, una stasi nella subsidenza, seguita da un sollevamento portò ad una erosione della piattaforma triassica in misura progressivamente maggiore procedendo verso le unità più interne, cioè verso la Tetide ligure. Tale erosione, che verosimilmente si verificò su di un substrato tettonicamente controllato, portò alla formazione di sequenze sedimentarie assai diversificate, talora mancanti di tutti i terreni triassici o persino dell'intero tegumento permiano. Nell'area studiata (ed in limitate aree esclusivamente appartenenti alla porzione più esterna dell'unità di Ormea), la lacuna mesozoica è ben più di una semplice superficie di erosione; i depositi ad essa associati ("*Siderolitico*" *Auct*.) sono costituiti sia da un corpo di peliti rosse interposto fra le sopracitate unità formazionali, sia da una breccia di origine carsica che penetra profondamente le sottostanti dolomie ladiniche. E' stata condotta una ricerca stratigrafica di dettaglio su questi depositi, unitamente ad un'analisi delle microfacies e petrografico-composizionale, al fine di determinare le caratteristiche dei paleosuoli e del carsismo, di raccogliere maggiori informazioni sulla loro origine e sull'età. Inoltre, è stato discusso il significato regionale e l'importanza di questi depositi grazie ad un confronto a grande scala con il dominio brianzonese classico e con altre località dell'arco alpino occidentale che mostrano una unconformity del tutto simile. Alla luce dei dati raccolti, per l'evento carsico in esame viene proposta un'età compresa fra il Triassico Superiore e il Lias (sino al Baiociano Superiore ?).

1. Introduction

In the framework of classical western Alpine paleogeography the Ligurian Alps include rock sequences derived from the paleo-European continent (Dauphinois, Sub-Briançonnais, outer, intermediate and inner Briançonnais domains), from its margin (Prepiemontese *s.l.*) and from the Piemontese-Ligurian Ocean. Geodinamically the study area of this paper belongs to the external part of the Ligurian Briançonnais domain (Fig. 1), where sedimentary gaps are usually more reduced than in the middle and internal sectors and the Paleozoic rocks are followed by a thick Mesozoic sedimentary cover. The most complete succession of the external parts is known from the Ormea Unit (Vanossi, 1974b) and is characterized by unique stratigraphic features caused by the intense involvement of the margin in strong changes of the sedimentary environment driven by the opening of the Penninic Ocean. The Middle Triassic units include a 300 m-thick shallow-marine carbonate deposit (Costa

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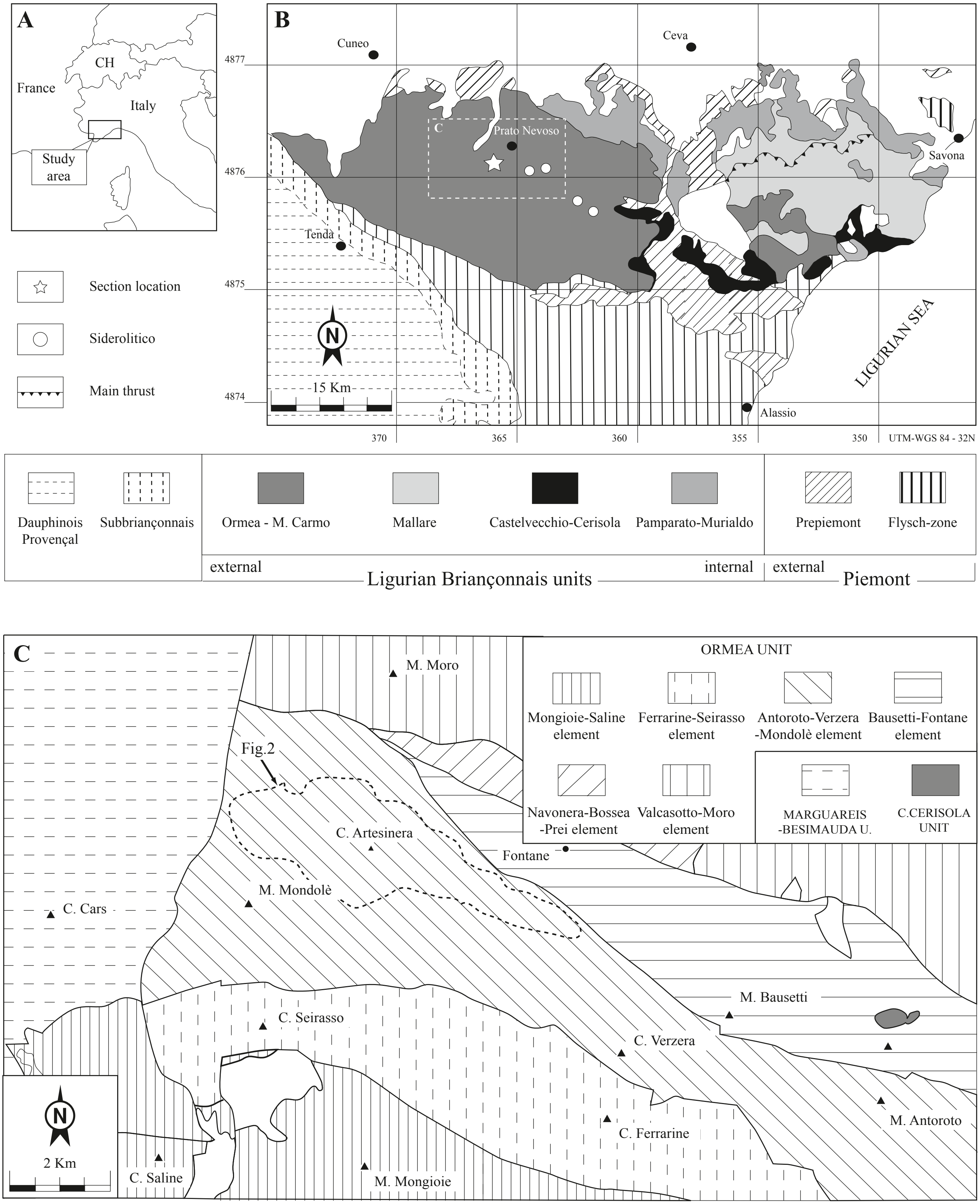

Fig. 1. Location of the study area (A), general tectonic sketch of the Ligurian Alps (B) and scheme of the Ormea unit tectonic elements (C) (after Vanossi 1974a, 1991; mod. and new data).

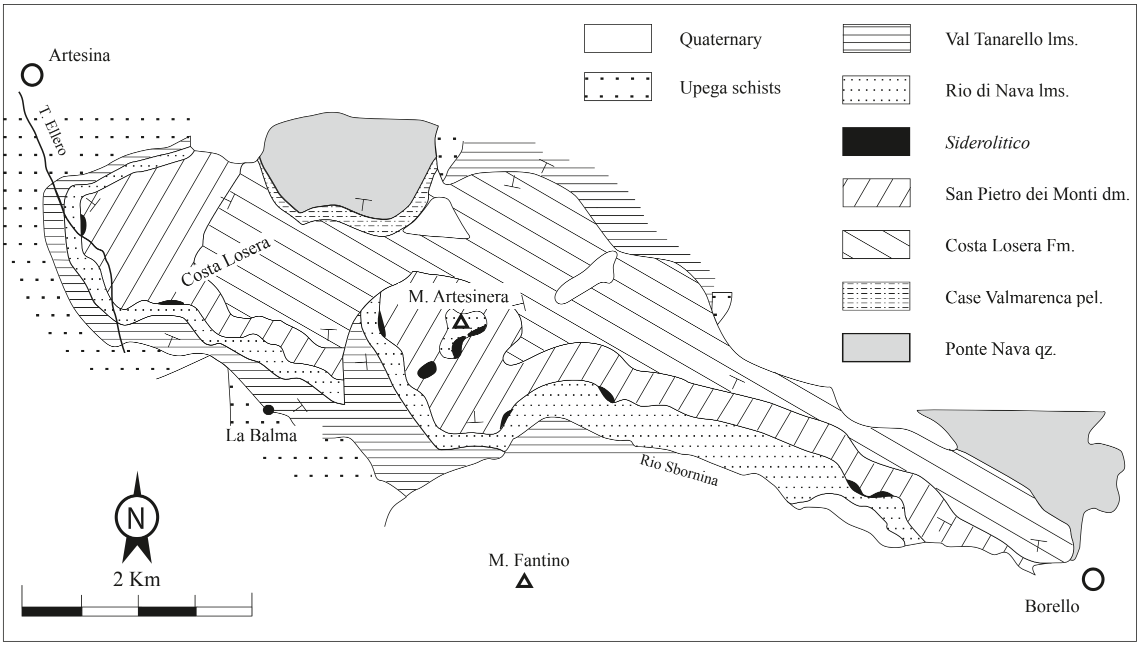

Fig. 2. Geological map of the studied area.

