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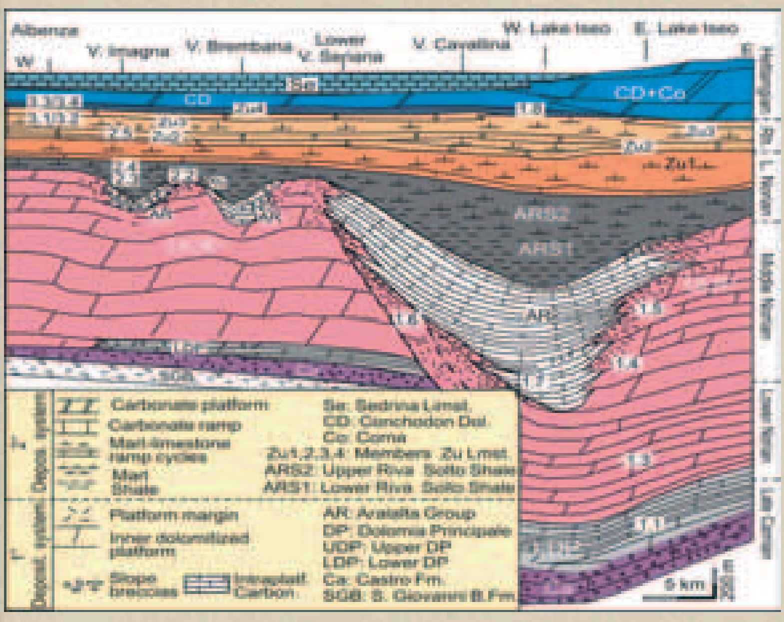
32nd INTERNATIONAL GEOLOGICAL CONGRESS

THE LATE TRIASSIC-EARLY JURASSIC OF THE LOMBARDY BASIN: STRATIGRAPHY, PALAEOGEOGRAPHY AND PALAEONTOLOGY



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Post-Congress **P68**

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THE LATE TRIASSIC-EARLY JURASSIC OF THE LOMBARDY BASIN: STRATIGRAPHY, PALAEOGEOGRAPHY AND PALAEONTOLOGY

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Front Cover:
Late Carnian-Hettangian stratigraphic setting of the Bergamasc Alps

Leader: F. Jadoul
Associate Leaders: M.T. Galli, F. Berra, S. Cirilli, P. Ronchi, A. Paganoni

1. Introduction

In the course of this three-day field trip you will become familiar with the main factors controlling the stratigraphic, palaeoenvironmental and palaeogeographic evolution of the Upper Triassic-lowest Jurassic succession in the Western Southern Alps of Central Lombardy (Figure 1).
The sedimentary succession records the earliest stages of the evolution of a passive margin, dominated by synsedimentary tectonic, that will lead to the Liassic opening of the Jurassic Alpine Tethys. The following (late Cretaceous-Tertiary) closure of this seaway led to the folding and overthrusting of these successions, that are now preserved in different tectonic units that can generally be restored in order to reconstruct their original palaeogeographic relationships.

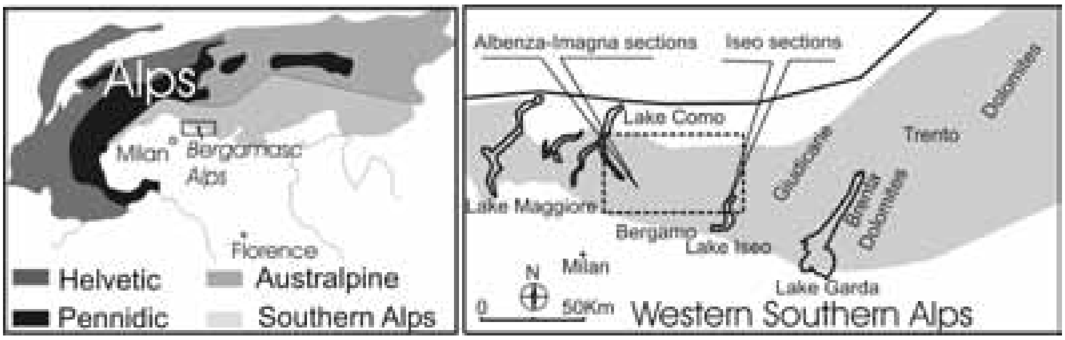

Figure 1 - Structural Alpine Domains and geographical location of the Bergamasc Alps.

The successions that will be observed in the excursion belong to a slightly deformed portion of the Alpine chain, and give the opportunity to study the syndepositional tectonics and the sedimentological and diagenetic processes that affected the Upper Triassic-lowest Liassic rocks of this portion of the Lombardy Basin.

2. Regional geologic setting: stratigraphy and palaeogeography

The upper Carnian to Rhaetian succession of the Lombardian Southern Alps is organized in two superimposed depositional systems and outcrops along the E-W. The thick Upper Triassic succession of Lombardy is bordered by less subsiding structural highs to the S (subsurface data; Errico et al., 1979), the Trento Platform to the E and the Varese High to the W (Figure 2). The uppermost Carnian-Rhaetian succession exhibits variable thickness (from 500 to 4000 m; Assereto and Casati, 1965), related to sedimentation controlled by transtensive tectonics (Norian asymmetric rifting; Jadoul et al., 1992).
The lower depositional system (uppermost Carnian to middle Norian) lies on shallow water carbonates, evaporites and siliciclastics (sabkha facies) of the S. Giovanni Bianco Fm. and is represented by the shallow water limestones and breccias of the Castro Fm. covered by the thick carbonate platform of the Dolomia Principale (DP) and coeval basin facies (Aralalta Group). The upper depositional system (Late Norian-Hettangian) consists of subtidal mixed shale-carbonate units Riva di Solto Shale (ARS) and Zu Limestone (Zu) passing to the Hettangian carbonate platform Conchodon Dolomite (CD). The boundary between the two systems is well-marked and denotes a sharp change in the sedimentological regime. Relationships and thickness of the whole Late Triassic succession are shown in Figure 2; the palynological biostratigraphy is presented in Figure 3.

2.1. The upper Carnian-middle Norian dolomitized carbonate platform (Dolomia Principale) and the intraplatform basin carbonates (Aralalta Group).

The DP of the western Southern Alps is up to reaches its maximum thickness (about 2000 m) on the eastern side of Lake Iseo. In the visited area, the DP deposition started probably during the latest Carnian in restricted shallow water basins, lagoons and tidal flats, as recorded by 200-300 m thick, dark bedded dolomites with intraformational breccias and microbialites (Lower Member of DP; Stop1.1).
These subtidal facies are overlain by stacked

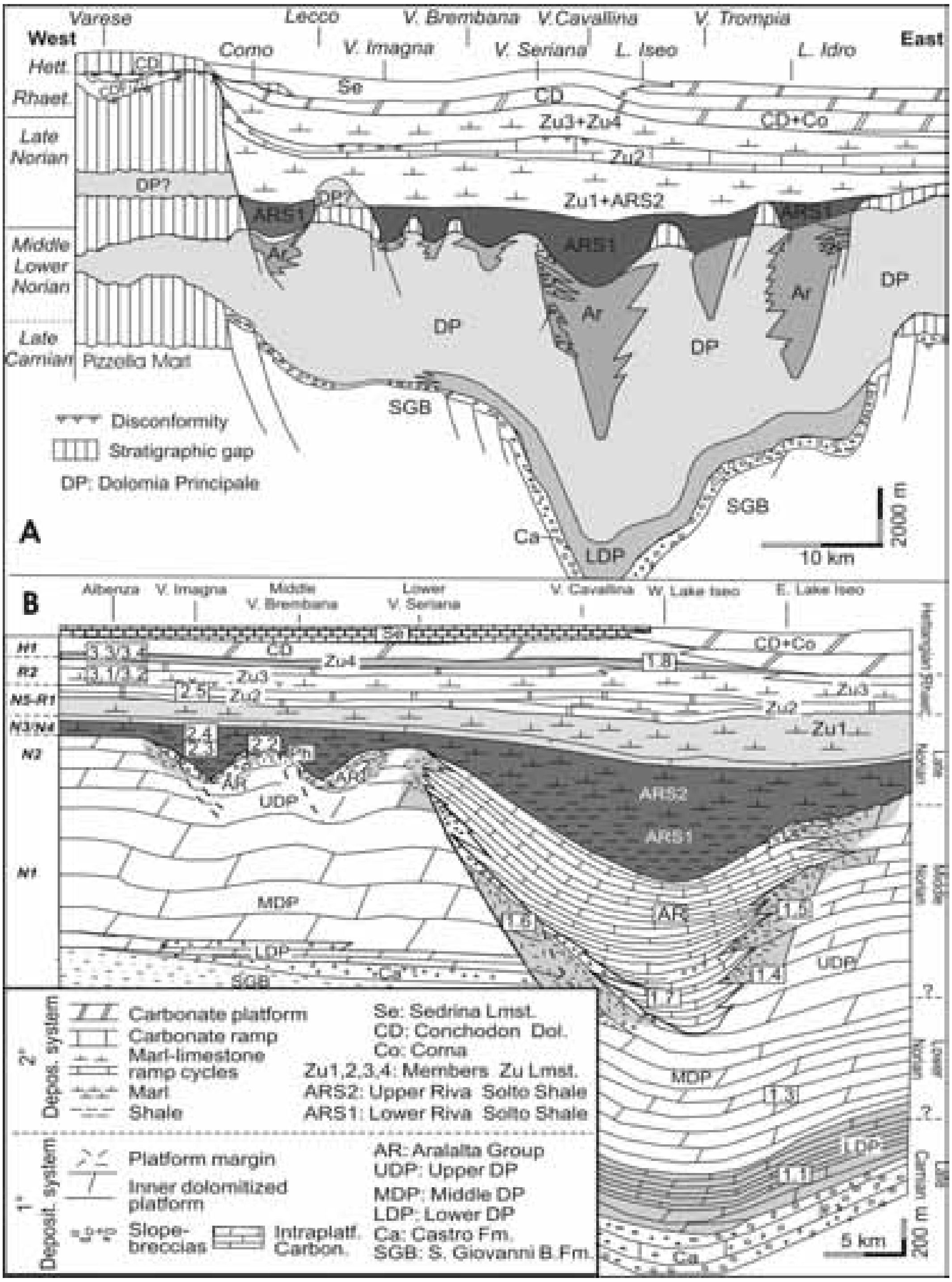

Figure 2 - Late Carnian-Hettangian stratigraphic settings of the Western Southern Alps (a) and of the Bergamasc Alps with the stratigraphic location of the Stops (b) (modified from Jadoul et al., 1994).

shallowing upward cycles (5 to 25 m thick) which consist of several dm to m-thick peritidal cycles with Dasycladales and locally tepees, pisoids and flat-pebble breccias at the top. This middle part of the DP is cross-cut by sedimentary dikes, testifying syndepositional extensional tectonics that will lead to the development of small intraplatform basins.

The intraplatform basin successions (up to 1000 m thick) consist of well bedded, fine crystalline, dark dolomites, limestones and rare organic-rich, laminated, marly limestones (Dolomie Zonate and Zorzino Limestone of the Aralalta Group; Jadoul, 1985; Figure 2 and Stop 1.7). The depositional processes are dominated by gravity flows and slumpings (Jadoul, 1985). The intraplatform basins are interpreted as semigrabens (Picotti and Pini, 1988; Jadoul et al., 1992; Trombetta, 1992) generally exhibiting two margin types (Figure 4): one is tectonically controlled, the other is a flexural margin. The tectonically controlled margins are located to the W of the basins in central-western Lombardy, and to the east in the Lake Idro area (Jadoul, 1985; Lualdi and Tannoia, 1985; Trombetta,1992). The depocenter shifted from the Lake Idro area towards the Lake Iseo area, where the Norian succession is about 3000 m thick (Assereto and Casati, 1965).

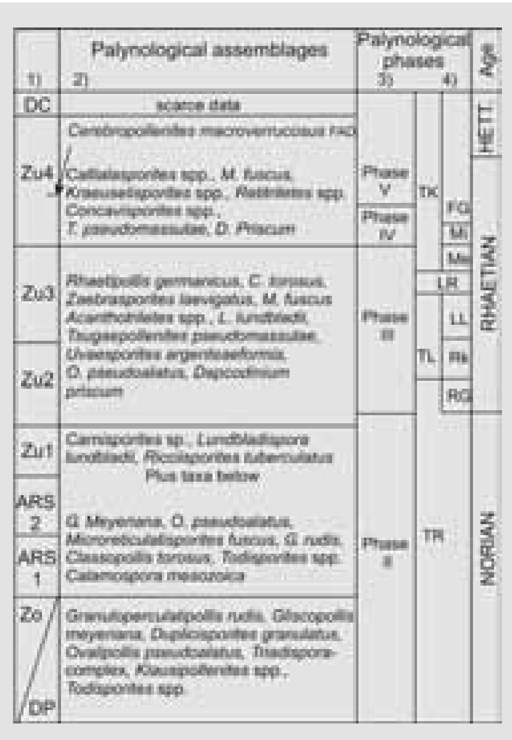

Figure 3 - Chronostratigraphy of the Upper Triassic-Lower Jurassic succession in Lombardy based on palynological assemblages. 1) Lithostratigraphic units; 2) palynological assemblages with selected species; 3) palynological phases according to Schuurman (1979) and 4) Morbey (1975).

The complete development of the DP carbonate platform during the upper Norian records important palaeoenvironmental and geodynamic changes involving the whole western Tethys (Figure 5). The upper DP in Lombardy exhibits margins colonized by peculiar serpulid patch reefs and microbial mounds associated to thick carbonate breccia bodies (Cirilli and Tannoia, 1985; Berra and Jadoul, 1996, Zamparelli et al., 1999; Stops 1.5, 1.6; Figure 4), the development of which was controlled by synsedimentary tectonic and high subsidence rates. These peculiar buildups at the platform margins have been interpreted as an ecological adaptation to restricted and stressed conditions of the intraplatform basins developed during the upper Norian rifting in the westernmost Tethys (Cirilli et al., 1999; Fig.5). A relative sea level fall at the top of the DP depositional system is recorded by local carbonate platform progradation, meteoric diagenesis or erosional disconformity documented at the top of platform, together with the findings of herbivorous terrestrial reptiles in the coeval uppermost Aralalta Group (Wild 1989; Stefani et al., 1991; Renesto S., pers. comm.). A change in circulation pattern and nutrient distribution in marine waters could be ascribed to this sea level fall.

2.2. The crisis of carbonate platform deposition and the drowning of the platforms (middle-late Norian).

A sudden crisis of the carbonate production, recorded in both the platform and basin facies, characterized the top of the first depositional system. The uppermost Zorzino Limestone (Zo) consists of a few meters of thin bedded, micritic limestones, micro-turbidites with slumpings (Stop 1.7), and organic-rich layers yielding vertebrates (reptiles and fishes) and invertebrates (crustaceans, crinoids and rare haermatipic corals) (Tintori et al., 1985; Pinna, 1986). The high concentration of organic matter (OM) and well preserved fossils is probably related to low sedimentation rate and anoxic bottoms. Palynological assemblage documents the middle-late Norian boundary in this horizon (Figure 3).

The carbonate platform succession of structural highs exhibits lenses of dolomitic breccias, marly dolomites with wood and cuticle remains and locally, a thin phosphatic hardground at the top.

2.2.1. The lower Riva di Solto Shale (ARS1) (middle-late Norian).
The lower part of ARS (ARS1, 0 to 250 m thick) is present within the more subsiding areas (Figure 2). The unit mostly consists of black, thin laminated organic rich shales, marly shales and minor dark grey marls, muddy limestones and paraconglomerates. Slumpings and locally, fossil-rich layers (Stop 2.4) are common in the whole ARS1. The middle-upper portion contains lenticular micritic limestone horizons (up to 18 m thick) that intercalate within the shales (stratigraphic marker of Valle Imagna) (Stops 2.3; 2.4). Thin phosphatic hardgrounds with sphalerite, barite, fluorite and celestine mineralizations are locally present. This unit deposited in restricted basins with anoxic bottom and distally steepened ramp.
The palynofacies are characterized by a high proportion of allocthonous continental debris, such as sporomorphs, cuticule and wood remains and of amorphous organic matter (AOM). Palynofacies content in ARS and in the lower member of Zu (Zu1) is quite similar: only a slight decrease in AOM content upwards is documented.
Shales fills the basins onlapping on the basin margins and extend on structural highs (Albenza, M. Zucco, Catramerio, S. Pellegrino) that are locally

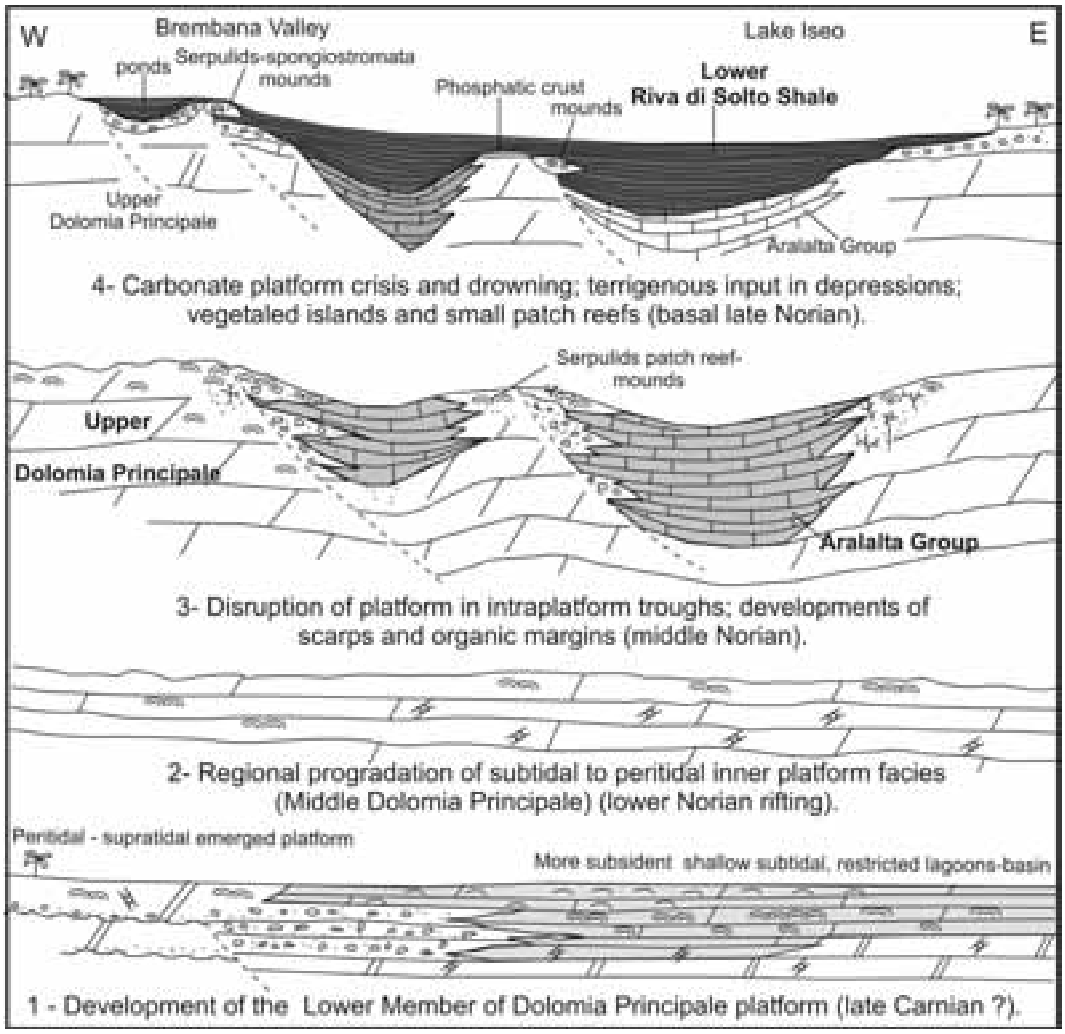

Figure 4 - Stratigraphic-palaeogeographic evolution of the Dolomia Principale depositional system in Lombardy (Jadoul et al, 1994).

characterized by stratigraphic gaps and thin (5 to 15 cm thick) dark crusts of calcium phosphate, with irregular botryoidal features or filling fractures and cavities (Pizzo Formico). Small mounds composed of serpulids, cyanobacteria, encrusting foraminifers, Dasycladales and problematica document short periods of recolonisation.
This particular lithofacies marks the platform flooding and may correspond to the basal argillaceous sediments of the ARS1 deposited in the troughs (Figure 4). Palynological assemblage refers the ARS1 to the middle-late Norian (phase II of Schuurman (1979) and TR zone of Morbey (1975); Buratti et al., 2000).

