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Syntectonic Upper Cretaceous deep-water sequences of the Lombardy Basin (Southern Alps, Northern Italy)

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Key words: Cretaceous, Lombardy basin, Southern Alps, stratigraphy, synsedimentary tectonics, turbidite systems, Italy

ABSTRACT

Five deep-water stratigraphic units, bounded by unconformities, characterize the Aptian – Campanian succession of the Lombardy Basin and are thought to represent supercycles in the sense of Haq et al. (1988). The discontinuities progressively develop from the conformable basinal successions towards the NE margin as a consequence of its synsedimentary mobility. Each supercycle is characterized by the deposition of a major longitudinal turbidite system, which is covered by or interfingers with resedimented slope deposits, fed by the basin margins. Compositional and paleocurrent trends allow for the distinction of extrabasinal and local supply. The siliciclastic longitudinal turbidite systems developed from E to W. Austro-Southalpine basement and sediments were the source areas. The intrabasinal resediment bodies are represented by pelagic turbidites, megabeds and submarine slides and slumps.

The depositional features of the Cretaceous supercycles of the Lombardy Basin indicate the following:

1) The five supercycles and their bounding discontinuities have a tectonic origin. The regional orogenic activity in the Central and Eastern Alps was responsible for the clastic composition of the extrabasinal turbidite systems. Although eustatic and climatic changes were recorded by some prominent sedimentary events (carbonate to clastic transition, black shale deposition, fertility-productivity fluctuations), the strong overprint by synsedimentary tectonics makes it difficult to establish a conventional sequence stratigraphic framework of sequences and system tracts.
2) Synsedimentary tectonic activity affected the basin during Aptian to Campanian time. At first the basin underwent inversion of the former extensional setting. Then a local basin margin, mostly active during Cenomanian and Turonian time, began to grow in the NE sector. Within the regional framework the Lombardy Basin became a foreland basin located to the south of the S-vergent decollement nappes of the Southalpine Cretaceous belt.
3) Synsedimentary mobility of the basin margins is closely connected with the Cretaceous orogenic evolution in the Central and Eastern Alps, as documented by the contemporaneous development of the longitudinal turbidite systems, fed by Austro-Southalpine units under deformation, the progressive evolution of the unconformities over the basin margins and the emplacement of mass gravity deposits.

RESUME

Cinq séquences dépositionelles delimitées par des discontinuités caractérisent la succession Aptien – Campanien du Bassin Lombard. Les discontinuitées se développent à partir du secteur du bassin jusqu'aux marges, comme conséquence de l'activité tectonique synsédimentaire. Chaque séquence est caractérisée par la déposition d'un système turbiditique principal, interdigité avec des dépôts de glissements sous-marins provenant de la région marginale.

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Cette architecture a été déterminée par la tectonique synsédimentaire affectant les marges N et NO du Bassin Lombard lors de la mise en place d'une première chaîne à plis et chevauchements des Alpes Méridionales de la Lombardie.

Les systèmes turbiditiques longitudinaux ont été alimenté par l'érosion des nappes Austroalpines et du socle et de la couverture des Alpes Méridionales.

La liaison entre la déformation crétacée des unitées Austroalpines et la structuration des Alpes Méridionales est documentée par le développement contemporain des discontinuités aux bords du bassin, des glissements sous-marins et des systèmes turbiditiques longitudinals.

RIASSUNTO

Cinque supersequenze (2° ordine nel senso di Haq et al. 1988) delimitate da discontinuità caratterizzano la successione Aptiano – Campaniana del Bacino Lombardo. Le discontinuità si sviluppano progressivamente dalle aree bacinali verso quelle marginali, come conseguenza della mobilità tettonica sinsedimentaria di queste ultime. Ciascuna supersequenza è caratterizzata dalla deposizione di un sistema torbiditico principale, con allineamento longitudinale, interdigitato con corpi risedimentati in massa dai margini del bacino. I sistemi torbiditici longitudinali sono stati alimentati dall'erosione di basamenti e coperture del tutto somiglianti alle unità Austroalpine e Sudalpine.

Il legame tra la deformazione cretacica delle unità Austroalpine e la tettonica sinsedimentaria nel Sudalpino Lombardo è indicato dallo sviluppo contemporaneo delle discontinuità marginali, dei sistemi torbiditici longitudinali e dei maggiori risedimenti gravitativi.

Introduction

The Cretaceous deep-water units of the Lombardy Basin (Southern Alps, northern Italy) consist of turbidite systems associated with chaotic deposits and pelagic marly limestones. The stratigraphy of this upper Cretaceous succession was relatively well established since the 50's, by Venzo (1954), Aubouin et al. (1970), Bichsel & Häring (1981), Gelati et al. (1982), who recognized the relationship between the Southalpine Upper Cretaceous Flysch and the Alpine orogeny. Castellarin (1976) proposed that Cretaceous deep-sea fans, fed by a northern source (Austroalpine nappes), prograded from E to W into the Lombardy Basin. More recently Doglioni & Bosellini (1987) hypothesized that the flysch sequences were deposited in a foreland basin facing a Late Cretaceous fold and thrust belt in the area of the future Southern Alps. Based on heavy mineral assemblages Bernoulli & Winkler (1990) recognized that the clastic materials were derived partly from high-grade metamorphic terranes in the Southern Alps or Austroalpine nappes, partly from a Orobic type, lower grade metamorphic basement.

The present paper illustrates the stratigraphic framework and evolution of the Aptian-Campanian sequences of the Lombardy Basin. The work is based on 1:10.000 scale mapping of the area between lakes Como and Iseo (Fig. 1) and on sedimentological and stratigraphic analysis of more than one hundred stratigraphic sections. The litho- and biostratigraphic database of the Aptian to Maastrichtian succession, and a geological map of the same region have been presented elsewhere (Bersezio & Fornaciari 1987, 1988a, Fornaciari et al. 1988, Bersezio 1992, Bersezio et al. 1992). Here we integrate these data with the new results and interpretations, attempting to reconstruct the evolution of the Cretaceous Lombardy Basin, and to precise the relationship between the architecture of the Cretaceous sequences, the tectonic activity in the future Southalpine area and the Cretaceous, precollisional orogenic evolution in the Alpine region (Flügel et al. 1987, Bernoulli & Winkler 1990, Polino et al. 1990, Ring 1992).

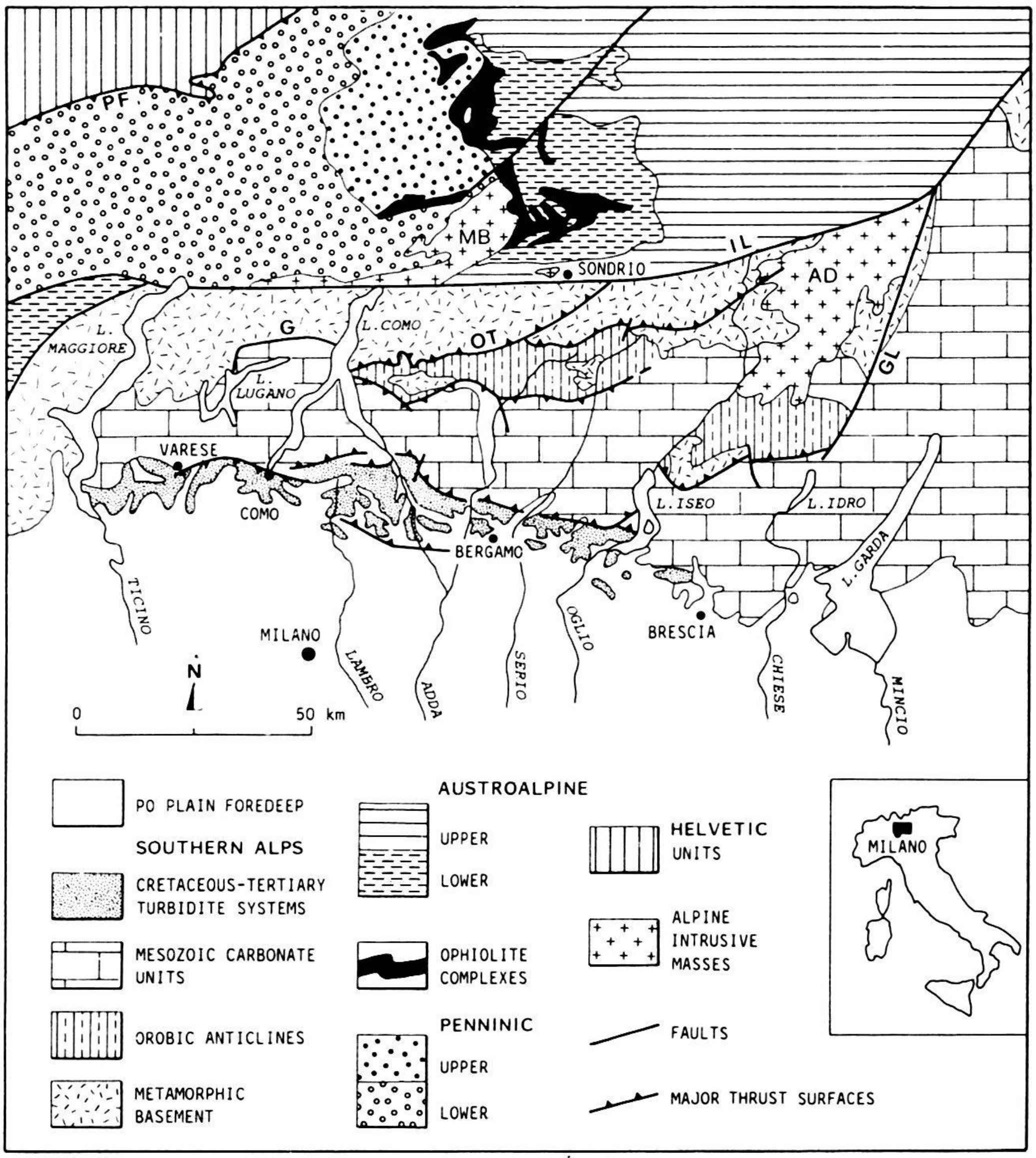

Fig. 1. Simplified geological scheme of the Central Alps. PF: Penninic Thrust; IL: Insubric Line; GL: Giudicarie Line; G: Grona – Val Grande Line; OT: Orobic Thrust; MB: Masino/Bregaglia intrusive bodies; AD: Adamello intrusive bodies.

Geological framework

The Cretaceous Lombardy Basin was a deep-water basin developed on the thinned continental crust of the submerged, distal continental margin of the Adria plate, or Apulian promontory (Channell et al. 1979, Bernoulli et al. 1979, Winterer & Bosellini 1981, Bernoulli et al. 1992). Concerning Late Cretaceous time, a setting behind the subduction zone is generally assumed for this basin, as a result of the Adria-Europe convergence (Castellarin 1976, Laubscher & Bernoulli 1982, Polino et al. 1990, Ring 1992).

The Cretaceous units of the Lombardy Basin overlie a deepening-upwards succession of Hettangian-Early Cretaceous age consisting of carbonate turbidite wedges and associated pelagic sediments. These infill the previous, rift-related extensional basins, represented by a sequence of half grabens above tilted blocks (Gaetani 1975, Weissert 1981, Winterer & Bosellini 1981, Bernoulli et al. 1992). This framework was replaced by the development of the Late Cretaceous asymmetrical basin, which has approximately an E-W strike in present-day coordinates.

Although the Aptian to Campanian turbidite systems built up a 2.5 km thick succession, the basin was never filled up. As a consequence deep-water, uppermost Campanian – Maastrichtian, hemipelagic marlstones separate the Cretaceous turbidite sequences from the Paleogene turbiditic and pelagic deposits (Kleboth 1982, Bernoulli et al. 1987).

The Cretaceous tectonic activity in the area which now represents the Lombardian Southern Alps, is still a matter of debate, as the age of thrusting in the different parts of the Southern Alps is not well constrained (Doglioni & Bosellini 1987, Castellarin et al. 1987, Bernoulli et al. 1989, Forcella & Jadoul 1990, with references therein). S-vergent thrusts have been cross-cut, in the eastern Orobic Prealps, by the Upper Eocene Adamello intrusive masses (Brack 1981, Zanchi et al. 1992), but no structural evidence exists to attribute a Late Cretaceous age to the tectonic activity.

Neogene deformation deeply affected the whole Cretaceous succession in the frontal sector of the Southalpine fold and thrust belt (Gaetani & Jadoul 1979, Laubscher 1985, Cassano et al. 1986) (Fig. 1). The structural framework of the area is characterized by two parallel alignements of regional ramp anticlines striking N110. They are separated by a belt of south vergent fault-propagation folds and reverse faults (Bersezio & Fornaciari 1988b). The northern alignement represents the so-called "Flessura Pedemontana" (Fig. 2) (Desio 1929; "Steep Rand Zone" of De Sitter & De Sitter-Koomans 1949); the southern one consists of the Adda and Bergamo-Zandobbio anticlines. N-S strike-slip faults and transfer zones link the structures (Bersezio & Fornaciari 1988b).

The deformation of the outcropping section is related to the upward propagation of deep thrust planes, repeating at least the whole Carnian-Jurassic section. The regional decollements are probably located within Carnian evaporites, Norian-Rhaethian shales and Aptian marlstones. In the western sector, around Como, the Oligo-Miocene foredeep clastics (Gonfolite Group, Gelati et al. 1988) are backthrusted over the Upper Cretaceous units, with the development of a "wedge into and split apart system" of Burdigalian or Late Miocene (Tortonian?) age (Bernoulli et al. 1989).

As a consequence of late alpine thrusting, the Cretaceous succession of the Prealps around Bergamo belongs to a WNW-ESE trending narrow belt consisting of several different tectonic units, stacked from NNW to SSE. Therefore facies and thickness variations can be appreciated mostly along the E-W trend. Nevertheless N-S changes can be recognized across the thrust boundaries, with the resulting paleogeographic indetermination due to the unknown amount of shortening.

Upper Cretaceous stratigraphy

The following lithostratigraphic description emphasizes the presence and distribution of unconformities, that bound the Cretaceous units in the northern and eastern areas, as schematized in figures 2 and 3.

