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Middle-Late Jurassic syndepositional tectonics recorded in the Ligurian Briançonnais succession (Marguareis–Mongioie area, Ligurian Alps, NW Italy)

**Carlo Bertok · Luca Martire · Elena Perotti ·
Anna d'Atri · Fabrizio Piana**

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Abstract The Middle–Upper Jurassic succession of the Marguareis–Mongioie area (Ligurian Briançonnais Domain), developed in a protected shelf environment evolving into a pelagic plateau, bears clear evidence of synsedimentary tectonics such as: growth fault-related structures; neptunian dykes; marked lateral variations in stratigraphic thicknesses testifying to the juxtaposition of sectors characterized by different sedimentation and subsidence rates; discordant, anomalous stratigraphic contacts corresponding to paleoescarpments; nodular beds showing evidence of fluidification interpreted as seismites; and the occurrence of sand-sized quartz grains pointing to denudation of Permo-Triassic quartz-rich rocks. Such evidence documents an important Middle-Late Jurassic post-breakup tectonic activity, which was more effective in controlling the basin topography than the Early Jurassic syn-rift tectonic phase. Two main tectono-sedimentary stages, one occurring during the Bathonian, the other falling within the Callovian–Kimmeridgian interval, were reconstructed. The first stage can be referred to a fault-related activity occurring shortly after the initial stages of oceanic spreading of the Ligurian Tethys; the second can be genetically related to the far effects of the first rifting stage of the Bay of Biscay and the Valais basin.

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C. Bertok (✉) · L. Martire · E. Perotti · A. d'Atri
Department of Earth Sciences, University of Turin,
via Valperga Caluso 35, 10125 Turin, Italy
e-mail: carlo.bertok@unito.it

F. Piana
Institute of Geosciences and Earth Resources, Turin Unit,
National Council of Researches, via Valperga Caluso 35,
10125 Turin, Italy

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1 Introduction

The Briançonnais domain is a major unit in the Alpine orogen that crops out from the Central to the Ligurian Alps, where it takes the name of Ligurian Briançonnais. In general, it consists of Permian volcanic and volcano-sedimentary rocks overlain by partially detached Meso-Cenozoic sedimentary successions. It shows different degrees of deformation and metamorphism that on the whole decrease from the internal to the external part. Recently, Piana et al. (2009) have pointed out that in the External Ligurian Briançonnais the Alpine deformation was partitioned into highly strained, km-scale shear zones and relatively poorly deformed tectonic units. In the latter, primary stratigraphic features, such as depositional architecture, sedimentary structures and microfacies, are largely preserved. Pervasive tectonic foliations, originating from pressure dissolution processes, do occur but are confined to marly and clayey intervals of the succession.

In the frame of the Alpine palaeogeography, the Briançonnais has classically been interpreted as a part of the passive northern continental margin of the western Tethys (Faure-Muret and Fallot 1954; Amaudric du Chaffaut et al. 1984; Vanossi et al. 1984; Lemoine et al. 1986; Lemoine and Trümpy 1987; Lanteaume et al. 1990), separated after the opening of the Piemont-Liguria ocean from the rest of the European continent by the Valais ocean branch according to some authors (e.g. Frisch 1979). According to the classical view, the Early Jurassic hiatus, ubiquitous in the Briançonnais Domain, is considered as the direct result of a rifting process that gave rise to a horst-and-graben structure, whereas the renewal of sedimentation during the Middle Jurassic and the subsequent transition to pelagic conditions during the Late Jurassic marked the end of the extensional tectonics and the onset of thermal subsidence (Lemoine et al. 1986; Faure and Megard-Galli 1988; Tricart et al. 1988). Most of the pre-Alpine extensional structures in the Briançonnais domain have been consequently related to the rifting phase that preceded the opening of the adjacent Ligure-Piemontese ocean.

Our data, however, question this classical view and document a complex subsidence history of the Ligurian Briançonnais, characterized by a polyphase syndepositional tectonics during the Bathonian–Kimmeridgian, i.e. well after the beginning of the oceanic spreading. The occurrence of post-breakup tectonics in present-day deep water rifted margins has been well documented and extensively discussed in the last years (e.g.: Péron-Pinvidic et al. 2007; Péron-Pinvidic and Manatschal 2009). Stratigraphical and sedimentological evidence of a relevant post-breakup tectonic activity has been reported by far more rarely from the Mesozoic successions of the rifted continental margin of the Alpine Tethys (e.g.: Claudel and Dumont 1999).

This paper provides a facies description and interpretation of the Jurassic succession of the Marguareis–Mongioie area, with special attention to an uncommonly rich set of structures (neptunian dykes, angular unconformities, paleoescarpments, wedge geometry of lithosomes, seismites, abrupt appraisal of clastic input) that allowed to define the fundamental role played by tectonics during the Middle–Upper Jurassic sedimentation in the Ligurian Briançonnais in great detail.

2 Geological setting

The Ligurian Alps are a stack of four main groups of tectonic units, which have always been assumed to correspond to four adjacent main paleogeographical domains: the Dauphinois and Ligurian Briançonnais domains as parts of the European continent; the Pre-Piedmont domain as the margin of the European continent; the Piedmont-Ligurian domain as the contiguous oceanic basin (Vanossi et al. 1984; Lemoine et al. 1986). These units were stacked since the Late Eocene by SW-ward thrusting events, coeval with subduction of continental crust along an intracontinental shear zone dipping towards the more internal domains. In the present-day geometrical setting, the Pre-Piedmont units rest on the Briançonnais units, which in turn are thrust onto the outermost Dauphinois Domain. Detached cover units of inner Piedmont-Ligurian domain (*Helminthoides* Flysch) overlie all these units and locally conceal the Briançonnais–Dauphinois boundary (Vanossi et al. 1984; Seno et al. 2003, 2005) (Fig. 1a).

The Ligurian Briançonnais Domain can be subdivided into two main sectors: the Internal Ligurian Briançonnais, that was involved in the subduction channel up to a maximum depth of about 30 km, developing high-pressure blue schist parageneses (Messiga et al. 1982; Goffé 1984); and the External Ligurian Briançonnais, that was not involved in the subduction and developed only low grade to anchizone metamorphism (Messiga et al. 1982; Seno et al. 2003, 2005). Our paper deals with the central part of the External Ligurian Briançonnais, and is geographically located between Cima della Fascia in the west and Monte Mongioie in the east, and Colle del Lago dei Signori in the south and Porte Biecai in the north (Fig. 1b). As shown by Piana et al. (2009), this sector is composed of km-scale low-strain units which escaped the severe effects of Alpine deformation and lack significant transposition and metamorphic recrystallization, so that the stratigraphy and the sedimentary evolution of the succession can still be successfully investigated.

The Mesozoic-Cenozoic succession of the Ligurian Briançonnais is the result of a complex evolutionary history that started with Triassic intracontinental rifting, continued with the formation of the European passive continental margin during the Jurassic opening of the Ligure-Piemontese ocean, and ended with the beginning of continental collision in the latest Cretaceous-Paleogene (Boillot et al. 1984; Crampton and Allen 1995). This Mesozoic-Cenozoic succession rests on volcanic and volcanoclastic rocks of Carboniferous-Permian age and is subdivided into several lithostratigraphic units (Boni et al. 1971; Vanossi 1972, 1974) (Fig. 2).

Apart from the early works of French authors (Faure-Muret and Fallot 1954; Guillaume 1965, 1969; Lanteaume 1958, 1968) and Vanossi (1963, 1972, 1974), the most important contribution to the knowledge of the Jurassic stratigraphy of the Cima della Fascia–Monte Mongioie area is by Lecanu et al. (1978). More specific sedimentologic studies on the Jurassic of the Ligurian Briançonnais were carried out by Lualdi (1994a, b, 2000, 2005) and Lualdi et al. (1989), but they mainly concern the Internal Ligurian Briançonnais.

3 Methods

Nine stratigraphic sections have been measured in the Jurassic succession (Figs. 1b, 3, 4). Additional observations and sampling were performed in the Mongioie sector. For petrographic observations we used peels and thin sections including cathodoluminescence analysis with the

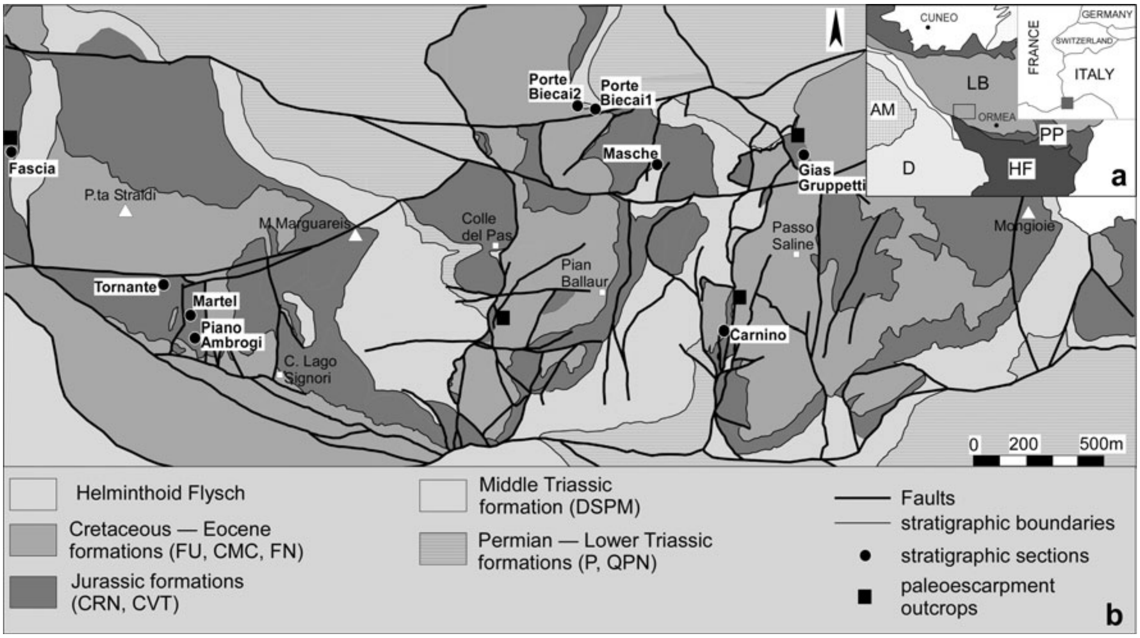


Fig. 1 **a** Location of the study area. *AM* Argentera massif, *D* Dauphinois units, *HF* Helminthoid Flysch (Ligurian unit), *PP* pre-Piemontese units, *LB* Ligurian Briançonnais units. **b** Geological sketch of the study area, with the location of the stratigraphic sections and the paleoescarpments described. Abbreviations used in the legend and in the main text: *P* Porfiroidi, *QPN* Quarziti di Ponte di Nava, *DSPM* Dolomie di San Pietro dei Monti, *CRN* Calcari di Rio di Nava, *CVT* Calcari di Val Tanarello, *FU* Formazione di Upega, *CMC* Calcari della Madonna dei Cancelli, *FN* Flysch Noir. Modified after Piana et al. (2009)

aid of a CITL 8200 mk3 equipment (working conditions: about 17 kV and 400 μA). Our work used the geological maps and the structural analyses by Piana et al. (2009) and Musso et al. (2009) for the definition of the main tectonic contacts and the geometry and internal architecture of the tectonic units (Fig. 1b).