Losera Formation and S. Pietro dei Monti Dolomites) widespread over a large area in the Italian Maritime Alps. Above this unit there is a transgressive neritic limestone of Bathonian age ("*couches a Mytilus*" of the French AA., *i.e.* Rio di Nava Limestones, Lualdi, 1994). This deposit marks the progressive drowning of the Briançonnais platform, ending with Eocene turbidites. The coupling of these two sedimentary complexes therefore masks a considerable omission, reported in the literature as the "briançonnais gap." Between these units, there is a discontinuous deposit of red/green pelites and schists with chloritoid and hematite, Fe-oxides cemented breccias and black or green marls filling erosional pockets, fissures and internal cavities ("*Siderolitico*" *Auct*.). The resulting karst network locally penetrates the underlying Middle Triassic rocks for a few hundred meters. The remnants of these deposits and the associated nondepositional surfaces are the only evidence of syn-rift sedimentation in the Ligurian Briançonnais domain. We interpret this sequence according to the evolution of a passive continental margin: the end of subsidence and subsequent uplift that led to a progressive erosion of the Triassic carbonate platform from outer to inner units.

We present a precise stratigraphic framework for the Ligurian *Siderolitico* and its sedimentary character determined by a detailed analysis of field evidence in the study area. A facies analysis of the karstified beds and associated carbonates sheds light on the depositional environment of the Middle Triassic and Lower Jurassic interval. We find evidence for a general trend of emersion and subaerial exposure for the Anisian-Ladinian carbonate complex, and for a *non-deposition* gap in the Upper Triassic to Lower Jurassic. We also point out that coeval subaerial exposure is common in the successions of different paleogeographic domains in the western alpine chain and all along the margins of the opening western arm of Tethys (see 5. Regional comparison and *e.g.* Ciarapica 2007). Our conclusion reveals a possible regional significance of these horizons in rifting areas.

1.1 Materials and methods

Microfacies and petrographic analisys of both the paleokarst and the host rock has been carried on more than 50 standard thin sections and polished slabs. Detailed observations of microstructures of both the karstic breccias and the pelites were performed with a Nikon Labophot2-pol microscope equipped with a CITL 8200 MK4 cathodoluminescence system. Luminescence was induced with a beam current range of 13–20 KV and 0.6–0.8 mA on 30 micron standard petrographic sections. Analysis has been carried on at Sedimentology Lab (SLAB – Pavia University). X-ray diffraction has been conducted on 20 samples of paleokarst prepared at X-Ray powder diffractometry Lab (Pavia University) and processed with a Philips Analytical X-Ray B.V. PW 1800 copper anode.

2. Geological setting

The field area is located in the imbricate of the Ormea unit known as the Antoroto-Verzera-Mondolé structural element (Vanossi 1974a), belonging to the outer Ligurian Briançonnais domain (Vanossi *et* al. 1984). Better outcrops can be found north of the Tanaro River, especially at Costa Losera, M. Antoroto, Cima Artesinera and Rio Sbornina (Fig. 2, 3).

Upper Permian to Tertiary terrains are preserved here, although they are significantly deformed and dislocated by

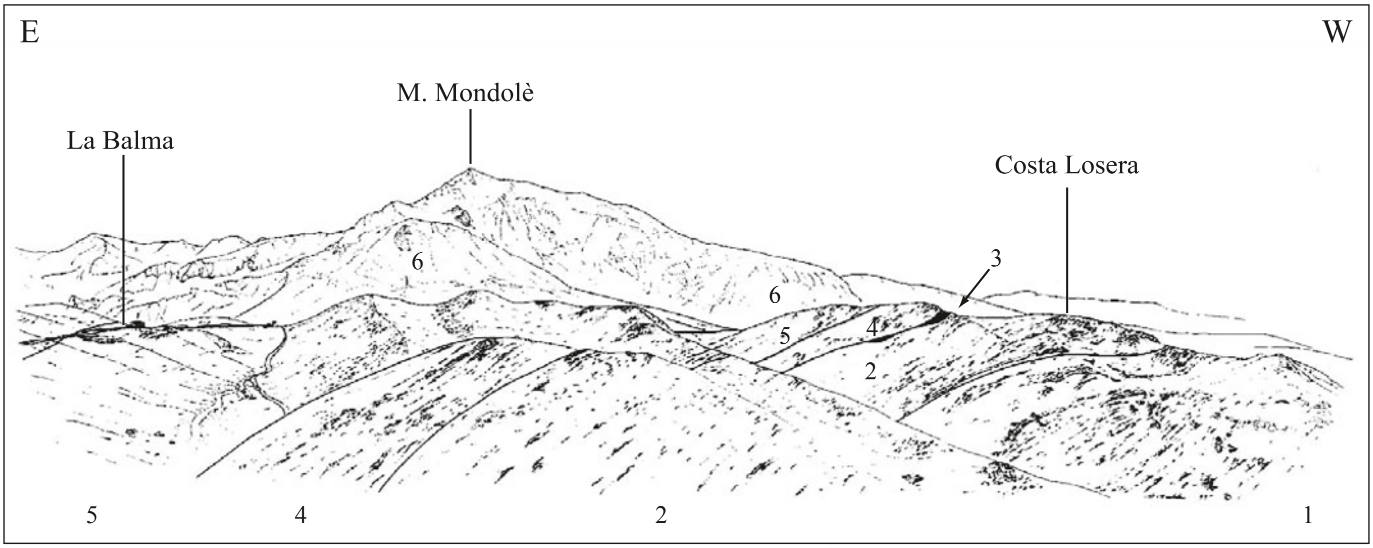

Fig. 3. Southern view of the Costa Losera Formation type-area. 1: Costa Losera Fm. – Anisian; 2: San Pietro dei Monti dolomites – Ladinian; 3: "*Siderolitico*"; 4: Rio di Nava limestones – Dogger; 5: Val Tanarello limestones – Malm; 6: Upega Schists – Upper Cretaceous/Eocene.

