

THE HETTANGIAN SHALLOW WATER CARBONATES AFTER THE TRIASSIC/JURASSIC BIOCALCIFICATION CRISIS: THE ALBENZA FORMATION IN THE WESTERN SOUTHERN ALPS

FLAVIO JADOUL* & MARIA TERESA GALLI*¹

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Abstract. This study investigates the stratigraphic and sedimentologic setting of an early Hettangian carbonate platform in the Lombardy Basin, taking into account the Triassic-Jurassic (Tr-J) post-crisis evolution and the geodynamic setting related to the beginning of the Early Jurassic rifting. The historical name of this platform (“Conchodon Dolomite”), not adequate for the absence of *Conchodon* and for the mainly calcareous lithology, has been replaced with Albenza Formation. The depositional model of this carbonate platform unit is coherent with a leeward Great Bahama Bank-type environment, without any reefs facing deep water environments. The unusual abundance of ooids and marine cements, in the basal progradational ramp-type margins, reflects temporal variation in the saturation state of seawater after the Tr-J crisis, possibly due to marine calcified cyanobacteria blossom. The absence of biotically induced margins related to the (biocalcification) Tr-J crisis and the concomitant tectonic fragmentation, with different subsidence rates of the Tethyan passive margin, conditioned the drowning and the eastward retrogradation of the Albenza platform.

Riassunto. L'assetto stratigrafico e l'analisi delle facies carbonatiche del Hettangiano inferiore del Bacino Lombardo rappresentano l'oggetto di questo lavoro. Il nome dell'unità litostrostratigrafica di riferimento (“Dolomia a Conchodon”), non adeguato sia per l'assenza di *Conchodon* che per la litologia prevalentemente calcarea, è stato sostituito con quello di Formazione dell'Albenza. Il modello deposizionale di questa unità di piattaforma carbonatica è coerente con gli attuali ambienti sottovento del Great Bahama Bank, ma senza reef adiacenti agli ambienti di bacino intrapiattaforma. La inusuale abbondanza di ooidi e di cementi marini precoci nei margini di rampa prossimale progradante alla base della formazione riflettono variazioni temporali di saturazione delle acque dopo la crisi al passaggio Triassico-Giurassico, presumibilmente in relazione con l'esplosione di batteri calcificanti. L'assenza di margini biotici, legata alla crisi di biocalcificazione e ad una concomitante frammentazione tettonica, con diversi tassi di subsidenza sul margine passivo della Tetide alpina hanno condizionato sia l'annegamento della piattaforma sia la sua rapida retrogradazione verso est,

dove persiste l'aggradazione del sistema di piattaforma carbonatica peritidale della Corna.

Introduction

The Hettangian represents a key stage after the diversified Upper Triassic carbonate platform ecosystems of the Tethyan realm and the reorganization of shallow water depositional systems. It also testifies to a recovery period following the biological crisis close to the Triassic-Jurassic (Tr-J) boundary (Sepkoski 1996). Several (sometimes concomitant) mechanisms have been suggested for the end-Triassic extinction (Hesselbo et al. 2007 and references therein), however, after a long period of studies it is reasonable to retain that a no sudden extinction event involved the biotic realms and that the marine and non marine biota suffered different fate (Galli et al. 2007).

The Hettangian time was also typified by the beginning of plate reorganization (Bertotti et al. 1993; Sarti et al. 1993) coinciding with the imminent rifting phase leading to the Central Atlantic Ocean and to the Alpine Tethys openings. In the Alpine Tethyan realm as well as in the Apennine sectors (cf. Passeri & Venturi 2005), the Rhaetian-early Sinemurian stratigraphic and paleoenvironment settings are dominated by platform to ramp carbonate systems characterizing the monotonous, locally dolomitized, lithofacies associations of the Apulian successions (Corna Fm.-“Conchodon Dolomite” in the Southern Alps: Cassinis 1968; Gnaccolini 1964, 1965; Lower Calcari Grigi-Mt. Zugna Formation in the Trento Platform, Dolomites and Carnia regions:

* Dipartimento di Scienze della Terra ‘Ardito Desio’, Università degli Studi di Milano, Via Mangiagalli 34, 20133 Milano, Italy.

¹ E-mail: maria.teresa.galli@unimi.it

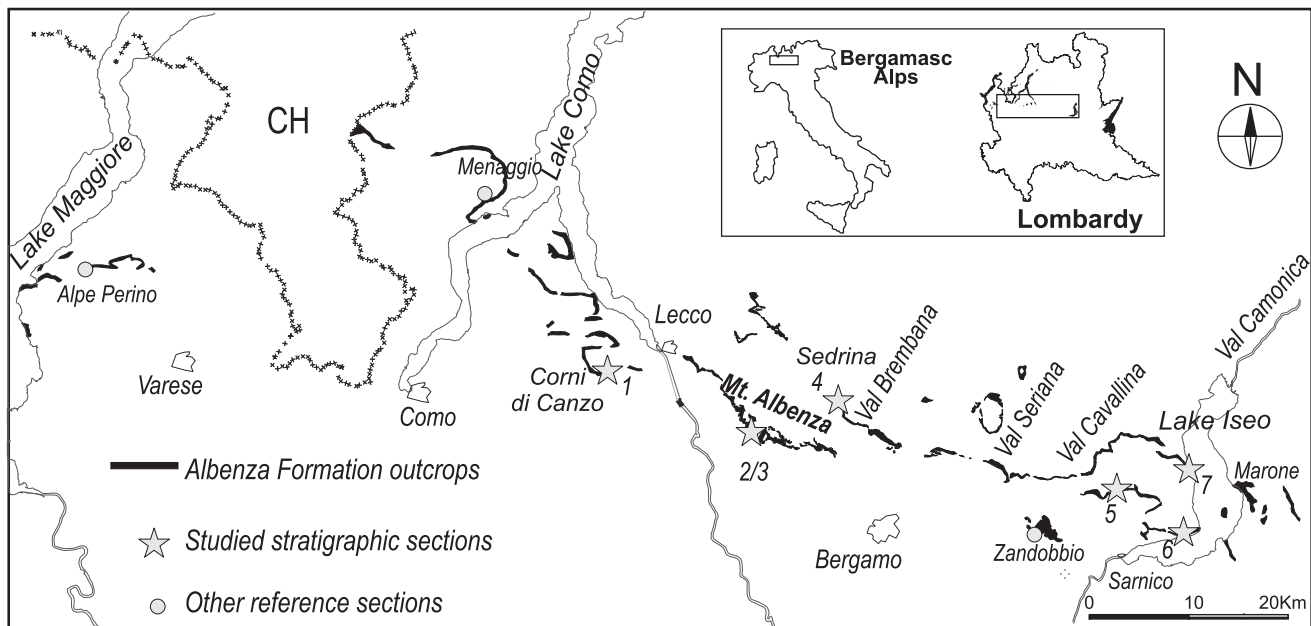


Fig. 1 - The studied area and sections: 1) Sasso Malascarpa (45°51'12"N; 9°19'25"E), 2) Italcementi inactive quarry (45°46'35"N; 9°30'28"E), 3) Italcementi active quarry (45°46'44"N; 9°31'19"E), 4) Ghisalberty (45°47'18"N; 9°37'25"E), 5) Adrara (45°43'07"N; 9°57'30"E), 6) Predore (45°40'54"N; 10°0'55"E), 7) Tavernola (45°42'37"N; 10°2'50"E). The Italcementi inactive quarry and Italcementi active quarry sections, have been mentioned in the text also as Albenza sections.

Bosellini & Broglio Loriga 1971; Masetti et al. 1998; Cozzi et al. 1999; Schirolli 1997; the Calcare Massiccio Formation in the Apennines: Piali 1971; Passeri & Venturi 2005). In the shallow water successions the transition between the Rhaetian and Hettangian systems is scarcely recognisable (Brenta succession: Masetti et al. 1985; Binda 2007), while major facies changes are notable in the Tr-J succession of the marginal platforms and the proximal carbonate ramps (Galli et al. 2007).

This paper is aimed at the characterization of the stratigraphic and sedimentologic setting of the Hettangian in the Lombardy Basin, taking into account the aforementioned Tr-J post-crisis evolution and the geodynamic setting related to the beginning of the Early Jurassic rifting. Furthermore, we present the litho- and chronostratigraphic revision of the Conchodon Dolomite herein renamed as Albenza Fm. The Conchodon Dolomite *Auctorum* has been usually considered a shallow water succession, developed on the passive margin of the westernmost Southern Alps, sandwiched between the Rhaetian Zu Limestone Fm. (Gnaccolini 1965) and the Early Jurassic siliceous limestones of the Sedrina Limestone (Francani 1967) and the Moltrasio Limestone (Stoppani 1857) formations.