2.2.2. Palaeoenvironmental meaning of the ARS1.
The argillaceous sedimentation of ARS1 marks the sharp transition with the upper depositional system that was probably controlled by climatic changes, such as increased rainfall that favored the fluvial delivery of fine siliciclastics from continental areas. Rivers-estuaries probably run from Europe to the coast of the Tethyan gulf, where the argillaceous sediments were trapped in N-S depressions. Carbonate production decreased, as a consequence of the large siliciclastic influx and the decreased salinity, related to the input of large masses of fresh water.
Deposition of laminated organic rich clays and marls occurred in anoxic sea-floors as testified by the abundance of preserved AOM. Sedimentologic and paleontologic data suggest seafloors located below the photic zone in prevalent anaerobic-quasi anaerobic conditions.
The local co-occurrence of marine and terrestrial fossils in several horizons of this lithozone (Stop 2.4) indicates emerged areas (where fresh water was available) close to this basin. Geometry and thickness variations of ARS1 inherited the previous palaeogeography. Slumpings and paraconglomerate bodies, with intraformational carbonate clasts, record bathimetric variations within the basins, presence of slopes and persistence of synsedimentary tectonics.

2.3. The cyclic Upper-Norian-to-Rhaetian carbonate ramps with mixed sedimentation.
ARS1 is overlain by 500 to 1500 m of limestone-marls asymmetric cycles showing upward gradual carbonate enrichment. This succession is represented by the upper Riva di Solto Shale (ARS2) and the three members of Zu Lmst. (Zu1, Zu2 and Zu3). The lower boundary with ARS1 is gradual. The upper boundary of the succession is sharp, from bioclastic limestones with oncoids and Megalodontids to well thin bedded calcilutites (Zu4 member). The palynological (Figure 3) and foraminiferal assemblages indicate a late Norian-Rhaetian age.

2.3.1. The upper Riva di Solto Shale.
This unit (ARS2, up to 350 m thick, Upper Norian), has a greater extension than ARS1 (Figure 2). The passage from ARS2 to the overlying Zu1 is marked by the increased occurrence of intercalated limestone. This definition of the boundary (Gnaccolini, 1965) implies a transitional zone up to 100 meters thick: due to the general trend of the succession, we propose to set the boundary at the carbonate bank showing the first evidences of a shallowing trend (rare stromatolites and evaporitic lithofacies) just below a *Gervilleia* rich marker bed.
The ARS2 is characterized by *Bactrillium* bearing laminated shales, marls, marly limestones and calcilutites, locally bioturbated and fossiliferous, arranged in 6 to 30 m thick asymmetric cycles deposited on a mid-outer ramp. The fine terrigenous sediments at the base of the cycle show well-developed parallel lamination. Rare paraconglomerates are present at the base of the cycles. Thin bioclastic calcarenites, with prevalent pelecypods, often micritised or affected by microborings commonly intercalate within marls and shales. These layers may record storm wave episodes (Masetti *et al.*, 1989).
The palynological assemblage is referred to the upper phase 2 of Schuurman (late Norian; Figure 3).

2.3.2. The Lower Zu Limestone (Zu1 member) (late Norian).
The cyclic organization of this lithofacies is similar to that of ARS2, but for less common black shale intercalation and slumpings. This unit (200 to 500 m thick) is characterized by the upward increase of fossil content and limestone intercalations (7 to 20 m thick). Thin bioclastic lenses commonly intercalate within laminated marls and marly limestones: bivalves, echinoids and brachiopods are the most common fossils. The microfacies consist of bioturbated mudstones, wackestones and rare intrabioclastic packstones with foraminifers (*Aulotortus* spp., *Agathammina* spp., *Glomospirella* spp. and rare *Triasina* sp. (in V. Cavallina). In Zu1 of V. Imagna at least two horizons, characterized by vuggy carbonates, evaporite pseudomorphs (replaced by chalcedony, celestine and feldspar) and planar stromatolites are present.
Asymmetric and subordinate symmetric cycles (3-

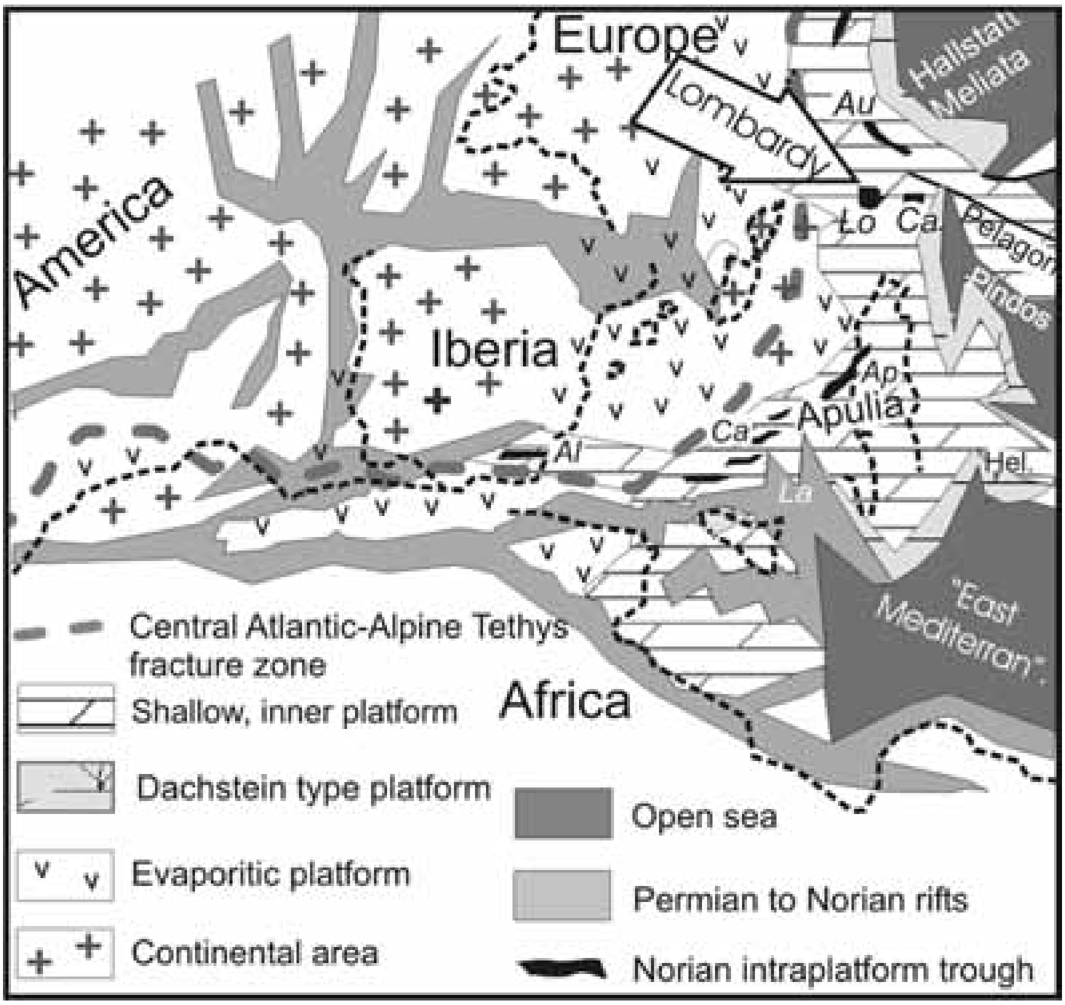

Figure 5 - Late Norian palaeogeography of the Western Tethys (from Cirilli et al., 1999).

4 m up to 30 m thick), are well developed. High energy, bio-intraclastic floatstones with clay chips and less common bioturbation mark the top of some cycles. The upper Zu1 documents a further increase in carbonate and a shallowing and shoaling upward trend. In structural high areas the succession ARS2-Zu1 is generally condensed and it is difficult or not possible to distinguish the two units, that directly overlie the DP.

Palynofacies are always characterized by high proportion of continental organic matter (miospores and palynomacerals) and by moderate to low percentage of AOM.

Lithofacies, microfacies and palynofacies associations of Zu1 identify prevalent low-energy subtidal environments. Sea bottoms were oxygenated and carbonate mud deposition was still associated with periodic terrigenous input. Carbonate mud was produced in situ in the middle-outer part of the carbonate ramp and exported basinward during the regional carbonate platform progradations.

2.3.3. The middle Zu Limestone (lower Coral Limestone, Zu2 member) (Rhaetian *pp*.).

Zu2 represents a carbonate platform succession, which spread throughout the Lombardy Basin with different facies and thickness, representing a stratigraphic marker 50 to 100 m thick (Figure 2). In the western-central Lombardy the lithofacies organization documents the evolution of a prograding carbonate ramp from mid to inner conditions. The stacking pattern of the facies identifies some major cycles (15 to 20m thick), with shallowing-shoaling upward trend, locally recorded by peritidal facies with fenestrae, dolomitized limestones, stromatolites and/or oolitic grainstones (Stop 2.5). On structural highs carbonates are dominant, whereas in the more subsiding areas thin marls intercalation persist.

The dominant subtidal carbonates consist of bioturbated mudstone-wackestones, with scattered coral framestones (mainly *Retiophyllia* spp.) and foraminiferal packstones, bafflestones with calcisponge and porostromata (Lakew, 1990). Bioclastic calcarenites locally rich in echinoids are common at the base of the cycles.

In the most subsiding areas (Val Taleggio and Val Cavallina-Iseo) muddy lithofacies prevail, documenting the passage to deeper and outer carbonate ramp environment.

The shallowing upward trend at the top of the Zu2 represents the final progradation of the ramp system, characterized by local dolomitized facies and a disconformity at the top (Stop 2.5).

The well preserved palynological assemblage recorded in the marls at the base of Zu2, a few meters above a *Homomia* sp. and *Cardita* sp. bearing marly bed, indicate a late Norian-Rhaetian age (Figure 3; Stop 3.1).

The two episodes of carbonate enrichment represented by the Zu 1 and 2 could be related both to a decreased terrigenous input and to an increased carbonate production, probably related to sea level fluctuations.

2.3.4. The upper Zu Limestone and the second Coral Limestone (Zu3 member, Rhaetian *pp*.).

This unit, present in the whole Bergamasc Alps, records a new transgressive-regressive third order cycle developed along a mid-inner carbonate ramp with fine cyclic terrigenous input. Zu3 thickness ranges from 120 to over 200 m.

Three lithozones have been recognized, each representing a different evolutive stage of the ramp depositional system:

-Zu3a consists of a 7.5 to 15 m thick marly limestones, shallowing and coarsening upward asymmetric cycles that exhibit local iron-oxides crusts at top of the carbonate banks and rare evaporitic facies within the basal marly horizons.

-Zu3b is represented by alternated grey to greenish marls and black marly shales grading to marly limestones and micritic limestones. Evaporitic facies within the middle part of cycles, and mammillary, iron-oxide thin crusts (hardgrounds) at top cycles often characterize the facies association of the mid-ramp in the less sudsiding areas (Albenza) (Stop 3.1).

-Zu3c corresponds to the upper (40-50 m thick) calcareous part of the succession (second Coral Limestone marker) and records the second regional carbonate platform progradation (inner ramp facies associations; Stop 3.2) with patch-reefs and local evidences of meteoric diagenesis at the top (Lakew, 1990; 1994).

Palynofacies from Zu3 contain a high total amount of OM. The percentage of continental derived organic debris (miospores and palynomacerals) is high. An increase in marine OM (dinoflagellate cysts, foraminifer linings and algal spores) is recorded in the uppermost part of the Zu3c. The AOM is generally from low preserved to absent. Both the facies and palynofacies arrangements indicate general well oxygenated conditions of the depositional environment. In such conditions the good preservation rate of particulate OM, is indicative of high sedimentation rate, denoting that the OM can quickly be buried beneath the oxidizing water-sediment interface and be preserved also in well oxygenated conditions.

The quantitative analysis of palynological assemblages from ARS and Zu shows a progressive upwards increase of xerophytic elements which become dominant in the Zu3. The rapid increase of xerophytic sporomorphs and the decrease in AOM suggest a shifting towards warmer and probably dryer climate, during the deposition of the upper portion of Zu Limestone.

The top of Zu3c is marked by a paraconformity (Stop 3.2) interpreted as a regional drowning unconformity at the top of the last Zu platform progradation.

2.4. The platform drowning at the T/J boundary (uppermost Zu Limestone -Zu4 member- outer ramp).

The thin bedded and not cyclic Zu4 member (Stops 1.8; 3.3; 3.5) consists of 15 to 30 m thick prevalent micritic limestones, poor in fossils. It represents a regional stratigraphic marker in the central Lombardy developed between two shallow water carbonates units (Zu3 member and CD). At the base bioturbations and slumpings are present, whereas at the top oolitic-bioclastic fine calcarenites alternate with mudstones yielding sponge spiculae, rare radiolaria and small chert nodules. The lithofacies evolution documents a major transgression with monotonous outer carbonate ramp facies associations at the base and a gradual transition to shallower platform environments toward the top. The relative sea level rise that controlled the deposition of Zu4 created the necessary accommodation space for the CD platform progradation. Palynological studies carried out on several sections enabled the location of the T/J boundary (Figure 3) in the micritic limestones at the lower part of this member (Cirilli et al., 2000; Galli, 2002).

2.5. The early Hettangian Conchodon Dolomite.
This unit documents the last and most conspicuous regional carbonate platform progradation in the Lombardy Basin, occurred during the early Hettangian. Its thickness ranges from about 100 m to over 250 m in the Lake Iseo area. The lower part of the CD consists of grey oolitic grainstones with micrite lithoclasts and bioclasts, which represent the platform shoals prograding margin on top of the Zu4 (Stop 3.4). The upper part of this Bahamian-type carbonate platform consists of fine peloidal packstones and oolitic grainstones.

3. Sequence and cyclostratigraphy
(with contributions by M. Clasps and D. Masetti).

3.1. Third order cycles-depositional sequences
The Dolomia Principale.
Within this thick unit only one sequence has been recognized (Gaetani et al., 1998). Our analysis point out a possible existence of a second regional transgressive-regressive third order cycle at the top of DP (Figure 2), cycles N1 and N2 corresponding respectively to the lower-middle DP and the upper DP).

The Riva di Solto Shale, Zu Limestone and Conchodon Dolomite (cycles N3-H1) (Figs. 2, 15).
Five third order cycles have been recognized in the Upper Norian-Lower Hettangian of Bergamasc Alps on the basis of the organization of IV order high frequency cycles, each with a thickness that exceed 80-100 m.

-The first one (N3) begins with the crisis of DP carbonate productivity (lower boundary of ARS1). On structural highs and margin areas, hardgrounds with phosphate crusts mark the lower sequence boundary, identifying the transgressive event overlying the breccias at the top of the DP. The upper boundary corresponds to a thick decameter carbonate marker-bed locally capped by a paraconformity or erosional surface separating ARS1 from ARS2 (Valle Imagna). Cycle N3 is probably of local meaning and tectonically controlled, in fact, eastward it is indistinguishable from N4.

- The N4 cycle (ARS2) is characterized at the base by a renewed terrigenous input, whereas the top exhibits thickening upward shale-marly limestone asymmetric cycles with prevalent micritic limestones and locally coarsening upward subtidal carbonates or 'evaporitic type' facies (Costa-Rota Imagna).

- Cycle N5-R1 (Zu1 and 2, up to 350 m thick). The base exhibits thickening upward outer carbonate ramp cycles (Zu1), followed by the regional inner carbonate ramp progradation of the Zu2 over the whole Lombardy basin. The top of the cycle is characterized by tidal facies and oolitic shoals, locally capped by a disconformity (Stop 3.1). This boundary has been interpreted as a sequence boundary (Gaetani et al., 1998) between the two major Rhaetian-Early Hettangian sequences of the Western Southern Alps.