The Upper Cretaceous succession developed starting from the Early Aptian, during which fine-grained siliciclastic sediments replaced the pelagic calcilutites of the Maiolica Fm. (upper Tithonian – lower Aptian) (Barberis et al. 1992 and references therein).

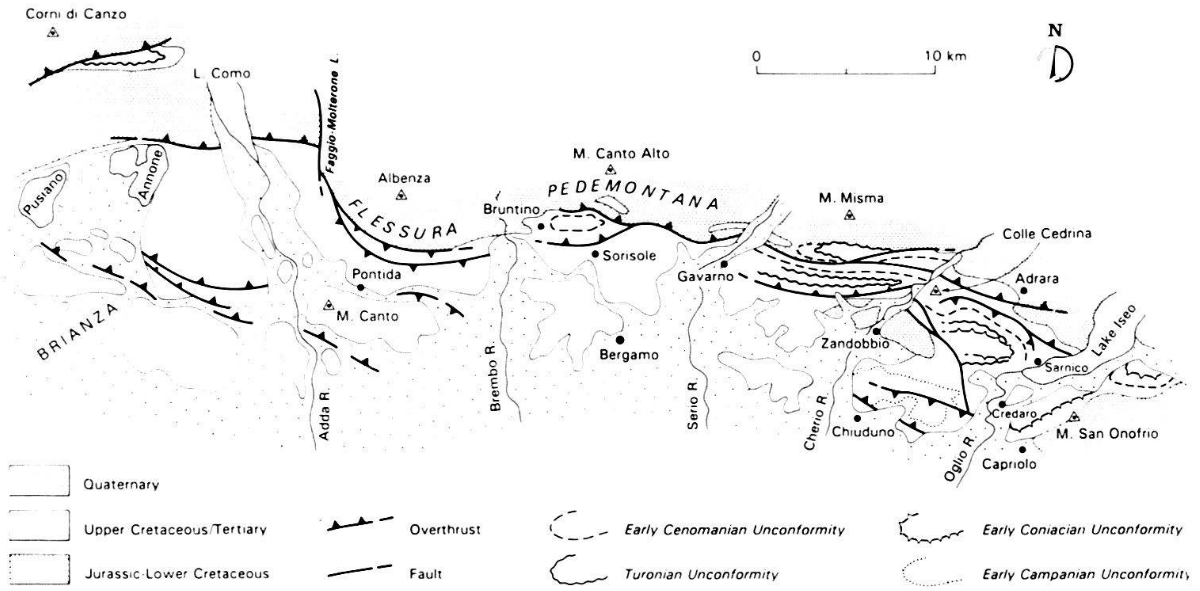

Fig. 2. Simplified structural scheme of the study area. The location of the major unconformities has been reported.

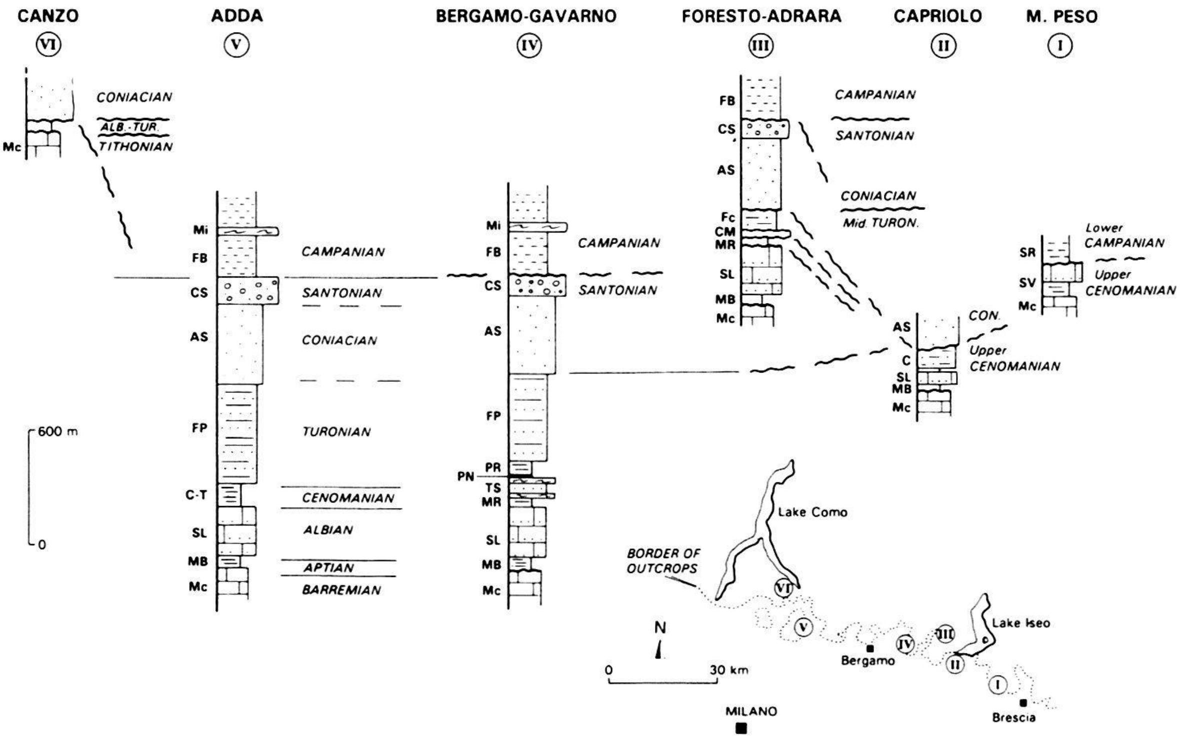

Fig. 3. Lithostratigraphic correlation scheme of the Upper Cretaceous turbidite systems in the Bergamo Prealps. Mc: Maiolica Fm.; MB: Marne di Bruntino; SL: Sass de la Luna; MR: Marne Rosse; CM: Chaotic Megabeds; TS: Torbiditi Sottili; SV: Scaglia Variegata; C: Cenomanian base-of-slope succession of Capriolo – M.S. Onofrio; C-T: Cenomanian/Lower-Middle Turonian units of the basinal area; PN: Peliti Nere Superiori; PR: Peliti Rosse; FP: Flysch di Pontida; Fc: Flysch di Colle Cedrina; AS: Arenarie di Sarnico; CS: Conglomerati di Sirone; SR: Scaglia Rossa; FB: Flysch di Bergamo; Mi: Missaglia Megabed.

Berriasian – Albian unconformity

The boundary between Maiolica Fm. and the overlying terrigenous units (Marne di Bruntino) can be transitional or unconformable. In the former case a transitional lithozone, mostly consisting of pelagic turbidites, early Aptian in age, is present (Barberis et al. 1992). By contrast the unconformable boundary is represented by a sharp contact between calcilutites and shales, corresponding to variable time gaps through the basin, with maximum hiatuses in the Corni di Canzo and Zandobbio areas (Fig. 2, 3) (Berriasian – Middle Albian and Valanginian – Early Albian respectively), that were the sites of Jurassic structural highs (Gaetani 1975).

Marne di Bruntino

The Marne di Bruntino Fm. (Lower Aptian – Upper Albian) (Venzo 1954, Passeri 1969, Gelati et al. 1982) consist of hemipelagic and turbiditic marlstones and siltstones, of middle to lower bathyal environment (Arthur & Premoli Silva 1982), with recurrent black shales. Three lithozones have been separated (Bersezio 1992) (Fig. 4).

The lower lithozone (MB1, Lower p. p. – Upper p. p. Aptian; thickness 0–35 m) consists of pelagic mudstones and claystones. Black shale layers are interbedded within red, purple red, grey or olive-green intervals. The $CaCO_3$ content increases from the lower carbonate-free unit to the upper marlstones.

The intermediate lithozone (MB2) represents a fine-grained turbidite system, which developed from the Aptian/Albian boundary to the Middle Albian, building up a lenticular body (thickness 0–70 m) (Fig. 4). To the N and NE, this body is locally bounded at the base by an erosional discontinuity, overlain by silicified conglomerates, mainly composed of sedimentary lithoclasts. To the S and SW, the turbidites wedge out within hemipelagic marlstones. An approximatively NE-SW elongation of the turbidite body can therefore be inferred in present-day coordinates. The turbiditic sediments are represented by very fine-grained, quartz-rich, hybrid arenites, containing redeposited orbitolinids and Algae, associated with siltstones and mudstones and with some marly, graded megabeds and slumps. Sole marks indicate provenance from E and NE. The megabeds contain intraclasts and epi- to mid-bathyal benthic foraminifers, which suggest a local provenance from a slope environment.

The upper lithozone of the Marne di Bruntino (MB3, Upper Albian in age, 5–30 m thick), again consists of hemipelagic marlstones with interbedded intrabasinal, marly turbidites. The occurrence of calcareous, pelagic turbidites marks the upper formational boundary of the Marne di Bruntino.

Sass de la Luna

The uppermost Albian Sass de la Luna, mostly consisting of calcareous and marly pelagic turbidites, is up to 350 m thick in the central part of the area (Bergamo, Fig. 2) and thins out to less than 20–120 m respectively to the N, NW and SE of this sector (Pusiano, Sorisole, M. S. Onofrio (Fig. 2) and Brescia area (Fig. 1)). The formation consists of noncyclical sequences of sheet-like turbidite layers, composed by micrite, intraclasts, pelagic microfossils (planktonic foraminifers, radiolarians, calcispheres), nannofossils and

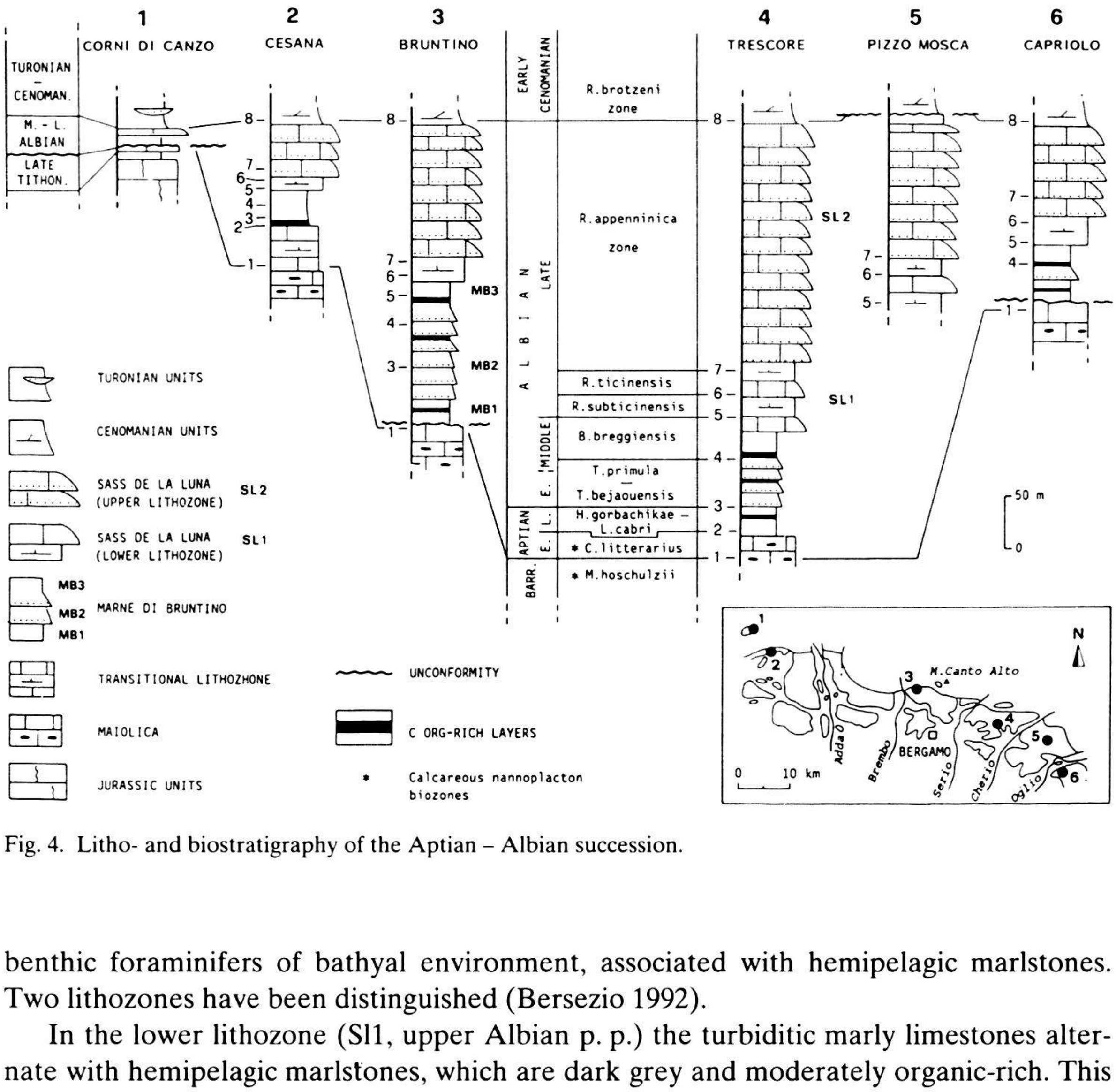

Fig. 4. Litho- and biostratigraphy of the Aptian – Albian succession.

benthic foraminifers of bathyal environment, associated with hemipelagic marlstones. Two lithozones have been distinguished (Bersezio 1992).

In the lower lithozone (Sl1, upper Albian p. p.) the turbiditic marly limestones alternate with hemipelagic marlstones, which are dark grey and moderately organic-rich. This unit thins out towards N and NW, passing to a reduced succession of red hemipelagic marlstones with very rare turbidites (Albenza, Annone, Cesana; Fig. 2, 4).

In the upper lithozone (SL2, uppermost Albian) the hemipelagic marlstones are less abundant, and the pelagic turbidites are more calcareous than below. Very thick, graded megabeds, with intraclastic pebbly mudstones at the base, become more and more frequent upwards. The deposition of the SL2 lithozone therefore marks a sudden increase of sedimentation rate (up to 200 m/MA without correction for compaction). Paleocurrent trends indicate provenance from S and SE, according to the present-day coordinates.