The lithostratigraphic revision of the Conchodon Dolomite, assigned firstly to the Hettangian by the Geological map 1:100 000, Varese 31 (1932) and subsequently to the Rhaetian by several Authors (Gnaccolini 1964), is necessary taking into account the absence of *Conchodon* (which instead are present in the upper Zu

Limestone: Jadoul et al. 2005) and the mainly calcareous lithology in central-western Lombardy (Conchodon Kalk of Kälin & Trümpy 1977). Furthermore, the historical name 'Dolomia a Conchodon' firstly introduced by Negri & Spreafico (1869) as 'Dolomia a *Conchodon infraliasicus*' referred to the 'Dolomia superiore di Lombardia' of Stoppani (1861), suffered during the last decades also several problems of synonymy variously named as 'dolomia superiore di Lombardia', 'dolomia retica', 'Formazione a Conchodon', 'Conchodon dolomit', 'schistes a Conchodon' and 'Conchodon-Kalk'.

It is opinion of the writers that also the formations, introduced (but not formalised) to characterize the Hettangian-early Sinemurian carbonate platform-ramp lithofacies association of the Southern Alps should be reconsidered as regional members. More useful could be introduce a new hierarchic subdivision (e.g. Massiccio group) enclosing all the earliest Jurassic carbonate platforms of the Apulian domains.

The present study is mainly focused in central Lombardy, between Lecco and the Lake Iseo (Fig. 1) and completes the regional lithostratigraphy and paleogeography of the Rhaetian-early Sinemurian in western and central Lombardy (Jadoul et al. 2005; Galli et al. 2007). In Jadoul et al. (2005) the Rhaetian/Hettangian carbonates of western Lombardy have been revised and only the Lower Jurassic carbonates are attributed to the equivalent Albenza Fm. analyzed in the present study. Eastwards (Val Trompia, around Botticino) the Albenza Fm. is replaced by the lower Corna Fm. (Cassinis 1968)

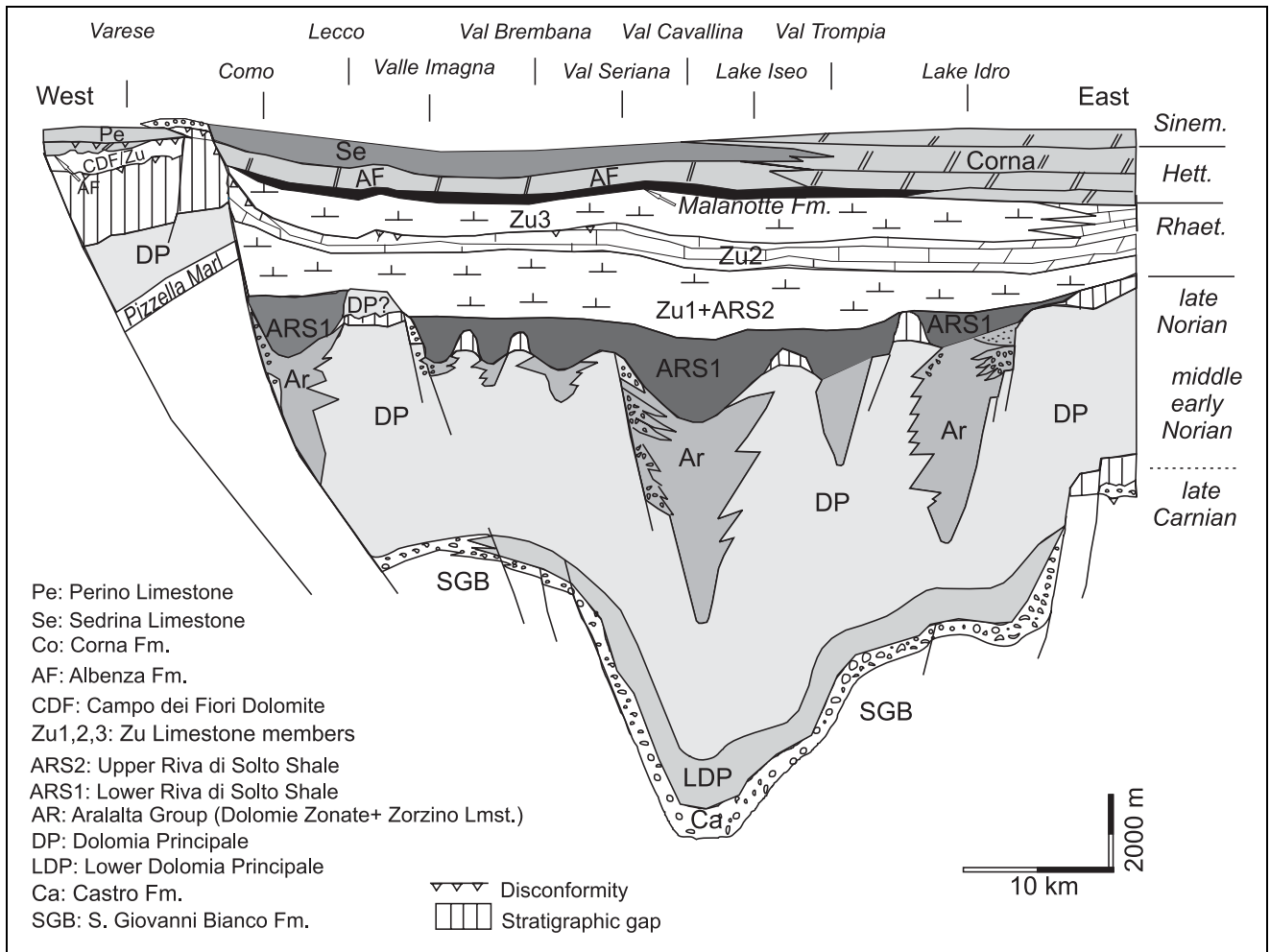


Fig. 2 - Regional lithostratigraphic scheme of Late Triassic-Early Jurassic succession of the Lombardy basin (after Jadoul et al. 1994, 2004).

attributed to the Hettangian-early Sinemurian and more eastwards up to the Pliensbachian (Schirolli 1997 and references therein).

Regional geologic setting

The Norian-Early Jurassic sedimentary succession of the Southern Alps of Lombardy records all the stages of the passive margin evolution (Bertotti et al. 1993; Jadoul et al. 2004 and references therein), related to the opening of the Alpine Tethys. The Upper Triassic basins exhibit variable thickness (from 500 to 4000 m; Assereto & Casati 1965) controlled by transtensive tectonics (Norian asymmetric rifting; Jadoul et al. 1992) and are bordered by structural highs to the South (sub-surface data; Errico et al. 1979), the Trento Platform to the East, and the Varese high to the West.

The upper Carnian to lower Hettangian succession (Fig. 2; Jadoul et al. 1994; Gaetani et al. 1998) is characterized by two depositional systems. Their boundary denotes a change in the sedimentologic and oceanographic-climatic regimes in the late Norian, cor-

responding to the crisis of the Dolomia Principale platform (Jadoul et al. 1994; 2004). The upper depositional system (late Norian-Hettangian) consists, at the base, of different types of shale-carbonate ramp cycles (Riva di Solto Shale and Zu Limestone formations) developed on the tilted blocks of the Norian rifting event (Jadoul et al. 1992). It passes upward into the transgressive Hettangian thinly-bedded, open subtidal micritic limestones (Malanotte Formation; Galli et al. 2007). In the next the two Hettangian formations which sandwich the Albenza Formation are shortly described.

a) The Early Hettangian Malanotte Formation

The Malanotte Fm. (Galli et al. 2007) represents a lithostratigraphic unit cropping out from East to West (for about 60 Km), in the Western Southern Alps of Lombardy, from the Lake Iseo to the Lake Como (Fig. 2). This formation (15 to 30 m thick) consists of thin bedded micritic limestones, very poor in fossils. It represents a marker developed in the central Lombardy between two shallow water carbonates units (Zu Limestone Fm. and Albenza Fm.). At the base, bioturbated bed surfaces and small slumpings are frequent, whereas at the top oo-bioclastic fine calcarenites alternated with

calclutites yielding sponge spiculae, rare radiolarians and small chert nodules. Palynological and chemostratigraphic studies carried out on several sections enabled the location of the Tr-J boundary (Fig. 3) in the lower part of this formation (Cirilli et al. 2000; Galli et al. 2005, 2007).

The lithofacies association and the vertical stratigraphic evolution document a marine transgression recorded by the transition from monotonous outer carbonate ramp facies associations at the base toward shallower environments at the top. The relative rapid sea level rise that controlled the deposition of the Malanotte Fm. created the necessary accommodation space for the Albenza platform progradation.

b) The late Hettangian Sedrina Limestone Formation

This succession (Francani et al. 1967; Gaetani 1970) is cropping out only in central Lombardy, where a second Early Jurassic marine transgression is recorded during the late Hettangian leading to an open shelf carbonate succession (lower Sedrina Limestone). This Hettangian formation ends with oo-bioclastic carbonates (upper Sedrina Limestone; cf. Predore section of Fig. 4) representing the last shallow water carbonate progradation in central Lombardy (Lecco and Bergamasc Alps) coming from the eastward Corna platform.

