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FIELD TRIP GUIDE-BOOK

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PRE-SYMPOSIUM FIELD TRIP GUIDE

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TRIASSIC MICROBIALLY-INDUCED CEMENTS AND MICROBIAL CARBONATES: EVINOSPONGE FROM THE LADINIAN CALCARE DI ESINO AND MICROBIAL MOUNDS FORM THE NORIAN DOLOMIA PRINCIPALE

INTRODUCTION

During this field trip you will become familiar with microbial and microbially-induced limestones and cements from two carbonate systems, different for ages, depositional architecture and tectonic setting: the Ladinian Esino Limestone and the Norian Dolomia Principale. The characteristics of the microbial and microbially-induced carbonates strongly reflect the diverse environmental and paleogeographic conditions which controlled the evolution of the two considered carbonate factories.

The two systems were deposited on the Tethys margin, the oldest (Ladinian) during a tectonically quiet interval in the Central Southern Alps, whereas the Norian one was characterized by intense syndepositional extensional-transtensional tectonics (JADOUL ET AL., 1992a).

Later, the sedimentary succession records from the Early Jurassic the earliest stages of the evolution of a passive margin that will represent since the Middle Jurassic the southern margin 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. The successions which will be observed in the excursion belong to a slightly deformed portion of the Alpine chain (Fig. 1), and give the opportunity to study the sedimentological and diagenetic processes that affected the Middle and Upper Triassic units of this portion of the Southern Alps (Lombardy Basin).

During the field trip we will visit the two systems in the reverse stratigraphic order due to logistics.

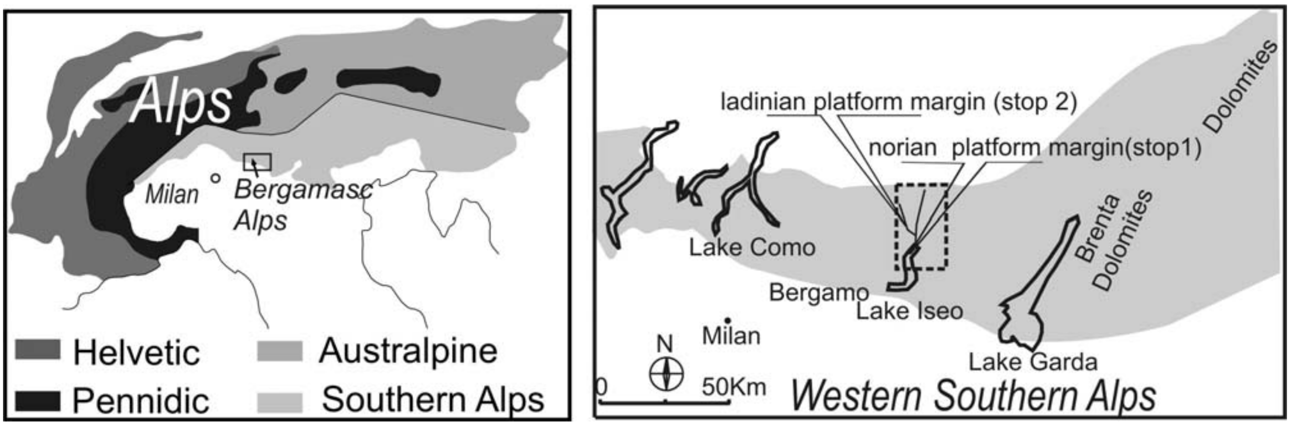


Fig. 1 – Location of the field trip area (modified after JADOUL ET AL., 2004)

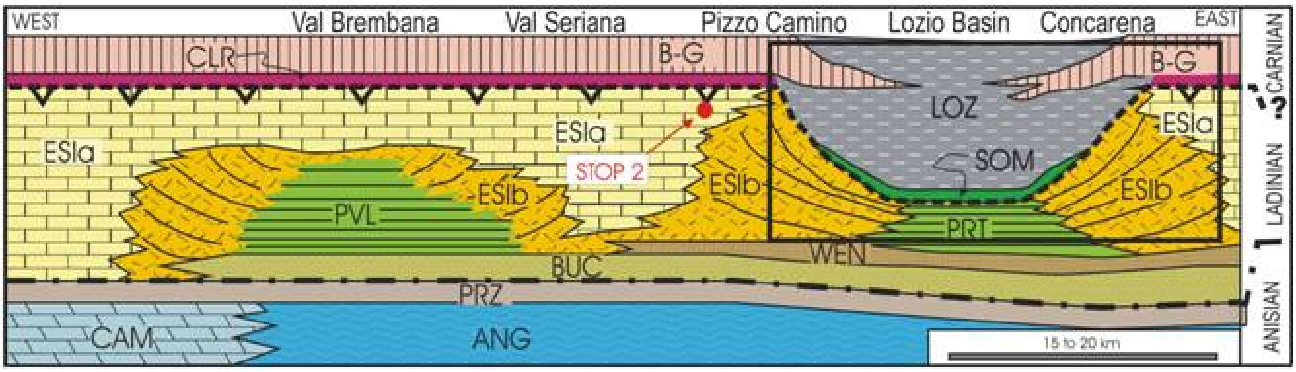


Fig. 2 - Simplified stratigraphic scheme across Central Lombardy from Anisian to Carnian (modified after BERRA, 2007)

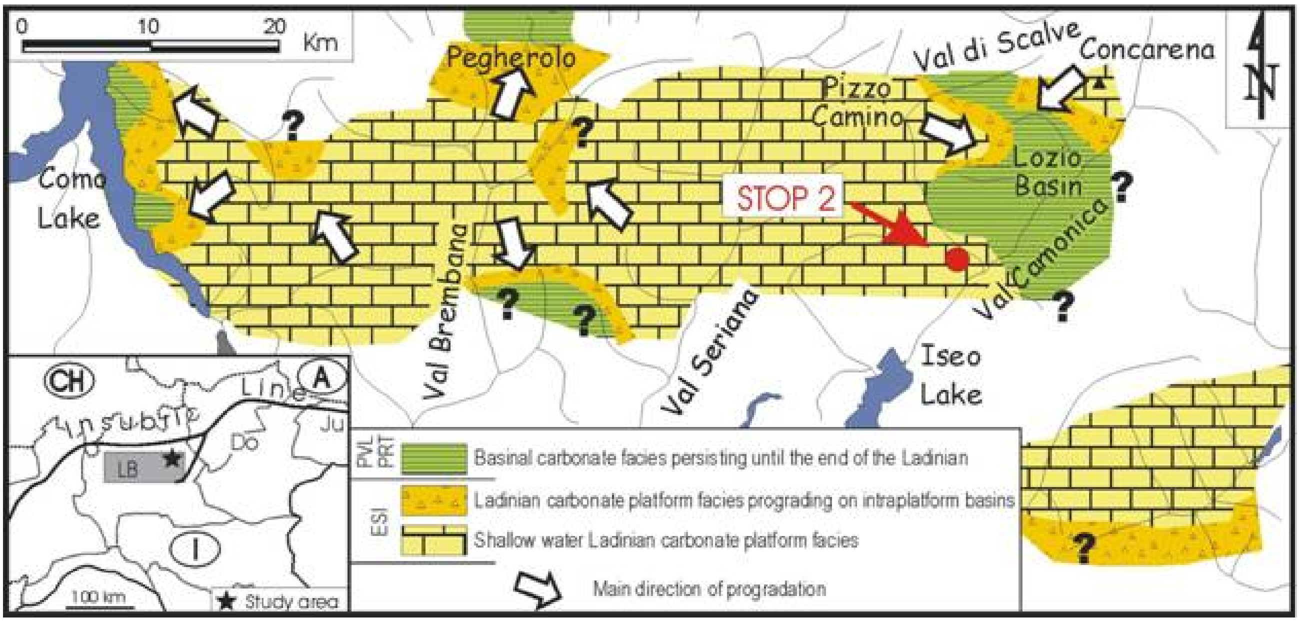


Fig. 3 – Simplified paleogeographic sketch of Central Lombardy during the deposition of the Esino Limestone (modified after BERRA, 2007)

REGIONAL GEOLOGIC SETTING

Ladinian succession

The Ladinian succession of the Southern Alps is characterized by the presence of thick carbonate platforms separated by basinal troughs and seaways, where deep water sediments were deposited (Fig. 2, Fig. 3). In Lombardy the carbonate platforms (Esino Limestone) are mainly represented by inner platform facies rimmed by reefal and sandy margin facies evolving to slope breccias (JADOUL ET AL, 1992b; BERRA, 2007).

In western Lombardy shallow-water facies prevail and basinal facies are deposited in narrow seaways and troughs. Before the end of the Ladinian the basinal facies were generally overlain by shallow-water successions (Esino Limestone) due to platform progradation. In some places (eastern Lombardy, Lozio Basin, and northern Lombardy, Pegherolo Massif), basinal facies persisted throughout the Ladinian as platform progradation was not sufficient to close the intraplatform basins

(Fig. 2). In these areas, the flat-topped carbonate platform (Esino Limestone) reaches a maximum thickness of about 700m and rapidly pinches out basinward with steep clinostratified (about 35°) slopes.

The inner platform facies are generally represented by calcareous, light-coloured, thin-bedded, intra-bioclastic packstones, often rich in fragments of dasyclad green algae, oncolitic horizons and stromatolitic layers. Oolitic beds are locally present. The overall stratigraphic characteristics of the succession resemble those of many Ladinian inner platform successions studied throughout the Southern Alps (i.e. Latemar: GOLDHAMMER ET AL., 1990; Esino Limestone: JADOUL ET AL., 1992b; Marmolada: BLENDINGER, 2001). The inner platform facies are bordered by a narrow reef belt characterized by abundant coral framestones, sponges and *Tubiphytes* that also colonize the upper part of the slope. The reef belt (SEELING ET AL., 2005) passes laterally into slope deposits, represented by a monotonous succession of massively-bedded clinostratified breccia deposits. These deposits mainly consist of clast-supported breccias, with a maximum size of clasts that often exceed two metres and an average size of a few decimetres. Cement-filled voids between the clasts document the scarcity of fine-grained components. The larger cavities are filled with laminated internal sediments that commonly contain ostracods. Only in the deeper part of the slopes, where the size of the clasts decreases, fine-grained sediments fill the intergranular space. Dissolution cavities partially or totally filled by concentric and botryoidal cements (evinosponge: JADOUL & FRISIA, 1988; FRISIA-BRUNI ET AL., 1989) are present, mainly in the upper slope facies. In some of the coeval Ladinian platform deposits of the Dolomites, clinostratified deposits on build-up flanks contain lenses of breccias produced in situ by translational sliding and fragmentation of automicrite in early diagenetic stages, with displacive growth of fibrous calcite cements (BLENDINGER, 2001). In the Esino Limestone, clasts are polygenic and they generally are derived from reef-upper slope facies. Clasts of *Tubiphytes* bafflestones and coral framestones are common, together with coarse bioclastic packstones (often yielding gastropods and pelecypods). Microbialites and clasts consisting of automicrite are also present, suggesting a minor occurrence of in situ brecciation. Within the clasts, margin organisms generally show a random orientation, documenting that they are not in growth position but resedimented from the higher part of the slopes. The heterogeneous composition of the clasts, their lithofacies and the high-angle of depositional surfaces (35–40°) fit a model for their origin of accumulation of coarse, non-cohesive and mud-free sediments (KENTER, 1990; HARRIS, 1994) produced by unstable portions of the upper slope and reef belt. Their instability was not related to syndepositional tectonics, but more likely to oversteepening of the margin due to high growth rates of the reef dwelling organisms. Submarine rock falls were generated when the reef margin became too steep and/or during severe storms, leading to the progradation of the platform. A similar origin of the slope breccias has been suggested for the coeval facies of the Latemar and Rosengartner-Catinaccio platforms in the Dolomites (HARRIS, 1994; MAURER, 2000) and for the Carboniferous platforms of western Kazakhstan (Tengiz oil field, WEBER ET AL., 2003).

