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The Middle-Late Triassic of
Lombardy (I) and Canton Ticino (CH)

By Flavio Jadoul and Andrea Tintori

704 *MAURIZIO GAETANI, MARIO GNACCOLINI, FLAVIO JADOUL, EDUARDO GARZANTI*

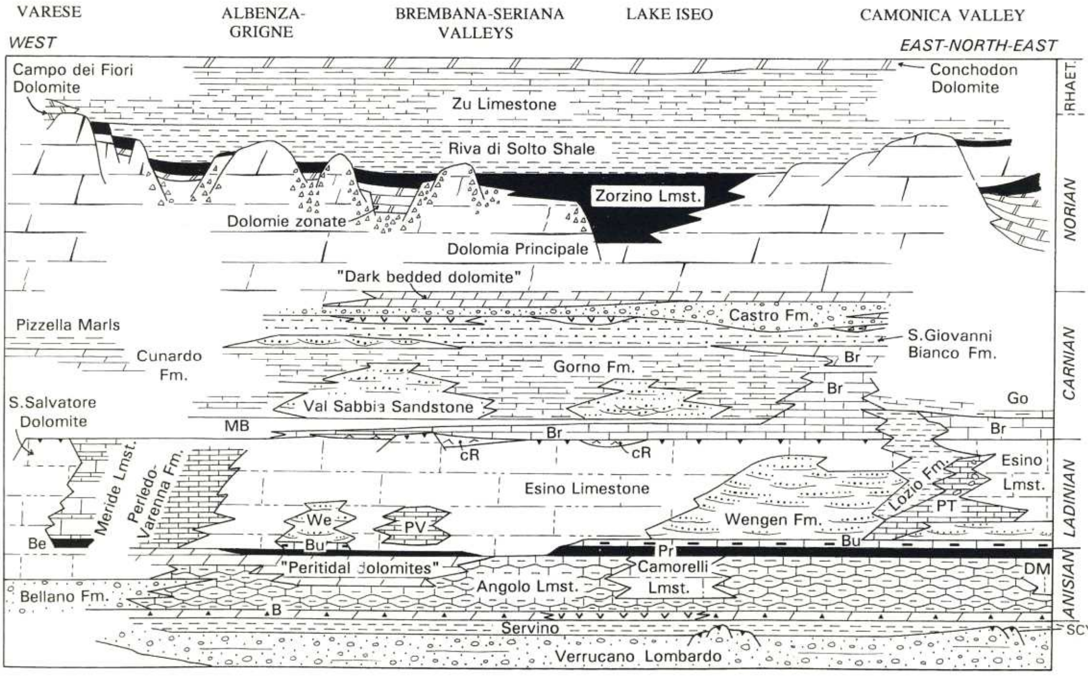

FIG. 2.—Triassic stratigraphic framework in Lombardy (modified after Jadoul and Rossi, 1982). B = Bovegno Formation; DM = Dosso dei Morti Formation; Pr = Prezzo Limestone; Bu = Buchenstein Formation; Be = Besano Formation; PV = Perledo-Varenna Formation; We = Wengen Group; PT = Pratotondo Formation; cR = Calcare Rosso; Br = Breno Formation; MB = Calcare Metallifero Bergamasco Formation; Go = Gorno Formation. The Aralalta Group consists of the Dolomie Zonate and Zorzino Limestone.

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September 2, first day

by Andrea Tintori and Markus Felber

MONTE SAN GIORGIO IS UNESCO WORLD HERITAGE SITE

Monte San Giorgio is among the most important fossil-bearing sites in the world, in particular concerning the middle Triassic fauna (245-230 million years ago). Following the UNESCO inscription of the Swiss side of the mountain in 2003, the Italian side has been inscribed in 2010, stating that:

"Monte San Giorgio is the only and best known evidence of the marine Triassic life but also preserves some important remains of terrestrial organisms. The numerous and diverse fossil finds are exceptionally preserved and complete. The long history of the research and the controlled management of the paleontological resources have allowed thorough studies and the classification of exceptional specimens which are the basis for a rich scientific paper production. For all these reasons Monte San Giorgio represents the main reference in the world concerning the Triassic faunas."

THE GEOLOGICAL HISTORY OF MONTE SAN GIORGIO

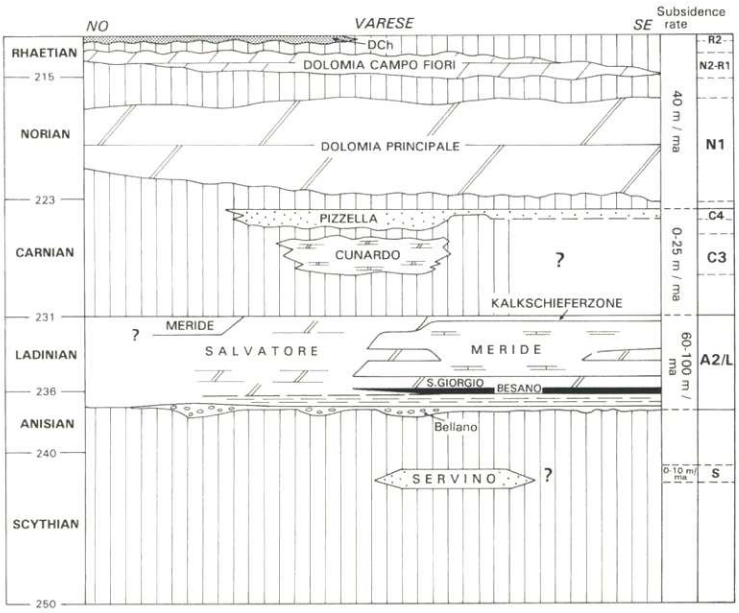
Monte San Giorgio belongs to the broad tectonic feature named *Sudalpino*, which encompasses all the rock formations lying South of the Insubric Line.

The oldest rocks of Monte San Giorgio outcrop in spots along the shores of the Ceresio Lake, between the Brusino Arsizio custom house and the built-up area of Porto Ceresio. They represent the topmost part of a thick gneiss succession of pre-Permian age (more than 300 million years ago) which extensively outcrops in the territories of Monte Ceneri, Valcolla and Malcantone, and, less widely, near Melide and Morcote. The gneiss is overlain by Permian volcanic rocks: in the area of Varese and Lugano rhyolites and quartz porphyry (Cuasso al Monte, Carona, Arbostora) are widespread as well as andesites (northern spur of Monte San Giorgio, between Riva San Vitale and Porto Ceresio). They all represent large eruptions occurred about 260 my ago.
The first sediments deposited on the wide volcanic units date to the early Middle Triassic (Anisian, about 245 my ago): these continental conglomerates and sandstones, named Formazione di Bellano (n. 108 e 109) suggest an intense erosional activity.
From this moment on, the marine environment is established and will last for at least 200 my.
The palaeogeographic subtropical position of Monte San Giorgio determined a warm climate, locally giving rise to shallow water carbonate platforms: near Lugano, for example, the *Dolomia del San Salvatore* is a thick and regular succession of dolomitic rocks of Anisian-Ladinian age (about 235-240 my)(n. 108 and 109). The situation was remarkably different in the San Giorgio basin where frequent changes occurred from shallow water to deeper lagoonal conditions: the latter environment is well represented in the *Grenzbitumenzone* (also called *Formazione di Besa*no or *Zona Limite Bituminosa (ZLB)*) as well as in the *Calcare di Meride*. The lagoon frequently favoured an optimal preservation of the rich fauna inhabiting both the sea and the dry land nearby.
From late Anisian to top Ladinian, repeated episodes of scarce oxygenation affected the bottom water enabling many organisms to fossilize, particularly vertebrates. The *Formazione di Besano* contains three different faunal associations: the standard of their preservation depends on the lithology, consisting of dolomites alternated with bituminous schists..In the latter fossils are often found scattered due to weak currents that moved the seabed. The *Calcare di Meride* on the contrary, provides well preserved specimens. Many are the fossil bearing beds across the hundreds meter thick formation (Cava Inferiore, Cava superiore, Cassina, Kalkschieferzone the best known), yielding exceptionally well preserved organisms such as small fishes, crustaceans, insects. To this particular process certainly contributed bacterial films which coated the dead organisms preventing them from the chemical action of water.
In the earliest Carnian (about 230 my ago) a temporary and partial regression caused a shallowing of the sea water in some areas, in some other the land emerged. This is well expressed by the coloured *Marne del Pizzella*, also containing gypsum lenses like those found near Meride.
During the Norian (about 225 my ago) carbonate platforms were widespread again: very large and thick outcrops of *Dolomia Principale* are found throughout the “Sudalpino”. The topmost part of the Triassic sequence is the *Serie di Tremona* (Norian-Rhaetian), consisting of fossil bearing limestones with variable content in oolites, occasionally dolomitized.
At the beginning of the Jurassic (Hettangian, about 205 my ago), most of the southern Ticino region was dry land: erosional and Karst processes were active. The Sinemurian (Lower Liassic) saw a new, consistent marine transgression, accompanied by tectonic vertical movements producing deep basins separated by higher blocks. East and west of Monte San Giorgio the Monte Generoso and Monte Nudo deep basisns had very high subsidence rates, while the Arzo-Besazio-Tremona area was constantly around the sea level (*Arbostora threshold*). The rocks between the deep basins and the threshold were affected by complex fault systems, occasionally by very wide cracks, later filled by sediments at different times. The result are varicoloured breccias called *Macchia Vecchia.* Proof of the huge gap created by the Sinemurian subsidence is the *Calcare di Moltrasio*: this cherty limestone formation is 3000 m thick in the Monte Generoso basin, about 1500 m thick in the Monte Nudo basin; the stratigraphically correspondent *Broccatello,* outcropping at Arzo, and belonging to the threshold structure, shows a thickness of only 100 m (approximately).
From Upper Liassic (about 185 my) the area of Monte San Giorgio is also involved in subsidence and sedimentation becomes similar to that of the adjacent basins. In the Arzo-Clivio-Saltrio zone the stratigraphic succession encompasses the formations *Unità di Morbio* and *Rosso Ammonitico Lombardo*, consisting of limestones, calcarenites, and nodular marly limestones.
At the southern foot of the mountain, in the Besazio-Ligornetto-Stabio-Viggiù region, upon the described sequence we find Middle-Upper Jurassic units ascribed to the *Gruppo delle Radiolariti* and *Rosso ad Aptici*: they are made up of marls, limestones, radiolarites, and are known altogether as *Selcifero Lombardo*.
The fact that nowadays on MSG layers are not horizontal is due to the Alpine orogeny that tilted the rock formations, now appearing as a monocline with 30° SW dip under the Po river plain. As a matter of fact, in the AGIP boreholes of

Gaggiano, Trecate and Villafortuna, the same units are found as deep as about 4.500 m, and represent the source-rocks of one among the European richest onshore hydrocarbon reservoirs.
The above described Mesozoic units are widely overlain by Quaternary sediments (2,5 my ago to present).
As a consequence, the visitor on Monte San Giorgio will observe widespread deposits consisting of slope debris, glacial and fluvio-glacial (very rarely lacustrine) sediments, often hiding the rocks below. The glacial sediments besides part of the fluvial deposits have been produced by glaciers moving towards the southern foot of the mountains; during their retreat they have left behind sediments and characteristic features like moraines (simple or complex like amphitheatres): north and west of Stabio as well as in the surroundings of Clivio and Viggiù complex morainic structures are visible.

Several springs dot the mountain: among them we already cited the carbonate spring, giving rise to the only tufa on Monte San Giorgio. Also peculiar are the spurts near the *Terme di Stabio*, whose sulphur bromine-iodine waters are probably related to the Triassic units underground.
All the rock units described above belong to the World Heritage Property; the middle Triassic units belong to the World Heritage Area. Both are part of the Monte San Giorgio UNESCO World Heritage site

September 2, first day, morning



After Gaetani et al., 1998. Since then we consider now the Formazione di Cunardo as early Ladinian on the base of ammonites (Calabrese & Balini , 1995) and vertebrates (Lombardo et al., 2006)

THE CALCARE DI MERIDE

The *Calcare di Meride* (CM) is the result of a long period, spanning most of the Ladinian, characterized by basinal carbonate deposition, sometimes with a slight shale contribution (marly limestones). The unit is well stratified, layers are 10-15 cm thick on the average. The composition is mostly calcium carbonate (nearly pure) and the color dark grey or light brown; though, alteration of the scarce organic matter contained make the rock appear as light grey. On Monte San Giorgio we hardly find a well exposed section of CM. We must search along streams and military roads. The reason is that stratification facilitates fracturing and weathering, and, consequently, the formation of soils where vegetation flourishes. Along this road we meet various CM outcrops: it is easy to see that the same lithotype can be present across hundreds of meters of thickness. As a consequence, even a very small outcrop is sufficient to recognize the unit, but, on the other hand, the great homogeneity prevent us from understanding the stratigraphic position inside the formation. Only the upper CM (the *Kalkschieferzone*) is identifiable by its well laminated marly limestones. However, thin, slightly marly, laminated layers are common through the entire succession of CM. A few of them, particularly rich in fossils, have been given a name: *Cava Inferiore*, *Cava Superiore*, *Alla Cassina.* Though scattered specimens have been collected also on the Italian side, scientific excavations in these levels have only concerned the Swiss side of MSG. These fossiliferous layers were discovered during the search for bitumen in the early XX century because associated to layers with great organic matter content. Many other laminated beds could contain interesting fossil remains, but they have never been investigated in details. Along the way uphill, you will see also layers containing ‘soft-sediment clasts’ They appear as carbonified plant remains at first sight: actually they are algal film slabs ripped out from shallow waters during storms and then deposited again on a deeper seabed together with carbonate mud.

THE LOWER CALCARE DI MERIDE

STOP 1 - ACQUA DEL GHIFFO

The Calcare di Meride is about 500 m thick and consists mainly of regularly bedded micritic limestones with thin marly joints (Furrer 1995). It begins about 150 m above the Formazione Besano after the Dolomia del San Salvatore. The lower CM is usually poor in fossils, with the exception of three metric vertebrate beds (but possibly more levels yielding vertebrates are present as the ones already investigated have been discovered following mining for the bituminous shales). Between 1927 and 1933, B. Peyer discovered these fossil beds with numerous and well preserved small pachypleurosaurid *Neusticosaurus*, a few specimens of the larger sauropterygian *Ceresiosaurus calcagnii* and one specimen of *Macrocnemus bassani*. Only a few actinopterygian fishes and one echinoid (*Serpianotiaris hescheleri*) had been reported. Following Sander (1989), the three vertebrate beds are characterized by dominant pachypleurosaur species: the Cava inferiore beds by *Neusticosaurus pusillus*, the Cava superiore beds by *Neusticosaurus peyeri* and the Cassina beds by *Neusticosaurus edwardsii*.
More recently, new small excavations were organized by H. Furrer from the PIMUZ in collaboration with M. Felber, then curator at Museo cantonale di storia naturale di Lugano. In 1995 and 1996, bed by bed studies on a surface of about 10 m2 were carried out in the Cava inferiore beds at the locality Acqua del Ghiffo. These beds, consisting of black shales, fine laminated limestones and dolomites, are only 1.50 m thick and related to a lower and an upper volcaniclastic layer, 4 and 3 m thick respectively. Together with a new juvenile specimen of *Ceresiosaurus calcagnii*, almost 100 more or less complete *Neusticosaurus pusillus* have been found, mainly adult specimens 30-40 cm long, even if also rare juveniles are present. Very common are isolated *Neusticosaurus* bones and coprolites with bones of the same pachipleurosaurid. The new fish material consist of about 40 specimens belonging to at least 8 species.

	Cava inferiore	Cava superiore
Saurichthys curionii	AdG (1)	
Saurichthys macrocephalus	AdG (1), Ca (1)	
Saurichthys sp.	AdG (3)	AdG (2)
Peltoperleidus triseries	AdG (1), Ca (1)	
Ctenognathichthys bellottii	VSe (1)	
Stoppania ornata	VSe (1)	
Luganoia lepisosteoides	VSe (1)	
Peltopleurus rugosus	AdG (6), Afe (3)	
Peltopleurus cf. *lissocephalus*	AdG (1), VSe (1)	
Peltopleurus sp.	AdG (3)	
Peripeltopleurs vexillipinnis	Ca (2)	
Habroichthys minimus	AdG (2), Afe (2), Ca (1)	
Habroichthys sp.	AdG (2)	
Eosemionotus sp.	AdG (12), Afe (2), VSe (1)	
Archaeosemionotus sp.	AdG (4), Afe (2), VSe (4), Ca (2)	
‘*Legnonotus’* sp. indet.	AdG (1)	
Besania micrognathus	AdG (5), Afe (1)	AdG (1)
Ducanichthys aculeatus	AdG (2)	
Placopleurus sp. indet.	AdG (2)	
Placopleurus besanensis	Afe (1)	
Undescribed genus & species	AdG (1)	

Abbreviations: AdG = Aqua del Ghiffo, Afe = Aquaferruginosa, Ca = Cascinello, VSe = Val Serrata. The number in brackets indicates the total number of specimens found so far. After Burgin, 1999.

It is very clear that fishes are quite rare, especially in the Cava Superiore beds.
Clumpy concentrations of ostracods can be observed on many bedding planes and are interpreted as regurgitations of fishes. These ostracods probably lived in the shallow oxic water of the surrounding carbonate platform, where also the rarely found crustacean *Halicyne*, the serpulid *Spirorbis*, bivalves, gastropods, lingulid brachiopods and the common dasycladacean algae lived.
In 1997 a similar excavation started about 20 m higher in the Cava superiore beds, a 10 m thick interval of very well laminated bituminuous limestones and shales, only interrupted by rare bentonites (volcanic ash falls), micritic limestones, displaying sometimes graded calcarenites at the base. Fossil content mainly consist of small pachypleurosaurid *Neusticosaurus peyeri*.

Biostratigraphic data are poor. Wirz (1945) reported from the lowermost *Calcare di Meride* a fossiliferous bed with *Daonella moussoni* , *Arpadites arpadis* and "*Trachyceras archelaus*", revised by H. Rieber as *Protrachyceras* cf. *P. ladinum*. In 1998, about 40 m above, in the Cava superiore beds, we collected some specimens of *Arpadites* cf. *A.arpadis* (determination H. Rieber). Both ammonoid species occur in better dated sections of eastern Lombardy and the western/central Dolomites in the *gredleri* Zone of Early Ladinian.

THE KALKSCHIEFERZONE

THE CA’ DEL FRATE SITE

In the last 30 years, the University of Milano fish-team paid particular attention to the youngest levels of Meride Limestone, the Kalkschieferzone, which crops out between Valceresio (Varese - Italy) and Canton Ticino (Switzerland), in order to study its faunal composition. Fossil collection in this unit has been random until the beginning of the 80's when systematic field works were started with a joint project set up together with the Civico Museo Insubrico di Storia Naturale di Induno Olona in the locality of Ca' del Frate (Viggiù - Varese) (Tintori et al. 1985; Tintori 1990a). As Cristina Lombardo started her Ph.D. thesis in 1995, a new excavation campaign was done in the fall 1996/spring 1997 on a surface of about 12 square meters, subdividing the main fossiliferous level, about one meter thick, in very thin (2-5 cm) units. Other than to collect new specimens for the rarest species, which often did not happen, we wanted to look for the most natural fish assemblages. Rarity of fossil fishes prevents from carrying on a lamina by lamina work, the only way to be sure that a fossil assemblage represents the natural one. Apart from a few massive, barren layers, only one fish species is always present, *Prohalecites porroi*, often in mass mortality surfaces. Also the crustacean *Schimperella* is quite common and has been found by hundreds specimens. Four other fish genera can be considered quite common. One of them, *Peltopleurus* with the new species *P. nuptialis*, seems to have here a short stratigraphic range, from unit 14 to 15m. However, this species is rather widespread as it has been found also near Meride, in the Perledo-Varenna Limestone and in an unknown site along the eastern coast of the Maggiore Lake. The other three, the neopterygian *Allolepidotus bellottii* and the basal actinopterygians *Perleidus altolepis* and gen.n. A, have a rather regular distribution, though only in few units they have been found altogether. The other species are very rare with only one or few specimens recovered, with the exception of a new species of *Perleidus* which has been found in a single unit (17b) where it is very common (11 specimens in the 20 mm thick unit). The fact that all these genera are always found together with *Prohalecites* is very important if compared with the Meride results. As we will see further on, *Prohalecites* is absent in the lower part of that section, while the other genera are still present. *Saurichthys*, one of the most common Triassic fishes, is still lacking from Ca' del Frate.
Another interesting observation is that the estherid *Laxitestella* is usually absent when fishes are present: apart from *Dipteronotus*, which has been always found in paralic environment, we have a single *Prohalecites* on the same surface with *Laxitestella* here at Ca' del Frate. As estherids are related to fresh water, it seems that most of the fish species could be considered as marine.
The Ca' del Frate fauna has been the subject of many studies: about 3000 fishes, rare reptiles and numerous crustaceans have been found (Tintori & Renesto 1983, 1990; Tintori 1990b; Tintori 1990c; Renesto 1993; Lombardo 1997, 1999; Tintori & Lombardo 1999). Description of new fish taxa, as well as re-description of already known ones, mainly from the Perledo-Varenna Limestone, are still in progress together with material from the somewhat older site of Val Mara near Meride.. The importance of this site for middle Triassic fishes is enormous, as it will also allow a better understanding of the so-called Perledo-Varenna fauna (Tintori & Lombardo, 1999).
When the specimen number is sufficiently high, like for *Caelatichthy*, *Perleidus altolepis* and *Allolepidotus bellottii*, they cluster in size-classes (Lombardo, 1997; Tintori & Lombardo, 1999). The regularly spaced sampling of fish populations could be the result of particularly high mortality rates recurring each year in the same period. Alternatively, attritional mortality was seasonally sampled when conditions for preservation were good. In both cases, this kind of sampling may be related to the seasonality of Kalkschieferzone depositional environment. The water of this shallow lagoon, in fact, influenced by the nearby emerged area, was likely subject to sudden changes in salinity and temperature, owing to alternate wet and rainy seasons of a monsoon-like climate (TINTORI 1990b).

UNIT	THICKNESS MM	*PROHALECITES*	*PELTOPLEURUS*	*PERLEIDUS ALTOL.*	*DANINIA*	*CAELATICHTHY*	*ALLOLEPIDOTUS*	*ANEUROLEPIS*	*'LEGNONOTUS'*	*FURO*	GEN.N. C	*LARIOSAURUS*	*SCHIMPERELLA*	*LAXITESTELLA*	PLANTS	BIOTURBATIONS	COPROLITES	FISH GENERA N.	N. OF SPECIMENS
9	60																		
10	60																		
11a	80																		
11b	60	M											RR	RR			RR		
12	65												R	RR					
13	50	CC	?										R	RR	RR			2	1
14	50	CC	I										R	RR	RR			2	1
15a	45			II		I		X					R		RR		RR	4	4
15b	19	C		I				I					R	C	RR			3	2
15c	24	C	I	I		IIII	I						C	RR				5	7
15d	35	C	I			I							C		RR		RR	3	2
15e	40	C	II			I			I				C		RR		RR	4	4
15f	20	C	I			III							C		RR		RR	3	4
15g	35	C	IIII	I		I						X	CC		RR		RR	4	6
15h	17	C		II									C		RR			2	2
15i	50	C		III		IIIII							C		RR		R	3	8
15l	35	M	I	III		II	IIIII					X	C				R	5	11
15m	60	C	III	III			IIIII			?			C		RR		R	4?	13
15n	30																		
15°	40	RR		I		I	II				I	I	RR				R	5	5
15p	25																		
15q	44	M		II								II	?				R	2	2
15r	25	RR		I														2	1
16a	40	M		III		II	IIII						M					4	9
16b	25	R		II		I											C	3	3
16c	55	R		II			I							M			C	2	3
17a	25	C		I					I					M			C	3	2
17b	20	R		II	C	I			I								C	4	15
17c	50	RR					I											1	1
18	>20	I							I	I?	I							4	3
TO	120	M	15	30	11	23	20	1	4	2?	2	2+	M	M				11?	108

Ca' del Frate Section. C, common; CC, very common; R, rare; RR, very rare; MM, mass mortality surfaces / hundreds or thousands specimens

Though some are only represented by very few specimens, most of the 15 fish species found at Ca' del Frate, show significant size variations, with a predominance of small and medium sized individuals. Their study (Lombardo, 1997) revealed that this variation is due to ontogeny: different growth stages have already been described for *Prohalecites porroi* (Tintori, 1990b), where the vertebral column shows the major changes. In other studied species the transformations involve the body proportion and shape, the tooth shape, the degree of squamation, development of fin fulcra and the intensity of ornamentation of the dermal bones. The smallest specimens usually show incomplete squamation, the fins lack fringing fulcra and the head is longer than the maximum body depth, which indicates the very young age. According to literature, all of these characters are indicative for a very young age. The presumed adults have a complete squamation, fulcra are present on all fins, the ganoine covering is complete on all scales and all dermal bones and the head is shorter than the maximum body depth.

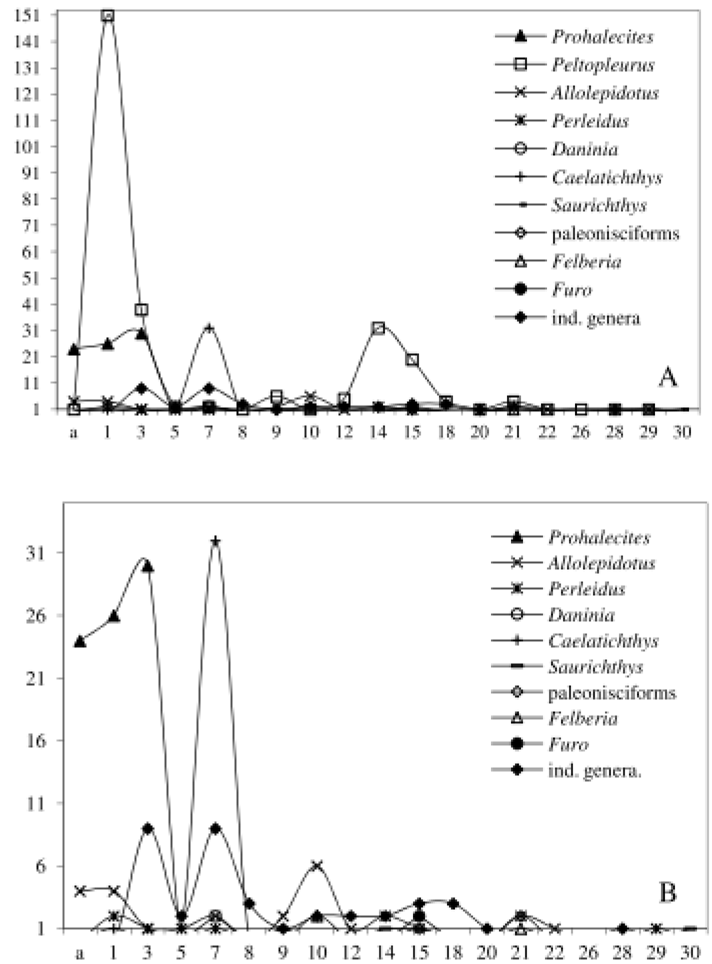
Ontogenetic transformations have been well observed in the following species*: Aneurolepis macroptera*, *Perleidus altolepis*, *Allolepidotus bellottii*, *Caelatichthy*, gen. n. B *obtusus* (=*Legnonotus obtusus* in Tintori & Renesto, 1983) and gen.n. D sp. n. (Lombardo, 1997).

Peculiar reproductive strategies are inferred by the structures found in specimens of *Peltopleurus nuptialis* (Lombardo 1997, 1999); this small fish shows, like many other peltopleuriforms (Bürgin 1990b, 1992) and perleidiforms (Bürgin, 1992; Tintori & Lombardo, 1996), sexual dimorphism. Some specimens, thought to be males, possess a modified anal fin which has been interpreted as a "gonopodium-like" device for internal fertilization (Bürgin, 1990b) or, more probably, to improve external insemination. This new species of *Peltopleurus* is also characterized by tubercles on nasal and rostral bones, yielded only by the presumed males, and hook-like structures on the first ray of the fins, found on all specimens. Because of their distribution on the body, these structures are interpreted as secondary sexual traits.
Last, but not least, we have found a few reptile embrios: they can be confidently ascribed to *Lariosaurus* (Renesto et al, 2003) of which two adults and a juvenile have been also recovered from this site. Nothosaur embrios are not a novelty as they have been already described from the Monte San Giorgio area: however, the increasing number of specimens available seems to indicate a possible viviparity of nothosaurs themselves, as it looks highly unlikely that they were so often washed in the basin from a nest on the beach.