Shallow water carbonates persist through the whole Hettangian-early Sinemurian time (Corna Fm. on the Botticino high, Schirolli 1997), while eastward (up to the Ballino Fault) a subtidal to slope-basinal Hettangian-lower Sinemurian succession characterizes the through between the Botticino and the Trento platform highs (lower Tofino Fm.: Castellarin 1972; Bertotti et al. 1993; Picotti 2003).

Westward a very small platform (Alpe Perino Limestone; Jadoul et al. 2005) developed at the base of the M. Nudo basinal succession around the west side of the Arbostora early Liassic belt (Bernoulli 1964; Kälin & Trümpy 1977). During the Early Sinemurian a definitive platform drowning occurred in the most part of western Southern Alps as a consequence of an evident increase of tectonic subsidence in several North-South orientated half-grabens of Lombardy (Bertotti et al. 1993) with pelagic cherty limestones, marls and several carbonate turbidites wedges (Moltrasio and Val Trompia limestones: Bersezio et al. 1997; Schirolli 1997; Tofino Fm. p.p.: Castellarin 1972; Picotti & Cobiانchi 1996; Val d'Oro Fm.: Casolari & Picotti 1997).

Lithostratigraphy and facies analysis of the Albenza Fm.

Seven stratigraphic sections have been studied between the Triangolo Lariano and the Lake Iseo (Fig. 1, 4). Mt. Albenza has been designed as type area for the

Albenza Fm., with the Italcementi active quarry (Fig. 4) as type section (see Appendix 1). The previous reference section (Gnaccolini 1964) in the Galbiga-Crocione-Tremezzo mountains group (Menaggio area), will not further be used because of its not easy accessibility, the mainly recrystallized lithofacies and the absence of detailed description. It remains as reference section for the north-western Lombardy.

Stratigraphic boundaries

The transition from the Malanotte to the Albenza formations is either abrupt (as in the Mt. Albenza type area; Fig. 3 and Appendix 1) or gradational and coincides with a regional environmental change (Galli et al. 2005, 2007). In the Mt. Albenza, the Malanotte Fm. is overlain by cross-bedded, well-sorted, grey oolitic grainstones of the basal Albenza Fm. (Fig. 5, 6), displaying a downlap bed geometry with an angle of 25°-30°. A rapid increase of fine to coarse, light nut-brown oolitic grainstones with local lime-mud intraclasts characterizes the transitional boundary in the other sections (e.g. Brumano, Adrara, Ghisalberti, Corni di Canzo). Irregular nut-brown to whitish chert nodules are present at the base of the Albenza Fm. in the Mt. Castello, Brumano and Val Taleggio areas.

The upper boundary with the Sedrina Limestone is generally characterized by a deepening upward trend (open subtidal carbonates). The basal transitional succession (up to 3-4 m thick), shows a gradual grey colour changing, with locally grey-green marly interbeds, and frequent fossiliferous bioturbated limestones (Fig. 4) with silicified pelecypods, brachiopods, echinoderms and rare corals (Albenza, Adrara and M. Cavlera sections; Gaetani 1970; McRoberts 1994). In the Bergamasc Alps, the basal fossiliferous limestones is known as "Grenzbivalvenbank" (Kronecker 1910; Rossi Ronchetti & Brena 1953; Gaetani 1970; McRoberts 1994) and consists of fossiliferous lenses rich in echinoids, bivalves (*Clamys thiollieri*) and locally corals.

Eastwards and south-eastwards (East Iseo area and Zandobbio hills) the Albenza Fm. is gradually replaced by completely dolomitized facies ("pietra di Zandobbio" or "dolomia di Zandobbio"; Gaetani 1970; Bersezio & Calcagni 1995). Here, the Hettangian succession is affected by a regional dolomitization and the transition from the Albenza to the Sedrina Limestone formations is characterized by the appearance of bedded, amalgamated and bioturbated grey dolomicrites with thin marly interlayers, passing upward to bedded dolostones/limestones, with small brachiopods (*Terebratulida*; Gaetani 1970) and scattered chert nodules.

Thickness

In the Como and Bergamasc Alps, the Albenza Fm. show few variations in thickness (from 90 to 120 m), however it is very reduced (from zero up to a few

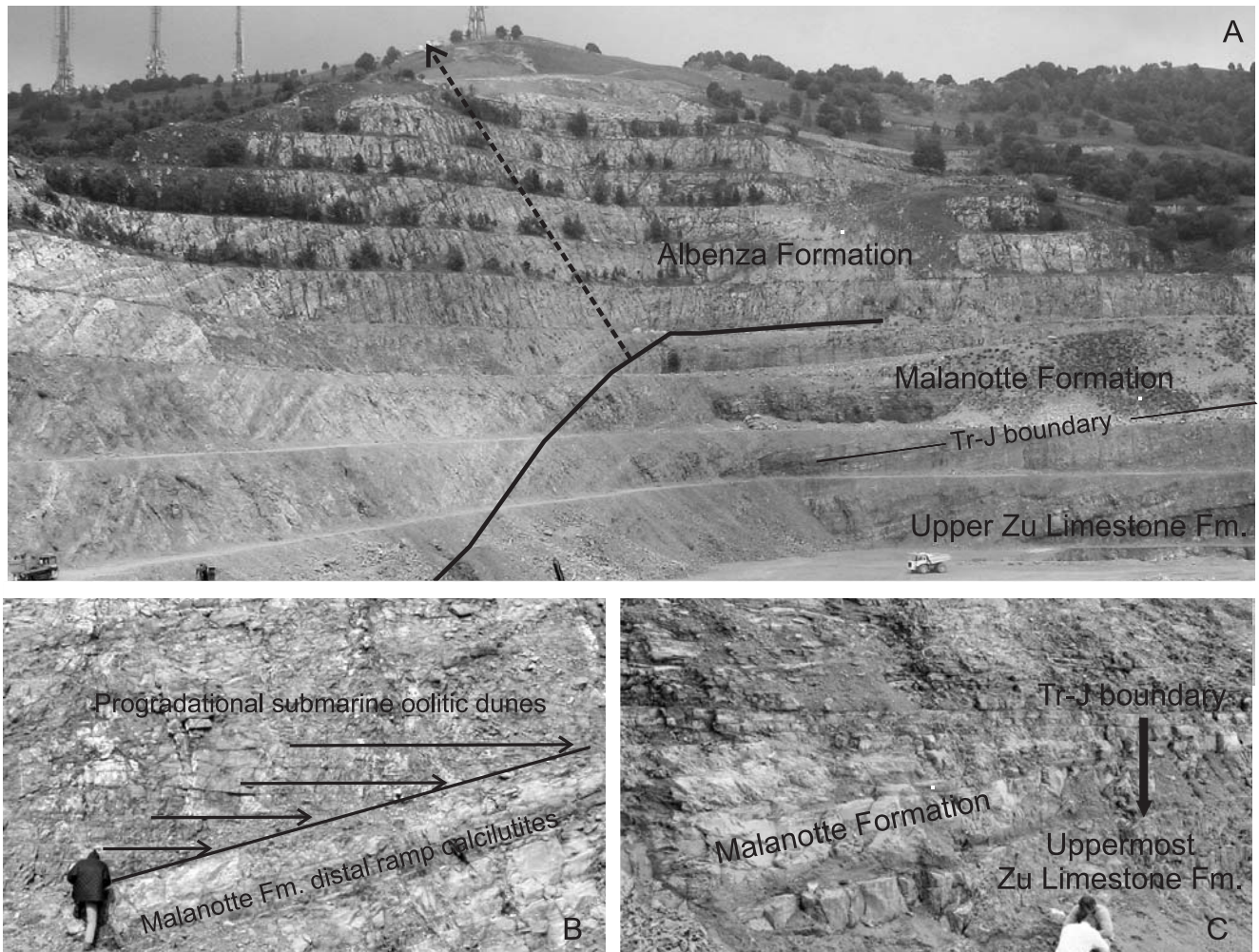


Fig. 3 - A) The Italcementi active quarry with the Albenza Fm. type section. B) The progradation of the oolitic calcarenites (Facies A2) on the uppermost Malanotte Formation. C) The Tr-J boundary succession in the lowermost Malanotte Fm.

tens of meters) close to the late Hettangian-early Sinemurian paleo-highs and their escarpments (Campo dei Fiori-Saltrio, Roncola-Mt. Botto, Mt. Cavallo-Lonno, Nese and Val Trompia; Wiedenmayer 1963; Bersezio et al. 1997; Vercesi & Bissolati 1985). Westward of the Arbostora paleo-high (western Lombardy – Varese area) the Albenza Fm. deposited and/or is now preserved under the late Hettangian unconformity only in the Mt. Nudo basin depocentre (30-40 m thick; Jadoul et al. 2005). The thickest successions are recognized in the depocentre of the Sinemurian-Pliensbachian subbasins (Ubiale: ~150 m; Tremezzo: ~80 m, Gnaccolini 1965; Iseo: ~200 m).