The lithozone gradually thins downflow, towards N, W and SE. To the N, the thinner successions of the SL, with basinal facies, cover the MB2 turbiditic lithozone, while the thicker successions are located southwards (Fig. 2, 4).

Early – Middle Cenomanian unconformity

In the conformable successions of the most southern and western areas, the Albian-Cenomanian boundary is accompanied by a facies variation, from pelagic turbidites to calcilutite-marlstone alternances (top of Sass de la Luna) and to hemipelagic red-grey marlstones (Marne Rosse Fm., Bersezio & Fornaciari 1988a). By contrast an unconformity characterizes the northern and eastern outcrops, where the Marne Rosse Fm. is absent (east of Serio river) or incomplete at the base (region between Serio and Brembo rivers) (Fig. 2, 3).

Cenomanian units

Marne Rosse Fm.

The Marne Rosse Fm. consists of red hemipelagic marlstones, with subordinate intercalations of pelagic turbidites and intraformational pebbly mudstones (thickness 0–40 m), Early – Middle Cenomanian in age. The western and southern conformable successions mostly consist of parallel-bedded, red to grey, hemipelagic marlstones and pelagic calcilutites. This facies association is replaced by a slump-dominated association in the south-easternmost outcrops around Lake Iseo (Capriolo area, Fig. 2). In the northern unconformable successions, east of the Brembo river, lenticular pebbly mudstones and calcareous turbidites are frequently interbedded within red marly limestones (Bersezio & Fornaciari 1988a).

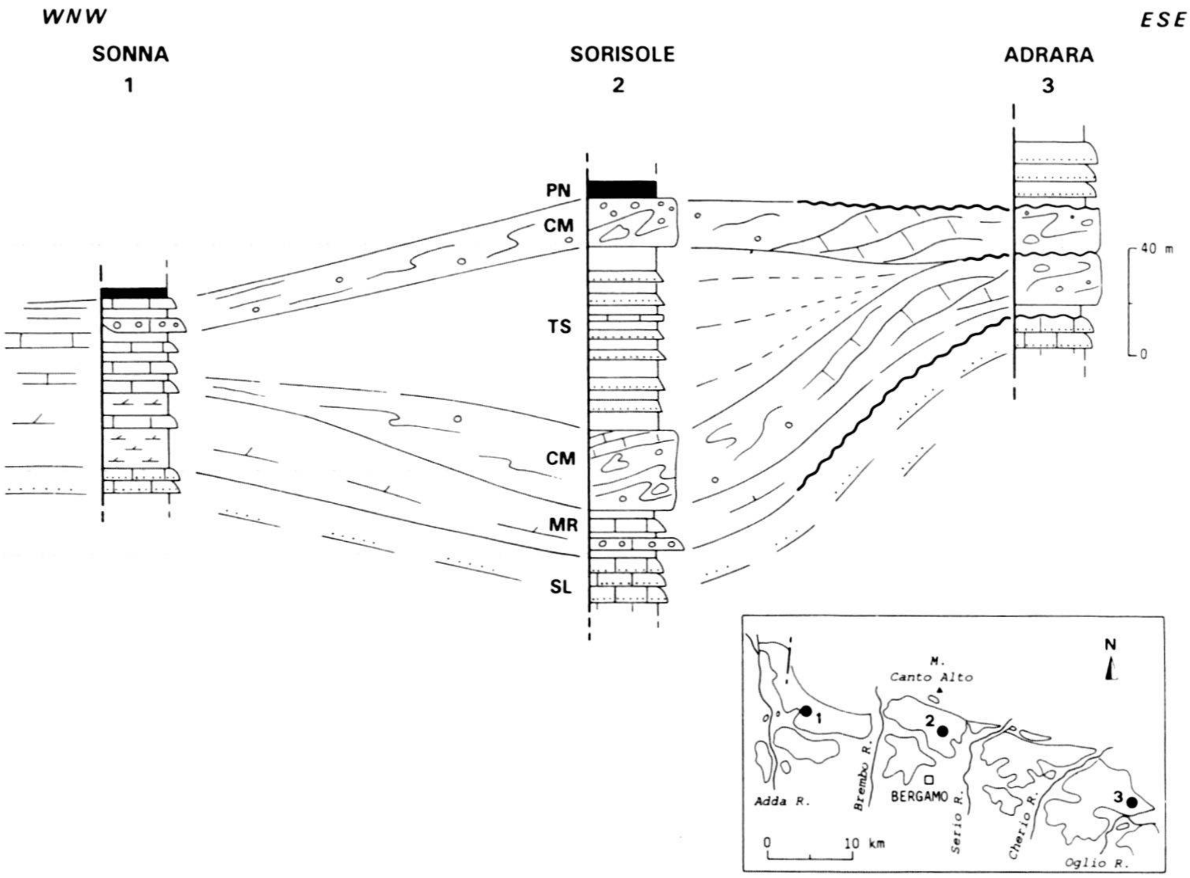

Fig. 5. Lithostratigraphic scheme of the Cenomanian succession based on selected sections. SL: Sass de la Luna, MR: Marne Rosse, CM: Chaotic Megabeds and lateral equivalents, TS: Torbiditi Sottili, PN: Peliti Nere Superiori.

Chaotic megabeds

Two Upper Cenomanian chaotic megabeds represent basinwide marker units, observed over an area of at least 500 km^2 (Banchi Caotici, Bersezio & Fornaciari 1988a). Their thickness ranges from 0 to 60 m. The presence of a third chaotic layer is restricted to the region between Serio and Cherio rivers. Correlative chaotic beds crop out in the westernmost Cretaceous exposures around Varese (Bichsel & Häring 1981).

In the Bergamo Prealps the lower chaotic megabed is intercalated in the lower 10 m of the Upper Cenomanian turbidite unit (Torbiditi Sottili), while the upper one occurs at the top of this unit. Considering the present-day WNW-ESE distribution of exposures, the two megabeds merge towards the NE and E, where the Torbiditi Sottili lithosome wedges out. By contrast they thin out in the western and southernmost areas, where they correspond to turbiditic marly limestones (Fig. 5).

The chaotic megabeds mostly consist of pelagic limestones and marlstones lacking internal structure. In the northeastern area both of them are composed of plurimetric slabs of pelagic calcarenites and mudstones of Albian to Cenomanian age, embedded in a lime matrix with a fluidal texture (slide facies). Blocks of the Upper Albian Sass de la Luna, up to 50 meters across, can be recognized. Westwards and southwards, a continuous transition from the slide facies to calcareous turbidites can be observed. These features suggest a N and NE provenance of the blocks. The south- and south-western areas received only the turbidites resulting from the downcurrent modification of the mass gravity flows. This interpretation is supported by ancient and recent examples of submarine mass gravity deposits in carbonate and siliciclastic systems (Woodcock 1979, Weissert 1981, Cook & Mullins 1983, Alvarez et al. 1985, Kleverlaan 1987, Barnes & Lewis 1991).

Torbiditi Sottili

The Torbiditi Sottili Fm. (Bersezio & Fornaciari 1988a), represents a thin turbidite wedge, Late Cenomanian in age, consisting of thin-bedded, fine-grained sandstones, hemipelagic marlstones and very thin-bedded pelagic and turbiditic limestones. The unit has its maximum thickness (70 m) between the Brembo and Cherio rivers (Fig. 2, 5), gets progressively thinner (less than 20 m) towards the W and S and finally laps out above the first chaotic layer towards the NE and the E. The eastern termination of the Torbiditi Sottili wedge is represented by less than 3 m of red argillaceous marlstones, Late Cenomanian in age, embedded between the two chaotic megabeds. These red marlstones are absent around Adrara, where a minor hiatus (latest Cenomanian p. p.) is documented (Fig. 2, 5).

The thin eastern and northern successions consist of lenticular turbiditic strata with subordinate hemipelagic marlstones. The thicker successions of the central area mostly consist of sheet-like, thin- to medium-bedded turbidite layers, locally forming thickening-upwards sequences. The southernmost and western successions are characterized by marlstones, associated with thin-bedded turbidite siltstones.

The turbiditic sandstones are fine-grained, hybrid litharenites, lacking sedimentary rock fragments. The extrabasinal lithic grains are metamorphic rock fragments. Measurements of paleocurrent directions indicate provenance from E and NE.

Turonian units

The Turonian succession is rather complex due to the significant thickness and facies variations occurring from west to east (Fig. 3). It comprises five main lithostratigraphic units: Peliti Nere Superiori, Peliti Rosse, Flysch di Pontida, Flysch di Colle Cedrina, Turonian units of the northern thrusts.

Peliti Nere Superiori

The Peliti Nere Superiori (Venzo 1954, Aubouin et al. 1970) consist of 0–30 m thick succession of black and dark grey, massive or stratified, mudstones and siltstones. The age of the Peliti Nere Superiori (uppermost Cenomanian – lowermost Turonian) coincides with the global anoxic event OAE 2 (Arthur & Premoli Silva 1982).

Four main lithofacies are associated: dark hemipelagic mudstones, fine-grained marly and calcareous turbidites, fine-grained siliciclastic turbidites and black shales. The black shales are characterized by TOC up to 3% weight, mostly consisting of amorphous organic matter. On the whole the Peliti Nere Superiori can be interpreted as pelagic sediments recording anoxic conditions in the deepest part of the basin.

Peliti Rosse

The Peliti Rosse unit (Flysch Rouge, Aubouin et al. 1970) of Early p. p. – Middle Turonian age in the complete section consists of a lower interval with red shales and silicified calcilutites, followed by an upper interval formed by a turbidite system where red/grey shales are interbedded with fine-grained, graded sandstone beds. The two intervals form a coarsening-upward trend. The overall thickness ranges between 50 and 150 meters. In the Sorisole/Gavarno area a calcareous, chaotic megabed, similar to the Cenomanian ones, is intercalated in the succession (section 2, Fig. 6).

The composition of arenites is quartzo-feldspathic with average values Q=63%, F=20%, L=17%. Lithic grains are dolomite and gneiss or ganitoid rock fragments. Paleocurrent directions are from E and NE.

The Peliti Rosse turbidite system is essentially characterized by two typical facies association which are:

- fine to medium-grained "classical" turbidites consisting of thin to medium-bedded Tb-e and Tc-e Bouma sequences, without cyclicity;
- thin sandstone beds with sharp wavy boundaries, sometimes showing oblique lamination, with incomplete Tc-e Bouma sequences. In both cases the sand/shale ratio is about 1:1.

The former facies association characterizes the western area (Brianza, Fig. 2, 6) where the unit is about 150 m thick. It is interpreted as consisting of basin plain turbidites. The latter facies association is typically found in the Sorisole area and in the northernmost outcrops in the western area, where the unit is thinner than in the western setting. The relatively frequent occurrence of sharp and wavy-bounded beds, lacking the finer grained population of the turbidity flows, suggests some bypassing processes. These features are in agreement with a relatively more "proximal" depositional setting for this facies association with respect to the previous one.

The turbiditic sandstones rapidly disappear to the west of the M. Misma area (Fig. 2) where the Peliti Rosse are only represented by red shales and marls, with thin-bedded silicified calcilutites. Finally in all the eastern area the unit is absent.

Flysch di Pontida

The youngest Turonian turbidite system is represented by the Flysch di Pontida (Upper Turonian; De Rosa & Rizzini 1967), which consists of a monotonous succession of fine- to medium-grained sandstones, up to 450 m thick. These thin- to medium-bedded turbidites are laterally continuous, with complete or incomplete Bouma sequences. The Flysch di Pontida has a quartzo-lithic composition with average values Q=46 F=3 L=51. Lithics mostly consist of dolomite, chert and low-grade metamorphic rock fragments.

In the area west of the Brembo river both the lower and the upper boundaries of the Flysch di Pontida are transitional. Paleocurrent directions are from ENE. The facies associations suggest deposition in a basinal environment.

Several mixed siliciclastic/calcareous megabeds, 1 to 5 m thick, are interbedded both in the Peliti Rosse and Flysch di Pontida unit (Aubouin et al. 1970, Bichsel & Haering 1981). They form graded beds showing a typical internal organization. The lower interval of the megabeds is composed by pebbles and cobbles, typical of the Southalpine and Austroalpine successions, among which only cherts are usually sub-angular. This interval is rapidly replaced upwards by a foraminifera-bearing division of intrabasinal origin, then followed by a thick resedimented marly unit.

The association of extrabasinal and intrabasinal material suggests that the calcareous megabeds derived from collapse and recycling of older unconsolided turbidite clastics and intrabasinal pelagic materials along a marginal slope of the basin.

Flysch di Colle Cedrina

The Middle Turonian Flysch di Colle Cedrina (Gelati et al. 1982) represents the typical unit of the northeastern sector of the Turonian basin (Fig. 6). It unconformably overlies the 2nd Cenomanian chaotic megabed, with a hiatus spanning the Early and Middle Turonian. This formation is irregular in shape with a thickness ranging from 0 to 200 metres.

The unit consists of two typical facies associations which are:

- massive marly beds with interbedded lenticular conglomerate bodies, up to 5 m thick, where cobbles of oolitic grainstone and chert are frequent;
- tabular, thick and very thick, graded beds with a lower microconglomerate, followed upwards by a bioclastic, resedimented, marly interval.

The massive sandy mudstones are composed by quartzo-lithic grains and planktonic foraminifers embedded in a calcareous muddy matrix. This facies represents base-of-slope, mass flow deposits. The tabular and graded beds represent thick, mainly carbonatic turbidites.

The Flysch di Colle Cedrina interfingers with and is capped by fine-grained, tabular, marly turbidites, equivalent to the Flysch di Pontida, with an irregular thickness, ranging from 0 to 80 meters.

In the northernmost outcrops of the Adrara area, the Flysch di Colle Cedrina rapidly thins and disappears. The Turonian units are absent between the Cenomanian chaotic carbonates and the overlying Coniacian Arenarie di Sarnico.

Turonian deposits of the northern thrusts

The Turonian successions that belong to the northern thrusts of the Flessura Pedemontana, in the Albenza and M. Misma regions (Fig. 2), are characterized by peculiar features.