alpine tectonics. Their stratigraphic relationships are shown in Figure 4, and briefly described with an emphasis on Mesozoic terrains and the Anisian-Dogger interval. The Middle Triassic unit consists of the Costa Losera Formation (Anisian, Lualdi & Bianchi 1990) and the S. Pietro dei Monti Dolomites (Ladinian); these form a thick carbonate sequence, now mostly dolomitized, deposited in a shallow-water environment. The Costa Losera Formation (CLo) is mostly calcareous, starting with a characteristic facies known as "*marbres phylliteux*" (Lower Anisian) of grey to brownish marble-limestones. The pristine lamination and thin micaceous levels of these beds are often completely masked by pervasive burrowing that is distinctive of this interval. Upper Anisian dolomites are interbedded with marbles and characterized by several autoclastic breccia horizons formed by heterometric clasts welded by oxidized pelite and replaced by transparent dolomitic cement in the upper part of the succession. A thin limestone sequence (2–5 m) with greenish micaceous levels marks the transition to Upper Anisian rocks. These mica-chlorite beds have been previously related to altered tephra horizons, remnants of a well-known Triassic volcanic event (Lualdi & Seno, 1986). The overlying grey limestones and dolostones are pseudomorph-rich and contain successive stages of intraformational breccias and red pelite layers. There are large (up to 20 to 30 m wide) cavities here filled with dolomitic breccia and top-sealed by a red pelitic layer. A 7 metre-thick bed made of whitish limestone marks the transition to the S. Pietro dei Monti Dolomites. This is a monotonous succession of grey dolostones that locally begins with a greenish/reddish pelitic layer that may represent altered tephra horizons either originating in the Ladinian volcanic activity (Caby & Galli 1964) or being residual soils generated during subaerial exposure of the Upper Anisian- Lower Ladinian platform. Gypsum/anhydrite pseudomorphs and microbial laminations are common in the S. Pietro dei Monti dolomites (SPMD), which are locally replaced by a calcareous lens. Intraformational breccias fill small cavities and form sedimentary pockets throughout the formation. A major unconformity marks the top of Ladinian rocks (Fig. 5.6) and a residual soil, the *Siderolitico*, is located between the Triassic dolostones and the Dogger limestones. In the study area, this residual soil reaches a maximum thickness of about 5 m and is formed by silty pelites with a chloritic- calcitic-hematitic composition. Laterally, this bed passes to a dolomitic conglomerate often associated with cm-thick dark pelitic crusts (Fig. 5.5). Its age can be tentatively assigned to the Lias-Bajocian by comparing it with the "*membre de Chavanette*" (Septfontaine 1983) of the western Chablais (Haute-Savoie, France). Sampling for the palynological content as performed by Chateauneuf et al. (1973) in the eastern Chablais and Simmenthal was unsuccessful, although thin amorphous coal horizons are scattered in from the classic Briançonnais area to Liguria (Mercier 1977 *cum ref.*). The overlying Rio di Nava limestones (Bathonian) form a well-bedded calcareous complex up to 90 metres thick (20 metres in the study area). These pure limestones are commonly interbedded with dark marly limestones characterized by a reddish alteration, calcarenites and micro-breccias (both with calcareous and Triassic dolomitic clasts). Foraminifera (Fig. 5.4) suggest this complex to be of Bathonian age. In the Antoroto-Verzera-Mondolé structural element, the first stages of sedimentation after the *Siderolitico* are characterized by significant reworking and winnowing of the "red soil" and the underlying Triassic carbonates. This may be the evidence for erosion of a nearby emergent area that resulted in a local abundance of reddish micro-breccias and well-sorted arenites. The Rio di Nava lms. (RNL), on

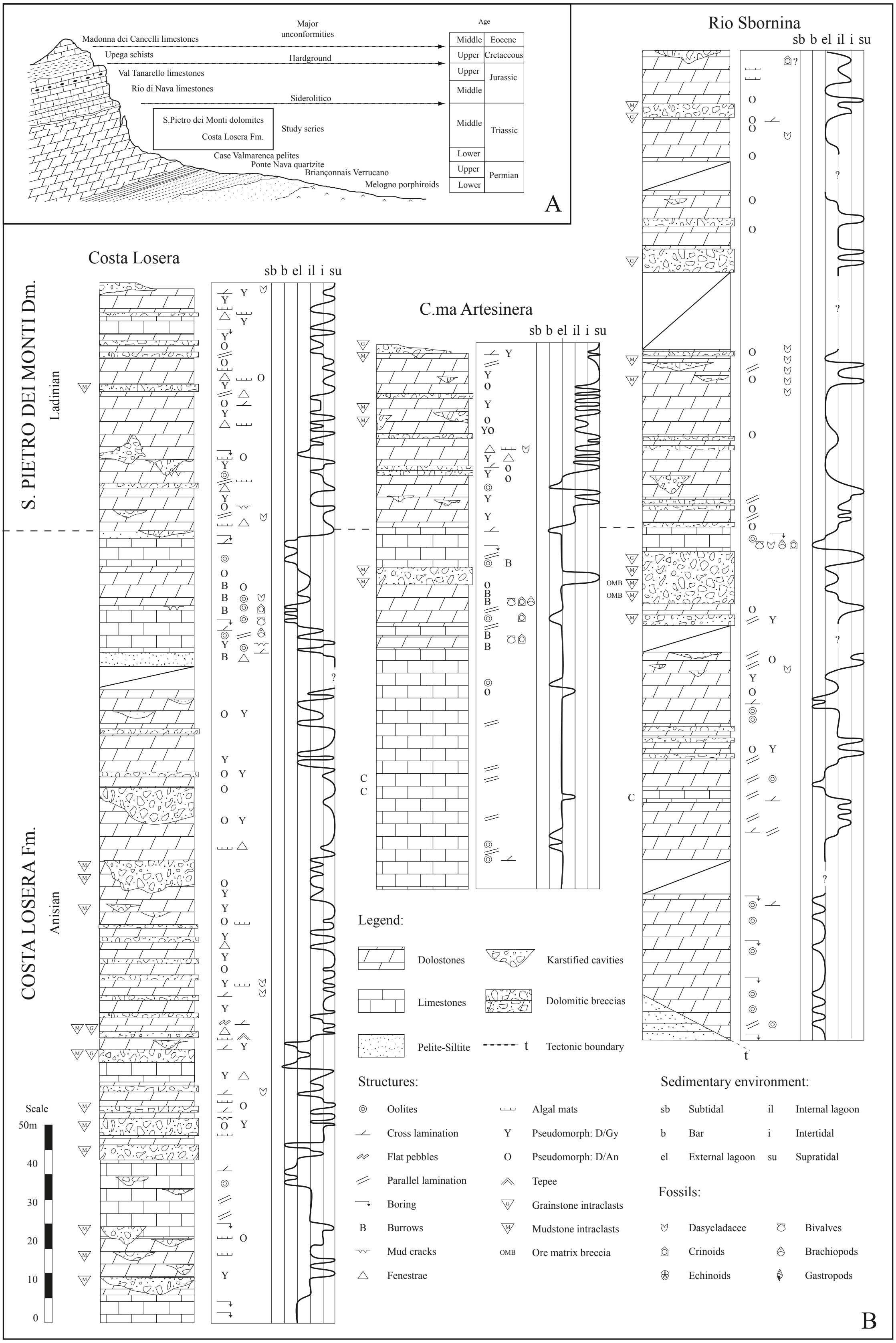

Fig. 4. Stratigraphy of the Ormea unit (A) and studied sections (B).