4 Facies description

The Jurassic succession of the study area consists of only two formations: the Calcari di Rio di Nava (CRN) and the Calcari di Val Tanarello (CVT) (Boni et al. 1971; Vanossi 1972, 1974).

4.1 Calcari di Rio di Nava

The thickness is extremely variable, from 25 to 70 m. Five facies have been distinguished.

4.1.1 Conglomerate facies

The conglomerate facies occurs in a dm- to m-thick interval of poorly sorted conglomerates with subangular to subrounded elements at the base of the CRN, and is present only in the Fascia and Porte Biecai sections. At the base, clast-supported facies occur; the clasts (2–10 cm ø) are mainly composed of Triassic dolostones. In the upper part, clasts are smaller and a matrix-supported texture prevails; in addition to dolostones, clasts of ooid- and microoncoid-bearing grainstones and dark lime mudstones also occur. Both clasts and matrix show a variable degree of reddening; the matrix is extensively dolomitized and is crossed by clay-rich dissolution seams.

4.1.2 Grainstone facies

This facies has been observed only in the Fascia section and in the Mongioie area; it is never more than a few metres thick. It is represented by generally red-colored, bioclastic limestones, organized in m-thick massive beds. Microscopically it consists of grainstones with microoncoids, peloids, cortoids, superficial ooids, thick-shelled bivalves, gastropods, echinoderm fragments, benthic foraminifera (e.g. *Meyendorffina* sp.) and intraclasts (Fig. 5a). The pores are filled with a fine-grained blocky spar. In the Mongioie area, this facies contains dm-large fragments of coral boundstones (Fig. 5b).

4.1.3 Black laminated lime mudstone facies

This facies has been recognized in all stratigraphic sections and represents most of the CRN stratigraphic thickness (15–60 m). It is composed of monotonous dark lime mudstones with rare bioclasts, mainly echinoderm fragments; the micrite fraction is commonly recrystallized to

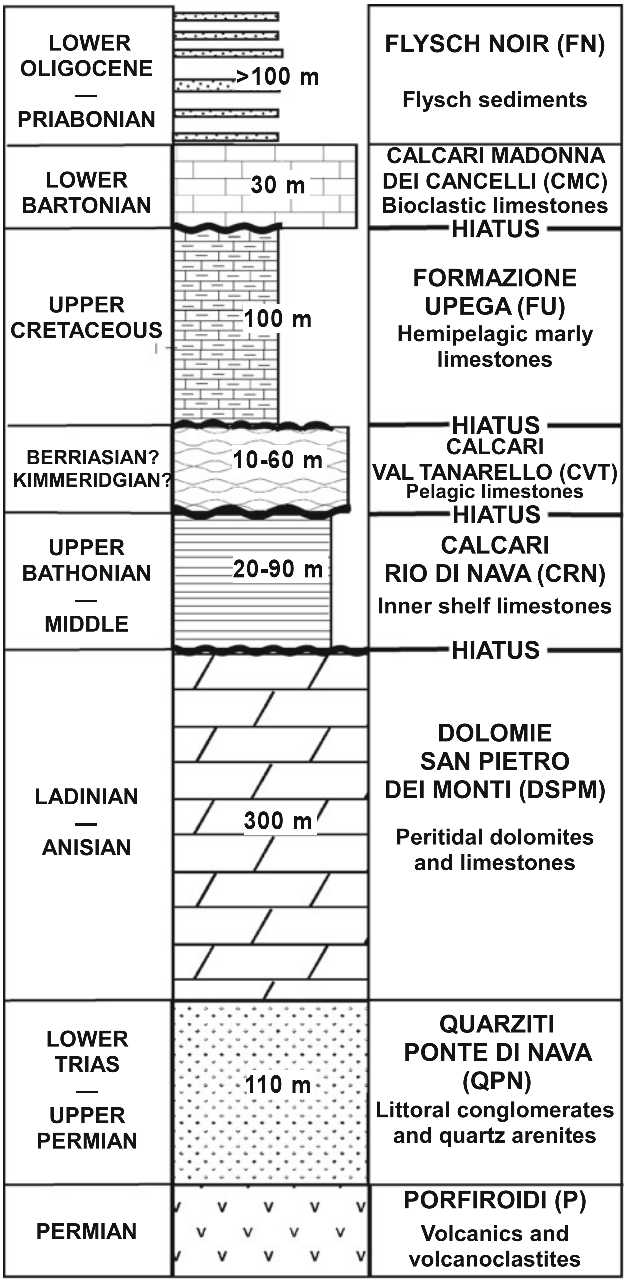


Fig. 2 Simplified stratigraphic section of the External Ligurian Briançonnais succession

microspar. These limestones do not show any bedding but are characterized by an ubiquitous mm-thick lamination defined by subtle textural differences (grain size of microsparite, abundance of echinoderm debris) (Fig. 6a). Commonly microstylolites occur at the boundary between laminae and document an overprint of the sedimentary lamination by pressure dissolution. Locally, where the lime mudstones are interbedded with coarse-grained layers of different facies (e.g. lithoclastic breccia facies: see below), the laminae are deformed and appear wrinkled. Depressions occur just below the largest clasts whereas a mound is formed between the clasts. No clear sign of erosion is visible (Fig. 6b).

Locally, partial dolomitization (10–30%) is clearly recognizable that gives rise to euhedral dolomite crystals 30–100 µm in size. A delicate bioturbation is only locally visible and is represented by soft-sediment burrows, less than 1 mm in diameter, referable to *Chondrites*.

4.1.4 *Oncoidal-bioclastic wackestone facies*

This facies occurs in very few beds interbedded with the black laminated lime mudstone facies. It consists of fossil-rich, massive, mud-supported dark grey limestones; skeletal grains include bivalves, gastropods, benthic foraminifera, and echinoderms. Moreover, mm-sized oncoids occur in variable amounts. Some of them consist of bioclasts and intraclasts coated by mm-thick crusts of micrite that locally show tubular structures. Others instead consist of fan-shaped nuclei showing a well developed tubular structure, in turn coated by 0.5–1 mm thick massive micrite rims. The tubular structures may be referred to *Cayeuxia*, that are interpreted as calcified cyanobacteria (Riding 1991) (Fig. 6c). Post-depositional deformation structures, giving rise to a nodular aspect, are present in some sections within this facies and the black laminated lime mudstone facies; they will be discussed in more detail in a separate chapter.

4.1.5 *Lithoclastic rudite facies*

This facies has been observed only in the eastern sector of the area where it occurs at the base of the CRN as 10–50 cm thick beds alternating with the black, laminated lime mudstone or the oncoidal-bioclastic wackestone facies. It is a matrix- to clast-supported lithoclastic breccia (Fig. 6e). The clasts are mm- to cm-sized, angular to well rounded, and two different types of clasts have been recognized: whitish Triassic dolostones and dark lime mudstones or packstones with peloids. The matrix is a partially dolomitized wackestone with rare echinoderm fragments, benthic foraminifera (*Meyendorffina* sp.), ooids, and peloids, but locally it is represented by a fine peloidal grainstone. These limestones always show an erosional base (Fig. 6d); locally normal grading and an ill-defined cm-thick parallel lamination are evidenced by textural changes (size of clasts, matrix-clasts ratio) (Fig. 6e).

4.2 Calcari di Val Tanarello

The CVT may be subdivided in two informal units, not present everywhere, bounded by a discontinuity. The lower one, at most few metres thick, is made of crinoidal