The transition from the slope to the basin is quite sharp, as the clinoforms pass abruptly into dark, bedded fine-grained calcarenites and mud-stones that characterize the deeper part of the basin (Pratotondo Limestone). These limestones mainly consist of dark, laminated, intraclastic packstones, are generally thin-bedded (average thickness around 10–20 cm, only rarely massive beds up to 3–10 m thick occur), and commonly show normal grading. These deposits probably formed during turbidite flows sourced on the carbonate highs. Locally, paraconglomerate beds up to a few decimetres thick are present.

Norian succession

The upper Carnian to Rhaetian succession of Central Lombardy (Southern Alps) consists of two superimposed depositional systems (JADOUL ET AL., 2004) which outcrop along the E-W direction (Fig. 4). The 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. The uppermost Carnian-Rhaetian succession exhibits variable thickness (from 500 to 4000 m; ASSERETO & CASATI,1965), related to sedimentation controlled by transtensive tectonics (Norian asymmetric rifting; JADOUL ET AL., 1992a). The lower depositional system (uppermost Carnian to middle-late Norian) lies on shallow water carbonates, evaporites and siliciclastics (sabkha facies, S. Giovanni Bianco Fm.) and is represented by the

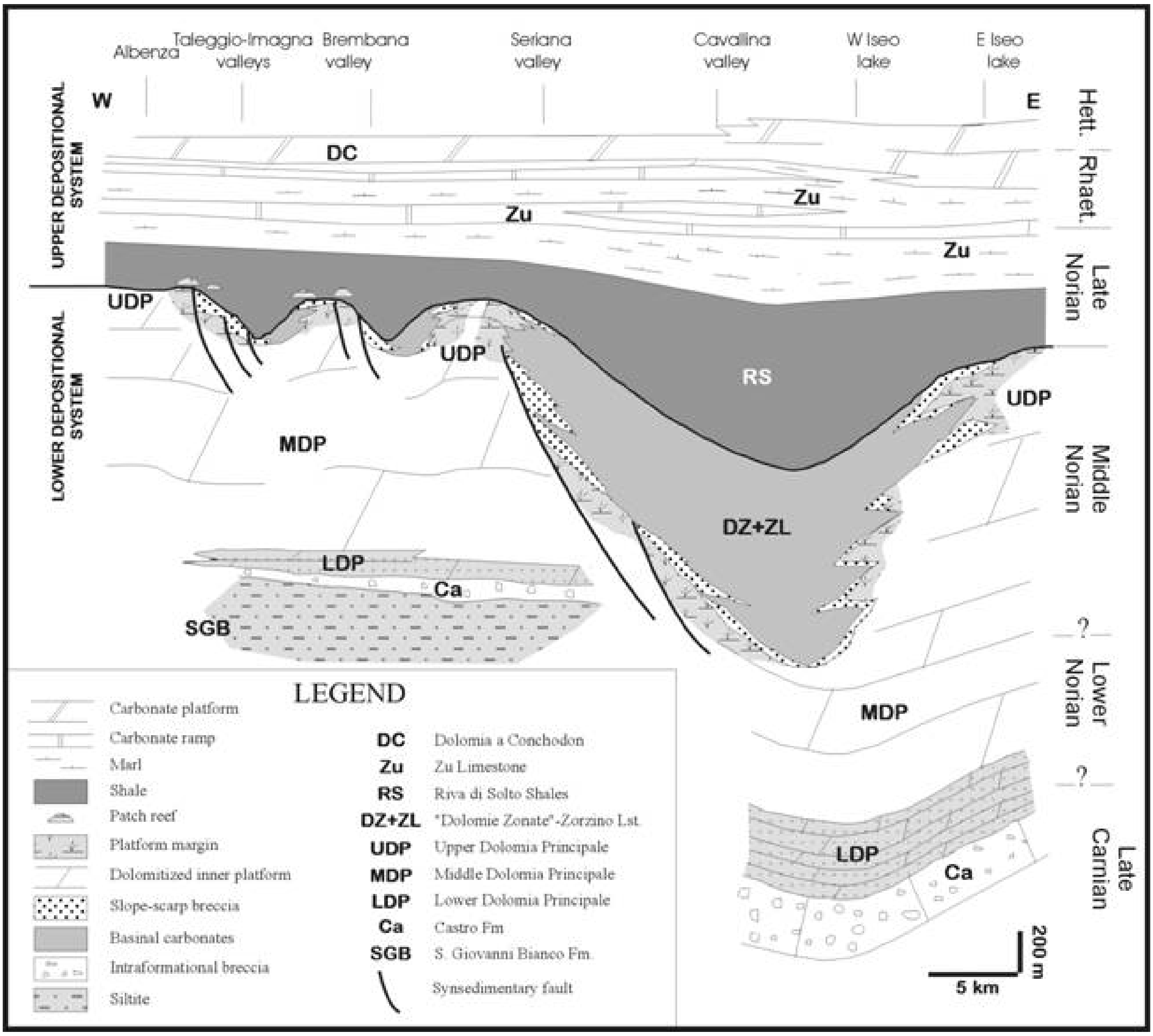


Fig. 4 - Stratigraphic scheme across the Late Carnian-Rhaetian succession in the central Lombardy (from BERRA & JADOUL, 1996)

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 (BERRA ET AL., in press).

The DP of the western Southern Alps reaches its maximum thickness (about 2000 m) on the eastern side of Lake Iseo.

The deposition of the DP probably began during 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). These subtidal facies are overlain by stacked 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. Sedimentary dikes are common, testifying syndepositional extensional tectonics that will lead to the development of small

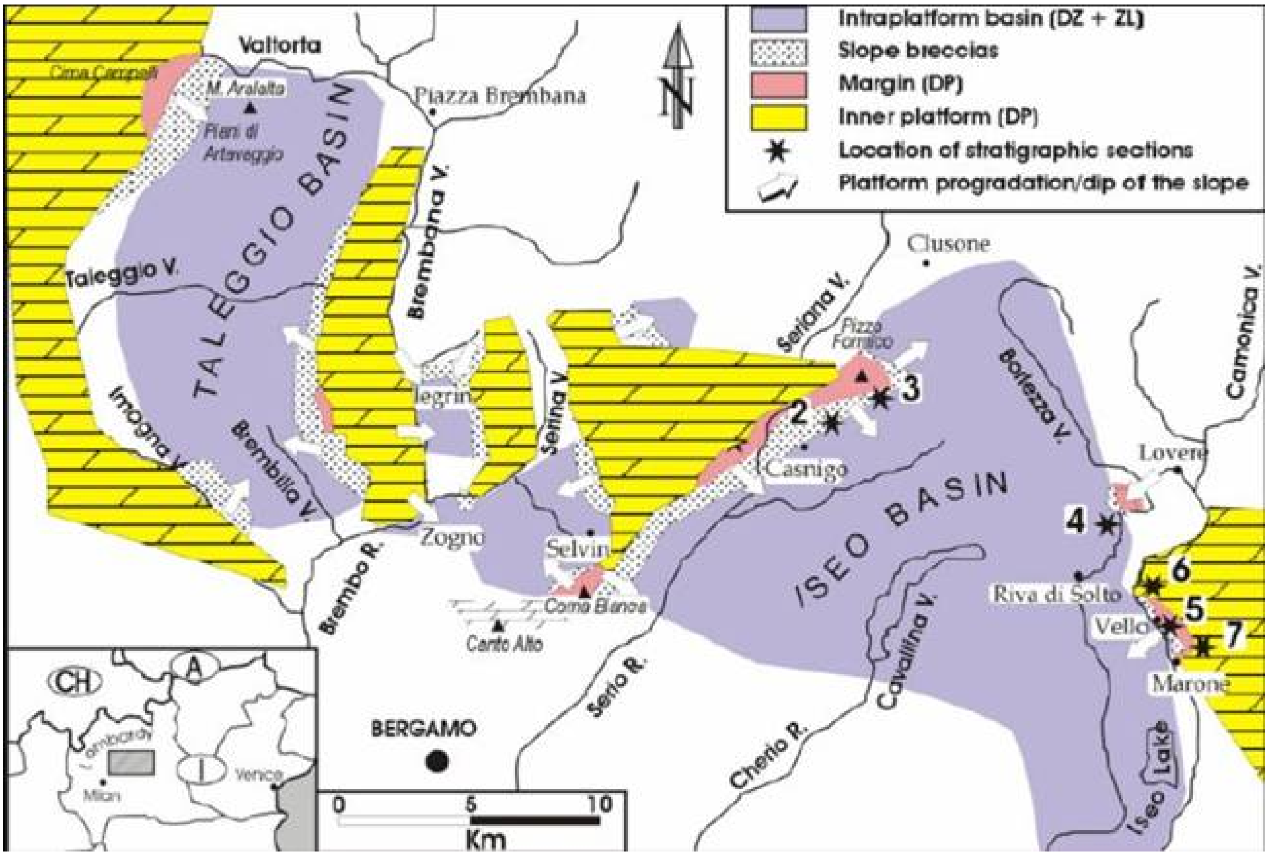


Fig. 5 - Paleogeographic reconstruction of the Central Lombardy during the deposition of the upper Dolomia Principale. The stop 1 is close to section "4" along the western side of the Iseo Lake (modified after BERRA & JADOUL, 1996).