- Cycle R2 (Zu3 up to 170 m thick) presents the same trend and facies organization of N5-R1 cycle. The well defined lower and upper boundary and the regional transgressive-regressive trend allow to identify this cycle as the last Triassic depositional sequence in Lombardy.

- Cycle H1 (100-300 m thick) is represented by Zu4 and the CD. The TST is recognized in the basin micritic limestones (lower-middle Zu4), while the lower shallow water CD carbonates record the High Stand progradation. The regression at the top of this depositional sequence is locally characterized by carbonate breccias, peritidal limestones and small tepee structures with pisoids (McRoberts, 1994). The overlying second Hettangian transgressive-regressive cycle (sequence H2) is represented by the three lithozones of the Sedrina Limestone (Gaetani, 1970).

3.2. High-frequency cyclicity (IV and V order) in the Upper Norian-Rhaetian.
The ARS2 and Zu Lmst. consist of thickening-upward, subtidal cycles organized in a composite hierarchy (Figure 6). Decimeter limestone-marl couplets are arranged in meter-scale asymmetric cycles grouped in bundles; such bundles are assumed to be related to fourth order cycles (Masetti et al., 1989). We will mainly focus on vertical pattern and thickness of this order of cyclicity. Cycles, 3 to 30 m thick, are formed by three parts: a lower argillaceous unit (black shale or marl); a middle, rhythmic part composed of limestone-marl couplets, where the carbonate semicouplets show a general thickening-up arrangement and a wholly carbonate unit that marks

the upper part of each cycle. Cycle tops are usually sharp, although they can be locally gradational, giving rise to a partially symmetric organization of the cycle (more typical in the Lake Iseo successions). The fifth order cycles (1 to 3 m thick) display an inner arrangement similar to the described major hierarchy. Variations in this general trend are shown in Figure 6, according to the depth of the depositional environment.

The A-type cycle characterizes the deepest portions of the basin, corresponding to ARS1 and 2. It is wholly muddy, up to 30 m thick. The lower part consists of black claystones poor in fossils. The middle unit is made by dm-scale laminated claystone/marl couplets, whereas dark micritic limestone with thin marly layers represents the cycle top. Occasionally slumps and paraconglomerates occur. The depositional environment can be referred to relatively deep (below storm wave's base) and poorly oxygenated sea-floor within intraplatform troughs and in the outer-slope ramp environments.

The B-type cycle is entirely muddy and differs from A-type on the basis of a higher carbonate/shale ratio and of the presence of thin bioclastic storm layers. The faunal assemblage evolves upcycle: the basal claystone/marl contains small endobiontic pelecypods, the upper part of the cycle is characterized by larger epibiontic pelecypods. The palynofacies from A and B-type cycles show a high percentage of terrestrial allochtonous material as common background indicative of the proximity of source areas. Dark brownish AOM and large fragments of poorly rounded and sorted inertinite, subordinate vitrinite and abundant pyrite dominate the palynofacies from argillaceous intervals. These palynofacies confirm oxygen-depleted bottoms. In B-type cycles the palynofacies is characterized by minor amount of AOM and high proportion of sporomorphs and poorly sorted rounded equidimensional inertinite. In the uppermost part of this cycle a blooming of fungi is associated with small fragments of poorly sorted and rounded equidimensional inertinite, which reveal more oxygenated sea floors. This cycle was deposited in a low-energy, outer deep ramp environment, where the shallower sea floor allowed the deposition of thin bioclastic storm-layer.

The C-type cycle, typical of Zu3b, exhibits a coarsening and shallowing-upward evolution. The lower portion of the cycle consists of bioturbated marls bearing poor associations of small pelecypods in thin storm layers. The central part is composed of an irregular alternation of black marls, yellow/reddish dolostones with carniola-type breccias and fine grained storm layers showing swaley and hummocky cross-stratification. The upper calcareous unit consists of cross-bedded grainstones capped by peloidal limestone. These fine-grained beds could be interpreted as: 1) inner ramp facies overlying cross-bedded sands during the progradational evolution of the cycle; 2) deeper ramp deposits corresponding to

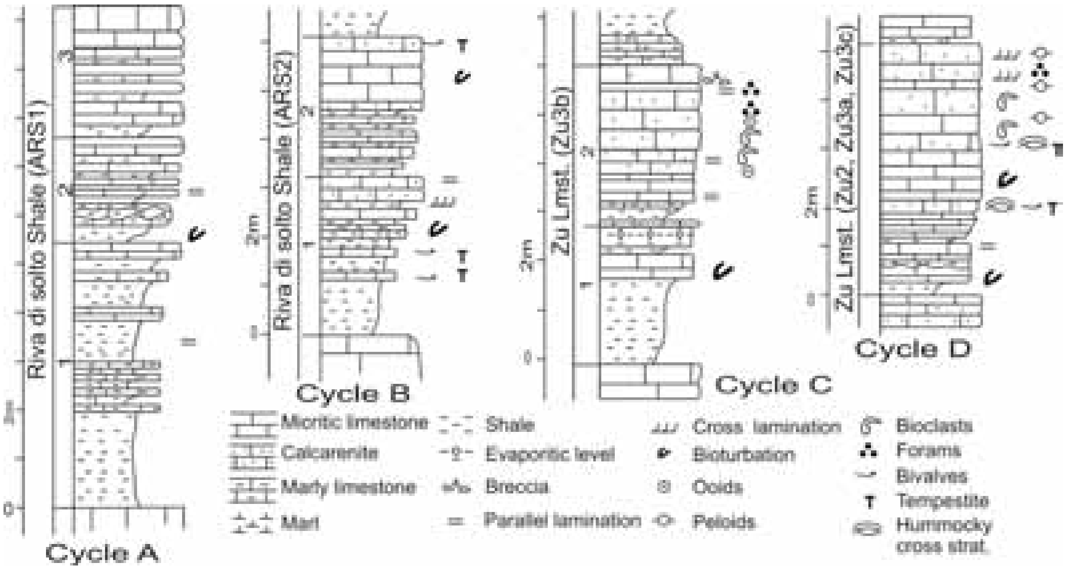

Figure 6 - Different 4th order asymmetric cycles of the Norian-Rhaetian succession. Numbers in vertical columns refer to higher frequency cycles.

a retrogradational phase. The top of the cycle is sharp and marked by a metallic oxide crust probably related to a non-depositional hiatus between two adjacent cycles. The increasing tempestite proximality, and the coarsening-up trend can be referred to a shallowing-up evolution of these cycles. Palynofacies parameters show that various signatures can be recorded across the cycle. These differences concern the relative abundance of the organic constituents and their preservation rate, which point to an analogous shallowing upward trend as evidenced by facies analysis. The depositional environment is referred to the mid-inner sectors of ramp.

The D-type cycle shows the same trend as the C-type, but the lower marly facies are replaced by thin marly interlayers and bioturbated or laminated fine wackestones\packstones. The cycle is almost entirely characterized by fine to coarse packstones and locally grainstones. In the upper part, bioclastic packstones and coral-rich boundstones may be intercalated. Palynofacies are characterized by high amounts of both marine and terrestrial OM whose relative percentages vary across the cycle: the amount of marine elements decreases upward cycle, while terrestrial fraction increases.

This cyclic organization is typical of the Zu2, Zu3a and Zu3c deposited in the more proximal, inner portion of the carbonate ramp.

Meter-scale, coarsening- and shallowing-up cycles, composed of subtidal carbonates similar to C and D-type cycles, have been described in several papers. The only interpretation of muddy asymmetric cycles without any coarsening-upward trend (cycles A and B, Figure 6) was published in Masetti et al. (1989) and Burchell et al. (1990), and applied to the same succession previously described. According to these Authors, the asymmetric carbonate signal was linked to eustatic fluctuations controlling productivity and accommodation at the top of the platforms, which represent carbonate mud productivity areas. The basinward exportation of carbonate mud was negligible in the deepening phase and increased during the shallowing evolution and the consequent decreasing in accommodation at the platform top. A subaerial exposure of large platform areas 'killed' the carbonate factory and finally stopped the carbonate mud supply to the basins. The same eustatic fluctuations could generate coarsening- and shallowing-up cycles in the uppermost portion of the ramps. A rough estimate suggested approximately 10^5 years as the order of magnitude for each cycle duration. Starting from the mentioned model, the objectives of this study are to evaluate the forcing mechanism responsible for producing the high-frequency cycles and to estimate the correlation with the fourth order glacio-eustatic fluctuations previously proposed.

3.3. The origin of high-frequency carbonate cycles (IV and V order): hunting for Milankovitch periodicities.

The possible origin of high frequency cyclicity includes: 1) autocyclic processes, 2) allocyclic tectonic processes, 3) Milankovitch glacio-eustasy.

Composite glacio-eustatic fluctuation seems to be the only mechanism able to generate the multi-hierarchic pattern of the Late Norian-Rhaetian high-frequency cycles. In particular the presence of an unequivocal deterministic law in the way they are recorded must be correctly considered. Collectively a number of evidences supports the idea that periodic glacio-eustatic variation (like Milankovitch-driven eustasy) could be the driving force producing this type of cyclicity. As illustrated in the Milankovitch theory the perturbations affecting the Earth's orbit are the precession, obliquity, short- and long-term eccentricity (19-23, 41-54, 95-123, 413 ka.). These perturbations have the potential to produce changes in the insulation pattern and to influence the climate at a global scale. Therefore they could be recorded in stratigraphic sequences.

The most reliable strategy in hunting for Milankovitch periodicities is the application of a composite system of spectral analysis methodologies (Claps in Jadoul et al., 1994). Each cyclic sequence is characterized by several parameters continuously fluctuating. By plotting these various data-sets along the stratigraphic axis it is possible to reconstruct their 'variance history'. The sequences of data here treated are thickness time series. The main objective of spectral analysis is to decompose the input time series into several elementary constituents, estimating the contribution of each single signal. The results are displayed in a power spectrum, and are given in terms of frequencies ratios between the different hierarchies of cycles.

DESCRIPTION OF THE OUTCROPS

DAY 1

The stratigraphic evolution and facies analysis of the Dolomia Principale (DP) depositional system.
Morning: the shallow-water Corna Trentapassi succession.

About 4 km of walking, with five stops, along the abandoned road on the eastern side of the lake. This thick succession (about 2 km, Figure 7A, B) represents most of the Norian, because intraplatform basin facies (Zo Limestone) are not developed in this area. The whole DP outcrops with sub vertical attitude and is interested by pervasive dolomitization, often with late diagenetic recrystallization (sparry white dolomite), Quaternary karstification and dedolomitization phenomena. Slope gravitational deformations and landslides, linked to the retreat of glacial bodies, are also present (Figure 7).

Stop 1.1:

Pleistocene dedolomitization along fractures.

On both sides of Iseo Lake, in correspondence to the valley narrowing between Monte Clemo and the Corna Trentapassi, the DP shows dedolomitized patches.

The dedolomitization is interpreted forming in different setting: from subsurface-deep burial to subaerial environments (Nader et al., 2003 with wherein references); the proposed model for the Iseo case points out that dedolomitization process is a surface one, that occurred in presence of meteoric derived waters and strictly associated to the advancing

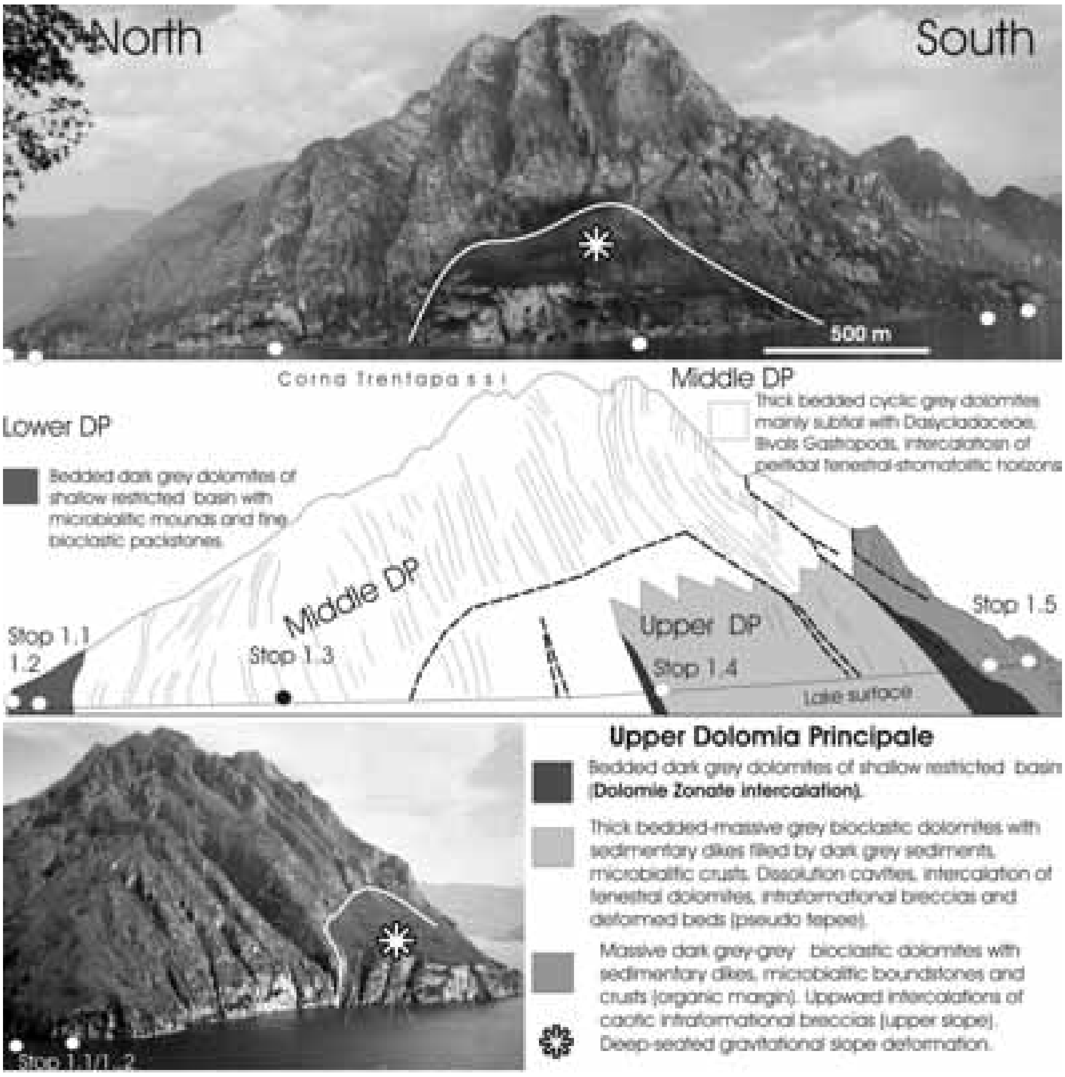

Figure 7 - The Dolomia Principale of the Corna Trentapassi section (east L. Iseo) with the location of the Stops.

and retreat of the Pleistocene glacier on the slopes of the valley.
The dedolomitization is shown along fractures in an area widespread from the lake level (185 m sl) upward to 650-700 m s. l. (Pleistocene glacial terraces, Corbari and Bini, 2001).
The calcitized patches, characterized by a white-gray color, are strictly related to fracture networks and their width ranges from few centimeters up to few meters on both sides of the fracture walls (Figure 8A).
Both the dedolomitized and non-dedolomitized fractures belong to the following three sets: the first has 110-120° strike with subvertical dip; the second group has the same strike and a 45° dip, and the third group has a 45-50° strike and 40° dip. It is likely that some of these fractures, formed during the late Alpine tectonic have been re-opened afterwards, allowing the dedolomitizing fluids flow in.
The fractures associated to dedolomitization may still be open or sealed by a thick (up to 5 cm) withish and honey/orange calcite cement, a speleothem-like texture (Figure 8B) and, locally in larger fractures-cavities, by 'pseudobreccias' or ochre-reddish laminated internal fine grained calcsiltites-lutites sediments with rare small ostracods. The petrographic observations demonstrated that the dedolomitization acted in the same way both at the large and the micro scale: the fluids percolated and permeated the rock along permeable ways represented by large fractures, small fractures, microfractures and crystal boundaries. The process is composed of two steps: the dolomite dissolution and the calcite precipitation (Figure 8D, E).
The dedolomitized fabrics show altered isotopic

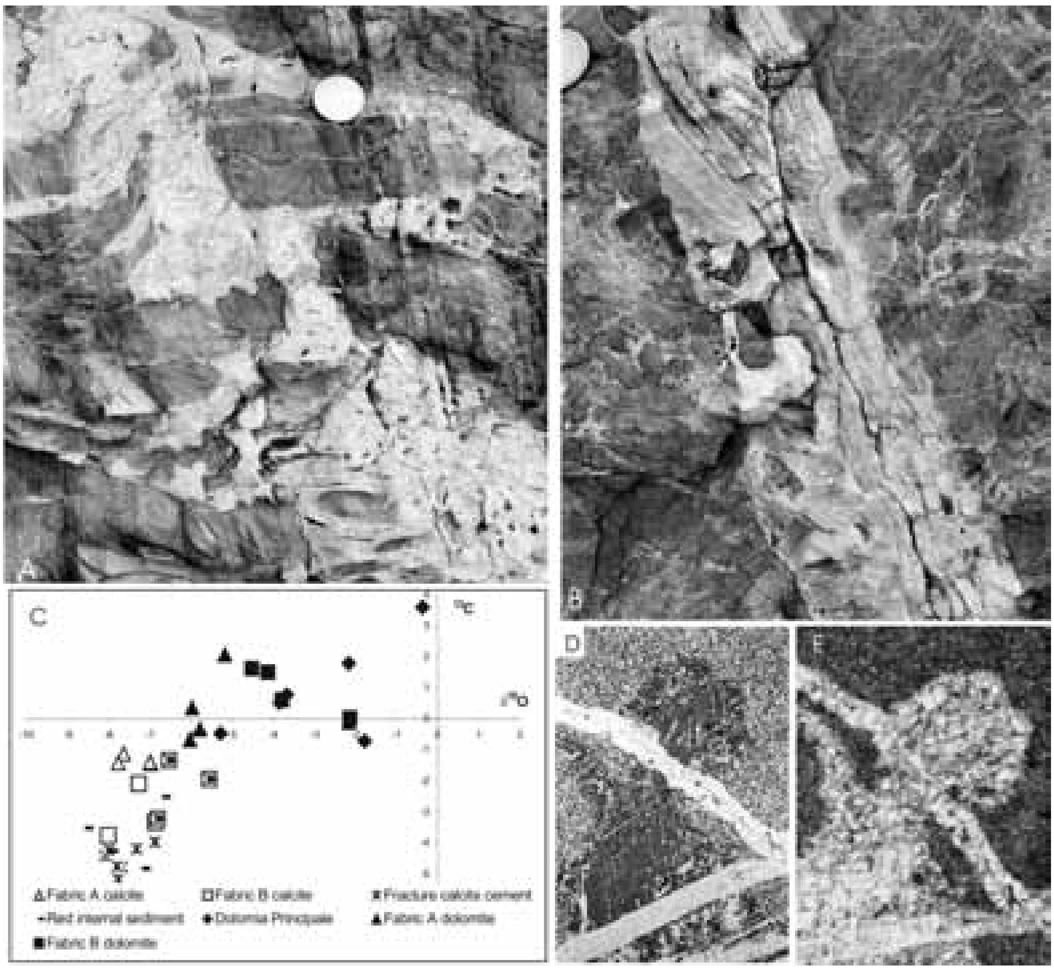

Figure 8 - Macro (A,B), microfacies (D,E) and geochemical features of the dedolomitization in the LDP.

signatures with a shift of the $\delta^{13}C$ and $\delta^{18}O$ toward more and more depleted values (Figure 8C) in relation to the increase of calcitization (from fabric A to B). The presented isotopic values suggest that dolomite maintains its DP original signature, while calcite records the signature of the dedolomitizing fluids (typical of a carbonate which underwent a subaerial diagenesis).