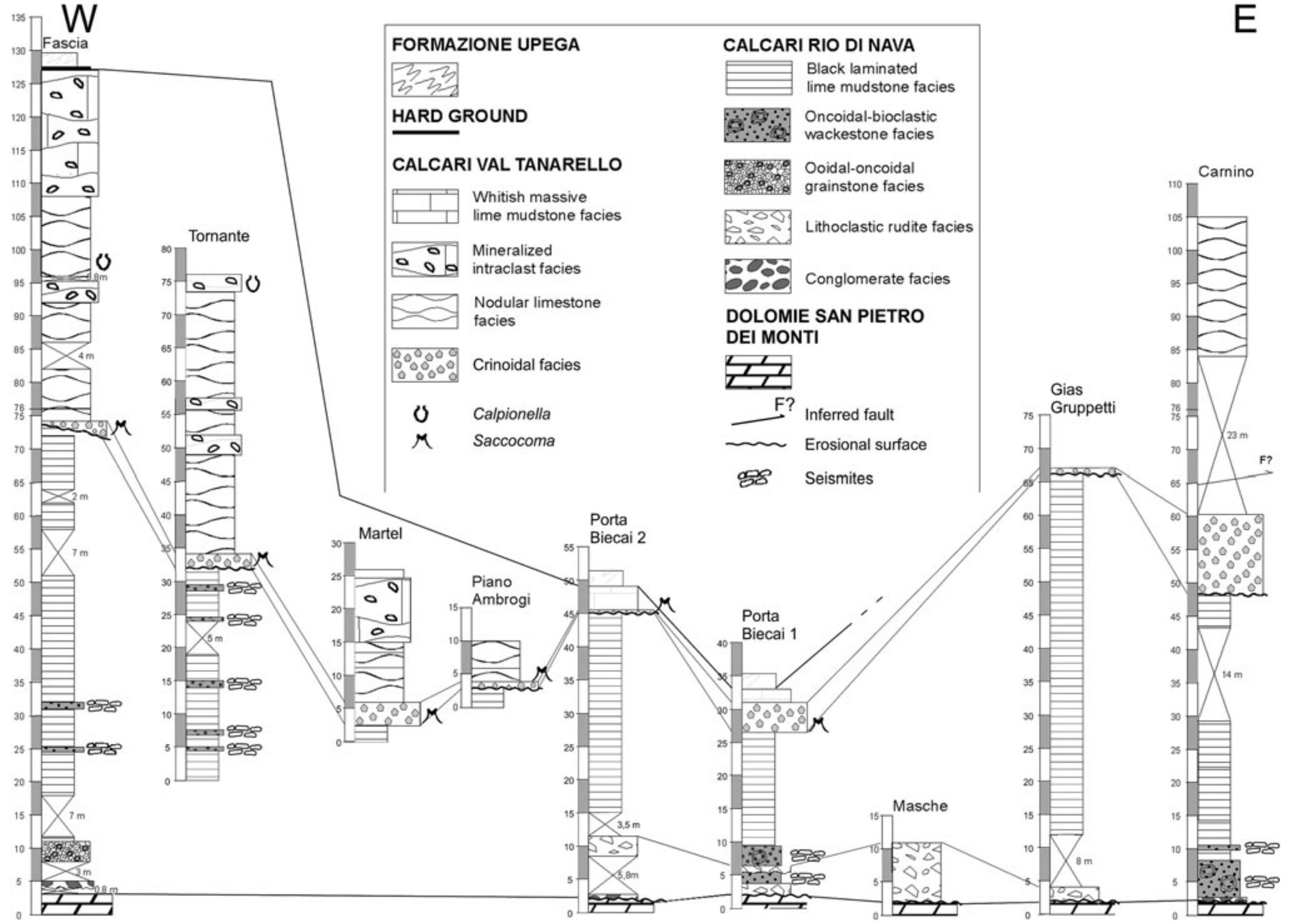
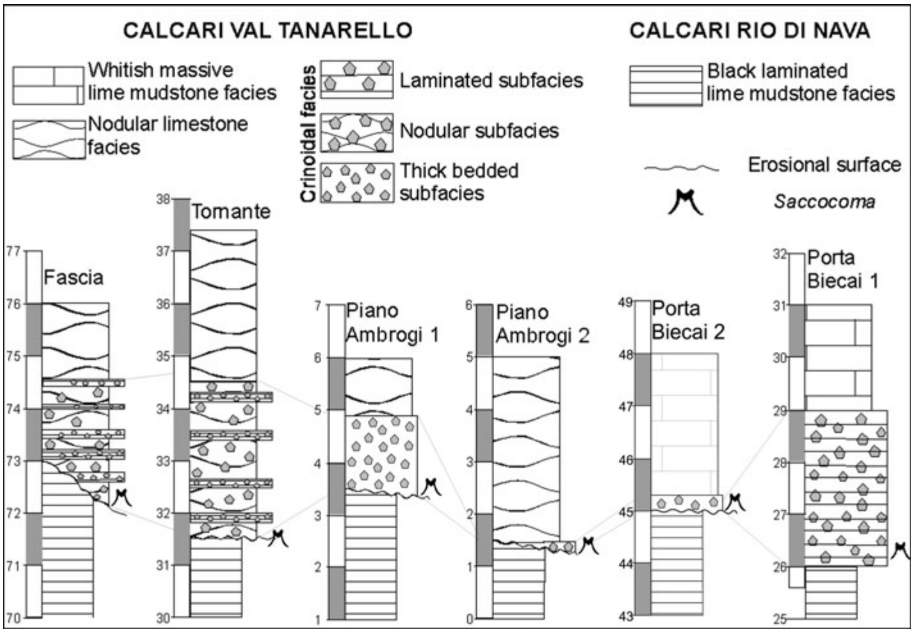


Fig. 3 Correlation of the stratigraphic sections. For sake of clarity the details of the crinoidal facies have been omitted; they are represented in Fig. 4. For location see Fig. 1b

Fig. 4 Detailed correlation of selected sections, aimed to highlight thickness and facies variations of the CVT crinoidal facies



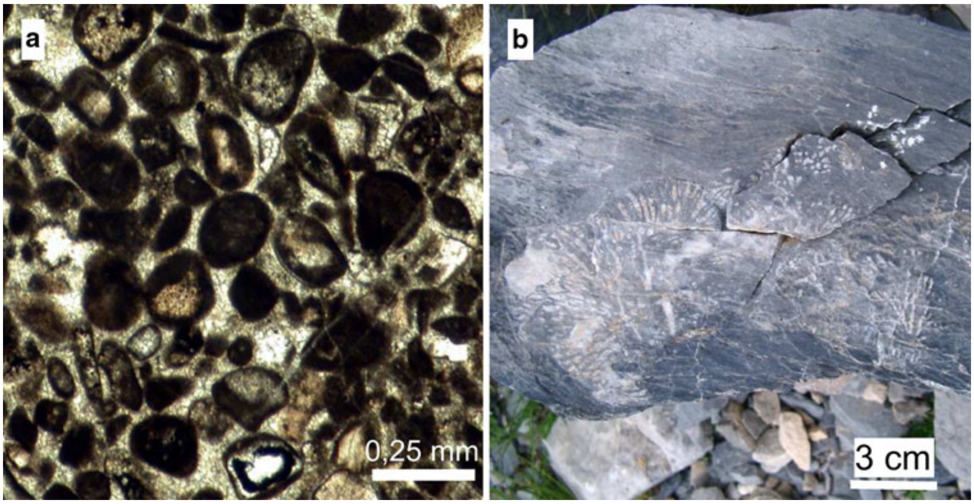


Fig. 5 Calcari di Rio di Nava grainstone facies. **a** Photomicrograph of the grainstone with microoncoids, cortoids and peloids (Fascia section). **b** Dm-large fragments of coral boundstones (Mongioie area)

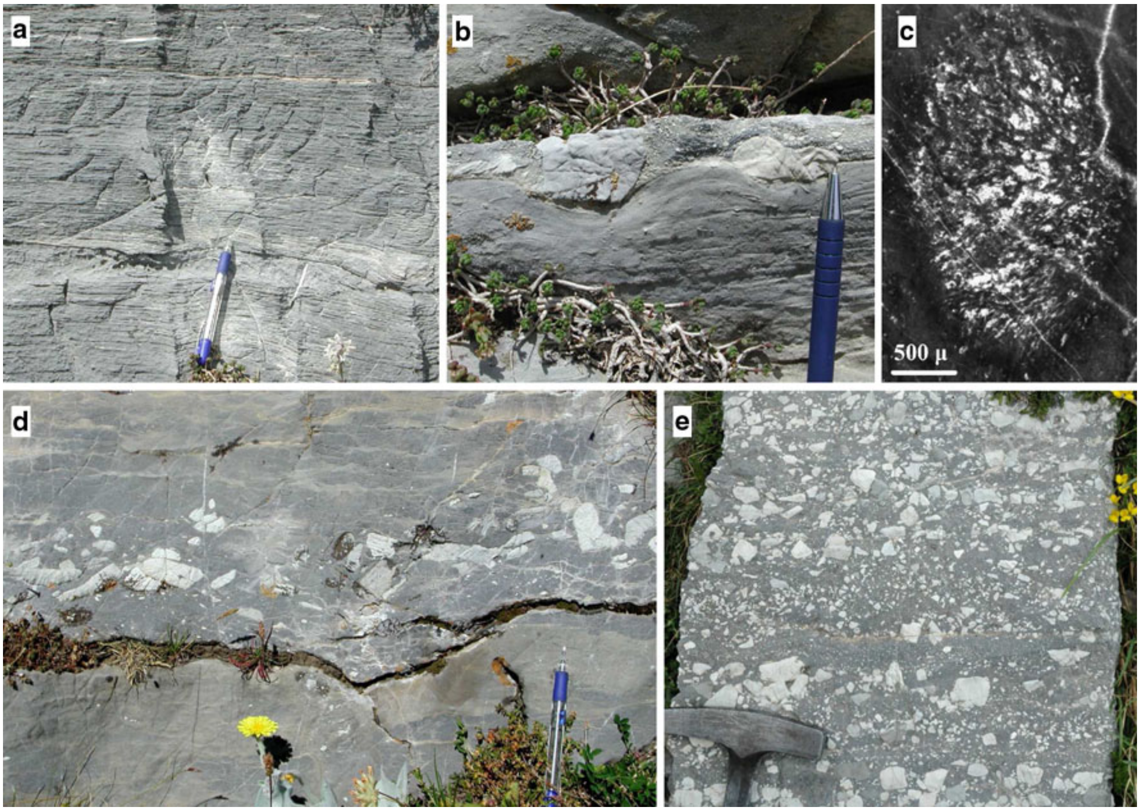


Fig. 6 **a** Calcari di Rio di Nava black laminated lime mudstone facies. The dark lime mudstones are characterized by a pervasive closely spaced layering, generally less than 1 cm thick (Porta Biecai 2 section). Pencil is about 15 cm long. **b** Close up of the boundary between the black laminated mudstone and a thin bed of lithoclastic breccia. Note the wrinkling of the laminae below the larger clasts. Pencil for scale (Porta Biecai 2 section). **c** Calcari di Rio di Nava oncoidal-bioclastic wackestone facies. Photomicrograph of tubular structures referable to *Cayeuxia* that locally occur as oncoid nuclei (Fascia section). **d**, **e** Calcari di Rio di Nava lithoclastic rudite facies. **d** Sharp erosional base of a lithoclastic-rudite-facies bed, incising the underlying oncoidal-bioclastic wackestone facies. Pencil for scale (Porte Biecai 1 section). **e** Poorly stratified, poorly sorted breccia showing a matrix- to clast-supported texture and a polymictic composition. Hammer head is 18 cm large (Masche section)

limestones; the upper one mainly consists of nodular limestones, red or white colored, and varies in thickness from few metres to 50 m. Four lithofacies have been identified.