Albenza. At the western end of the Albenza anticline, a regional, N–S striking fault zone, with alpine strike-slip activity, cross-cuts the overthrust Mesozoic units (Linea del Faggio Morterone, Zanchi et al. 1988, Schönborn 1990) (Fig. 2). The fault zone coincides with a Liassic synsedimentary tectonic lineament (Jadoul & Doniselli 1986).

At the southern termination of the Linea del Faggio, within the Cretaceous units, a poorly exposed turbiditic unit, about 300 m thick, interfingers with both the Peliti Rosse and the Flysch di Pontida. The typical facies of this unnamed unit, consists of tabular medium-to-thick-bedded turbidites, with complete or incomplete Bouma sequences (Ta-e, Tb-e, Tc/) interbedded with dark shales. Microconglomeratic lenticular beds and coarse-grained, massive sandstone strata, frequently occur within this succession.

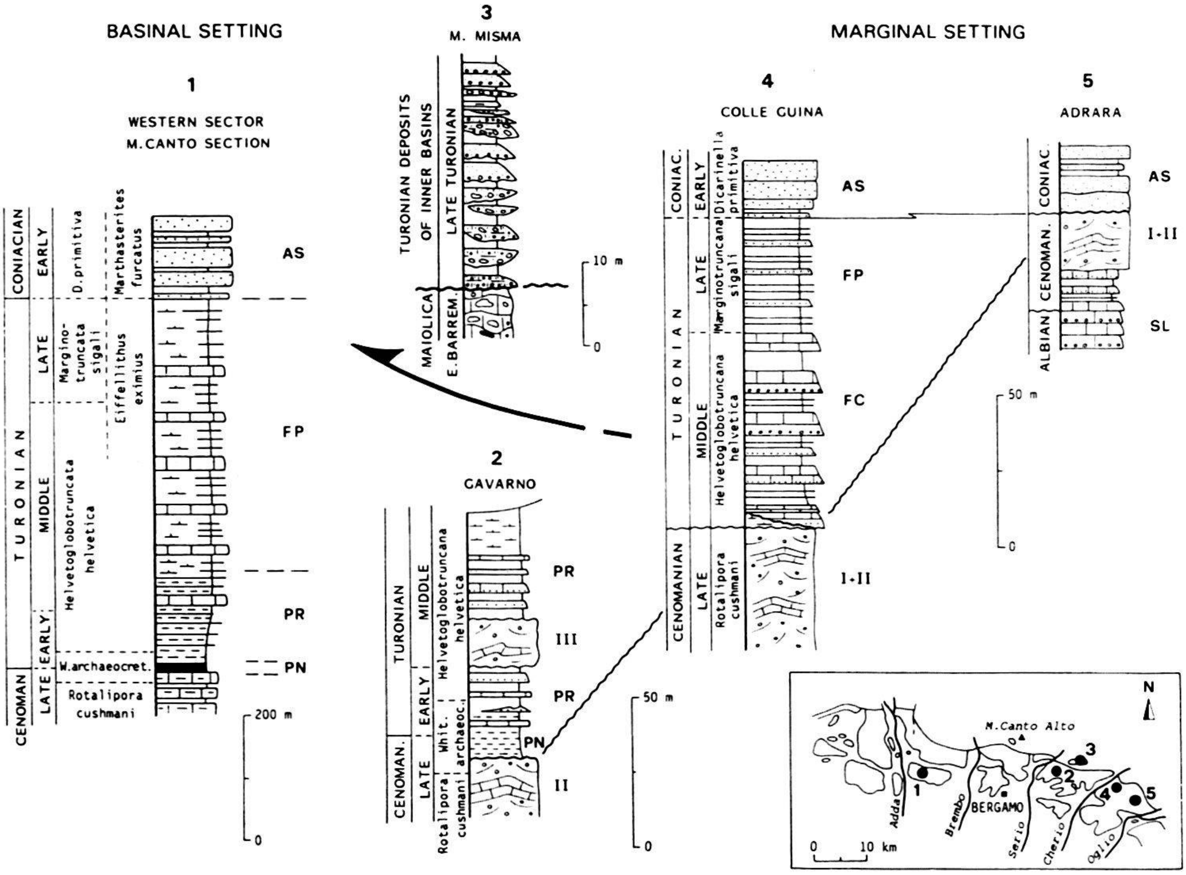

Fig. 6. Stratigraphy of the Turonian Sequence. SL: Sass de la Luna; I, II and III: Cenomanian and Turonian chaotic megabeds; PN: Peliti Nere Superiori; PR: Peliti Rosse; FC: Flysch di Colle Cedrina; FP: Flysch di Pontida; AS: Arenarie di Sarnico. Redrawn and modified after Bersezio et al. 1992.

The quartzo-feldspatic composition of sandstones is comparable to the composition of arenites within the Peliti Rosse. Sparse sole marks and the general stratigraphic relationships with the coeval Flysch di Pontida and Peliti Rosse units, indicate a northern provenance for these sediments. This "anomalous" provenance suggests that the Linea del Faggio might have acted during the Turonian time like a transversal, northern feeder point of clastics, into the E-W striking basin.

M. Misma. The thrust folds at the southern flank of M. Misma, present an Upper p. p. Turonian succession (Fig. 6), that consists of coarse-grained deposits, infilling an erosional surface, probably a slumpscar, at least 2 km wide and 200 m deep. The erosion progressively cuts down into the Barremian to Aptian succession (Bersezio et al. 1989).

This Turonian succession is formed by channelized conglomeratic beds with associated fine-grained overbank deposits and small-scale sandstone lobes. Slump deposits are preserved at the western flank of the erosional surface, below the Turonian clastics. The facies associations record repeated erosion and infilling stages (Bersezio et al. 1989).

The Turonian sandstones are fine to medium grained, hybrid arenites, with average composition of the siliciclastic fraction, Q=65, F=15, L=20, which is very similar to the composition of the Peliti Rosse turbidite sandstones. Lithic grains consist of felsitic volcanites, dolomites, cherts and gneisses. The intrabasinal fraction is represented by planktonic and benthonic foraminifers and calcareous intraclasts. Paleocurrent measurements indicate provenance from NE and E.

The M. Misma slump scar is here interpreted as a remnant of a northern marginal setting. The depositional features suggest a two step evolution. A slump scar was first cut into the Lower Cretaceous, partly unconsolidate sediments. This process, active during the Cenomanian, supplied materials to the Cenomanian chaotic megabeds, that spread over a large part of the basin floor. Later on, during the Middle Turonian, the slump scar acted as a sort of canyon, funnelling the gravity flows towards the basin. Age correlation, similarity of sandstone composition and facies trends of the Peliti Rosse turbidite system, suggest that the latter unit could have been fed through the M. Misma Turonian "canyon". At last the "canyon" was filled up by Upper Turonian sandstones.

Turonian unconformity

This unconformity is pointed out by the striking facies change of the Turonian succession from southwest to northeast and by the progressive disappearing of the same units in this direction (Fig. 7).

All over the western area (M. Canto/Albenza, Sorisole) in fact the typical Turonian succession is open by the Peliti Nere (Fig. 6), conformably overlying the 2nd Cenomanian chaotic megabed, and is followed upsection by the Peliti Rosse and the Flysch di Pontida.

To the east of the Serio river, three relevant variations affect the Turonian succession.

- The Peliti Nere unit is progressively reduced in thickness and supplies clasts to coeval debris flow deposits. The Peliti Nere is absent to the east of the Cherio river.
- The turbidite sandstone beds within the Peliti Rosse progressively disappear to the east of M. Misma area being replaced by red marls. Then the unit is missing to the east of the Colle Cedrina area.

- The Upper Flysch di Pontida is extremely reduced in thickness and interfingers with the chaotic slope deposits of the Flysch di Colle Cedrina (Fig. 7).
- Finally, in the Sarnico area the Turonian units are absent and the Arenarie di Sarnico directly laps onto the Cenomanian chaotic megabeds (Fig. 6, 7).

These depositional features document the development of a single progressive unconformity which bounds at its base the whole Turonian succession.

Coniacian – Santonian units

Arenarie di Sarnico

The Arenarie di Sarnico represent a siliciclastic turbidite system fed from the east, that prograded westwards (Bichsel & Häring 1981). Typical facies associations consist of massive amalgamated sandstones and alternating sandstones and shales. The lower boundary of the formation is represented by the transitional and conformable contact with the Flysch di Pontida in the area west of the Serio river and by the unconformity above the Cenomanian chaotic megabeds in the eastern area (Fig. 3, 8).

Compositionally the Sarnico sandstones are quartzo-lithic arenites (Q=47, F=3, L=50), with chert, dolomite, siltstone and low-grade metamorphic rock fragments. This lithic association is consistent with the erosion of a source area where South-Austroalpine sediments and metamorphic basement were exposed. The Arenarie di Sarnico form a quite tabular lithosome with an average thickness ranging between 350 and 400 meters. Based on the facies association and outcrop distribution the proximal and distal areas are distinguished.

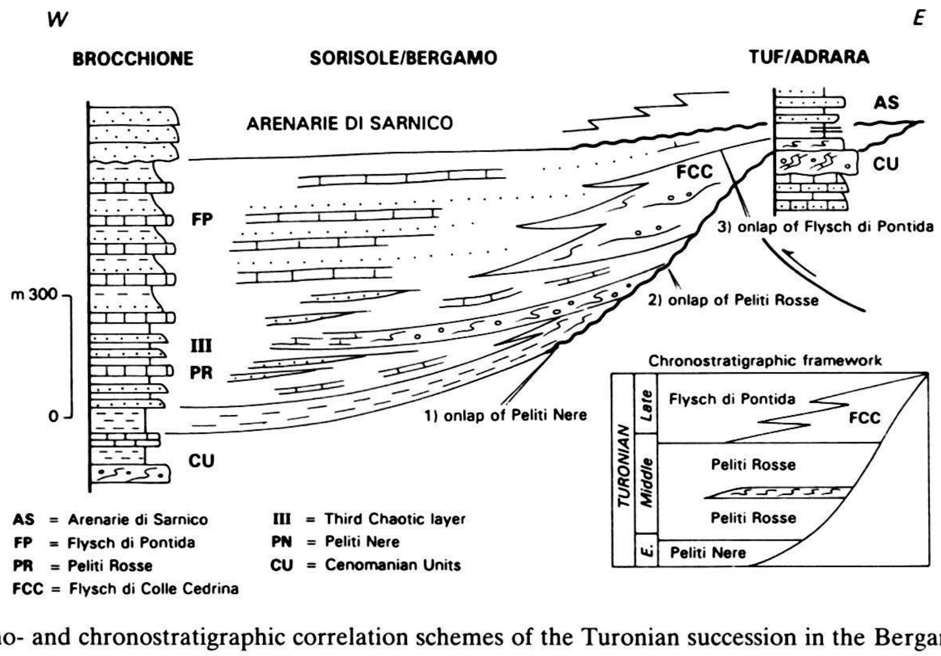

Fig. 7. Litho- and chronostratigraphic correlation schemes of the Turonian succession in the Bergamo Prealps. Legend of lithostratigraphic abbreviations as in figure 3. The Brocchione and Adrara sections are located in the M. Canto and Adrara areas, that are located in the index map of figure 2.

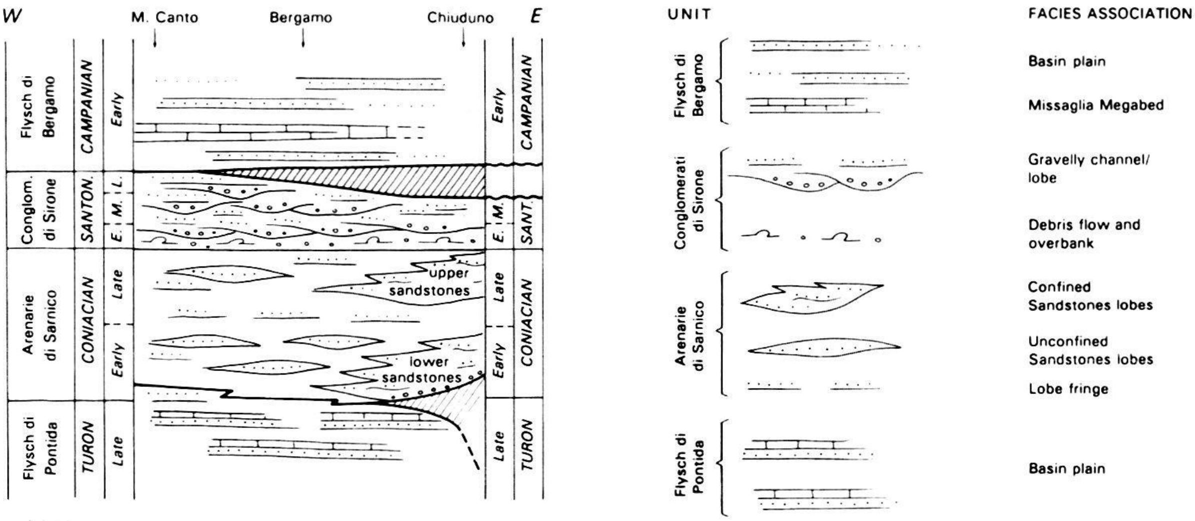

Fig. 8. Chronostratigraphic correlation scheme of the Coniacian – Santonian succession. The major facies associations have been reported. Hiatuses are represented by oblique hachure.

Proximal area

The proximal area is located to the east, in the Lake Iseo region. The lower boundary of the Arenarie di Sarnico is an erosional surface progressively downcutting the Flysch di Colle Cedrina and Flysch di Pontida and characterized by the presence of conglomerate lenses embedded in reddish chaotic calcilutites, up to 20 meter thick. In the conglomerate, pebbles of quartz, chert, metamorphic and volcanic rocks are found. In the easternmost outcrop (M. S. Onofrio, Fig. 2) the Arenarie di Sarnico overlie with an angular unconformity an Upper Cenomanian succession consisting of calcareous turbidites, hemipelagites and slumps.

