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Facies evolution of Late Cretaceous Flysch in Lombardy (northern Italy)[1]

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ABSTRACT

The sedimentary evolution of the Upper Cretaceous Flysch of Lombardy between Lago Maggiore and Brescia (northern Italy) has been investigated. The terrigenous resediments are up to 2000 m thick and are intercalated between basinal hemipelagic marls of Late Cenomanian (Scaglia rossa) and Late Campanian (Scaglia cinerea) age respectively. We could distinguish two depositional areas, that display different evolutions:

1. Varesotto, Mendrisiotto (western part): Terrigenous resediments from the Upper Cenomanian to the Campanian display basin plain facies (Varesotto Flysch and Coldrerio Flysch). Slope deposits in the Turonian are connected with a basin margin.

2. Brianza, Bergamasco, Bresciano (eastern part): From the Turonian to the Lower Santonian the westward progradation of a deep-sea fan system, including basin plain (Formazione di Pontida), outer fan to nonchannelized middle-fan (Arenaria di Sarnico) and channelized middle-fan deposits (Piano di Sirone) is clearly documented by an overall thickening- and coarsening-upward trend. In the Late Santonian, recession of the fan system led to deposition of outer-fan sediments (Flysch di Bergamo), before hemipelagic sedimentation resumed.

The flysch basin was elongated in a east-west direction and, to the east and south, confined by submarine fault blocks (Trento Plateau, Malossa High). The turbidity currents, carrying material derived exclusively from the southern continental margin of the Tethys and of South-Alpine to Austroalpine facies, entered the basin from the north and northeast and were deflected by the Malossa High into a longitudinal western direction.

RIASSUNTO

È stata studiata l'evoluzione sedimentaria del Flysch cretacico superiore Lombardo nella zona compresa tra il Lago Maggiore e Brescia (Italia sett.). I risedimenti terrigeni raggiungono uno spessore di 2000 m e sono intercalati tra marne emipelagiche di bacino, di età cenomaniana superiore (Scaglia rossa) e campaniana superiore (Scaglia cinerea). Possono essere distinte due aree deposizionali che presentano evoluzioni differenti:

1. Varesotto, Mendrisiotto (parte occidentale): i risedimenti terrigeni dal Cenomaniano superiore al Campaniano presentano facies di piana di bacino (Flysch del Varesotto e Flysch di Coldrerio). Depositi di scarpata nel Turoniano sono connessi con un margine di bacino.

2. Brianza, Bergamasco, Bresciano (parte orientale): dal Turoniano al Santoniano inferiore una generale tendenza all'aumento, verso l'alto, dello spessore e della granulometria testimoniano chiaramente un avanzamento verso ovest di un sistema di conoide di mare profondo che comprende:

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depositi di piana di bacino (Formazione di Pontida), depositi di conoide esterna fino a conoide intermedia non canalizzata (Arenaria di Sarnico) e depositi di conoide intermedia canalizzata (Piano di Sirone).

Nel Santoniano superiore l'arretramento del sistema di conoide porta alla messa in posto di depositi di conoide esterna (Flysch di Bergamo), prima della ripresa della sedimentazione emipelagica.

Il bacino di flysch era allungato in direzione est-ovest e, ad est e a sud, era delimitato da blocchi di faglia sottomarina (Plateau di Trento e Alto di Malossa). Le correnti di torbida che trasportavano materiale derivato esclusivamente dal margine continentale meridionale della Tetide e di facies da Sud-Alpina a Austroalpina, entravano nel bacino da nord e nord-est ed erano deviate dall'Alto di Malossa lungo una direzione longitudinale occidentale.

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Introduction

This paper is based on two Ph.D. theses on the sedimentology of the Late Cretaceous Lombardian Flysch that were carried out in the years 1978–80 at the Geological Institute of Basel University under the supervision of D. Bernoulli.