4.2.1 Crinoidal facies

This facies has been subdivided into three sub-facies on the basis of sedimentary structures (Figs. 4, 7a).

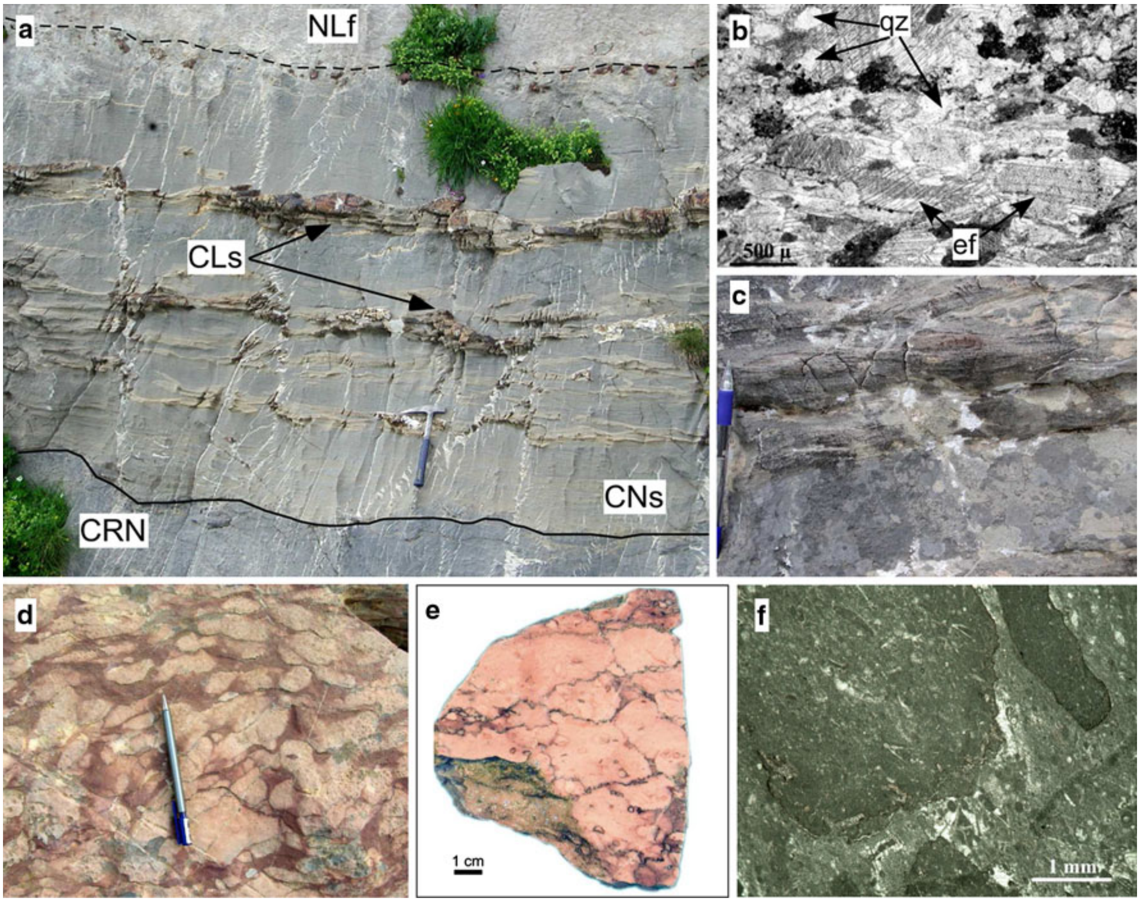


Fig. 7 **a**–**c** Calcari di Val Tanarello crinoidal facies. **a** The 3 m thick crinoidal facies level is composed of an alternation of nodular subfacies (CNs) and laminated subfacies (CLs) beds. The *solid* and *dotted lines* mark the discontinuities bounding the crinoidal facies at the base and at the top, respectively. *NLf* Calcari di Val Tanarello nodular facies, *CRN* Calcari di Rio di Nava (Tornante section). **b** Thick-bedded subfacies: photomicrograph of a grainstone with well recognizable echinoderm fragments (*ef*) with syntaxial overgrowths, and quartz grains (*qz*) (Piano Ambrogi section). **c** Detail of the laminated subfacies. Note the subtle low angle, sinusoidal cross stratification. Pencil is about 15 cm long (Tornante section). **d** Calcari di Val Tanarello nodular facies. Note the presence of nodules with sharp boundaries, interpreted as intraclasts (Piano Ambrogi area). **e**, **f** Calcari di Val Tanarello mineralized intraclast facies. **e** Polished slab showing the common occurrence of mm-sized iron-coated intraclasts (Martel section). **f** Photomicrograph showing the micro-bored and encrusted edges of *Saccocoma*-bearing intraclasts (Fascia section)

Thick bedded subfacies this subfacies crops out only in the Piano Ambrogi, Porte Biecai and Gias Gruppetti sections. It is organized in yellow to pink dm-thick beds, locally showing a well developed bed-parallel lamination. It consists of coarse grainstones with echinoderm fragments, peloids, *Saccocoma* debris and intraclasts (Fig. 7b). The intraclasts are made up of finely crystalline Triassic dolostones, and CRN peloidal grainstones and lime mudstones. Sand-sized quartz and mica mineral grains also occur. Where a lamination is present, it is defined by an alternation of grainstone and packstone showing the same particles. An early cementation in the grainstones is testified by the occurrence of syntaxial cement around echinoderm fragments.

Nodular subfacies this subfacies crops out in the Tornante and Fascia sections. It is characterized by reddish to greyish crinoidal limestones with a nodular structure. Nodules are 2–15 cm across and show both sharp and transitional boundaries with the matrix. They consist of packstones with bioclasts (*Saccocoma*, echinoderm and bivalve fragments), peloids, micritic intraclasts, and rounded quartz grains and are finer grained than the massive subfacies. The internodule matrix is crossed by dissolution seams that stop at the nodule-matrix boundary.

Laminated subfacies this subfacies has been observed in several sections. It is organized in cm- to dm-thick beds interbedded with the nodular subfacies. Locally these beds show a small-scale hummocky cross stratification and ripple cross lamination (Fig. 7c). The laminae consist of fine-grained packstones to grainstones with echinoderm fragments, *Saccocoma*, and quartz grains; the intergranular pores are filled by microcrystalline quartz cement. In some sections (Martel, Carnino) this silicification is very intense and gives rise to dm-thick white chert nodules and bands.

4.2.2 Nodular facies

It shows a massive aspect, with pink nodules in a brick red to purple matrix. Nodules are lens-shaped, some centimetres across and show transitional boundaries with the matrix. They consist of a bioclastic wackestone with echinoderm fragments and *Saccocoma*; locally sub-millimetric rounded quartz grains are present. The matrix is composed of wackestone to packstone with echinoderm fragments, *Saccocoma*, *Globochaete*, glauconite and quartz grains and is crossed by swarms of dissolution seams. Locally, nodules showing sharp boundaries with the matrix occur and can be interpreted as intraclasts (Fig. 7d).

4.2.3 Mineralized intraclast facies

This facies is organized in m-thick beds with a nodular to massive structure. It is composed of cream-colored or pink wackestones with bioclasts (ammonite shells, brachiopods, small gasteropods, echinoderm debris, *Globochaete, Saccocoma*, ostracods, *Calpionella* and benthic foraminifera such as *Lenticulina*), intraclasts, and scattered quartz grains. Differently from the nodular facies, the intraclasts are smaller (mm-sized), are made up of lime mudstone or wackestone with *Saccocoma* and are microbored and encrusted by Fe–Mn oxides at the edges (Fig. 7e, f).

4.2.4 Whitish massive lime mudstone facies

This facies occurs only in the two sections of the Porte Biecai sector. It consists of whitish massive lime mudstones with scattered tiny echinoderm fragments. An ill-defined parallel lamination is locally recognizable.

5 Facies analysis: interpretation

The Jurassic succession of the study area lacks physical sedimentary structures relevant for a detailed sedimentological interpretation. However, sediment texture and composition (e.g. type and abundance of allochems), and the paleontological content allow to interpret the facies described in terms of processes and paleoenvironments.

5.1 Calcari di Rio di Nava

The conglomerate facies represents the transgressive level at the bottom of CRN and documents the return of marine conditions after the prolonged hiatus that lasted from Late Triassic to early Middle Jurassic. Such a hiatus is ubiquitous in the Briançonnais Domain, and is commonly referred to a prolonged subaerial exposure (Faure and Megard-Galli 1988; Decarlis and Lualdi 2008). The red color of clasts and matrix is probably due to the reworking of soils developed during emersion. The occurrence of clasts of non-dolomitized ooidal and oncoidal grainstones together with Triassic dolostones shows that these conglomerates reworked also lithified products of the first stages of Jurassic sedimentation in addition to the exposed Triassic dolomite bedrock.

The grainstone facies documents the onset of carbonate sedimentation in a shallow setting. Warm and agitated waters favoured the development of clean-washed coated grain sands and the growth of small coral bioconstructions. The very limited thickness and areal extension of this facies indicate a rapid transgression that allowed shallow-water sediments to be only patchily deposited and/or preserved.

The features of the black laminated lime mudstone facies, that gave rise to some tens of metres thick packages of monotonous, laminated, almost sterile mudstones lacking any diagnostic sedimentological element, make their interpretation difficult. However, the muddy texture, the dark colour, the absence of bioturbation that allowed preservation of the fine lamination, and the rare occurrence of fossils, suggest a submarine environment characterized by very slow water circulation and oxygenation, in which sedimentation took place through settling of micrite particles on a mainly dysoxic and stagnant sea floor. The occurrence of wrinkling of laminae below breccia beds in place of a simple erosional surface suggests that these mudstones were in a cohesive, plastic state when the breccias were deposited. This again suggests a possible microbial origin of the lamination due to organic mats covering the sea floor and changing the rheological state of muddy, otherwise, loose sediments to elastic sheets of biofilm-bound sediment prone to continuous deformation (e.g. Stolz 2000). The occurrence of beds of the oncoidal-bioclastic wackestone facies, interbedded with these black laminated mudstones, testifies to depositional episodes characterized by easier exchanges with the open sea resulting in better oxygenation and higher water energy. Moreover, the presence of cyanobacteria remains (*Cayeuxia*) points to shallow water conditions, within the photic zone. A restricted lagoon-like environment, only episodically well connected with the open shelf, is thus proposed. No evidence of the barrier isolating this lagoon is available in the study area. In adjacent, more internal, sectors of the Ligurian Briançonnais, however, high energy facies and common coral bioconstructions have been reported (Lualdi 1994a) and document a present-day eastward transition to a possible platform margin.