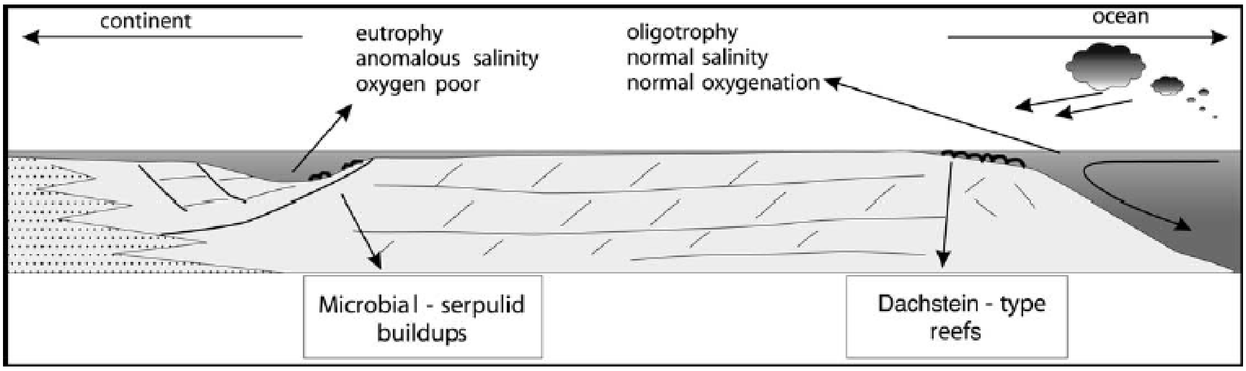


Fig. 6 – Simplified model of CIRILLI ET AL. (1999) showing the different environmental conditions of the Dolomia Principale reefs within intraplatform basins (microbial-serpulid buildups) and toward the open sea (Dachstein-type reefs) from IANNACE & ZAMPARELLI, 2002

intraplatform basins (Fig. 5) and to major thickness and facies changes. 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; Fig. 4).

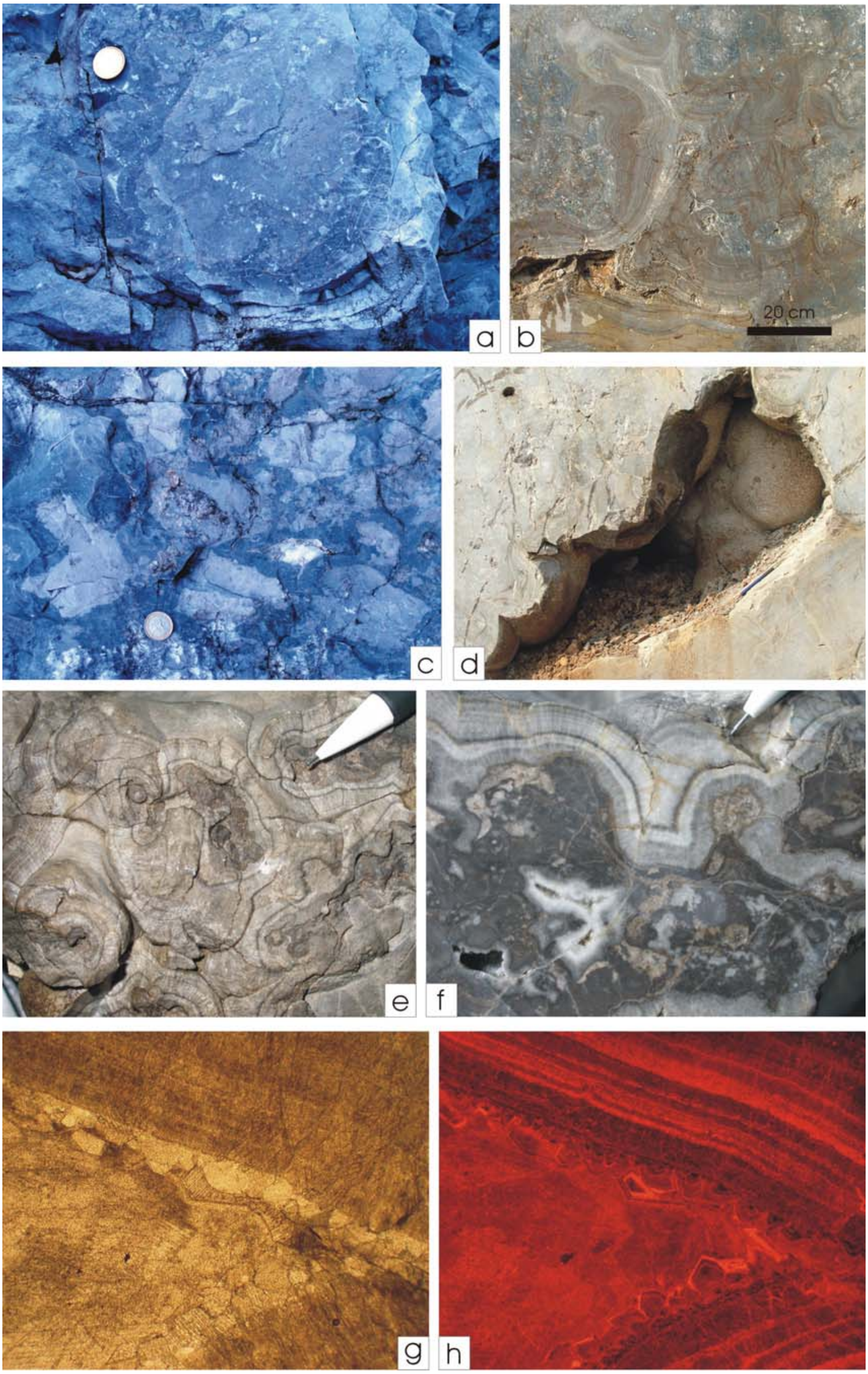
The depositional processes are dominated by gravity flows and slumpings (JADOUL, 1985).

The intraplatform basins are interpreted as semigrabens (PICOTTI & PINI, 1988; JADOUL ET AL., 1992a; 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 & TANNOIA, 1985; TROMBETTA, 1992; Fig. 5). In the depocenter at the Lake Iseo area the Norian succession is about 3000 m thick (ASSERETO & CASATI, 1965). At the borders of the intraplatform basins, margins colonized by peculiar serpulid patch reefs and microbial mounds associated to thick carbonate breccia bodies (CIRILLI & TANNOIA, 1985; BERRA & JADOUL, 1996, ZAMPARELLI ET AL., 1999) are common. The development of these margins 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 (BERRA & JADOUL, 1996; CIRILLI ET AL., 1999; IANNACE & ZAMPARELLI, 2002; Fig. 6). 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.; BERRA ET AL., in press).

Fig. 7 (FRONT PAGE) – Characteristics of evinosponge: a, c): breccias with clasts from upper slope-margin facies (common occurrence of Macrotubus and Tubiphytes) with intergranular porosity completely occluded by evinosponge (dark colour) at stop 2; b, d): large cavities on close to the margin of the Ladinian platform with metre-size evinosponge (Val Brembana). Note that the large evinosponge in d) is not completely closed by cements; e, f):hand specimens of evinosponge. Note in e) the evidence or partial dissolution predating the formation of the evinosponge; g, h): thin section microphotograph in transmitted light (TL) (g) and in cathodoluminescence (CL) (h). The evinosponge is represented by the concentric fibrous cements, whereas the equant calcie represents the later stage of cement precipitation. The evinosponge cement is generally dark in CL, whereas the late calcite is luminescent. Note the presence within the evinosponge cement of veils (dark in TL and luminescent in CL) which probably reflect the presence of organic matter, which can be interpreted as microbial mats.


a
b
20 cm
c
d
e
f
g
h

Stop 2 - Slope facies with evinosponge in the upper part of the Esino Limestone

In this stop it is possible to observe the texture of the slope facies of the Esino Limestone. The stratigraphic position of this stop (Fig. 2, 3) is in the upper part of the Esino Limestone, within prograding slope facies, mainly consisting of breccias with several pebbles coming from the margin of the Ladinian platform. The slope facies mainly consist of clast-supported breccias with a very high original porosity (Fig. 7). The voids between the pebbles are partly filled by isopachous crusts of cements which often completely fill the intergranular porosity. These cements have been called "evinosponge" (Fig. 7) according to STOPPANI (1858) who interpreted these structures as possible organisms. Where the voids are not completely filled by cements, is it possible to observe internal sediments or late, white blocky calcite.

The growth of the cements is generally continuous and no major breaks are observed in the crusts. The bathymetric distribution of the evinosponge covers all the slopes, from the outer margin lower slope. The size of the pebbles decreases from the top to the base of the slope, so that the larger cavities filled by evinosponges are observed along the upper slope (Fig. 7b, d).

The distribution of the evinosponges along the entire slope indicates that their origin can not be related to exposure, mixing zone cementation or local diagenetic processes. Evinosponges are truly marine cements as documented by their isotopic composition (FRISIA ET AL., 1989). A dissolution event is locally observed before the precipitation of the evinosponge cements. This probably triggered an increase in the original porosity of the margin and slope facies. Cathodoluminescence analyses indicate a black colour (Fig. 7g, h), suggesting that the precipitation of these cements occurred during an early-diagenetic stage. Furthermore, the presence of ostracods within the internal sediment which fill the larger evinosponge, suggests that their formation occurred when the burial was still shallow, in order to guarantee a connection of these cavities with the sea-floor, so to explain the occurrence of ostracods in these sediments. On hand-samples and in thin section, it is possible to observe concentric structures within the fibrous cement of the evinosponges.

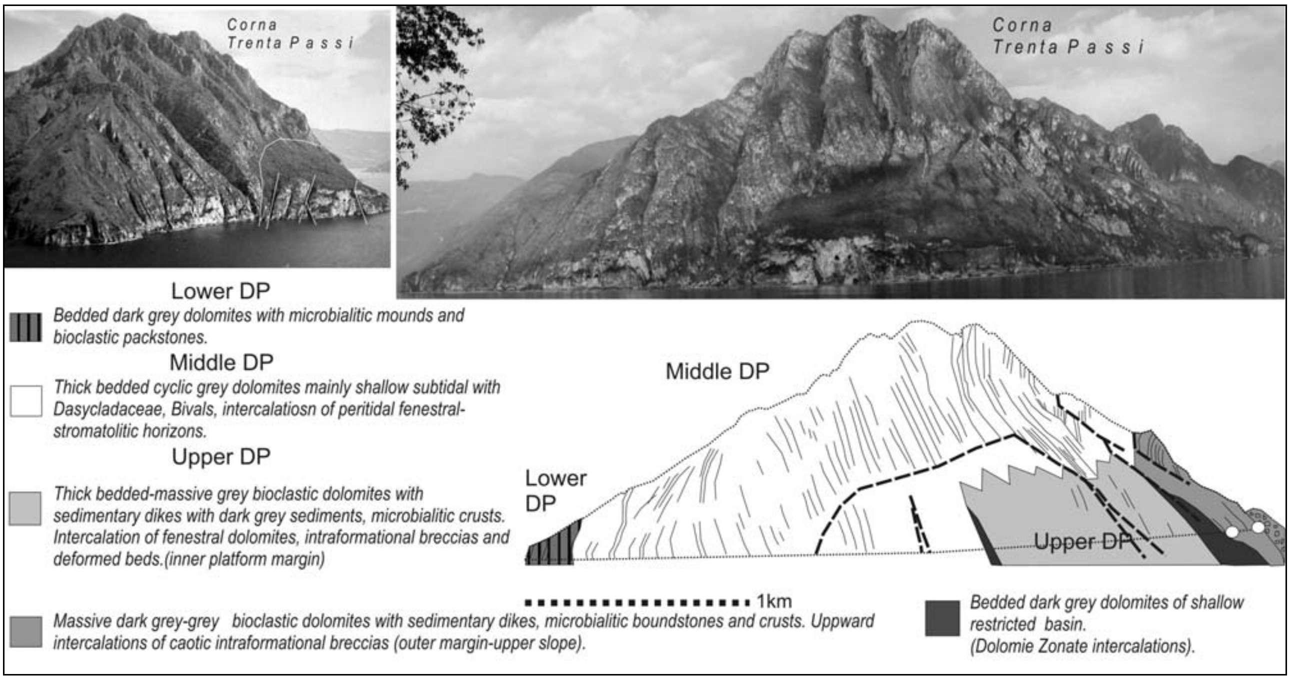


Fig. 8 – View of the Norian succession on the eastern side of the Iseo Lake (modified from JADOUL ET AL., 2005). Note the transition from the bedded inner platform facies to the massive margin-upper slope sediment characterized by serpulids and microbial mounds.