In the proximal area both depocentral and marginal depositional features are preserved. The depocentral succession is characterized by two thick sandstone intervals, both more than 50 meters thick, present at the base and at the top of the unit (Lower and Upper Sandstone bodies in figure 9). These bodies are composed of medium- to coarse-grained turbidites, organized in stacked, amalgamated sandstone packages. The Lower Sandstone directly overlies the basal conglomerate. The two sandstone bodies, which are separated by thin- to medium-bedded turbidites with scattered thick amalgamated beds, about 10 m thick, are interpreted as depositional lobes.

Moving northwards the sandstone bodies are replaced by alternating plane and parallel-bedded turbidites and amalgamated sandstone beds. The transition between basinal and marginal facies occurs within about 5 kilometers.

Distal area

In the distal area, located to the West in the Brianza region, both the lower and the upper boundary of the Arenarie di Sarnico are transitional, without any erosional surfaces at the base of the unit (Fig. 8). In the western paleogeographic domains there are no evidences of nearby structural margins. There the formation consists of several coarsening-upward cycles, about 20 meters thick, enclosed into acyclic thin-/medium-bedded turbidites. In the M. Canto area these cycles characterize lens-shaped bodies, about 1000 meters wide, which are interpreted as depositional lobes, surrounded by acyclic lobe fringe deposits (Fig. 8).

In the westernmost sector (Brianza), thick marly sandstone beds interfinger with the thin-/medium-bedded succession typical of the area. The thick sandstone beds show paleocurrent directions from NW, contrasting with the general eastern provenance and documenting that the Sarnico turbidite system, in its distal setting, was probably fed from different sources.

Early Coniacian unconformity

This unconformity is highlighted by the sharp lower boundary of the Arenarie di Sarnico in the Iseo area. There, the basal lag conglomerate identifies the local depocentre (Fig. 9) and is related to the erosional surface cutting down the Flysch di Colle Cedrina and the Cenomanian units at Monte S. Onofrio. Moving northwards, the progressive facies variation at the base of the Arenarie di Sarnico, from amalgamated sandstone packages to even-bedded turbidites, is interpreted as due to the onlap of the turbidite system above the uplifted margin (Fig. 9).

Conglomerati di Sirone

The Conglomerati di Sirone unit is a basinwide coarse-grained turbidite system, consisting of conglomerates, sandstones and pebbly sandstones facies. The lower boundary with the Arenarie di Sarnico is transitional and conformable (Fig. 8). It is represented by an interval, about 30 meters thick, of thin bedded turbidites with pebbly mudstones and slumps (Bichsel & Häring 1981, Fornaciari et al. 1988).

The boundary with the Campanian Flysch di Bergamo is transitional in the western area with an overall fining upward trend from conglomerate deposits to thin-/medium-bedded turbidites of the younger sequence. In the eastern area this boundary is sharp and unconformable with a hiatus spanning the Middle p. p. Santonian to Early Campanian (Fig. 8) (Erba, in Bersezio et al. 1992).

Sandstone composition is quartzo-lithic (Q=57 F=3 L=40), quite similar to that of the underlying Arenarie di Sarnico. Conglomerate pebbles derived from the erosion of metamorphic and sedimentary units of Austro-Southalpine affinity (Venzo 1954, Bichsel & Häring 1981). The Rudist fragments of Santonian age that are typically found in the formation (De Alessandri 1898, quoted by Venzo 1954), derive from Santonian reworking of platform/shelf materials, as documented by the coeval calcareous nannofossil association (Erba, in Bersezio et al. 1992) of the hemipelagic marls and shales interbedded with conglomerates.

Depositional features

The Sirone turbidite system is about 200 meters thick in the western region and thins eastwards to about 80 m, most probably owing to the presence of the upper unconformable boundary. In spite of this reduction, the facies associations do not change from east to west.

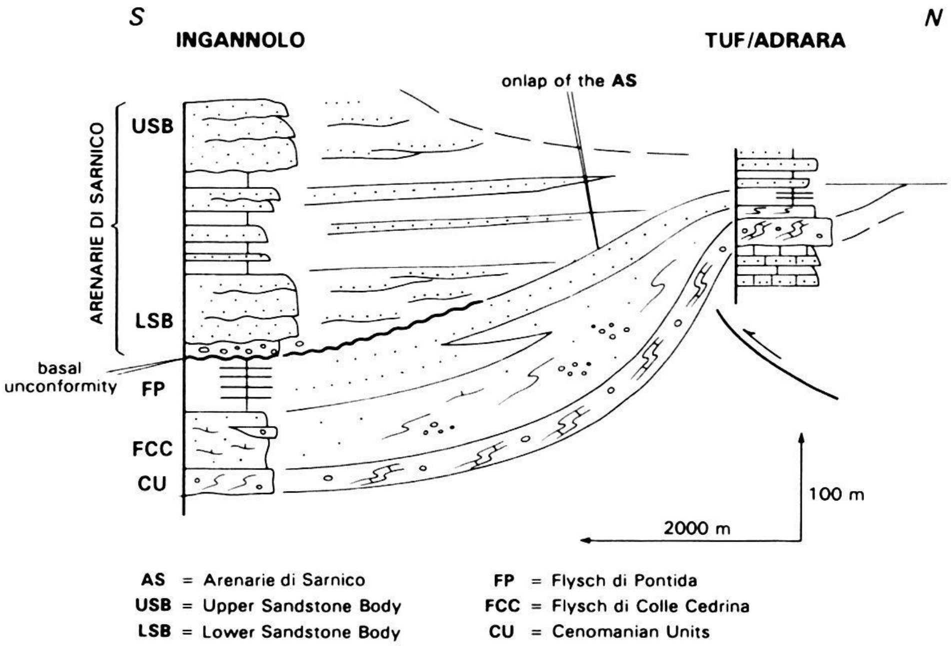

Fig. 9. Lithostratigraphic scheme of the proximal part of the Coniacian succession and interpretation of the relations with the Turonian units. Redrawn and modified after Bersezio et al. 1992.

Paleocurrent directions, deduced from flute cast measurements, arrangement of pebble clusters and depositional geometries indicate a northern and northeastern provenance and a progressive deflection of the gravity flows along an E/W axis towards the basinal area. The overall northern provenance can explain the facies uniformity between the eastern and western area, the outcrop belt showing a section nearly perpendicular to the clastic supply.

The depositional pattern is dominated by fining-upward cycles representing lenticular channelized bodies cross-cutting each other (Häring 1978, Bichsel & Häring 1981). Coarsening-upward cycles may laterally replace the fining-upward cycles.

In the western area, conglomerate facies are commonly more developed at the bottom and at the top of the unit. Debris flow deposits, as thick as 20 meters, are typically found in the lower section of the unit (Fornaciari et al. 1988). Massive and amalgamated sandstone beds, very similar to the Arenarie di Sarnico, are often associated with the conglomerates. Fine-grained overbank deposits laterally fringe the coarse-grained channelized bodies (Fig. 8).

The facies association of the Conglomerati di Sirone is interpreted as typical of a turbidite system characterized by channels with physically attached lobes (Fig. 8). On the whole the unit resembles a type 2 turbidite system of Mutti 1985.

Campanian unit

Flysch di Bergamo

The Campanian unit is essentially represented by a turbidite system, known as Flysch di Bergamo (Gelati & Passeri 1967). In the western area, the Conglomerati di Sirone – Flysch di Bergamo conformable boundary (Fig. 8), is marked by the sharp change of the sandstone composition, from quartzo-lithic to more feldspatic arenites (Q=56 F=19 L=25). The upper formational boundary, with the Maastrichtian Piano di Brenno, as exposed in the western area, is transitional.

Depositional features

The Flysch di Bergamo is characterized by different facies associations in the western and eastern areas. To the west (Brianza), where the unit is about 700 meter thick, the succession consists of acyclic, thin/medium and parallel-bedded, siliciclastic turbidites and marls.

Scattered coarsening upward cycles representing sandstone lobes, are enclosed in the acyclic succession. A calcareous megabed, up to 15 meter thick, (Missaglia megabed, Bernoulli et al. 1981) is present in the lower part of the unit in the whole western area. It thins and disappears eastwards, in any case being recognizable until the Cherio river. At the top of the unit, underlying the transition to the Piano di Brenno Formation, channelized conglomerate lenses occur.

The eastern sector (Iseo area) is characterized by siliciclastic and mixed turbidites, with calcareous bioclasts and quartzo-feldspatic grains (Pietra di Credaro, Gelati & Passeri 1967). Thick calcareous beds with conglomerates at the base are common in the lower part of the unit. Pebbles derived from the typical South-Austroalpine sequences, with abundant oolitic limestones. In the eastern area coarsening-upward cycles, representing depositional lobes, are typically found and can be as thick as 30 meters.

Early Campanian unconformity

The boundary between the Flysch di Bergamo and the Conglomerati di Sirone is unconformable in the eastern area (Fig. 3, 8). Such a boundary is characterized by the sharp contact of the even-bedded whitish turbidites of the Flysch di Bergamo over a debris flow at the top of the older unit, with pebbles of "Sirone" composition enclosed into a matrix of reddish marls. Biostratigraphic data (Erba & Fornaciari 1988, E. Erba in Bersezio et al. 1992) indicate a Middle Santonian age for the reddish marls and an Early Campanian age for the overlaying Flysch di Bergamo. The same hiatus, characterizing the unconformable lower boundary of the Flysch di Bergamo is found in the Bergamo hill (E. Erba in Bersezio et al. 1992).

The Upper Cretaceous sequences

The major unconformities, that have been previously introduced (namely the Berriasian-Albian, the Early-Middle Cenomanian, the Turonian, The Early Coniacian and the Early Campanian unconformities), frame five sedimentary units consisting of at least one "Longitudinal", siliciclastic, turbiditic lithosome, associated with hemipelagic sediments and turbiditic or chaotic, intrabasinal deposits, arranged perpendicularly to the basin elongation. The unconformities have been shown to correlate with the base of the turbiditic intervals and/or hemipelagic facies in the conformable successions, therefore representing basin-wide recognizable surfaces.

The sequences delimited by these boundaries represent genetically-linked sediment packages, that document variations of basin physiography, clastic input, sedimentation and subsidence rates. We named these sequences according to their age.

- The *Aptian-Albian sequence* consists of the transitional unit between Maiolica and Marne di Bruntino (pelagic turbidites), the Marne di Bruntino and the Sass de la Luna.
- The *Cenomanian sequence* consists of the Marne Rosse, Chaotic megabeds and Torbiditi Sottili. To the east of Lake Iseo, some 40 km west of the Garda escarpment (Castellarin 1972), the Cenomanian sequence consists of a thinner and monotonous sequence of grey/red marlstones (Aubouin et al. 1970, Bichsel & Haering 1981), bounded at the top by an unconformity overlain by Lower Campanian marlstones and lenticular sandstones (Scaglia Rossa p. p.).
- The *Turonian sequence* comprises Peliti Nere Superiori, Peliti Rosse, Flysch di Pontida and Flysch di Colle Cedrina. The Turonian deposits of the northern thrusts (M. Misma and Albenza areas) probably belong to the same sequence.
- The *Coniacian-Santonian sequence* is essentialy made up by the longitudinal turbidite system of the Arenarie di Sarnico and by the margin-supplied coarse-grained turbidite system of the Conglomerati di Sirone.
- The *Campanian sequence* comprises the Flysch di Bergamo and Pietra di Credaro, with the interbedded Missaglia megabed.

The stratigraphic architecture and sediment composition of these five Upper Cretaceous stratigraphic units, indicate that they developed, during time intervals at least 3 Ma long, as a response to synsedimentary tectonic activity that affected the basin margins and to variations of sediment supply. The latter was determined mostly by the tectonic evolution of the source areas. For these reasons, in our opinion, the Cretaceous sequences of the Lombardy Basin are comparable to the rank of supercycles of the sequence stratigraphic model (Haq et al. 1988, with references therein), representing tectonically-induced (super)sequences.

Geometry and evolution of the Late Cretaceous Lombardy Basin

Aptian – Albian

The pre-Aptian configuration of the Lombardy Basin still resembled the Jurassic extensional setting, with sub-basins separated by intrabasinal structural highs (Weissert 1981).

The transition from carbonate to turbiditic siliciclastic sedimentation occurred during the late Barremian to Aptian time, and was preceded by the deposition of pelagic turbidites in the conformable successions (lower part of the Aptian-Albian sequence), the development of paraconformities in the basinal settings and the development of erosional truncations in the marginal ones.

Starting from the Aptian-Albian boundary (upper part of the Aptian – Albian sequence), siliciclastic turbidites began to enter the basin from the E and NE (MB2 lithozone), spreading and thinning out towards the S and W. The unconformity underlying this turbidite body and the associated lenticular conglomerates and slumps suggest that a slope, marginal to the basin, could be present to the north.

The deposition of siliciclastic turbidites finished during the Middle Albian and was followed by pelagic-hemipelagic sedimentation, subsequently replaced by deposition of pelagic turbidites, during the Late Albian (Sass de la Luna, SL). As a consequence of provenance from S and SE, the Upper Albian turbidites covered the older turbidite system almost perpendicularly, with a southward shift of the depocenter and a resulting distal downlap geometry towards the N, where the upper Albian thinner successions overlie the older siliciclastic turbidites (Fig. 10).

Important features of the SL turbidite body are the impressively high sedimentation rate, the high frequence of turbiditic events and the recurrent presence of megabeds and intraclastic pebbly mudstones. Triggering of the gravitational slope failures by enhanced seismic activity provides a feasible explanation of these features.

Concerning the source area, some pelagic reliefs that could have been located to the S of the SL basin are well known in the buried thrusts of Monza and Malossa (Po plain subsurface, Errico et al. 1979, Pieri & Groppi 1981), where the Albian succession is represented by a thin drape of pelagic foraminiferal-radiolarian oozes, that overlie the reduced successions of older structural highs. Therefore it is suggested that Late Albian synsedimentary tectonic activity affected the southern source area of the SL, possibly represented by structures similar to the Monza and Malossa paleohighs, during a time of relative sea-level rise and highstand, the latter responsible for the stop of siliciclastic input and widening of the areas subjected to deposition of pelagic sediments.