Facies analysis

Six lithofacies associations (A - F) have been distinguished in the shallow water grey to nut-brown carbonates of the Albenza Fm. The A, B and C are dominant, both for frequency and regional extension, often interbedded, and locally form shoaling upward cycles (Fig. 4).

Facies A: oolitic calcarenites of high energy depositional environments. Three sublithofacies (A1, A2, A3) have been distinguished (Fig. 5, 6).

A1: well sorted calcarenites with prevalent superficial ooids at submillimetric (often micritized) diameter, with frequent cross bedding and laminations at small-medium scale (current ripples and herringbones) separated by reactivation surfaces. Micritic intraclasts up to decimetre large are locally floating in a fine oolitic matrix. The stratification, often in lenticular shape, is not always visible due to the amalgamated beds with decimetre scale (5-30 cm).

A2: clinostatified, thin bedded, fine and well sorted oolitic calcarenites. They are locally present at the base of the Albenza Fm. laying with evident downlap geometry (up to 5-6 m thick) on the underlying Malanotte Fm. (Mt. Albenza type-area; Fig. 3). The foreset beds show a NE progradation. The microfacies are dominated almost exclusively by sorted and micritized small (< 1 mm) and superficial ooids (McRoberts 1994). Rare *Involutina liassica* (Jones) are recorded (Fig. 6).

The figure displays three stratigraphic columns representing different geological sections: Adrara section (5), Predore section (6), and Tavernola section (7). Each column is divided into stages (Rhaetian, Hettangian, Serravalloian, Serravallo Limestone) and formations (Zu Limestone, Malanotte Fm., Albenza Fm., Serravallo Limestone). The columns show facies associations (A1, A3, C, B, C/B, D, D/A3, E, C/A3) and detailed logs of sedimentary structures and biological fossils. A legend on the right defines the symbols used in the logs, and a 20m scale bar is provided at the bottom right.

Legend

- Micritic limestone
- Calcarenite
- Marly limestone
- Marl
- Dolomitic limestone
- Dolostone
- Parallel lamination
- Cross stratification/lamination
- Oblique stratification/lamination
- Herringbone
- Slumping
- Bioturbation
- Ooids
- Oncoid/coated grain
- Fe-hardground
- Erosional surface
- Intraformational breccia
- Fenestrae
- Stilolite
- Fault
- Paraconglomerates
- Chert nodules
- Tepee, liferitic breccia
- Normal grading
- Microbialitic coating
- Megalodontids
- Sponge spiculae
- Crinoids
- Brachiopods
- Bivalves
- Gastropods
- Corals
- Bioclasts
- Stromatolite
- 'Triasina hantkeni' assemblage
- Sample
- Diagenetic pseudomorphs



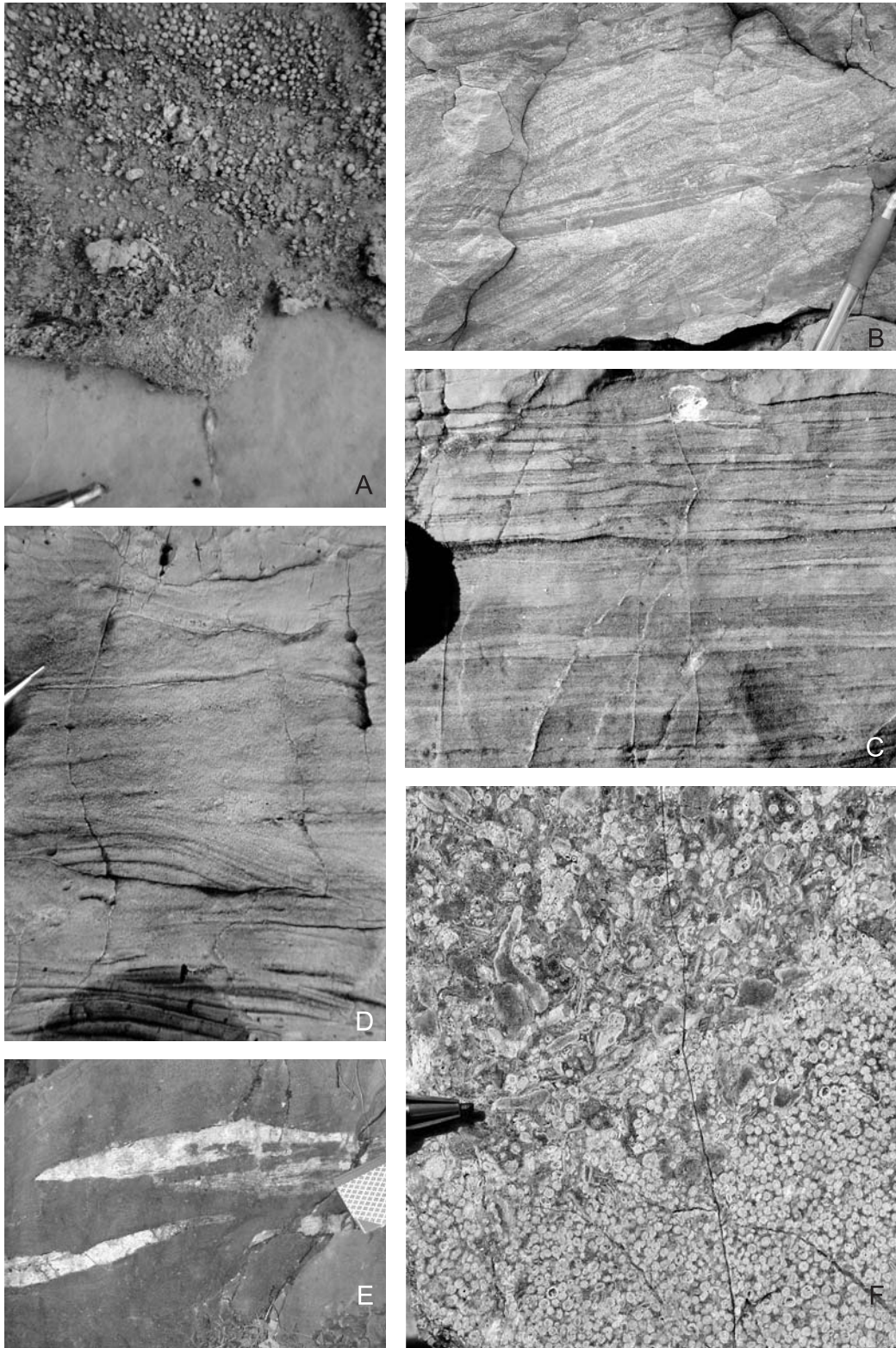


Fig. 5 - Albenza Formation macrofacies.
 A) Sharp erosional boundary between partially dolomitized oo-bioclasic grainstones (Facies B) and fine grained peloidal packstones (Facies C) (Italcementi inactive quarry section of Mt. Albenza).
 B) Cross laminated partially dolomitized fine grained oolitic grainstones/packstones with thin intercalations of peloidal packstones and microsparitic mudstones (Italcementi inactive quarry section of Mt. Albenza).
 C) Thin lenticular alternations of fine grained oolitic-peloidal packstones locally with smooth wave ripples (Facies C; Italcementi inactive quarry section of Mt. Albenza).
 D) Oolitic intraclastic grainstones to packstones with cross laminations (wave ripples) and erosional surfaces. Facies B, Italcementi inactive quarry section of Mt. Albenza.
 E) Massive oolitic intraclastic grainstones with white chert nodules. Basal sublithofacies A1 of Albenza Fm. (Adrara section).
 F) Oo-bioclasic grainstones passing upward to coarse packstones/grainstones and rudstones with aggregated grains and bioclasts with thick microbialitic coatings and micritization. Facies A and B. Lower Albenza Fm. (Italcementi inactive quarry section of Mt. Albenza).