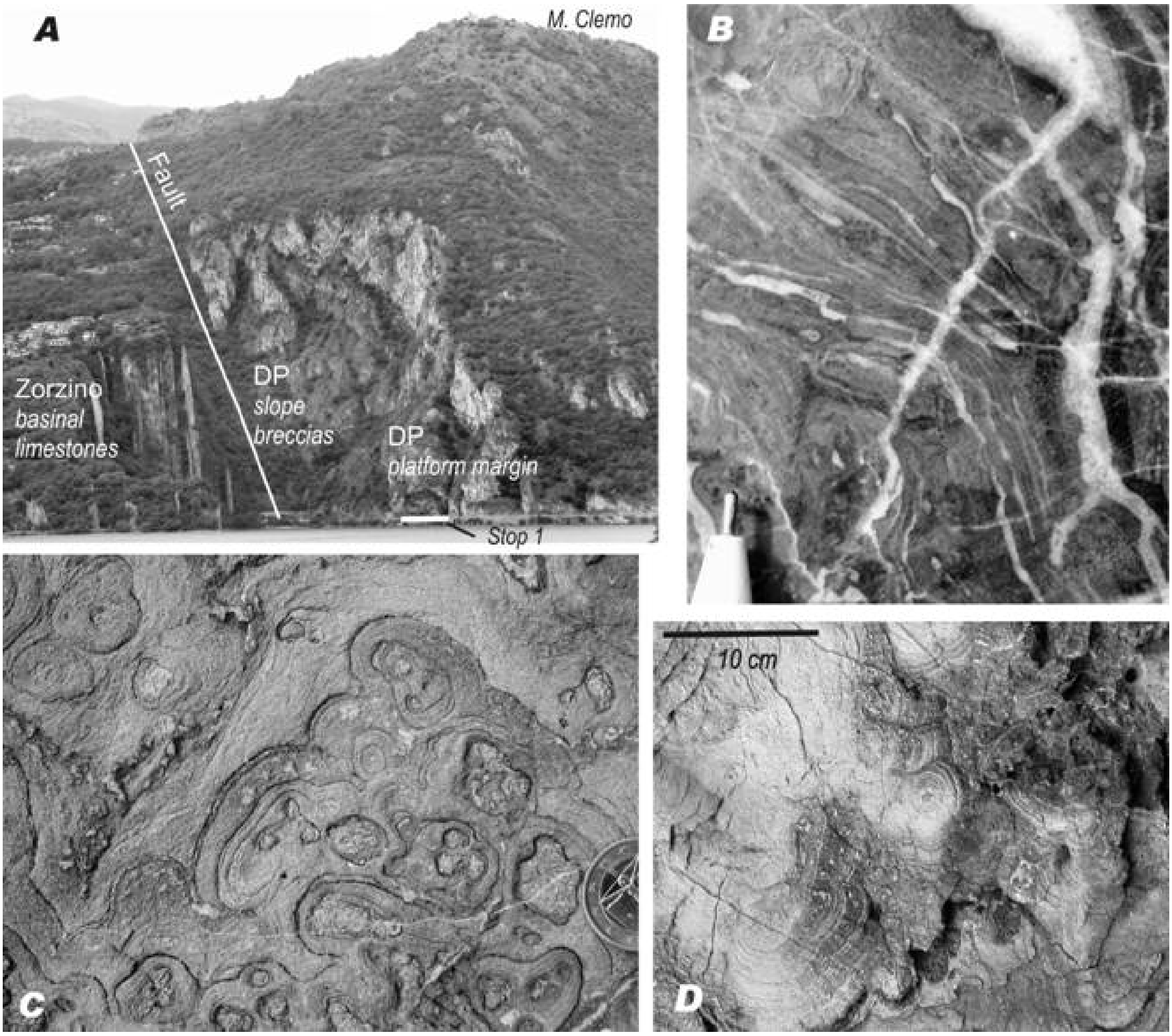


Fig. 9 - a) Position of stop 1 from the eastern side of the Iseo Lake and aspect of the microbial mound of the platform margin facies (b, c and d) (modified from JADOUL ET AL, 2004). Note the fault between the margin-slope facies and the bedded intraplatform basin limestone (Zorzino Limestone).

Observations indicate the occurrence of veils which are darker in transmitted light and luminescent in cathodoluminescence (Fig. 7g, h), strongly suggesting the presence of organic matter: the nature of this organic matter is still in study, but the observations suggest a possible microbial origin. Evinosponges represent the most important (in terms of volume) cementation event in the slope facies of the Ladinian platforms at least of the Southern Alps. The development of these structures at this precise stratigraphic interval suggest the occurrence of environmental (chimico-physical) conditions which favoured the precipitation of large volumes of marine cements. The presence of organic matter within these fibrous cements suggests that an important role was likely played by bacterial films which colonized the voids among the clasts of the slope breccias. Stable isotope analysis indicates a strong affinity between the signature of the host rock (pebbles in the slope breccias) and the evinosponge cements.

Stop 1 - Marginal and upper slope facies of the the Dolomia Principale platform.

From Stop 1, on the opposite side of Lake Iseo it is possible to observe the thick Norian succession of the Dolomia Principale (Corna Trentapassi section; Fig. 8).

In the upper part of the Dolomia Principale, the transition to basinal facies is preserved. Basinal facies consist of thick bedded dark grey dolomites with intercalation of dark grey, well bedded dolomitic arenite-siltites, locally laminated, with lenticular geometries. Within these facies, irregular, meter size bioconstructions are present. They consist of dark, homogeneous microbialitic patches, often reworked, associated with encrusted breccia blocks; upward domal, laminated microbialites, few meters in size (BERRA & JADOUL, 1996). The microfacies of this platform margin succession (JADOUL ET AL., 2004), interpreted as the outer-upper slope portion, are dominated by *Spongiostromata* bindstones and bioclastic intraclastic packstones-rudstones to floatstones with pelecypods (mainly *Modiolus* sp.), Dasycladales and rare benthic, sessil foraminifers (*Glomospirella* spp., *Agathammina* spp., *Tolypammina gregaria).*

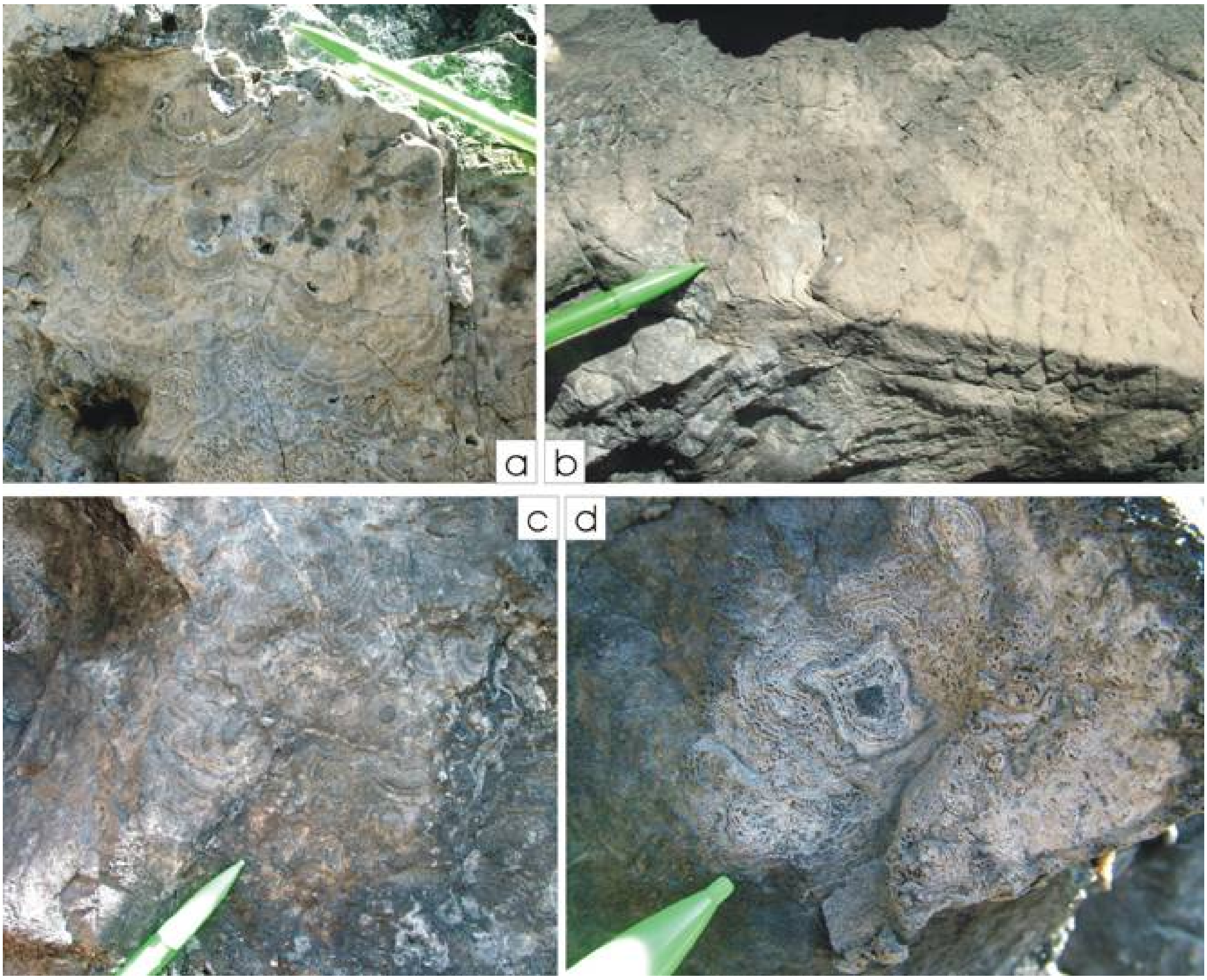


Fig. 10 - Details of the microbial mounds of the margin and of the upper slope at Stop 1. Some of the microbial crusts develop on the clasts on the upper slope.