Cenomanian

From the Cenomanian the E-W elongation and a northern margin to the basin can be definitely identified. In fact, the Cenomanian and Turonian longitudinal turbidite systems are preserved in those outcrops that belong to the present-day central sector of the Adda and Bergamo-Zandobbio anticlines. On the contrary, in the northern thrusts along the Flessura Pedemontana, the longitudinal turbidite bodies wedge out and/or interfinger with intrabasinal turbidites and chaotic deposits. The unconformities that frame the Cenomanian and Turonian (super)sequences, progressively develop towards the same areas, that are therefore characterized by erosional truncations and incomplete/unconformable success-

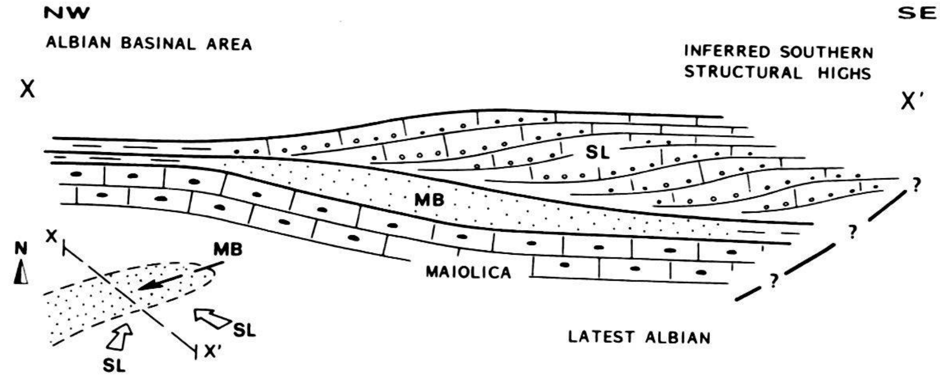

Fig. 10. Interpretative cross-section of the depositional geometry of the Aptian – Albian sequence. Not to scale. MB: Marne di Bruntino; SL: Sass de la Luna. Paleocurrent trends are schematized in the lower left.

ions. By these features the northern and eastern outcrops are interpreted as fragments of the Cenomanian-Turonian margins of the Lombardy Basin. The eastern end of the basin is preserved in the region east of Lake Iseo (M. Peso area, Fig. 3), where only thin hemipelagic deposits, with Scaglia-like facies are present. More eastwards, along the Garda escarpment tectonic system, an extensional/transtensional tectonic activity has been documented during the Upper Cretaceous by Castellarin et al. 1987.

During the Cenomanian, the northern marginal area is characterized by unconformable sedimentation of middle to upper Cenomanian pebbly mudstones and chaotic deposits, that overlay the Albian basinal successions. The chaotic megabeds have a wide E-W distribution in the Bergamo Prealps. Similar deposits are present also in the Varese area (Aubouin et al. 1970, Bichsel & Häring 1981), suggesting a prolongation of the marginal slope also there. The facies variations of the chaotic deposits, that contain clasts and blocks of Albian marlstones and pelagic turbidites (Sass de la Luna), indicate provenance from the N (Bersezio & Fornaciari 1988b). These facts suggest that a northern Albian basinal domain was uplifted during the Cenomanian, becoming part of the basin margin.

Turonian

In all the western area of the Lombardy Basin the Turonian succession is complete and shows transitional contacts with the bounding sequences. This area represents the Turonian basinal setting (Fig. 7). To the east of the Serio River and in particular in the northern outcrops, the facies variations are accompanied by the progressive development of the Turonian unconformity. This area represents the marginal setting which was affected by syndepositional tectonic mobility (Fig. 7). Thus the margin development can be considered a continuous process starting from the Middle Cenomanian, active through all the Turonian and recognizable up to the Early Campanian.

The general architecture of the Turonian sequence consists of anoxic pelagic deposits in the deepest part of the basin followed upsection by two stacked, E/W-elongated turbidite systems. Both of them are interfingered with massive failure deposits slumped from the northern margin. In fact, the Middle Turonian Peliti Rosse enclose a calcareous chaotic megabed similar to the Cenomanian ones (Fig. 6, section 2). The exclusively intrabasinal composition of this layer proves that no terrigenous sediments deposited on the slope until the Middle Turonian. Subsequently tongues of longitudinal turbidites of the Flysch di Pontida interfingered with and partly covered the base-of-slope deposits, represented by the Flysch di Colle Cedrina, consisting of mixed extrabasinal and pelagic sediments.

The geometries of the Turonian succession give some insights about the type of syndepositional tectonic activity. The most striking feature is the progressive onlap of younger and younger units above the northeastern margin. This depositional pattern is consistent with a progressive uplifting due to upfolding of the margin itself. Considering the Adrara area, where the Turonian sequence is missing and the Cenomanian one is severely reduced, at least 700 meters of vertical uplift along the basin margin can be calculated for the Cenomanian – Turonian time span.

The sedimentary features and geometries of the Cenomanian and Turonian sequences suggest upfolding to the north. Nonetheless it can be speculated whether the same features could be attributed to the alternative mechanism of normal faulting, in an extensional/transtensional regime. In this hypothesis one should expect the heterochronous emplacement of lenticular breccia bodies, related to fault scarps, more than the emplacement of basinwide chaotic megabeds. Moreover the erosional truncations related to steep fault scarps would have deeply incised the footwalls, reaching the succession below the Cretaceous units, thus resulting in a different composition and distribution, and greatest compositional heterogeneity of the mass gravity deposits, different configuration of unconformities and different shape of the turbidite wedges and of their lateral termination. At last, the redeposition of the Upper Albian bathyal sediments in an equally bathyal Cenomanian environment could hardly be explained by normal faulting.

This speculation is supported by the examples of extensional and transtensional basin margins, that are available for instance in the previous geological history of the Lombardy Basin (see for ex. Bernoulli et al. 1992, Castellarin 1972, Gaetani 1975, Winterer & Bosellini 1981). The Upper Cretaceous extensional geometries that have been demonstrated by Castellarin (1972) and Castellarin et al. (1987) along the boundary between the Trento Plateau and Lombardy Basin also contrast with the general architecture of the Upper Cretaceous Flysch.

Taking into account the provenance and compositional data, it can be concluded that the observed sedimentary geometries can best be explained by upfolding of the marginal domain, most likely due to the southwards or south-eastwards propagation of submarine thrust fronts, related to the emplacement of basement-involving thrusts to the north of the present Orobic thrust.

Coniacian – Santonian

The eastern sector (Iseo area) of the Arenarie di Sarnico (previously mentioned as "proximal" area) is interpreted as the infilling of a confined basin whose northern margin (Adrara area) had been tectonically uplifted (Fig. 9). On the other hand the southern edge of this basin seems not to be preserved in outcrops. In fact it is impossible to state whether the unconformable succession of Capriolo – M. S. Onofrio (Fig. 3, section II) where the Arenarie di Sarnico overlay Cenomanian base-of-slope deposits (Bersezio & Mensini 1992), represents the deepest part of the Sarnico basal erosional surface or the southern uplifted margin of the basin. In any case, the turbidite sandstones did not reach the Brescia area to the east where the Coniacian succession consists of a condensed section, a few meter thick, of reddish marls with lenticular turbidite beds (Aubouin et al. 1970). The orientation of the Sarnico "proximal" basin, as can be deduced by the stratigraphic data and the previous discussion, is about ENE/WSW in present-day coordinates. This trend more or less coincides with the orientation of a regional thrust fault (Val Trompia Line) emerging just to the northeast of the Iseo area.

The available outcrop belt does not allow to connect the Sarnico turbidite system with the Senonian turbidites preserved in the Giudicarie area, that were probably supplied from an eastern Austroalpine hinterland (Castellarin 1976), or to recognize, by contrast, a more local hinterland source area for the Arenarie di Sarnico. Moving downcurrent, the western Brianza region represents the unconfined basinal area for this turbidite system.

The boundary between the Arenarie di Sarnico and Conglomerati di Sirone turbidite systems is typically characterized by an interval ranging from 20 to 80 m in thickness with debris flow deposits and thin bedded turbidites. This interval can be interpreted as the product of slope failures at the margin of a northern shelf.

While the Sarnico turbidite system prograded from the East, the Sirone turbidite system was supplied from the north. Facies and thickness distributions suggest that a major feeder system was located in the Brianza region. Paleocurrent measurements and the homogeneity of facies association both in the western and in the eastern area, indicate that the unit might be formed by the coalescence of distinct turbidite systems forming a sort of apron to the northern slope (Fig. 11).

Campanian

The Campanian sequence is probably formed by the coalescence of turbidite systems, fed from the north and spreading along the E/W axis of the basin. At least two main units can be recognized. The first one, mainly siliciclastic, characterizes the western area. The second one was deposited in the eastern area where mixed siliciclastic and carbonate deposits occur. Facies associations indicate acyclic basinal deposition with scattered depositional lobes for both systems, that therefore developed in a rather uniform and unconfined depositional environment.

The Campanian turbidite system is laterally persistent, extending westwards as far as the Varese (Aubouin et al. 1970, Bichsel & Häring 1981) and Mendrisio area (Bernoulli et al. 1987). On the other hand the Campanian turbidite system is not present in the «Bresciano» region to the east and southwards, in the Malossa subsurface succession (Errico et al. 1979).

The model for the Campanian sequence in the western Brianza area has been discussed by Kleboth (1982). Unfortunately remnants of the original marginal setting or feeder system are not preserved so it is not possible to define the regional geometry for this sequence.

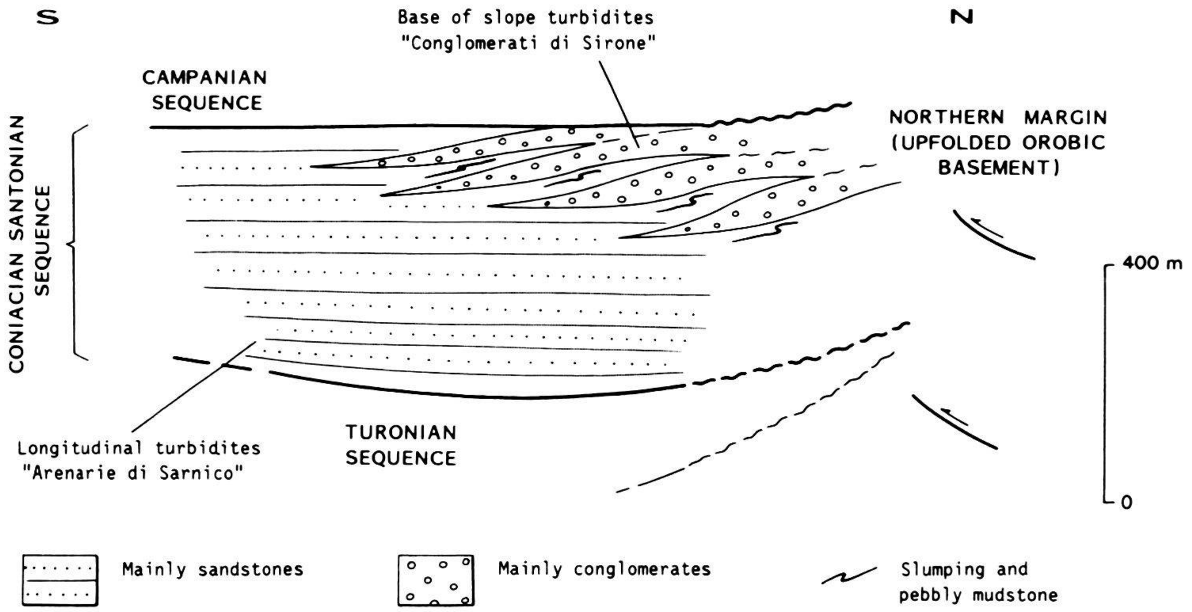

Fig. 11. Interpretative lithostratigraphic scheme of the Coniacian – Santonian succession. Not to scale.

Relationships with the Cretaceous Alpine orogeny

The close relationships between the Cretaceous alpine orogeny and the deposition of turbidite sequences through the Lombardy Basin have been hypothesized since the older works (De Sitter & De Sitter Koomans 1949; Venzo 1954, Aubouin et al. 1970), and have been stressed by the more recent interpretations (Castellarin 1976, Bichsel & Häring 1981, Gelati et al. 1982, Bernoulli et al. 1981, Doglioni & Bosellini 1987, Bernoulli et al. 1990, Polino et al. 1990, Massari & Medizza 1973, Massari 1990). Nevertheless, if there is a general agreement on the existence of a Late Cretaceous tectonic activity in the area of the future Southern Alps, and the alpine feeding of the Lombardian "flysch" is not questioned, the tectonic scenario for the Southalpine side of the Cretaceous orogeny is so far unclear.

The sketch in figure 12 summarizes the timing of Cretaceous tectonic events in the structural domains that most likely played a role in the evolution of the Southalpine "flysch". The reconstruction presented here suggests that, starting from the Cenomanian, the Lombardy Basin began to evolve like an asymmetric foredeep, with a steeper marginal slope to the N and NE, whose progressive upfolding is documented up to the Coniacian and with a more gentle southern relief, possibly linked to rising of a southernmost bulge (Doglioni & Bosellini 1987). This reconstruction does not contradict the well documented evolution of the inherited boundary between the Lombardy Basin and the Trento plateau more to the east (Castellarin 1976, Castellarin et al. 1987).

During Cenomanian and Turonian times, the northern tectonically active margin of the basin supplied intrabasinal resediments that interfingered with the longitudinal depositional systems. Since the unconformities that frame the Cretaceous sequences point to the progressive growth of the basin margins up to the Coniacian, and their development corresponds to, or is closely followed by the progradation of an extrabasinal, longitudinal, turbidite system, it can be concluded that the production of major unconformities within the Late Cretaceous Lombardy Basin was relatively synchronous with the tectonic acmes in the source areas.