The Lombardian Flysch (Fig. 1) is an up to 2 km thick sequence of terrigenous clastic deep-sea deposits and is the only flysch sequence in the Alps which is autochthonous with respect to the underlying basement. It conformably overlies a deepening-upward pelagic to hemipelagic sequence of Jurassic to Early Cretaceous age, deposited on the submerged southern continental margin of the opening Tethyan Ocean (BERNOULLI et al. 1979; BERNOULLI 1980). High and differential rates of subsidence during the Early Liassic, rifting phases in the future margin led to a distinct differentiation between submarine highs with limited sediment thickness and basins with increased amounts of hemipelagic and gravity flow deposition. The Lombardian Basin, delimited by the Trento Zone in the east and the Canavese Zone in the west, is subdivided into smaller troughs (BERNOULLI 1964; KÄLIN & TRÜMPY 1977) and submarine swells (WIEDENMAYER 1963). This submarine morphology was then more or less smoothed by pelagic sedimentation in increasingly deeper waters, but redeposition of pelagic sediment and variations in formational thickness still indicate some morphological differences (WEISSERT 1981). Whereas, in the Lombardian Basin, faulting activity decreased from the Middle Jurassic to the Late Cretaceous, the eastern margin of the Lombardian Basin was the site of active fault scarps, which were the source areas of large gravity flow deposits in the eastern part of the Lombardian Basin throughout the Cretaceous (CASTELLARIN 1970; BERNOULLI et al. 1981). This evolution set the stage for the Late Cretaceous terrigenous deep-sea sedimentation.

The Lombardian Flysch is intercalated between hemipelagic and turbiditic marls and limestones and reflects orogenic movements in the central Alps which did

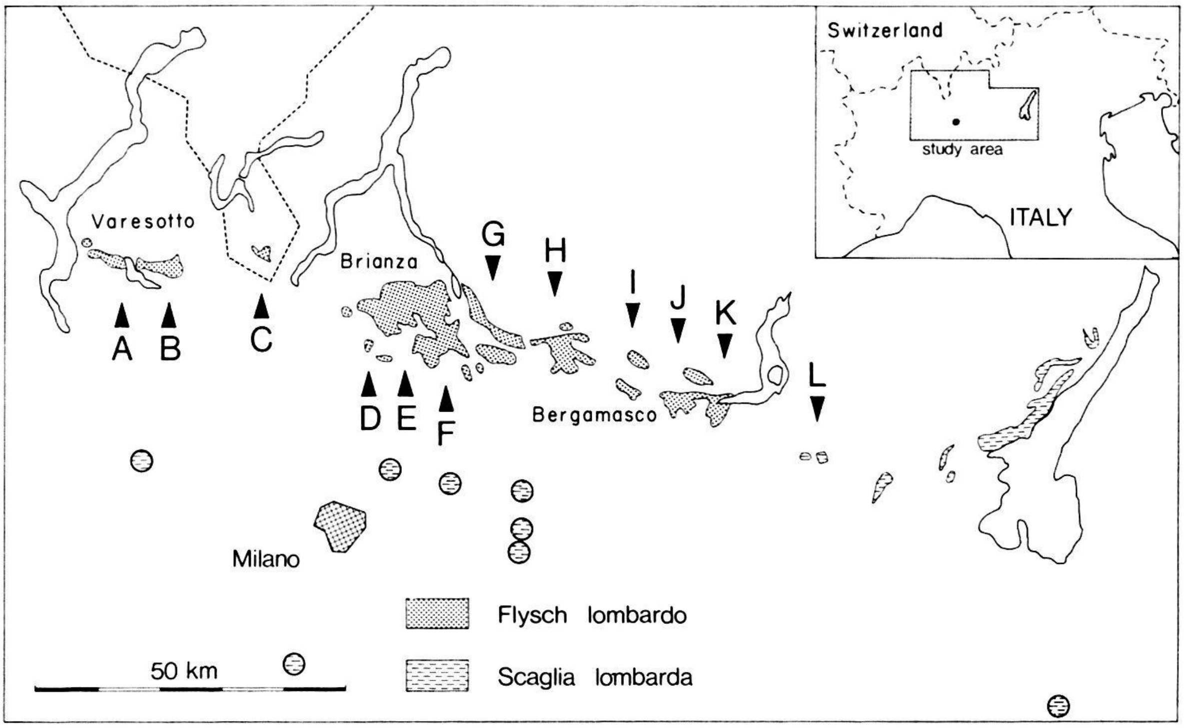

Fig. 1. Exposures of Upper Cenomanian to Lower Campanian sediments in Lombardy (northern Italy). A through L: Location of composite sections (Fig. 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 21). Well data (circles) after AGIP (1977) and GROPPI et al. (1976). A, B: Varesotto; C: Mendrisiotto; D–F: Brianza; G–K: Bergamasco; L: Bresciano.