The lithoclastic rudite facies provides several types of information: texture and composition of the clasts testify to the presence of lithified mainly dolomitic rocks exposed and subject to erosion; the occurrence of both angular and well rounded clasts shows different degrees of reworking and mechanical wearing in high energy environments; the occurrence of both matrix- and clast-supported textures indicates transport by high density flows; the interbedding with echinoderm-bearing, muddy lithologies proves deposition in low-energy marine environments. On the basis of these elements the following scenario may be envisaged. Gravelly beaches, lining rocky coasts where Triassic dolostones were exposed, were occasionally struck by storms that triggered the resuspension of gravels and incorporation, during the offshore-directed backflow, of fine-grained sediments. This resulted in more or less concentrated gravity flows that quickly came to rest without developing any typical storm-related depositional structure.

5.2 Calcari di Val Tanarello

The facies recognized in the CVT quite closely fit the array of more or less condensed pelagic sediments typical of the Tethyan Jurassic. Crinoidal limestones have been known for a long time to mark the drowning of shallow carbonate platforms and the transition to pelagic sedimentation on top of submarine plateaux (e.g. Jenkyns 1971) and more recently the role of palaeoceanographic factors, mainly affecting trophic resources and thus the composition of faunal assemblages, has been evidenced (e.g. Cobianchi and Picotti 2001). Even though the encrinites of the study area do not overlie peritidal limestones as in the case of cited examples from the Southern Alps or Sicily (see also Masetti and Bottoni 1978; Di Stefano et al. 2002), the crinoidal facies documents a sharp change from very low energy, nearly barren shallow-water settings to open marine, well agitated and oxygenated environments. The different subfacies recognized reflect minor variations in current efficiency in turn related to a rugged sea floor topography as described in detail below. The massive subfacies, with local development of parallel laminae, probably formed in the sectors more affected by bottom currents. The low-angle cross bedding and both concave- and convex-upward undulose laminae recognized in the laminated subfacies point to combined flows probably referable to the activity of storm waves and storm-induced backwash currents. The alternation of mud-bearing (packstones) and mud-free (grainstone) lithologies, the occurrence of micritic intraclasts, and the nodular structure, that results from burrowing, early differential cementation, and current reworking, indicate alternating phases of higher and lower hydrodynamic energy. The occurrence of quartz grains in all the crinoidal limestones has wider implications that will be discussed in a later section.

Most of the CVT, overlying the crinoidal limestones, is characterized by mud-supported sediments and varied fossil assemblages that include both benthic (echinoderms, foraminifera, brachiopods, gastropods) and notably planktonic and nektonic organisms (*Saccocoma*, calpionellids, ammonoids) that typically are found in pelagic facies. A nodular aspect and red color are quite ubiquitous in these limestones that correspond to the so called Marbres de Guillestre of the Briançon type area (Barféty et al. 1996). These in turn may be considered the equivalent of the calcareous Trento type Rosso Ammonitico facies well known in the Tethyan Mesozoic. In analogy to similar occurrences of this facies in other regions (e.g. Venetian Alps: Martire 1996; Sicily: Bertok and Martire 2009), several varieties of nodular limestones may be distinguished which result from different combinations of the main processes affecting these condensed pelagic sediments, such as early cementation, bioturbation, reworking and burial compaction. The transitional nodule-matrix boundaries in the nodular subfacies of the nodular facies point to localized early cementation within nodules, possibly guided by bioturbation and consequent porosity contrasts, followed by a selective burial compaction affecting only the previously uncemented matrix in which dissolution seams developed (Kennedy and Garrison 1975; Garrison and Kennedy 1977; Clari and Martire 1996). The occurrence of intraclasts in the nodular facies documents the occasional activity of currents resulting in the reworking of early lithified nodules. Microborings and Fe–Mn-oxide coatings at the intraclast edges in the mineralized intraclast facies record the prolonged exposure of reworked intraclasts at the sediment–water interface. On the whole, the nodular and mineralized intraclast facies of the CVT are the product of pelagic sedimentation on a current-swept submarine plateau. Sedimentation rates were low, in the order of millimetres/1,000 years; this allowed currents, albeit weak and sporadic, to cause early cementation, partial erosion and repeated breaks in sedimentation. The activity of currents hence seems to be the main factor leading to the different facies recognized. The whitish massive lime mudstone facies, at last, simply reflects pelagic sedimentation with no reworking.

6 Stratigraphic discontinuities

The two formations recognized within the Jurassic succession of the study area are bounded from each other, as well as from the under- and overlying formations (Dolomie di San Pietro dei Monti, DSPM, and Formazione di Upega, FU, respectively), by important discontinuities. Moreover,

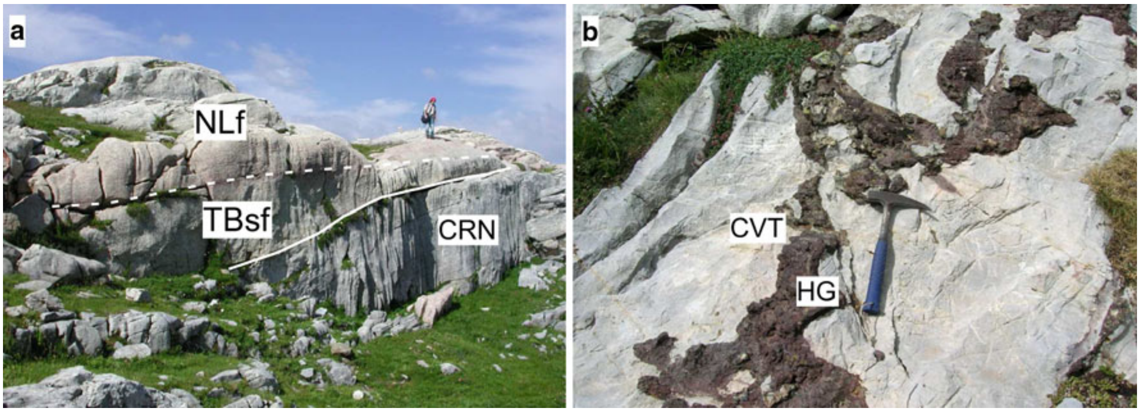


Fig. 8 Discontinuities. **a** Angular unconformity between Calcari di Rio di Nava (*CRN*) and Calcari di Val Tanarello (*NLf* + *TBsf*) in the Piano Ambrogi section, evidenced by the wedging out of a bed of the thick-bedded subfacies of the crinoidal facies (*TBsf*). **b** Patches of a mineralized crust (*HG* hard ground) coating the Calcari di Val Tanarello (*CVT*)-Formazione di Upega boundary. Hammer is 35 cm long (Piano Ambrogi area)

the CVT may be internally subdivided into two informal lithostratigraphic units (crinoidal limestones, below, and nodular limestones, above) that are also separated by an unconformity. All these discontinuities are associated with important vertical facies changes and mark critical events in the physiographic and depositional evolution of the basin. Their main features are:

DSPM–CRN boundary: it is represented by an erosional surface locally associated with a slight angular unconformity. The lowermost part of the CRN is composed of a polygenic conglomerate with elements of DSPM and less abundant CRN. The reddish color of the matrix, locally present, could be evidence for the subaerial exposure that is clearly documented by karstic features in other sectors of the Briançonnais Domain (Faure and Megard-Galli 1988; Decarlis and Lualdi 2008).

CRN–CVT boundary: the geometrical relationships between the two formations are variable; they may correspond to a paraconformity (Tornante, Carnino, Martel, Porte Biecai and Gias Gruppetti sections), a disconformity (Fascia section), or an angular unconformity (Piano Ambrogi section) (Fig. 8a). Locally this boundary shows a scoured morphology and a lag of cm-sized clasts of the CRN that point to a clearly erosional nature.

Crinoidal–nodular facies boundary: this surface is characterized by a facies change that, although less sharp than the two previous ones, documents a discontinuity in sedimentation. Locally (Pian Ambrogi and Tornante sections) further evidence is provided by an irregular morphology, the occurrence of a crust of Fe–Mn oxides, and the presence of scattered cm-sized clasts at the base of the nodular facies.

CVT–FU boundary: the Jurassic succession is topped by a mineralized hard ground with a dm-thick, black to dark red or green crust, composed of Fe–Mn oxides, phosphates, and glauconite (Caron et al. 1971; Lualdi et al. 1989) (Fig. 8b). The crust shows a stromatolite-like mounded morphology and internal fine lamination.

7 Bio-chronostratigraphy and correlation

The extreme scarcity of paleontological remains hinders detailed dating of the Jurassic succession. Only a rough subdivision in three bio-chronostratigraphic intervals is possible on the basis of the micropaleontological content of some selected beds.

1. The occurrence of *Meyendorffina* sp. allows to confirm the Bathonian age (Aurouze and Bizon 1958; Furrer and Septfontaine 1977) of the lower part of the CRN already evidenced by Lualdi (1994b). No data, on the contrary, are available regarding the top of the CRN in the study area. By analogy with other sectors of the Ligurian Briançonnais examined by Lualdi (1994a), who found *Meyendorffina* up to the top of the CRN, we can refer the whole CRN to the Bathonian.
2. The common presence of *Saccocoma* in the lowermost beds of the crinoidal facies of the CVT records that renewal of sedimentation above the CRN–CVT discontinuity took place in the Late Jurassic. In the French sub-Alpine basin, *Saccocoma* appears in the Middle Oxfordian and has an acme from latest Kimmeridgian to Late Tithonian (Dromart and Atrops 1988). By contrast, in the Trento Plateau (Southern Alps), *Saccocoma* appears and becomes common in the upper part of the Early Kimmeridgian (Martire 1996). Therefore a prolonged gap encompassing the

Callovian and possibly the whole Oxfordian is documented at the CRN–CVT boundary.