Radiometric absolute age determination ($^{230}U/^{234}Th$) indicates that calcite cements precipitated in the last 100000 years: age during which the area was subject to several advances and retreats of glacial tongues.

The field mapping, analytical data and the geomorphology of the area, allow us to propose a peculiar genetic model that involves the presence of the multiphase advances and retreats of the Pleistocene Camuno glacier in the area. The morphology of the valley is the main cause that allowed the glacier to be one of the triggering factors of the extensive dedolomitization. During glacial periods the presence of the Monte Clemo-Corna Trentapassi straight forced the glacier into a gorge causing strong pressure along the slopes. This pressure contributed to enlarge some of the fractures in the DP and provided the huge quantity of dolomite-undersaturated melting waters. The pressure flux of these waters caused the starting of dolomite matrix dissolution along the fractures and the calcite precipitation. During the interglacial periods, the lack of the ice pressure along the slopes of Iseo Lake caused the opening of the preexisting fractures, joints and faults. The humid and warm climate gave rise to the soils coverings and karst processes caused the extensive calcite precipitation along the joints. The glacial and interglacial environments alternated few times during the Quaternary: the restoration of the glacier compression in the gorge area (last Quaternary glacial stages) may has been responsible of the compaction observed on some dedolomitized breccia.

Stop 1.2:

The Lower Member of DP (250-300 m thick) (Figure 9).

This dark grey and bedded unit exhibits algal and microbial laminites (Figure 9A, C), intercalated with intraclastic packstones and intraformational breccias often recrystallised and mudstones (Figure 9A, B) that increase towards the upper part of this Member. These dark laminated facies form both laterally-linked hemispheroids and plane mats several decimeters thick. Microfacies show rhythmic alternation of dense micrite with fine fenestral fabric. These crusts are produced by the growth of microbial communities which trapped and bound the sediment. The top of the DP Lower Member may consist of transgressive, intraclastic packstones with rare pelecypods and intraformational breccias associated with strata deformation. Borings and bioturbations can be locally observed at the top of the mudstone beds. Rhythmic and, locally, cyclic facies arrangement indicate a shallowing upward trend, with cycle thickness ranging from several decimeters up to a few meters (Figure 9).

The depositional environment was prevalent subtidal with bottoms frequently characterized by anaerobic conditions that were unfavorable to sustain a rich benthic fauna: only bacterial or algal mounds are present (TOC up to 0,1%).

The observed facies associations, characterizing the first development of the DP platform all over the western Southern Alps, document at the Carnian/Norian boundary environments with anomalous salinity, probably adjacent to emerged lands, and humid climate.

The gradual passage to the DP (the transition zone is about 100 m thick) is marked by the intercalations of grey-dark grey thick bedded dolomites (prograding facies of the DP) and the fine bioclastic packstones, with small thin shell bivalves of the Lower Member.

Stop 1.3:

The shallow subtidal carbonates of the Middle DP (Figure 7).

This succession is very thick (over 1 km) and represented by light grey thick bedded or amalgamated beds of mainly shallow subtidal-lagoonal recrystallised dolomites. Beds and lenses of packstones-grainstones with reworked and sorted Dasycladales and small bivalves are frequently intercalated as well as small Megalodont rich beds and fenestral, planar stromatolite horizons.

The bulk of dolomitization of the DP occurred in the early stages of diagenesis and at superficial setting. In the inter-supratidal facies, dolomitization is related to capillary evaporation and reflux of marine-derived fluids, evaporated on the platform (Frisia, 1991). Most of the subtidal facies dolomitization is also early diagenetic. However, its completion occurred through several stages, up to burial temperatures over 60°C. Dolomitization of intraplatform basin facies occurred by marine-derived fluids and seems related to platform-derived, density-driven fluids.

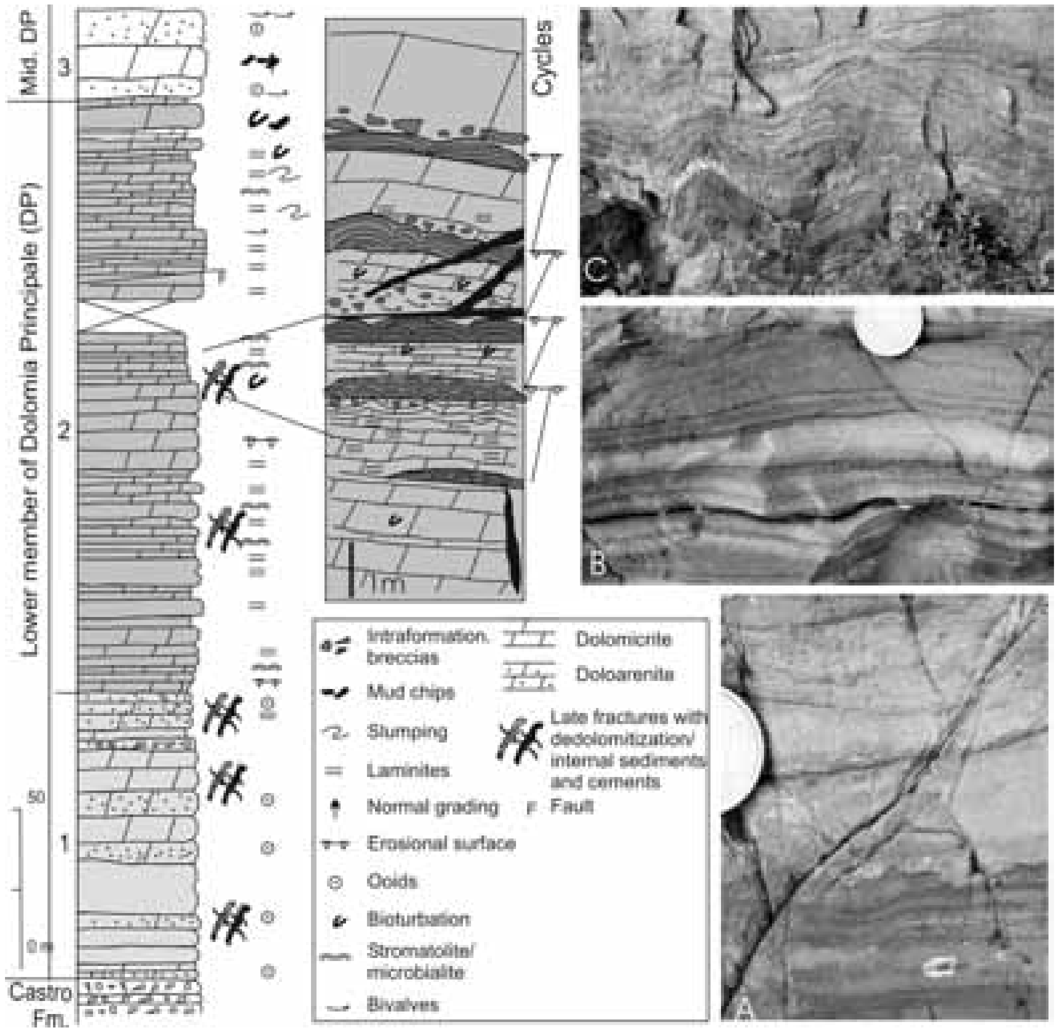

Figure 9 - Stratigraphic section with details of the Lower DP (Stop 1.2).

Stop. 1.4:

The upper Dolomia Principale: the transition facies to the platform margin, the first basin facies intercalation and the syndepositional tectonics (Figure 10).

Above the three tunnels and the massive grey dolomites rich in Dasycladales and locally with large Medalodonts, small sedimentary dikes with dark grey internal sediments (Figure 10) cut the peritidal dolomites (transition facies to the Upper DP). These dikes predates the first meter thick dark grey intercalation of well bedded dolomites (Dolomie Zonate), characterized by internal strata deformations ('pseudo tepee') affecting bioclastic packstones rich in Dasycladales. Upward, tensional fractures and subvertical sedimentary dikes filled by internal sediments became more frequents (Fig.10C).

Stop 1.5:

Microbialites and slope breccias of the Dolomia Principale platform margin (Figure 11).

The top of the Corna Trentapassi section shows massive to thick bedded dark grey dolomites with intercalation of dark grey, well bedded dolomitic arenite-siltites, locally laminated, with lenticular geometries. Deformations (slumpings) and chaotic intraformational breccias occur at the top.

Within these facies, irregular, meter size

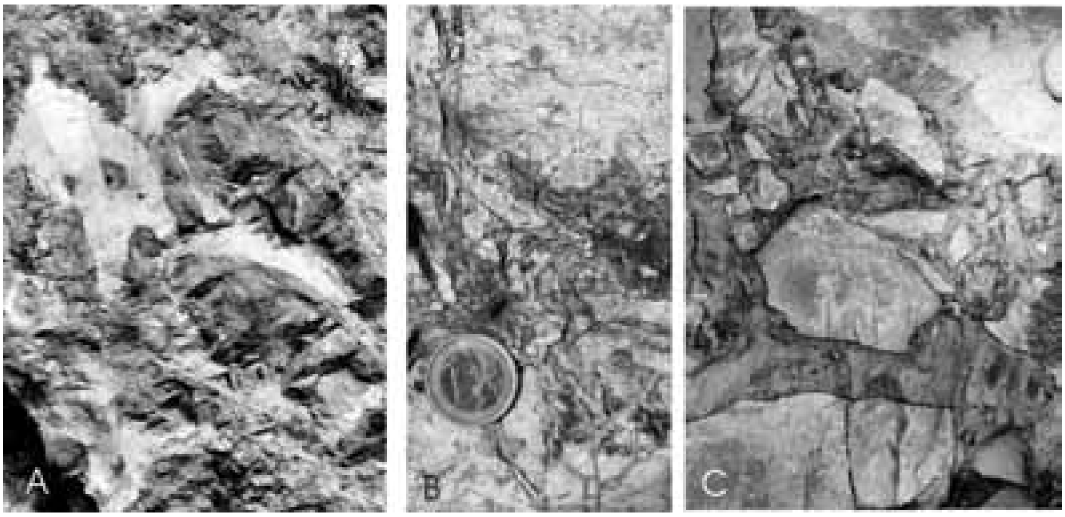

Figure 10 - Sedimentary dikes and breccias in the Upper DP (Stop 1.4).

bioconstructions are present (Figure 11A, B). They consist of dark, homogeneous microbialitic patches, often reworked, associated with encrusted breccia blocks; upward domal, laminated microbialites, few meters in size, can be observed. The microfacies of this platform margin succession, interpreted as the outer-upper slope portion, are dominated by *Spongiostromata* bindstones and bioclastic intraclastic packstones-rudstones to floatstones with pelecypods (mainly *Modiolus* sp.) (Figure 11C), Dasycladales and rare benthic, sessil foraminifers (*Glomospirella* spp., *Agathammina* spp., *Tolypammina gregaria)*. Locally, thick grey subtidal bioclastic (manly Dasycladales and pelecypods) prograding horizon up to few decameters thick are intercalate. The upper part of the platform margin complex is composed of partially colonized breccias, associated with intra-bioclastic packstones-rudstones and semilithified clasts of Dolomie Zonate (Figure 11). The upper DP continues in the Vello area with the similar margin-slope facies associated to a thick succession (up to 100 m) of Dolomie Zonate with at the top a new platform margin progradation represented by microbialitic and serpulid patch reefs, (Berra & Jadoul, 1996), also present on Stop 1.6.

The stratigraphic evolution of the Upper DP corresponds to repeated phases of growth and

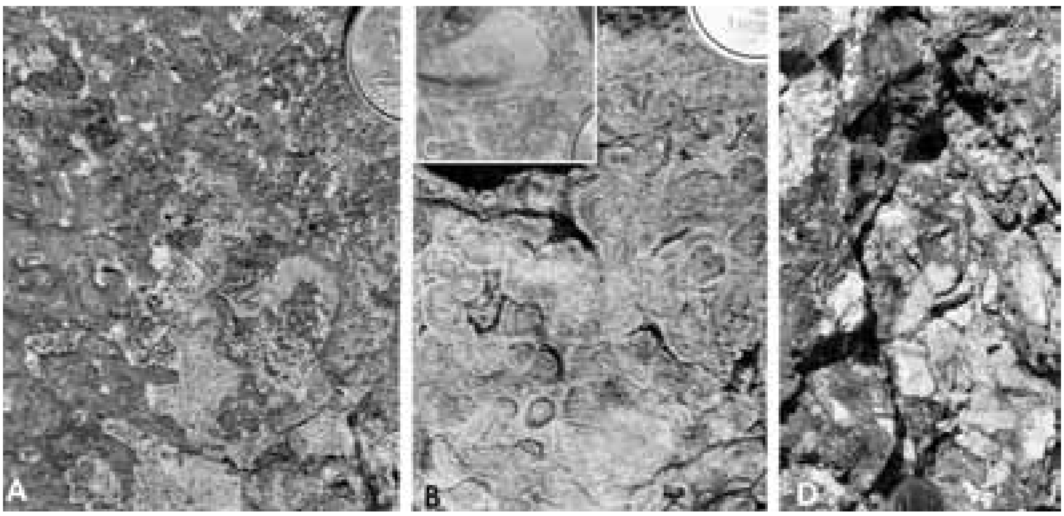

Figure 11 - Details of microbialites and breccias of Upper DP (Stop 1.5).

dismantling of the DP margin facies which prograded on the Iseo basinal area. The litho-bioclastic breccias and associated patch-reefs are characteristic of the whole upper DP depositional system in Lombardy, where the biogenic margins developed on the low-energy borders of the intraplatform basins.

The breccia bodies could represent the talus of the biogenic margins, but for the upper part that could be related to a tectonic controlled margin.

Afternoon: The middle Norian-Hettangian succession of western Lake Iseo.

In the afternoon by boat we cross the Lake Iseo from Marone to Castro. During the navigation it is possible to observe the panorama of the Corna Trentapassi succession and compare it with the more reduced DP (about 1 km thick) outcropping on the western side of the Lake Iseo overlain by a very thick Zo Lmst. (1 km) and ARS (up to 1 km) (Figure 7, 12A). During the cruise, it will be possible to discuss the structural setting of the sedimentary succession on the two side of the lake.

Stop 1.6:

Buildups of the Dolomia Principale platform margin on western Lake Iseo (Figure 12).

Along the road from Castro to Riva di Solto, at the top of the massive DP (Figure 12A) the typical dolomitized platform margin of the DP is thick and well preserved. In this outcrop (a few tens of meter thick), concretionary, large (up to meter in diameter) globular, mammillary microbial laminations, microbial coatings and amalgamated centimeter-decimeter sub-rounded oncoids are the dominant features of DP reefal facies (Figure 12B, C, D). The nucleus of some of recrystallised oncoids is

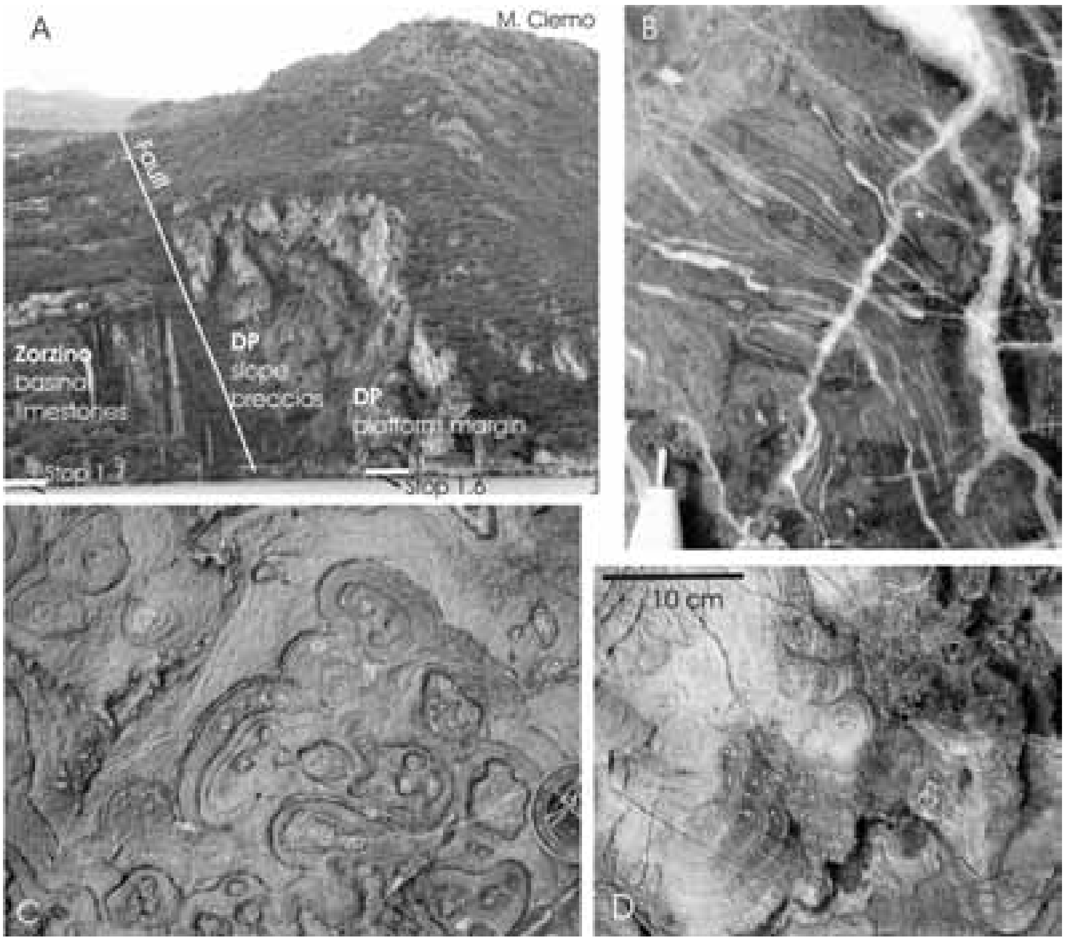

Figure 12 - Main features of the Dolomia Principale buildups of the Eastern Lake Iseo (Stop 1.6).

represented by small serpulid tubes.
Same microbial inter-lamina and the scarce matrix consist of fine to coarse bioclastic packstones with foraminifers, microbial bindstones, serpulids and small pelecypods. Late diagenetic silicization phenomena, dissolution cavities and sedimentary dikes are also present.