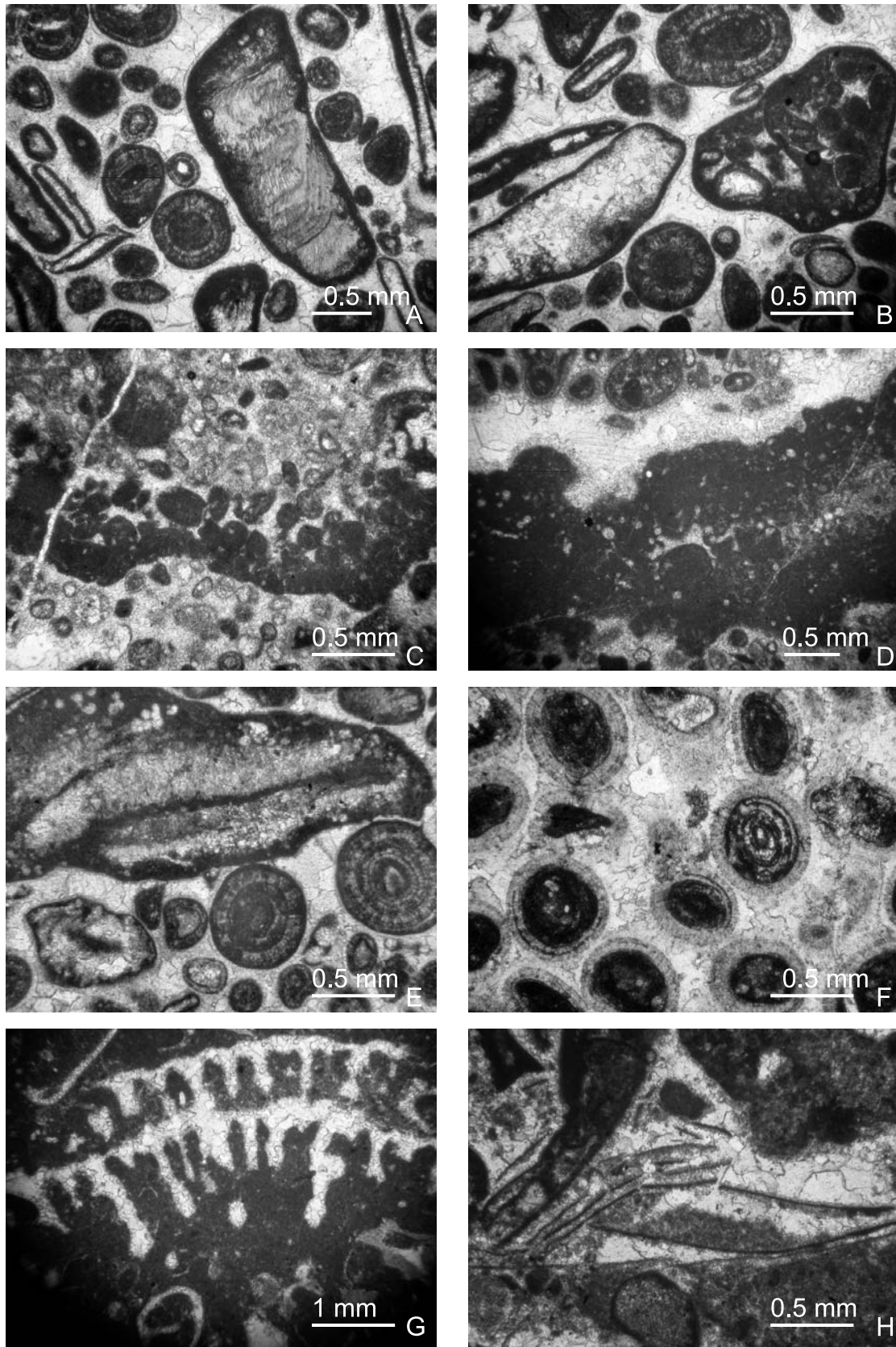


Fig. 6 - Albenza Formation microfacies.

A, B) Poorly sorted bioclastic oolitic grainstones with micritized thin coated brachiopods, pelecypods fragments and small radial concentric ooids and aggregated grains (cortoids). Lower Albenza Fm., Italcementi inactive quarry section of Mt. Albenza (sample J255bis). C, D) Typical microbialitic micritization, “grain aggregation” and enveloping of small ooids. Note the white spheres in the core of ooids, possibly represented Hexactinellida calcified siliceous sponges. Facies A3. Marginal facies of lower Albenza Fm. Italcementi inactive quarry section of Mt. Albenza (sample J258bis). E) Detail of bioclast microbialitic micritization and coating. *Involutina liassica* is present on the left side. Lower Albenza Fm. Italcementi inactive quarry section of Mt. Albenza (sample J255). F) Well sorted oolitic grainstones. The nucleus of small ooids consists of micritized of microbialitic fragments as in Fig. B. Sub-lithofacies A2. Clinofoms of submarine dunes of the basal Albenza Fm. Italcementi inactive quarry section of Mt. Albenza (sample J251). G) Bioclastic packstones with a coral fragment (Facies B). Uppermost Albenza Fm. Italcementi inactive quarry section of Mt. Albenza (sample J268). H) Bio-intraclastic grainstones/packstones with thin shell pelecypods and dissolution cavities. Calcarenitic intercalation in the upper Malanotte Fm. (sample J244). Italcementi inactive quarry section of Mt. Albenza.

A3: variously sorted oo-bio intraclastic calcarenites represented by grainstones and subordinated packstones. Grains are often reworked and consist of mainly superficial ooids, microbial coated grains, oncoids, aggregate grains (lumps and subordinated grapestones) and bioclasts (echinoids/crinoids, brachiopods, pelecypods, gastropods, rare dasycladaceans and bryozoans). Lime mudstone intraclasts and lithoclasts are locally frequent. Grains, in particular bioclasts and ooids, show frequently superficial micritization and microsparitization processes. The superficial ooids have frequently the nucleus constitute by micritic mucilaginous microbial fragments with calcitic spheres similar to Rhaxellid sponge microclere fragments (Haslett 1992; Schlagintweit et al. 2007; Fig. 6) and other microbial grains and coating fragments. The beds are frequently amalgamated with decimetre thickness with local erosional surface. Cross and oblique stratifications/laminations are frequent (ripples, submarine dunes, herringbones) and are often interbedded with facies C, constituting decametre thick horizons (Fig. 4, 5). The paleocurrent analysis (Mt. Albenza sections) shows a bimodal distribution, typical of the bars in the tidal channel, while the North/North-eastward direction is dominant. In the Tavernola section, at the base of the unit, A3 is intercalated with the facies C (Fig. 4) and represents the top of thickening and shoaling upward (decametre thick) cycles. Bioclasts are mainly present in the lowermost and uppermost parts of the cycles and consist of echinodermata fragments (echinoids, ophiurae and crinoids) irregular microbial coatings (in particular *Lithocodium* sp., Cherchi & Schroeder 2005), disputed alga or microproblematica (*Thaumatoporella parvovesiculifera*), locally bryozoans and rare solitary corals and small benthic foraminifers (Textularidae and Valvulinidae).

Facies B: well bedded peloidal fine calcarenites and calcisiltites, grey to light nut-brown in colour. They are mainly peloidal packstones associated with small intraclasts and micritized ooids (bahamites). Fecal pellets (*Parafavreina* sp. at the top of the Albenza and at the base of the Sedrina Limestone formations), coated grains/small superficial oncoids and microbialitic aggregates (Fig. 6) are occasionally frequent. Small skeletal grains (mainly molluscs) are rare and strongly micritized and/or coated by microbialites. Parallel laminations (not due to tractive supercritical currents) and subordinated bioturbations are also present. In the Tavernola, Sasso Malascarpa and Albenza sections (centimetres up to decimetres) coarse-grained, oncoidal sorted packstones/grainstones pockets with erosional base (subfacies A3) are intercalated (Fig. 4). Bioturbated intra-bio-oncoidal floatstones with matrix support are locally interbedded (Val Brembana and Lake Iseo areas). Microfacies, often recrystallized to microsparites, con-

tain small bivalves, gastropods, echinoids and ostracods. Solenoporaceae and lagenids are more diffused in the upper part of the formation and at the transition with the Sedrina Limestone.

Facies C: bedded limestones represented by wackestones and lime mudstones (light nut-brown to grey, rarely dark grey in colour) with frequent parallel laminations (mainly due to decantation and microbial activity). In the Albenza sections (Fig. 4), this facies, associated with fine peloidal packstones of facies B, is the more frequent and characteristic of the middle part of the succession, while in other sections from the Como to the Iseo lakes (cf. sections described by Gnaccolini 1965 and McRoberts 1994) is dominant in the lower and upper part of the unit.

Facies C is also common in the lower Sedrina Limestone with more diffuse open marine microbial laminations, foraminifers (nodosaridae, *Earlandia* sp.) and echinoids.

Facies D: dolomitized carbonates represented by facies B, C and A1 locally selectively dolomitized. Microfacies are represented by unimodal and polymodal subhedral planar crystals and anhedral to euhedral dolomite which replace grains and fill fractures and cavities. The dolomite bodies constitute strata-bound lenses and tongues with irregular boundaries, from whitish to brownish in the more altered outcrops. The dolomitization front consists of decimetre transition permeated by very small dolomite rhombs. The oo-bioclastic dolostones show strong recrystallization where the ooids are the first to be dolomitized.

In some sectors of central Lombardy (Zandobbio, eastern side of Lake Iseo, Lake Garda and Val Giudicarie) the entire earliest Jurassic platform is dolomitized ("Dolomia di Zandobbio" of the Jurassic high of Trescore-Zandobbio; Gaetani 1970; Bersezio & Calcagni 1995; and "Dolomia di Dosso della Torta"; Picotti 2003).