Locally, thick grey subtidal bioclastic (manly Dasycladales and pelecypods) prograding horizons up to few tens of meters thick intercalate. The upper part of the platform margin complex consists of partially colonized breccias, associated with intra-bioclastic packstones-rudstones and semi-lithified clasts of Dolomie Zonate and microbialitic and serpulid patch reefs (BERRA & JADOUL, 1996).

This situation can be observed also at Stop 1 (Fig. 9), where the margin facies of the Dolomia Principale crops out (Fig. 10).

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 an origin related to a tectonic controlled margin can not be excluded.

The composition of the margin association reflects the environmental conditions which were present at the borders of the inner platform basins in this part of the Southern Alps. This area was a few hundreds of Km apart from the margin of the Norian platform facing the open sea (Tethys Ocean). Due to the tectonic origin of these margins, it results that the connection between these basins and the open sea was extremely reduced. The completely different margin association between the inner platform basin margin and the open-sea margin supports that the environmental conditions in the inner platform basins was extremely stressed (CIRILLI ET AL., 1999). The prevalence of microbial boundstones and serpulids bafflestones strongly support this interpretation (Fig. 6).

Along the road from Castro to Riva di Solto, at the top of the massive DP (Fig. 9) 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 a meter in size) globular, mammillary microbial laminations, microbial coatings and sub-rounded oncoids are the dominant features of DP reefal facies (Fig. 9-10). The nucleus of some of recrystallised oncoids is represented by small serpulid tubes. Microbial boundstones are associated to fine to coarse bioclastic packstones with foraminifers, microbial bindstones, serpulids and small pelecypods, which also represent the matrix between the breccia clasts. Late diagenetic silicization phenomena, dissolution cavities and sedimentary dikes are also present.

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POST-SYMPOSIUM FIELD TRIP GUIDE

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THE TERTIARY PIEDMONT BASIN

The Tertiary Piedmont Basin (TPB) is located in Northwestern Italy and stretches along the Piedmont-Liguria border (Fig. 1). The TPB is a late- to post-orogenic basin that evolved in a piggy-back position on the Monferrato thrust belt. Its depositional history is strongly controlled by tectonic and eustatic events (Gelati & Gnaccolini, 1988; Mutti et al., 1995; Giglia et al., 1996; Capponi et al., 2001; Capponi et al., 2009).

The basin was filled with mainly marine sediments (upper Eocene - upper Miocene), which unconformably overlie the Ligurian Alps, the Sestri-Voltaggio Zone and the Northwestern sector of the Northern Apennine. The early stage of sedimentation of TPB includes a siliciclastic deposition evolving from upper Eocene breccias through lower Oligocene conglomerate to upper Oligocene - lower Miocene sandstone and silty-marl. These units, grouped into different formations, record a pre-transgressive and transgressive phase (time-transgressive from the eastern to the western sectors), characterized by the deposition of alluvial fan and fan delta siliciclastic conglomerates and sandstones, marine shallow-water coarse to fine grained siliciclastic sediments, and reef limestones (Gelati & Gnaccolini, 1988; Turco et al., 1994; Mutti et al., 1995, Quaranta et al., 2009) (Fig. 2).

These units are affected by long-wavelenght open fold; their axes trend N-S and their vergence is towards the east. Locally, deformations evolve into thrusts which caused overlap of the metamorphic basement onto the TPB sediments (Capponi et al., 2001; Capponi et al., 2009).

During Miocene time, at least the northern parts of the TPB evolved in a piggy-back position on the Monferrato thrust belt.

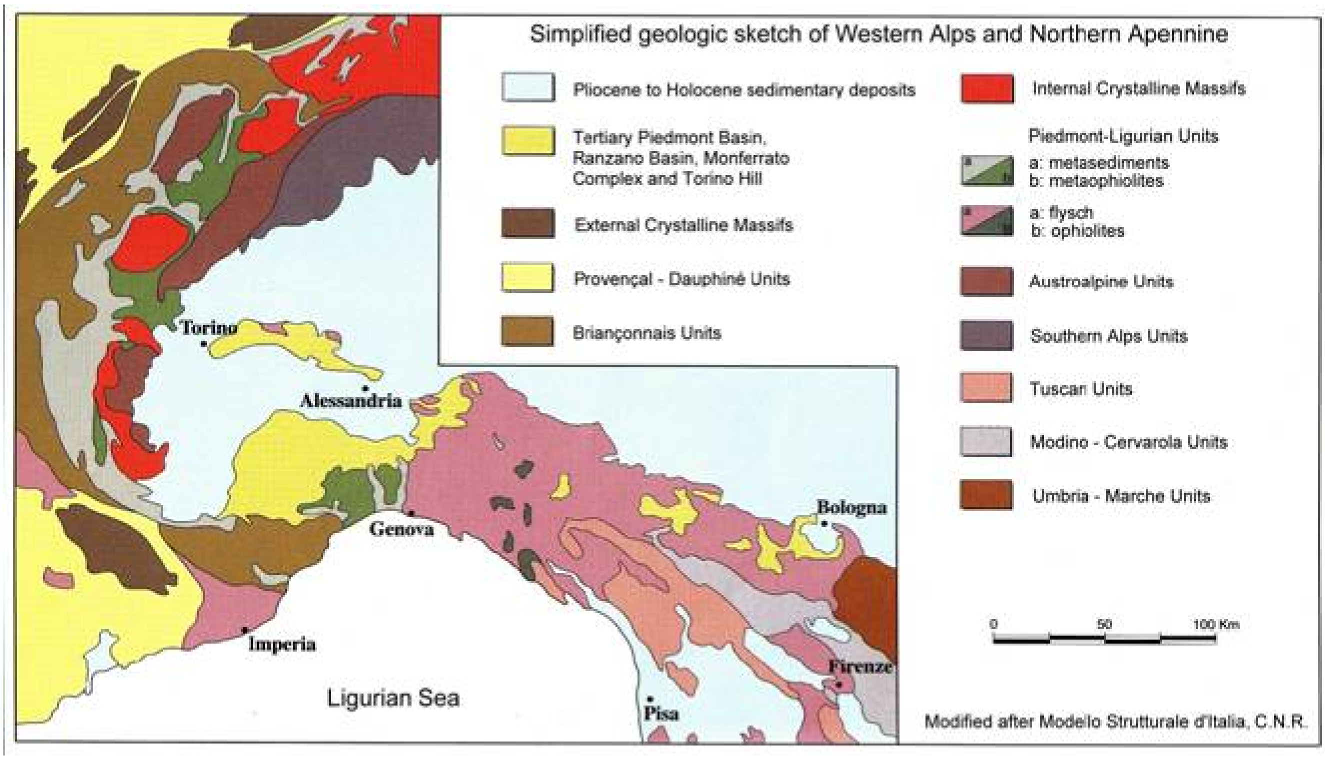


Fig. 1 - Geologic sketch of the TPB area

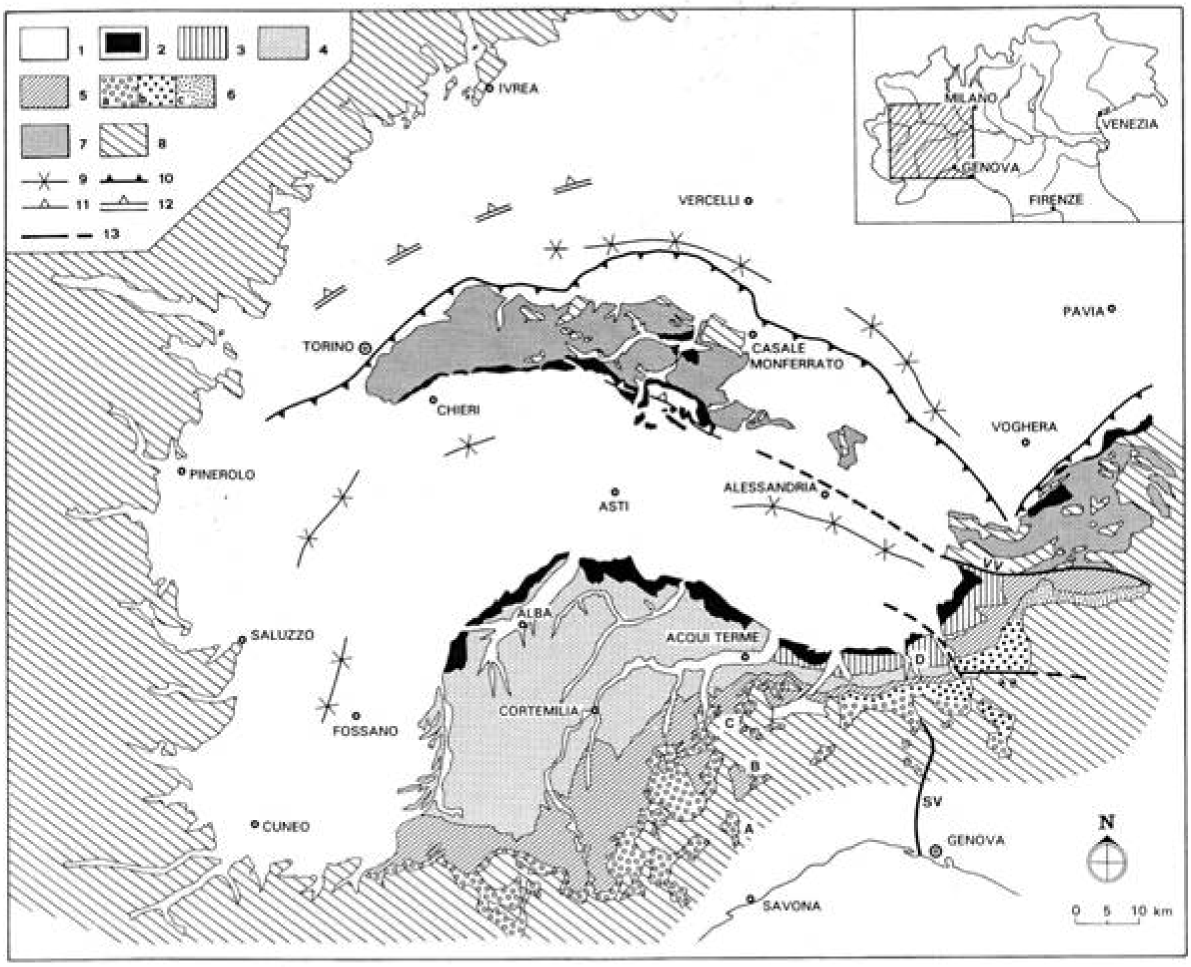


Fig. 2 - Geologic sketch map of the TPB, Monferrato Complex and Torino Hill, with the location of Santa Giustina (A), Maddalena (B), Ponzone (C) and Stazzano (D) sites (modified from Gelati & Gnaccolini 1996). 1) Pliocene to Recent deposits. 2) Messinian deposits. 3) Langhian to Tortonian shelf to slope deposits. 4) Upper Burdigalian to Tortonian mainly turbiditic succession. 5) Upper Oligocene to Burdigalian turbidite systems and hemipelagic mudstones. 6) Upper Eocene to lower Oligocene deposits: a) alluvial to coastal conglomerates, shallow marine sandstones and hemipelagic mudstone; b) slope and base-of-slope, resedimented conglomerates; c) mainly turbidites. 7) Upper Eocene to Tortonian siliciclastic deposits of the NW Apennines - Basso Monferrato - Torino Hill wedge. 8) Alpine and Appenninic allochthonous units. 9) Depocentre axis of the Plio-Quaternary basins. 10) Buried thrust-front of the Torino Hill - Basso Monferrato - NW Apennines wedge. 11) Buried south-vergent backthrusts of Basso Monferrato, active from Messinian onward. 12) Buried, pre-Burdigalian backthrusts of Western Alps. 13) Tectonic lines, SV= Sestri-Voltaggio Line, VV= Villarvernia-Varzi Line.