Stop 1.7:

The basin intraplatform succession (Zorzino Limestone) of western Lake Iseo (Figure 13).

Close to Stop 1.6, above the topmost DP, in a highly subsiding area, we observe the typical Zo facies association consisting of fine grained well bedded (15 to 40 cm thick in average) diluted and mud-dominated turbidites (Figure 13A) deposited in a basin palaeoenvironment. Only rarely, graded thin calcarenites with small current ripples and laminated marly limestones (up to 15 cm thick) intercalate within mudstones. Upward, two chaotic breccia lenses with dolomitization phenomena and platform-derived and basinal clasts record a platform progradation episode or tectonic instability of the platform margin-slope. Breccias are composed of intraformational and platform margin facies with *Porostromata*, *Spongiostromata* and serpulids. The recovering of the fine grained, micritic sedimentation follows.
The common micritic Zo facies and the adjacent east Iseo DP margin (Stops 1.5; 1.6) indicate that the eastern slope of the Iseo-Cavallina basin was a prevalent flexure without a huge tectonic escarpment and that the fine-grained carbonate of the Zo derived mainly from the winnowing of the DP platform. These periplatform muds were exported to the deeper basinal areas along this slope. Only locally, coarser deposits derived from the margin were able to reach the deeper part of the basin.

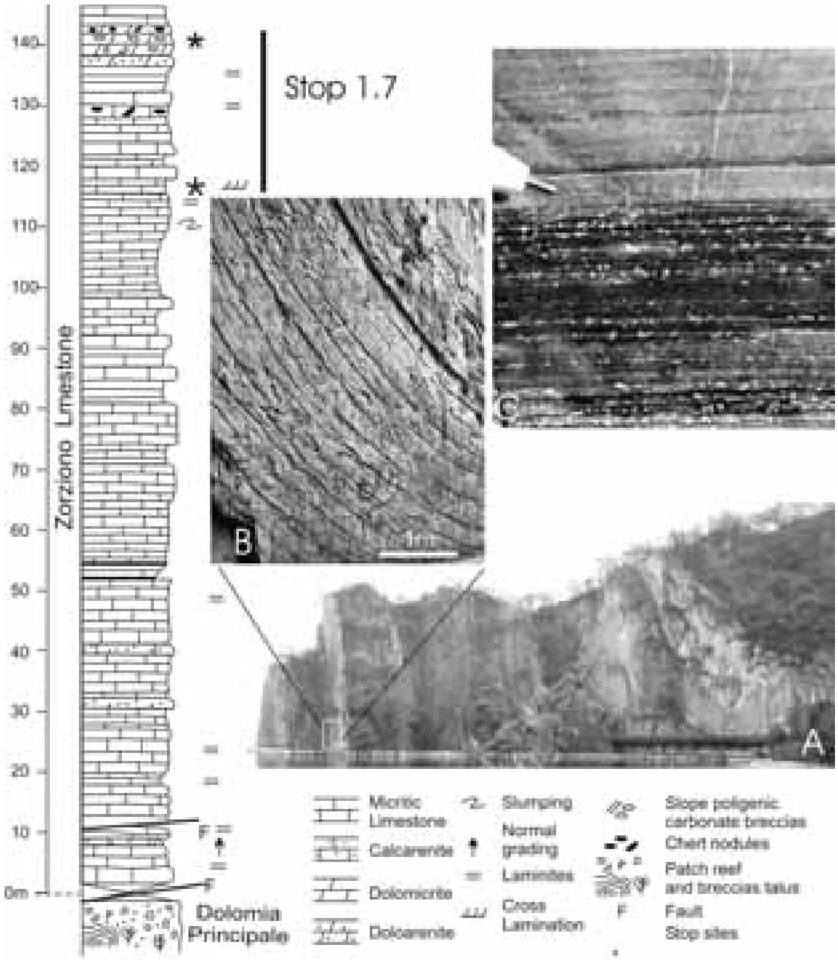

Figure 13 - Stratigraphic section of the Lower Zorzino Lmst. (Stop 1.7) with large problematic structures (A) and dark organic rich laminites (B).

Stop 1.8:

The Rhaetian-Hettangian succession in western Lake Iseo (Figure 14).

In this stop you can observe the upper Zu and the CD cropping out in the western coast of the Lake Iseo (Iseo section Figure 14).

The top of Zu3 member consists of cycles of prevalent bedded grey micritic bioturbated limestones with, at the base, thin marly layers. Bioclastic packstones-wackestones intercalate.

Zu4 member (about 25m thick) starts with a transgressive marly-silty level with parallel lamination rich in quarts and mica extraclasts. The lower part of the member consists of dark grey well bedded micritic limestones with slumpings and intraformational breccias. The upper part represent a transition with the overlying shallow water carbonates (CD) and consists of dark grey thickening upward limestones with bioclastic oolitic grainstones. The lower CD is characterized by prevalent oolitic calcarenites, with bioturbation and a thickening upward trend.

After the last stop in the late afternoon, we will reach Capo di Ponte (Val Camonica) where important prehistoric artwork (Unesco Heritage site) are preserved in an historic park.

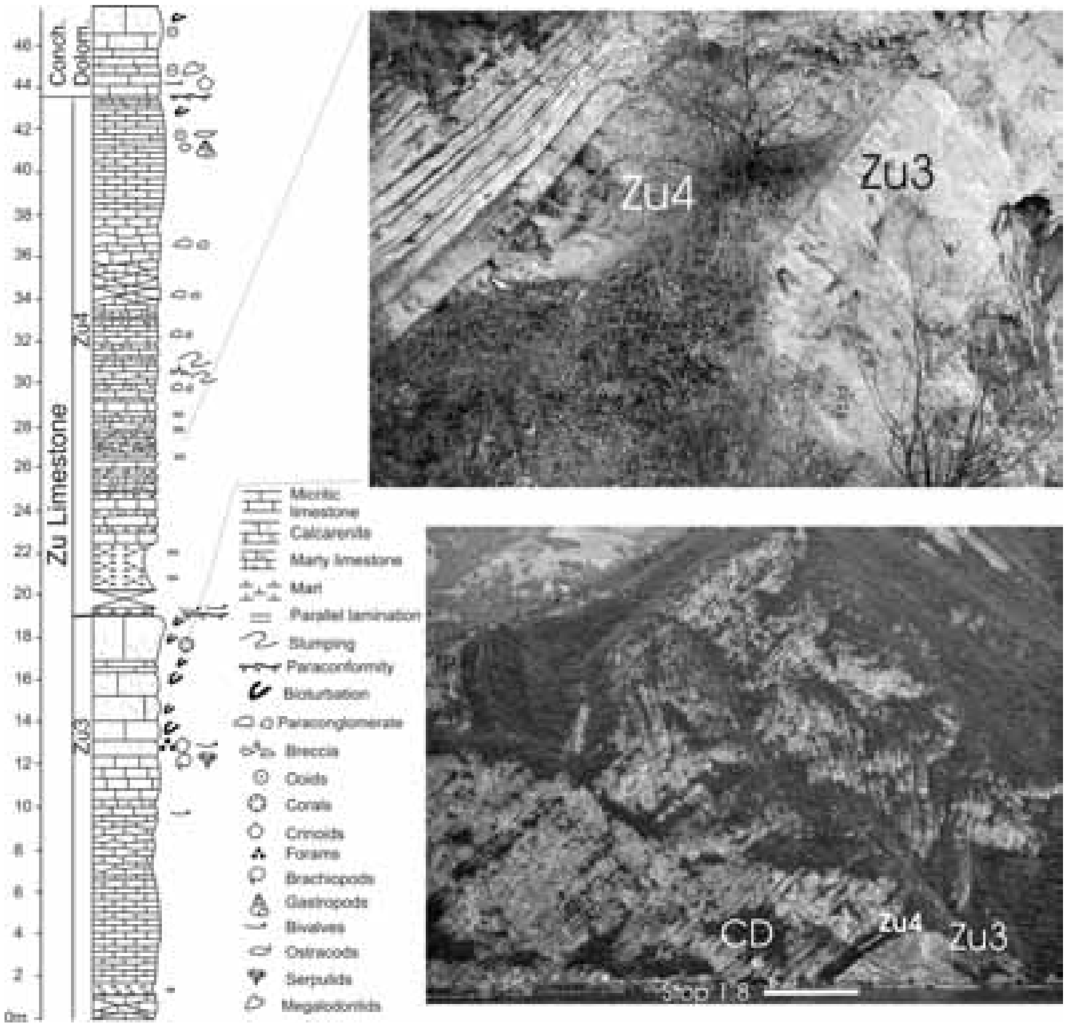

Figure 14 - Stratigraphic section of the T/J boundary of the western L. Iseo (Stop 1.8).

DAY 2

The Upper Norian-Lower Rhaetian fine siliciclastic to carbonate high-frequency cycles of the western Bergamasc Alps (Valle Imagna) (Fig.15).

From Lovere to Valle Imagna with the first Stop in the old town 'Bergamo Alta'.

Stop 2.1:

The Norian-Rhaetian collection at the E. Caffi Museum of Bergamo.

During the visit we have the occasion to observe a rich fossil collection, coming from several localities of the Bergamasc Alps. Wonderful and well-preserved fishes, reptiles and arthropods (crustaceans, insects) of the Zorzino Lmst. and of Riva di Solto Shale and corals of the Zu Limestone are in the Natural History Museum exhibit.

You can find more details in www. apt.bergamo.it

Lunch and a short visit of 'Bergamo Alta'.

Stop 2.2:

The ARS cycles of the lower Valle Imagna (Figure 16).

Along the Valle Imagna road, near Caschiettino-Ponte della Grata, one of the best exposed and complete section of the ARS2 crops out. The uppermost DP represents the base of the section. Since the deposition

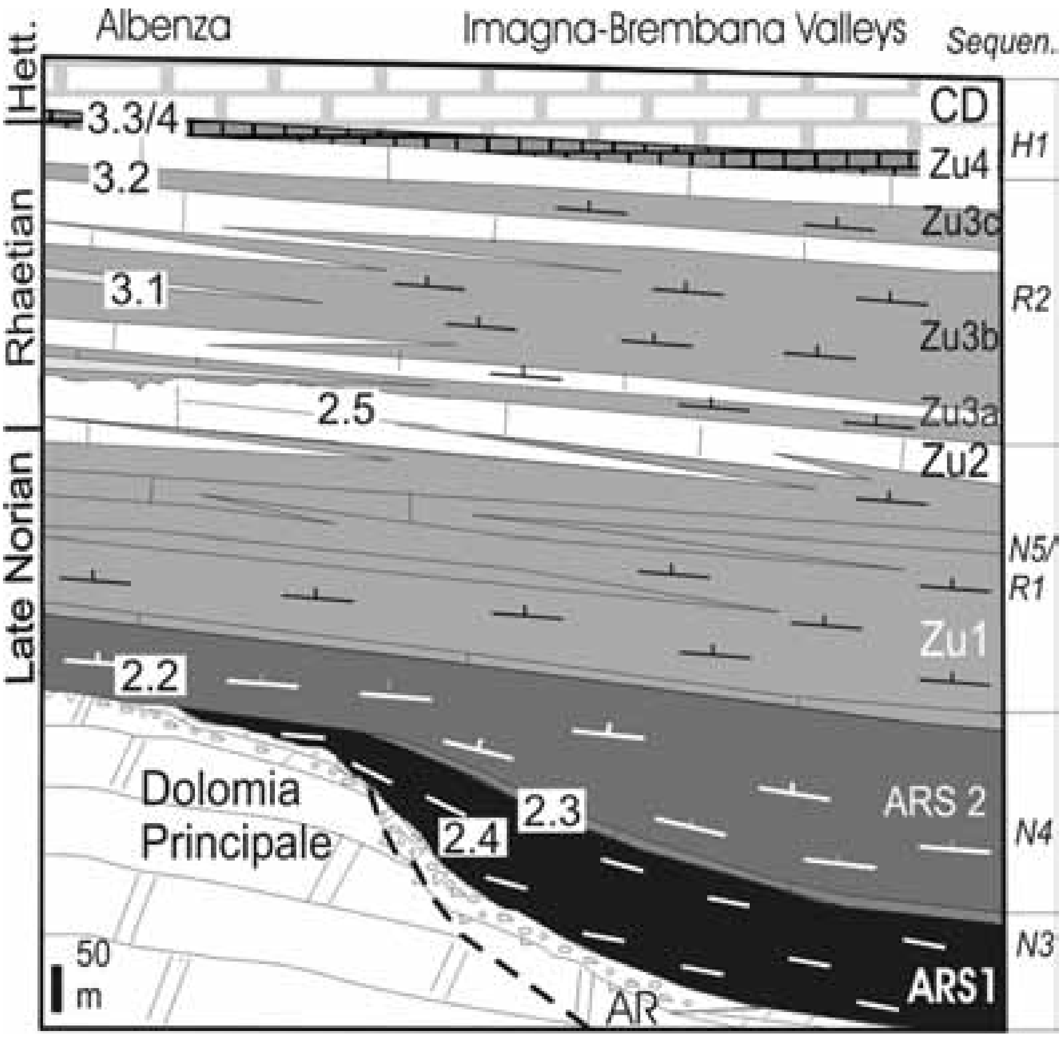

Figure 15 - Late Norian-Hettangian stratigraphic sketch of the Albenza-V. Imagna ramp depositional system.

occurs at the top of a structural high, the ARS1 did not deposit. The whole section (about 60 m thick) consists of 13 fourth order asymmetric cycles (B-type; Figure 6). Each fourth order cycle can be further subdivided in smaller-scale fifth order cycles (Figure 16B). The ARS2 fourth order cycles are mainly muddy and do not exhibit an evident coarsening-up trend clearly referable to a shoaling-up evolution of the depositional environment.
The typical cycle is characterized by a lower portion consisting of dark shales containing thin layers rich in monospecific assemblages of small pelecypods (Figure 16C), indicative of restricted environmental conditions. *Bactrillium* are also common. Toward the top of the cycle, limestones become more abundant: marls and limestones prevail with respect to shales.
Bedding is sometimes reworked by burrows (mainly Thalassinoides) introducing limestone into marls and vice-versa and deformed by synsedimentary structures such as slumping and loading. The boundaries between beds are usually transitional, and in particular the lower contacts of calcareous layers do not show erosional features. These layers are often bioturbated and consequently massive, but in some cases they are composed of many amalgamated events.
Palynofacies are dominated by brownish AOM associated with low to moderate percentage of

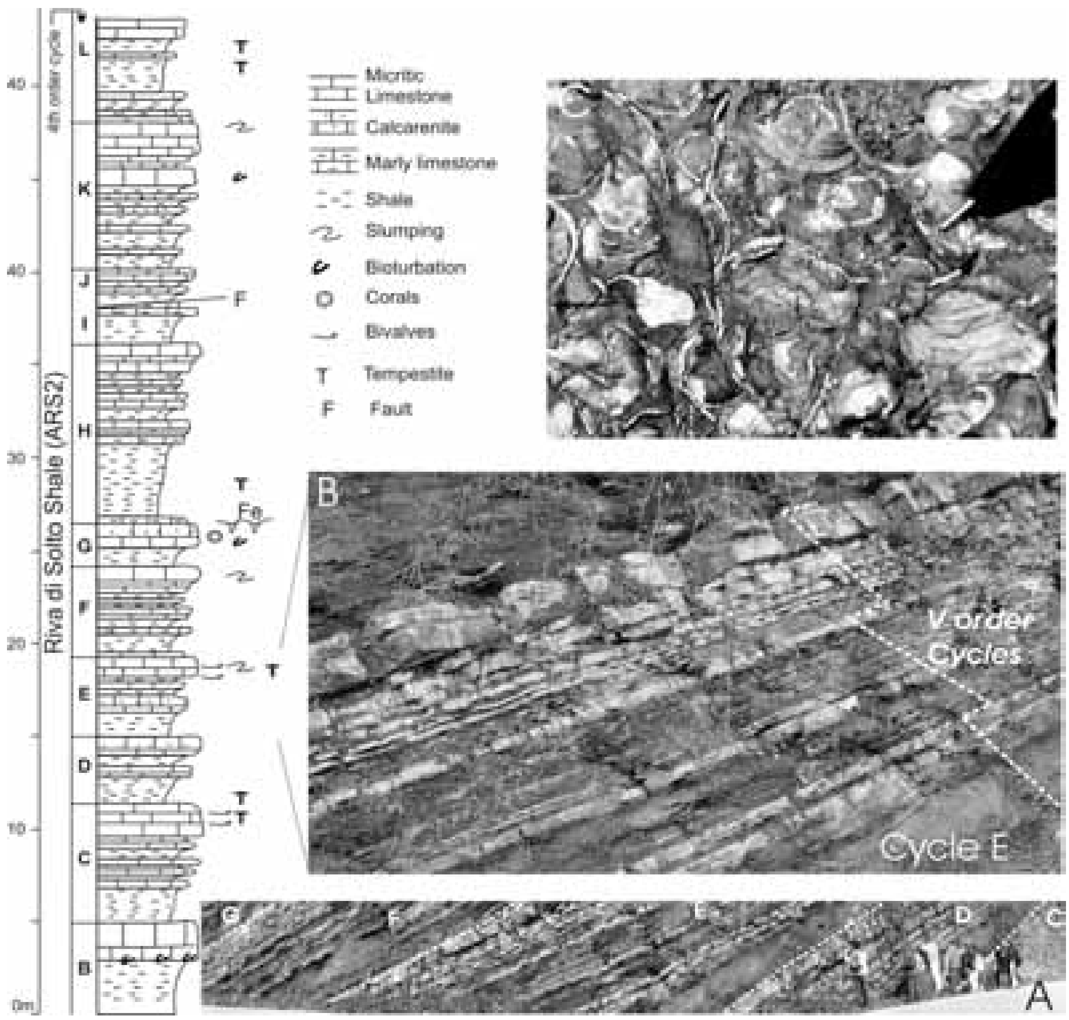

Figure 16 - Asymmetric cycles in the Riva di Solto Shale of V. Imagna (Stop 2.2).