The thickness of the Dolomia di Zandobbio is not estimable because of the lower boundary with the underlying Zu Limestone Fm. is not cropping out but it is reasonably more than 100 m thick. Stratigraphic observations in Zandobbio quarries show prevalent facies B and C strongly recrystallized and fractured. At regional scale the dolomitized facies, subordinated to the calcareous one, are more common around the Early Jurassic carbonate structural highs and paleofaults (Ronchi et al. in prep.).

Facies E: well bedded limestones (grey to nut-brown in colour) with laminitic facies, fenestrae and rarely loferitic intraclastic breccias and small tepee. It is often associated with C and is characteristic of the upper unit in few sectors of carbonate structural highs (e.g. Zandobbio paleohigh; Bersezio & Calcagni 1995).

Microfacies are represented by microbialitic microalgal bindstones intercalated with intraclastic microsparitic packstones with desiccation and dissolution cavities or lithoclastic rudstones. In the uppermost Dolomia di Zandobbio a particular facies is intercalated (E1). It consists of dark to light reddish marly dolostones with variable (decimetre up to metre) thickness, irregular geometry and not well defined boundaries. Facies E1 is also characterized by breccia horizons with geodic cavities, and beds with pseudo-tepee deformations (Bersezio & Calcagni 1995).

Facies F: thick bedded oncoidal limestones represented by wackestones-packstones with coated grains, oncoids and lumps (millimetre up to centimetre scale). They characterize the eastwards transition with the Corna Fm. This facies is subordinated to the previous ones and is located, almost exclusively, in the upper Albenza Fm. close to the Lake Iseo. On the contrary, in the Corna Fm. it is very common in subtidal interval of the peritidal cycles of the Botticino succession.

Microfacies are packstones with oncoids, fecal pellets (*Parafavreina* sp.), *Thaumatoporella parvovesiculifera*, Nodosariidae, sessil foraminifers and bioclasts of echinoderms.

Discussion

A) Biostratigraphic constraints

As is the case for the Albenza Fm., the lack of biotic diversity following the Tr-J extinction events hampers the accurate dating of low-latitude carbonate platforms dominating the southern and northern margins and microplates of western Tethys during the Early Jurassic (BauDagher-Fadel & Bosence 2007). However, some restrictions may be placed for the Albenza Fm. In fact, it is sandwiched between two Hettangian formations (Malanotte Fm., Galli et al. 2007 and Sedrina Limestone Fm., Francani 1967) even if ammonite zones are missing. Based on the palynological change from the Zu Limestone to the Malanotte formations and on the C_{carb} -isotope record compared with that of other worldwide sections having ammonite constraints, the Rhaetian-Hettangian transition has been located in the lowermost Malanotte Fm. (Cirilli et al. 2000; Galli et al. 2005, 2007). Galli et al. (2007) argued that the biotic crisis at the top of the Zu Limestone Fm. represents the local expression of the globally identified end-Triassic extinction event and there is no parallel crisis of the microflora. Palynological investigation carried out in the Albenza Fm. (Ghisalberti section; Fig. 4) testifies very poor organic matter and almost the total absence of palynomorphs possibly due to very oxygenated depositional environment.

Gaetani (1970) assigned the age of early Hettangian to the lower assemblage-zone of the Sedrina Limestone roughly corresponding to the "Grenzbivalvenbank" of Kronecker (1910) containing bivalves and sub-ordinated gastropods and corals.

Taking into account the presence of *Involuntina liassica* (Jones) in the basal oolitic calcarenites as well as that of other foraminifers (such as Textularidae and Valvulinidae), we retain possible to locate the Albenza Fm. in the *Siphovavulina gibraltarensis* biozone of BauDagher-Fadel & Bosence (2007) and, in particular, the age of the formation may be referred to the late Early Hettangian.

The Hettangian–Sinemurian boundary may be located in the cherty limestones of the lowermost Moltrasio Limestone (see discussion in Gaetani 1970). To summarize, the whole Hettangian succession is composed by the Malanotte, Albenza, Sedrina and the basal Moltrasio formations. This stratigraphic setting has been partially misunderstood by van de Schootbrugge et al. (2008).

B) Facies interpretation and stratigraphic evolution

It is possible to retain that the onset of the Albenza platform progradation on the Malanotte ramp micritic limestones has been quite fast as testified by the constant thickness, geometry and stratigraphic distribution of both the basal lithofacies A (10 to 20 meter thick; Fig. 4) and the geometry of the underlying Malanotte ramp depositional system (Galli et al. 2007). This progradation may be related to a reduced accommodation space on the platform and to the presence of a not very deep environments. The basal A2 clinofolds with the evident lateral NE migrations of the oolitic sand bars are coherent with the late Rhaetian-Hettangian paleogeographic reconstruction with the more open and outer ramp facies (Burchette & Wright 1992) in the lower Val Brembana (corresponding to the Ubiale basin of Bersezio et al. 1997). A similar N-NE deepening trend is also observable by the facies correlation between Zandobbio, Predore and Tavernola sections. The relative constant thickness of the Albenza unit in central Lombardy seems to confirm the fast platform progradation at the base and the synchronous drowning at the top. The timing of these events is not quantifiable due to the scarce biostratigraphic constraints.

The oolitic calcarenites (lithofacies A; Fig. 6), mainly abundant at the base and locally at the top of the Albenza Fm. (Fig. 4), may represent marginal shoals of proximal ramp facies. The absence of biotically induced margins (Schlager 2000) may be related to the (biocalcification) Tr-J crisis (Galli et al. 2005) and to a paleoenvironment control (leeward Bahamian type margin not facing intraplatform basin). The lack of reefal

biota has been replaced by the microbialitic activity, very pervasive in these well oxygenated environments (e.g. Riding 2000; Immenhauser et al. 2001; see discussion in E).

The intercalations of facies B with A, and progressively with C are typical of the middle part of the Albenza Fm. succession and represent the transition to inner platform environments (lagoons, channels and ebb-tidal deltas). The decameter thick shoaling upward trend (lithofacies A, B, and C organized in fifth to fourth hierarchic order cycles), may be related to the local carbonate production dynamics and to the different accommodation spaces of the onshore platform-ramp depositional systems (autocyclic mechanism; Ginsburg 1971; Hardie & Shinn 1986).

The facies C and E with subordinated B intercalations are characteristic of low energy, more protected environments of the inner platform. Peloidal rich facies (C) may be also typical of the more subsiding and relatively deep sectors (e.g. Ghisalberti, Adrara, and Tavernola sections; Fig. 4). The peloid origin may be due to microbial activity, micritization and also local precipitation (for discussion see Flügel 2004).

The lithofacies E and F are very rare in the Albenza succession but are dominant in the middle-upper Corna Fm. while in central Lombardy the facies F is also well represented in the lower and locally the upper Sedrina Limestone.

The sublithofacies E1 of present study, has been described and interpreted by Bersezio & Calcagni (1995), as the supratidal horizons, with *fenestrae* and tepee structures, of shallowing upward peritidal cycles of an inner carbonate platform. In our opinion lithofacies E1 has been strongly modified by diagenesis and in particular by burial dissolution and dolomitization processes.

The bedded, open subtidal limestones of the overlying lower Sedrina Limestone are here interpreted as deposited in a middle-outer shelf ramp, whose proximal depositional ramp was represented by the Corna shallow water carbonates. This Hettangian stratigraphic-paleogeographic evolution could be explained with a rapid transgression and drowning of the Albenza platform in central Lombardy which was not able, with the only oolitic supply, to compensate the sea level rise.

C) Dolomitization

The diagenetic facies D, grouping all the dolomitized Hettangian carbonates (e.g. Zandobbio succession and several intercalations of Albenza and Iseo sections), has been related to different late to early diagenetic processes connected with the evolution of the Late Cretaceous-Tertiary South Alpine foreland basin (Ronchi et al., in prep).

The 'Dosso della Torta member' (Picotti 2003) and the 'Dolomia di Zandobbio' (Gaetani 1970; Bersezio & Calcagni 1995) may be considered a regional dolomitized members of the Albenza or Corna formations (Fig. 7). In particular, the lithozone DZ1 of the "Dolomia di Zandobbio" (Bersezio & Calcagni 1995) corresponds with the Albenza Fm. The stratigraphic correlations and the nomenclature of the eastern Lombardy formations (Albenza and Corna), and the informal units of 'Pichea' and 'Dosso della Torta' members (Castellarin 1972; Picotti 2003) should be studied more in detail.

D) Depositional model

McRoberts (1994) proposes a depositional model based on microfacies analysis on the same stratigraphic sections of present paper. That model consists of "broad interplatform lagoon or a gently dipping homoclinal ramp with dominant environments including supratidal, intertidal tidal flat, shoal bank, subtidal restricted lagoon, subtidal open lagoon or shelf and minimal topographic relief". The carbonate facies described by the Author are coherent with a carbonate sedimentation in arid climate lacking terrestrial input (Irwin 1965). Such facies may be present in several modern carbonate environments in arid or semiarid region (e.g. Persian Gulf, western Australian and Southern Bahamian platforms).