This evolution is strictly connected with the Corsica-Sardinia roto-traslation and the related tectonic event that formed the arcuate morphology of the Western and Ligurian Alps (GIGLIA ET AL., 1996). The lower Miocene tectonic activity originated erosional surfaces, angular unconformities, turbidites, slumpings and channelling of shallow sediments with syn-sedimentary foldings (GHIBAUDO ET AL., 1985; GELATI & GNACCOLINI, 1988; GIGLIA ET AL., 1996). These bodies are covered by Langhian slope pelites, that grades upwards to shelf sandstone and fine conglomerate (Serravallian) that testify a shallowing event. They are followed by a new deepening phase with the deposition of sandy-silty and silty sediments with slumpings and channelling of shallow water sediments caused by a regional tectonic activity (top of Serravalian section; GHIBAUDO ET AL., 1985; GELATI & GNACCOLINI, 1988; GIGLIA ET AL., 1996). The TPB depositional history ends with the sedimentation of Tortonian marine pelites grading to pre-evaporitic deposits; these sediments are affected by intraformational unconformities, debris flows, and slumps (GHIBAUDO ET AL., 1985; GELATI & GNACCOLINI, 1988; GIGLIA ET AL., 1996).

THE OLIGOCENE CHARACEAE AND TRACHEOPHYTA OF SANTA GIUSTINA (SAVONA)

Stop 0 – The base of the S. Giustina - Giovo di Sassello stratigraphic section (lower Oligocene, total thickness about 170 m, Molare Fm.), that rests on the metamorphic rocks of the Voltri Unit, outcrops along the Sansobbia stream (LORENZ, 1969). This lithostratigraphic section is an interesting example of the Oligocene pre-transgressive and transgressive sedimentary evolution of the TPB. The sedimentation starts with non-marine (alluvial fan, river plain and lacustrine) very fine to very coarse grained siliciclastic deposits that grade upwards to fan-delta and brackish water sandstone and conglomerate (characterized by the occurrence of *Polymesoda* sp. and Potamididae facies).

They are overlain by beach and very shallow sublittoral deposits (siltstone, sandstone and conglomerate), in which small reefal buildups made of branching coral colonies are rarely interbedded (LORENZ, 1969).

Fig. 3 - Plant remains in the lower S. Giustina section

The lower part of S. Giustina section is composed of siliciclastic fine to very coarse grained siliciclastic sedimentary rocks that are the result of alluvial fan, river plain and lacustrine deposition. These rocks are characterized by the mass occurrence of terrestrial plant remains (leaves, trunks and branches) (Fig. 3), which are unevenly distributed throughout the section. Characeae oogons (among which *Nitellopsis* (*Tectochara*) *merianii* (L. & N. Grambast) Grambast & Soulié-Märschland) in the pelite beds, and turtle remains very rarely also occur (Fig. 4).

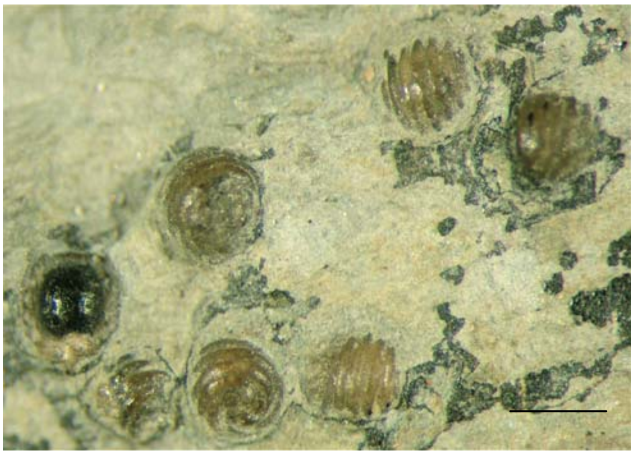


Fig. 4 - Characeae gyrogonites at S. Giustina. Scale = 1 mm

The fossil material in the Perrando Collection was collected in this site, and later studied by SQUINABOL (1889-1892) and PRINCIPI (1912-1921). and housed at the Dip.Te.Ris. and at the Museo Civico di Storia Naturale of Genova.

The abundant, diversified and well preserved S. Giustina flora is mainly composed of pteridophytes (about 17 genera), gymnosperms (about 7 genera), angiosperm-dicotyledons (about 90 genera), and angiosperm-monocotyledons (about 30 genera), among which palms are very abundant.

The occurrence of arboreous ferns (*Goniopteris polypodioides*), palms (*Flabellaria*) (Fig. 5), *Arecites* and *Cocos*), and of the dicotyledon genera *Artocarpus*, *Ficus*, *Cinnamomum*, *Magnolia*, *Eotrigonobalanus*, *Persea*, *Terminalia* and *Sloanea*, indicates a subtropical to tropical character.

It is noteworthy that a recent study on leaf morphometry carried out according to the method proposed by DOLPH & DILCHER (1980) and involving a total of about 800 specimens of dicotiledons, indicates that the S. Giustina fossil flora is comparable to modern tropical basal and premontane altitudinal belts (including tropical basal and premontane moist, wet and rain forest *life zone*) of the Tropical Western Hemisphere, sensu DOLPH & DILCHER (1980) (Vannucci & Bonci, unpublished data).

Therefore, an alluvial plane with flood areas, meanders and small lakes palaeoenvironment can be inferred; the occurrence of characee-rich levels and freshwater turtle remains corroborates this hypothesis.

Fig. 5.- The palm *Flabellaria mediterranea* from the S. Giustina section.

THE OLIGOCENE CORAL AND RED ALGAE REEF OF MADDALENA (SASSELLO, SAVONA)

The Oligocene reef of the TPB

The main Oligocene reefal complexes of the TPB fringe the northern and western border of Voltri Unit and the northern part of the Piedmontese and Briançonnais Units. They are absent in the easternmost part of the TPB, where the sedimentary cover rests on the flysch units, and do not occur in the westernmost sector of the TPB (QUARANTA ET AL., 2009). Since all reef developed close to the shoreline, their arcuate distribution might reflect the position of the Oligocene paleo-shoreline (QUARANTA ET AL., 2009).

According to QUARANTA ET AL. (2009), the TPB reefal buildups developed close to the paleoshoreline, have a early Rupelian - middle Chattian distribution, and are restricted to the central part of the southern margin of the TPB, running along a NE-SW alignment. Moreover, the Valzemola - San Bernardino reef is the youngest and the westernmost settlement, whilst the Val Lemme reef represents the oldest and easternmost one. Coral colony debris were found also eastward to the Val Lemme reef, in a sandstone bed of the Val Borbera Conglomerate outcropping in the Vobbia Valley (CARNEVALE ET AL., 2002), apparently extending eastward the distributional area of reef development.

The stratigraphic and geographic distribution of the Oligocene reefs of the TPB is interpreted as the result of a combined climatic and tectonic control (QUARANTA ET AL., 2009). The absence of biohermal buildups westward of Valzemola - Bric S. Bernardino reef was caused by unfavourable climatic conditions. The lack of biohermal settlements eastward of Val Lemme reef, notwithstanding the favourable climatic conditions, was probably caused by bottom instability and high sedimentation rate by syn-sedimentary tectonic activity along the Scrivia fault, during the late Eocene - early Oligocene interval, (QUARANTA ET AL., 2009).

The Oligocene TPB reefs are dominated by scleractinian corals as reef framestone, with minor bafflestone and/or bindstone. Spaces between colonies are filled by fine to coarse siliciclastic and/or bioclastic sediments, which also form the flank facies. Other abundant reef-dwelling forms are coralline algae, foraminifers and bryozoans. Relevant information on these reef complexes was provided by LORENZ (1969), PFISTER (1980, 1985), FRAVEGA & VANNUCCI (1987), FRAVEGA ET AL. (1987), PIAZZA (1989), FRAVEGA ET AL. (1994), VANNUCCI ET AL. (1993), VANNUCCI ET AL. (1997), VANNUCCI ET AL. (2003), QUARANTA ET AL. (2009).

In the following paragraphs the taxonomy of the recorded corallines has been revised, therefore some species have been included in families or subfamilies which are different from those reported in early literature..

The Maddalena section

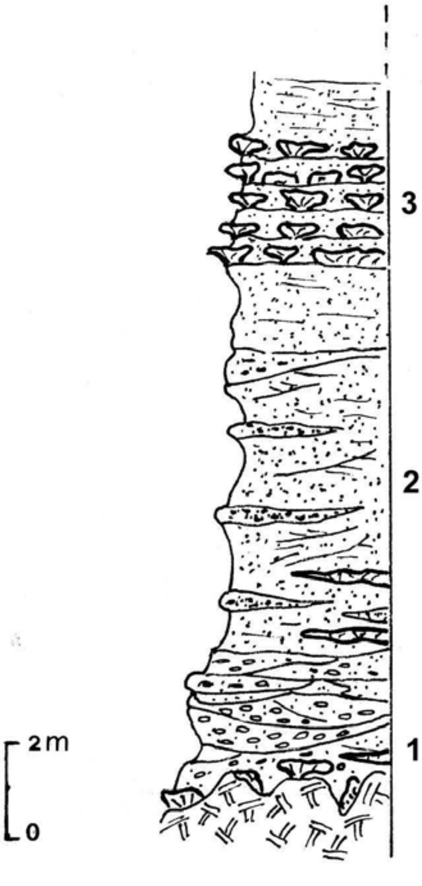
The Maddalena lithostratigraphic section (upper Rupelian – lower Chattian, total thickness about 13 m, Molare Fm.) can be summarized as follows (FRAVEGA ET AL., 1987, FRAVEGA & VANNUCCI, 1987) (Fig. 6).