STOP 2 -THE VAL MARA (MERIDE) SITE D

Concerning the Swiss side, in 1994 the Museo Cantonale di Storia Naturale di Lugano and the Paläontologisches Institut und Museum der Universität in Zürich made an excavation in the upper part of middle Kalkschieferzone of Val Mara (Furrer 1995; Bürgin 1995). Since some differences in faunal composition from the various localities were noticed, a field work in the upper part of the lower Kalkschieferzone of Val Mara - which had not been taken into consideration in previously excavations (Furrer 1995; Bürgin 1995) - was started in 1997 by the Museo Cantonale di Storia Naturale di Lugano and the Dipartimento di Scienze della Terra dell'Università degli Studi di Milano (Tintori et al. 1999; Lombardo et al., 1999).
The fossiliferous levels of this site (identified with letter D), intercalated to barren beds, are placed between layer 102 of Scheuring (1978) and layer 60 of Wirz (1945). The choice of this site has been decided after the find of some new species of the genus *Peltopleurus* and of a lower jaw of *Saurichthys*, genus reported for the first time in the Kalkschieferzone. Besides fishes, conchostracans (freshwater crustaceans) are randomly diffuse, sometimes concentrated in mass mortality layers, and terrestrial plants are very common.
Within this part of the sequence characteristic assemblages have been identified, with species exclusive of certain levels, such as *Felberia* Lombardo & Tintori, 2004 and others which show a wider distribution and which were also found in other localities of the middle Kalkschieferzone. This fauna is characterized by the genus *Peltopleurus*, which is present with several species differing in the scales pattern, teeth morphology and shape of the body. *Peltopleurus* is widely spread in the Kalkschieferzone, but in these levels it shows a great specific variability, being also always present with one of the many species. All the species yielded by this late Ladinian unit are quite small, seldom being more than 3 cm long.
The scheme below summarizes the results of both the campaigns of 1997 and 1998: the different assemblages have been emphasized but in some cases they could be further divided in other subgroups. The first assemblage includes the lower part of the series (D30 - D26 – owing to position of the sequence, this part has been only poorly excavated): finds are represented by some specimens of *Peltopleurus* (sp. n. C and D) besides a specimen of *Perleidus altolepis* and the lower jaw of *Saurichthys* sp. The genus *Peltopleurus* characterizes also the second assemblages (D22 - D20) with at least two species, *Peltopleurus* sp. n. D and E; it must be stressed, however, that the poor preservation often does not allow a specific determination of the specimens belonging to this genus. *Allolepidotus bellottii* is also present within these layers. At least two species of *Peltopleurus* (sp. n. B and sp. n. D) are typical of the third assemblages (D15 - D14), which includes also a single specimen of *Allolepidotus bellottii* and ?*Furo*. The fourth assemblage (D10 - D7) is characterized by *Allolepidotus bellottii* (the only species found throughout the series), *Perleidus altolepis, Perleidus* sp.n. A, Gen. n. A sp. n (this latter with specimens found on the same bed) and *Peltopleurus* sp.. As a matter of fact, the single layer D7 could constitute an assemblage of its own, being characterized by *Allolepidotus, Perleidus* and gen. n. A, thus the typical Ca' del Frate assemblage, but without *Peltopleurus nuptialis* and, chiefly, *Prohalecites*. From layer D9 comes a large specimen of *Saurichthys* (the other specimen, represented by the isolated lower jaw comes from D30) and isolated scales. The last assemblage, typical of the higher levels (D3 - DA), is made up by *Prohalecites porroi*, a new species of *Peltopleurus* (*Peltopleurus* sp. n. C) and *Allolepidotus bellottii*.
Some general observations can be made on the grounds of the data collected so far in this site. First of all, the finds in the lower Kalkschieferzone of Val Mara add some information on the vertical distribution of the single species. One of the most interesting results concerns the occurrence of *Prohalecites porroi*: this species, which constitutes about the 95% of the Ca' del Frate fauna, is found only in the very upper part of the series here considered, while it is missing in the lower part of the lower Kalkschieferzone. At the same time, species which are usually associated to *Prohalecites* (*Allolepidotus bellottii, Perleidus altolepis, Caelatichthys*) in the Ca' del Frate layers are also found in the lower levels of site D of Val Mara: this could mean the appearance of the genus *Prohalecites* in correspondence of the layer D3. *Allolepidotus bellottii*, which is quite common in the Kalkschieferzone of Ca' del Frate, is reported for the first time in Val Mara and in the lower Kalkschieferzone; also the presence of *Perleidus altolepis* in layers D7 and D 29 and of *Caelatichthys* in D7, increases the vertical distribution of these species, found for the first time in the lower Kalkschieferzone. As mentioned before, the genus *Peltopleurus* shows in this site a great specific variability, with at

least three species exclusive of these levels (*Peltopleurus* sp. n. C, *Peltopleurus* sp. n. D and *Peltopleurus* sp. n. E), while the most common species found at Ca' del Frate, *Peltopleurus nuptialis* (Lombardo, 1999) is lacking. With the exception of *Peltopleurus* sp. n. B, which has been found in the whole Kalkschieferzone, the other species of *Peltopleurus* have a restricted vertical distribution and they seemingly exclude one another. Studies on peltopleurids of the Kalkschieferzone are in progress, but the sequence of different species of *Peltopleurus* in a relatively short time span could be indicative of a rapid evolution of the genus. Interesting is also the presence in these levels of *Saurichthys*, well represented in almost all the Middle Triassic ichthyofaunas, but apparently missing in the Kalkschieferzone until these finds in Val Mara.
The field campaigns in the site D of Val Mara have confirmed the great variability of the faunal composition of the different fossiliferous levels of the Kalkschieferzone; this variability seems to be essentially due to the instability of the depositional basin, besides the rapid evolution of at least one genus, *Peltopleurus*.
No reptile remains has been found here, but the great surprise was that, for the first time in the Triassic MSG series, a few fossil insects saw the light during the summer 1998 (Krzeminski & Lombardo, 2001). Since then, a certain number of specimens has been collected and a PhD student is now working on them at the Milano University, while Bechly & Stockar (2011) also published a new find. Though not in large number, the insect fauna looks quite well differentiated, pointing to a possible rich terrestrial environment nearby.
Field work continued till the summer 2003, when the uppermost part of this fossiliferous level was exploited.



Distribution of the fish genera across the Val Mara site D lower part, Bed a being the top of the fossiliferous sequence. A) All genera considered. B) All genera but *Peltopleurus*, to allow a better definition of the distribution of the remaining genera. Paleoenvironmental conditions changed around bed 8-9 as many more specimens are recorded in the younger beds.

STOP 3 – FORMAZIONE DI BELLANO

Between the latest Paleozoic (Permian) and the earliest Mesozoic (Triassic) Monte San Giorgio, together with western Lombardy and southern Canton Ticino, lay on the fringe of the Tethys, a very wide oceanic gulf wedging into the Pangea, the super-continent composed by most of the lands above sea level. Our Earth thus had a very different aspect from the one we are used to. In the time from 270 to-245 million years ago, here, where today we see Monte San Giorgio, there was a plain, gently sloping down to a shallow sea eastward. The sea water occasionally lapped against this area like it had done in the early Triassic; then, starting from Upper Anisian, the region was constantly below the sea level until the end of the Mesozoic. This outcrop, in the Rio Vallone, clearly shows evidences of the long period characterized by continental deposition. We observe a succession of clastic rocks: from the finer reddish siltstones to the dark sandstones (cemented sand) up to the coarser conglomerates, here well visible.

Though detailed studies have never been carried out on this succession, we are fairly certain it does not contain the Permian Verrucano Lombardo, peculiar reddish conglomerate outcropping eastward. This proves the area was affected by erosion in the latest Permian, while at the beginning of the Triassic the shores were occasionally flooded by sea water (see *Formazione del Servino*); the result is that marine sediments are intercalated to continental deposits. On the Swiss side of the mountain, in fact, possible Lower Triassic marine fossils have been found. In the Anisian a new tectonic uplift event caused another erosional phase of the Permian volcanic rocks and of the underlying metamorphic units in the Insubria region. The resulting clastic formation is called *Formazione di Bellano* and outcrops from here to the Grigne group, on the Como lake. The sea then progressively came in from the east, and the deposition gradually changed, from siliceous sandstones to sandstones mixed to dolomitic clasts up to shallow marine carbonates (Dolomia del Salvatore) when the frankly marine history of Monte San Giorgio began.

White quartzite pebbles in the Formazione di Bellano

STOP 4 -RIO PONTICELLI – FORMAZIONE DI BESANO

This site is where the Italian paleontological research was taken up again about a century after Stoppani started it (1863-1878). In 1974 the staff of *Museo Civico di Storia Naturale di Milano* chose this hollow for a small excavation because the *Formazione di Besano* (FB) here outcrops with passable logistical conditions. The Italian side of Monte San Giorgio, in fact, shows rock beds dipping in the slope: they ‘cut’ through the mountain making it difficult to investigate a wide bed surface. Obviously, the wider the surface, the higher our chances of finding interesting specimens. From data collected through many years of research on both sides of the mountain we gather that fossil remains are homogeneously distributed across this unit (FB), suggesting a relatively small sedimentation basin (a few square kilometers).

The *Formazione di Besano* (also called *Scisti ittiolitici* or *Scisti Bituminosi di Besano* or, in German, *Grenzbitumenzone*) is the best investigated unit , due to its remarkable thickness (an average of 12 m) but also to its constantly rich fossil content, both vertically and horizontally (even though the mountain is small and the maximum distance is about 5 km). On this ground, we can state that at any site we choose to search for fossils in the *Formazione di Besano*, we would get a high number of specimens. In particular we would probably have many fishes, several reptiles like *Mixosaurus* and *Serpianosaurus* (the most common) and possibly also some rare species such as *Tanystropheus longobardicus*, also called ‘the giraffe reptile’.

The excavation activity, though, has ceased earlier than planned. Logistics was too complicated both to obtain a wide enough surface and to investigate the whole thickness of the unit. A few years after, in 1984, the Milano museum moved the research northward, near the Swiss boundary, to a locality called *Sasso Caldo,* where they have worked for about 20 years. Sasso Caldo is the largest excavation concerning the *Formazione di Besano* (FB) on the Italian side of Monte San Giorgio. Week after week, the staff of the *Museo Civico di Storia Naturale di Milano* has carried out the research for 20 years, from 1984 to 2003. Hundreds of fishes and a few reptiles have been collected: most of them have not been studied yet (as usual in a big excavation). The choice of the site was not simple: the rock layers dip against the slope and for this reason it is complicated as well as expensive to obtain a layer surface of at least 100 square meter, the minimum size for a really productive systematic excavation in the FB. Another problem is rain: the bottom of the excavation easily becomes a pool!

Like at the renowned *Punto 902* excavation on the Swiss side, the entire thickness of the FB has been investigated at Sasso Caldo. Since the formation can be split up into three parts, characterized by different paleontological and lithological composition, a detailed fossil collection is fundamental. The central section is the richest in oil shales, that here are present in thicker beds; in the upper part laminated dolomites (anyway containing a small quantity of bitumen) are predominant. These differences express environmental changes. The middle unit represents the maximum depth of the lagoon, whereas the lower and top parts show gradual passages respectively from the underlying *Dolomia del Salvatore* and to the overlying *Dolomia del S. Giorgio,* both deposited in very shallow water. The land surrounding the sedimentation basin of the FB were just a few meters above sea level.

Like lithology, the fossils in the FB show different assemblages in the three parts of the formation. The most evident variation concerns the distribution of the fish genera: several are common in only one of the three sections and very rare in the others. Regarding reptiles, sauropterygian (pachypleurs and nothosaurs) are usually complementary to ichthyosaurs: where the first are common the second are very scarce and vice-versa. This is especially true for the upper part were only sauropterygians have been so far found.

Bituminous shales and dolostones of the Formazione di Besano

STOP 5 – OLD MINES SELVABELLA - PIODELLE

The industrial search and exploitation of the bitumen contained in the *Formazione di Besano* came before the scientific research; then they continued hand in hand for a century. In the earliest stage, possibly lasted a few centuries, the inhabitants of this region used very little quantities of the hydrocarbon substance to meet their daily needs; though, it was certainly far from the ideal solution, due to the acrid smell the bitumen produces while burning. When the industrial activity began, there was a great hunt for every possible source of energy. We observe here the rock beds cutting the mountain with a 45° dip, and we can imagine how hard the mining work was for the men. We must also remember that the volume of the target lithotype is by far less than that of the intercalated dolomites, which, although useless, had to be carried outside. Galleries were fairly narrow: as we can still appreciate, the rock beds making up the ceiling tend to sag down, with great collapsing danger.

A portion of the mine was open air: from the trail running on the dolomite debris we observe the withdrawn rock wall. The oil shale used to be carried down the slope my means of a small ropeway. This area witnesses how men’s activities can change the natural morphology. But, on the other hand, it also shows how fast nature wins the territory back, covering all the debris with vegetation to the extent that it is hard to recognize anything.

The pattern of the localities where oil shales were mined is not linear because depends on the outcrops. Many faults interrupt the outcropping rock. The upstream cave shows a sub-vertical tectonic wall left of the entrance, representing a so called slickenside, a polished surface made by the rock movement: the layers of the *Formazione di Besano* are interrupted by this sliding surface. To reach their prosecution beyond the fault we should go down the slope. The mean entity of the dislocation caused by the several faults on Monte San Giorgio is of a few dozen of meters.

The northernmost mine of the Selvabella/Piodelle area ends against a fault

September 3, second day, morning

THE BASINAL SEQUENCE OF NORTHERN GRIGNA
(South slope)

edited by ANDREA TINTORI

With contributions by MAURIZIO GAETANI, ANDREA TINTORI, FABRIZIO RETTORI, CRISTINA LOMBARDO, ALDA NICORA, ALESSIO CECCONI, SILVIA FRISIA, FABRIZIO BERRA –Tranlations by MARTA BOCCALETTI

This trip takes place on the southern side of the Northern Grigna, near the Scudo Tremare, where one of the Middle Triassic basinal successions of the northern Grigna block widely outcrops. Some vertebrate and invertebrate fossil bearing sites will been also visited, and their environmental and taphonomic characteristics discussed.

The landscape of the Lombardy Prealps is very similar to that of the Dolomites. The weak snowfall of May 2007 accents morphology.

Stop. 1 – THE 'BANCO A BRACHIOPODI'

The sequence from the *Calcare di Angolo* to the base of the *Formazione di Buchenstein* thoroughly outcrops along a detachment trench.

Calcare di Angolo

Denomination. This unit was first introduced by Assereto & Casati (1965). It is a complex association of grey, well bedded carbonate lithofacies comprising calcsitites and mudstones, rarely arenaceous limestones and hybrid sandstones; sometimes dolomites and dolomitic limestones in the topmost part. Thickness ranges from a few tens of meters to more than 300 m.
Outcrop area. In the Grigna group, most of all in the northern block, and in central Lombardy.
Lithology. Dark grey limestones are predominant in the eastern outcrops: they are well bedded, with 15-40 cm thick planar beds, and no terrigenous coarse contribution. In the areas where this unit more widely crops out different lithofacies can be distinguished, both vertically and horizontally:

1) Calcareous lithofacies: grey limestones (mudstones and wackestones), in 10-30 cm thick, slightly nodular horizons, often joint to form metric beds, with thin intercaltions and silty or shaly joints. The lower part can be slightly dolomitized. Total thickness up to 300 m.
2) Silty lithofacies. Grey (brownish where altered) siltstones and fine to very fine sandstones, with calcareous cement, very rich in muscovite, in 20-50 m thick horizons, often joint in metric beds. They show fining-upward cycles, 5-10 m thick, ending with nodular limestones bound by siltstones or very fine sandstones. This lithofacies laterally passes to the Formazione di Bellano. Total thickness up to 160 m.

3) Top dolomitic lithofacies. It consist of light grey dolomitic limestones and dolomites, in 20-60 cm thick, sometimes weakly nodular beds, occasionally with stromatolitic laminae and layers of laminar *fenestrae*. Thickness is generally less than 20 m.
4) Banco a Brachiopodi . The topmost lithozone of the *Calcare di Angolo* is similar to the nodular limestones of the calcareous lithofacies but differs in yielding a rich fossil fauna. Crinoids are very abundant (sometimes they make up encrinites) as well as brachiopods. In the sections of southern Grigna and, most of all, of the Coltignone block, across a thickness of 5 m limestone contains matrix-supported oncoids (wackestone) with a diameter of 1-2 cm. This lithozone, from 3.5 to 18 m thick, is observed in almost all the sections of the unit.

Stratigraphic relationships. In the northern Grigna block the *Calcare di Angolo* lies between *Carniola di Bovegno* and *Calcare di Prezzo* and it is laterally indented with the *Formazione di Bellano*. Everywhere else the lower part of the formation is tectonically cut off. Toward its top the unit sometimes passes to the *Calcare di Prezzo* or to a marginal facies of this latter, transitional between the *Banco a Brachiopodi* and the base of the *Formazione di Esino*.

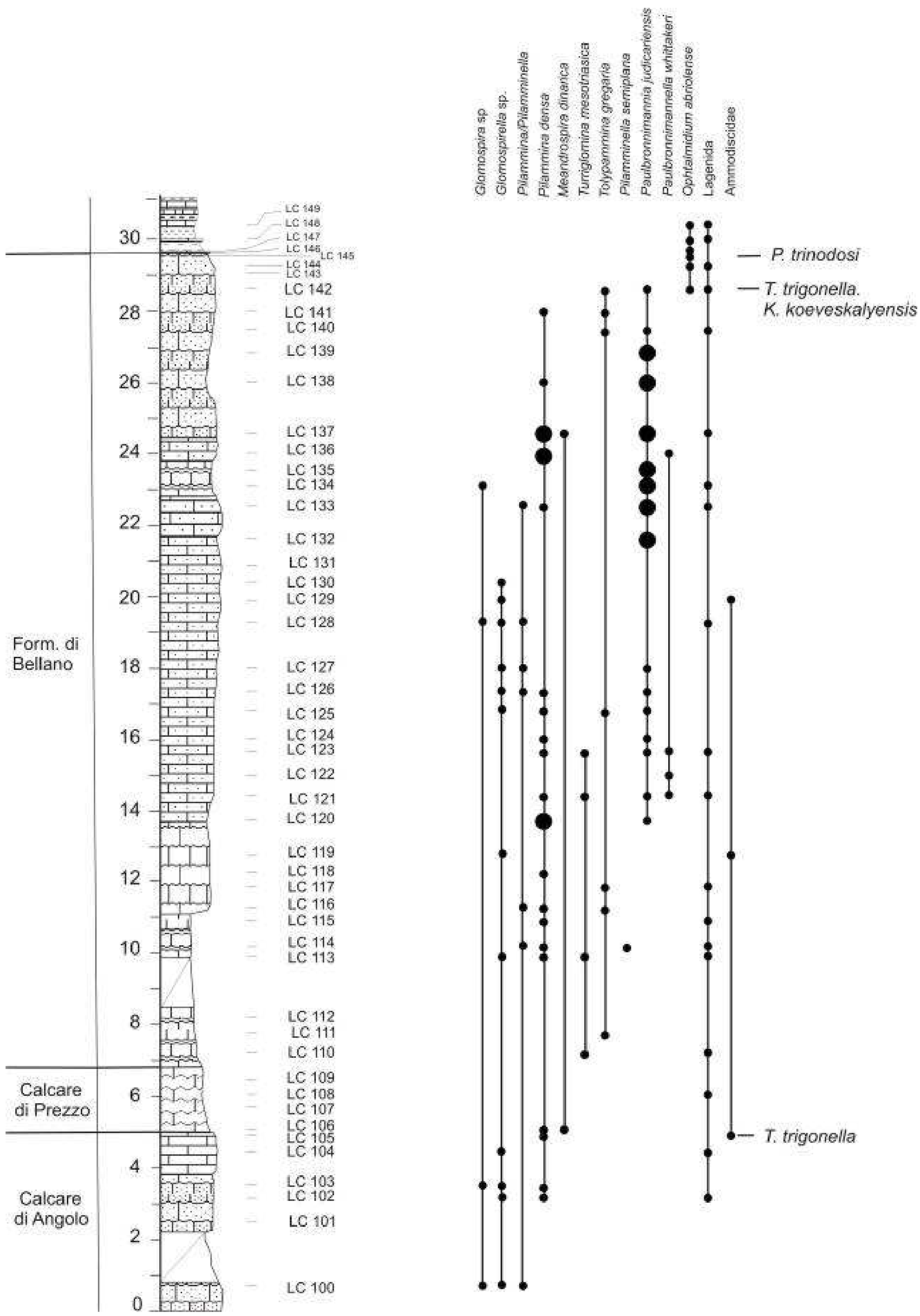
Fossils. The lower unit is generally barren; 50-100 m above, the only macrofossils are small gastropods, while the micro-foraminifers are not rare. The species *Meandrospira dinarica* Kochanki-Devidé, sometimes together with *Pilammina densa* Pantic, is quite important. The *Banco a Brachiopodi* is renowned for being very rich in crinoids: some horizons are packed with crinoid stem plates (columnalia) , in addition to brachiopods. Among these latter *Tetractinella trigonella* (Schlotheim) is dominant on other taxa like *Mentzelia mentzeli* (Dunker), *Decurtella decurtata* (Girard), *Decurtella vivida* (Bittner), *Aulacothyroides alius* (Popiel-Barczik), *Punctospirella fragilis* (Schlotheim) and *Angustaethyris angusta* (Bittner). The top part of the *Banco a Brachiopodi* in Val Meria can contain abundant *Paulbronnimannia judicariensis* (Premoli Silva). D. Germani (pers.comm.) has found the following conodonts in the *Banco a Brachiopodi* of Val Meria: *Paragondolella bifurcata* Budurov & Stefanov, *P. hanbulogi* Sudar & Budurov, *P. praeszaboi praeszaboi* Kovacs, Papsova & Perri, *P. bulgarica* Budurov & Stefanov. At the base of the southern Grigna block the bivalve genus *Entolium* is common while *Plagiostoma* sp. is only occasionally found. Scattered bryozoan colonies have been found SE of Baita dello Scudo.

Age. The Calcare di Angolo is of Anisian age. A more precise dating is difficult: the range is from the Aegean sub-age to earliest Pelsonian. *Meandrospira dinarica* is well represented all across the formation, suggesting that much of it has been deposed during the Pelsonian, when also the *Banco a Brachiopodi* had its origin.

Environment. The *Calcare di Angolo* was sedimented in a wide, shallow-water marine bay. The lower part of the unit is the expression of a restricted environment, with scarcely oxygenated bottom water. Upper in the stratigraphic sequence, the environment was probably more laterally variable, both westward and (possibly) northward: periodically, deltas prograded into the basin. Besides the cyclicity of sediments, an important factor was the spreading of limivorous organisms: their activity during the fossilization and lithification processes produced the typical nodular horizons. The improved oxygenation and environmental diversification allowed foraminifers and micro-gastropods to thrive in many associations. In the topmost part of the unit, some sections instead of delta sediments show carbonate sediments, precociously dolomitized because of temporary emersions. This is proved by *fenestrae* –bearing layers. This variegated environment was later homogeneously covered by the bioclastic sands of *Banco a Brachiopodi* : widespread crinoid prairies provided support and protection to brachiopods, foraminifers and conodonts. This horizon proves a great biodiversity and a connection with open sea, in a transgressional phase.

The foraminiferal associations (Roberto Rettori & Alessio Cecconi)

Benthic foraminifera associations suggest a Pelsonian age up to the Banco a Brachipodi: *M. dinarica*, *T. mesotriasica*, *P. densa*, *P. semiplana*, *P. judicariensis* e *P. whittakeri*. In particular, *P. judicariensis* and *P. whittakeri* are exclusively Pelsonian. They all are known in the Pelsonian both of eastern and western Tethys. Near its top the succession is characterized by the first appearance of *O. abriolense*, known in the Illyrian-Longobardian of southern Appennines (Rettori, 1995). Then, bio-events indicate a Pelsonian-Ilyrian age of the sequence; nonetheless, bathymetric and environmental factors might have contributed to the change in the benthic foraminifera community.