not affect the Lombardian Basin in Cretaceous times. VENZO (1954), who described the Lombardian Flysch, was the first to consider this fact. He interpreted the coarse clastic intervals within the mainly sandy deposits as the result of penecontemporaneous orogenetic movements (prima fase parrossistica del orogenesi sudalpina). Similar conclusions were reached by AUBOUIN et al. (1970) in a synthesis of Lombardian paleogeography, where they attempted a reconstruction of the development of the flysch basin in relation to Alpine orogenesis. Following VENZO (1954), they distinguished different phases of sedimentation – their "trilogie lombarde" –, defined by three different facies as a result of rising and fading orogenetic movements with a maximum in the Early Santonian:

1. faciès terrigènes antérieurs aux flyschs (Aptien–Cénomanien),
2. flyschs (Cénomanien supérieur–Campanian),
3. faciès terrigènes postérieurs aux flyschs (Campanien–Eocène inférieur).

The provenance of the clastic material has been discussed by SAMES (1970) and CADEL (1975). In contrast to most authors (DE ROSA 1965, VICENTE 1966, GNACCOLINI 1971, AUBOUIN et al. 1970, CASTELLARIN 1970, 1976) who locate the source areas in the northeast, north or northwest, SAMES suggests a transport from a Lombardian ridge in the south of the basin. CASTELLARIN (1976) has applied deep-sea facies models to the Lombardy Flysch which he interprets as the result of prograding deep-sea fans filling up an east–west striking basin from the north and northeast. He rejects a close source such as the Insubric ridge proposed by AUBOUIN et al. (1970), but links the flysch deposition with tectonization of the Austroalpine realm, which was deformed in this period (OBERHAUSER 1968).

Within the last ten years coherent models of facies distribution in turbidite sequences have been developed from the examination of recent and fossil examples. Methods of facies analysis have been established by several authors (MUTTI & RICCI LUCCHI 1972, 1975; WALKER 1975, 1976, 1978; NORMARK 1970, 1978) allowing the distinction of deposits from different depositional environments in deep-sea fan systems. The primary goal here is to give a sedimentological reinterpretation (facies analysis) of the flysch sequence by application of these models and a paleogeographical reconstruction of the Lombardian Basin in the Late Cretaceous.

Terminology

The term facies in turbidite description is defined by MUTTI & RICCI LUCCHI (1975) as a layer or a group of layers showing lithologic, geometric and sedimentologic characters which are different from those of adjacent layers. A facies is considered to be the product of a specific depositional mechanism or several related mechanisms acting at the same time. By this definition a facies can be described by the following observable features of the sediment:

1. composition,
2. texture (grain size, sorting, matrix content),
3. layer thickness,
4. geometry and size of the layer or bed (shape, lateral continuity, lateral thickness variations),
5. sand/shale ratio,
6. sedimentary structures and vertical sequence of structures.

In the Lombardian Flysch we were able to distinguish 10 different facies types in the sense of MUTTI & RICCI LUCCHI (1975): A_1, A_2, B_2, C_1, C_2, D_1, D_2, D_3, E, G.

A combination of different facies types defines a facies association as the expression of a depositional environment. In the Lombardian Flysch, the facies associations can be related to basin plain, outer/lower and mid-fan environments, as defined below:

Basin plain facies association: "The basin plain facies is characterized by the predominance of hemipelagic mudstone with randomly interbedded thin sandstone beds exhibiting 'classical' distal turbidite characteristics. Facies G and D are most common ... Bedding surfaces are parallel, and facies and bedding are continuous for great distances and great thicknesses. Paleocurrent directions are variable, but tend to align with longitudinal dimensions of the trough. Sandstone beds usually show no cyclicity in their deposition." (INGERSOLL 1978, p. 220.)

Outer/lower fan facies association: "The outer-fan association is characterized by regularly interbedded mudstone and sandstone, which commonly exhibits thickening-upward (negative) cycles due to the progradational origin of depositional lobes. The sandstone primarily occurs as proximal to distal turbidite beds with little channelization (predominantly facies C and D). Lobe deposits occur within outer-fan associations and are differentiated from the surrounding outer-fan surface deposits by their higher sandstone to shale ratios (predominance of facies C over facies D), more common negative cycles ..." (INGERSOLL 1978, p. 221.)

Midfan facies association: "The middle-fan includes a depositional lobe or suprafan at the terminus of the leveed valley. The coarsening- and thickening-upward sequences of sandy turbidites on the upper suprafan (channelized midfan) are cut by numerous channels, channel remnants, and isolated depressions, whereas the lower suprafan (nonchannelized midfan) is relatively free of such features." (NORMARK 1978, p. 912.)