Substrate: metamorphic roks of the Voltri Unit (metaophiolites, calceschists and micaschists)

1 - coarse conglomerate with interbedded sandy lenses and coral buildups; besides corals, the fossil content includes mollusk remains, bryozoans and very rare *Nummulites* and coralline algae. Stop 1.

2 - coarse sandstone and fine conglomerate with mollusk remains, scattered coral colonies; *Nummulites*, lepidocyclinids, and coralline algae. Stop 2.

3 – calcarenite/hybrid arenite and coral/coralline algae limestone thin to medium strata rhythmic alternation, the fossil content also includes mollusk shells and fragments, *Nummulites* and abundant lepidocyclinids. Stop 3.



Fig, 6 - Simplified stratigraphic section of Maddalena

The upper Rupelian - lower Chattian Maddalena reef has a core composed of coral framestone. It exhibits a low relief and is interpreted as a rough-water incipient or failed fringing reef (LORENZ, 1969; FRAVEGA ET AL., 1987, QUARANTA ET AL., 2009).

Coral colonies mainly have a massive growth morphology and form a fossil assemblage including the following species (according to FRAVEGA ET AL., 1987): *Actinacis* cf. *rollei* (Reuss), *Antiguastrea lucasiana* (De France), *Astreopora meneghiniana* (D'Archiardi), *Astreopora tecta* (Catullo), *Astreopora* sp., *Astrocoenia* sp., *Colpophyllia* sp., *Cyatoseris radiata* (Michelotti), *Diploria crebriformis* (Michelotti), *Diploria* sp., *Euphyllia* sp., *Favia irregularis* Prever, *Favia subdenticulata* (Catullo), *Goniopora ramosa* (Catullo), *Hexastrea elegans* (De Angelis), *Hexastrea laxelamellata* (Michelotti), *Leptoria* sp., *Michelottiphyllia anceps* (Michelotti) = *Hydnophora pulcra* Michelotti (in BOSELLINI, 1999), *Michelottiphyllia crispata* (De Angelis) = *Hydnophora affinis* Michelotti (in BOSELLINI, 1999), *Michelottiphyllia* sp., *Pocillophora* sp., *Stylocoenia taurinensis* (Michelin), *Stylophora* cf. *tuberosa* (Catullo), *Stylophora* sp., *Variabilicosta perrandi* (Prever), *Variabilifavia perrandi* (Prever).

A large number of coral specimens in the Prever-Perrando's Collection housed at the Dip.Te.Ris. of the Genoa University are from the Maddalena reef, and were studied by Prever (1921-22).

Stop 1 – Corals colonize the metaophiolites and the conglomerate pebbles (Fig. 7).

Fig, 7 - A massive coral colony (arrow) growing direcly on metaophiolite.

This first colonization was suffocated by gravelly and sandy sediments which were later colonized by corals. Coral colonies have mainly massive, encrusting, globular growth morphology; fragments of branching corals (*Stylophora*) are also present. The fossil content also includes mollusk fragments, bryozoans and rare ostracods and foraminifers (rotaliids, miliolids and *Nummulites fichteli*) and coralline algae. The rare coralline algae mainly overgrow the conglomerate pebbles and are referable to *Lithothamnion* and/or *Phymatolithon*, among which encrusting-warty thalli of *Lithothamnion exuberans* Mastrorilli[1] and *Lithothamnion tectifons* (Mastrorilli)[2] have been identified.

Stop 2 – In the first 6 meters we can observe the interbedding of more or less large, massive coral colonies in the siliciclastic sediments. Fragments of branching corals also occur. Besides corals, the fossil fauna include bivalves (oysters and pectinids), rare gastropods, echinoid plates and spines, bryozoans and foraminifers (among which rotaliids, miliolids, textulariids, *Neoalveolina* sp., *Heterostegina* sp., *Amphistegina* sp., *Operculina complanata*, *Nummulites fichteli*, *Nummulites vascus*, *Eulepidina* sp., and rare globigerinids).

Coralline algae largely encrust the sediments and form small rhodoliths (laminar or laminar/columnar structures frequently with loosely packed encrusting or encrusting-warty thalli), rare small free-living branches are also present.

Mastophoroids are dominant (55%) and are represented by a high number of encrusting thalli of *Neogoniolithon contii* (Mastrorilli) Quaranta et al. (Fig. 9) and encrusting-warty to warty thalli of *Spongites* cf. *albanensis* (Lemoine) Braga et al.. Melobesioids (25%) reach a subordinate position and are characterised by the dominance of encrusting-warty thalli of *L. exuberans*, *Lithothamnion* or *Phymatolithon* spp., *Mesophyllum fructiferum* Airoldi and rare lumpy/fruticose thalli of *Lithothamnion valens* Foslie. Lithophylloids (15%) are less important and occur with encrusting-warty thalli of *Lithophyllum sassellense* Fravega & Vannucci[1] and ?*Lithophyllum perrandoi* Airoldi; sporolithacean algae (5%) are rare and represented by *Sporolithon statiellense* (Airoldi) Vannucci et al. Finally, Corallinoideae intergenicula are also present.

Sandstone and siltstone forming the upper part (2 m) are characterized by a poor fossil content, including nummulitids and lepidocyclinids. Encrusting coralline algae only occur at the top and are dominated by *N. contii*.

Stop 3 – Calcarenite and hybrid arenite and coral/coralline limestone thin to medium strata rhythmically alternate, with the coral growth starting from a loose sediment stabilized by encrusting coralline algae (Fig. 8).

Fig. 8 - Coral and coralline alternation

Fossil fauna also includes mollusk and echinoid remains, bryozoans and foraminifera (among which lepidocyclinids are very abundant).

The algal assemblage is dominated by Mastophoroideae (about 50%), subordinate but well represented Melobesioideae (about 37%), rare Lithophylloideae (about 9%) and very rare Sporolithaceae (about 4%). Geniculate coralline algae are also present. *N. contii* is the most abundant species (about 55%) among mastophoroids (Fig. 9), other relevant members are (in order of decreasing abundance): *Lithoporella* (*L. melobesioides* (Foslie) Foslie and *L. minus* Johnson), *S.* cf. *albanensis* and ?*Spongites* cf. *personatus* (Airoldi) Vannucci et al..

L. exuberans, *L. roveretoi* Airoldi, *Lithothamnion moretii* Lemoine[3], *L. tectifons*, *M. fructiferum* and *Mesophyllum* cf. *obsitum* Airoldi are the most frequent melobesioids species. *Sporolithon airoldii* (Fravega) Vannucci et al. and *?L. perrandoi* are the sporolithacean and lithophylloid dominant species, respectively.

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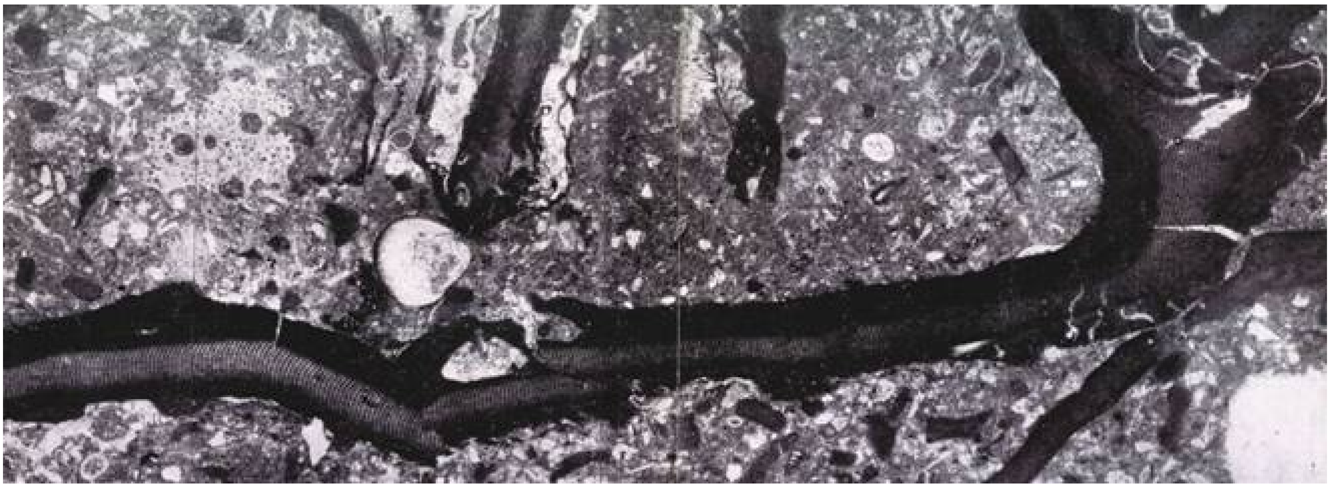
[1] The holotype (housed at the Dip.Te.Ris. of Genoa University) shows all the characters of the genus.

[2] Species under revision. The taxonomic allocation at the rank of genus is doubtful.

[3] The specimens show all the characters of the Genus and of the species and conform the description of the holotype.

Fig. 9 - A typical thallus of the substrate-stabilizer coralline *Neogoniolithon contii*



Paleoecology

Stop 1 – The co-occurrence of larger foraminifera and abundant coral colonies in living position indicate warm waters (BOSELLINI & PERRIN, 2007) and shallow infralittoral depths. The sedimentological evidence corroborates this bathymetric allocation, therefore the occurrence of Melobesiods (the only one group of coralline algae recovered) seems to be in disagreement with this reconstruction. However, the dominance of melobesioid and/or sporolithacean algae in shallow water has been often observed in the fossil record and these anomalous fluorishing and high diversification have been explained involving abiotic and/or biotic factors, e.g. water temperature influenced by freshwater influx (PIAZZA, 1989; VANNUCCI ET AL., 1997), water turbidity caused by fine sediment transit and/or eutrophyc water (VANNUCCI ET AL., 2003; WILSON, 2005, 2008; BRANDANO ET AL., 2007); peculiar autoecology of recorded species (PIAZZA, 1989; VANNUCCI ET AL., 1997).

Stop 2 and 3 – The dominance of Mastophoroid algae, the subordinate position of melobesioids (even if they are abundant and well diverisfied), and the rarity of lithophylloids and sporolithaceans suggest a shallow sublittoral paleo-environment.

We suppose (according to FRAVEGA & VANNUCCI, 1987) that the encrusting species *N. contii* can be regarded as a substrate stabilizer that precedes and prepares the development of the proper biogenic framework.