sporomorphs, equidimensional inertinite, dispersed spheroidal and angular crystals of pyrite. Diagenetic and weathering pattern are indicative of a primary nature of the lithological alternations in the central part of the cycle.
The palynofacies study of similar cycles in other sections (Laxolo, Valle Imagna) shows a rapid decrease in palynomorphs specimen and a blooming fungal filaments associated to poorly sorted and rounded equidimensional inertinite. The palynofacies variation across the cycle shows a trend from disoxic-anoxic conditions in the lower part (testified by preserved AOM and pyrite) to more oxygenated conditions at the top, where the OM is degraded by fungi, bacteria and burrowers.
Cyclicity seems related to the amount of shale *vs*. limestones, documenting both an intrabasinal and extrabasinal source of the sediments. According to the fact that limestones are almost absent at the base of the cycle and shales are absent at the top, it is possible to recognize that the mechanisms that controlled the cyclicity was able to control both the extrabasinal input and the intrabasinal carbonate production. It is therefore possible to suggest that the delivery of shales was probably related to humid conditions which favored the transport of fine-grained terrigenous material from the European continent to the Tethyan gulf via fresh water. This was able to lower the salinity in the Lombardy Basin preventing a large productivity of limestones. During the arid portion of the cycle, shales were trapped on the European continent, whereas the normal marine conditions in the Lombardy Basin favored the production and accumulation of limestones. The time series (Claps, in Jadoul et al., 1994) show that all the overimposed fluctuations (lithologic couplets, basic fifth order and fourth order cycles) exhibit a thickening-up tendency, which is reflected in an asymmetric trend. The spectral analysis permits to discard a stochastic mechanism in producing the described cyclicity. The studied section represents the first case where obliquity is identified as dominant over the precession cycle, which so far has been recognized as the common expression of Milankovitch periodicity recorded in supplier platforms. Considering that the obliquity control is stronger at the middle latitude and that the Tethyan gulf was placed more southward, it is possible to suggest that cyclic climatic changes on the European continent (passage from arid to humid conditions) are reflected in the Tethys gulf due to the periodic input of shales and fresh waters.

Stop 2.3:

The upper ARS1 of the Ponte Giurino quarry (Figure 17).

Along the Valle Imagna road, close to Stop 2.2, we can observe a different ARS succession, separated by a fault from the previous one.

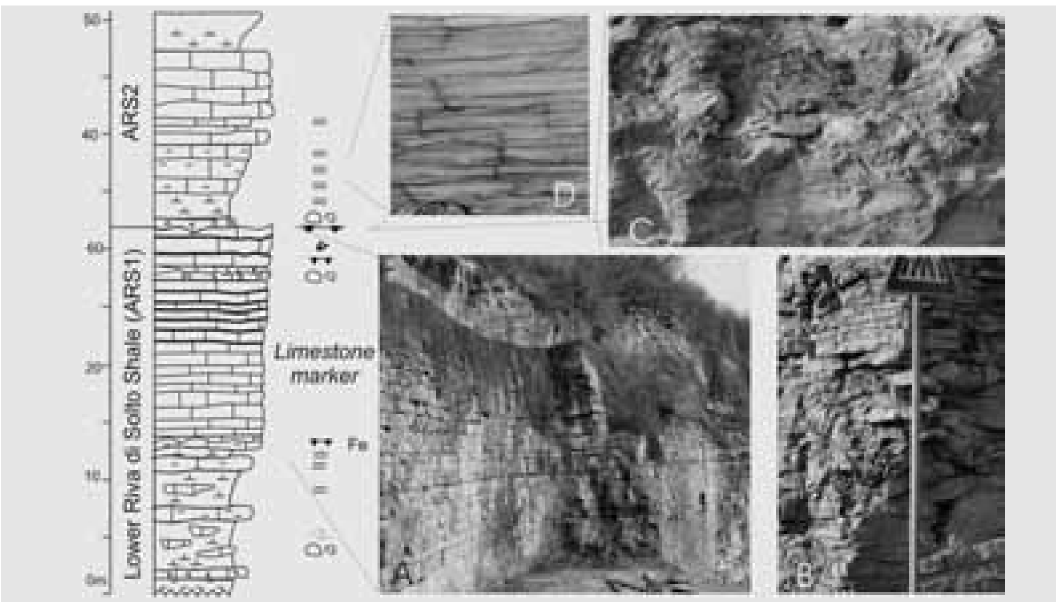

Figure 17 - The ARS1/AR2 boundary at Ponte Giurino (Stop 2.3).

A thick A- type cycle (Figure 6) at the top of the ARS1 and the boundary with the ARS2 are cropping out. The base consists of black shales, marls with slumpings (Figure 17B) and large clay chips, covered by laminated marls and marly limestones. The top of the cycle is characterized by a 17 to 20 m thick micritic carbonate horizon (stratigraphic marker in Valle Imagna) (Figure 17A) represented by monotonous dark grey mudstones with thin marly interlayers. Near the top fine matrix-supported paraconglomerates are present. The top of the cycle is characterized by a paraconformity (Figure 17C) exhibiting small intraformational breccia lenses (boundary ARS1/ARS2). In other outcrops of the Imagna Valley this boundary is also marked by a low angle unconformity. The overlying marly and marly limestone succession is characterized by rhythmic and planar arrangement of the laminae (1 to 20 mm thick) (Figure 17D). The organic matter analysis are described in A-type cycle (chapter 3.2). The palynofacies from this interval show cyclic pattern, each of 7-9 laminae. Each light-dark couplet shows in the dark laminae an enrichment in AOM (up to 60%), which often masks the sporomorphs, associated with pyrite and, in the light ones, an increase of fungal remains and inertinite.

Stop 2.4:

The fossiliferous ARS1 at Ponte Giurino (Figure 18).

This Stop is in the Brunone lateral Valley near the sulphurous spring (few minutes walking), about 60 m above the boundary with the DP. The outcrop exhibits well-bedded and laminated lithofacies association of an A-type cycle (Figure 6). At the base we observe fossiliferous, laminated shales and marls (Figure 18A) which pass upwards to marly, laminated limestones with large slumping structures (Figure 18B), and to bedded, laminate dark mudstones at the top. Shales and marls exhibit a rich fauna consisting of crustaceans (Arduini and Brasca, 1984), decapods (Garassino and Teruzzi, 1993), rare pelecypods and isopods. Pholidophoridae and Pholidophopleuriformes (Zambelli, 1986) are the most common fishes, whereas predators, such as gliding fishes (Tintori and Sassi, 1992), *Saurichthys*, and *Birgeria* are less common. Rare durophagous fishes have been recovered (Tintori, 1982). Findings of insects (*Italophlebia gervasuttii)*, a flying reptile and lepidosaurs indicate the presence of adjacent emerged lands. Fossil collection has been visited in the E. Caffi Museum (Stop 2.1).

The upper part of ARS1 yielded a palynological assemblage (Figure 3) which referred to the middle-upper part of Schuurman's phase II (Morbey's TR Zone, 1975, mid-late Norian) (Buratti et al., 2000; Buratti, 2002).

Palynofacies are dominated by AOM and by a high proportion of continental derived fragments, such as sporomorphs, cuticle and wood remains, indicative of relative proximity of the source area. In such depositional environments the presence of great amount of OM could be related to high sedimentation rate and to anoxic bottoms. The biofacies, lithofacies and palynofacies associations are therefore consistent with a faint slope and anoxic bottoms. However, rare anellids and bioturbation characterize a few bed surfaces recording short periods of poorly oxygenated bottom conditions (oxygen-related biofacies from anaerobic to quasi-anaerobic; Bottjer and Savrda, 1992). Despite the complete anoxia recorded at the sea floor, the peripheral parts of the basin and the upper water column must have had oxygen enough to sustain the flourishing benthonic and nektonic community. The local presence of terrestrial fossils indicates emerged areas adjacent to the basins. The emerged lands provided a great nutrient supply associated with a consistent freshwater contribute, as confirmed by the presence of the fresh-water alga *Pediastrum*. This event was probably related to a period of higher continental runoff bringing large amounts of terrestrial particles and low-density freshwater. These factors led to an intensified water stratification and low disoxic to anoxic environments, providing the necessary conditions for the deposition of organic rich shales (Buratti et al., 2000). The freshwater influence and the significant presence of hygrophitic palynomorphs can be related to a climate humidification. This is also supported by sedimentological evidence such as the high sedimentation rate documented by the thickness of the ARS1 and by the presence of abundant c1ay ('argillaceous event') in the depositional environment, which led to a regional crisis in carbonate productivity.

The whole ARS succession lacks sedimentologic evidences of shallowing or coarsening upward trends. The structures from the base of cycles indicate deposition on a gentle slope. They could be deposited on a distal carbonate ramp, although transitional facies to a mid-inner carbonate ramp have not been recorded in the studied areas. The presence of mudstones poses the question about their source area. We infer that the carbonate source was probably located westwards or southwards.

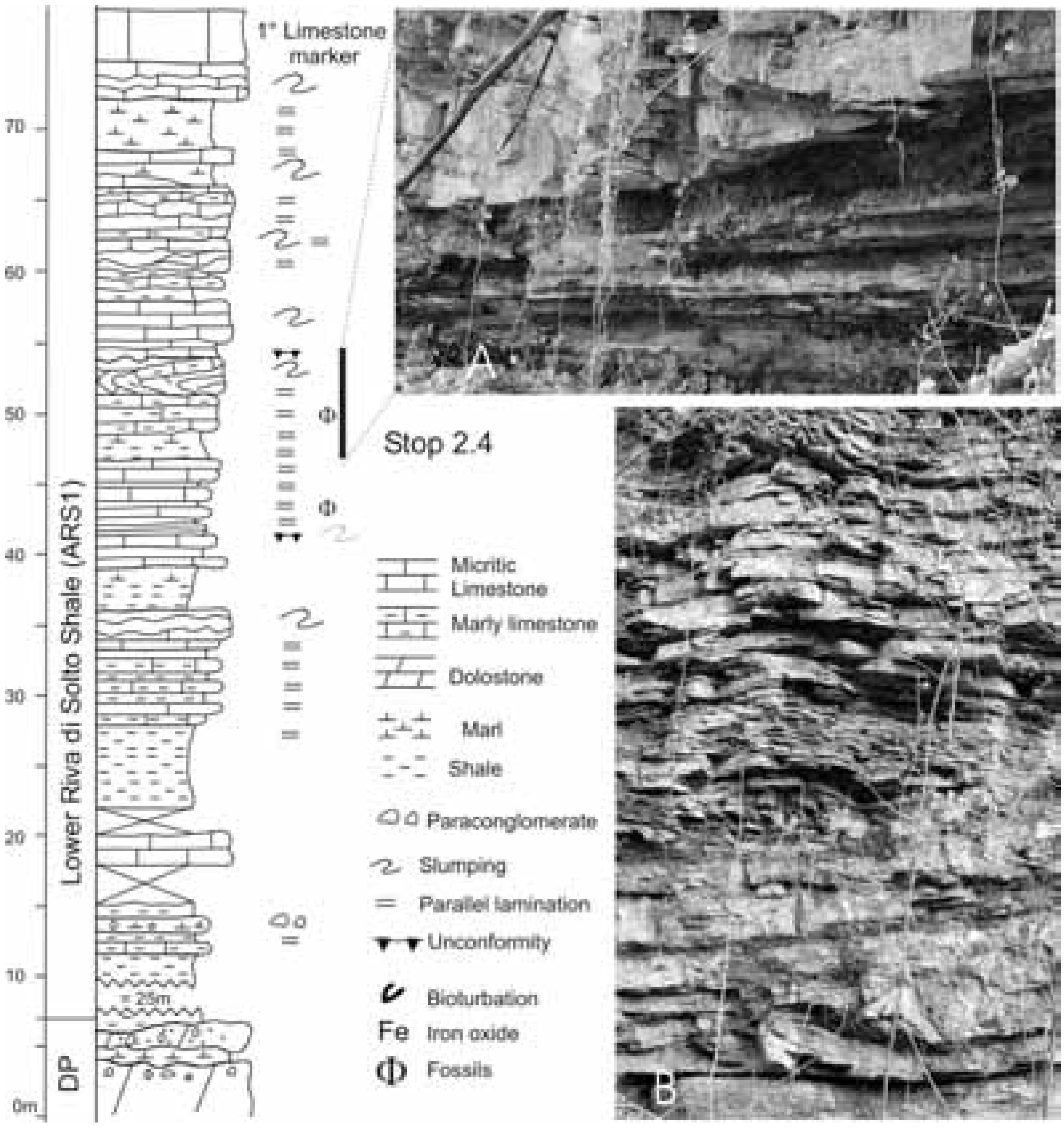

Figure 18 - The ARS1 section of Ponte Giurino (Stop 2.4).

Stop 2.5:

The Norian-Rhaetian transition and the first Rhaetian carbonate platform (Zu2) of Brumano (higher Valle Imagna) (Figure 19).

Along the Rota Imagna-Brumano road the whole Zu Limestone succession crops out. The visit focuses on the first, thick Rhaetian carbonate platform (Zu2). The Zu1-Zu2 transition (Stop a, Figure 19) consists of meter to decameter marl-limestones cycles. Marls contain large pelecypods (*Homomia* sp., *Cardita* sp., *Trigonia* sp.) (Figure 19A) and a palynologic association which records the Norian-Rhaetian transition (Figure 3). The overlying bioturbated limestones at the top of the cycles yield corals, brachiopods, crinoids and foraminifers, phosphate clasts and quartz grains.

The Zu2 is characterized by a sharp decrease of the fine siliciclastic content (Figure 19). Three minor subdivisions can be recognized within the Zu2 carbonates.

a) Lower Zu2: the platform succession is characterized by a 18 m thick, shallowing upward and, in part,

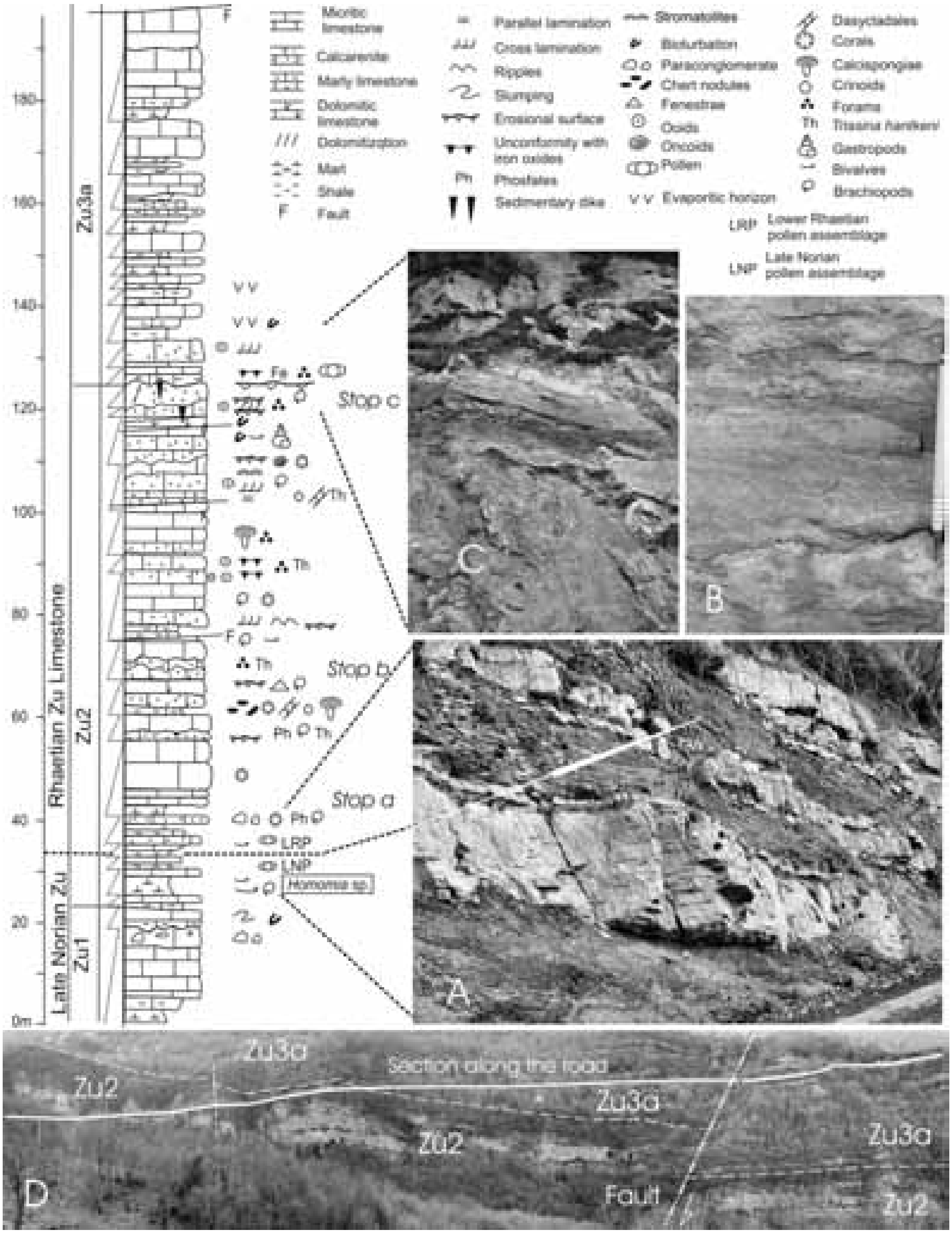

Figure 19 - The Norian-Rhaetian transition and the platform progradation (Zu2) of the Brumano section (Stop 2.5).

coarsening upward carbonate cycle (D-type cycle) consisting of mudstones-wackestones and associated *Retiophyllia* spp. patch reefs at the base. Bioclastic packstones with sponge, echinoids, *Microtubus* sp., *Porostromata* and foraminifers (among which *Triasina hantkeni*; Figure 22) and mudstones overlying fine breccias are more common at the top (Stop b, Fig 19).

b) Middle Zu2: it is characterized by intra-bioclastic packstones with fenestrae, covering marly limestones with chert nodules and interspersed corals. Towards the top of this part of the succession, the trend is still shallowing and coarsening upward and the facies commonly consist of intra-bioclastic, foraminiferal packstones, bioclastic storm-layers and oolitic grainstones. Cross laminations and wave ripples are quite common.

c) The upper Zu2 (Stop c, Figure 19): it consists of two major shallowing and coarsening upward cycles (D-type) with bioturbated mudstones and wackestones at the base and, upward, bioclastic packstones, oolitic grainstones and rare stromatolitic bindstones. Small *Porostromata* colonies and associated bioclastic lenses with brachiopods (*Rhaetina gregaria*) characterize the base of the prograding oolitic shoals. Erosional surface (Figure 19B), cross bedded calcarenites and small sedimentary dikes are also present near the top of this unit that is partially dolomitized (last 6-7 m) and show a regressive trend responsible for the development of a discontinuity with fine, bioclastic breccia pockets and oolitic grainstones at the top (Figure 19C).