3. *Calpionella* specimens have been recognized only in two sections (Fascia and Tornante sections), where they document the latest Tithonian-earliest Cretaceous interval. In the Fascia section *Calpionella* occurs already in the middle part of the CVT and thus suggests that the upper portion of this formation could represent the earliest Cretaceous. Planktonic foraminifera assemblages, including *Ticinella*, occurring within the crust developed at the CVT-FU boundary or just above it, are referable to the Middle Albian and allow to infer that most of the Early Cretaceous is missing.

The correlation of the stratigraphic sections reveals marked and meaningful variations in the Jurassic successions (Figs. 3, 4). All the lithostratigraphic units recognized show important thickness changes: the CRN range from about 25 m to over 70, the crinoidal unit of the CVT from 0 to 10 m, the upper unit of the CVT, nodular and massive, from 2 m to over 50 m. On the whole, the CRN thickness changes mirror those displayed by the CVT so that sectors characterized by higher Jurassic sedimentation rates are juxtaposed with others with lower rates. In detail, the Biecai sector stands out for the most reduced thicknesses that increase both eastward and, especially, westward where, in the Fascia sector, the maximum thickness of the Jurassic successions is attained (127 m).

More complex is the pattern of distribution of facies. In general, in the CRN, the facies related to shallower environments and higher hydrodynamic energy occur in the lowermost part, whereas the middle and upper parts with the black laminated lime mudstone facies are characterized by homogeneity. The Biecai sector, again, differs from the rest of the area because it is the only one where the lithoclastic rudite facies is developed, and the CVT is represented only by the whitish massive facies. In the other sectors, the low degree of bio-chronostratigraphic resolution hinders detailed correlation of facies within the CVT. However, a trend may be recognized with an upward increase of reworking of sediments, from nodular facies to mineralized intraclast facies, that may be related to an increase in sporadic high energy episodes.

8 Synsedimentary tectonics: sedimentological and stratigraphic evidence

Many sedimentological and stratigraphical observations at different stratigraphic levels clearly point to synsedimentary tectonics.

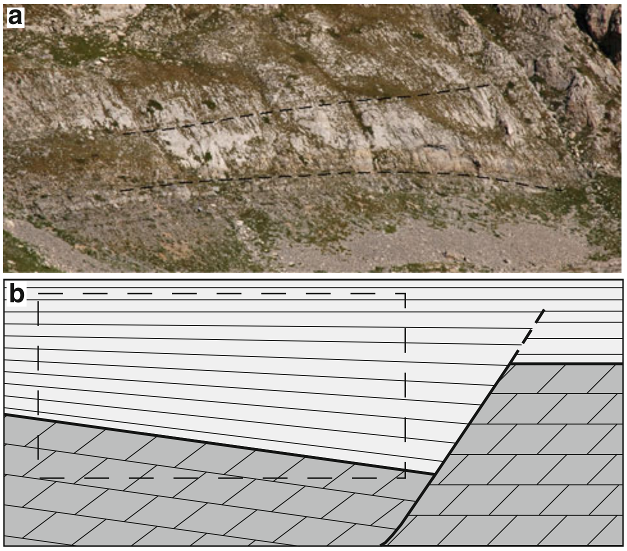


Fig. 9 **a** Structure probably related to a growth fault within the Calcari di Rio di Nava on the eastern side of the Cima della Fascia. *Dotted lines* mark two bedding planes within the CRN. This geometry can be interpreted as the result of a syndepositional tilt related to a normal fault, as sketched in **b**. The *boxed area* shows the area of **a**

8.1 Growth fault-related structures

On the eastern side of the Cima della Fascia, the middle portion of the CRN is wedge-shaped, tapering to the south, and shows a reduction of bed inclination up-section in the northern part, where the wedge is thicker. This geometry may be attributed to a syndepositional tilt related to the opening of a small scale semi-graben generated by a normal fault that however is not directly observable because of the overprint by Alpine tectonics (Fig. 9a, b). The total displacement probably did not exceed 10–20 m so that neither facies changes nor discontinuities were generated. The slightly greater accommodation space created close to the bounding fault, however, resulted in an increasingly thicker succession from south to north.

8.2 Neptunian dykes

In the Pian Ambrogi and Biecai sections a complex pattern of irregular sub-vertical to sub-horizontal fissures has been observed mainly in the upper part of the CRN. In the Biecai section, where the CRN are the thinnest (about 20 m) some small dykes penetrate down to the top of the Triassic DSPM. The fissures are a few millimetres to some centimetres wide; the smallest are filled with red to yellowish micrite whereas the largest contain a matrix-supported breccia with mm- to cm- sized angular clasts of the encasing rocks and a red micritic matrix. Locally two sets of fractures with different infillings (yellow vs. red) are observed to crosscut one another, thus documenting a

Fig. 10 Neptunian dikes. Complex pattern of fissures within the Calcari di Rio di Nava in the Piano Ambrogi area. Two sets of fractures with different infillings and crosscutting one another are clearly recognizable (*red infilling* large arrow; *yellow infilling* small arrows). Camera lens cap for scale is 4 cm in diameter

polyphase history of fracturing and filling (Fig. 10). In the Biecai sector dykes are mainly subvertical and may be traced laterally for several metres. It is thus possible to observe that they are associated to some metres of displacement of the neighbouring blocks. No fossils have been recognized in the fissure fillings; however, the stratigraphic position of the fissures, that stop at the CRN/CVT boundary, and the red colour, that in the whole Jurassic succession only occurs within the CVT, allow to refer this fracturing and filling event to the Late Jurassic. Neptunian dykes are a common feature in ancient passive continental margins where they are particularly frequent at the top of drowned carbonate platforms (e.g. Wendt 1971; Castellarin 1972; Bernoulli and Jenkyns 1974; Winterer and Sarti 1994; Winterer et al. 1991) and reflect a general state of instability whose primary causes must be searched for in the overall geological setting. The significance of the Marguareis–Mongioie neptunian dykes will be interpreted in a wider context below.

8.3 Seismites

In the Carnino, Fascia and Biecai sections pseudonodular strata are developed in the lower part of the CRN where they occur as dm- to m-thick beds interbedded with the oncoidal-bioclastic wackestone or black laminated lime mudstone facies (Fig. 11a). The best exposure is in the Carnino section where they make up the lowermost 8 metres of this formation (Fig. 3). The nodular structure results from the presence of sharp-edged cm- to dm-sized portions of grey sediments separated by a yellowish marly and partially dolomitized matrix. The “nodules” commonly show ellipsoidal or lozenge shapes, but flat, elongated slabs, parallel to bedding and some cm-thick, also occur and locally appear more or less intensely bent (Fig. 11b). Moreover, lozenge-shaped “nodules” locally show an imbricated arrangement (Fig. 11c). The “nodule” to matrix ratio may vary consistently, from beds with nodules floating in the yellowish matrix (Fig. 11d) to nearly intact grey limestone beds crossed by bed-parallel, wavy, mm-thick yellow seams that separate nodules or more continuous bed slabs that basically fit to each other. The mud-supported texture of the matrix and the common lozenge shape of nodules with acute tips indicate that current erosion and production of intraclasts can be ruled out. Also the classical mechanism of localized early cementation, leading to formation of nodules with gradual boundaries with the matrix (e.g. Jenkyns 1974; Kennedy and Garrison 1975; Clari and Martire 1996), can be excluded. The structures described appear to be part of a continuum in a process of post-depositional, internal disruption of shallow buried sediments related to the existence of horizontal shear stresses. Such mechanism probably affected alternations of partially lithified, ductile sediment layers, giving rise to “nodules”, and unlithified ones resulting in the generation of a loose matrix. The relative proportion in thickness of lithified versus unlithified layers generated the different fabrics observed, from a simple in situ brecciation to a nearly complete dismembering of sediments (Fig. 12). The former recall the autoclastic breccias of Montenat et al. (2007), whereas the latter are comparable to boudinage structures of Plaziat et al. (1990) and flat-pebble conglomerates of Kullberg et al. (2001). Taking into account the relatively shallow water setting of the CRN, seismic shocks, triggering the fluidization of the unconsolidated sediments and the rupture of the semi-lithified ones, seem to be a probable causative mechanism of this post-depositional deformation, as suggested for comparable structures by the authors cited above. The peculiar shape of nodules, furthermore, that suggests extensional shear stresses parallel to bedding within ductile sediments, may be probably related to the tangential component of the gravity force. It is thus possible to infer that at least locally sloping depositional surfaces existed that favoured downslope sliding phenomena and more or less intense chaoticization of rheologically heterogeneous, partly fluidized sediments. The imbricated fabrics of “nodules” suggests that the heterogeneous degree of internal dismembering of beds and/or the occurrence of local obstacles could impede the downslope flow and result in small scale overthrusts among bed slabs. The pseudonodular beds of the CRN are thus a further example of seismites (Seilacher 1969, 1984). Dolomitization, at last, may be referred to a later diagenetic phase that did not affect the clasts but developed selectively only in the more porous matrix.