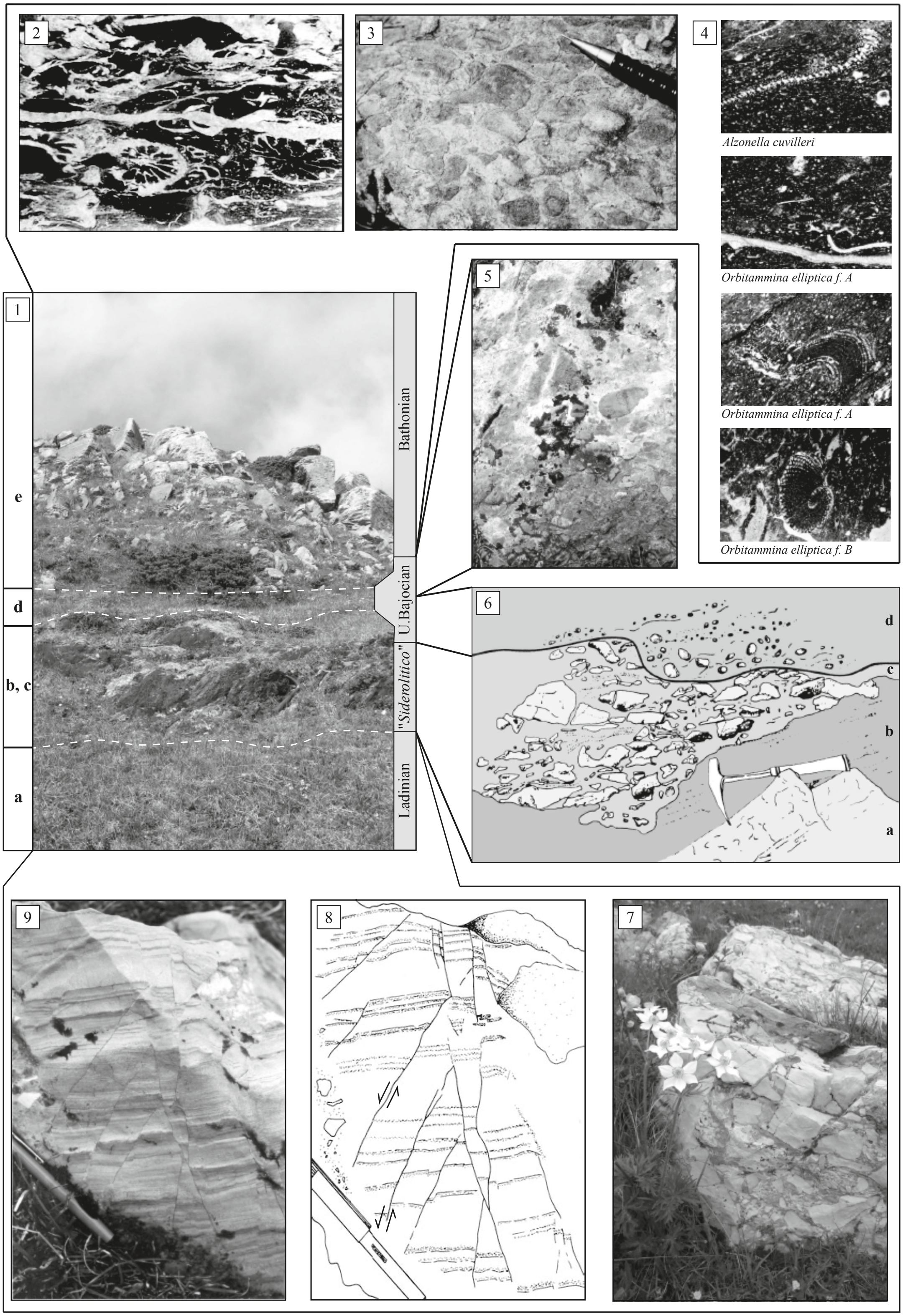

Fig. 5. Overview of the key-features of the Costa Losera succession.1: The T/J boundary at Costa Losera: a. SPDM dolomites; b. *Siderolitico*, reddish pelites facies; c. *Siderolitico*, monogenic breccia facies; d. *Mémbre de Chavanette* conglomerate; e. Rio di Nava lms. 2–4: Rio di Nava lms. Microphotograph of a coral association and Bathonian biomarkers. 5: Basal conglomerate of the Rio di Nava lms. (cfr. *Mémbre de Chavanette*, see text), well-rounded clasts are made both by dolomites and red pelites. 6: Simplified scheme of the stratigraphic relations into the T/J boundary interval, showing the two major unconformities. 7–9: The roughly-shaped breccia of the karstic fillings in the SPDM dolomites and evidence of synsedimentary tectonics in the pelitic facies.

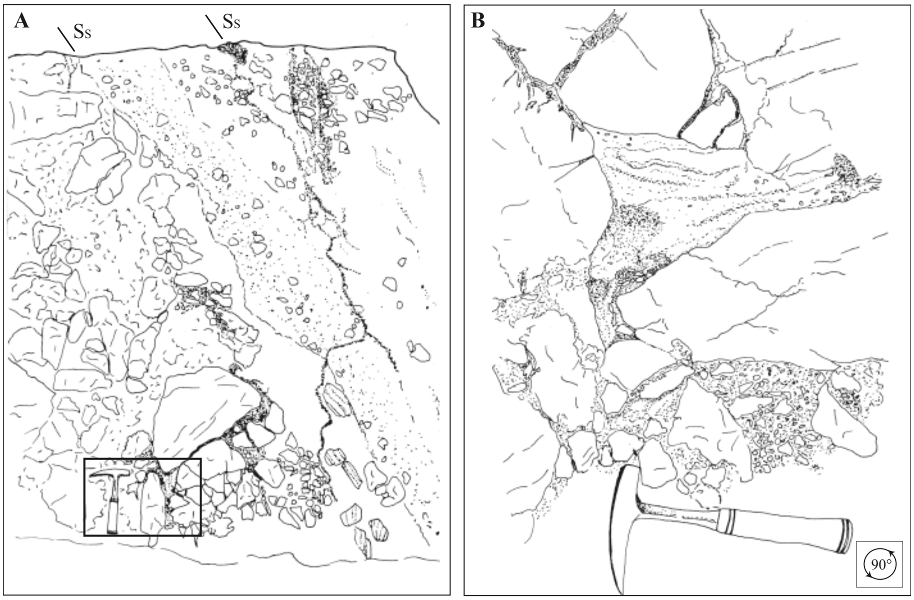

Fig. 6. Metric-size block of *Siderolitico* in the Rio Sbornina valley interpreted as the remnant of a large karstic cavity filling. The polished surface (A) evidences a primary layering (Ss) separating different clast-sized areas. Near the upper-right corner, the dolomitic ladinian host rock is visible. The detail (B) shows a fine pelitic filling of a sedimentary pocket (cfr. "trash zone" of Sangster 1987).

the other hand, mainly represents a shallow-water carbonate succession, with common high-energy facies and rare build-ups (*i.e.* C.ma Artesinera patch reef, Lualdi 1994).

Within the Triassic formations, four major depositional cycles and sequences (CI-CIV and S1-S9) of the Briançonnais *s.s.* (Megard-Galli & Baud 1977) can be distinguished (Lualdi 1990). The sedimentary trend shows the development of a shallow-water carbonate platform with frequent fine-clastic input in its lower part. An attempt to correlate palaeoenvironments, eustatic cycles and major emersion with the better-known Briançonnais *s.s.* domain (Baud 1987 *cum ref.*) and the Southern Calcareous Alps leads to the recognition of:

– a deepening-upward sequence during Cycle I (Anisian);
– a set of shallowing-upward short sequences during Cycle II (Late Anisian-Early Ladinian);
– a transgressive trend during the Ladinian (C III and C IV).

Although most of the area was submerged, hypersaline highs (*e.g.*, M. Grosso, M. Carmo) locally survived until the complete emersion of the Ligurian Briançonnais platform.

In the RNL four main shallowing-upward sequences of the third order can be distinguished. These are expressions of environmental change affecting the neritic realm and forming a *trait d'union* with the highs of the *domaine à Mytilus s.s.* (starved lagoon), the *domaine intermediaire* (rim of the shelf) and the basin of the *domain à Cancellophycus s.l.* (Septfontaine 1983). The uppermost sequence marks the progressive drowning of the platform introducing the subsequent Val Tanarello basinal limestones (Malm).

3. Paleokarst features

3.1. General character

The karstified beds (i) within the Middle Triassic carbonates and (ii) that lie on top of SPMD are basically composed of two lithologies: a monogenic breccia and a siltitic/pelitic residual soil. Breccias are confined to sedimentary pockets and large cavities generated by dissolution of the host rocks (Fig. 6). Karstic cavities in the area have a variety of dimensions and geometries, from centimetres to 30 metres caves. They are filled with breccia bodies and finer laminated pelites, which can come from the host rock itself or can originate at the surface and pass through karstic cavities to the sedimentation sites.

Silts and pelites on top of the DSPM are well bedded. Nevertheless, their relationships with the breccias are often very complex, and lateral transitions from coarse to finer layers and hematitic crusts have been observed in several places in the succession. Also if found in different geological context, close analogies can be inferred with the intraformational breccias described by Mussman et al. (1987) from the Ordovician Knox unconformity (Appalachians) and with the "stratal dissolution-collapse" breccias in James & Choquette (1987) from the Mississippian Madison Formation.

Conjugate normal faults were generated in the paleokarst and are especially well exhibited in the thin-laminated red siltites (Fig 5.8–9). Examples of tension-gashes and stylolites exist in both the paleo-cavities and in the host rock itself (at cm-dm scale). Several pieces of evidence of differential laminae grown on both sides of the fractures and progressively reducing in throw along the same fault prove that extensional tectonics were syndepositional. Similar evidence has been reported by Baud & Masson (1975) in the Préalpes Médianes (Saint-

Triphon). Therefore tectonics played an active role in karst development through the opening of deep cracks in the host rock that successively acted as ducts for dissolution processes. Although extensional tectonics of Ladinian age were seen by Lualdi (1990) in the SPMD, these must be related to an earlier extensional phase, while the former are linked to a later stage based on the supposed age of the paleokarst (Early Jurassic?, see further). This assumption is consistent with generalised liassic extension observed in the classic Briançonnais and Mediane Prealps (Baud & Masson 1975). Far to be a unique case it is interesting here to extend the comparison with other coheval bauxitic gaps situated along the western Tethyan margin (Bardossy & Dercourt 1990; Di Stefano et al. 2002; Mindszenty & D'Argenio 2002). Bardossy & Dercourt (1990) reported 115 bauxite deposits between Spain and the Black Sea ranging from Pliensbachian to Paleocene: the result of this listing prove the karstic origin for the 97% of the sites and the deposition on low coastal plains with active tectonics.