The overlying Zu3 records the recovery of marl-limestone cycles (Zu3a) (Figure 19D). The first cycle is still transitional, with prograding oolitic shoals at the top. The arrangement of the overlying asymmetric cycle differs in the minor fossil content and for the predominant laminated mudstones, dolomitized marls and ochre, vuggy marly limestones (C-type cycles). These represent the lower Zu3 facies which will be observed in detail on Stop 3.1

The facies evolution of Zu2 illustrates a general shallowing trend related to the prograding carbonate ramp system on the Imagna-Taleggio depression (Figure 15). The eustasy-controlled shallowing trend also allowed the development of inner-middle ramp facies on the Albenza-Imagna sector (top of the succession) and local subaerial exposures.

The overlying, cyclic lower Zu3 facies record a progressive crisis of carbonate production in the ramp system polluted by terrigenous input (Figure 15).

DAY 3

The upper Rhaetian carbonate ramp cycles, the Triassic-Jurassic transgression and the Hettangian carbonate platform (Mt. Albenza).

On the private road of the Italcementi Quarry (Stops 3.1; 3.4) and on the Valcava-Torre dei Busi road (Stop 3.5) in the Mt. Albenza (from 1000 to 1115 m) it is possible to observe in two different sections the uppermost Triassic-lowermost Jurassic succession of the Bergamasc Alps, represented by the upper Zu (Zu3 and Zu4 members, about 150 m thick) and the lower Hettangian CD. The Rhaetian/Hettangian boundary, still matter of a controversial debate, is here documented in a marine succession.

A clear assessment of the Triassic/Jurassic (T/J) system has been hindered by the scarcity of continuous marine sections spanning the Rhaetian/Hettangian (Hallam and Wignall, 1997). This is why the T/J boundary is better defined in continental settings (Kent and Olsen, 1999) but remains a matter of debate in marine sections (i.e. Hesselbo et al., 2002 and references therein).

Stop 3.1:

The Rhaetian marly-carbonate cycles of the upper Zu Limestone (Zu3 member) (Figure 20).

Along the private road of the Italcementi quarry the Zu3-CD Albenza succession is well cropping out.

The cyclic Zu3 member consists of three different lithofacies associations: Zu3a, mainly represented by D-type cycles, Zu3b exclusively with C-type cycles and Zu3c characterized by D-type cycles (Stop 3.2).

The lower succession (Zu3a) is composed of 7.5 to 15 m thick marly limestone asymmetric cycles (IV order) exhibiting bioturbations and local iron-oxides crusts at top of the carbonate banks.

In the middle part of the succession (Zu3b; Figure 20) cycles are thinner (2.5 to 8 m thick) with finer siliciclastics and lacking evidences of shallowing or coarsening upward trend. At the base they are characterized by grey and dark grey marls with pelecypods (i.e. *Rhaetavicula contorta)* and *Bactrillium*. Laminated or bioturbated marly bioclastic limestones (echinoids, ostracods, crinoids, brachiopods) containing phosphatic and quartz grains intercalate within the marls. Bioclastic and oolitic thin storm layers (Figure 20C) characterize the lower-middle part of the carbonate intercalations. Oolites exhibit iron oxide rims. A few cycles at the middle part of the succession are characterized by carniole-

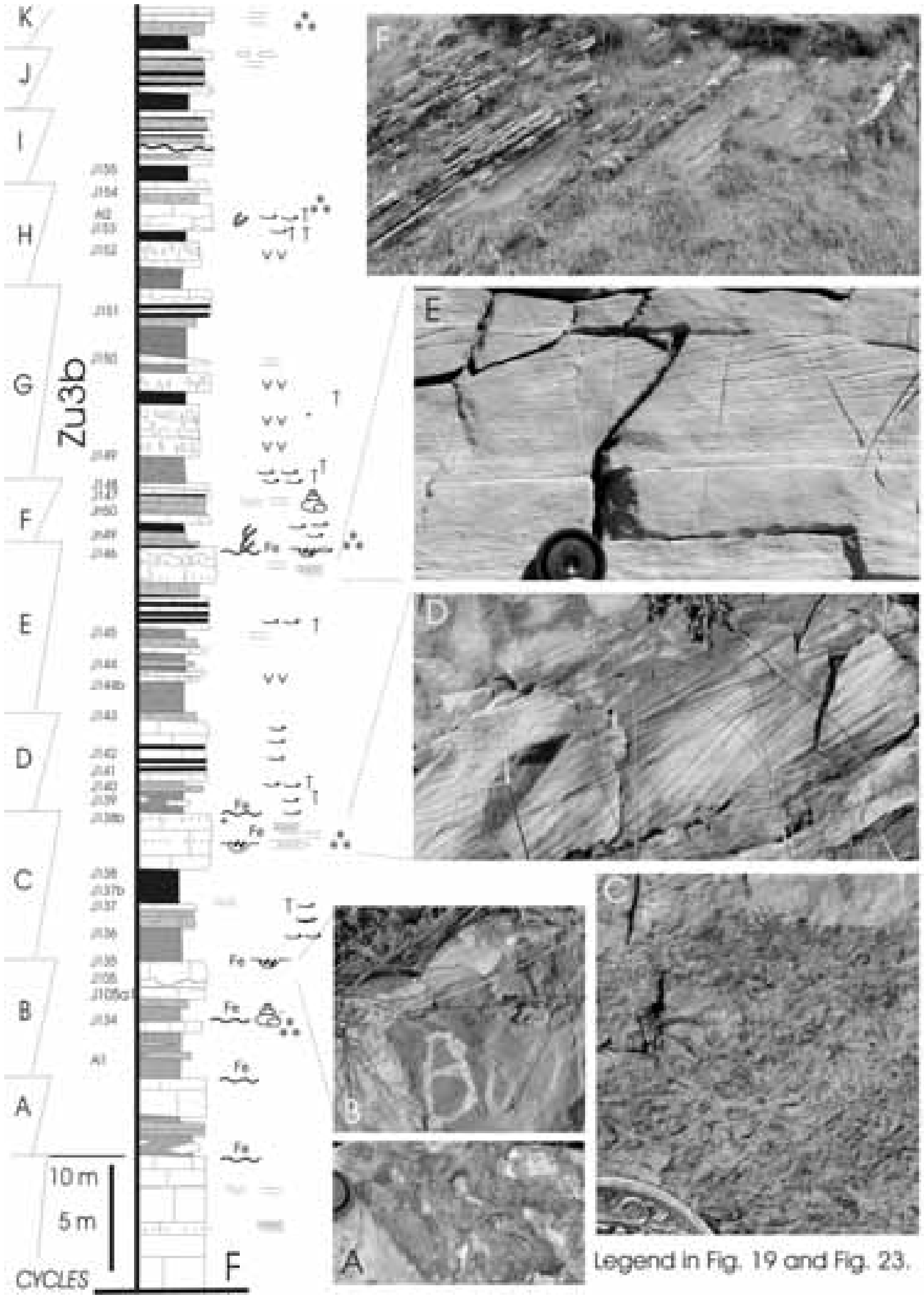

Figure 20 - Italcementi section with cyclicity and macrofacies of Lower-Middle Zu3 (Stop 3.1).

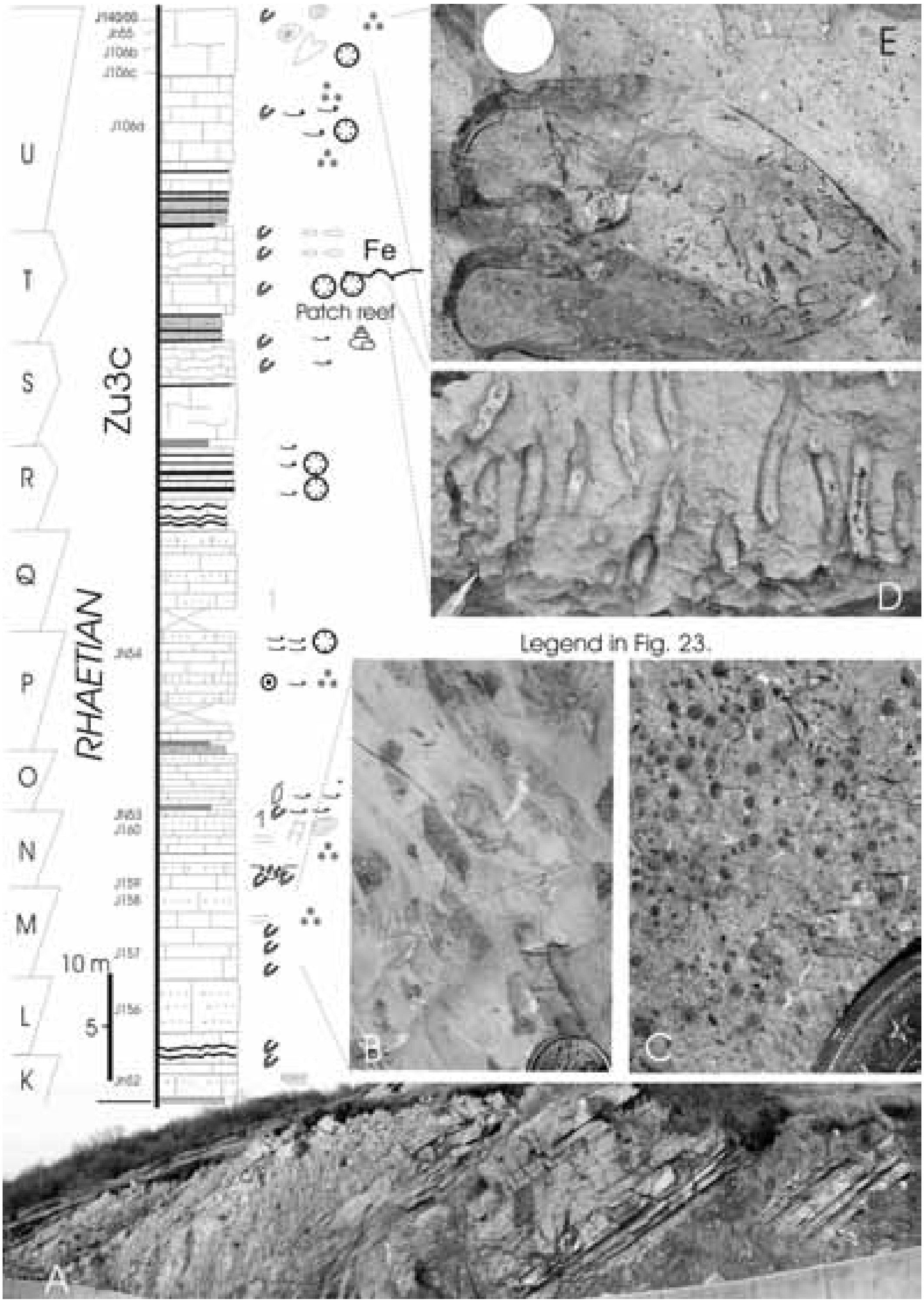

Figure 21 - Italcementi section and macrofacies of the upper Zu3 (Stop 3.2).

type marly limestones, with evaporite molds, and black shaly intercalations.
Carbonates of the upper cycles are mainly fine grained and in the middle part they are occasionally intercalated with fine oolitic and intra-bioclastic packstones with rare cross laminations, ripples and erosional surfaces (Figure 20D, E). Bioturbated wackestones-packstones with fecal pellets (*Parafavreina* sp.) are frequent at the top of these beds. Top cycles are outlined by bioturbations and by iron-oxide microbial crusts (Figure 20A, B), interpreted as non-depositional surfaces (hardgrounds). These horizons record the crisis of carbonate productivity and the abrupt shift to terrigenous sedimentation.
Palynofacies contain high percentage and high species diversity of sporomorphs often in tetrad status, associated with other terrestrial phytoclasts (tracheids, cuticule and wood remains). A peak of xerophytic sporomorphs is recorded in the carniole-type horizons.
Facies association of this succession is interpreted as a mid ramp environment. In the Albenza area this terrigenous-carbonate sedimentation records also hypersaline and restricted conditions and hiatuses at the top of several asymmetric cycles (Zu3a and Zu3b).

Stop 3.2:

The shallow-water, uppermost Rhaetian, progradational carbonate cycles (lithozone Zu3c) (Figure 21).

The uppermost Zu3 member (Figure 21A) is characterized by an increase of biogenic and oolitic packstones-grainstones intercalated with laminated or bioturbated (Figure 21B) mudstones-wackestones. The fossil assemblages are richer in the last carbonate banks (Figure 21): foraminifers (Aulotortidae among which *Triasina hantkeni*) (Figs. 21C, 22), corals, sponges, problematica and encrusting organisms (Lakew, 1990). A few coral patch-reefs (*Thecosmilia* sp.) (Figure 21D) are present and large Megalodontids (Figure 21E) and oncoids characterize the top of the last cycle (Figure 21).
Palynofacies show an increase in marine OM (i.e. dinoflagellate cysts, foraminifer linings and algal spores), reflecting high productivity, low rate of terrigenous pollution and shallow water normal marine conditions.
Zu3c identifies the second, regional progradation of the carbonate platform. Facies organization of Zu3c documents the last Rhaetian carbonate inner ramp progradation in central Lombardy testified also by its shallowing and shoaling upward trend. This regression could be related to a relative sea level fall at the end of Triassic.

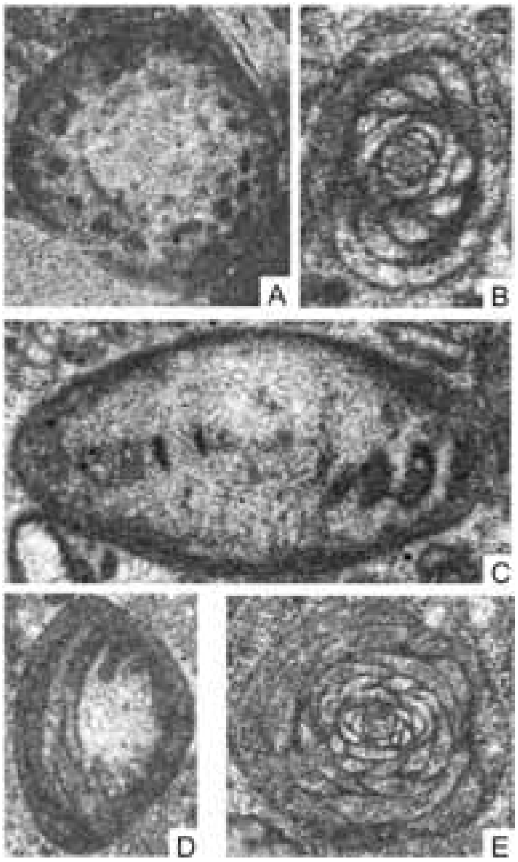

Figure 22 - Foraminiferal assemblages of Zu. A: Triasina hantkeni, B: Gandinella falsofriedli C: Aulotortus gr. sinuosus, D: Auloconus permodiscoides, E: Pilammina sulawesiana.

Stop 3.3:

The transgressive micritic limestones (Zu4 member) and the T/J boundary in the inactive Italcementi quarry (Figure 23).

In the western Albenza area, the sharp Zu3/Zu4 boundary (Figure 23) is outlined by a hiatus, marked by a Fe-rich hardground which may represent a sedimentation gap at the base of Zu4 member in the Albenza structural high. It may be correlated with a marly horizon present in the lowermost Zu4 member in the eastern area (Iseo section, Figure 14). It could indicate the presence of a more complete stratigraphic succession in the eastern Bergamasc area then to the western Albenza.