Our macro and micro facies interpretation is substantially concordant with the regional setting described by McRoberts (1994), but some differences need to be discussed. In the Iseo sections (Fig. 4; Predore and Tavernola named by McRoberts respectively as Pozzo Glaciale and Portirone sections) our facies analysis highlights that the intertidal-supratidal carbonates are less abundant and the peritidal cycles are more frequent in the southern sectors (Predore and Zandobbio successions; Fig. 7) while more subtidal successions are present in the depocentre of the subsequent Early Jurassic troughs (e.g. Tavernola and Ghisalberti). Furthermore, McRoberts depicts the oolitic shoals as adjacent to intertidal muds or within restricted lagoon, while, in our opinion, as aforementioned, the basal shoals highlight a proximal ramp progradation on a more open environment (Malanotte Fm.).

Our depositional model for the Albenza Fm. fits more with a leeward Bahamian-type environment without any margin reefs facing deep water environments. The crinoids abundance and the absence of hypersalinity indicators suggest prevalent normal marine waters. This setting was possibly controlled by monsoonal climate as suggested by the presence of paleosols in the upper Zandobbio succession (Bersezio & Calcagni 1995) and 'terra rossa' paleosols, plant fragments and pedogenetic carbonate breccias in the Varesotto structural high (Lualdi 1999; Jadoul et al. 2005). This recon-

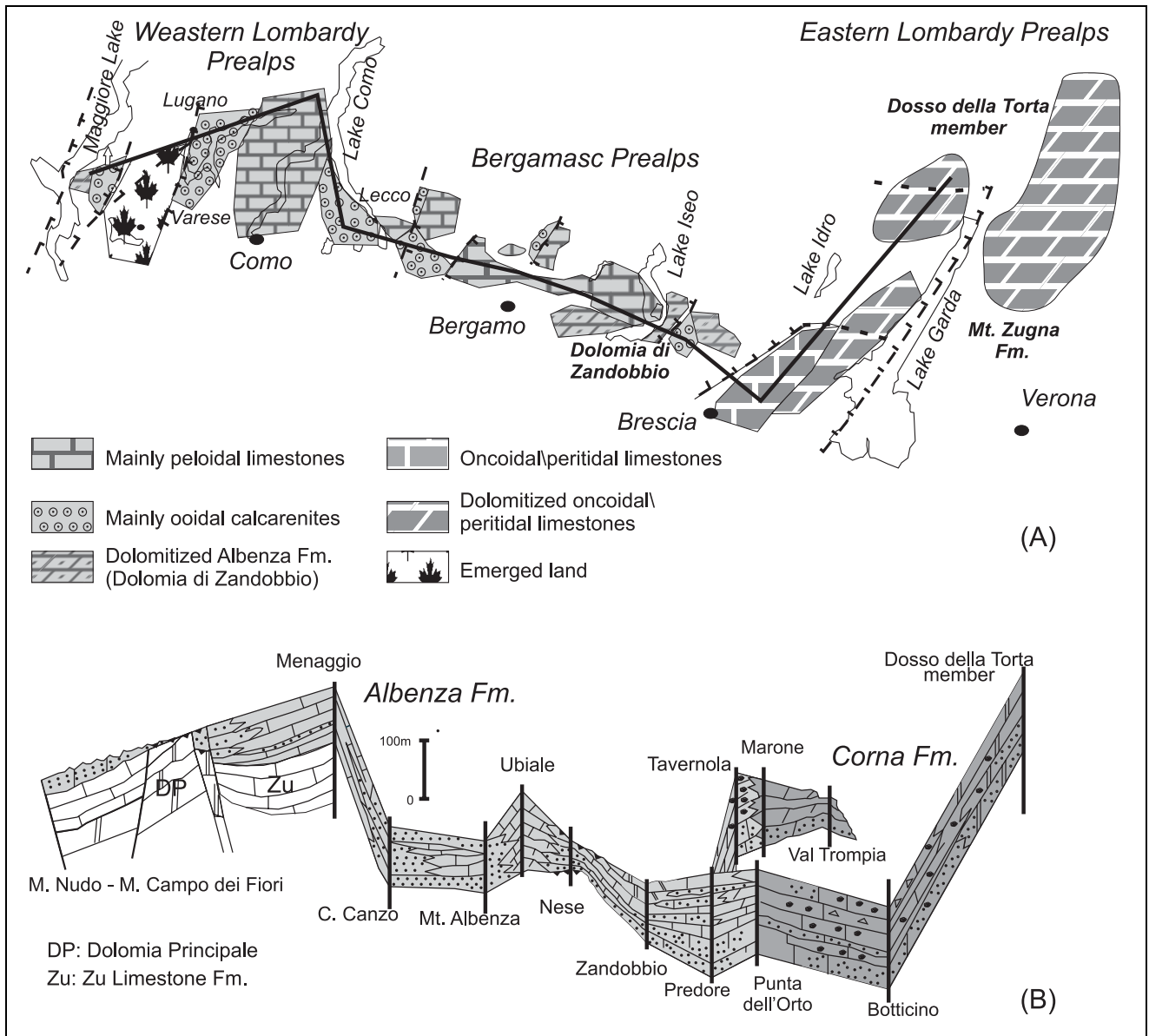


Fig. 7 - Late Triassic-Early Jurassic paleogeographic map (A) and stratigraphic reconstruction (B) of the Lombardy Basin (after Jadoul et al 2005).

struction could be also supported by the finding, in the basal ‘Saltrio Beds’ of Varesotto, of a floating carcass of a dinosaur (‘Saltriosaur’; Dal Sasso 2003) as well as dinosaur track megasite in the lower Hettangian Mt. Zugna Formation of the Calcarei Grigi in Dolomite (Avanzini et al. 2007), needing for its survival of wide emerged area, populated also by herbivorous.

E) The early Hettangian “cyanobacterial calcification event” and the carbonate factory

The Albenza Fm. flourishes after the Tr-J biotic crisis which is everywhere associated with the disappearance or strong reduction of biocalcifying organisms (cf. Galli et al. 2005). The scenario is represented by reef bioconstructions drastically reduced (Wood 1999) and replaced by oo-bioclasic sandy margins stabilised by

microbialitic and mucilaginous glue possibly derived from cyanobacteria (Fig. 6). In shallow-water oxygenated environments, such as in the marginal oolitic shoals of the Albenza platform, cyanobacteria can thrive in the water column and at the sediment-water interface (Riding 2000). Various metabolic processes, such as photosynthetic uptake of CO₂ and/or HCO₃⁻ by cyanobacteria, can increase alkalinity and stimulate carbonate precipitation. Furthermore, extracellular polymeric substances, widely produce by microbes (Decho 1990) for attachment and protection are important in providing nucleation sites and facilitating sediment trapping (Costerton et al. 1978; Christense & Characklis 1990; Riding 2000). The effect of microbial on precipitation and on localization of carbonate sediments (Fenchel & Finaly 1995; Banfield & Nealson,

1997; Ehrlich, 1998) are noticeable in a wide variety of depositional settings as well as other coatings, grains and matrices within sediments (Nealson 1997; Riding & Awramick 2000).

The unusual abundance of ooids and marine cements in the early Hettangian high energy proximal ramp could reflect temporal variation in the saturation state of seawater (Riding 1991) possibly due to marine calcified cyanobacteria (*Lithocodium* and other problematica) and could represent a further record of the cyanobacterial calcification events (CCEs; Riding 1992) recognized also in the Cambrian to Early Ordovician, Late Devonian and Permian-Triassic (e.g. Riding 2000). If CCEs represent periods of elevated carbonate saturation, they may correspond with one or more of the following: high global temperature (which enhances precipitation rate); low sea-level and low skeletal abundance (which increase availability of calcium and bicarbonate) and development of alkalinity pumps from stratified basins (see Riding 1993; 2000). In the early Hettangian, the first two factors are coherent with our depositional model, while the alkalinity may be strictly related to the CAMP (Central Atlantic Magmatic Province) volcanism (Marzoli et al. 1999). However, the meaning of the pure chemocalcification as responsible of the oolitic blooms is still open. May it testify the renewed equilibrium of the chemical-physical parameters of the atmosphere-hydrosphere system after the Tr-J crisis?

The large positive C-isotope excursion observed in bulk carbonate of the Hettangian Albenza formation (Adrara section; van de Schootbrugge et al. 2008) has been related to elevated $p\text{CO}_2$, likely resulting from CAMP eruptions. A return to background carbonate carbon isotope values seems to coincide with a resurgence of shelly fossils during the middle to late Hettangian and likely marks a decrease in $p\text{CO}_2$.