3. 1. 1. Monogenic breccias

Monogenic breccias are widely interbedded with Triassic rocks for one hundred metres depth; lens shaped beds range from 2 to 10 metres in thickness (Costa Losera).

Breccias are composed of matrix-supported dolostone angular clasts (average 10 cm, locally close to 1 m^3) and laminites. Clasts invariably belong to the Triassic dolostones. Using a matrix as a discriminant, two types of breccia can be distinguished.

– *Rock-matrix breccias* (Fig. 7), in which the clastic matrix is composed of iron-rich red/yellowish argillites or siltites with little dolomitic fine-grained debris. The transition between breccia and the host rock is often progressive. It commonly occurs in the extremities and in the uppermost part of the breccia lenses as a highly fractured dolostone with closely spaced fragments ("crackle breccia" *sensu* Sangster 1987). Space between breccia fragments is often partly filled with internal sediment consisting of silt-size or finer oxidized angular and poorly-sorted grains, with alternate reddish-gray lamination. Very fine grains (mostly varve-like red/violet clay) fill the bottoms of some cavities as well as narrow intergranular ribbons ("trash zone" *sensu* Hill et al. 1971).

The drastic heterometry and angularity of the breccia clasts, together with the invariable monogenity, suggest an *in situ* collapse origin. The frequent fractures – both karstic and syntectonic – in the host rock support the dissolution and break up of the host dolostones. In many cases, the silty oxidized matrix lies disconformably on clasts, evidence of later infiltration and deposition.

– *Cemented breccias* in which the angular dolomitic clasts "float" in white crystalline sparry dolomite cement. These differ from the rock-matrix breccia, in which the matrix is a clastic sediment; in the cemented breccia, the matrix is a chemical precipitate. Fine grains are often absent in the interstices between the clasts.

These must not be confused with autoclastic breccias; they are due to early diagenetic dissolution and are not related to the later karst. The formation of autoclastic breccias can be related to the dissolution of evaporitic layers by intergranular undersaturated fluids with meteoric and phreatic origin/influence. This leads the formation of small cavities, which are successively filled with different kinds of sediments that, in the study area are formed by clear dolomitic sparite.

3. 1. 2. Hematitic pelites

Reddish-violet hematitic and greyish pelites form a well-stratified complex on top of the SPDM. The lower boundary is characterized by an unconformity in some places marked by a thin breccia horizon. The total thickness of this unit reaches 5 metres at its maximum near the Costa Losera section, where it is mainly formed by the red- to-violet pelite. Some layers show strong alteration, their colour turned to brown and the rock is considerably weakened. Lenses of greyish and greenish pelite are interbedded in the middle of this unit. No structures have been observed other than a very fine even lamination formed by clear and dark alternating laminae. The Late Bajocian–Bathonian transgression reworked clasts of the Siderolitico and newly embedded them as small rounded pebbles (see Fig. 5.5). A few metres above this, the RNL become pure limestone with progressive loss of the ruditic fraction.

3.2. Microfacies

An optical microscope analysis brought to light some common features of the monogenic breccias. The reddish matrix is very fine and does not respond to the optical observation. It consists of a dark opaque material, sometimes brownish, with recognizable crystals but no notable structures. In some samples, transmitted light with parallel nicols reveals that the brown mass is formed of acicular, iso-oriented neoformation crystals, evidence of metamorphism. Clasts are generally fine-grained dolostone or limestone (mainly mudstone and rarer wackestone) and are sometimes roughly shaped but mostly well rounded. Round pores are very common in the clasts and were apparently generated by dissolution of primary structures or their pseudomorphs, successively filled by hematitic opaque sediment and cement. Spaces between major clasts are filled by a finer breccia, matrix supported conglomerate, hematitic pelite or calcite fibrous cement. Relationships between filling materials are often very complex but are almost gravity-controlled. For example, in Figure 8 a duct between two major grains of the breccia is filled successively by different materials. Clasts pictured here come into contact not far outside the photo area (the texture here is clast supported but this is not the rule in all examined sections). This is a common pattern of three cement layers (1 in Fig. 8B) deposited near grain surfaces, as evidenced by cathodolumi-

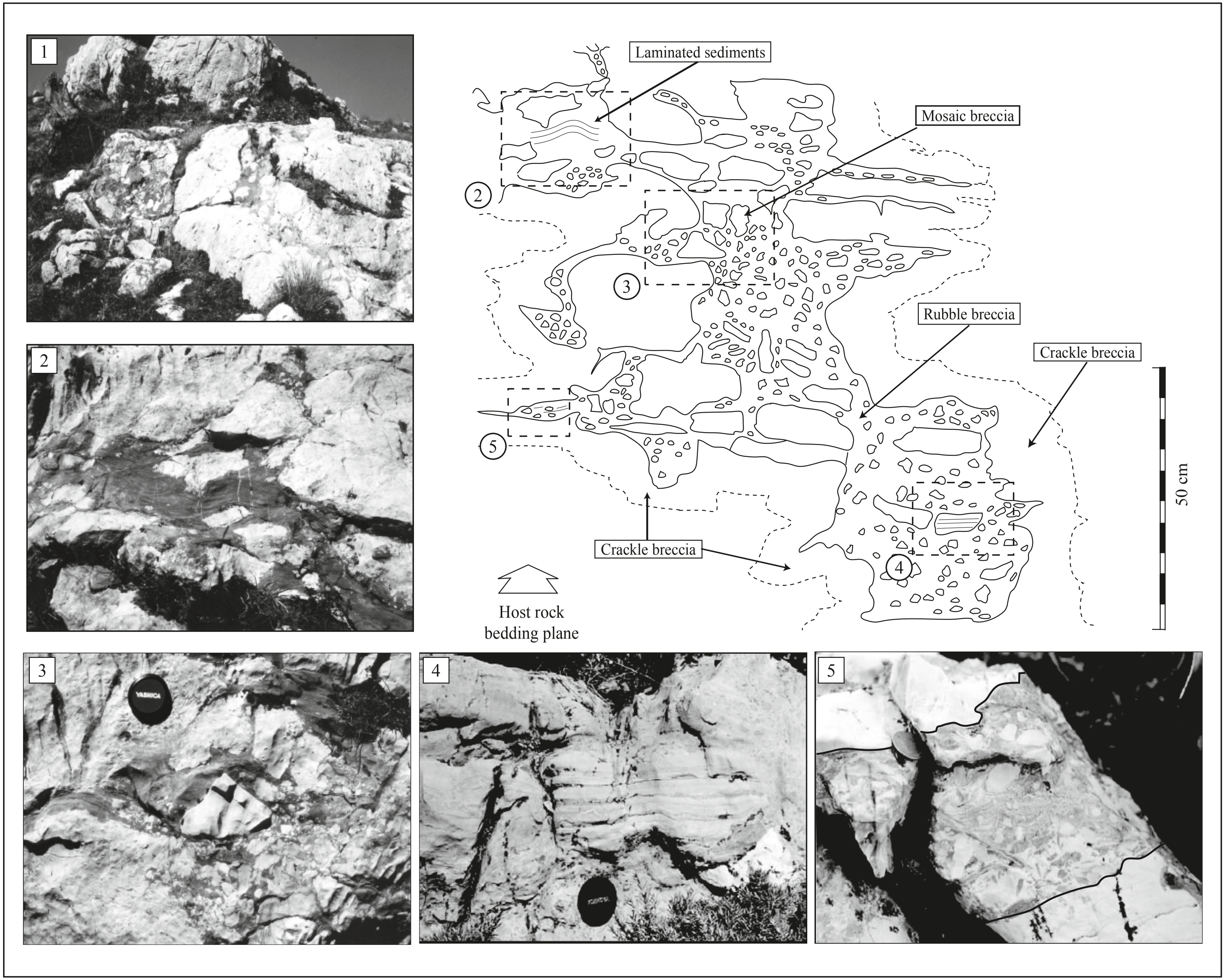

Fig. 7. Some aspects of the monogenic breccia that fills a karst cavity near Costa Losera. Numbered areas on the breccia body are related to the corresponding photos.1: View of the Costa Losera area dolomites and red karstic breccias. 2: Laminated pelites (*in situ*) surrounding roughly-shaped dolomitic clasts. 3: Mosaic-breccia near the boundary with the crackle breccia zone. 4: Blocks of laminated pelites (displaced from the original stratigraphic position during the monogenic breccia emplacement). 5: Dm-sized sill.