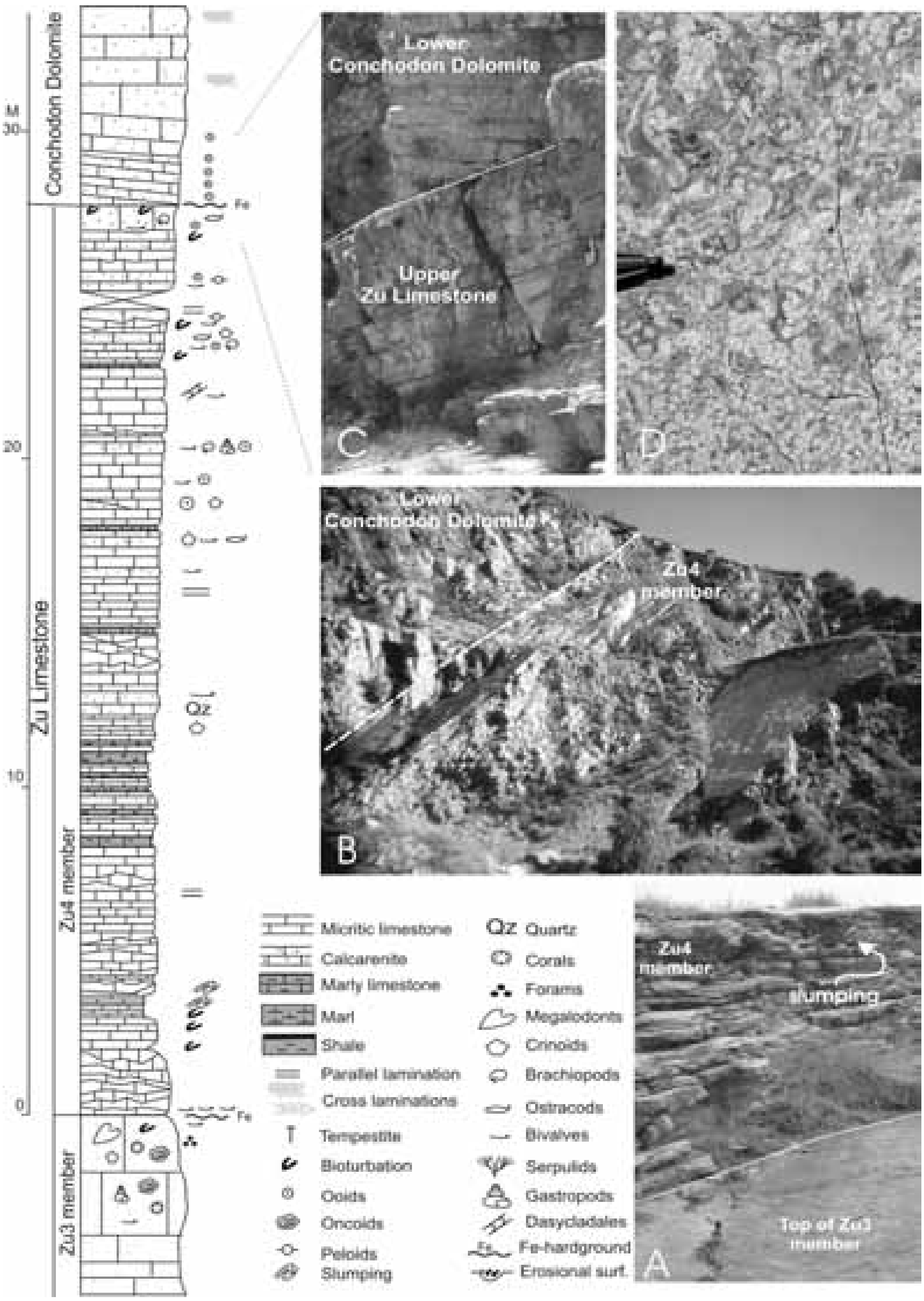

Figure 23 - Zu4-Lower Conchodon Dolomite in the Italcementi quarry (Stops 3.3; 3.4).

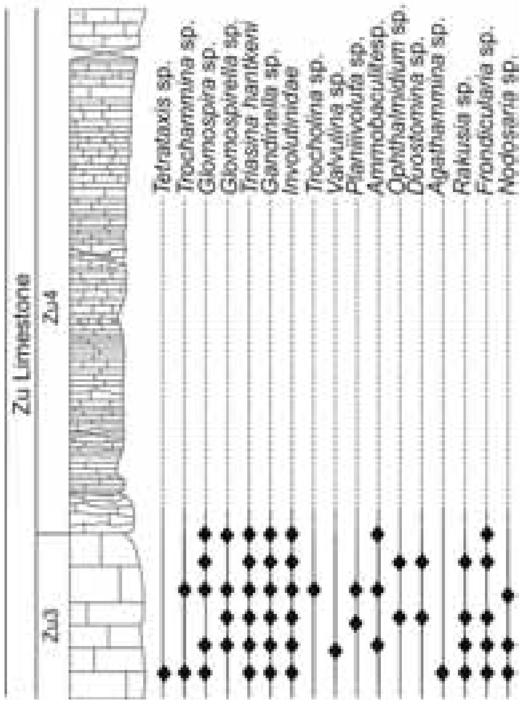

Figure 24 - Foraminiferal distribution in the upper Zu Limestone (simplified from Lakew, 1990).

Zu4 differs from the other Zu members in lacking any evidence of cyclicity. It represents a stratigraphic marker horizon, up to 30 m thick, separating the upper Rhaetian from the lower Hettangian shallow-water carbonates.

It consists of thinly bedded (centimeter to decimeter scale) grey–dark grey micritic limestones, with marly intercalations decreasing upward (Figure 23).

Zu4 may be subdivided in two different lithofacies associations:

1) The lower part consists of prevalent mudstones-wackestones, with rare thin-shelled bivalves and crinoids. Bed surfaces are often bioturbated with thin intercalations of intraclastic-peloidal packstones. Slumping phenomena are frequently present (Figure 23A).

2) The upper part (Figure 23B, C) differs from the underlying in the progressive upward increase of calcarenites consisting of bioclastic wackestones-packstones with thin-shelled bivalves, crinoids, ostracods and gastropods. They are intercalated to mudstones passing to grainstones, containing reworked ooids, peloids, intraclasts and bioclasts mostly represented by bivalves, brachiopods, gastropods, Dasycladales, crinoids and rare bryozoans.

Macrofacies and microfacies analysis from Zu4 member did not reveal any fossils useful for

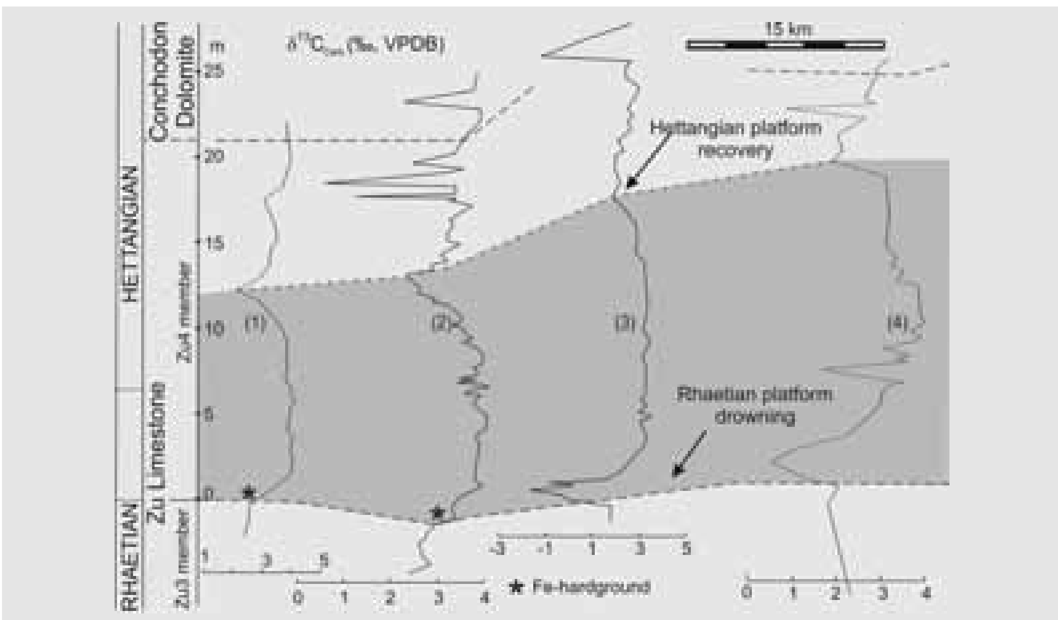

Figure 25 - Chemostratigraphic data from Mt. Albenza sections: (1) Valcava-Torre dei Busi road, (2) Italcementi, (3) Malanotte and (4) Iseo section.

biostratigraphic correlation. The rich micro- and macrofaunal assemblages, characterizing the underlying strata abruptly disappear at the top of Zu3 member (Figure 24). Palynological studies carried out on numerous sections have enabled the location of the T/J boundary in the micritic limestones of the lower Zu4 member.

Based on the palynological composition from Zu3 to Zu4 and on the first occurrence of *Cerebropollenites macroverrucosus*, Cirilli et al. (2000) and Galli (2002) propose to locate the palynological T/J boundary in the Zu4 mudstone succession (Figure 3).

A detailed stable isotope study of the Zu4 document that this unit exhibits an excellent preservation of the isotopic signal as testified by the reproducibility of data in all the investigated sections (Figure 25). A marked negative anomaly at the base of a positive excursion has been identified in the Eastern sections (Figure 25). Although the sampling density was very high, in the more proximal area (Albenza) the negative excursion is absent, possibly due to condensation/sedimentary gap and iron mineralization at the top of the drowned carbonate ramp (Lakew, 1990; Jadoul et al., 1994).

The detailed C-isotope records across the marine T/J boundary interval in the Lombardy Basin document (Galli et al. submitted) that the C-isotope anomaly coincides with the end-Triassic biotic crisis and with a widespread carbonate-platform drowning. Galli et al. (submitted) argue that a sudden increase in atmospheric CO_2 was responsible for the C-cycle perturbation and, consequently, for the marine biotic crisis at the end of the Triassic.

Lithological features and facies analysis of Zu4 underline an important relative sea-level rise that controlled the deposition of micritic limestones all over the inner-outer Rhaetian ramp system, leading to a more uniform outer ramp depositional environment. The transgressive event of the Zu4 may be related to the well known transgression recognized in the lower Hettangian of the Western Europe (Hallam and Wignall, 1999).

The abundant ooid facies of the lower CD present in all the Albenza area seems to represent the proximal-high energy margin of the rimmed carbonate ramp that separates the peloidal lagoon facies from the more open subtidal environment.

Stop 3.4:

The Early Hettangian Bahamian-type platform (Conchodon Dolomite) (Figure 23).

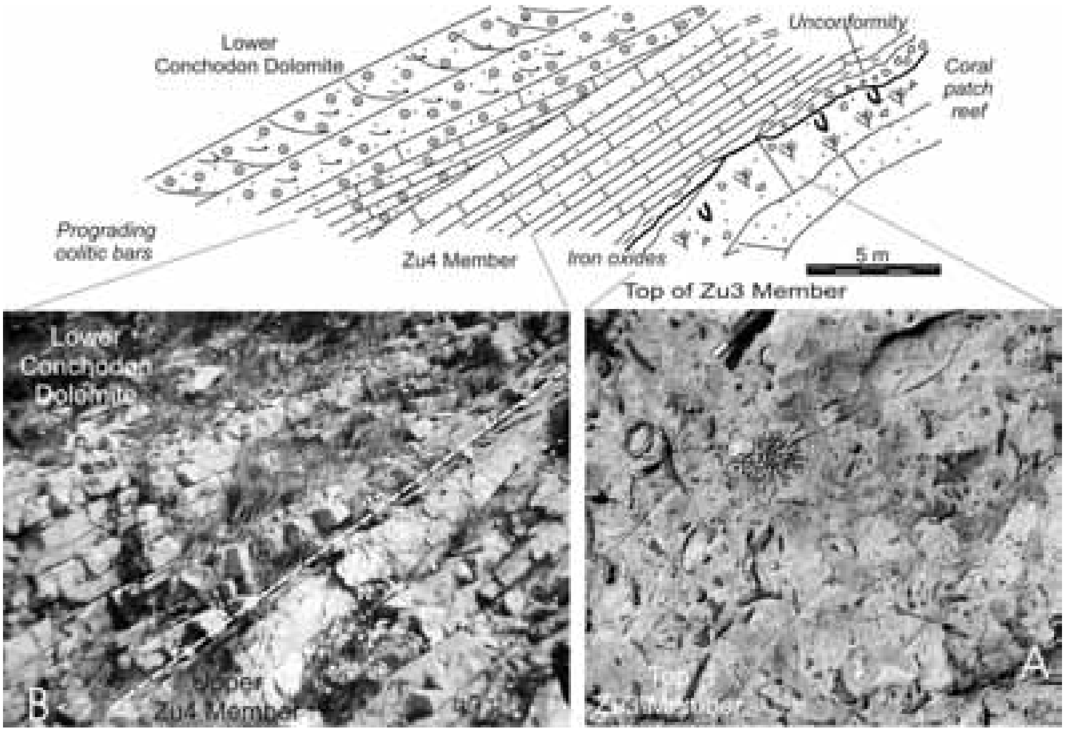

Figure 26 - Details of the Zu Limestone-Conchodon Dolomite transition along the Valcava-Torre dei Busi road.

In the Albenza area (Figs. 23D, 26), the Zu4 is overlain by the evident downlapping (with angle of 25-30°) cross-bedded oolitic bars of the basal CD. The lower part of the CD is mainly represented by oolitic grainstones passing upward to fine to coarse grainstones, with selective dolomitization and bio-intraclast pockets and frequent cross and herringbone laminations. Grainstones often containing micritised ooids, grapestones, lumps and coated grains (Figure 23D), are prevalent at the base, while upwards they are intercalated with peloidal packstones. Bioclasts are mostly bivalves, brachiopods, Dasycladales, Lithocodium fragments, echinoids and rare bryozoans. The Zu4-CD succession documents a new transgressive-regressive third order cycle (Figure 15) (interpreted as the first Hettangian depositional sequence) and a significant physiographic change of the depositional environment with a major contribute of carbonate productivity with respect to the Rhaetian sequences. The fine mixed siliciclastic-carbonate ramp (Zu) was finally replaced by a Bahamian type carbonate platform (CD) that, in the lower part still maintains a proximal ramp-type physiography.

Stop 3.5:

The Triassic-Jurassic boundary on the Valcava-Torre dei Busi section (Figure 26).

On the Valcava-Torre dei Busi road (about 1000 m in altitude) (Figure 26) the uppermost Triassic-lowermost Jurassic succession is well cropping out, showing the sharp Zu3-Zu4 contact (Figure 26A), the transgressive micritic limestone (Zu4 member) and the Zu–CD transition characterized by the same downlap (25-30°) (Figure 26B) observed on Stop 3.4. Palynological (Figure 3) and stable isotope results (Figure 25) of this section have been summarized on Stop 3.3.

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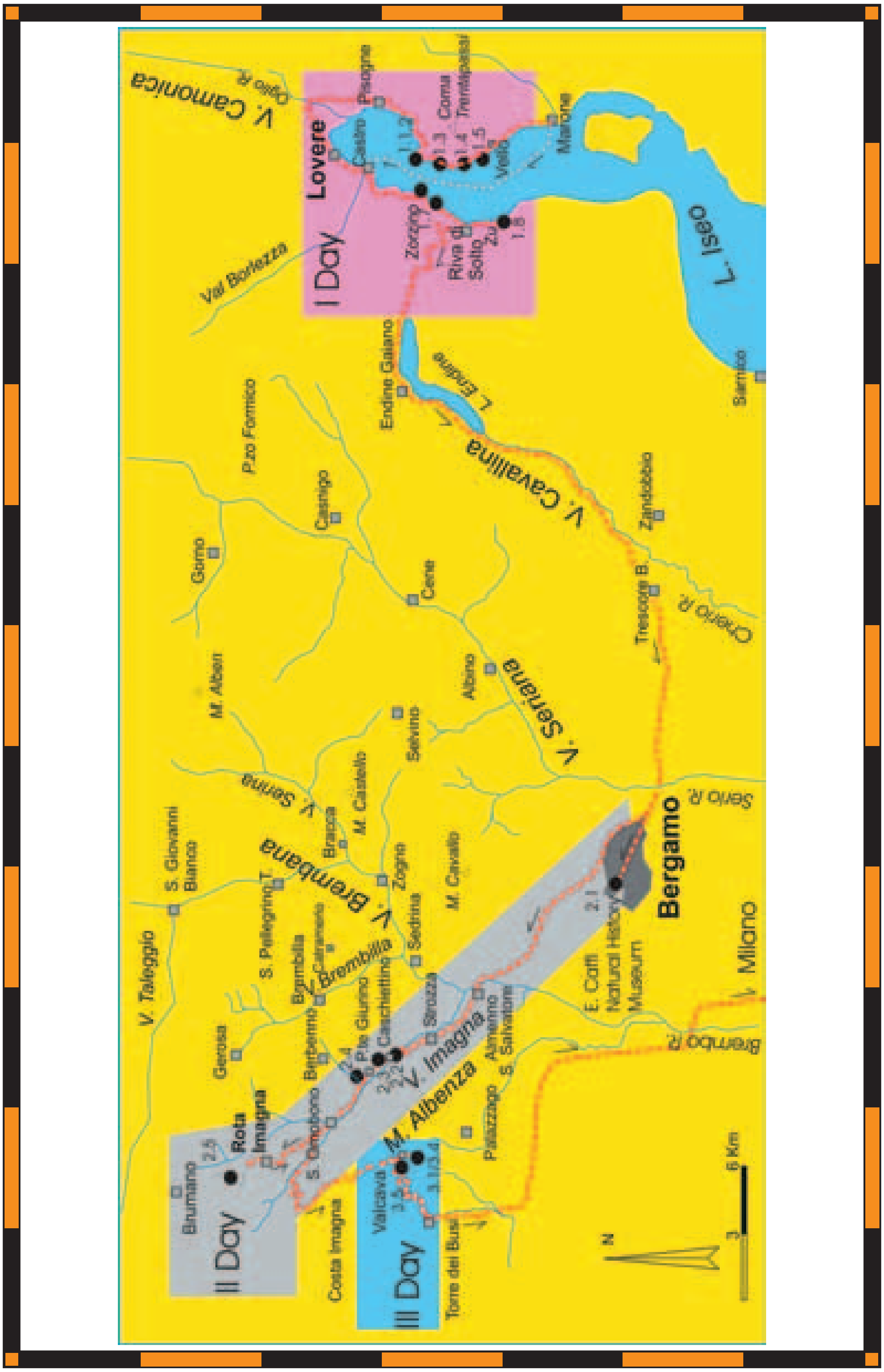
Back Cover:
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP



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