THE BURDIGALIAN RHODOLITHS OF PONZONE (ALESSANDRIA)

Stop 4 - The Burdigalian section of the central part of the TPB is made of upper circalittoral silty-marls and sandstones (locally glauco-arenites), in which oncolithic rudstone and floatstone bodies unevenly occur as resedimented bodies.

The Bric Cardinelle lithostratigraphic section (total thickness about 80 m, Visone Fm., Fig. 10) is composed of a well bedded sandstone and sitly-sandstone with interbedded “cut-and-fill” channellized bodies made of rhodolithic rudstone and floatstone (Fig. 11) and minor siliciclastic conglomerate; the sandstone and silty-sandstone frameworks generally include more or less abundant (20-80% of the framework component) glauconite grains (PIAZZA, 1989).

The fossil fauna is composed of echinoids, brachiopods, mollusks, worms, bryozoans, and planctonic and benthic foraminifera, among which *Miogypsina globulina* (Michelotti), which allows to date this section to the lower Burdigalian (PIAZZA, 1989). These lithofacies deposited (or re-deposited) in warm open shelf condition, at a depth exceeding 50 m. The rhodoliths sampled in this section (PIAZZA, 1989; FRAVEGA ET AL., 1993) exhibit spheroidal (92%) and ellipsoidal (8%) shape (diameter or major axis: 1-7 cm), laminar mainly concentric (52%) or laminar-columnar (48%) structure, clastic (56%) or bioclastic (44%) nucleus.

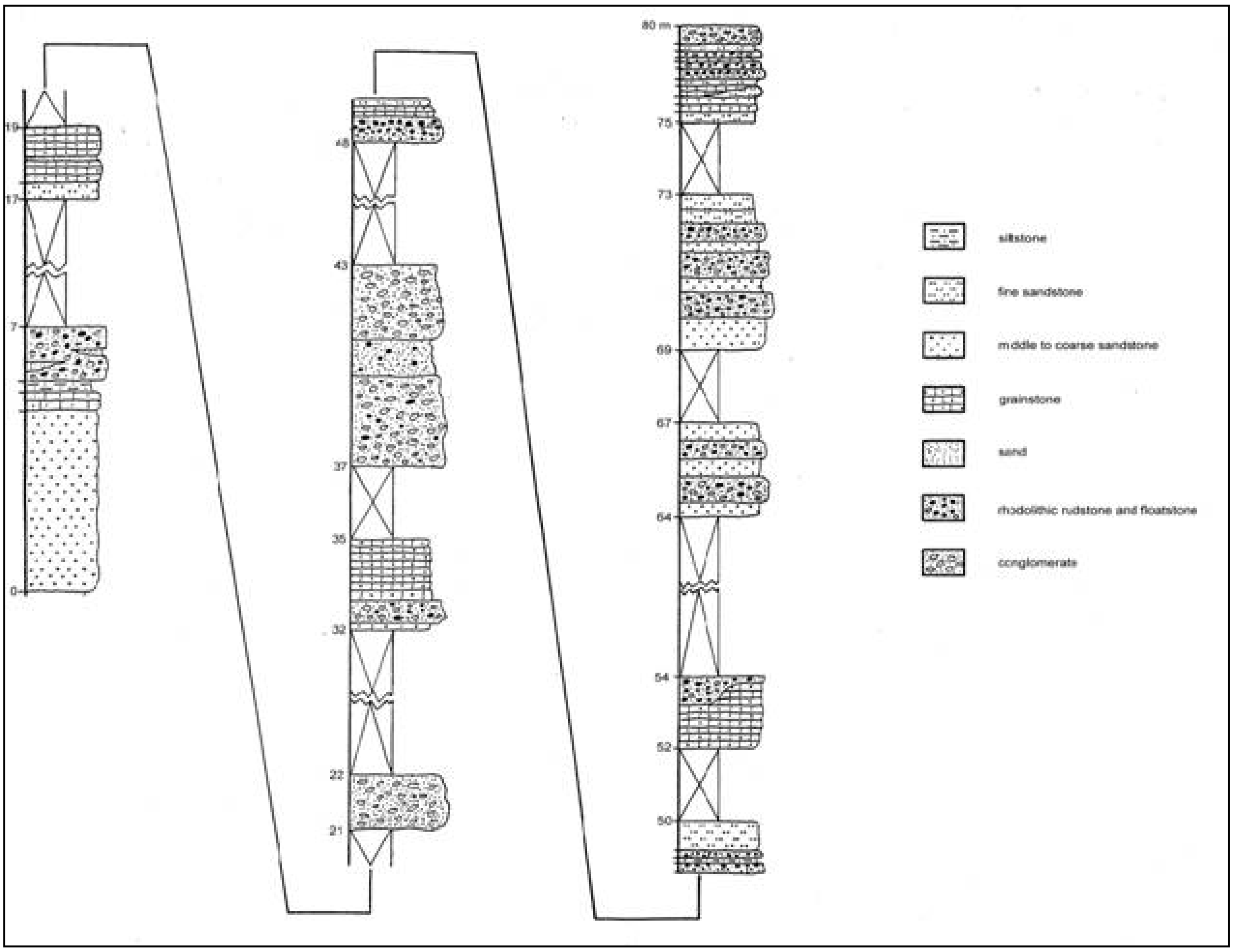


Fig. 10.- Simplified stratigraphic section of Bric Cardinelle, Ponzone (modified from PIAZZA, 1989)

Fig. 11.- Rhodolithic rudstone of Bric Cardinelle

The algal assemblage is dominated by melobesioids (62%, with *Lithothamnion* and/or *Phymatolithon* totalizing 40%), followed by mastophoroids (23%), rare lithophylloids (7%) and sporolithaceans (8%). The most widespread species are *Mesophyllum roveretoi* Conti, *Lithothamnion ponzonense* Conti and *Spongites albanensis* Braga et al.. *Lithothamnion roveretoi* Airoldi, *L. exuberans*, *Phymatolithon calcareum* (Pallas) Adey & McKibbin and ?*L. perrandoi* also occur. Encrusting (50%) or encrusting-warty (37%) growth forms are dominant, while warty-lumpy or lumpy (5%) ones randomly occur. Available data indicate that the rhodoliths formed in warm waters, under high energy conditions, on sea-floor located at the transition from the Infralittoral Zone to the Circalittoral Zone.

THE SERRAVALLIAN RHODOLITHS OF STAZZANO (ALESSANDRIA)

Stop 5 - The Serravalian section of the central part of the TPB is made of outer shelf silty marl and siltstone grading upwards to inner shelf sandstone (hybrid arenites) and fine conglomerate followed by sandy-silty and silty sediments, in which are interbedded slumps and conglomeratic or biocalciruditic lenticular bodies (GHIBAUDO ET AL., 1985) (Fig. 12-13).

The Stazzano lithostratigraphic section (upper Serravallian, total thickness about 13 m, Serravalle Sandstone Fm.) is a classic exposure of the top of the Serravalle Sandstone Formation, where we can observe the silty deposits in which the channels filled by rhodolithic rudstone and floatstone are cut. The fossil fauna includes echinoids, brachiopods, mollusks, worms, bryozoans, and benthic and planctonic foraminifers (FRAVEGA & VANNUCCI, 1982).

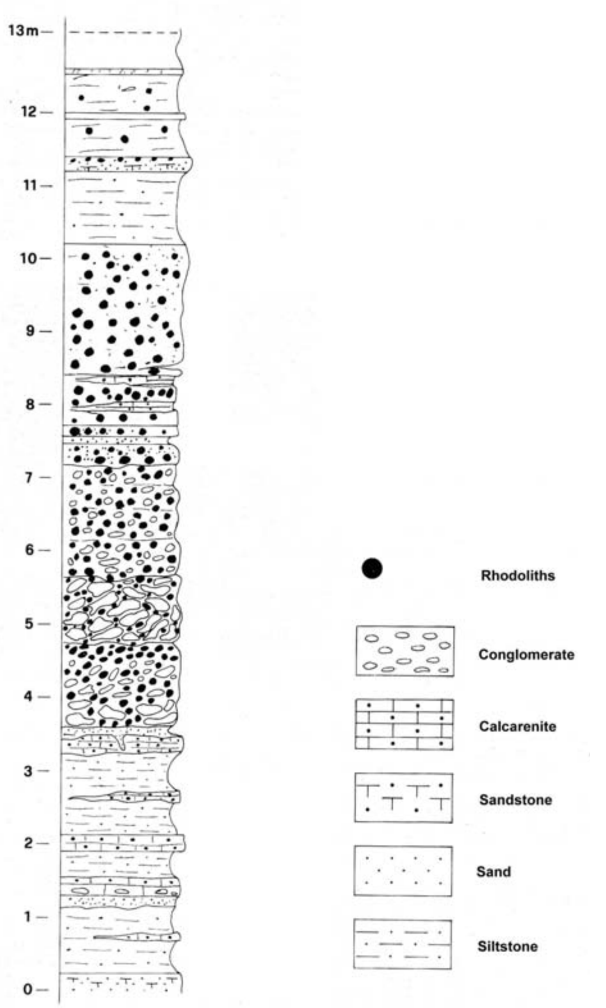


Fig. 12.- Simplified stratigraphic section of Stazzano (modified from FRAVEGA & VANNUCCI, 1982)

The rhodoliths from this section show (VANNUCCI, 1980; FRAVEGA & VANNUCCI, 1982; FRAVEGA ET AL., 1993) spheroidal (93%) and ellipsoidal (7%) shape (diameter or major axis: 2-6 cm) (Fig. 14). Their structure is laminar (mainly concentric) or laminar-columnar (94%) and subordinately columnar or branching (6%), with the latter confined in the innermost part of the coating sequence. They show a bioclastic nucleus (96%) that in rare cases is a lumpy to fruticose coralline alga (4%).

Fig. 13.- Rhodolith-rich biocalciruditic bodies along the Scrivia River (Stazzano)

Fig. 14.- Pluricentimetric rhodoliths of Stazzano

The algal assemblage is dominated by Lithophylloideae (41.5%) mainly *Lithophyllum* (40.1%) and rare *Titanoderma* (1.4%). Melobesioideae (33.1%) are represented by several species of *Lithothamnion* and/or *Phymatolithon* (16.2%) and *Mesophyllum* (16.9%). Mastophoroideae reach to the 24%, while Sporolithaceae (1.4%) are occasional. The most abundant species are *Lithophyllum racemus* (Lamarck) Foslie, *Mesophyllum gignouxi* Lemoine and *Mesophyllum sancti-dyonisii* Lemoine. Encrusting-warty (54%) or encrusting (33%) growth forms are dominant; warty-lumpy to lumpy (10%) and fruticose (3%) growth forms rarely occur.

Available data indicate that the rhodoliths formed in warm waters, under mid-high energy conditions, on the soft sediments of the inner part of the Infralittoral Zone.

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