Glomospira sp
Glomospirella sp.
Pilammina/Pilamminella
Pilammina densa
Meandrospira dinarica
Turriglomina mesotriasica
Tolypammina gregaria
Pilamminella semiplana
Paulbronnimannia judicariensis
Paulbronnimannella whittakeri
Ophtalmidium abriolense
Lagenida
Ammodiscidae
P. trinodosi
T. trigonella.
K. koeveskalyensis
T. trigonella
Form. di Bellano
Calcare di Prezzo
Calcare di Angolo
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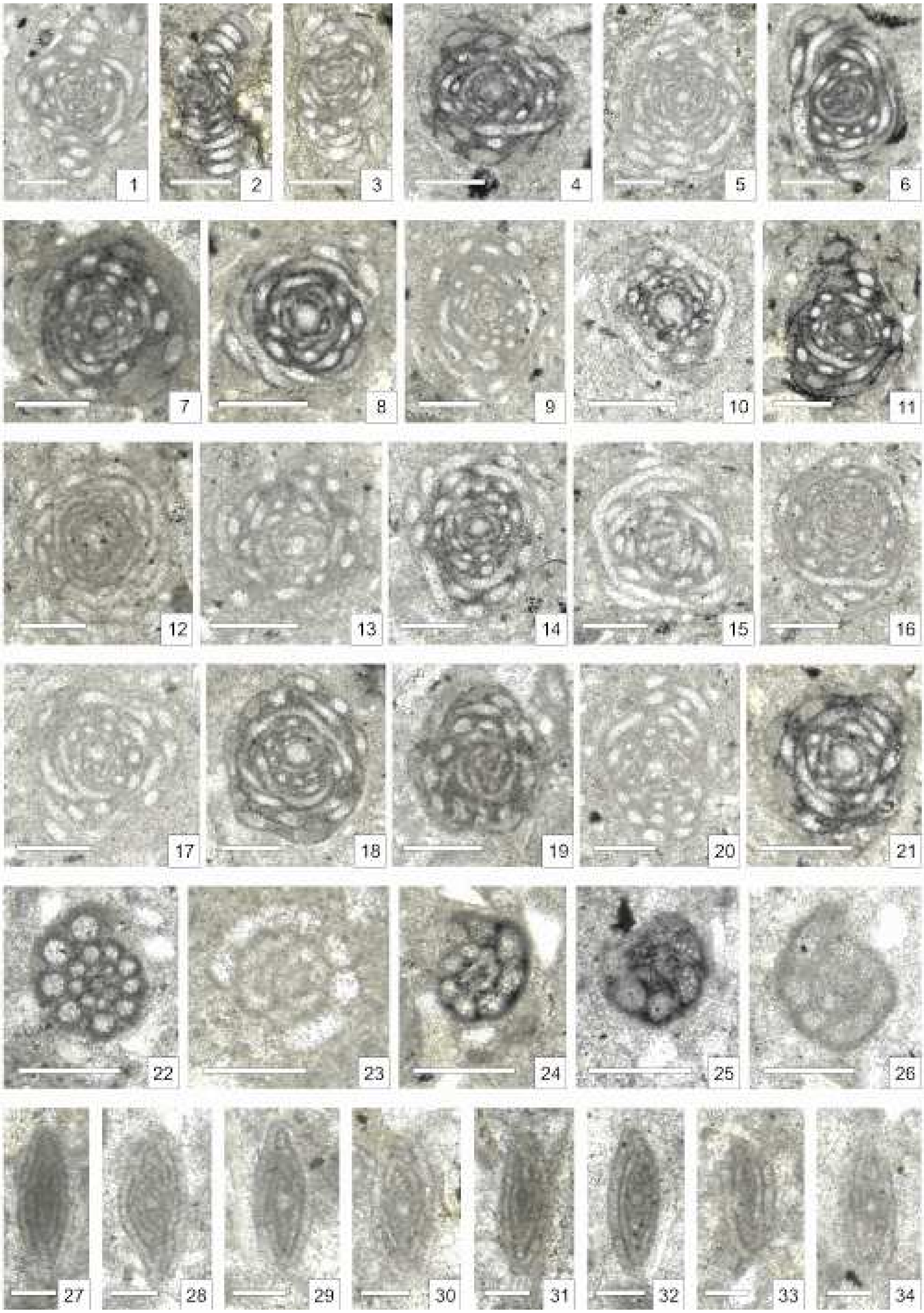
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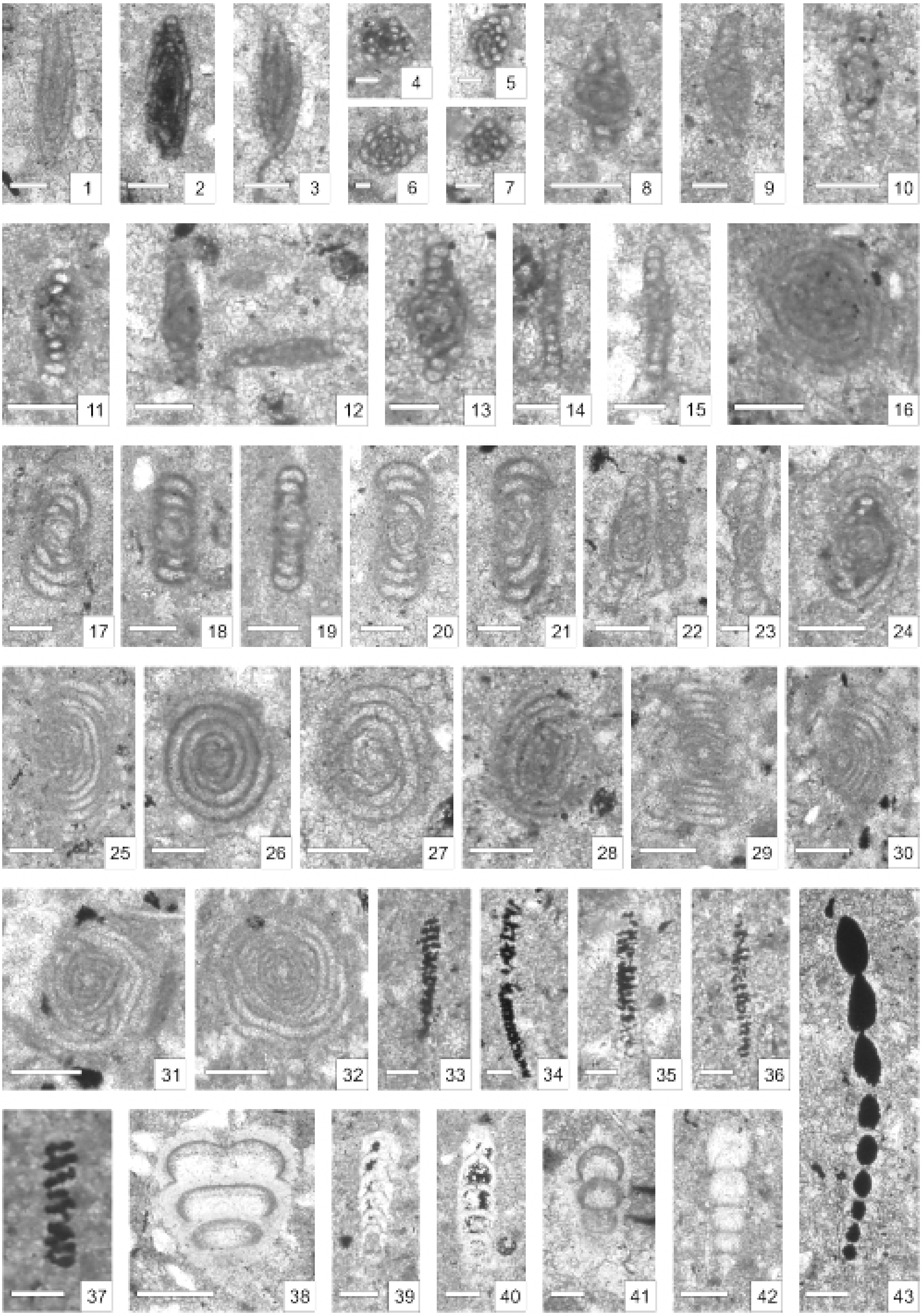
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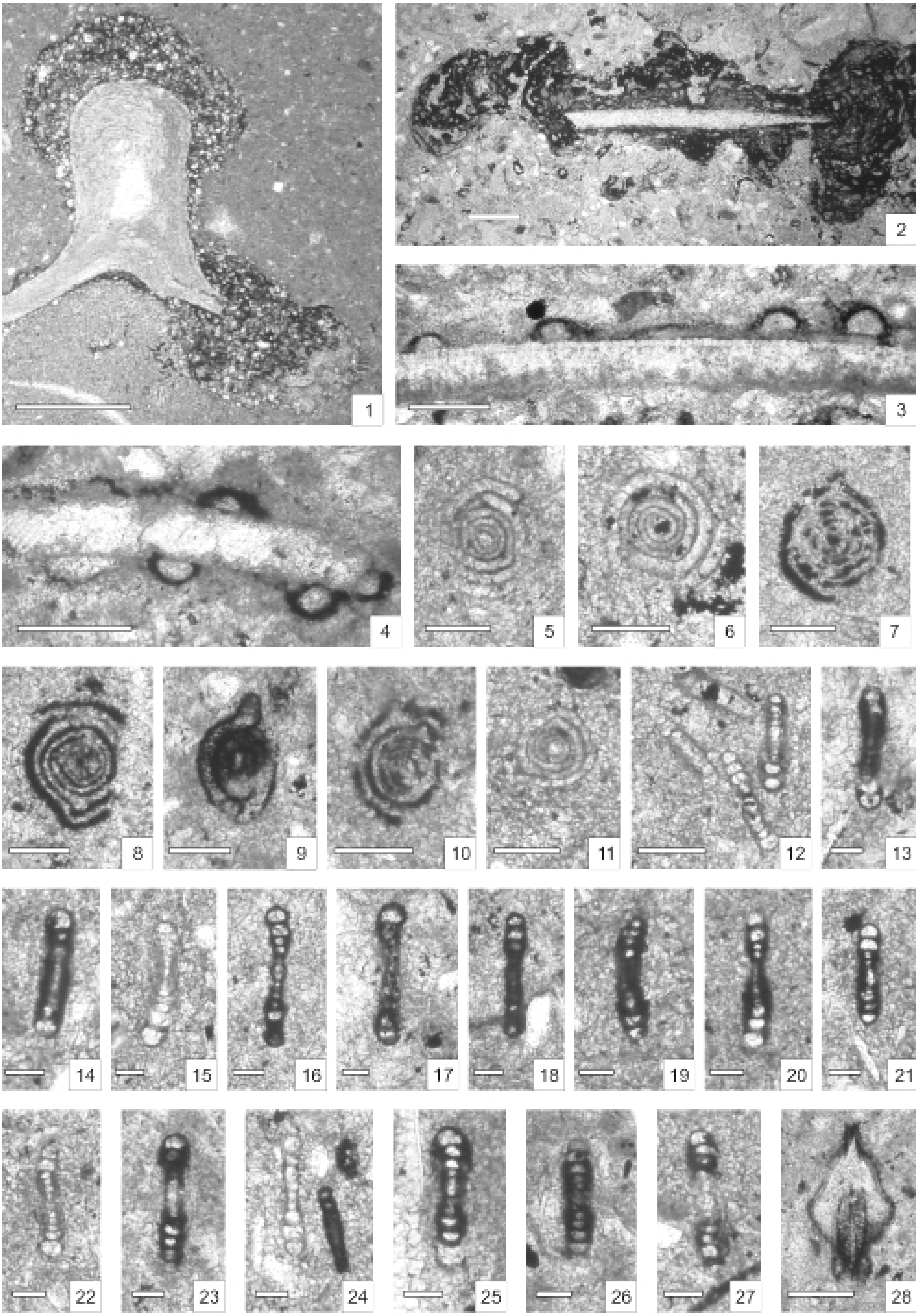
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Plate 1

1-3 *Pilamminella* spp.
1) sample LC 114; 2,3) sample LC 116.
4-21 *Pilammina densa* Pantic
4, 6-8, 11, 18-19, 21) sample LC 116; 5, 10) sample LC 122; 9, 13, 16-17, 20) sample LC 114; 12) sample LC 137; 14-15) sample LC 120.
22-26) *Meandrospira dinarica* Kochansky-Devidè & Pantic
Sample LC 137.
27- 34) *Paulbronnimannia judicariensis* (Premoli Silva)
27-30, 34) sample LC 132; 31) sample LC 133; 32) sample LC 137 ; 33) sample LC 124.

Scale bar: 1-26) 200 µm ; 27-34) 100 µm.

Plate 2
1-7 *Paulbronnimannia judicariensis* (Premoli Silva)
1) sample LC 124; 2, 7) sample LC 135; 3) sample LC 137; 4) sample LC 133, 5) sample LC 145 ; 6) sample LC 132.
8-16 *Paulbronnimannella whittakeri* Rettori
8-10, 13, 16) sample LC 121; 11) sample LC 116; 12, 14-15) sample LC 122.
17-21 *Glomospirella triphonensis* Baud, Zaninetti & Bronnimann
17, 20) sample LC 102; 18-19, 21) sample LC 103; 22-23) sample LC 125.
24-32 *Glomospirella* spp.
24-25, 28) sample LC 121; 26) sample LC 102; 27) sample LC 101; 29-32) sample LC 125.
33-37 *Turriglomina mesotriasica*(Koehn-Zaninetti)
33, 36-37) sample LC 121; 34) sample LC 110; 35) sample LC 123.
38-43 Lagenida
38, 41) sample LC 137; 39-40) sample LC 113; 42) Lagenida, sample LC 128; 43) Lagenida, sample LC 149.

Scale bar: 1-3, 8, 10-12, 16-21, 23-24, 26-28, 39-43) 100 µm; 4-7, 9, 13-15, 33-37) 50 µm; 22, 25, 29-32, 38) 200 µm

Plate 3
1-2 *Tolypammina gregaria* Wendt
1) sample LC 110; 2) sample LC 141.
3-4) Encrusting foraminifers
3) sample LC 127; 4) sample LC 130.
5-12) *Ophthalmidium* spp.
5, 6, 11,12) sample LC 149; 7) sample LC 146; 8) sample LC 142; 9) sample LC 123; 10) sample LC 147.
13- 28) *Ophthalmidium abriolense* (Luperto)
13, 17) sample LC 142; 14-15, 18, 21-22, 24, 27) sample LC 149; 16,23,25) sample LC 146;19-20) sample LC 147; 26) sample LC 123; 28) sample LC 124.

Scale bar: 1-2) 600 µm; 3-4, 28) 200 µm; 5-12) 100 µm; 13-27) 50 µm.

Formazione di Bellano
Denomination. This unit was first introduced by Gaetani (1982) with the name *'Conglomerato di Bellano'* and later renamed *'Formazione di Bellano'* in Gaetani et al. (1987).

Outcrop area. It occupies a continuous belt at the foot of southern and northern Grigna.

Lithology. The rocks that distinguish this formation from the partially eteropic *Calcare di Angolo* are: fine conglomerates with volcanic and crystalline clasts; hybrid micaceous litharenites and hybrid dolomites. Qualitatively analyzed on thin sections, sandstones have the following composition: feldspatic litharenites, lithic arkoses rich in microcline, volcanic rocks with felsitic structure and with granophyre and orthogneiss fragments. These latter prove a relative lift of the varisite basement and of the Permian volcanic rocks lying westward (Schiunnach et al., 1996).

Thickness. Maximum thickness is around 130 m.

Upper boundary. It is an abrupt contact with *Banco a Brachiopodi*; where this is not present, the contact is either with *Calcare di Prezzo* or *Membro dell'Albiga (Formazione di Esino).* In this case, the topmost *Formazione di Bellano* frequently shows a peculiar horizon consisting of hybrid sandstones packed with crinoid skeletal plates, laterally equivalent to *Banco a Brachiopodi*.

Fossils. The recorded macrofossils have no particular value. Undetermined crinoids are common in the upper part of the unit, in stratigraphic position correspondent to the *Banco a Brachiopodi*. On the contrary, the association collected westward near Monte San Giorgio. (Sommaruga et al. 1998), with palinomorphs and benthic foraminifera, is rich and diagnostic (Premoli Silva & Rossi in Delfrati & Schiunnach, 2000).

Age. The fossils of this unit confirm a Pelsonian and Illyrian age, also suggested by the stratigraphic position. The flora described from the Capo San Martino outcrop, near Lugano, indicate an Illyrian age also for the lower part of the formation.

Paleoenvironmental interpretation. The remarkable lateral variability, with coarse facies besides locally bioclastic marine sediments intercalations, suggest the environment was a delta fan with a western source (Grona, Lugano)

Calcare di Prezzo

Denomination. The name *Prezzo-Kalk* (Bittner, 1881) was drawn on by Assereto & Casati (1965).

Outcrop area. This formation extensively outcrops only in the central-eastern N Grigna. East of Valsassina it is found in Valle della Snella, below Piani di Bobbio, and in the Sodadura *klippe*.

Lithology. Two lithofacies are peculiar of this unit. In the lower part there are grey nodular limestones, with 5-10 cm nodules bound up by siltstones and shales. About 15 m from the base shaly intercalations appear and in about 2 m the nodules are by far reduced in number. In the second lithofacies dark grey limestones in almost planar beds alternate to blackish, fissile shaly siltstones. The thickness of beds is comparable in the two lithofacies; nonetheless, towards the top the intercalations progressively get thinner.

Thickness. The total thickness is rarely more than 40-45 m.

Lower and upper boundaries. This formation overlies the *Banco a Brachiopodi* (Calcare di Angolo). The boundary corresponds to the first consistent silty-shaly horizons. Where the *Calcare di Prezzo* is exclusively represented by transitional facies, its dolomitic limestones increase in thickness until bedding is indistinct: this lithology is referred to the *Calcare di Esino*. In the sections where the formation shows its maximum thickness, instead, it is overlaid by the *Formazione di Buchenstein* and the boundary is often marked by greenish or grey volcanic tuffs.

Fossils. Though scattered, Brachiopods are still present all across the section, with *Koevekallina koeveskalyensis* (Stur) e *Piarorhynchia trinodosi* (Bittner). Ammonites here are very rare, possibly because of diagenesis, while in the central-eastern Lombardy they are quite commonly found in this unit.

Age. Rare *Paraceratites* sp. support the traditional dating of this formation to upper Anisian (Illyrian); further confirmation comes from the conodonts found in more eastern areas.

Paleoenvironmental interpretation. This unit is the first step of the facies differentiation characterizing the middle Triassic of southern Alps, the basinal facies. Basins were not more than 50-100 m deep depressions, where micrite, abundantly produced on the adjoining growing carbonate platforms, was accumulated. Clay and silt were also transported into the basin by rivers coming from the near land, probably lying west and north of the Grigne. The peculiar shale-limestone alternance has been variously interpreted, either as primary or as a result of diagenesis. The absence of traction structures seem to exclude the hypothesis of turbidity currents carrying fine sediments.

The Prezzo/Buchenstein boundary

Formazione di Buchenstein

Denomination. This unit was first described in the Dolomites (Richthofen, 1860), where its thickness is remarkable and different facies have been referred to it. For this reason Viel (1979) proposed elevating the formation to the group level. Though, in Lombardy its thickness is smaller, generally less than 100 m, and facies are more homogeneous. As a consequence it is traditionally used as a simple formation.

Outcrop area. The *Formazione di Buchenstein* consistently outcrops only in the south-central N Grigna. It is missing in the other two blocks of the Grigne. East of the Valsassina its presence is patchy and limited to the north-western margin of the *Klippe* del Bruco. The most interesting sections are on the south side of the mountain belt Sasso dei Carbonari-Zucco di Chignoli-Alpi di Mogafieno and between Valle dell'Acquafredda and Valle di Baredo (N Grigna).

Lithology. Several lithotypes can be distinguished, showing typical associations.

1. Grey, micritic limestones in thin to medium beds, sometimes metric, joined beds, locally rich in dark chert nodules or bands.
2. Dark grey micritic limestones in centimetric planar beds, with parallel laminations (more or less evident) and local dark, silicized laminae. Sometimes thin pelitic intercalations. **Vertebrate level.**

3. Grey, chipping marls making metric packs in the middle part of the unit.
4. Fine (silt or clay-size), locally coarser (sand-size) grey to greenish pyroclastic rocks; sometimes the coarser levels show a brownish alteration. Quite common fininig upwards horizons. This lithotype is frequently intercalated to the calcareous lithotypes: thickness ranges from a few centimeters to some meters. Four levels have a great thickness, up to 20 m, and are used as lithostratigraphic key beds for local (Pasquarè & Rossi, 1969) and regional correlations (Brack & Rieber, 1993). The pyroclasts generally have acid compostion, referable to a dacite lava.
5. Grey calcarenites and calcirudites, in centimetric to metric beds. Calcirudites contain clasts with size up to 10-20 cm, belonging to clastic limestones originated on the adjacent carbonate platform (today *Calcare di Esino*). Because the horizons of this lithotype are not thick enough to be mapped, they are considered as part of the *Formazione di Buchenstein.*
6. In Valle dell'Acquafredda, under the *Calcare di S. Calimero* there are grey, shaly micrites in 20-50 cm thick layers, for a total thickness up to 70 m; they are referred to the *Formazione di Buchenstein*.

The lithofacies 1 is prevalent in the lower part of the formation, while intercalations of lithofacies 2 mainly appear in the middle-upper part. The pyroclastic levels are concentrated in the lower and middle part; the lithofacies 5, being associated with the margin of the Esino carbonate platform, prevail in the interval near the *Formazione di Esino*. Lithofacies 6 is limited to the central part of the basin.

Thickness. From 0 to 160-170 m in the N Grigna.

Stratigraphic relationships. Lower contact is with *Calcare di Prezzo*. The boundary is transitional and conventionally placed where the blackish, silty-shaly intercalations disappear, 1-2 m below the first consistent pyroclastic layer (*Orizzonte Rifugio Riva*, Pasquarè & Rossi, 1969). Only in Val Meria a metric calcirudite bank (lithofacies 5) represents a good marker for the base of the *Formazione di Buchenstein* and makes it easier to place the boundary with the underlying *Calcare di Prezzo*. Towards the top we observe the passage to the carbonate platform of the *Formazione di Esino*. The boundary can be abrupt in case it coincides with the base of a prograding megabreccia. Somewhere else, the upper boundary is with the *Formazione di Wengen*: with an abrupt contact, we find dark grey, laminated calcsiltites followed (in few meters) by graded arenitic-siltitic sequences.

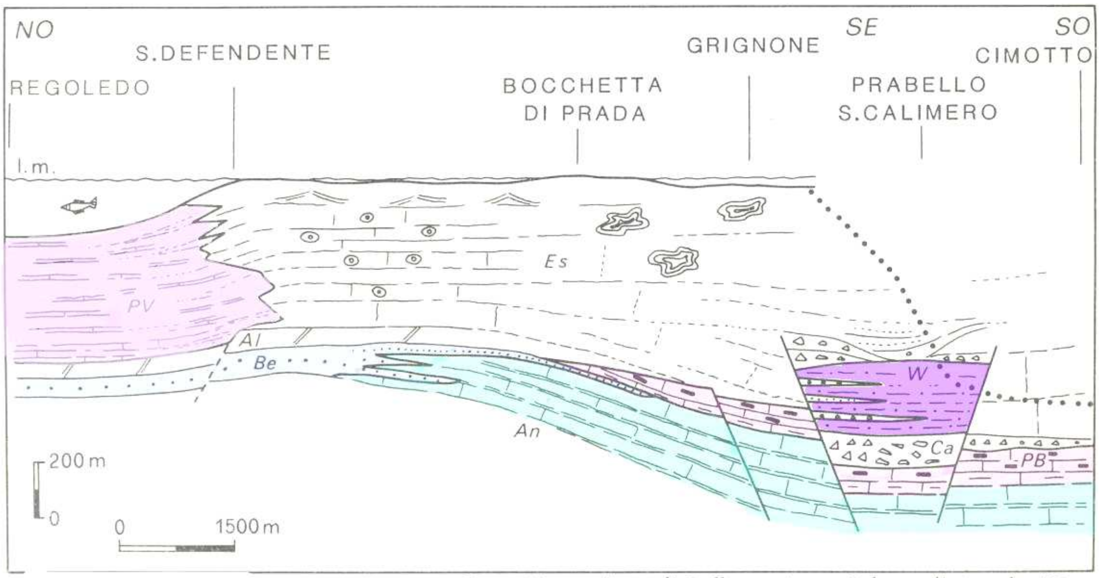
Fossils. The scarce invertebrate macrofossils of this unit are represented by poorly preserved ammonites and by bivalves, like *Daonella taramellii* Mojsisovics . Though, a **fish-bearing layer**, with subordinate crustaceans, has been recently discovered near the Baita dello Scudo, in coarsely laminated limestones containing chert bands of the lower part of the unit. *Saurichthys, Ctenognathichthys, Habroichthys, Placopleurus* are the most common genera, sometimes concentrated in mass-mortality horizons.

Age. This unit has always been ascribed to the lower Ladinian; recent studies on the conodonts contained in the vertebrate horizon confirm this age. Chert, with biogenic and volcanic origin, starts to be regularly deposited around the Anisian/Ladinian boundary.

Paleoenvironmental interpretation. The *Formazione di Buchenstein* represents the acme of the facies differentiation characterizing the Middle Triassic of the Southern Alps. This typically basinal formation was deposited on the bottom of 100-300 m deep depressions; the micrite was flushed from the adjacent carbonate platforms. The abundant silica has its origin in the thriving of radiolarians, advantaged by the water silica saturation caused by volcanic activity; the volcanoclastic sediments in fact are the result of explosive eruptions of fairly near volcanoes. Though, these were not too near: the volcanic rocks are missing on the carbonate platform and the horizons are often normally graded, suggesting that the sediments were transported into the basin by tractive currents. In some cases the pyroclastic material directly falling into the basin water reached the bottom by decantation.

Stop 2. Continuing on the steep slope below the Baita dello Scudo we meet a brachiopod-rich layer, possibly the upper one, not the classic *Banco a Brachiopodi*. *Tetractinella* is very common here.

Stop 3. **The fish level**. From the Baita dello Scudo we go back to the former creek and go up some meters to the excavation site. In this same creek the entire sequence of the *Formazione di Buchenstein* is exposed, up to the contact with the overlying *Formazione di Esino*, making up the face above.



Be = Formazione di Bellano; An = Calcare di Angolo; PB = Calcare di Prezzo e Formazione di Buchenstein; Al = Dolomia dell'Albiga; PV = Calcare di Perledo–Varenna; Es = Calcare di Esino; Ca = Lingua del Calimero; W = «Wengen» dell'Acqua Fredda. La linea punteggiata indica il limite degli affioramenti.

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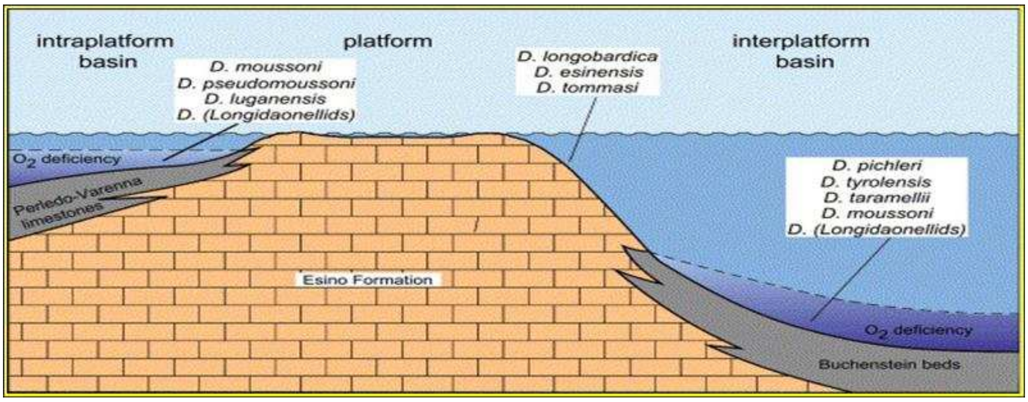
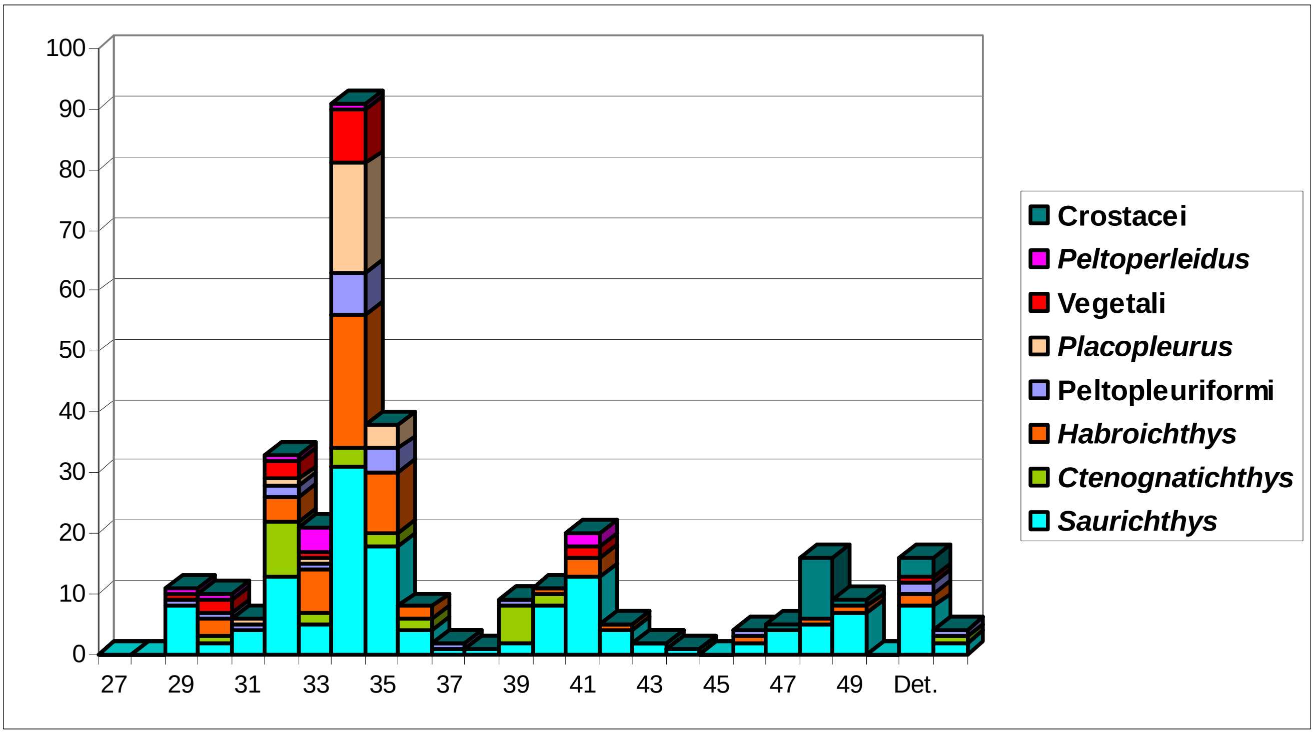


This vertebrate assemblage is very similar to the lower one yielded by the *Calcare di Perledo-Varenna* and by the topmost part of the *Formazione di Besano*. It must be pointed out that the 'historical' vertebrate fauna from the Perledo-Varenna is actually composed of at least three different assemblages, the middle one similar to those from the lower *Calcare di Meride* and the upper one very close to the *Kalkschieferzone* one.