Few data are available on the efficiency of the early Hettangian carbonate factories respect to the Rhaetian ones. Beerling & Berner (2002) calculated a huge C cycle perturbation across the Tr-J boundary, involving the release of ~8000-9000 Gt as CO_2 during the CAMP basaltic eruption and ~5000 Gt C as methane. Elevated atmospheric CO_2 levels could have caused the acidification of the water column and subsequently hampered the early Hettangian carbonate factory production.

Based on the thickness of the Hettangian formations (Malanotte, Albenza, Sedrina and lowermost Moltrasio formations, with an average of 225-250 m) and the duration of the Hettangian stage, sedimentation rate values ranging from 60 to 125m/Ma have been obtained considering a long (~3.8 Ma; Gradstein 2004) or a short Hettangian (~2 Ma; Schaltegger et al. 2008). These values are very reduced with respect

to the sedimentation rates predicted for the short (250-300 m/Ma) or long Rhaetian (125-150 m/Ma). In particular, the abundance of strongly micritized and coating bioclasts and the intense micritization of the ooids could testify that the early Hettangian carbonate factory, even if developed in favourable environmental conditions (T-factory *sensu* Schlager 2003), in a wide portion of the Western Tethyan realm (similar to the Great Bahama Bank, today), was not particularly productive. However, the scarcely diversified lithofacies association led nevertheless to the rapid progradation and to good efficiency and equilibrium, despite the rare biocalcifying organisms.

The progressive crisis and the rapid retrogradation of the Albenza platform may have been conditioned by two main factors: the consistent fragmentation with different subsidence rates of the Southern Alps passive margin (Bertotti et al. 1993; Sarti et al. 1993) and the scarcely efficiency of the Hettangian carbonate system lacking of bioconstructed margins adapted to compensate the fast sea level rises during the transgressive trends ("catch up" phase *sensu* Kendall & Schlager 1981). Because very sensitive to the bathymetric variations, the oolitic factory do not has presented the necessary versatility respect to the eustatic rises. Also a different accommodation rates could have played a primary role. Other mechanism have been suggested for Early Jurassic carbonate factory drowned during the Sinemurian. Passeri & Venturi (2005), for example, indicate that the causes of the drowning of the Calcare Massiccio platform are mainly related to ecological change connected to the progressive opening of seaways between the former La Spezia basin and the central Atlantic basin. The influx of the Atlantic water should have caused a drop in salinity and temperatures and an increase in the biological productivity, hampering the production both of ooids and biogenic carbonates.

Conclusion

In this paper the historical name of "Conchodon Dolomite", not adequate for the absence of *Conchodon* and for the mainly calcareous lithology, has been replaced with Albenza Formation of Hettangian age. Preserving until now the original name has evidenced the lithological incongruence of the name "Conchodon Dolomite" which present a complete dolomitization on a few southern and eastern Liassic structural highs or close to paleofaults. We consider the 'Dosso della Torta member' and the 'Dolomia di Zandobbio' (Gaetani 1970; Bersezio & Calcagni 1995; Picotti 2003) as correlative members of the Albenza and/or

Corna formations diversified only by the dolomitization (Fig. 7).

The depositional model depicted for the Albenza shallow water carbonates fits with a leeward Great Bahama Bank-type environments, without any margin bioconstructions adjacent to intraplatform basins. The unusual abundance of ooids and early marine cementation in the basal high energy proximal ramp calcarenites could testify temporal variation in the CaCO_3 saturation state of seawater possibly due to marine calcified cyanobacteria. The absence of biotic- margins related to the (biocalcification) Tr-J crisis and the concomitant tectonic fragmentation, with different subsidence rates of the western Southern Alps passive margin, conditioned the drowning and the eastward fast retrogradation of the Albenza platform.

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Appendix

The type section of the Albenza Fm. is located in the Italcementi active quarry (Fig. 2, 8) of Mt. Albenza (1240-1350 m in altitude).

Description of stratigraphic horizons (drowned in Fig. 4) from the bottom:

- 1) Bedded dark grey calcilutites with thin marly intercalations, bioturbated at the top of the beds (uppermost Malanotte Fm.; 2.5 m).
- 2) Thin bedded clinostatified dark grey fine oolitic calcarenites at the base of the Albenza Formation (base of Albenza Fm.; 2.2-3.5 m).
- 3) Grey-nut brown fine to coarse calcarenites in amalgamated beds (20 to 70 cm thick) (11 m).
- 4) Oo-bio-intraclastic calcarenites with micritized lithoclasts, small oncoids, coated grains, superficial ooids and bioturbations. Bioclasts are mainly bivalves (7.5 m).
- 5) Alternations of well bedded (10-40 cm thick) oolitic calcarenites (grainstones), bioturbated at the base, and calcilutites-calcisiltites (lime mudstones-fine packstones). The oolitic calcarenites show oblique and parallel laminations, basal erosional surfaces, and local selective dolomitization. In the middle-upper part, fine to coarse oolitic calcarenites (grainstones) in lenticular beds with cross stratification (tidal channels). The trend is shoaling upward (15 m).
- 6) Thin bedded dark grey calcisiltites (packstones) in discontinuity on the underlying level. In the upper part oncoidal calcilutites-calcisiltites (mudstones-packstones) with rare cross and oblique laminations (2.8 m).
- 7) Bedded dark grey fine calcilutites-calcisiltites with parallel laminations (2.5 m).
- 8) Light grey calcarenites with cross laminations at small scale, herringbones and cross stratification with erosional base (tidal channel) (0.75 m).
- 9) Bank of light grey fine calcilutites (mudstones to fine peloidal packstones) (3.1 m).

10) Bank of light grey, fine calcarenites with cross laminations and partial dolomitization. Lenticular beds with erosional base are present (3.5-5 m).

11) Fine calcilutites with fine to medium grey to nut-brown dolomitized calcarenitic intercalations (5 m).

12) Grey fine calcilutites with whitish dolomitized lenses. Rare beds with parallel laminations (16 m).

13) Grey calcisiltites alternated with fine calcarenites with cross lamination at small scale. Dolomitized banks are present at the base and at the top of the horizons (4.6-5 m).

14) Fine grey, calcarenites in strata-bound partially dolomitized lenses with irregular boundaries alternated with well bedded calcilutites and calcisiltites (recrystallized mudstones and fine peloidal packstones) (7.5 m).

15) Three lenticular strata-bound horizons of dolostones with fine calcilutites intercalations recrystallized in microsparites (7.5-8.0 m).

16) Calcilutites intercalated with calcisiltites (mudstones to fine peloidal packstones) with parallel laminations (5.5 m).

17) Fine grey calcilutites and calcisiltites (mudstones to fine peloidal intraclastic packstones) overlying the basal dolomitized lens, with fenestrae prism cracks, flat dolomitized pebbles, and small tepee. In the upper part thin marly limestones brown-ochre thin interlayers (2-2.5 m).

18) Thin alternations of light grey calcilutites and fine calcarenites-calcisiltites thinly laminated at the base. In the upper part light nut-brown calcilutites with thin calcisiltites intercalations and stilolites (5-6 m).

19) Fine to medium calcarenites with cross bedding characterized by oolitic intercalations and dolomitized lenses (eastern quarry section; top of Albenza Fm.; 7.5 m).

20) Well bedded grey calcilutites and subordinated calcisiltites with very thin ochre marly calcilutites (eastern quarry section; base of Sedrina Limestone Fm.).

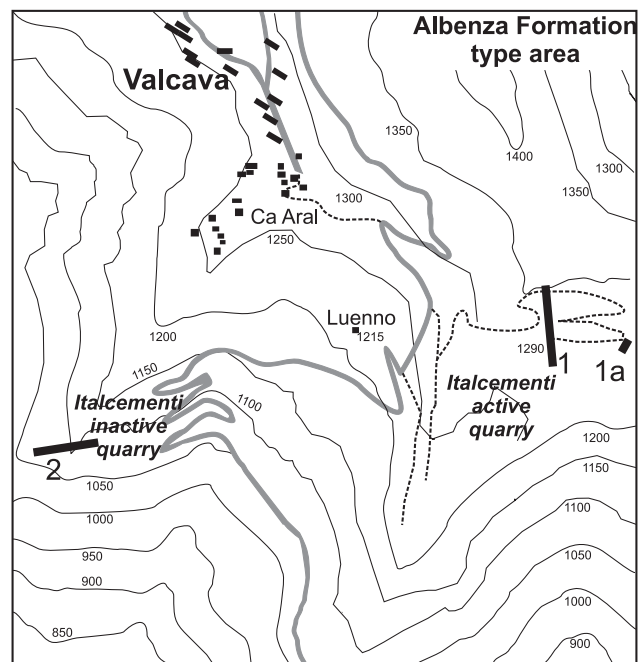


Fig. 8 - Type area of Albenza Fm. with the location of the Italcementi active quarry (1), Italcementi active (eastern) quarry (1a) and Italcementi inactive quarry (2) sections.

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