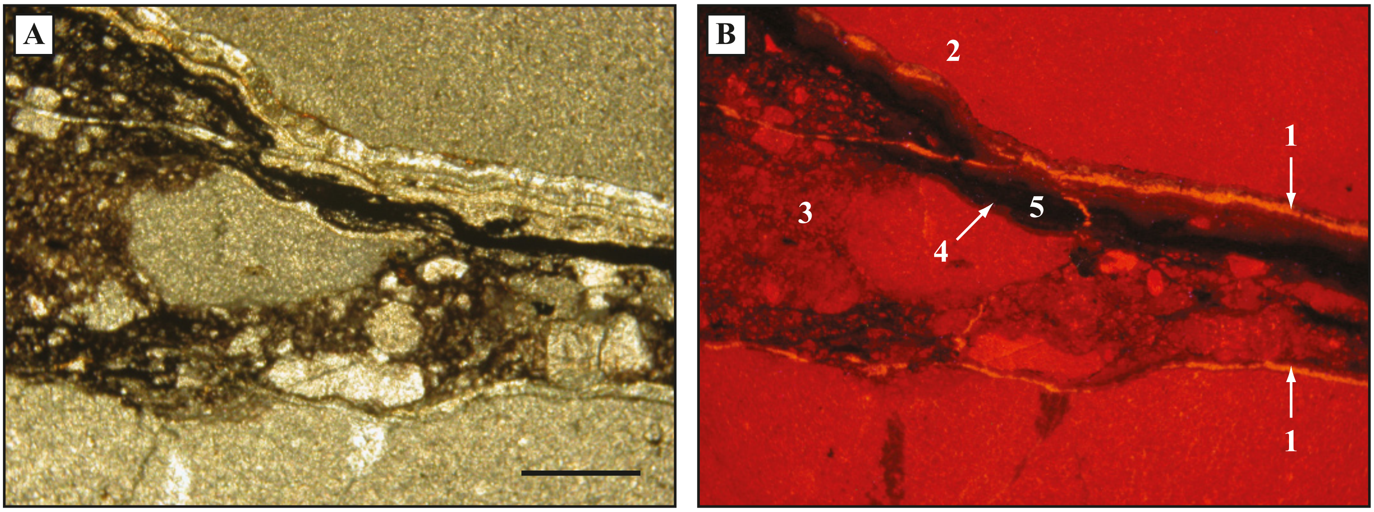

Fig. 8. Polarized light (A) and cathodoluminescence (B) microphotographs of a duct filling sampled in the DSPM Dm. Scalebar 1 mm, see text for microfacies details.

nescence analysis. A specular dull-bright-dull sequence can be observed at the top and bottom of the duct. The upper layers are more developed and form convex domes in the left side of the pictures (2), evidence for gravity-controlled percolation of water. Following this, a reddish conglomerate and microconglomerate (3) cover the pavement of the duct. These kinds of deposits are chaotically organized elsewhere, although in this thin section reverse grading appears. Another cement rim (4) precipitated and sealed up the conglomerate; on the top of the cavity it grew in multiple steps over earlier cement. The dark layer, which appears much more continuous in CL picture (5), is the last filling and is formed by a fine hematite-rich pelite.

Interpretation

This analysis indicates that after dissolution, clasts of the host rock are at first still present in the matrix (collapses still active or their products still circulating), followed by deposition of mainly residual pelites. The two events are separated by an interruption of terrigenous sedimentary feeding. The described evolution of duct filling can be extended to the small cavities (mm to cm scale) of the examined sections with minor variations, while larger cavities (dm to m scale) show more complex geometries and successive stages of winnowing.

Microscopic observations of the reddish pelites of Siderolitico do not provide information on minerals and grains. The only clear structure is an even lamination affecting finer layers.

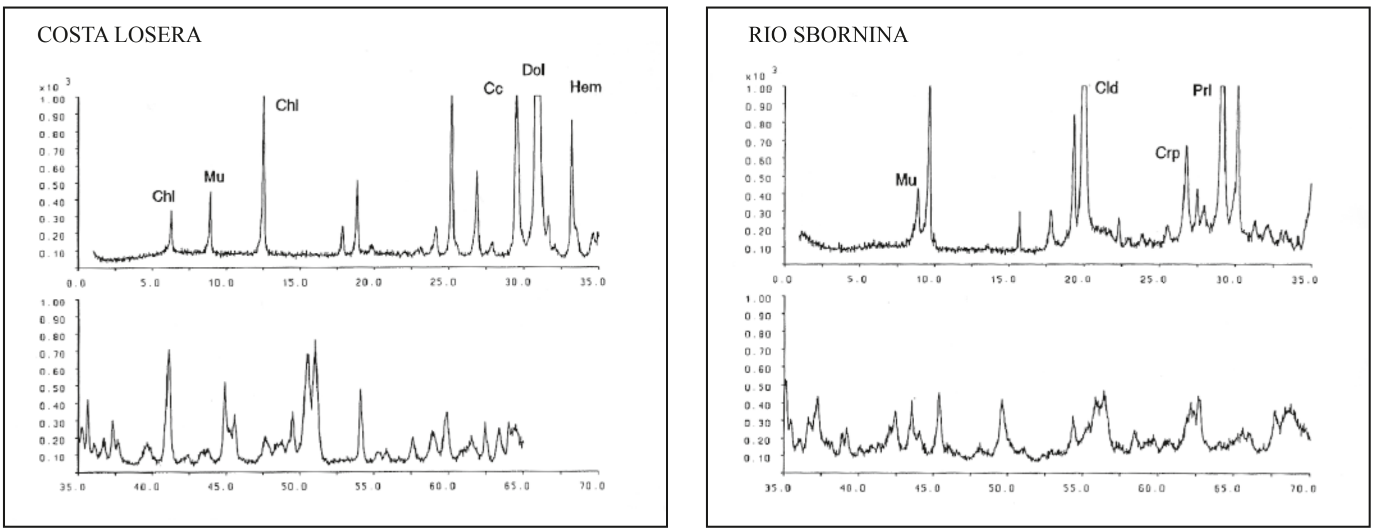

Fig. 9. X-ray diffraction plots of two *Siderolitico* samples corresponding to the monogenic breccia of Costa Losera and the greyish pelitic facies of Rio Sbornina. Keys: Cc-Calcite, Chl-Chlorite, Cld-Cloritoid, Crp-Carpholite, Dol-Dolomite, Hem-Hematite, Mu-Muscovite, Prl-Pyrophyllite.

Opaque iron minerals are abundant; the red colour is concentrated in some laminae more than others. A mainly chemical degradation origin is supposed for these beds in which most of the carbonate clasts have been completely obliterated by subaerial exposure, as shown by Fe-oxide abundances.

3.3. Mineralogy and petrography

X-ray diffractometry of 20 samples of red breccia and *Siderolitico* beds show that the mineralogical compositions of the two lithologies are different (Fig. 9). The matrix of the DSPM interbedded paleokarst is mainly composed of calcite, dolomite, muscovite, chlorite and hematite with minor compositional variations. Pelites of *Siderolitico* contain muscovite, paragonite, diaspore, chlorite, chloritoid, Mg-Fe carpholite, pyrophillite and hematite. This last might be missing in the greyish samples, but the composition varies significantly from one sample to another. In thin section a porphyroblastic microstructure with small chloritoid and carpholite crystals (0.1–0.5 mm) is surrounded by a fine matrix, formed by phyllosilicates and Fe-oxides. These appear to be randomly oriented, except for those sections cut from schistose samples that have porphyroblast directions following the main foliation.

Interpretation

Mineralogical assemblage confirms an originary bauxitic composition for the Siderolitico before metamorphism (see also Goffe 1977; Goffe & Saliot 1977).