It was in 1981, during a field excursion with M. Gaetani's students, that A. Tintori found here some scattered fish remains. For many years the exploitation of this possibly interesting new vertebrate level of the early Ladinian was left aside. Most of the researches on the Middle Triassic vertebrates, in fact, were focused on the Monte San Giorgio area, by far one the most important sites for this kind of fossils, as you already know. Only in the fall of 2003, a small excavation was started in the northern Grigna site: the result was such promising that during 2004-2005 and 2007-2009 larger excavations were carried out, allowing the collection of more than 1500 fish specimens as well as a few crustaceans and a star-fish. This latter is the only specimen found in the Middle Triassic outside the German Muschelkalk. So far, not a single remain of reptiles has ever been found. Most specimens show poor preservation, but some others can be very nicely preserved and allow detailed descriptions.
Regarding fishes, well preserved specimens need a long and careful preparation: some of them may be considered new taxa or allow better description of previously know species. It is worth citing several interesting 'Subholosteans' and basal Neopterygians (Lombardo et al, 2008) as well as some very large (up to more than 1 m) *Saurichthys* (*S. costasquamosus*, *S.* n.spp. A and B). Many small fishes are found on mass mortality surfaces, implying sudden changes in the environmental conditions, possibly related to the volcanic activity testified by the presence of thin cinerite layers (Pasquarè & Rossi, 1969). The presence of relatively large crustaceans, though quite rare, was a surprise: they are usually almost absent in many of the major Middle Triassic Lagerstaetten, except for the new Middle Anisian locality of Luoping (Yunnan, S.China, pers.obs.). It must be underlined that crustaceans are usually found in beds where no fishes (or very rare) are present and, apart from small fragments, well preserved specimens are absent from the main fish-

bearing beds. At least in one case (bed 48 uppermost surface) we can consider the presence of a few crustaceans remains as due to a sudden, catastrophic event, even though there are no other organisms than crustaceans.
The total thickness of the fossiliferous level is about 135 cm, but a few intercalated beds are barren. Furthermore, the local presence of slumped beds did not allow the regular splitting along the broad lamination, preventing us from a detailed search.



Number of named specimens from each bed. *Saurichthys* high number is probably due to large size of most specimens while for *Habroichthys* and *Placopleurus* the mass mortality surfaces may well explain such a large amount.

This total section has been carefully described by Pasquarè & Rossi (1969), but without any paleontological bias. At the time, the section cropped out much better: however, we can place our fossiliferous level inside their Level 46 (Pasquarè & Rossi, p. 21, fig. 5) using, as a marker, the presence of concentric nodular chert a few meters below a greenish cinerite level (Level 49). This peculiar chert nodules are found just below our fossil-bearing level, and the greenish cenerite is a few meters above it. The lithology of the level is not, at first glance, a favourable one to look for well preserved vertebrates: well bedded grey limestone with thin, black chert beds and nodules, and only a broad internal lamination. Thin clay/marly levels may separate the single limestone beds: following the more or less faint lamination, each bed is sometime hardly splitted. Most of the limestone beds are thin biocalcarenites and their surfaces are often covered by thin layers of brown stuff, possibly of volcanic origin (Pasquarè & Rossi 1969). Furthermore, the bed surfaces are occasionally somewhat stylolithic, explaining the poor preservation of the fishes lying on these surfaces. These are not good enough for detailed studies. The best preserved fossils are those found just below the bed surface, covered by a very thin layer of marls, or just in the middle of the bed itself; in this case they can be detected only in section, after the slab has been broken. Thus, the preparation of most specimens is highly time-consuming and must be carried on very carefully because the rock is very hard and often uneven, due to the presence of chert. So far, only 2/3 out of the more than 1500 specimens have been identified, at least at genus level (most of them will not have any further scientific use). The remaining 1/3 is still waiting for preparation as they show up only in section.

Ctenognatichthys bellottii, known also from the Formazione di Besano and the Calcare di Perledo-Varenna

Saurichthys costasquamosus with ***Ctenognathichthys*** remains in the gut

The star-fish found in 2011

Formazione di Esino

Denomination. The name was introduced by Stoppani (1857) in the form 'dolomia o calcare di petrefatti di Esino' and taken up by HAUER (1858) as "*Esinokalk*". This name identifies the middle Triassic very thick calcareous-dolomitic complex. Authors have often used the lithologic name of 'Calcare di Esino' or 'Dolomia di Esino'. Though, dolomitization is not uniformly distributed: it may shortly change both laterally and vertically. For this reason we preferably use the generic name of 'formation' (*Formazione di Esino*). Local lithozones have been proposed (JADOUL et al., 1992a; 2000), but no one has been formally recorded.

Outcrop area. The unit has been called after the locality of Esino Lario, (in Foglio Lecco), whose surroundings yield rich molluscan faunas described by Stoppani. The N Grigna is therefore the type-area. This formation makes up the structure of the three blocks making up the Grigne Group and Pizzo d'Erna; it outcrops as well in patches on the eastern slope of Valsassina (Zucco Angelone, Coma Muschiada) and at the head of Val Taleggio (Corno del Bruco). Moreover, outcrops are also found on the right side of Valle Brembana, from Camerata Cornello up to Olmo al Brembo. The total outcrop area is no less than 50 km^2 in this region of Lombardy.

Thickness. It reaches 1200 m in the Coltignone block; the average thickness is 800 m. Much smaller (around 250 m) is the thickness of the *Unità di Muschiada*.
Fossils. The *Formazione di Esino* is only locally rich in macrofossils. If gastropods are fairly common, bivalves are not uniformly distributed, but accumulated in lenticular bodies, representing the platform tidal channels. The fossil layer "Sass di Lümach" (meaning 'stone of snails' the name is enlightening..) is very popular: here Stoppani's collection was taken and the same can be said of the specimens described by Rossi Ronchetti (1959, 1960). The list of the several species identified can be found in the cited papers. The bivalve *Daonella tommasii* (Schatz, 2005) is peculiar of the *Calcare di San Calimero*. The find of ammonite specimens (among them *Iberites*) on the eastern slope of the Tre Sassi in N Grigna is quite important. On thin sections, microproblematica like *Tubiphytes* sp. and *Tolypammina gregaria* as well as rare foraminifers are recognized. Dasicladacean thalli are frequently found in facies deposited in subtidal, restricted areas; *Diplopora annulata* is particularly common, occasionally in rich layers.

Age. Inside the middle Triassic. The age of the base is determined by the underlying formation. Where the *Esino* directly overlies the *Banco a Brachiopodi* (yielding an upper Pelsonian fauna) the base is reasonably inferred to be upper Anisian. Nonetheless, as it progrades toward the basinal units, its base gets younger, and probably limited to the Ladinian. Where the *Esino* overlies the *Formazione di Wengen*, its base may be as young as upper Ladinian. Unfortunately, we miss more precise data. The Tre Sassi ammonite horizon is referable to the upper Ladinian *Archelaus* Zone and is stratigraphically below the fossil-bearing lenses of the popular locality Sass di Lümach. Here fossil fauna is still of Ladinian age; it is the youngest fossiliferous layer. The top part of the unit, deeply affected by diagenesis (revealed by dissolution structures and cements) has no fossils to help with a more detailed dating than a generic Ladinian.

Paleoenvironmental interpretation. During the Late Anisian–Ladinian, the Southern Alps were characterized by generally attached platforms to the west-south-west (central Southern Alps, Esino Limestone) and isolated platforms north-eastward (Dolomites; Latemar Limestone, Marmolada Limestone, Sciliar Dolomite). In the Lombardy Basin the prograding carbonate platform of the Esino Limestone covers, after a drowning event, the Upper Anisian basinal to peritidal facies (Jadoul & Rossi,1982; Berra et al., 2005). The Esino Limestone includes inner platform facies rimmed by a sandy margin and a narrow reef. The reef facies laterally pass to thick bodies of slope breccias (Jadoul et al., 1992; Berra, 2007), which prograde basinward and interfinger with resedimented basinal limestones. The flat-topped Esino Limestone platform reaches a maximum thickness of about 700–800 m (Casati & Gnaccolini, 1967) and rapidly pinches out basinward with steep (ca. 35°) clinostratified slopes (Fig. 3). The Ladinian basinal succession, coeval with different evolutionary stages of the Esino Limestone, begins with the deposition of marly limestones (Prezzo Limestone) and nodular cherty limestones (Buchenstein Fm.), locally covered by dark, bedded intra-bioclastic packstone and wackestone (Perledo–Varenna Limestone). In the wider basins and close to the toe-of-the-slope, volcanoclastic sandstones (Wengen Formation) interfinger with the Perledo–Varenna Limestone.

In the Grigna Settentrionale massif, the Esino Limestone overlies the dark marly limestones and cherty mudstones of the Prezzo and Buchenstein Formations. The lower Esino, partially eteropic to the Buchenstein Formation, consists of 400m of poorly bedded, intra-bioclastic packstones and grainstones with crinoids, bivalves and brachiopods. These sediments are overlain by the carbonate buildup. Within the buildup it is possible to recognize the following lithofacies :

1. Shallow subtidal and peritidal facies, consisting of well bedded bioclastic-intraclastic packstones with dasyclad algae (*Diplopora annulata*, Pia ; *Diplopora exuberans*, Pia), gastropods, bivalves and cephalopods (*Arpadites* sp.). The limestone is locally dolomitized. In the peritidal facies, 'embryonal tepees' (Assereto & Kendall, 1977) are common.

2. Open subtidal facies with patch reefs consisting of bioclastic packstones and boundstones. Frame-work building organisms are mainly represented by Porostromata, *Tubiphytes* and calcisponges. The evinosponges are very common in this facies, which makes up the upper and middle massive belt in the Grigna Settentrionale.
3. Prograding margin and slope facies consisting of packstones and boundstones with *Tubiphytes*, corals and sponges. It outcrops only in a few places as a result of Alpine overthrusts. When present, however, it contains the evinosponges.

The top of facies 1, in this area, consists of a regressive peritidal sequence, about 50 m thick, characterized by 'mature' tepees, pisoids, hemispheroids and both planar and cross-cutting dissolution cavities. Based on its stratigraphic setting and structures, we correlate this upper part of the platform with the Calcare Rosso member of the Valle Brembana (Assereto & Kendall, 1977; Assereto & Folk, 1980;). The uppermost beds of facies 2 and 3 are cross-cut by huge palaeokarst cavities filled with internal sediments. The peritidal facies does not outcrop.

In Valle Brembana, the bottom and upper sequences of the Esino Limestone are represented by inner platform facies consisting of intraclastic-bioclastic packstones, interlayered with stromatolitic bindstones and less frequent packstones-grainstones with Dasycladacean algae. The central part of the sequence, 300-500 m thick, is a thick-bedded, subtidal, intra-clastic wackestone-packstone with oncoids, large gastropods (*Omphaloptiycha*, *Natica* sp., T*rachynerita*) and bivalves. The top of the Esino Limestone is characterized by palaeokarst cavities which are overlain by peritidal sediments of the Calcare Rosso member forming a low angle onlap. Above the Calcare Rosso, continuing peritidal sequences are represented by the well bedded, light coloured limestones of the Formazione di Breno and the dark grey limestones of the Calcare Metallifero Bergamasco. The Esino Limestone has been recrystallized, as well as partially dolomitized. The least recrystallized facies are those containing blue-green algae and *Tubiphyfes*, which formed coatings that preserved the original textures.

The Formazione di Esino wall above the upper beds of F. di Buchenstein

Formazione di Wengen

Denomination. This unit was first described in the Dolomites (Mojsisovics, 1879), where it shows differentiated facies and remarkable thicknesses. Viel (1979) proposed its elevation to the 'group' rank. In the 'Foglio Lecco' it nonetheless show more homogeneous facies and smaller thickness, so that it is traditionally used with the rank of 'formation'. Though, the only outcrop (eastern side of the N Grigna) does not appear to be connected to any comparable outcrop and the exposed sequence largely depends on local factors. For all these reasons the name 'formation' partially appear as improper.

Outcrop area. The *Formazione di Wengen* is found only on the eastern side of the N Grigna, while it is absent from the other two blocks of the Grigna. The most representative sections are in Valle dell'Acquafredda, at the top of the T. Cornisella (Cügnol Strecc e Cügnol Larg).

1. Dark grey, mainly volcanoclastic arenites, with subordinate silicoclastic fraction, graded and passing to siltstones, marls or shales. Layers from 30 to 70 cm thick.
2. Dark shales and mudstones in thick, metric packs.
3. Marls, calcilutites, and marly limestones.
4. Graded, arenaceous or silty calcarenites, passing to marls and shales, in horizons from 20 cm to 1 m thick.
5. Calcarenites, calcirudites and carbonate megabreccias with either carbon or silicoclastic and/or volcanoclastic matrix. Horizons up to 6 m thick.

Plants remains are commonly found in the middle and upper parts of the unit. Pyroclastic layers (exclusively pyroclastic) are absent except for a site, between Alpi di Mogafieno and the Traversata Alta, where altered tuffs are found, similar to those of the *Formazione di Buchenstein*.

Thickness. From 0 to 400 m.

Stratigraphic relationships. The preserved parts of the Formazione di Wengen have a markedly lenticular shape: as a consequence, the stratigraphic relationships are largely variable. The lower contact involves either the *Formazione di Buchenstein* or the first prograding bodies of *Formazione di Esino*. In the first case, the boundary is where the first consistent silty-shaly layers appear, then passing in a few meters to turbiditic sequences with arenitic base. In the second case (*Esino*) we observe a lateral contact in the outcrop when the terrigenous sediments of *Wengen* aggrade on the first bodies of the carbonate platform (Gaetani et al., 1998). The top boundary of *Formazione di Wengen* with *Formazione di Esino* is abrupt when this latter starts with a prograding megabreccia: a spectacular example is observed on top of the two eastern creeks of T. Cornisella (Cügnol Strecc). Lateral indentations with *Esino* bodies are found at the head of the Foppa del Ger, as well as between Zucco del Falò and Vendüi Olt.

Fossils. Macrofossils, particularly scarce in this unit, are represented by bivalves, like *Posidonomiya wengensis* Mojsisovics. Recently, some *Daonella lommeli* specimens as well as a single *Celtites epolensis* have been found in the lower part of the unit. Despite a tireless research and the abundance of plant remains, pollens have never been found because of the extensive diagenesis processes.

Age. This unit has always been referred to the Ladinian; on the basis of the new fossil finds it should be ascribed to the Longobardian.

Paleoenvironmental interpretation. This unit was deposed in a very peculiar environment, an extremely narrow basin (not more than 2 km width), laterally interfingering with the carbonate platform. Subsidence rate must have been remarkable (more than 150m/ma?) if the formation thickness is at least 400 m at the basin center. Turbiditic sequences in the lower part and repeated megabreccias, calcirudites and calcarenites witness of a rapid and continuous morphologic change. Moreover, clinoforms in the Formazione *di Esino* on the southern side of Pizzo Solivo and south-eastern side of Corno Buco, with their 30° (at least) inclination, further confirm this interpretation. Diffused remains of vascular plants suggest land was not far; similarly, the frequent volcanoclastic sediments indicates the volcanic eruptions were probably nearby. These same volcanic sediments, deposited on the land and successively transformed in a soil, could have provided later on the pelitic fraction of the unit. Also silicoclasts coming from the crystalline basement are contained in this unit, proving that on land either the basement itself or the overlying terrigenous sediments (*Verrucano Lombardo* and *Formazione del Servino*) were being eroded. In Gaetani et al. (1987) and in Landra et al. (2000) the different depositional interpretation are discussed.

September 3, afternoon

by Maurizio Gaetani and Andrea Tintori

The road running from the Valsassina bottom all around the Grigna Settentrionale and its northern spurs (Pizzi di Parlasco, Monte Agueglio/Sasso di S. Defendente) crosses the southern side of Val Muggiasca and a part of the Calcare di Perledo-Varenna type-section, and further on the Formazione di Esino and the younger units Calcare Metallifero Bergamasco and Formazione di Gorno, of Carnian age. Many sites along this part of the road have a magnificent view on the central Lario lake, particularly in autumn, when the air is clean.

CALCARE DI PERLEDO VARENNA TYPE-SECTION

This sequence has been proposed as type-section by Pasquarè & Rossi in 1974. The lower part is perfectly visible along the road, while the upper part only outcrops in the groove above.

The sequence consists of a monotonous succession of dark grey limestones (mudstones, wackestones) in planar beds, 10-20 cm thick. Its lower boundary is transitional: dolomites are darker and darker, while the intercalated thin, dark, calcareous levels are ever more frequent until they become predominant. Pyroclastic horizons, studied by Pasquarè & Rossi (1969, 1974), are well evident; three of them are especially interesting in the considered section. The lowest one has a remarkably higher content in sanidine then the others. In the picture, the hammer marks the base of the main tuff level. A few meters above, *Gondolella constricta* (Mosher & Clark), *G. trammeli* Kozur, *G. cf. longa* (Budurov & Stefanov), *Gondorella sp.* have been found: this association is ascribed to lower Ladinian.

CALCARE DI PERLEDO-VARENNA: Pyroclastic horizons

Denomination. Stoppani (1857) used the names ‘calcari di Varenna’ and ‘scisti di Perledo’. Pasquarè & Rossi (1970) formalized the unusual name of ‘Calcare di Perledo-Varenna’ despite the fact that almost the entire unit is made up of the Varenna limestones while the Perledo level, much more marly, is limited to the topmost part.

Outcrop area. The Calcare di Perledo-Varenna only outcrops in the Grigne group and Valsassina. It is widely present in the Northern Grigna Coltignone block, in the type area around Varenna and Perledo and between Mandello del Lario and Lierna; marginal patches, proximal to the interfingering with Formazione di Esino, outcrop in South Grigna block. The best sections lie between Mandello del Lario and Grumo (Lierna), while the base of the unit is only visible on the northern boundary of N Grigna. Similar basinal sediments outcrop in Valle Brembana (Bergamo).

Lithology. Three main different lithotypes are distinguished. Gaetani et al. (1992) also pointed out 12 lithofacies whose exhaustive description can be found in the cited paper.

1. Grey-dark grey limestones (mudstones and wackestones) in planar beds, 10-30 cm thick. They can either show thin laminations or no structure at all, and make up about 90% of the unit thickness.
2. Black, fissile marls and shales, sometimes intercalated to the lithology n. 1; in the topmost part of the unit their thickness can be greater; they possibly either show millimetric laminations or no structures at all.
3. Calcarenites or packs of slumped beds with lithofacies n. 1

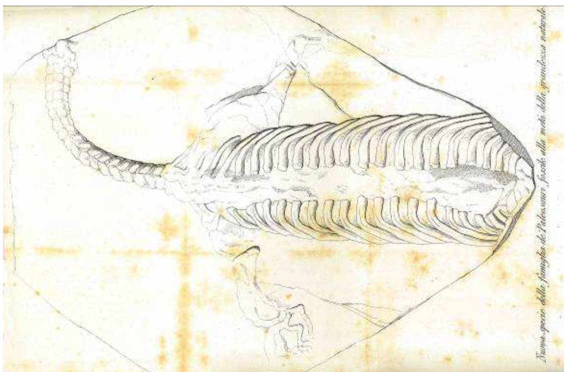
The lower part of the unit contains peculiar dolomitized horizons.

Thickness. This formation reaches a maximum thickness of 500 m in the type-section, at Parlasco (Gaetani et al., 1992).

Stratigraphic relationships. The base of this unit exclusively crops out between the lake and the village of Parlasco; it consists of dark grey dolomites in planar beds , 20-40 cm thick, intercalated to metric beds of lighter-colored dolomites. Toward the top of the formation, dolomitic, marl, and tuff levels alternate to the laminated limestones, allowing a transitional boundary with the overlying Formazione di Lierna. The unit laterally interfingers with the *Formazione di Esino* which in Val Meria (S Grigna) then covers the Perledo-Varenna.

Fossils. Macrofossils are scarcely found in this formation: they are bivalves, most of all *Daonella*. Microfossils are represented by conodonts and rare benthic uniserial foraminifera (Nodosariidae). Vertebrates are well known since the XIX century, with the nothosaurid reptile *Lariosaurus* and several fish genera such as *Perleidus, Prohalecites, Saurichthys* and many others (Tintori & Lombardo, 1999). The historical fauna denominated ‘Perledo Vertebrate Fauna’ was collected in the XIX century, actually all across the Perledo-Varenna unit. On the grounds of the recent studies we now know the fauna can be separated at least in three different assemblages, roughly corresponding to: topmost Formazione di Besano (earliest Ladinian), lower Calcare di Meride (‘alla Cassina’ beds, again earliest Ladinian) and Kalkschieferzone of Calcare di Meride (late Ladinian).

Age. This unit is of Ladinian age; there are evidences both of lower and upper Ladinian (Gaetani et al., 1992).
Depositional environment. The Calcare di Perledo-Varenna has been deposed in a restricted, medium depth basin, among the carbonate platforms of the Calcare di Esino (Gaetani et al., 1992). The bottom water must have been anoxic or at least disaerobic: bioturbations in fact are only rarely found. Superficial water, on the contrary, allowed the life of fishes, marine reptiles, necto-benthic bivalves (like *Daonella),* conodontophorid organisms. The limestones are almost totally made up of micrite, abundantly produced on the adjoining carbonate platform and transported inside the basin.



Lariosaurus balsami: the original drawing by Balsamo Crivelli, 1839

The southern slope of the Northern Grigna (photo M.Gaetani)

Making POLENTA

Piani di Bobbio and Piani di Artavaggio from the Antonietta Lodge

The late Norian-Early Hettangian stratigraphic and paleogeographic evolution of western Bergamasc Alps

F. Jadoul* & M.T. Galli*

with collaboration of G. Muttoni*, M. Rigo** ,Cirilli S.***

* Dipartimento di Scienze della Terra, Università di Milano, via Mangiagalli 34, 20133, Milano, Italy
** Dipartimento di Geoscienze, Università degli Studi di Padova Via Gradenigo, 6, 35131 Padova
*** Dipartimento Scienze della Terra, Università di Perugia

Introduction

The two day fieldtrip is focused on the stratigraphic and paleogeographic evolution of the Norian-earliest Jurassic succession in the Southern Alps of Central Lombardy (Fig. 1), recording the earliest stages of a passive margin, locally with very high subsidence and synsedimentary tectonic, that will lead to opening of the Jurassic Alpine Tethys.

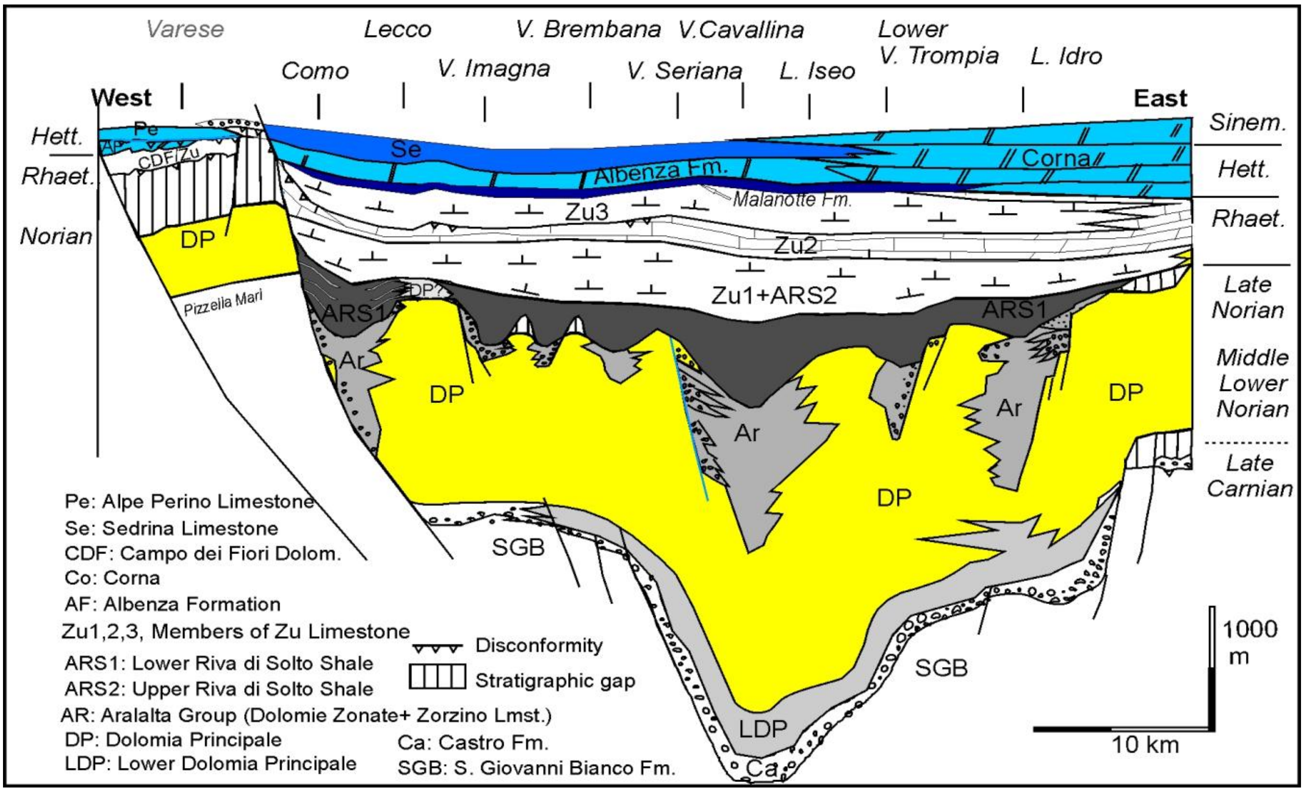


Fig.1 Stratigraphic scheme of L. Triassic-E. Jurassic of western Southern Alps (Lombardy, Jadoul & Galli 2008)

1. Late Triassic regional geologic and stratigraphic setting

Two depositional systems have been recognized in the upper Carnian to lower Hettangian succession (Jadoul et al., 1994; Gaetani et al., 1998). The lower depositional system (late Carnian to middle Norian), lies on shallow-water carbonates, evaporites and siliciclastics representing a coastal sabkha depositional environment of the S. Giovanni Bianco Fm.. It is represented by the shallow-water limestones and intraformational breccias of the Castro Fm., and is covered by the thick carbonate platform of the Dolomia Principale and the coeval intraplatform basin carbonates (Aralalta Group). The upper depositional system (late Norian-Hettangian) consists of a subtidal mixed and cyclic shale-carbonate ramp depositional environment (Riva di Solto Shale and Zu Limestone) developed on the tilted blocks of the Norian rifting event (Jadoul et al., 1992a). It passes upward into the Hettangian carbonate platform (Albenza Fm.)

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

The Dolomia Principale of the western Southern Alps reaches its maximum thickness (about 2000 m) on the eastern side of Lake Iseo. In the visited area, the Dolomia Principale 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 Dolomia Principale).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, microbial macro encodes and laminations, locally tepees, episodes and flat-pebble breccias at the top. 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;Fig.1). The depositional processes are dominated by gravity flows and slumpings mainly related to slope failures (Jadoul, 1985, Fig 4). The intraplatform basins are interpreted as half-graben (Picotti and Pini, 1988; Jadoul et al., 1992a; Trombetta, 1992) generally exhibiting two margin types: one is tectonically controlled; the other is a flexural margin (gentle block tilting).

The upper Dolomia Principale in Lombardy exhibits margins colonized by peculiar microbial-serpulid patch reefs and microbial mounds associated to thick carbonate breccia bodies (Berra and Jadoul, 1996). These peculiar buildups at the platform margins have been interpreted as an ecological adaptation to restricted and stressed conditions of the intraplatform basins in the westernmost Tethys (Cirilli et al., 1999). A change in circulation pattern and nutrient distribution in marine waters could be also one factor of the crisis of the Dolomia Principale depositional system.