Turbidites entered the Lombardy Basin from different and separate feeding points, that were active in different times. Provenance from the north s. l., i. e. from erosion of high grade metamorphic basement, volcanites and minor sedimentary units most probably located in the western Southalpine domain, has been documented for the Early – Middle Turonian and the Campanian. It results in the petrographic signature of the Peliti Rosse, the coeval coarse-grained turbidites of the Albenza and M. Misma feeding points, the Flysch di Bergamo and Pietra di Credaro (Fig. 13). The uplift and erosion of the western Southalpine and Orobic-like source areas were reflected by the activation of the feeding points of the Albenza and M. Misma areas, during the Early-Middle Turonian, and in general by input from the north during the Santonian and Campanian. These peaks of tectonic activity determined the contemporaneous mobility and uplift of the margins of the Lombardy Basin.

A coeval tectonic activity is recorded in the Austroalpine nappes of Eastern Switzerland, where evidences for Late Cretaceous (Turonian?) westward thrusting, in the present-day coordinates, followed by latest Cretaceous to early Tertiary post-nappe extension, have been presented (Schmid & Haas 1989; Froitzheim 1992).

During Late Turonian to Late Coniacian time, provenance from a more eastern source area, characterized by prevalent erosion of sedimentary units and lower grade

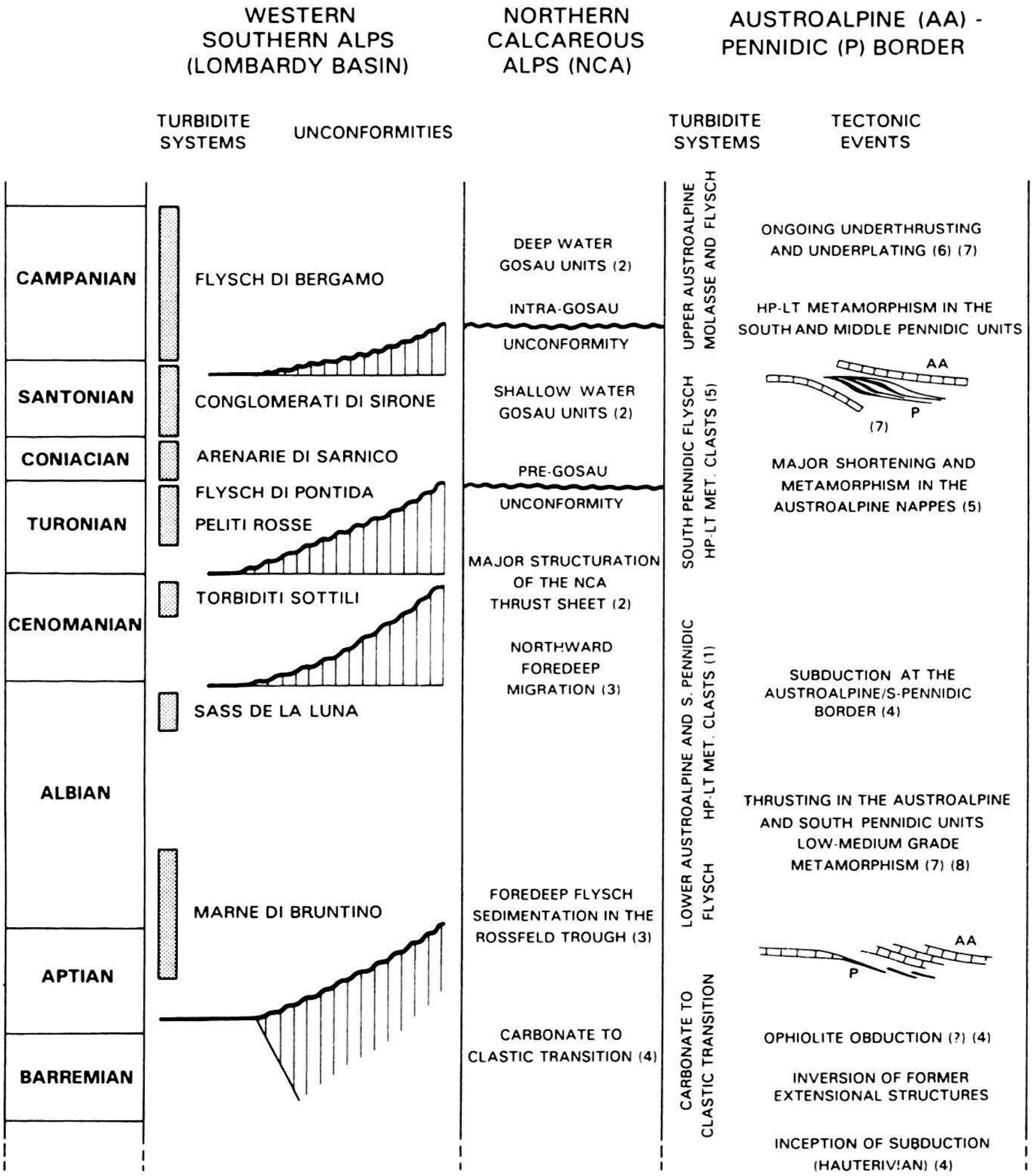

Fig. 12. Comparison between the depositional features of the Cretaceous sequences of the Lombardy Basin and the sedimentary and geodynamic evolution of the Eastern/Southern Alps. References: Winkler & Bernoulli 1986 (1), Flügel et al. 1987 (2), Decker et al. 1987 (3), Winkler 1988 (4), Bernoulli & Winkler 1990 (5), Polino et al. 1990 (6), Ring 1992 (7), Thöni 1983 (8).

metamorphics, again with South- and Austroalpine affinity, determined the composition of the Flysch di Pontida and Arenarie di Sarnico (Fig. 13), in agreement with the heavy mineral assemblage determined by Bernoulli & Winkler (1990). The progradation of the two turbidite systems closely followed the peaks of uplift in the eastern Austroalpine domain (Bernoulli & Winkler 1990) (Fig. 12). By contrast the Conglomerati di Sirone document erosion of a northern hinterland domain, probably close to the basin margin and characterized by the existence of Santonian shelf marginal rudist-reefs.

The interfingering of the Flysch di Pontida both with part of the clastic units fed by the northern feeder points, and with the slope resediments supplied by marginal collapses (Turonian chaotic megabeds, Flysch di Colle Cedrina), and the stratigraphic relationships between the Arenarie di Sarnico and the Conglomerati di Sirone, confirm the relative synchronism of the deformation and uplift of the different source areas and the tectonic mobility through the site of deposition.

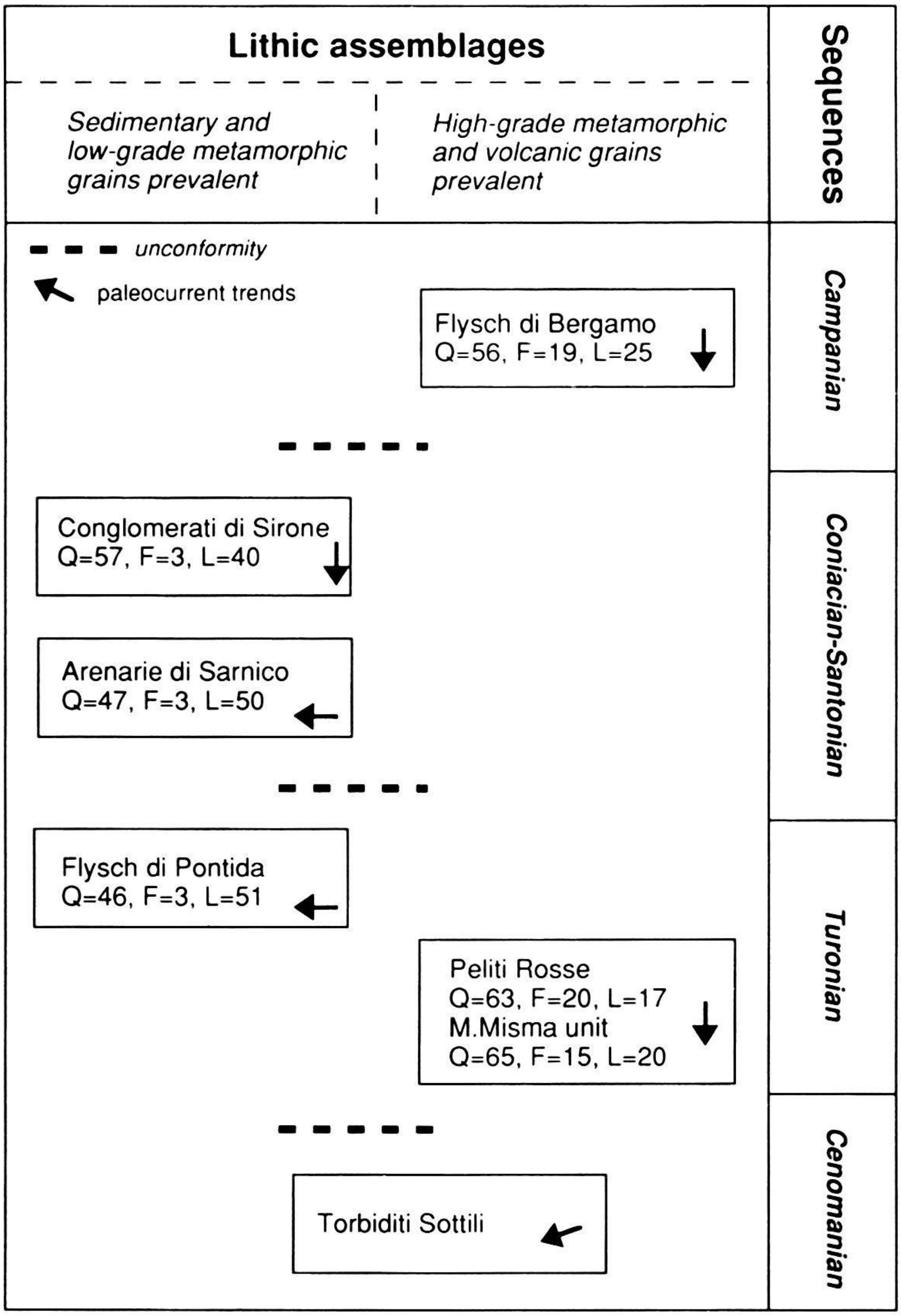

Fig. 13. Composition of arenites, of the Cenomanian – Campanian turbidite systems.

Conclusions

1) The five major stratigraphic units that deposited from the Aptian to the Campanian in the Lombardy Basin, record the relatively synchronous tectonic history of the Austroalpine/Southalpine source areas and of the northern and eastern margins of the basin itself. The unconformities that bound these sequences developed progressively during different stages of growth of the marginal slopes. The sequences are characterized by the deposition of a main longitudinal turbidite system, covered by, and/or interfingering with slope resediments and chaotic deposits fed by the basin margin.
2) Compositional and/or paleocurrent data and facies trends allow to discriminate between different source areas for the Middle Turonian, Santonian and Campanian turbiditic units, mostly fed by the north and north-west, vs. the Upper Cenomanian, Upper Turonian and Coniacian longitudinal, westward prograding units. The former depositional systems (Peliti Rosse, Turonian units of the Albenza and M. Misma areas, Conglomerati di Sirone, Flysch di Bergamo) mirror the deformation of the Cretaceous western Southalpine domain. In this area, tectonic units involving basement slices characterized by contrasting post-Variscan metamorphic gradients (Diella et al. 1992) could have been already exposed to erosion. The latter units (Torbiditi Sottili, Flysch di Pontida, Arenarie di Sarnico) document the evolution of a more eastern and northern Austroalpine/South Penninic domain (Bernoulli & Winkler 1990).
3) A comparison of the Cretaceous tectono-stratigraphic events in the Central – Eastern Alps with the corresponding framework of the Lombardy Basin, documents the link between the activity of the Late Cretaceous orogenic wedge (Polino et al. 1990) and the deformation and uplift events in the domain of the future Southern Alps. The inferred emplacement of a Cretaceous Southalpine fold and thrust belt (Doglioni & Bosellini 1987) or at least of minor *décollment* nappes (Bernoulli & Winkler 1990) is supported by the stratigraphic features of the Cretaceous sequences of the Lombardy Basin, that can therefore represent the foreland basin developed in the back of the orogenic wedge (Polino et al. 1990, Ring 1992).
   The development of the Cenomanian-Turonian and, later on, of the Campanian turbidite units, marks the principal Late Cretaceous tectonic events that occurred in the Southalpine domain, adjacent to the Lombardy Basin. Between these two periods of tectonic acme, the Upper Turonian and Coniacian turbidite systems prograded through the basin, most likely controlled by the tectonic activity affecting their eastern Austroalpine source area.
4) The local tectonic control on the architecture of the depositional systems is superimposed to the variations of sediment supply. For this reason the five Cretaceous stratigraphic units of the Lombardy Basin represent tectonically-induced sequences, comparable to the tectonic supercycles of the sequence stratigraphy model.

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REFERENCES

ALVAREZ V., COLACICCHI R. & MONTANARI A. 1985: Synsedimentary slides and bedding formation in Apennine pelagic limestones. J. sediment. Petrol. 3, 720–734.

ARTHUR M.A. & PREMOLI SILVA I. 1982: Development of widespread organic carbon-rich strata in the Mediterranean Tethys. In: Nature and Origin of Cretaceous Carbon Rich Facies (Ed. by S.O. SCHLANGER & M.B. CITA), Academic Press, London 7–54.

AUBOUIN J., SIGAL J., BERLAND J.P., BLANCHET R., BONNEAU M., CADET J.P., GUILLOT P.L., LACOUR A., PIAT B. & VICENTE J.C. 1970: Sur un bassin de flysch: stratigraphie et paléogéographie des flyschs crétacés de la Lombardie (versant sud des Alpes orientales, Italie). Bull. Soc. géol. France (7) 12, 4, 612–658.

BARBERIS A., FOSSATI S., BERSEZIO R. & ERBA E. 1992: Lithostratigraphy and biostratigraphy of the Maiolica Formation from the Lombardy Basin (Southern Alps). Mem. Soc. geol. ital. 45, 111–117.

BARNES P.M. & LEWIS K.B. 1991: Sheet slides and rotational failures on a convergent margin: the Kidnappers Slide, New Zealand. Sedimentology 38, 205–221.