The very fine grained and altered minerals affect observations with optical microscopes. An electron microscope and microprobe analysis defines fields of paragenesis stability, and suggests a metamorphic environment in which these rocks were re-equilibrated (Colmi 1991). They indicate that the metamorphic climax was at 3 to 5.5 Kbar and 300 to 330 °C (greenschists). Metamorphism is more evident at the microscale, where recrystallization is almost complete and rocks are characterized by meta-minerals blastesis and sometimes a close crenulation cleavage. While at the field scale the sedimentary structures are easily observed, seen with an optical microscope, recrystallization is complete. As a result, the preservation of organic matter in these rocks is inhibited both by the unfavourable high O_2 content (hematite) and by the metamorphism that destroyed microfossils and spores.

4. Paleokarst age

Any attempt to date the Ligurian Briançonnais paleokarst through its paleontological and palynological content failed because of the metamorphic facies. Thus, the only available dates can be estimated by stratigraphic position. The obvious limit of this approach is that we can evaluate but an estimated "karst period" (Bosak et al. 1989) however, we cannot distinguish between different "karst phases" that certainly occurred during apparent 50 My of the Briançonnais sedimentary gap. We can assume that the youngest datable rock found near the base of the karstic beds belongs to the Capo Noli Formation (M.te Carmo Unit, intermediate Briançonnais domain, Lualdi 1991) ascribed to the Early Carnian (*Lamelliconus procerus* LIEBUS and *L. multispirus* OBERHAUSER). In the study area, this formation is not present and the youngest rocks known from below the karst belong to the DSPM (Ladinian). Immediately above the red pelites of *Siderolitico*, follows a m-thick conglomerate with rounded dolomitic clasts and detrital quartz; the conglomerate can be correlated to the "*membre de Chavanette*"(Septfontaine 1983) that can be reasonably ascribed to the Bajocian *l.s*.

The marine transgression that ends the karst period is represented by the RNL; the first occurrence of *Alzonella cuvilleri* BERNIER & NEUMANN and *Orbitammina elliptica f.*A D'ARCHAT suggests the formation is of Bathonian age. The assumption of an **Early Carnian to Late Bajocian gap**, although still valid for the study area and for most of the Briançonnais domain, may have local exceptions. A Late Triassic transgression was reported on the basis of a spot-outcrop level of dark marly limestones in which a probable *Triasina* cfr. *hantkeni* MAJZON was recognized (Fierro & Vanossi 1965; Lualdi 1994). The limited occurrence of this thin level and the generalized absence of Late Triassic clasts in the later residual allows us to consider it a local accident rather than evidence of an overall environmental change. Our observations of paleokarst age are comparable to those found in the literature for the French and Swiss Briançonnais. An age comparison with other paleogeographical sectors (*e.g.,* the Swiss and French Mediane Prealps and the Vanoise, as pointed out by Faure & Megard-Galli 1988) characterized by the same general emersion, reveals similar results, even though obtained from different and heterogeneous lithologies. The poorly-sorted carbonate breccias of the Prealpes Romandes, composed of Triassic dolostones and Early Jurassic limestones, suggest a fluvial environment reported as Late Liassic to Early Dogger by Renz in 1935. The *Filicales* flora (Chateauneuf et al. 1973) indicates a marsh-to-flood plain environment with scattered hills in the Bajocian-Bathonian; the seldom preserved bauxites, laterites, and residual soils, especially in the inner sectors where geochemical dissolution strongly acted, were are referred to the Jurassic (*i.e.,* the Préalpes médianes rigides: Badoux & De Weisse 1959). The karstic fillings up to 1000 metres deep (St Triphon klippe, Mediane Prealps, Baud & Masson 1975) but generally a few hundreds metres (300 m French Briançonnais (Faure & Megard-Galli 1988) were dated as Middle to Late Liassic/?Early Dogger (Carixian-Toarcian/?Aalenian) by Baud & Masson (1975).

Concerning the Ligurian *Siderolitico* and related breccias, we suggest that multiple stages of emersion and karstification may have taken place since the Late Triassic throughout the Late Bajocian. The production of different kinds of sediments and their reworking can be evaluated by studying the composition of the breccias and the nature of the cements. Beside this, the paleotopography of the substrate may affect the timing of deposition from place to place; unfortunately, this diachronism cannot be quantified due to the lack of paleontological data. In our opinion, most of the chemical-*vs*-physical degradation

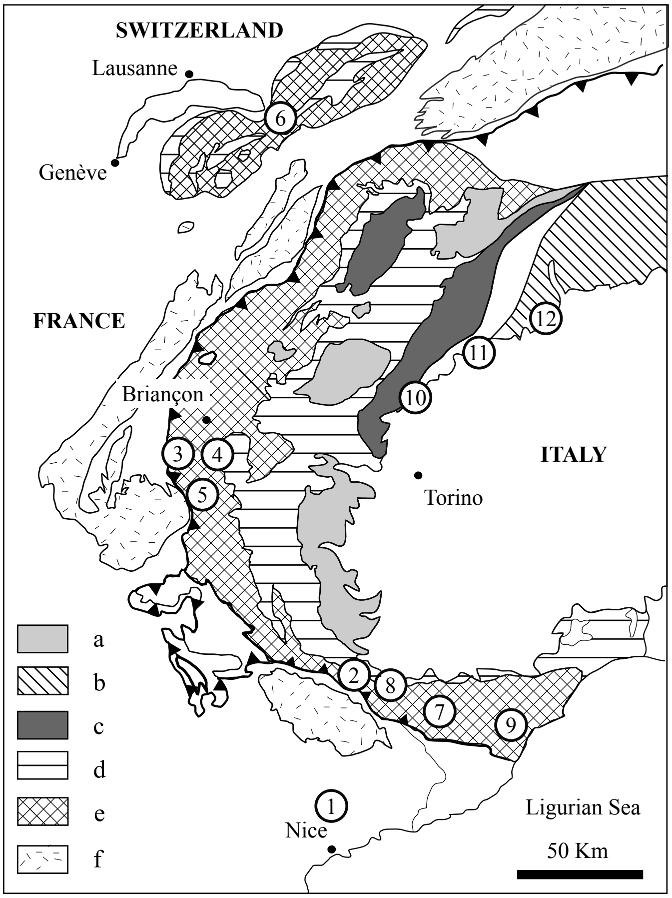

Fig. 10. Map of the Western Alps and main paleogeographic domains: a. Internal massifs; b. Southern Alps; c. Austroalpine; d. Piemontese; e. Briançonnais; f. External massifs. See text for number location.

took place during the Liassic up to the Bajocian. This process might have had embryonic phases already as early as the Late Triassic.

5. Regional comparison

The study area appears to have lost a major part of its Mesozoic sedimentary cover. Late Triassic to Early Jurassic rocks are presently missing near the Ligurian Briançonnais series; this feature is well-known in literature as the "Briançonnais gap." Similar erosional events appear to have affected terrains of coeval age in different domains of the Western Alpine orogen, where both thin residual soils and more developed paleokarsts as well as continental breccias directly lie on the surface of the Ladinian carbonate platform. Locally, they represent the only sedimentary record for about 50 my. Late Triassic clasts are missing or very locally present, supporting the hypothesis of prolonged non-depositional subaerial exposure of large areas of the Middle to Late Triassic platforms until after the Middle Jurassic. A brief review of the stratigraphy and paleogeographic arrangement of the Late Triassic/Liassic boundary in the Western alpine sector (Fig. 10) can be delineated as follows:

– *Provençal-Dauphinois domain* (1): while external series are mostly complete, red soils can be found in the inner part of the domain (Maritime Alps, SE France). Liassic rocks are mostly missing, with the exception of a Rhaetian-Hettangian platform followed by a red-breccia paleokarst and Bajocian limestones (Dardeau 1984). Geze (1960–63) and Colombo & Rollet (1965) also pointed out an important gap between the Rhaetian and Upper Bathonian, widespread in the Nice arc area.

– *Subbriançonnais domain* (*sensu* Debelmas 2001) (2, 3): The structural units belonging to this domain and studied by Gidon (1972) in the Stura Valley near Cuneo (Italy) contain a wide gap including Late Triassic to Early Jurassic terrains. The M. Salè unit nevertheless shows continuous deposition from the Rhaetian to Lower Liassic; this succession is directly overlained by Malm limestones (facies "*argovien*"). A similar continuity of sedimentation can be observed in northern parts of the domain, particularly in the NNW-Briançon area (Grande Moenda, Perron des Encombres, Petit Galibier and Lauzette-Roche Olvera: Barbier 1963) where Late Triassic/Rhaetian terrains are conformably followed by a complete Jurassic sequence.