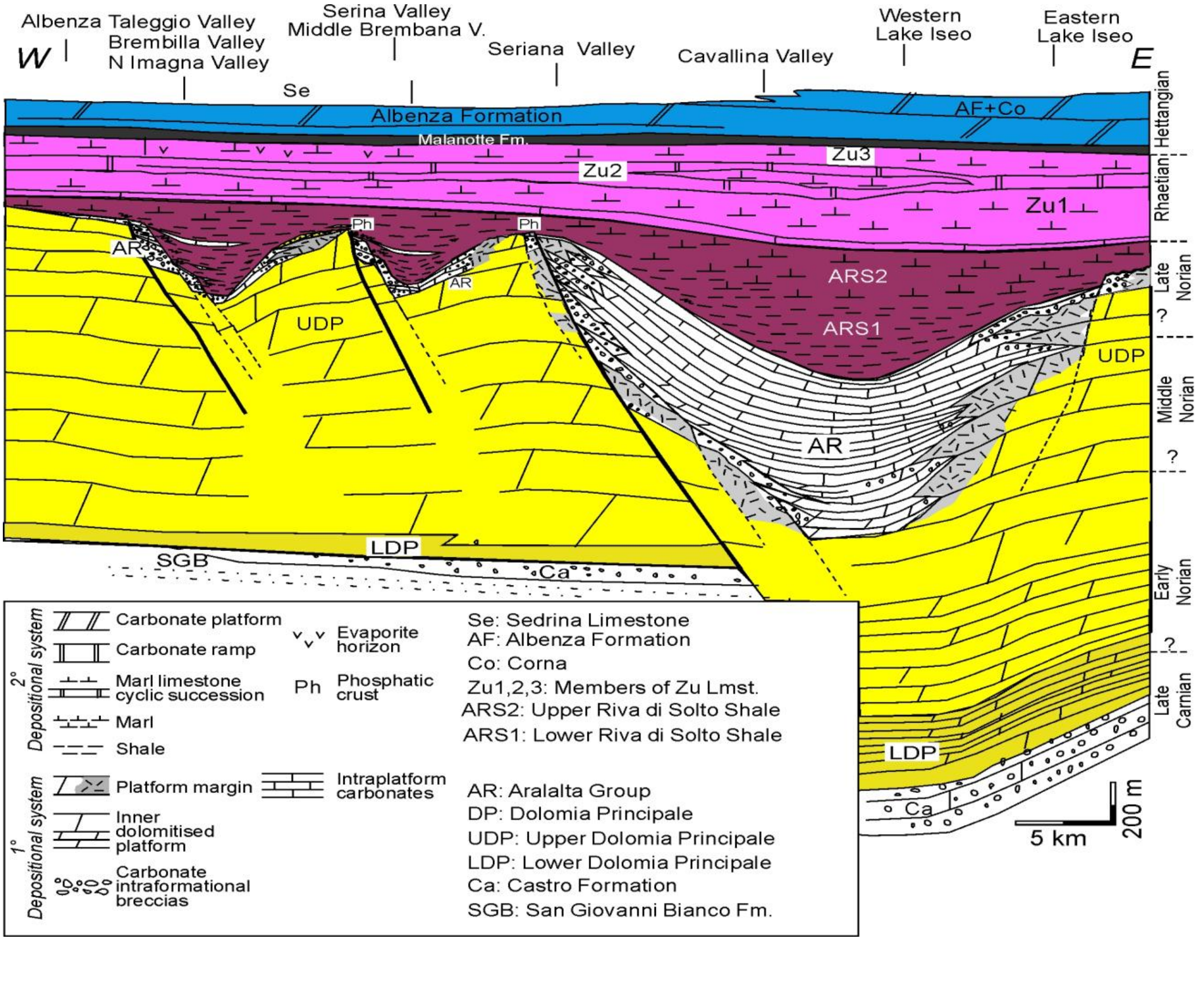


Fig. 2. Stratigraphic scheme of the Late Triassic-earliest Jurassic succession of the Bergamasc Alps (Jadoul et al., 1994, 2004).

1.2. Crisis of carbonate platform deposition and drowning of the platforms (middle-late Norian)

A sudden crisis of the carbonate production, recorded in both platform and basin facies, characterized the top of the first depositional system (Berra et al.,2010). The uppermost Zorzino Limestone consists of a few meters of thin bedded, calcilutites, thin calciturbidites with slumpings, and organic-rich interlayers yielding vertebrates (reptiles and fishes) and invertebrates (crustaceans, crinoids and rare haermatipic corals) (Tintori et al., 1985; Pinna, 1986). Palynological assemblage documents the middle-late Norian boundary in this horizon (Jadoul et al., 1994; 2004, Cirilli et al., 2000).

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

1.2.1. 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 Fig. 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 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 Imagna Valley) (Stop 1.3). 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 (Jadoul et al., 1994; Cirilli et al, 2000). Shales fill the basins and progressively onlap the margins of structural highs that are locally characterized by stratigraphic gaps and thin dark crusts of calcium phosphate. Lenticular small carbonate mounds with abundant microbialites , (cyanobacteria), serpulids, encrusting foraminifers, Dasycladales and problematica document local and ephemeral carbonate recolonisation around a few paleoheights. This particular lithofacies (Artavaggio Member of Jadoul,1985) marks the platform flooding and may correspond to the thick basal black shales (ARS1) deposited in the troughs. 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).

1.2.2. 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 (Berra et al.,2010), 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 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 bathymetric variations within the basins, presence of slopes and persistence of synsedimentary tectonics. This unit deposited in restricted basins and locally with a distally steepened ramp depositional model.

1.3. The cyclic 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 by the three members (Zu1, Zu2 and Zu3) of the Zu Limestone Formation. The lower boundary with ARS1 is gradual, the upper boundary of this ramp system is sharp from shallows marine bioclastic limestones with oncoids and Megalodontids to the thin bedded calcilutites (Malanotte Fm.).

1.3.1. The upper Riva di Solto Shale (ARS2, up to 350 m thick, late Norian)

This unit has a greater extension than ARS1 (Fig. 2). The passage to the overlying Zu1 is marked by the increased occurrence of intercalated limestone (Gnaccolini, 1965) and implies a transitional zone up to 100 meters thick. We propose to set the boundary at the beginning of the up to decameter thick well-organized marl-micritic limestone cycles. 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 and may record storm wave episodes. The palynological assemblage is referred to the upper phase 2 of Schuurman (late Norian) (Jadoul et al., 1994). The depositional model of cycles of this unit may be a distal ramp controlled by different sedimentary inputs.

1.3.2. The Lower Zu Limestone (Zu1 member) (200 to 500 m thick)

The cyclic organization of this lithofacies is similar to that of ARS2, but shows less black shale intercalations and slumpings. This unit is characterized by the upward increase of fossil content and limestone intercalations (7 to 20 m thick). Thin bioclastic lenses commonly alternate with laminated marls and marly limestones: bivalves, echinoids and brachiopods are the most common fossils. The microfacies consist of bioturbated mudstone, wackestone and rare intra-bioclastic packstone with foraminifers (*Aulotortus* spp., *Agathammina* spp., *Glomospirella* spp. and rare *Triasina* sp. Asymmetric and subordinate symmetric cycles (3-4 m up to 30 m thick) are well developed. High energy, bio-intraclastic floatstone with clay chips and less common bioturbation mark the top of some cycles. The upper Zu1 documents a further carbonate increase and local shallowing\shoaling upward trends. Palynofacies are always characterized by high proportion of continental organic matter (miospores and palynomacerals) and by moderate to low percentage of AOM (Jadoul et al., 1994; Cirilli et al, 2000). Lithofacies and palynofacies associations of Zu1 identify prevalent low-energy subtidal environments, sea bottoms were oxygenated and carbonate mud deposition was associated with periodic terrigenous input. The depositional environment was very similar to ARS2.

1.3.3. The middle Zu Limestone (lower Coral Limestone, Zu2 member)(50 to 100 m thick)

Zu2 represents a shallows water carbonate depositional system which spread throughout the Lombardy Basin with different facies and thickness (Fig. 2). 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 grainstone (Stops 1.7 and 1.8). Carbonates are dominant around the previous norian paleohighs whereas in the subsiding-deeper areas marls intercalations persist.

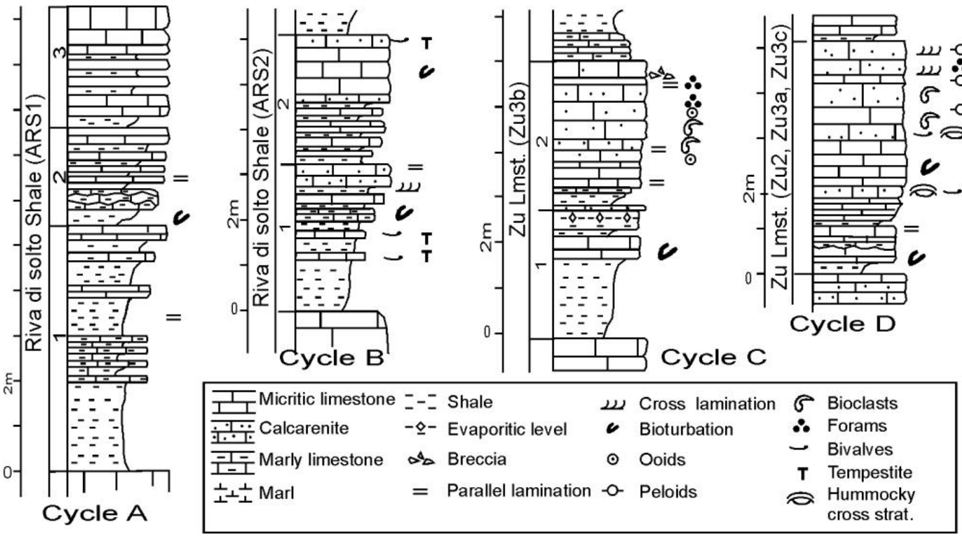
The carbonates consist of subtidal bioturbated mudstone-wackestones, mainly deposited below the fair-weather wave base, with scattered coral framestone (mainly *Retiophyllia* spp. frequently present also in marly horizons.) and foraminiferal packstone, bafflestone with calcisponge and porostromata (Lakew, 1990). In the most subsiding part of the Lombardy basin (Val Taleggio and Val Cavallina-Iseo) the bedded, muddy lithofacies prevails representing the prevalence of outer ramp environments below storm waves. The shallowing upward trend at the top of the Zu2 represents the progradation of the inner ramp system (Stop 1.8).

1.3.4. The upper Zu Limestone and the second coral limestone (Zu3 member, 120 to over 200 m)

This unit, records a new transgressive-regressive cycle developed along a mid-inner carbonate ramp with fine cyclic terrigenous input. Three lithozones represent different evolutive stages of a regional 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, and mammillary, iron-oxide thin crusts (hardgrounds) at top cycles often characterize the facies association of the mid-ramp in the less subsiding areas .
- Zu3c corresponds to the upper (40-50 m thick) calcareous part of the succession (second Coral Limestone marker) and records a second regional carbonate platform progradation (inner ramp facies associations) (Stop 2.3) with patch-reefs at the top (Lakew, 1990). Palynofacies from Zu3 contain a high total amount of OM (miospores and palynomacerals . An increase in marine OM (dinoflagellate cysts, foraminifer linings and algal spores) is recorded in the uppermost part of the Zu3c. The quantitative analysis of palynological assemblages from ARS and Zu shows a progressive upwards increase of xerophytic elements which become dominant in the Zu3 and suggests a shifting towards warmer , dryer climate, during the upper Zu Limestone (Jadoul et al., 1994; 2004).The top of Zu3c is marked by a paraconformity (Stop 2.4) interpreted as drowning unconformity.

1.3.5. The late Norian-Rhaetian high-frequency cyclicity (IV and V order)



The four types of cycles.

The ARS2 and Zu Limestone consist of thickening-upward, subtidal cycles organized in a composite hierarchy. (IV order cycles, Masetti et al., 1989). Dark brownish AOM and large fragments of poorly rounded, sorted inertinite, subordinate vitrinite and abundant pyrite dominate the palynofacies from argillaceous intervals and confirm oxygen-depleted bottoms for the lower ARS. In the upper ARS and lower Zu cycles (type B) the palynofacies are characterized by minor amount of AOM and high proportion of sporomorphs and poorly sorted inertinite. C-type cycle of Zu3b, exhibits a coarsening and shallowing-upward evolution. and the depositional environment is referred to the mid-inner sectors of ramp. D-type cycle shows the same trend of the C-type, but the cycle is almost entirely characterized by fine to coarse packstone and locally grainstone. If we consider the whole Rhaetian Brumano-Albenza composite section of (Stops 1.6,1.7 and 2.2-2,4) (dated by Rigo at al.,2009), at least 50 high frequency cycles are recognizable, their duration is less than 10^5 years also considering a 4 My long Rhaetian stage.

1.4. The platform drowning at the T/J boundary (Malanotte Fm., 15 to 30 m thick)

The thin bedded Malanotte Fm. consists of micritic limestones, poor in fossils. It represents a stratigraphic marker in the central Lombardy. At the base bioturbations (bedding surfaces) and small slumpings are frequently present, whereas at the top oolitic-bioclastic fine calcarenite alternate with mudstone. 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 and low sedimentation rates controlled the deposition of the Malanotte Fm. and created the accommodation space for the Albenza platform progradation. Palynological and C-isotope studies carried out on several sections enabled the location of the T/J boundary in the lowermost part of this formation (Galli 2002; Galli et al., 2005; 2007).

1.5. The early Hettangian Albenza Formation (100 m to over 250 m in Iseo Lake)

This unit documents the last regional shallow water carbonate progradation in the Lombardy Basin, occurred during the early Hettangian. The lower part of the Albenza Fm. consists of grey oolitic grainstone with micrite lithoclasts and bioclasts, which represent the platform shoals prograding margin on top of the Malanotte Fm.. The upper part of this Bahamian-type carbonate platform consists of fine peloidal packstone and oolitic grainstone (Jadoul & Galli, 2008).

Description of the outcrops

THIRD DAY: The Middle-Late Norian Piani di Artavaggio escarpment-slope succession

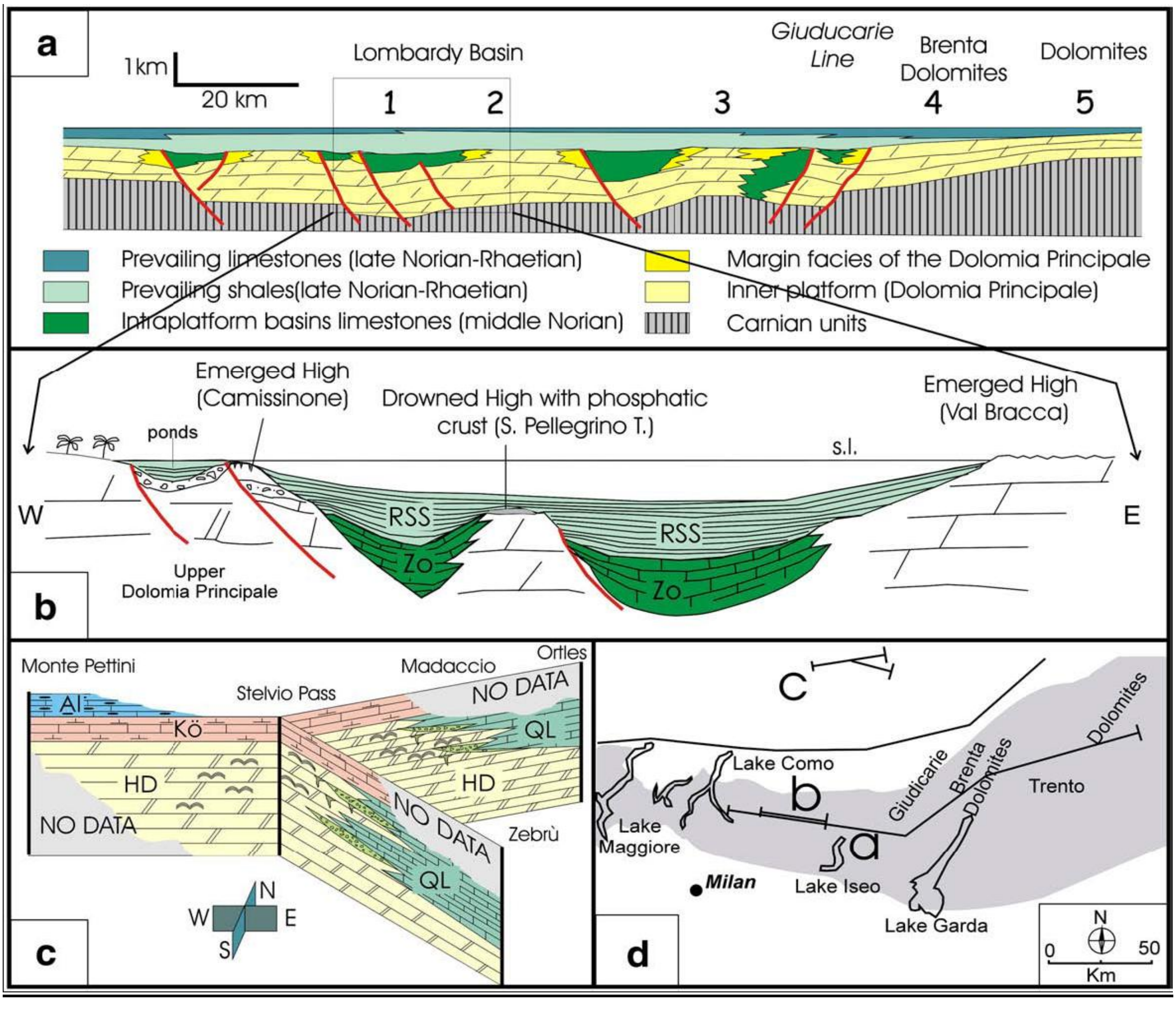
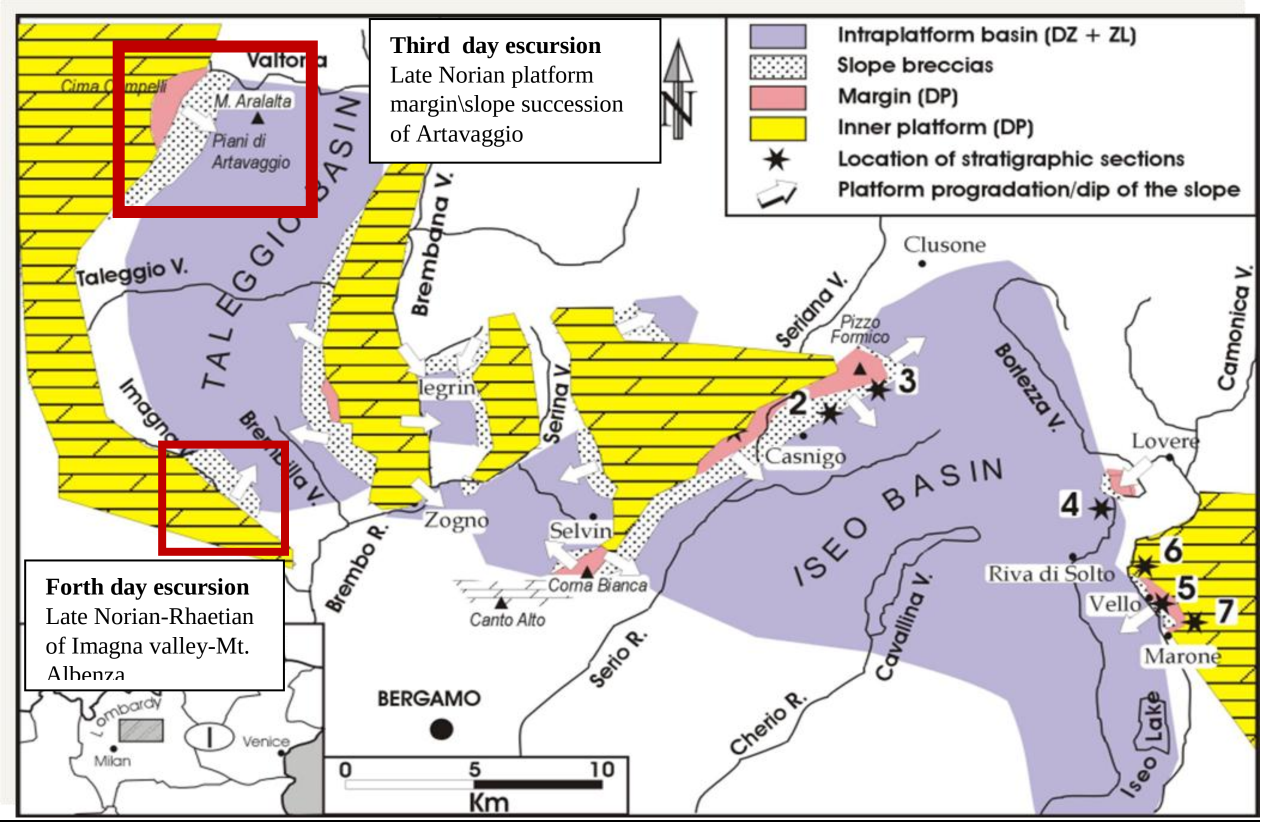


Fig. 1a. Stratigraphic setting of the DP/HD systems and overlying units in the Southern Alps and in central Austroalpine. a) Simplified stratigraphic reconstruction along a west to east section across the Southern Alps (modified after Jadoul et al., 1992; Berra & Jadoul 1996)

Fig.1b Late Norian paleogeographic map of basin and platform environments (Berra & Jadoul, 1996)



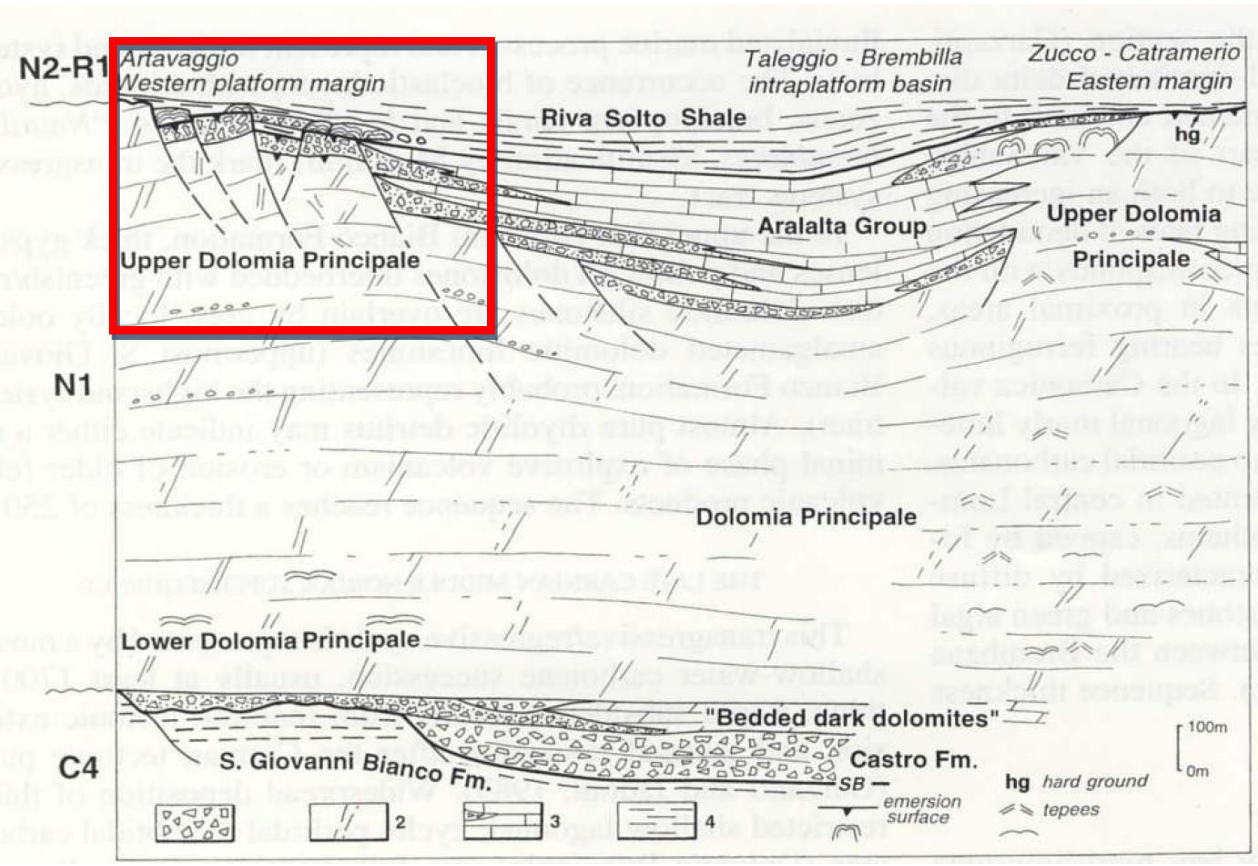


Fig. 2.—Stratigraphic architecture of the norian Dolomia Principale\Aralalta Group depositional systems: the Artavaggio tectonically controlled, retrogradational, platform margin and the intraplatform Taleggio-Imagna basin (western Bergamasc Alps). (l) polygenic, intraformational carbonate breccias (2)shallow subtidal to peritidal platform dolomites (3) dark grey intraplatform turbiditic carbonates and (4) black anoxic basinal shales and marls (modified from Gaetani et al, 1998). The red square evidences the visited succession

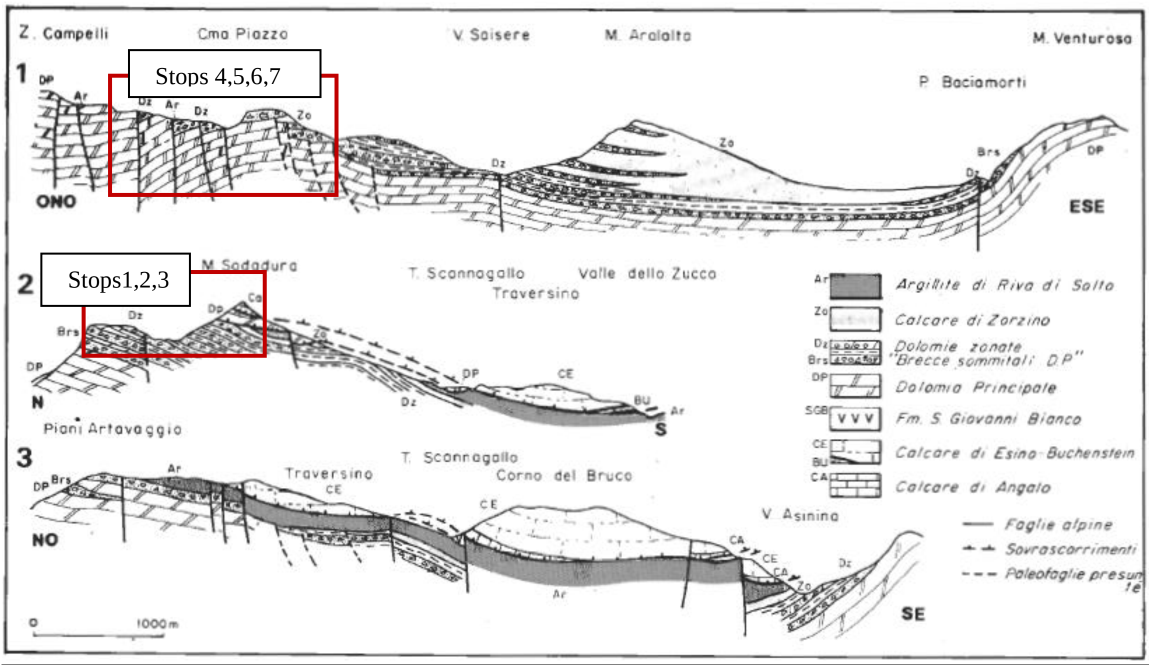


Fig.3 Geological profiles of the Artavaggio area with preserved the relationships between the DP platform margin and the Aralalta intraplatform basin (profile 1) (Jadoul 1985).