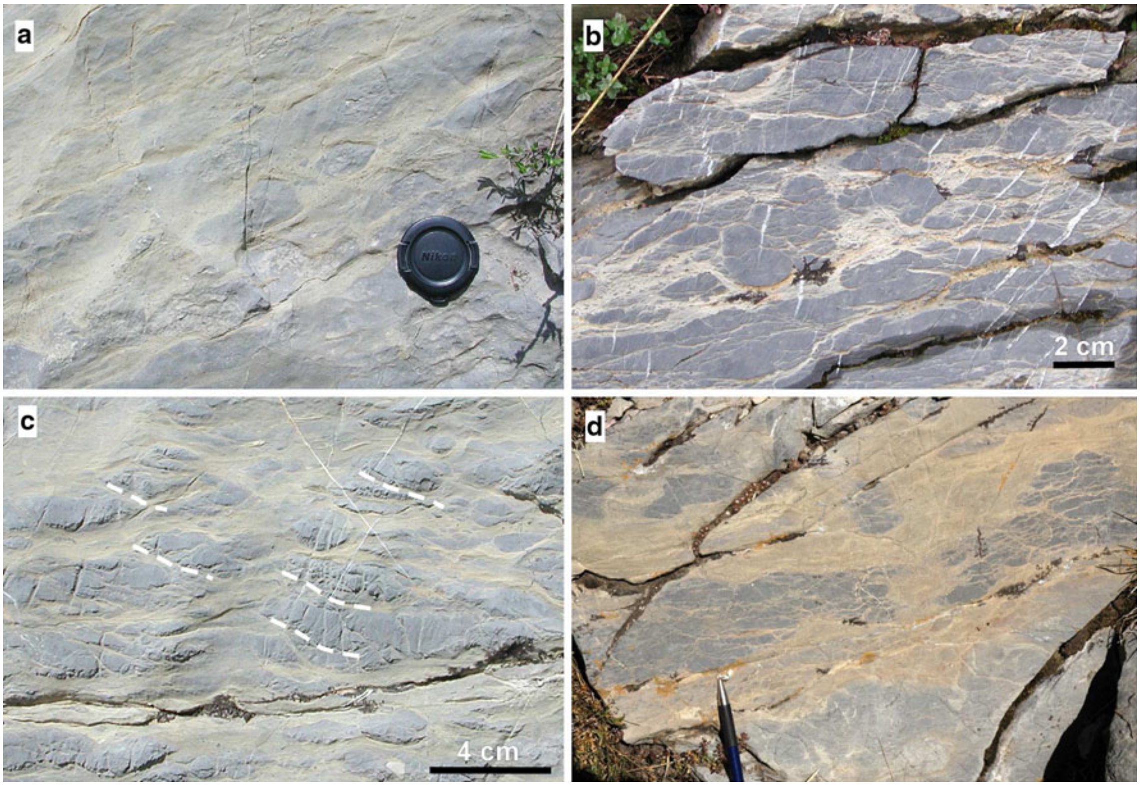


Fig. 11 Calcari di Rio di Nava pseudonodular limestones interpreted as seismites. The nodule/matrix ratio changes from bed to bed. Note: the close interbedding of nodular and homogeneous beds (**a**), the prevailing flat shape of the clasts, their wedging out edges, the variability in size, and the good fit of adjacent clasts (especially in **b**); the locally developed imbricated arrangement of clasts (**c**) underlined by *white dotted lines* that mark surfaces of superposition of one clast over another. **a**–**c** Carnino sector. **d** Biecai sector

8.4 Escarpments

An anomalous, non-concordant, stratigraphic boundary between the CRN and CVT has been locally recognized. A brief description of the main features of this boundary from four key outcrops is given in the following.

Gias Gruppetti: a small portion of the Jurassic succession is exposed, including the CRN/CVT stratigraphic boundary, gently dipping eastward. An erosional surface, dipping westward by about 60°, abruptly cuts through the CRN strata and is overlain by whitish limestones referable to the CVT; they are organized in massive beds that, approaching the erosional surface, become thinner and steeper and show evident onlap geometric relationships with the surface itself (Fig. 13a).

Cima della Fascia: on the eastern slope of the Cima della Fascia, the whole Jurassic succession is exposed with a good outcrop continuity. Locally, the top of the CRN limestones is incised for a few metres by an irregularly shaped erosional surface, with local concave-up geometry, on the whole dipping southward by 20°–40°. A matrix-supported breccia with mm-sized clasts of micritic limestones rests on this surface; it is laterally discontinuous and is not more than 10 cm thick. The lower portion of the CVT, here made up of subhorizontal, pink nodular limestones passing up-section into whitish nodular limestones with cherty layers, leans on the erosional surface with clear onlap relationships (Fig. 13b).

Similar features have also been observed in the upper Vallone delle Saline, few hundred meters south of the Passo delle Saline, and in the Piaggia Bella area, some hundred meters south of the Colle del Pas. In the latter locality, only a few decimetres of the CVT have been preserved which crop out in a patchy way (Fig. 13c). This is due to the very irregular morphology of the erosional surface incising within the CRN.

These peculiar geometrical and stratigraphical relationships point to the existence of quite steep and irregular escarpments that developed in the uppermost part of the CRN and were covered in the Late Jurassic by thin and discontinuous pelagic sediments of the CVT. These escarpments show a limited areal extension, as they never exceed a few tens of meters along strike, but are widespread in the whole study area. Because of unfavourable outcrops, it was not possible to define the vertical relief of the escarpments. However, this is inferred to be greater than 10–15 m.

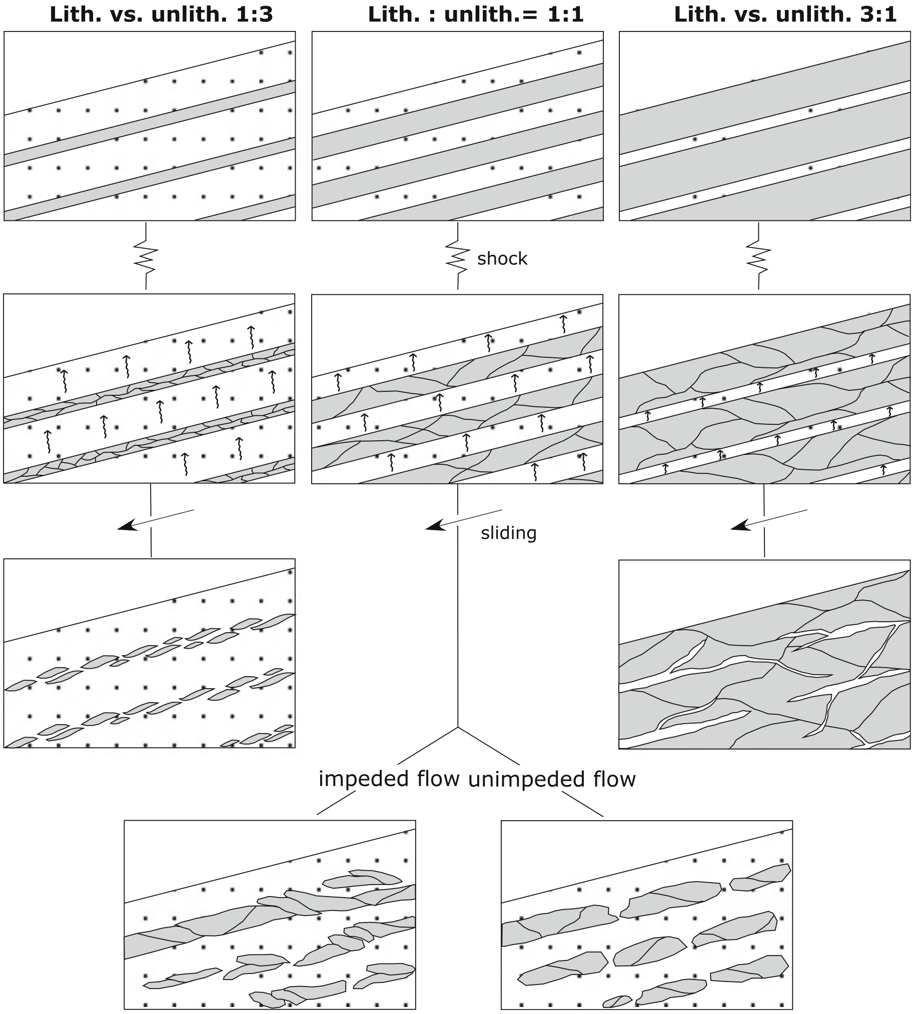


Fig. 12 Interpretive sketch of the processes leading to the formation of seismites. Seismic shocks and the existence of sloping depositional surfaces triggers the internal disruption of shallow buried sediments, resulting in different fabrics depending on the original relative proportion in thickness of lithified (*grey parts*) versus unlithified layers (*stippled parts*), and on the possible occurrence of obstacles impeding the flow of the fluidized sediment

Paleoescarpments in marine environments are increasingly recognized, especially in extensional continental margins (e.g. Castellarin 1972; Santantonio 1993; Di Stefano et al. 2002; Montenat et al. 2002; Bertok and Martire 2009) where their height ranges from few tens to several hundred metres. Their genesis is commonly related to tectonics, either directly generating fault scarps or indirectly triggering gravitational collapses that in turn result in the creation of slide scars. The depositional setting inferred for the CRN and the limited vertical and horizontal sizes of the escarpments lead to favour gravitational mechanisms probably induced by a rejuvenation of the sea floor topography by normal faulting.

9 Discussion and conclusions

Facies analysis accomplished on the Marguareis–Mongioie area succession shows an overall deepening trend of the Ligurian Briançonnais throughout the Middle-Late Jurassic, in perfect agreement with that reported for the whole Briançonnais Domain (Lemoine et al. 1986; Lanteaume et al. 1990; Barféty et al. 1996). After a rapid transgression over the subaerially exposed top of the Triassic peritidal dolostones, a quite enigmatic environment characterized by shallow depth, very low water energy and dysoxic sea-bottom conditions was established. It is here interpreted as a sort of lagoon effectively isolated from the open sea to the present-day east by a barrier of oolitic shoals and patch reefs preserved in other units (Lualdi 1994a). Only occasionally was this lagoon affected by high-energy events, probably related to storms, leading to the deposition of coarse-grained sediments coming from the barrier itself or from locally existing gravelly coasts. In the late Middle Jurassic this platform drowned. The hiatus associated with the drowning event documents sediment bypass in a submarine environment, probably related to current winnowing. Crinoidal sands mark the renewal of sedimentation on a submarine plateau swept by currents, locally showing the influence of storms. After another