– *Briançonnais domain s.s.* (4, 5) and *Préalpes Médianes* (6): toward the external units (*e.g.*, the Champcella nappe) the same sedimentary sequence and similar gap as those found in the investigated Ormea unit can be observed, with Ladinian dolomites followed by a Bathonian conglomerate (Debelmas 1983; Claudel & Dumont 1999). The interlayering of a residual breccia ("*breches ravinants*") of inferred Carnian age between these terrains can be considered as the counterpart of the *Siderolitico*. In the more intensely subsiding areas and in the internal units, in more than one succession (*e.g. Vallée de la Durance-Barrachin*) the top carbonate platform deposits are dated as Norian or Rhaetian. Deposition continues until after the Hettangian/Sinemurian (as in the ligurian prepiemontese domain) with thin bioclastic limestones (in Debelmas 1980). In the Durance Valley (St-Crépin-Guillestre), an angular disconformity separates Norian carbonates from Late Jurassic deposits, underlining tilting during platform uplift (Debelmas et al. 1983).

In the Préalpes, the transition to the *membre de Chavanette* (base of the "*Couches à Mytilus"* Formation) is marked by a chaotic breccia reworked from the underlying Late Triassic beds. A Late Liassic-to-Early Dogger (?) age is suggested by Baud et al. (1989).

– *Ligurian Briançonnais domain* (7, 8): this structural high emerged in the Middle Triassic, and its carbonate platform began to be eroded. General isostatic emersion took place from the Ladinian- ?Carnian to Bajocian. Only locally did a Rhaetian transgression occur. Triassic deposits were largely removed during emersion and chemical dissolution rather than physical degradation with red metapelites (*Siderolitico*) was widespread.

This subaerial weathering, related to increased uplift of the "Briançonnais high" towards the European continental margin, represented during the Early Liassic a synchronous event of the sedimentary stasis of the Prepiemontese units (Middle Hettangian – Lower Sinemurian, Lualdi 2005) just before platform drowning. Bertok (2007) reports an angular unconformity in the northern face of Rocca Ferà (Marguareis area) between the DSPM and the RNL.

– *Prepiemontese unit* (9)*:* the external unit of Arnasco-Castelbianco (Vanossi et al. 1984) has a few metres of thin-bedded limestones (sometimes nodular) directly overlying a Sinemurian hardground (*rotiforme* zone) probably related to a submarine rise rimming the Briançonnais basin. Internal units (*e.g.* Case Tuberto) became drowned areas within which several uplifted blocks were isolated; the general deepening of the inner Prepiemontese began during the Early-to-Middle Sinemurian (*bucklandi* zone), while other inner Piemontese units (such as the Montenotte "Trias-Lias" *Auct.* and the M. Gazzo-Isoverde, Marini 1982; Lualdi 1991) appear to have drowned during the Late Rhaetian or Early Hettangian.

– *Canavese zone* (10): although the sedimentary cover is tectonically displaced and the rock succession is insufficiently dated, a comparison with the western Southalpine series of the Canavese zone suggests a *post*-Sinemurian emersion (Sturani 1964), indicated by a reddish breccia described in Baggio (1965) and Biino & Compagnoni (1989). Ferrando et al. (2004) point out the existence of red breccias and (neptunian) dykes in the Montalto Dora area very similar to the "Macchia Vecchia" facies of Wiedenmayer (1963); the inferred age is Late Liassic (or Middle Liassic in Baggio). Authors do not detail a significative environmental pertinence for these deposits but a generic submarine origin as neptunian dikes. The associated red sandstones are similar to those at the base of Monte Fenera (Bernoulli 1964). Elsewhere, Ahrendt (1972) mentioned some polymictic breccias that he ascribed to the Tertiary. According to Ferrando et al. (2004), the formation must be correctly assigned to a *post*-Triassic, *pre*-late Jurassic age, especially for its analogies with the Saluver Formation of the lower Austroalpine Err nappe (Finger 1978).

– *Southern Alps domain* (11, 12): the Lombardy basinal area, although fragmented in a horst and graben setting, shows continuous subsidence from the Middle Triassic to Dogger. In western Lombardy, a recent contribution by Jadoul et al. (2005) points out the presence of paleosols and pedogenic carbonate breccias of Hettangian age that support the existence of a widely emerged area until the Lower Sinemurian.

The westward termination of the basin shows incomplete successions that progressively grade into generalized emersion of the Ladinian carbonate platform and to deposition of paleosols and subordinately shallow-marine sandstones (Fantoni et al. 2003). Domerian limestones mark the drowning of this realm after an apparent gap of about 40 Ma.

It is worth remembering that Casati (1978) studied the "*Breccia di Invorio,*" west of Lago Maggiore, made up of dolomitic, Permian-volcanics and metamorphic clasts outcropping without any visible stratigraphic boundary; he tentatively dated the breccia to Lias.

6. Conclusion

The Antoroto-Verzera-Mondolè structural element (Ormea unit) is a good site to study the Mesozoic sedimentary gap in the Ligurian Briançonnais domain. We performed a detailed stratigraphic analysis along the Triassic-Jurassic succession that allows us to identify two main facies of the "*Siderolitico.*" The monogenic breccia (i), which develops in cavities in the San Pietro dei Monti Dolomites, is identified as a product of paleokarstification of the host rock (partly in the vadose zone); hematitic pelites (ii), which constitute a well-stratified unit on top of the SPMD, are considered a physically-chemically degraded paleosol. Metamorphism limits our ability to establish precise time-relationships between the two facies. The stratigraphic boundaries and the complex geometry of the sedimentary bodies do not solve the problem, but *it is reasonable to assume that they were generated by several karstic events during a single long-lasting karst period*. This was related to a generalized Briançonnais uplift in the Late Triassic and preceding Jurassic rifting. Paleokarst age is an open problem, due to the lack of paleontological data. The long time span determined by the stratigraphic positions of residual deposits in the study area (Middle Triassic to Middle Jurassic) can be compared to the suggested age of similar deposit in the Western Alpine arch. With local differences, we can observe generalized emersion from the Middle-Late Triassic up to Late Liassic-to-Dogger along two belts facing the Ligurian Ocean. Thus, considering a macroscale system and not a horst and graben detailed configuration, emerged areas are concentrated along two major tongues, facing deep basins with complete successions for the Late Triassic to Dogger interval. Two main facing uplifted domes rimmed the Tethyan basin and external basins. The study area belongs to the western dome, which probably suffered longer and more intense uplift, as shown by younger roof rocks and collapse breccias in the associated units. In the "European" realm, karstic rocks date a Late Bajocian-Early Bathonian transgression and lie over Middle-to-Late Triassic carbonates. Extensional tectonics has been proposed in these sectors during the Liassic; evidence for this can be recognized in some synsedimentary faults in the Siderolitico breccias. For these reasons, we propose a Late Triassic-to-Liassic age (up to Upper Bajocian?) for the "*Siderolitico.*" In addition, a strict comparison between the "Champcella nappe" of the classic Briançonnais domain and the Ormea unit suggests similarities of the examined Mesozoic terrains so close that the Champcella area could be considered the northern counterpart of the external Ligurian Briançonnais units.

Acknowledgements

We would like to thank the late M. Vanossi for an early reading of the manuscript and useful suggestions. A. Baud, A. Mindszenty and H. Weissert for the critical review and bibliographical updating. We also thank U. Bianchi and C. Colmi for their unpublished MD thesis. AJE for the supervision of the english version of the text. Cathodoluminescence was performed in the LAIF laboratory (Resp. A. Di Giulio) of the Dipartimento Scienze della Terra of the Pavia University. Thanks to M. Setti for diffractometric analysis. The research was supported by M.U.R.S.T. (F.A.R. M. Cobianchi) and PRIN grants (Coord. A. Lualdi).

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Manuscript received November 19, 2007
Revision accepted July 14, 2008
Published Online first: December 8, 2008
Editorial handling: H. Weissert & S. Bucher