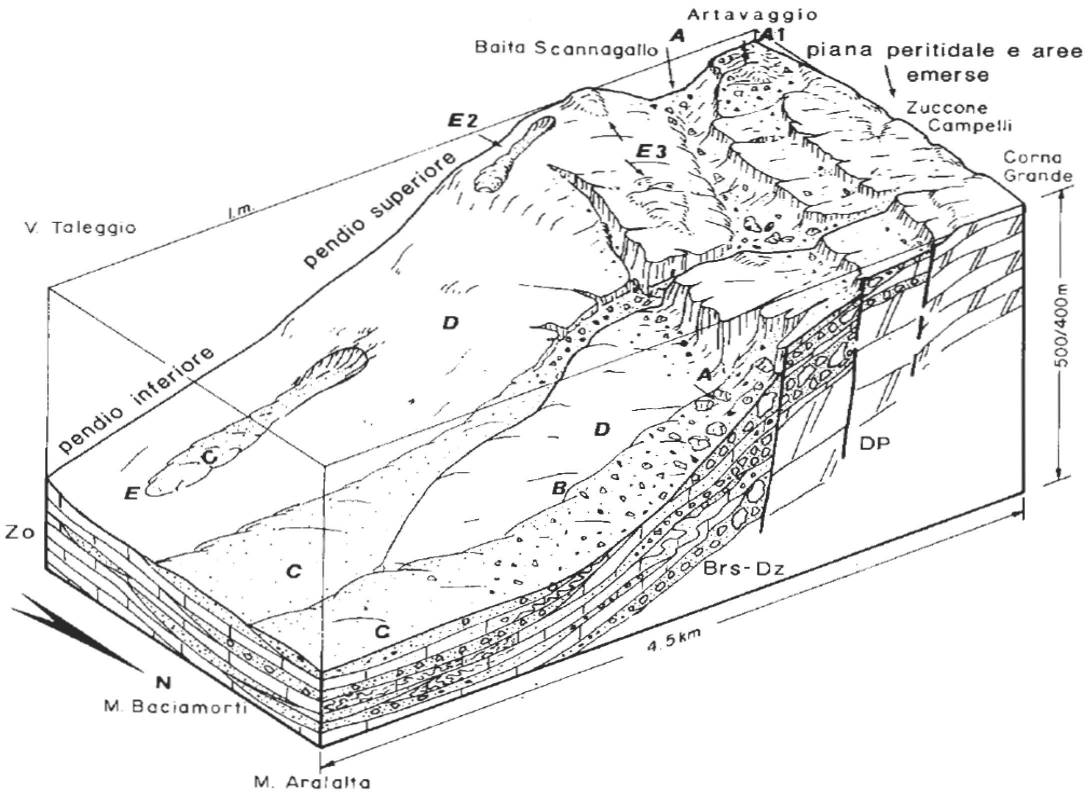
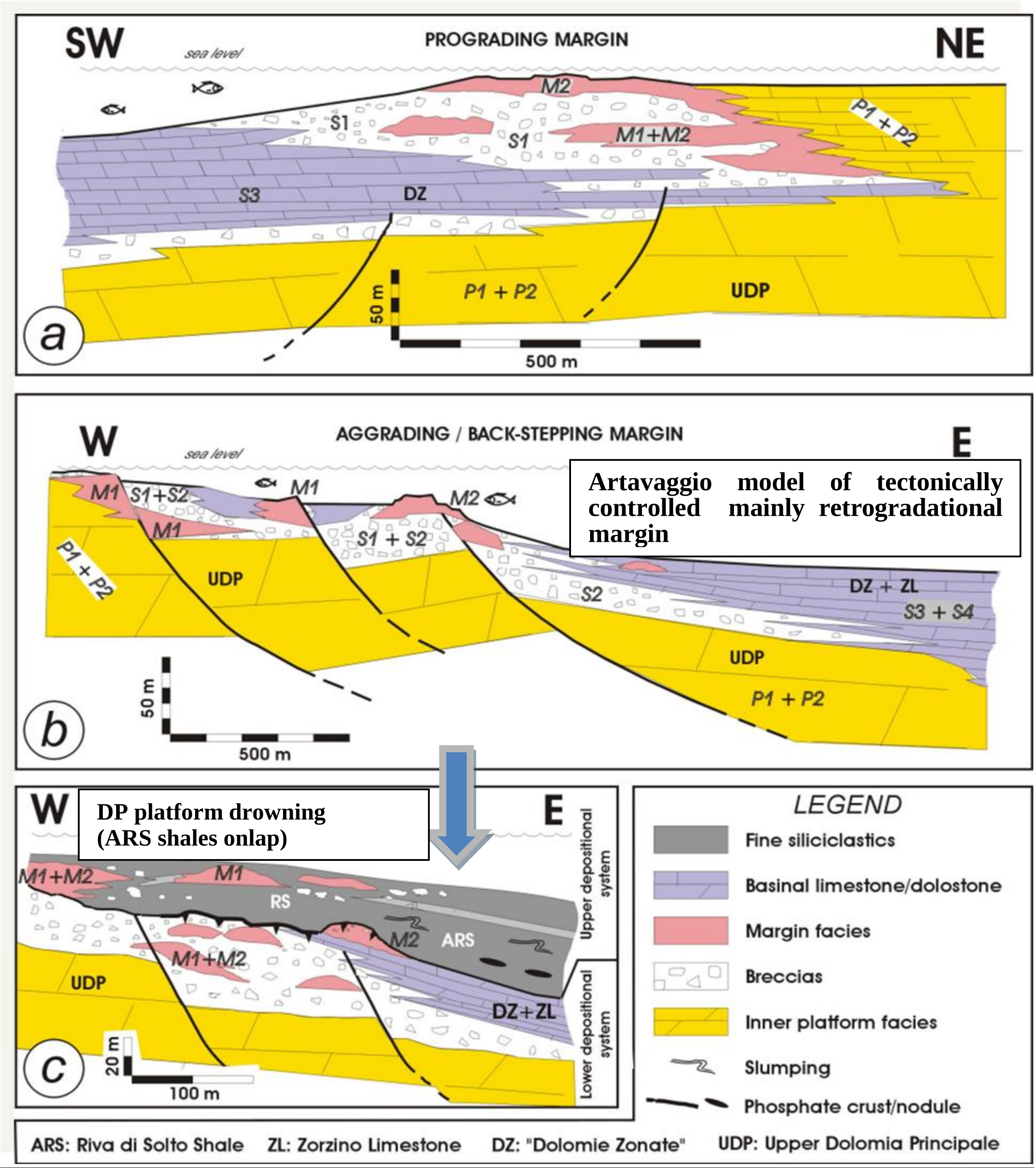


Fig.4 Depositional model of the Late Norian Artavaggio western margin of the Taleggio Basin (Jadoul 1985) dominate by large mass transport: several slope failure scars, talus breccias, and local turbiditic systems, possibly related to small canyons. A, B, C, D lithofacies association of the Aralalta Group (polygenic, intraformational breccia, Dolomie Zonate, Zorzino Lmst.) ,E3 Artavaggio member microbial serpulid mound



Berra & Jadoul 1996

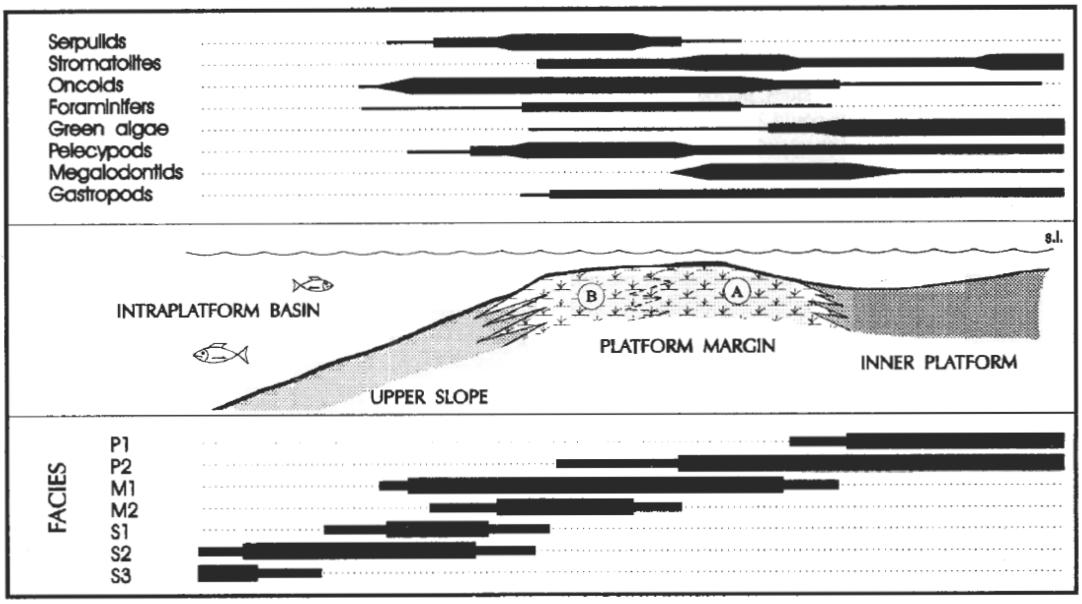
Fig. 5. Reconstruction of lithofacies distribution and margin evolution recognised in the upper Dolomia Principale (a = Vello, b = Piani dArtavaggio) and in the lowermost Riva di Solto Shale of Piani d'Artavaggio (c).

	Facies	Description	Microfacies	Environment
Dolomia Principale	P1	Grey thick bedded subtidal dolostones. Metric shallowing upward cycles; at the top stromatolitic microbialites. Massive and amalgamated beds.	Mainly Pk and Wk, bioclastic-intraclastic and pellettiferous Pk; locally Ms and stromatolitic Bs.	Restricted inner platform
Dolomia Principale	P2	Massively bedded medium to coarse doloarenites. Bioclasts and oolites are locally common.	Intraclastic and bioclastic Pk; oolitic and bioclastic Gr.	Sandy platform/ tidal channels
Dolomia Principale	M1	Massive dolomitized microbial mats, oncoids. Subordered serpulids, porostromata, pelecypods. Abundant cements and internal sediments.	Microbial Bs, marine phreatic/isopachous spatic cement and internal microspatic sediments.	Platform margin and upper slope mounds
Dolomia Principale	M2	Serpulid patch reefs, up to 1-2 m in height. Associated microbial carbonates, porostromata, oncoids and pelecypods.	Bf, with Ms and microsparitic-peloidal cements in the pores and voids between the worm tubes.	Low-energy platform margin
Aralalta Group – "Brecce sommitali"	S1	Wedging deposits of massive dolomitized breccias mainly deriving from the dismantling of platform margins (facies M1 and M2).	Rs with clasts containing mainly M1 and M2 facies. Matrix: Ps, Ws.	Talus deposits (bioconstructed-margin breccias)
Aralalta Group – "Brecce sommitali"	S2	Badly selected dolomitized and heterogenic deposits, with clasts derived from the tectonic dismantling of different part of the platform.	Rs with clasts mainly consisting of S3, P1, P2 facies, less commonly M1 and M2. Matrix: Ms and Ws.	Talus deposits (polygenic breccias)
Aralalta Group – 'Dolomie Zonate'	S3	Bedded dark doloarenites with intercalations of breccia bodies with clasts derived from the inner platform, slope and margin.	Mainly intraclastic/ bioclastic Pk and Ws; Rs with P1, P2, S2 and locally M1 and M2 facies.	Proximal slope
Aralalta Group – Zorzino Lst.	S4	Fine grained, well-bedded laminated dark limestones and normally graded calcarenites (turbidites).	Ms, Ws and pellettiferous and fine intraclastic Pk.	Distal slope/ basin floor

FACIES = P:Platform; M:Margin; S:Slope - MICROFACIES = Ms:Mudstone; Wk:Wakestone; Pk:Packstone; Gr:Grainstone; Bs:Bindstone; Bf:Bafflestone; Rs:Rudstone

Table 1. Main lithofacies associations recognised in the Dolomia Principale depositional system.

From Berra & Jadoul 1996



Berra & Jadoul 1996

Fig. 6. Distribution of the most common organisms along the Dolomia Principale platform margin, and lithofacies association: A) inner side of the margin, B) outer side of the margin, mainly bioconstructed. Thickness of the black lines is related to the relative abundance of organisms and lithofacies.

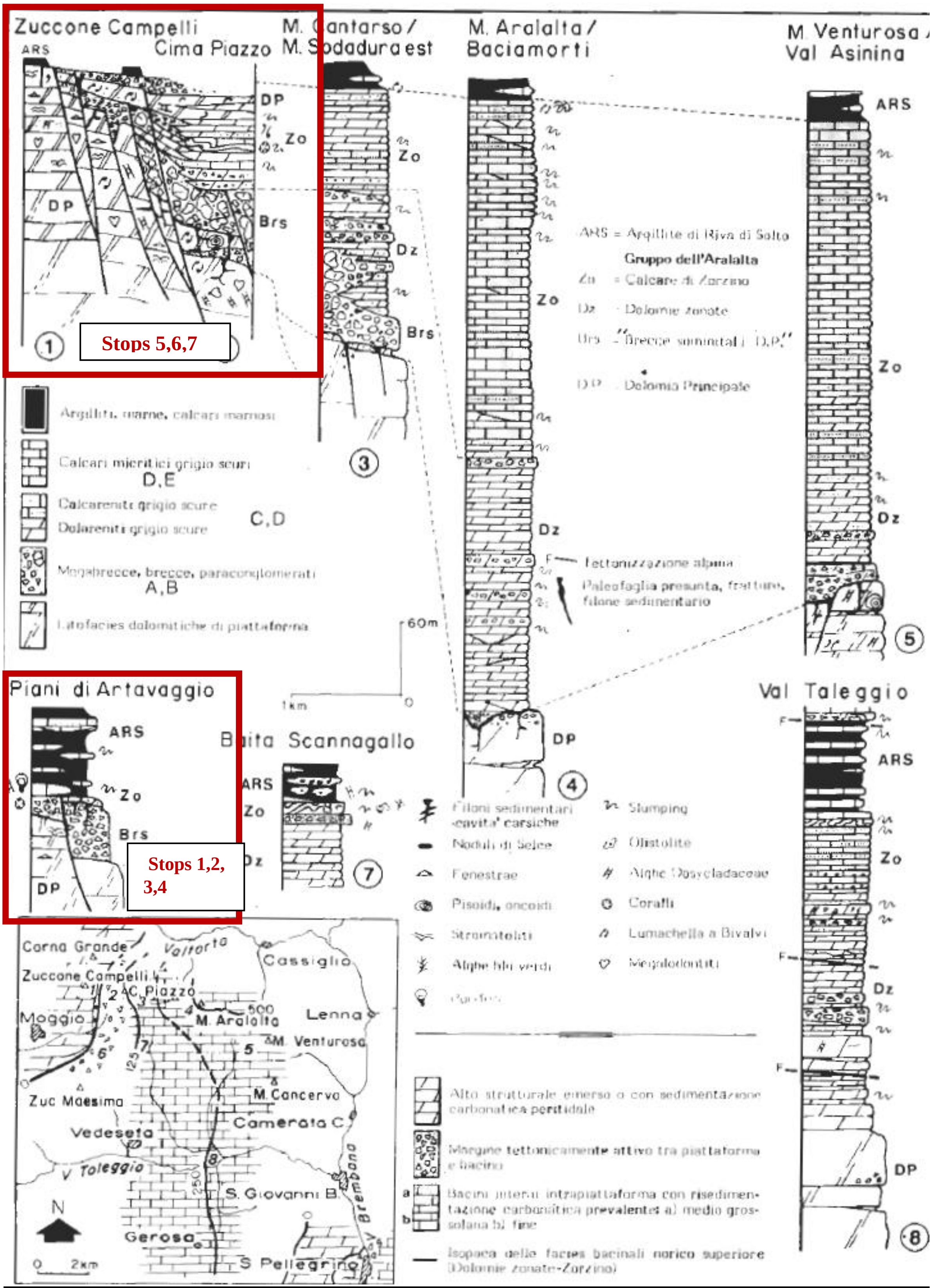


Fig.7 Stratigraphic log of the succession of Artavaggio: the Campelli carbonate high, the large mass transport and slope failure (talus breccia\slope facies) of Artavaggio, Cima di Piazzo, the thick lower slope\basin succession of Aralalta (modified from Jadoul, 1985)

The escarpment\slope succession of Piani di Artavaggio (stops. 1,2,3,4)

The main facies of the carbonate platform, escarpment\slope and basin are synthesizes in tab1, their paleogeographic distribution on different type of margin evolution is reported in fig 5, 6.

Stop 1 The polygenic dolomitic breccias at the top of Dolomia Principale (DP).

(see the tab1 for the lithofacies of DP, escarpment\ slope and basin).Near the building of the arrival of the cableway there is a first nice outcrop of chaotic, polygenic breccias with dark grey clasts of Dolomie Zonate, grey of Dolomia Principale (fine grained and fossiliferous (dasycladaceae, serpulid) also a few clasts of reworked breccia, and laminated microbialites. The matrix is generally abundant but locally breccias are grain supported. The lower boundary of the breccia is erosional above well bedded, deformed Dolomie Zonate and locally at the base of the breccia horizon are present boulders and mounds of dark grey dolomitized microbialites.

Fig 8.Stop 1 the typical fine and coarse slope lithofacies association of the Aralalta Group.

Stop 2 Microbialites and serpulids mounds of the Artavaggio Member .

The "Artavaggio Member" is a lenticular and peculiar unit local present at the top of the Zorzino\Dolomie Zonate fms. or at the base of the Riva di Solto Shale (Jadoul,1985, Berra & Jadoul,1996)) and only in the marginal succession of the Taleggio Basin. Just above the breccia of stop 1 outcrops a lens of massive, dark grey fossiliferous limestones with a microbial framework, laminations and associated with small serpulids patches, with microbial coating, and thin shell bivalves. Rare solitary and small colonies of corals are locally present.

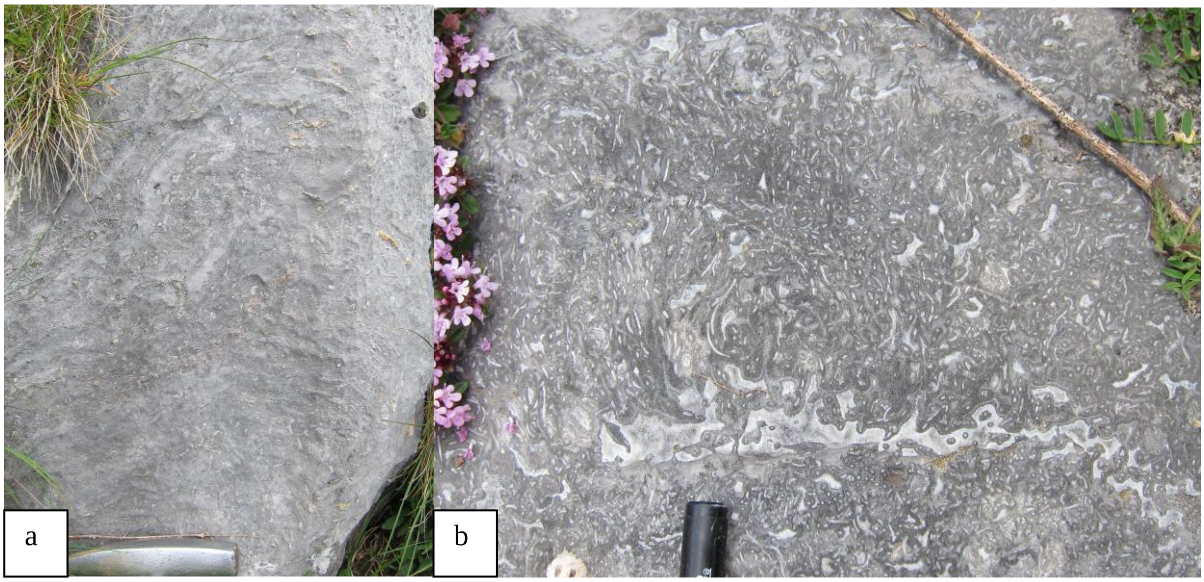


Fig.9 Stop 2 Microbial (a) and serpulid ((b) bindstone and bafflestone in the “Artavaggio Member” dark grey limestones.

Stop 3. The boundary between the upper polygenic breccias and the Lower Riva di Solto Shale.

A few hundred of meters laterally to the stop 2 outcrops the sharp stratigraphic boundary between dolomitized polygenic breccias and dark shales with rare thin bedded, laminates calcilutites. Here it is well exposed the upper bedding surface of the dolomitic breccias with clasts and boulders with several lithofacies of the DP, Dolomie Zonate and microbialites (Fig.6b, (bindstone crusts and serpulid bafflestone probably deriving from the reworking of the Artavaggio Member mounds) and abundant fine grained matrix associate with mud infiltration and sin sedimentary deformations (Fig.10a)

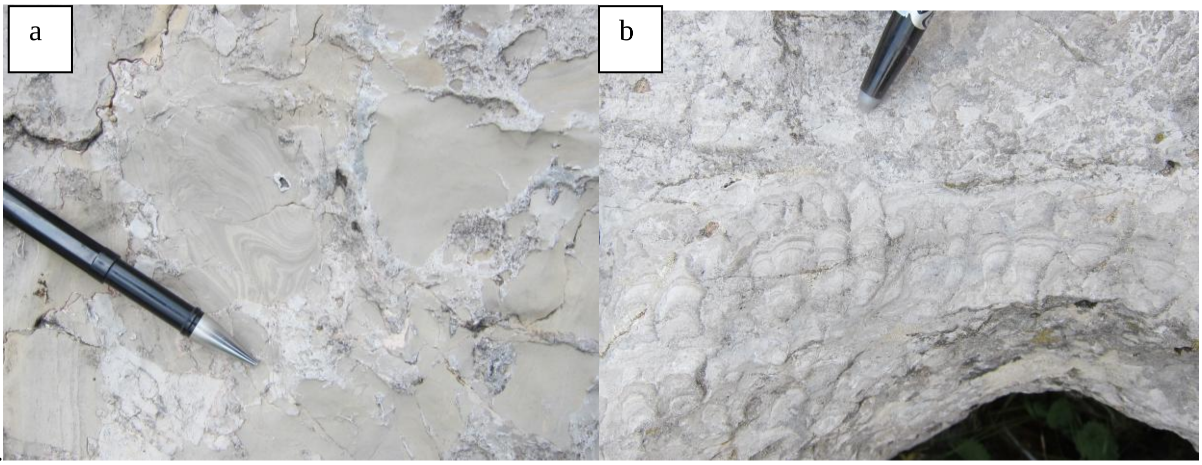


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Fig.10 Stop 3 Soft deformations in fine grained mudstones as matrix or sindiagenetic infiltration (10a) and detail of a microbial dolomitized boulder (10b).

Stop 4 Slope sedimentary structures and deformations in the Dolomie Zonate

Along the road to Nicola refuge (1800m altitude) outcrops a 4\5 m thick sequence that represents the two main lithofacies association of Dolomie Zonate. The base is characterized by well bedded fine to coarse dolarenite\rudite and \laminated dolosiltite with typical mass transport sedimentary structures (erosional basal surfaces, normal and reverse grading, small and large scale slumping deformations, paraconglomerates with flat pebbles) . They are overlying by a massive horizon of matrix supported chaotic, polygenic dolomitic breccias with erosional base that documents a catastrophic, debris flows. This lithofacies organization is peculiar of the western Taleggio Basin. (Fig3,4,7)

Fig.11 Stop. 4 Sinsedimentary deformations and sedimentary structures in the well bedded Dolomie Zonate.

The carbonate platform and the escarpment, proximal slope facies associations (Stops 5-6-7)

Stop 5 The escarpment\slope succession of Cima di Piazzo.

Along the southern slope of Cima di Piazzo it is possible to observe the boundary between the dolomitic inner platform facies (DP) and the lateral and overlaying mass transport megabreccia\ breccias of the Aralalta Group (talus, slope failures). The upper DP is represented by thick bedded light grey recrystallized dolostone with fossiliferous intercalation (Dasycladaceae, Megalodont sp. , small bivals, gastropods) and planar to hemispheroidal microbial horizon. The overlaying and locally discordant breccia horizon presents, at the base, prevalent breccias of DP (clasts were well lithified and sometime fractured before sediment reworking) followed by breccia with dominant microbial facies and at the top by more polygenic breccia (abundant dark grey laminated clasts and matrix deriving from the Dolomie Zonate (Fig.4, 12). Along the eastern crest of C.ma Piazzo at about 1970 m of altitude, outcrop dark fine grained grey limestones and plattenkalk type facies of the Zorzino Lmst. with large scale slumpings and the presence of a few intraformational olistoliths.

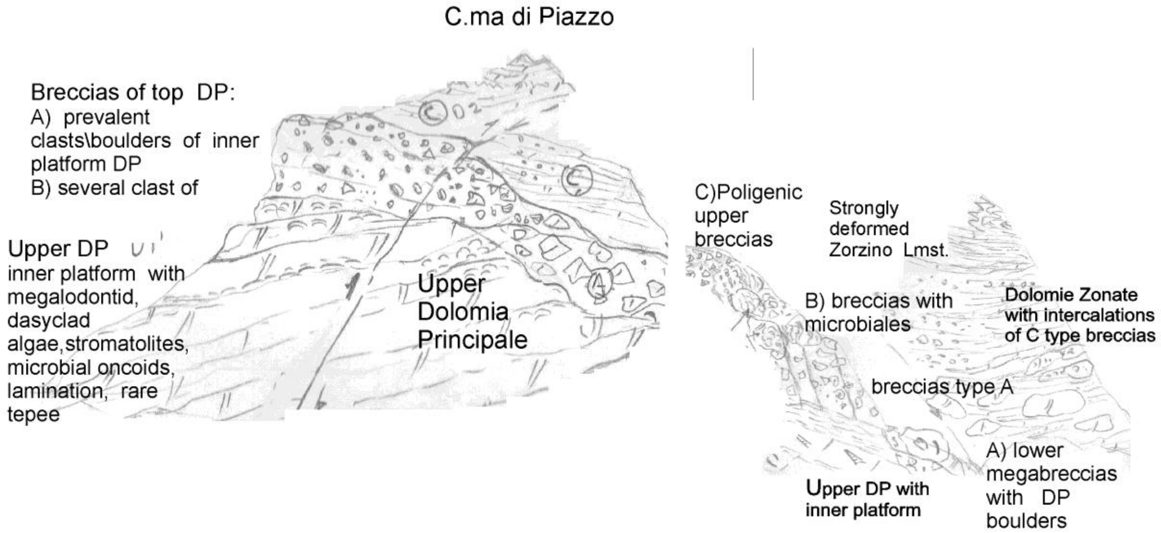
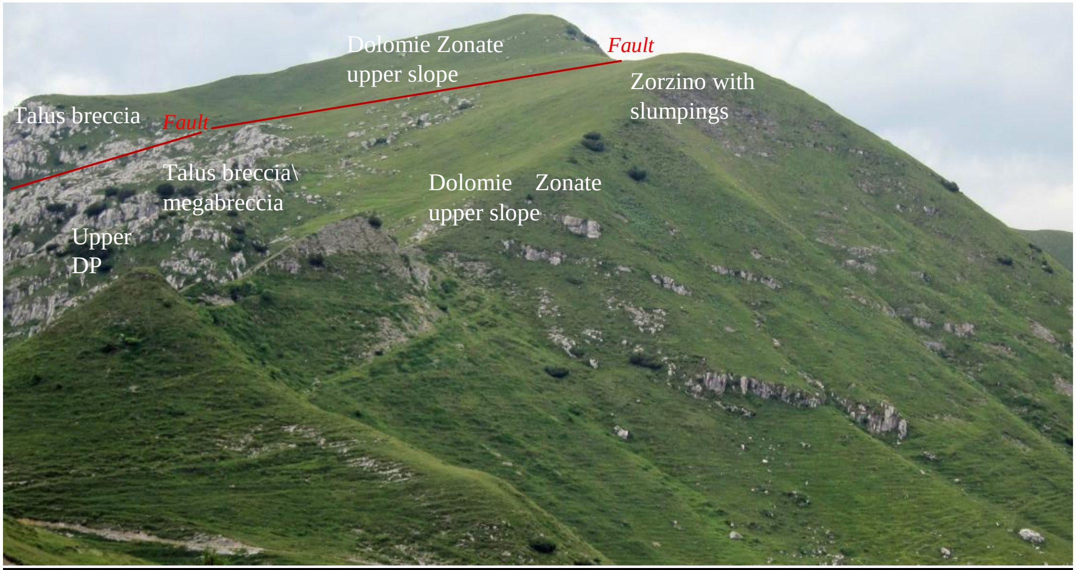


Fig 12 Geological sketch with the geometric relationships between the DP platform and the C.ma Piazzo escarpment, talus\slope facies that represent the western termination of the Taleggio basin (see Fig. 1b, 2,3,4,7



Stop 6. Facies of the upper Dolomia Principale.