BERNOULLI D. & WINKLER W. 1990: Heavy mineral assemblages from South- and Austroalpine Flysch sequences (Northern Italy and Southern Switzerland): source terrains and palaeotectonic implications. Eclogae geol. Helv. 83, 287–310.

BERNOULLI D., CARON C., HOMEWOOD P., KÄLIN O. & VAN STUIJVENBERG J. 1979: Evolution of continental margins in the Alps. Schweiz. mineral. petrogr. Mitt. 59, 165–170.

BERNOULLI D., BICHSEL M., BOLLI H.M., HÄRING M.O., HOCHULI P.A. & KLEBOTH P. 1981: The Missaglia Megabed, a catastrophic deposit in the Upper Cretaceous Bergamo Flysch, Northern Italy. Eclogae geol. Helv. 74, 421–442.

BERNOULLI D., BECKMANN J.D., BOLLI H.M. & GUNZENHAUSER B.A. 1987: Upper Cretaceous deep water sediments near Prella (Southern Alps, Mendrisiotto, Switzerland). Mem. Sci. geol. (Padova) 39, 49–71.

BERNOULLI D., BERTOTTI G. & ZINGG A. 1989: Northward thrusting of the Gonfolite Lombarda (South Alpine Molasse) onto the Mesozoic sequence of the Lombardian Alps: implications for the deformation history of the Southern Alps. Eclogae geol. Helv. 82, 841–856.

BERNOULLI D., HEITZMANN P. & ZINGG A. 1990: Central and Southern Alps in southern Switzerland. Tectonic evolution and first results of reflection seismics. Mém. Soc. géol. France, 156; Mém. Soc. géol suisse, 1: Mem. Soc. geol. ital. Vol. spec. 1, 289–303.

BERNOULLI D., BERTOTTI G. & FROITZHEIM N. 1992: Mesozoic faults and associated sediments in the Austroalpine-Southalpine passive continental margin. Mem. Soc. geol. ital. 45, 25–38.

BERSEZIO R. 1992: La successione Aptiano – Albiana del Bacino Lombardo. G. Geol. Bologna (3) 54, 125–146.

BERSEZIO R. & FORNACIARI M. 1987: Cretaceous sequences in the Lombardy Basin: stratigraphic outline between the lakes of Lecco and Iseo. Mem. Soc. geol. ital. 40, 187–197.

– 1988a: Geometria e caratteri stratigrafici della sequenza Cenomaniana nel Bacino Lombardo (Alpi Meridionali). Riv. ital. Paleont. Strat. Milano 94/3, 425–454.

– 1988b: Tectonic framework of the Lombardy foothills (Southern Alps), between Brianza and Lake Iseo. Rend. Soc. geol. ital. 11, 75–78.

BERSEZIO R. & MENSINI L. 1992: Le relazioni tra le Arenarie di Sarnico (Coniaciano) e le unità cenomaniano-turoniane nell'area di Capriolo – Corno Pendita (BS) (Bacino Lombardo, Alpi Meridionali). Riv. ital. Paleont. Strat. 98, 45–60.

BERSEZIO R., ERBA E. & FORNACIARI M. 1989: The Barremian-Turonian erosional unconformity in the M. Misma area (Bergamo, Southern Alps). Riv. ital. Paleont. Strat. Milano 94, 619–630.

BERSEZIO R., FORNACIARI M. & GELATI R. 1992: Geologic Map of the Southalpine foothills between Brianza and Iseo Lake. Mem. Soc. geol. ital. 45, 107–110.

BICHSEL M. & HÄRING M. 1981: Facies evolution of Late Cretaceous Flysch in Lombardy. Eclogae geol. Helv. 74, 383–420.
BRACK P. 1981: Structures in the southwestern border of the Adamello intrusion (Alpi Bresciane, Italy). Schweiz. mineral. petrogr. Mitt. 61, 37–50.
CASSANO E., ANELLI F., FICHERA R. & CAPPELLI V. 1986: Pianura Padana, interpretazione integrata di dati geofisici e geologici. AGIP, 73° Congresso Soc. Geol. Ital. Roma, S. Donato Milanese.
CASTELLARIN A. 1972: Evoluzione paleotettonica sinsedimentaria del limite tra piattaforma veneta e bacino lombardo, a nord di Riva del Garda. G. Geol. Bologna (2) 1, 1–171.
– 1976: Ipotesi paleogeografica sul bacino del Flysch Sudalpino Cretacico. Boll. Soc. geol. ital. 95, 501–511.
CASTELLARIN A., FESCE A., PICCOTTI V., PINI A., PROSSER G., SARTORI R., SELLI L., CANTELLI L., & RICCI R. 1987: Structural and kinematic analysis of the Giudicarie deformation belt. Implications for compressional tectonics of Southern Alps. Mineral. Petrogr. Acta, Bologna 30, 287–310.
CHANNEL J., D'ARGENIO B. & HORVATH F. 1979: Adria, the African promontory in the Mesozoic Mediterranean paleogeography. Earth Sci. Rev. 15, 213–292.
COOK H. & MULLINS H. 1983: Basin margin environments. In: Carbonate Depositional Environments (Ed. by SCHOLLE P.A., BEBOUT D.G. & MOORE H.). Amer. Assoc. Petrol. Geol. 33, 540–617.
DECKER K., FAUPL P. & MÜLLER A. 1987: Synorogenic sedimentation on the Northern Calcareous Alps during the Early Cretaceous. In: Geodynamics of Eastern Alps (Ed. by H.W. FLÜGEL and P. FAUPL), Deuticke, Wien, 126–141.
DE ROSA E. & RIZZINI A. 1967: Prealpi Flysch near Bergamo. In: Sedimentological characteristics of some italian turbidites. (Ed. by A. ANGELUCCI). Geol. romana 6, 356–362.
DESIO A. 1929: Studi geologici sulla regione dell'Albenza (Prealpi Bergamasche). Mem. Soc. Ital. Sci. nat., Mus. civico – Milano 10, 1–156.
DE SITTER L.U. & DE SITTER KOOMANS C.M. 1949: The geology of the Bergamasc Alps (Lombardia, Italy). Leidse Geol. Meded. 143, 1–257.
DIELLA V., SPALLA M.J. & TUNESI A. 1992: Contrasting thermomechanical evolutions in the Southalpine metamorphic basement of the Orobic Alps (Central Alps, Italy). J. metamorphic Geol. 10, 203–219.
DOGLIONI C. & BOSELLINI A. 1987: Eoalpine and Mesoalpine tectonics in the Southern Alps. Geol. Rundschau, 76, 735–754.
ERBA E. & FORNACIARI M. 1988: Age of the Cretaceous turbidite systems basin (Southern Alps) in the Lombardy. 1st Meeting of the IGCP n.262 Project. Working Group 2 – Pelagic Facies, Urbino, 1989, Abstract volume, 31.
ERRICO G., GROPPI P., SAVELLI S. & VAGHI C. 1979: Malossa field: a deep discovery in the Po valley, Italy. Amer. Assoc. Petrol. Geol. Bull. 66, 525–538.
FLÜGEL H.W., FAUPL P. & MAURITSCH H.J. 1987: Implications on the Alpidic evolution of the eastern part of the Eastern Alps. In: Geodynamics of the Eastern Alps (Ed. by H.W. FLÜGEL & P. FAUPL) Deuticke, Wien, 407–415.
FORCELLA F. & JADOUL F. 1990: Deformazioni post-Adamello nelle Alpi Orobie. Stato dell'arte ed ipotesi di lavoro. Studi geol. Camerti, vol. spec. 1990, 139–151.
FORNACIARI M., NOLLI V. & REDAELLI M. 1988: Le unità Cretaciche tra Montevecchia e Colle Brianza (Prov. Como): caratteri stratigrafici e lineamenti strutturali. Ist. Lomb. Accad. Sci. Lett.; Rend. (B) 122, 159–184.
FROITZHEIM N. 1992: Formation of recumbent folds during synorogenic crustal extension (Austroalpine nappes, Switzerland). Geology 20, 923–926.
GAETANI M. 1975: Jurassic stratigraphy of the Southern Alps; a review. In: Geology of Italy, The Earth Sci. Soc. of the Lybian Arab Republic (Ed. by C. SQUYRES) Tripoli, 377–402.
GAETANI M. & JADOUL F. 1979: The structure of the Bergamasc Alps. Rend. Acc. Naz. Lincei (8) 66, 411–416.
GELATI R. & PASSERI L. 1967: Il Flysch di Bergamo, nuova formazione Cretacica delle Prealpi Lombarde. Riv. ital. Paleont. Strat. 73, 835–850.
GELATI R., CASCONE A. & PAGGI L. 1982: Le unità stratigrafiche Aptiano-Maastrichtiane delle Prealpi Bergamasche. Riv. ital. Paleont. Strat., 88, 75–112.
GELATI R., NAPOLITANO A. & VALDISTURLO A. 1988: La Gonfolite Lombarda. Stratigrafia e significato nella evoluzione oligo-miocenica del margine sudalpino. Riv. ital. Paleont. Strat., 94, 285–332.
HAQ B.U., HARDENBOL J. & VAIL P.R. 1988: Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: Sea level changes: an integrated approach. Soc. Econ. Paleontol. Mineral. Spec. Publ. 47 (Ed. by C.K. WILGUS, B.S. HASTINGS, C.G.St.C KENDALL, H.W. POSAMENTIER, C.A. ROSS & J.C. VAN WAGONER), 71–108.
HÄRING M. 1978: The Sirone Conglomerate: a deep sea fan deposit in the Upper Cretaceous Flysch of Lombardy. Mem. Soc. geol. ital. 18, 57–62.

JADOUL F. & DONISELLI T. 1986: La successione del Lias inferiore di Morterone (Lecchese). Mem. Soc. geol. ital. 32, 49–66.

KLEBOTH P. 1982: Stratigraphie und Sedimentologie der höheren Oberkreide und des Alttertiärs der Brianza (Provinz Como, Italien). Mem. Sci. Geol. (Padova) 35, 213–292.

KLEVERLAAN K. 1987: Gordo Megabed: a possible seismite in a Tortonian submarine fan, Province Almeria, Southern Spain. Sedimentary Geology 51, 113–135.

LAUBSCHER H.P. 1985: Large scale thin-skinned thrusting in the Southern Alps: kinematic models. Geol. Soc. Amer. Bull. 96, 710–718.

LAUBSCHER H.P. & BERNOULLI D. 1982: History and deformation of the Alps. In: Mountain Building Processes (Ed. by K.J. HSÜ), 169–180, Academic Press, London.

MASSARI F. 1990: The foredeeps of the northern Adriatic margin: evidence of diachroneity in the deformation of the Southern Alps. Riv. ital. Paleont. Strat. 16, 351–380.

MASSARI F. & MEDIZZA F. 1973: Stratigrafia e paleogeografia del Campaniano – Maastrichtiano nelle Alpi Meridionali. Mem. Ist. Geol. Mineral. Università di Padova 28.

MUTTI E. 1985: Turbidite Systems and their relations to depositional sequences. In: Provenance of Arenites (Ed. by G.G. ZUFFA) NATO ASI Series, Reidel Publ. Co., 65–93.

PASSERI L. 1969: Marne di Bruntino. Studi Illustrativi Carta Geologica d'Italia 2, 1–9.

PIERI M. & GROPPI G. 1981: Subsurface geological structure of the Po Plain, Italy. CNR Progetto Finanlizzato Geodinamica, publ. n. 414.

POLINO R., DAL PIAZ G.V. & GOSSO G. 1990: Tectonic erosion at the Adria margin and accretionary processes for the Cretaceous orogeny in the Alps. Mém. Soc. géol. France 156; Mém. Soc. géol. suisse 1; Mem. Soc. geol. ital. Vol. spec. 1, 345–367.

RING U. 1992: The Alpine geodynamic evolution of Penninic nappes in the eastern Central Alps: geothermobarometric and kynematic data. J. metamorphic Geol. 10, 33–53.

SCHMID S.M. & HAAS R. 1989: Transition from near surface thrusting and intra basement décollement: Schlining thrust; eastern Alps. Tectonics 8, 697–718.

SCHÖNBORN G. 1990: A kinematic model of the Western Bergamasc Alps. Eclogae geol. Helv. 83, 665–682.

THÖNI M. 1983: The thermal climax of the early eoalpine metamorphism in the Austroalpine thrust sheet. Mem. Sci. Geol. Padova 36, 211–238.

VENZO S. 1954: Stratigrafia e tettonica del Flysch (Cretaceo-Eocene) del Bergamasco e della Brianza orientale. Mem. descr. Carta Geol. ital. 31.

WEISSERT H. 1981: Depositional processes in an ancient pelagic environment: the Lower Cretaceous Maiolica of the Southern Alps. Eclogae geol. Helv. 74, 339–352.

WINKLER W. 1988: Mid to Early Late Cretaceous Flysch and Melange formations in the western part of the Eastern Alps. Paleotectonic implications. Jb. Geol. Bund. Anst. 131, 341–389.

WINKLER W. & BERNOULLI D. 1986: Detrital high pressure – low temperature minerals in a late Turonian flysch sequence of the Eastern Alps (western Austria). Implications for early Alpine tectonics. Geology 14, 598–601.

WINTERER E. & BOSELLINI A. 1981: Subsidence and sedimentation on Jurassic passive continental margin, Southern Alps Italy. Amer. Assoc. Petrol. Geol. Bull. 65, 394–421.

WOODCOCK N. 1979: Size of submarine slides and their significance. Jour. struct. Geol. 1, 137–142.

ZANCHI A., CHIESA S. & GILLOT P.Y. 1992: Tectonic evolution of the Southern Alps in the Orobic chain: structural and geochronological indications for pre-Tertiary compressive tectonics. Mem. Soc. geol. ital. 45, 77–82.

ZANCHI A., FORCELLA F., JADOUL F., BERNINI M., BERSEZIO R., FORNACIARI M., ROSSETTI R. & TORAZZI S. 1988: The Faggio – Morterone transverse line: mesoscopic analysis and kinematic implications. Rend. Soc. geol. ital. 11, 279–286.

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