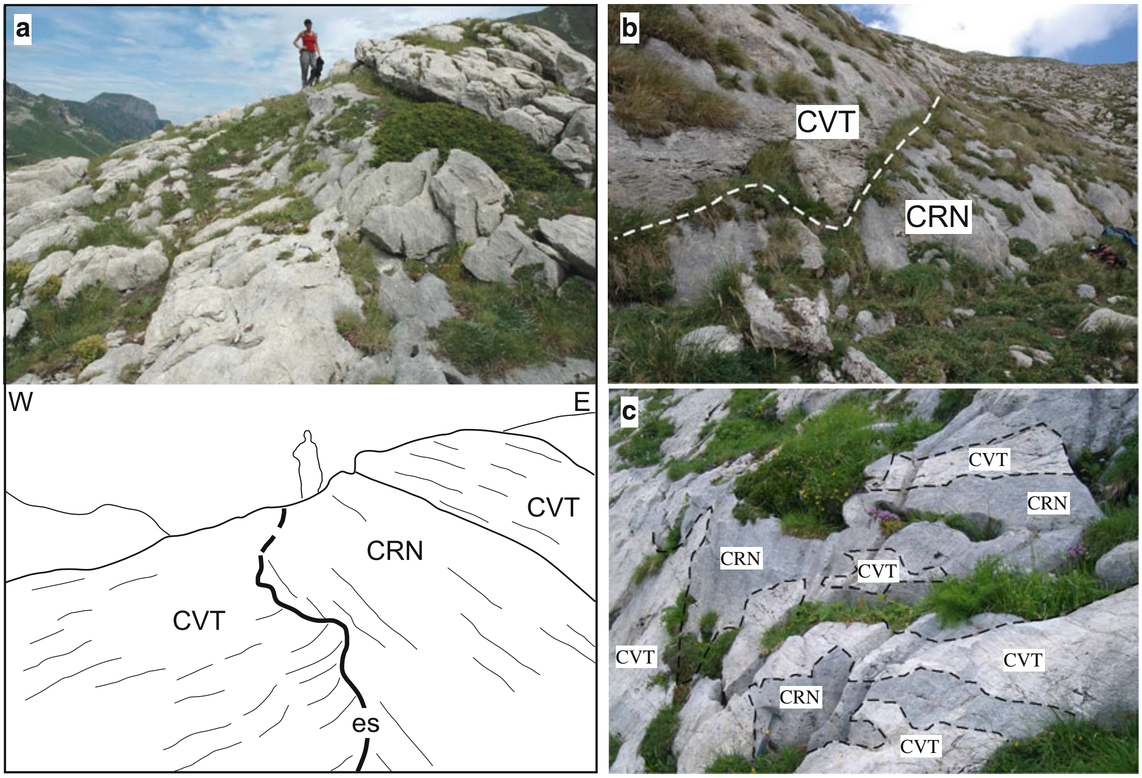


Fig. 13 Outcrops of paleoescarpments. **a** Photograph and corresponding sketch showing an erosional surface (*es*), abruptly cutting through the Calcari di Rio di Nava (*CRN*), dipping to the right, overlain by whitish limestones referable to the Calcari di Val Tanarello (*CVT*) in the foreground, dipping to the *left*. *Thin lines* indicate bedding (Gias Gruppetti area). **b** Subhorizontal Calcari di Val Tanarello limestones lean with onlap relationships on an erosional surface (*dotted line*) cutting through the Calcari di Rio di Nava limestones (Cima della Fascia). **c** Dm-thick small patches of Calcari di Val Tanarello sediments draping an irregular erosional surface cutting through the Calcari di Rio di Nava limestones (Piaggia Bella area)

discontinuity, pelagic sedimentation started and led to the deposition of mud-supported lithologies with development of nodular, Rosso Ammonitico-type structures.

Far from showing a layer cake architecture, the Jurassic succession of the area is characterized by significant variations in thickness of both the Middle Jurassic CRN and Upper Jurassic CVT. This suggests a differentiation of the area into fault-bounded blocks characterized by different subsidence rates during the whole Middle-Late Jurassic and by different sediment thicknesses but identical facies. In fact, an irregular topography of the sea floor inherited from the rifting stage would have led to facies changes in the basal part of the formation with a progressive attenuation of both facies and thickness differences up-section. Moreover, the occurrence of lithoclastic breccias in the northeastern sector shows the proximity of a presumably emerged area where erosion and reworking of mainly Triassic dolostones was taking place in the Bathonian.

Our stratigraphic and sedimentologic analysis reflects the syndepositional tectonic activity reported above. Two major tectono-sedimentary stages, which followed the well known Late Triassic-Early Jurassic stage, related to the Ligurian Tethys rifting, may be recognized:

1. A Bathonian stage. It is clearly documented by marked thickness changes, growth fault structures, lithoclastic breccias, and seismites in the CRN.
2. A Callovian (?)–Kimmeridgian (?) stage. The angular unconformity locally present at the CRN–CVT boundary is the most compelling evidence of tilting of blocks and points to another faulting stage with a clear extensional character. The observed parallel evolution of formational thicknesses of CRN and CVT suggests a reactivation of the pre-existing Bathonian fault network during this stage (2). Neptunian dykes, locally associated with vertical displacement, are part of a system of fractures that affected the underlying Bathonian limestones, and even the Triassic dolostones, and were filled with red micrite of the CVT. Escarpments onlapped by CVT sediments are the scars of submarine landslides probably induced by gravitational instabilities, in turn related to fault activity, block tilting and the generation of slopes. The common occurrence of sand-sized quartz grains and clasts of DSPM and CRN within the crinoidal facies at the base of the CVT documents a major rejuvenation of the topography of the basin and its surroundings, with

denudation and erosion at least down to the Early Triassic sandstones if not to the underlying Permian rocks.

The resulting scenario stresses the importance of syn-sedimentary tectonics in the Middle-Late Jurassic evolution in the Briançonnais Domain. Such tectonic activity was previously reported uniquely before the Bathonian, and as being related to the syn-rift stage in the Alpine Tethys evolution (Lemoine et al. 1986; Faure and Megard-Galli 1988; Tricart et al. 1988), although breccias and conglomerates resulting from late Middle Jurassic uplift and subaerial exposure had been described by Septfontaine (1983). In the Marguareis–Mongioie area, the relatively uniform facies at the base of the CRN shows that the Bathonian transgression took place over a generally flat erosional surface. A slight angular unconformity, locally recognizable, and the occurrence of lithoclastic rudites with prevailing clasts of Triassic dolostones are the evidence of a subdued topography.

The inferred role of the Middle-Late Jurassic post-rift activity was, by contrast, much more effective in shaping the stratigraphic architecture, triggering gravitational instabilities, and delivering quartz grains to the basin.

The Bathonian tectonic event recorded in the lower part of the CRN could be referred to the initial stages of oceanic crust formation in the Ligurian Tethys, although these have been dated to the Bajocian (Bill et al., 2001). Péron-Pinvidic et al. (2007) and Péron-Pinvidic and Manatschal (2009) have recently pointed out that after the accretion of oceanic crust between the Iberia–Newfoundland margins, deformation spread out over the previously accreted oceanic crust involving the continental margins. We propose that a similar delocalization of deformation took place also during the Ligurian Tethys evolution, when the Briançonnais continental margin was affected by faulting shortly after the onset of the oceanic spreading in the Bajocian.

Features and interpretations similar to those discussed above for the Callovian (?)–Kimmeridgian (?) stage have been presented by Barféty et al. (1996) and Claudel and Dumont (1999) in a revision of the tectono-sedimentary evolution of the Briançonnais Domain in the classical sections of the Briançon area. In particular, Claudel and Dumont (1999) conclude that this Late Jurassic phase was, in the Briançonnais Domain, more important than the Early Jurassic one as far as both depth of erosion and displacements along faults are concerned. Other authors (Vanossi 1965; Menardi-Noguera 1988; Seno et al. 2005) reported the occurrence of CVT sediments directly overlying Middle Triassic dolostones or even Permian volcano-sedimentary rocks from nearby areas (Capraun unit of the Internal Ligurian Briançonnais). In light of the features observed in the Marguareis–Mongioie area, this could be reinterpreted as Upper Jurassic sedimentation over escarpments incising at different levels into the substrate.

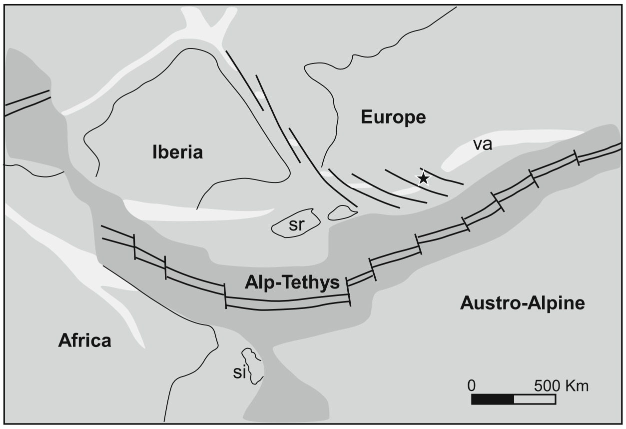


Fig. 14 Paleogeographic map of the Western Tethys in the Kimmeridgian, showing the location of the Marguareis–Mongioie area (*black star*). *Light grey* continental crust, *dark grey* oceanic crust, *white* continental rift areas. *sr* Sardinia, *si* Sicily, *va* Valais basin. Redrawn after Stampfli et al. (2002)

This Late Jurassic phase of extensional tectonics can be referred to the Iberia/Europe margin evolution. The easternmost part of this margin, according to some authors (Handy et al. 2010; Loprieno et al. 2010), was affected by the opening of the Valais ocean in the Early Cretaceous, whereby the remnants of this ocean are preserved in the Valais units in Savoy. The Valais opening led to the breakaway of a Briançonnais microcontinent from Europe, and was linked to the oblique spreading in the Bay of Biscay, at the westernmost part of the Iberia/Europe margin (Frisch 1979; Stampfli 1993; Stampfli et al. 1998; Handy et al. 2010). In the Ligurian Alps the existence of the Valais ocean has been questioned (Seno et al. 2005; Bonini et al. 2010), and as a matter of fact the External Ligurian Briançonnais is nowadays directly juxtaposed to the Dauphinois domain, with no evidence for the existence of an interposed oceanic suture. However, whether the Valais ocean extended southward up to the Ligurian sector or not, the Marguareis–Mongioie area was located along the E–W trending wide plate boundary between Iberia and Europe (Fig. 14). A Late Jurassic transtensional tectonic activity with displacements in the order of hundreds of kms, preceding the Early Cretaceous opening of the Bay of Biscay and the Valais basin, has been documented along this boundary (e.g.: Jammes et al. 2009), and deeply influenced the depositional history of the Ligurian Briançonnais basin.

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