Along the western slope of C.ma di Piazzo . Below the breccias horizon, outcrops a thick and monotonous succession of light grey thick bedded shallow subtidal dolostone locally with evidences peritidal cyclic sedimentation. Subtidal facies are generally poorly fossiliferous but are present several horizons rich in Dasycladaceae, gastropods, and small megalodont, (a marker horizon with large, up to 20 cm megalodon is present just at the top of the DP in the Cima Campelli area (Fig13d) . Intertidal and supratidal facies are represented by planar stromatolites, fenestral dolostone often associated with microbial oncoids, hemispheroids and embryo tepee. Small sinsedimentary fractures and dykes , mainly N-S orientated, are widespread in the uppermost DP of the western margin of the Taleggio Basin.

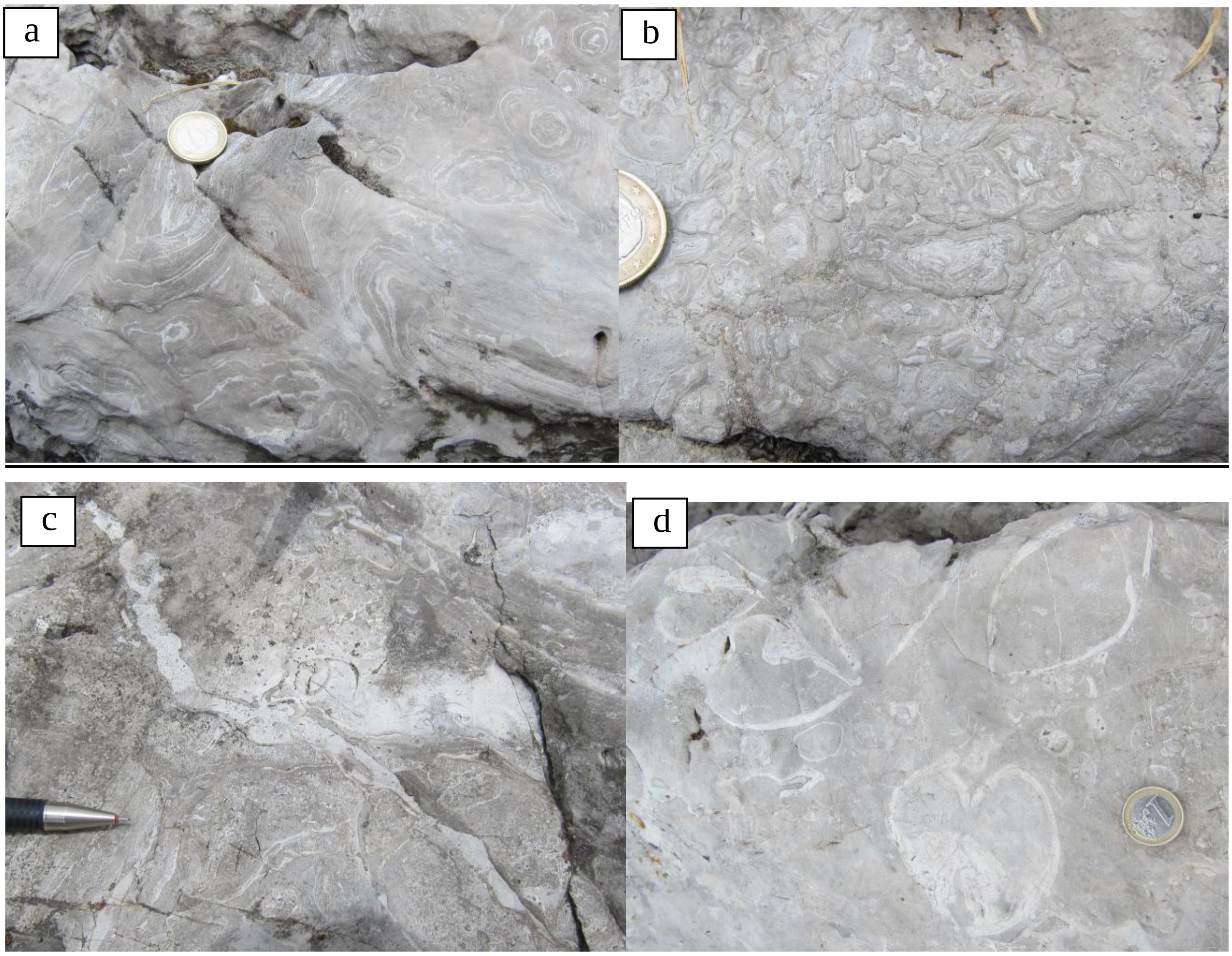


Fig.13 The Upper Dolomia Principale inner platform macrofacies of the Campelli-C.ma Piazzo carbonate high. Fig13a,b) Subtidal with dark grey microbial large and small scale oncoids; c) dark grey microbialite associated with inter-supratidal facies with abundant internal sediments in tensional fractures. The carbonate cements are not so widespread in the Norian carbonate platform margin\slopes in comparison to the ladinian platforms (Esino, Sciliar depositional systems). This early diagenetic character could be an important factor favoring large carbonate exportations and mass transports along the slopes d) Subtidal megalodont rich marker horizon at the top of the Dolomia Principale.

Stop7. The giant microbial mounds of Campelli.

At 1970m altitude, along the track to Cima Campelli and at the top of the DP outcrop a 7-9 m thick lens of m-scale domal microbialites (Fig15) (M1-M2 facies of Fig 5c). This lithofacies is associated with a reduced in thickness breccia succession and represents the upper slope facies attached to the last Dolomia Principale carbonate highs

Fig.15a Giant microbial laminated mound, b) detail of the internal structures

Fourth DAY

a) The upper Norian-lower Rhaetian fine siliciclastic to carbonate high-frequency cycles (western Bergamasc Alps). Field trip stops from 1.1 to 1.(Fig. 1 and Fig. 4).

b) The Rhaetian ramp cycles and the T/J stratigraphic boundary . Field trip stops from 2.1 to 2.7

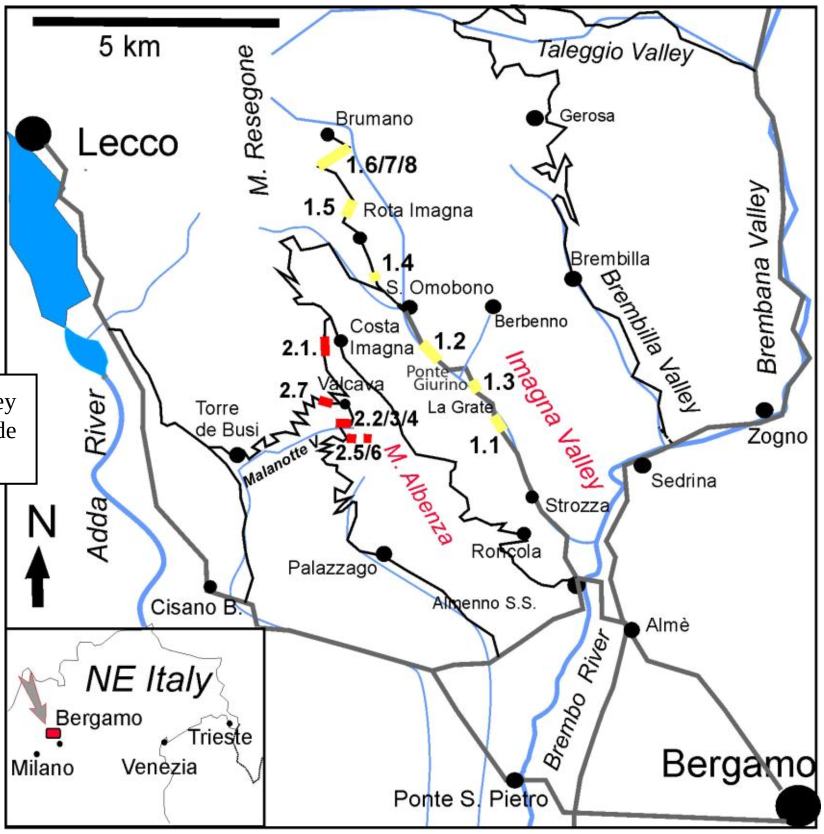


Fig 1 Itineary of the Albenza Imagna valley fieldtrip with all the stops of the fieldtrip guide of Fist 2007 (Jadoul et al. 2012)

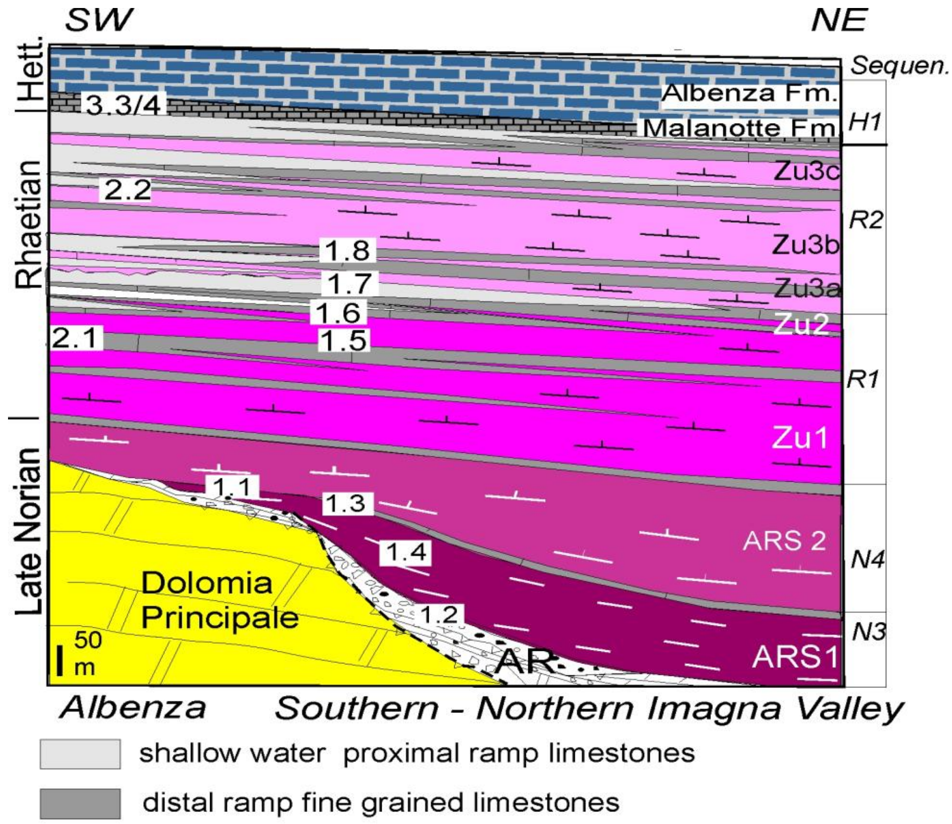


Fig. 2. Late Norian-Hettangian stratigraphy of the Albenza-Imagna Valley, the geometries of the ramp depositional systems and location of all the stops described during the FIST 2007field trip (Jadoul et al., 2012) (modified from Jadoul et al.1994, Gaetani et al.1998).

a) The upper Norian-lower Rhaetian fine siliciclastic to carbonate high-frequency cycles

Stop 1.1. This stop (Fig. 3) shows the stratigraphic setting and cyclicity of the ARS 2 in the lower Imagna Valley The succession is relatively reduced in thickness (as on the Mt. Albenza) and lacking of the ARS1 and Aralalta Group facies).The deposition occurred at the margin of the Albenza late Norian carbonate high.

The whole section (about 60 m thick) consists of 13 fourth order asymmetric cycles (B-type; Fig. 3). Each fourth order cycle can be further subdivided in smaller-scale fifth order cycles (Fig. 5B). 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 (Fig. 5C), 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.

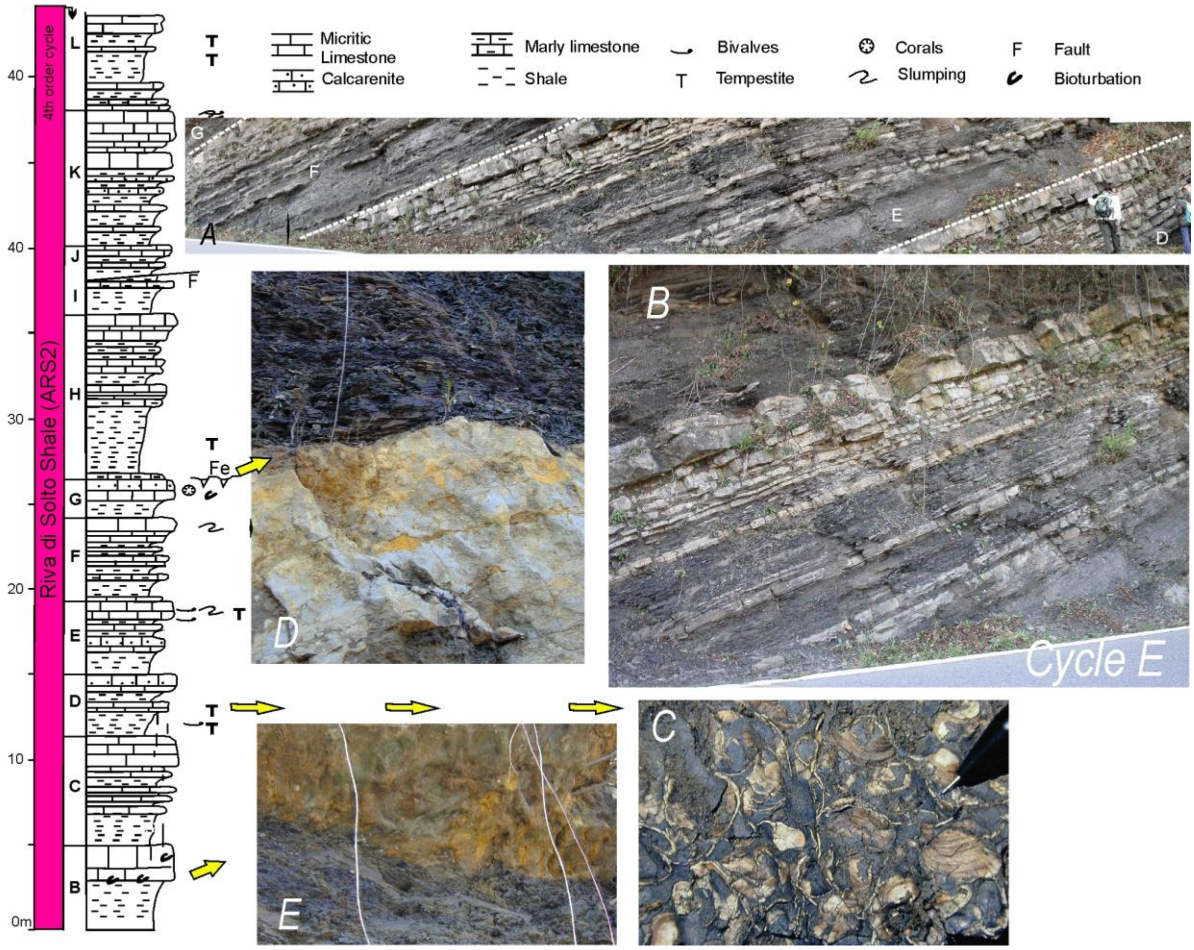


Fig. 3. Stop 1.1. Asymmetric cycles in the Riva di Solto Shale of Imagna Valley. Major details in the text.

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 palynofacies study of similar cycles in other sections (Laxolo, Imagna Valley) shows a rapid decrease in palynomorphs specimen and blooming fungal filaments associated to poorly sorted and rounded inertinite. The palynofacies variation across the cycle shows a trend from disoxic-anoxic conditions in the lower part to more oxygenated conditions at the top, where the OM is degraded by fungi, bacteria and burrowers. 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 that favored the transport from the European continent. 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.

Stops 1.2, 1.3 and 1.4. These stops are different from the previous one for the major thickness of the Late Norian fine siliciclastic succession and for (tectonically controlled) slope facies belonging to the Aralalta Group (uppermost breccias of the Dolomia Principale and Dolomie Zonate very similar to the Artavaggio slope\escarpment succession) and to the basal ARS. This succession characterizes the stratigraphic and tectonic evolution of the eastern margin of the Mt. Albenza structural high and of the overlooking basin of the Northern Imagna Valley.

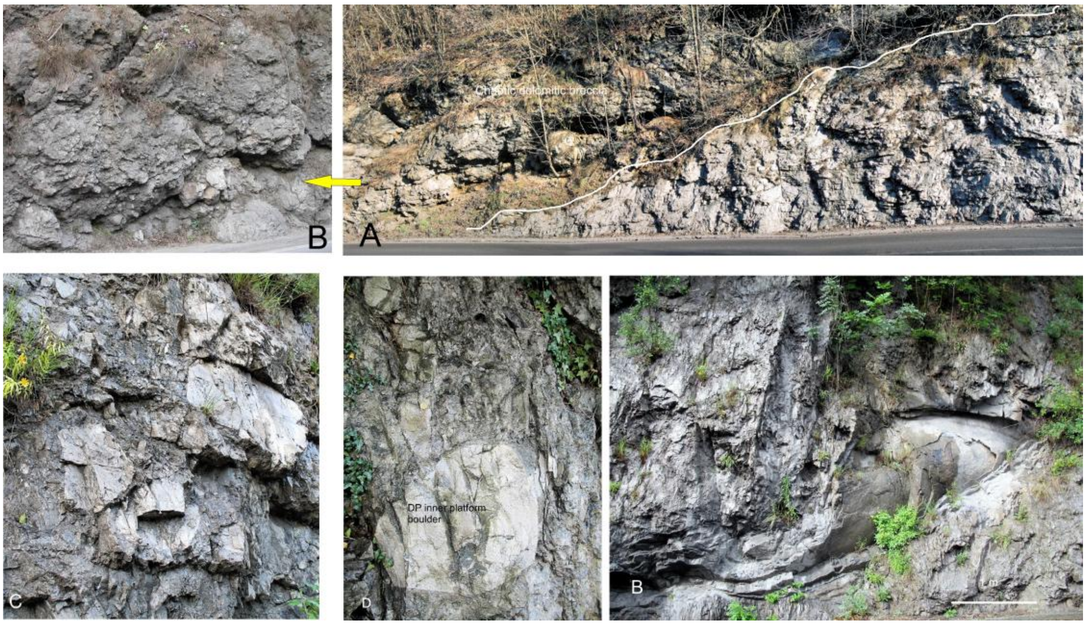


Fig. 4 Stop 1.2. A: Panoramic view of the canalized breccia horizons, large sindepositional deformations (slumping) at the top of the Dolomia Principale\Dolomie Zonate.

Stop 1.2. Slope breccia of top DP. Along the road from the Ponte Giurino pitch to the S. Omobono Valley, the uppermost Dolomia Principale is represented by lenses of polygenic and dolomitized chaotic breccias (Fig. 4 and Fig. 5 often with matrix support characterizing lenticular and canalized bodies. Breccias are also intercalated with fine blackish well bedded dolomites (Dolomie Zonate) locally characterized by slumpings and lenticular geometries (Fig. 4).

Stop 1.3. The micritic carbonates of the ARS1 The top of the cycle is characterized by a 17 to 20 m thick micritic carbonate horizon ((Fig. 4A) represented by monotonous dark grey mudstone with thin marly interlayers. Near the top fine matrix-supported paraconglomerates are present and the top is characterized by a paraconformity (Fig. 4C) (boundary ARS1/ARS2). . The overlying marly and marly limestone succession is characterized by rhythmic and planar arrangement of the laminae.

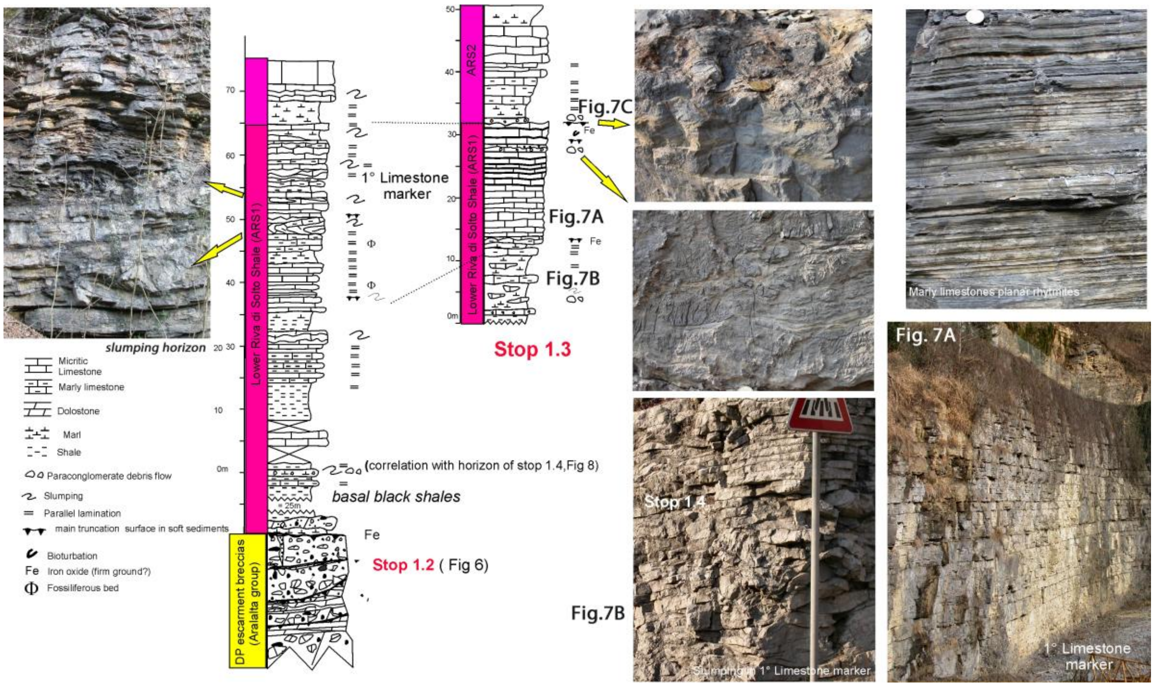


Fig. 4. The breccias at the top of the Dolomia Principale (Stop 1.2), the micritic carbonate marker (Stop 1.3), the ARS1 section (Stop 1.4) and the ARS1/ARS2 boundary of Ponte Giurino.

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, fungal remains and inertinite (Jadoul et al., 1994; 2004).

Stop 1.5. The ZU section along the road to Brumano (Fig. 5,6).

This thick succession consists of two outcrops separated by about 20 m of covering

The Lower Zu succession (Zu1, Fig 5 right log) consists of monotonous alternations of shaly marls or marly limestones and micritic limestones stratified at the top, a fossiliferous marker horizon (*Gervilleia* sp.) is also present The facies cyclicity is here less clear respect to the upper Zu Limestone. This section has been recently studied for conodont analyses to better understand the age of the base of the Zu and for to define the boundary Norian-Rhaetian in the Lombardy Basin. The upper outcrop might be physically correlated to the Costa Imagna section, which is well calibrated with conodont biostratigraphy (see Stop 2.1, Fig. 5 and Fig.6). In the lowermost Zu of the Brumano section t (sample J282), a specimen of *Misikella posthernsteini* along with a *Misikella hernsteini* occurs, confirming the Rhaetian age. The presence of the *Misikella posthernsteini* together with *Misikella hernsteini* characterized the investigated Brumano section. (Fig 6) In the upper part of the lower Brumano outcrop, *Misikella koessenensis* occurs.. According to Moix et al. (2007), *Misikella koessenensis* appears already in the lower part of the *Misikella hernsteini-Parvigondolella andrusovi* Zone (uppermost Sevatian, upper Norian), even if extremely rare, and still present up to the whole *Misikella posthernsteini* Zone.

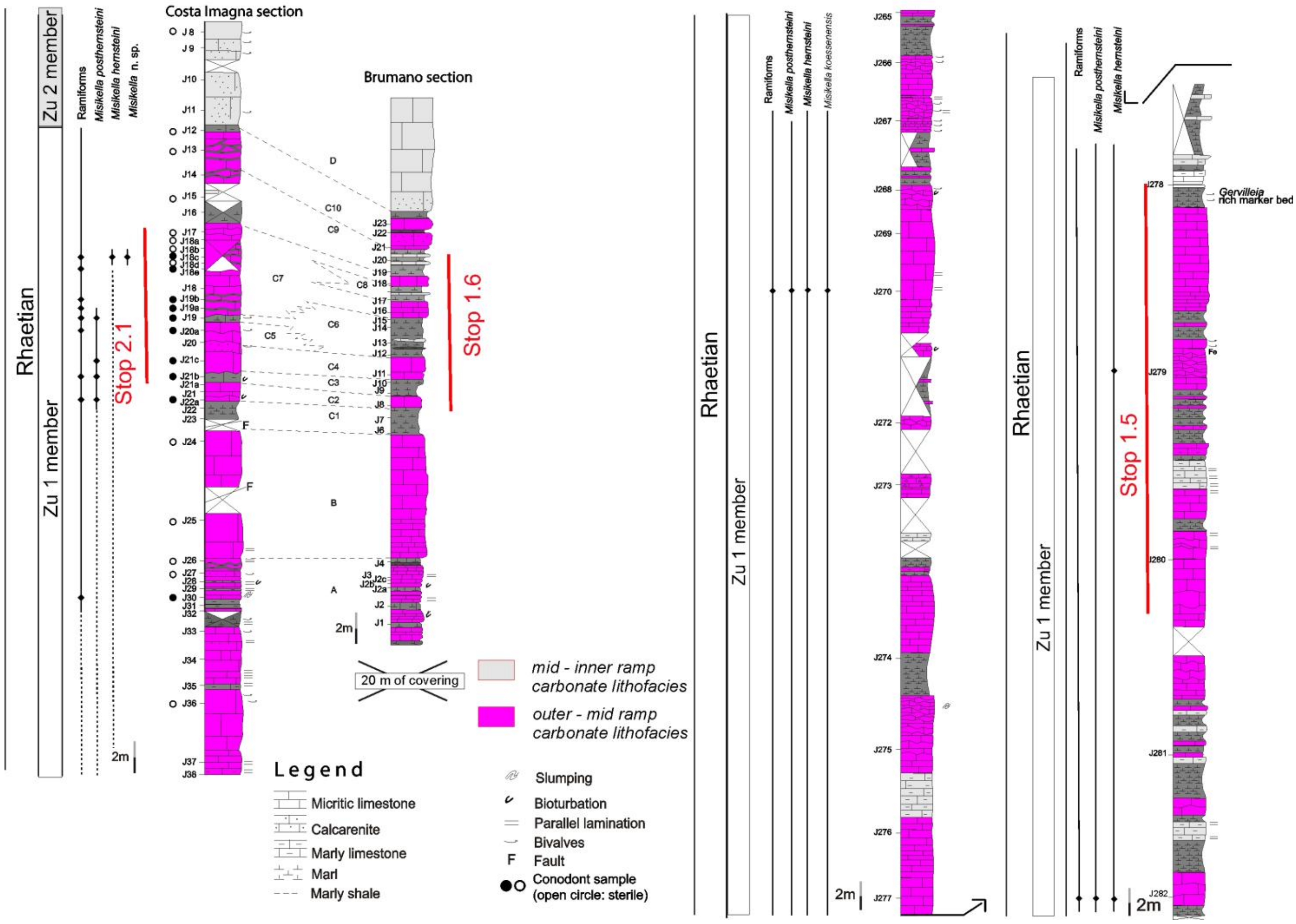
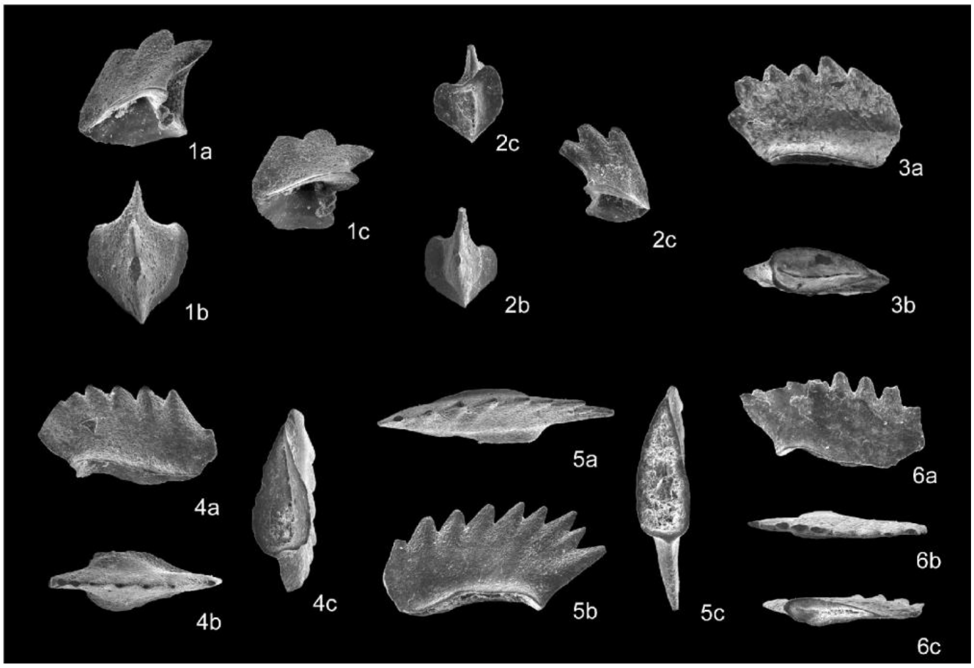


Fig.5. Stop 1.5 and Stop 2.1. Stratigraphic correlation between Brumano section and Costa Imagna section.

Fig. 6. Stop 1.5 and Stop 2.1. Conodont biostratigraphy in the Zu Limestones of the Costa Imagna section: 1 a, b, c) *Misikella posthernsteini* Kozur and Mock, 1974; 2 a, b, c) *Misikella posthernsteini* Kozur and Mock, 1974; 3 a, b) *Misikella hernsteini* (Mostler), 1967; Zu Limestones Fm., Zu 1 member, sample J 18c; 4 a, b, c) *Misikella hernsteini* (Mostler), 1967 5 a, b, c) *Misikella hernsteini* (Mostler), 1967; 6 a, b, c) *Misikella* n. sp. A;..

Stage		Ammonoid Zone	Conodont Zone by Kozur & Mock, 1991	
Lias		*Psiloceras planorbis*	*Neohindeodella detrei* Zone	
Rhaetian	upper	*Choristoceras marshi*	*Misikella ultima* Zone	
Rhaetian	upper	*Choristoceras ammonitiforme*	*Misikella posthernsteini* Assemblage Zone	*Misikella koessenensis* Subzone
Rhaetian	lower	*Vandaites stuerzenbaumi*	*Misikella posthernsteini* Assemblage Zone	*Misikella koessenensis* Subzone
Rhaetian	lower	*"Choristoceras" haueri*	*Misikella posthernsteini* Assemblage Zone	*Misikella hernsteini - Misikella posthernsteini* Subzone
Rhaetian	lower	*Parachocloceras suessi*	*Misikella hernsteini - Parvigondolella andrusovi* Assemblage Zone	
Norian (Sevatian)		*Sagenites reticolatus*	*Misikella hernsteini - Parvigondolella andrusovi* Assemblage Zone	



Stop 1.6. The Zu1-Zu2 transition (Fig. 5 and Fig.7) . It consists of meter to decameter marl-limestones cycles. Marls contain large pelecypods (*Homomia* sp., *Cardita* sp., *Trigonia* sp.). 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 (Fig. 11). Three minor subdivisions can be recognized within the Zu2 carbonates.

Stop 1.7. The Zu2 member..This stop and the next one are focused on the thick Rhaetian carbonate platform

a) Lower Zu2: is characterized by a 18 m thick, shallowing upward and, in part, coarsening upward carbonate cycle (D-type cycle) consisting of mudstones-wackestones and associated *Retiophyllia* spp. patch reefs at the base. Bioclastic packstone with sponge, echinoids, *Microtubus* sp., *Porostromata* and foraminifers (among which *Triasina hantkeni*) and mudstones overlying fine breccias are more common at the top .

b) Middle Zu2: it is characterized by intra-bioclastic packstone 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 packstone, bioclastic storm-layers and oolitic grainstone with cross laminations and wave ripples.

Stop 1.8. This stop is focused on the shallow water regressive platform carbonates at the top of the Zu2 member) and the overlying marly-limestone cycles of the upper Zu .

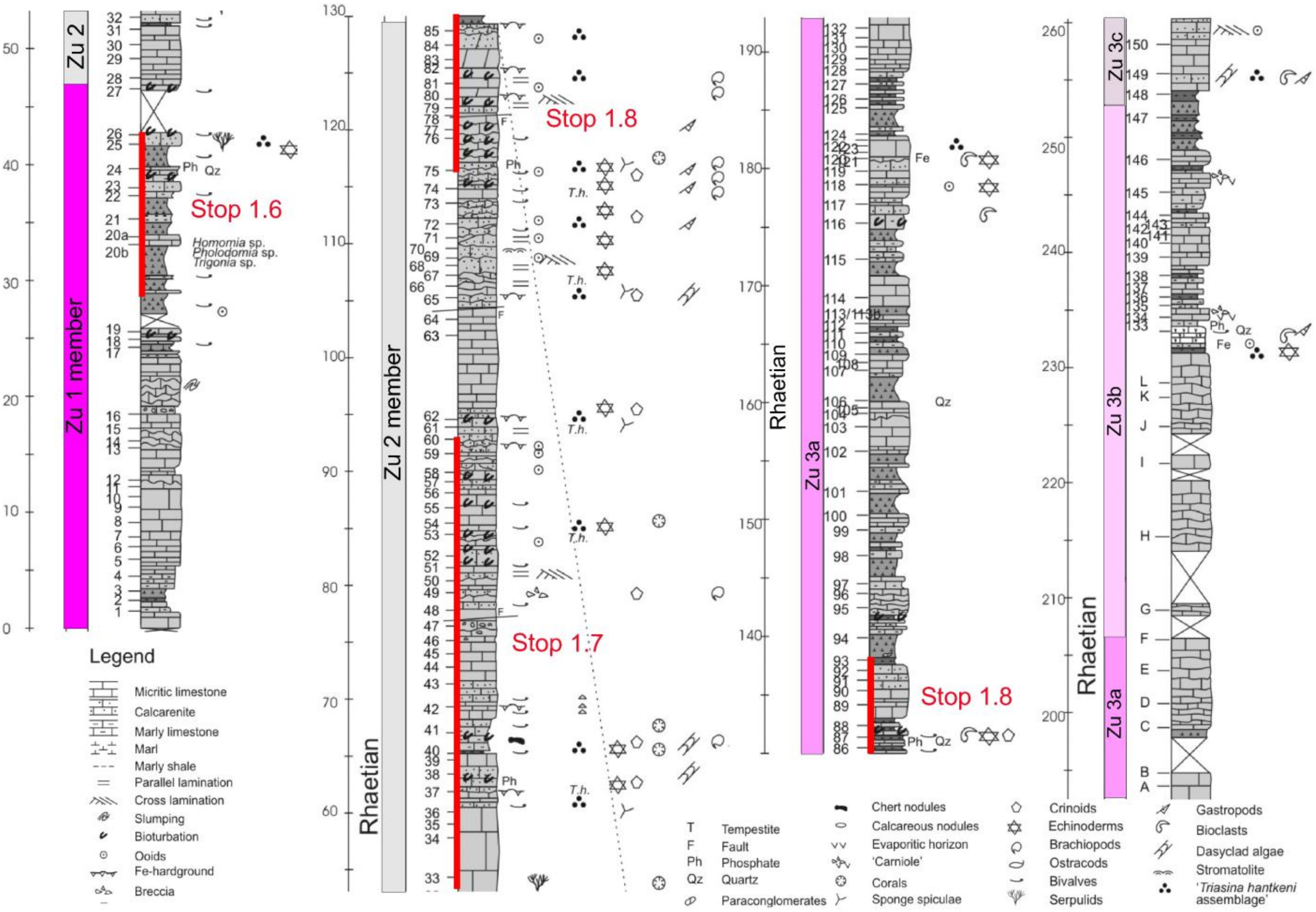


Fig.7

c) The upper Zu2 (Fig. 7): it consists of two major shallowing and coarsening upward cycles with bioturbated mudstones and wackestones at the base and, upward, bioclastic packstone, oolitic grainstone and thin planar stromatolitic bindstone. Small encrusted *Porostromata* colonies and bioclastic lenses with brachiopods (*Rhaetina gregaria*) characterize the base of the prograding oolitic shoals. Erosional surfaces, current ripples, cross bedding and sedimentary dikes characterize the top of this member that is also partially dolomitized and shows a local disconformity at the top) (Fig. 7).

The overlying succession records the recovery of marl-limestone asymmetrical cycles (Zu3a) (Fig. 7, see Stop 2.2.) . The lower Zu3 facies record a progressive crisis of carbonate production in the ramp system polluted by terrigenous input.

b) The Zu succession and the T|J boundary of Mt.Albenza

c)

Stop 2.1. Along the Costa Imagna-Valcava road the upper Triassic succession is cropping out (Fig. 6). It represents the sedimentation occurred in the structural high of the Mt. Albenza, as testified by the absence of the ARS1 . The lower Zu Limestone is typically cyclic, with mainly carbonate cycles less thick than previous outcrops described in Imagna valley (stops 1.5 and 1.6).. The conodont distributions are illustrated in Fig. 6.

Stop 2.2 and 2.3. The upper Rhaetian stratigraphy along the private Italcementi road on the SW side of Mt. Albenza. (Fig. 8). Along the road to an abandoned quarry the upper Zu Limestone \ Albenza Fm succession. is well cropping out. The upper Zu is subdivided into three lithozones. The lower one (Zu3a) consists of marls, marly and micritic limestones arranged in asymmetric cycles, rarely characterized by shallowing- and coarsening-upward trend .

The middle lithozone (Zu3b) is represented by thinner cycles (4 to 9 m thick) consisting of grey to greenish marls and black marly shales, marly lime mudstones and peloidal wackestones to packstone. Evaporitic facies and bioclastic, iron-rich packstone (tempestites) characterize the middle part of the cycles, while, iron-oxide crusts (hardgrounds\firmground) are frequently present at the top.

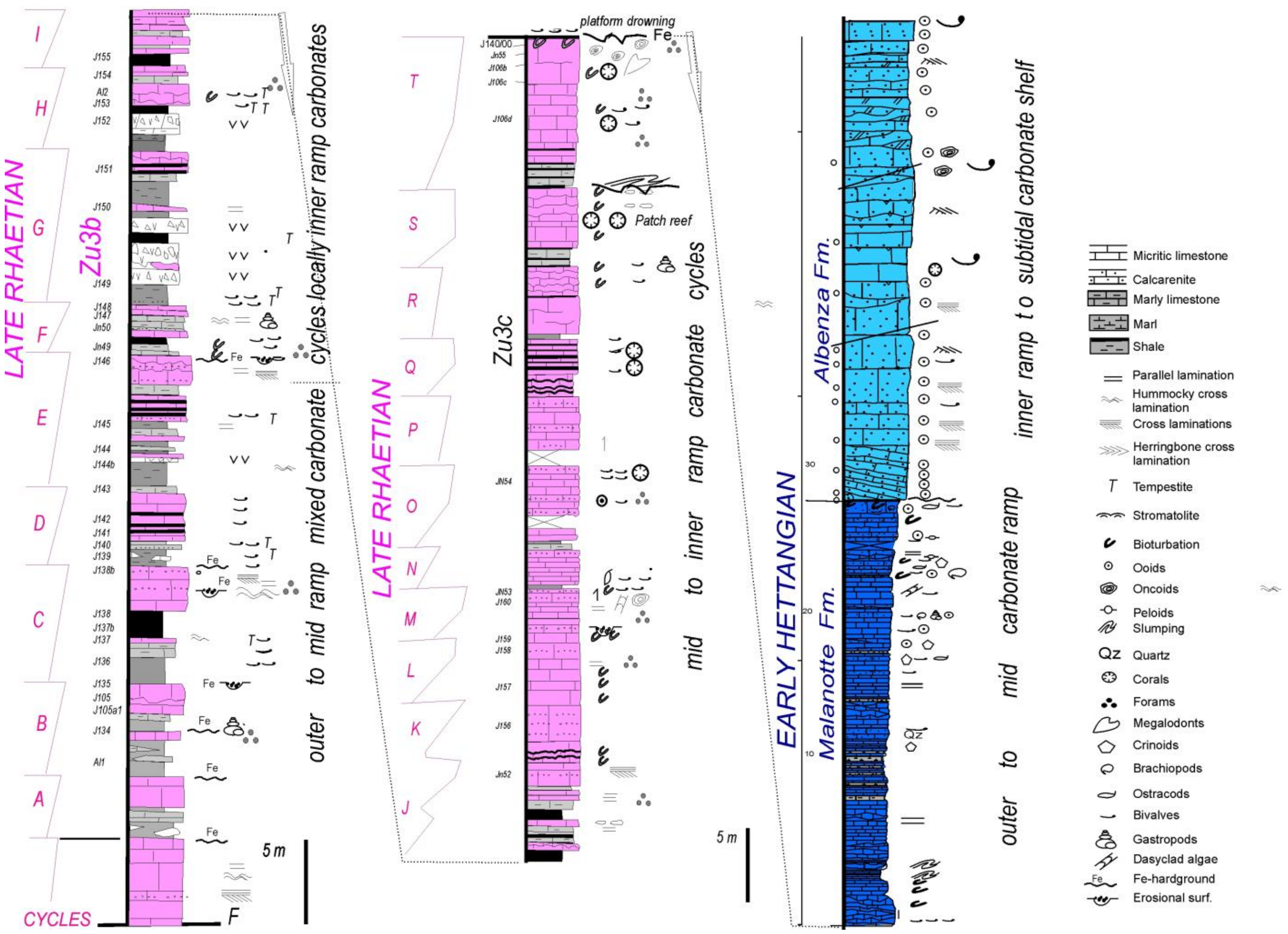


Fig. 8. Stops 2.2, 2.3 and 2.4. Stratigraphic log of the upper Zu Limestone to lower Albenza Formation succession in the Italcementi quarry section.

Palynofacies contain high percentage and high species diversity of sporomorphs often in tetrad status, associated with other terrestrial phytoclasts (tracheids, cuticule and wood remains). Facies association of this succession is interpreted as a mid-ramp environment, the fine siliciclastic - carbonate cyclic sedimentation records a few hypersaline restricted conditions and hiatuses at the top of several asymmetric cycles (Zu3a and Zu3b).

Stop 2.3. The upper lithozone (Zu3c; Fig.8) consists of bioturbated wackestones to shallow water packstone and grainstone. The fossil assemblages are very rich at the top of Zu3 carbonate succession: benthic foraminifers, corals, calcisponges, bryozoans, problematica and encrusting organisms (Lakew, 1990) are common, together with corals and calcispongia patch-reefs, with large megalodontids and oncoidal limestones.

The rich foraminiferal assemblage is dominated by *Triasina hantkeni* Majzon, with common *Gandinella falsofriedli* (Salaj, Borza, and Samuel), *Aulotortus sinuosus* Weynschenk and *Auloconus permodiscoides* (Oberhauser), whereas *Thaumatoporella parvovesiculifera* (Raineri), *Austrocolomia* sp., *Ammobaculites* sp., *Planiinvoluta* sp. and Nodosariidae are also present. Moreover, the microfacies is characterised by bivalves, crinoids, gastropods, calcisponges (*Sphintozoa*), coprolites ostracods, corals and dasycladaceae. Palynofacies show an increase in marine OM reflecting high productivity, low rate of terrigenous pollution and shallow water normal marine conditions.

Zu3c identifies the second, regional progradation of the carbonate platform (last Rhaetian carbonate inner ramp developed in central Lombardy).

The above mentioned section in the Italcementi Quarry has been studied for magnetostratigraphy in conjunction with the nearby Costa Imagna and Brumano sections extending to the base of the Rhaetian (Muttoni et al., 2010).

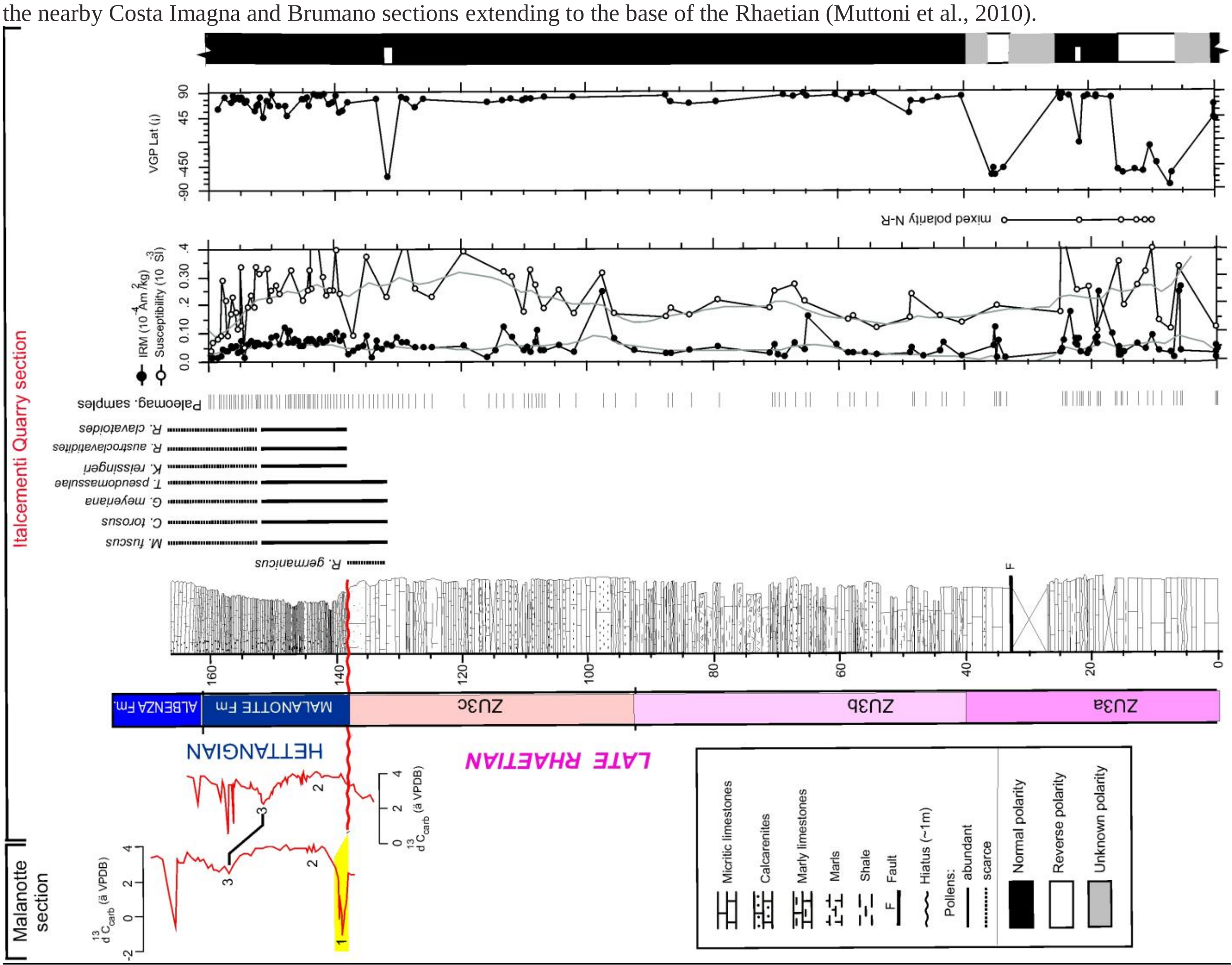


Fig. 9. Italcementi Quarry section. Magnetostratigraphy and biostratigraphy (Galli et al., 2005; 2007). See Muttoni et al. (2010) for more data and discussion.

Stop 2.4. The T/J boundary in the Italcementi quarries. (Fig. 8).

In the western Albenza area, the sharp Zu3 /Malanotte stratigraphic boundary is outlined by a paraconformity marked by a Fe-rich hardground which may represent a sedimentation gap at the base of the Malanotte Fm. in the western Albenza area. It may be correlated with a marly horizon present in the lowermost, section in the active Italcementi quarry (Malanotte section). The Malanotte Fm. represents a stratigraphic marker horizon, up to 30 m thick, separating the upper Rhaetian from the lower Hettangian shallow-water carbonates of Albenza Fm.. It consists of thinly bedded (centimeter to decimeter scale) grey-dark grey micritic limestones, with marly intercalations decreasing upward.

The Malanotte Fm. 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 packstone. Slumping phenomena are frequently present. 2) The upper part is characterizes by fine grained calcarenites (bioclastic wackestone-packstone with thin-shelled bivalves, crinoids, ostracods and gastropods) intercalated to mudstones passing upwards to grainstone with reworked ooids, peloids, intraclasts and bioclasts (bivalves, brachiopods, gastropods, Dasycladales, crinoids and rare bryozoans). The rich micro- and macrofaunal assemblages, characterizing the underlying strata abruptly disappear at the top of Zu3 member. Based on the palynological composition from the Zu3 member to the Malanotte Fm., Galli 2002; Galli et al. (2007) propose to locate the palynological T/J boundary at base of the Malanotte Fm. (Fig. 9).

A detailed stable isotope study of the Malanotte Fm. document that this unit exhibits an excellent preservation of the isotopic signal (Fig. 19).

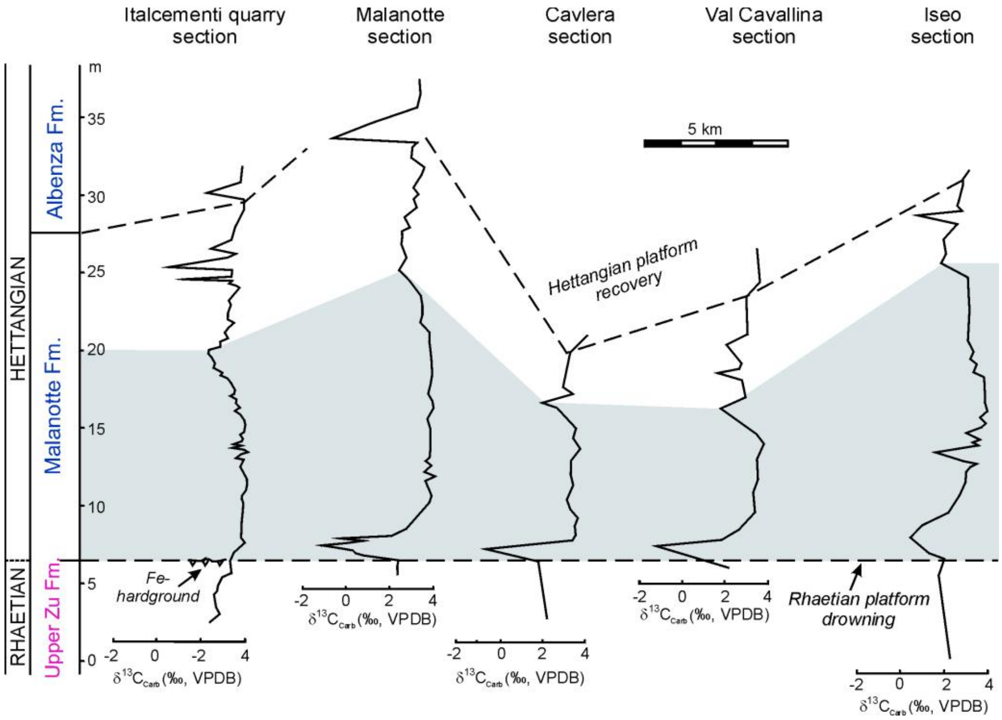


Fig. 10. C-isotope stratigraphy and correlation of the T-J boundary sections (from Galli et al., 2007; modified).

The C-isotope records across the marine T/J boundary interval in the Lombardy Basin document (Galli et al. 2005; 2007) that the C-isotope anomaly coincides with the end-Triassic biotic crisis and with the-platform drowning. Galli et al. (2005; 2007) argue that an increase in atmospheric CO_2 was responsible for the C-cycle perturbation.

The facies analysis of Malanotte Fm. underlines a relative sea-level rise that controlled the deposition of micritic limestones all over the Rhaetian shallow water ramp system, leading to an outer ramp depositional environment.

The abundant ooidal facies (Fig. 8) of the lower Albenza Fm. represent the high energy margin of the carbonate platform\ramp that separates the peloidal lagoon facies from the open subtidal environments (Jadoul & Galli 2008).

Stop 2.5. The stop is at the inactive Malanotte quarry (1000 m of altitude). In this quarry the Lower Hettangian succession (Malanotte, Albenza, Sedrina fms.) crop out as well as the boundary with the Rhaetian Zu Lmst. .

At the base of the Hettangian succession the meter thick marly horizon (with at the base Jurassic bivalves (Clamys; McRoberts, personal comm.) represents a regional marker.

Stop 2.6. The stop, located in the active Italcementi quarry (1180 m of altitude), is mainly focused on the T/J boundary. The base of the Malanotte Fm. is characterized by a local lens of intra-bioclastic calcarenites/rudites) with fragments of vertebrates and fishes.

Stop 2.7. The T\J boundary and the Early Hettangian succession along the Torre dei Busi-Valcava-road (about 1000 m in altitude) (Fig. 22). The Triassic- Jurassic boundary succession is here well cropping out, showing a sharp Zu3 -Malanotte contact, the transgressive early hettangian micritic limestones and then the fast progradation of the Albenza ooidal grainstone bars (downlap of 25-30°) geometry. Stable isotope results of this section are in Fig.10.

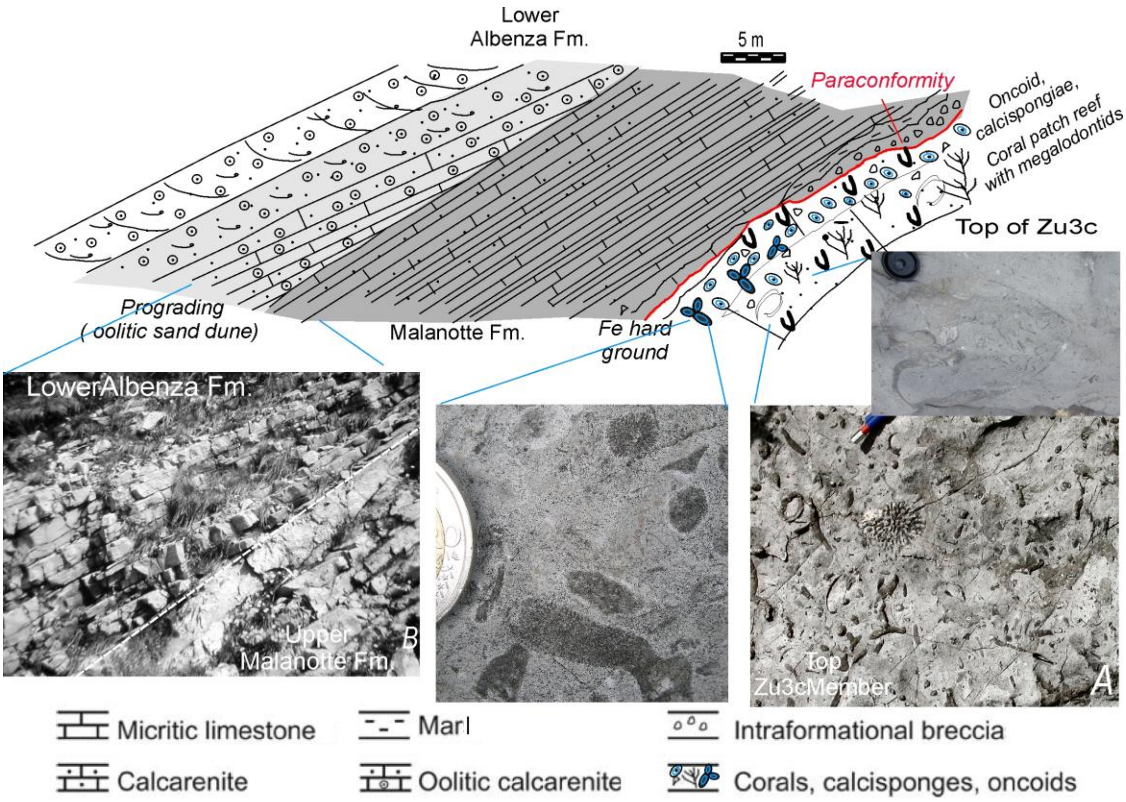


Fig. 11. Stop 2.7. The Valcava-Torre dei Busi section. A) Stratigraphic sketch of the Triassic/Jurassic boundary succession in the western Mt. Albenza. (from Galli et al., 2005; modified).

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