By different approaches, like studies of ancient and modern turbidite basins, two basically different deep-sea fan models have been established:

a) Highly efficient depositional systems are characterized by physical separation between channelized and nonchannelized sandstone bodies by mud-rich intervals (zone of bypassing) and by their large-scale (thickness 200->1000 m, extension >100 km). They are built up by voluminous, mud-rich currents (cf. MUTTI & RICCI LUCCHI 1975, MUTTI 1977, MUTTI 1979).

b) Poorly efficient depositional systems are of smaller scale (thickness 20-300 m, extension in the order of 10 km) with a supra-fan (sensu NORMARK 1970) built up by relatively small, sand-rich turbidity currents (NORMARK 1970, 1978; MUTTI 1979).

Stratigraphy

A stratigraphic diagram showing the relationship between the Upper Cretaceous formations of the Lombardian basin is given in Figure 2.

Sasso della Luna

The term "Sasso della Luna" was introduced by VARISCO (1881) for the well-bedded, light-colored marly limestones and marls occurring in the Bergamo region (Fig. 1). VARISCO attributed a Late Cretaceous age to this formation. The upper part has been dated as Middle Cenomanian by *Rotalipora reicheli* (MORNOD), the youngest species present. The Sasso della Luna is partly a lateral equivalent to the Scaglia bianca (Upper Albian-Lower Cenomanian, GANDOLFI 1942, LUTERBACHER 1965) and to the Scaglia rossa (Middle-Upper Cenomanian) in the west, but to the

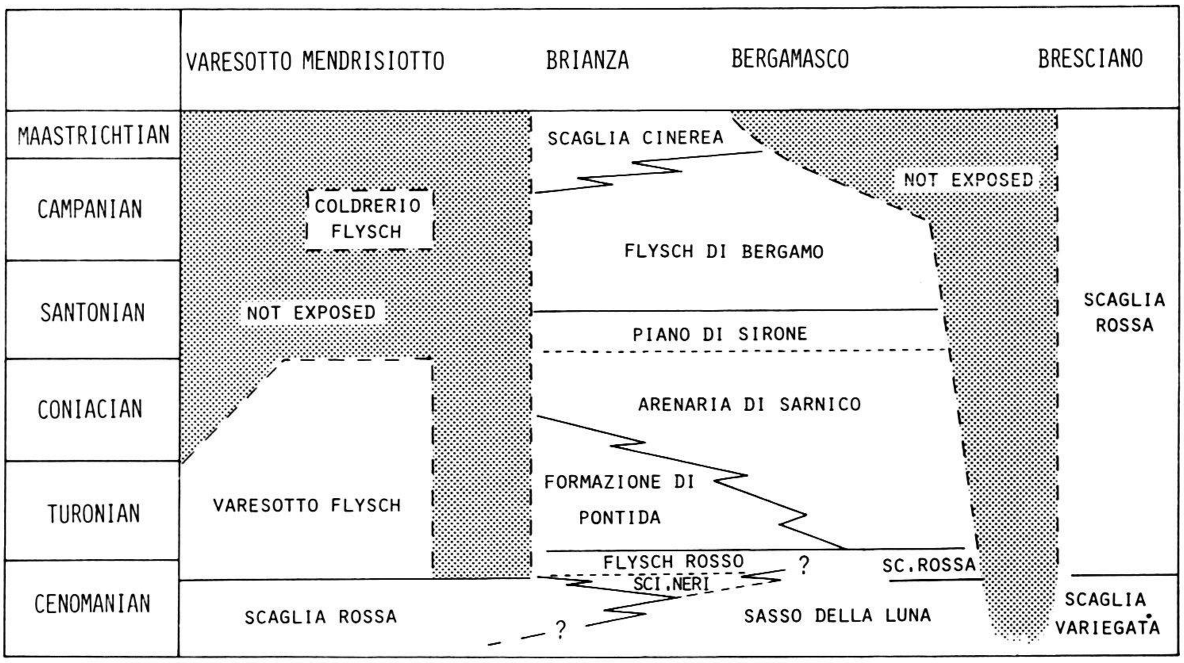

Fig. 2. Stratigraphic diagram of the Upper Cretaceous in Lombardy.

Scaglia variegata in the east. The formation is composed of resedimented biomicrites ("pelagic turbidites") consisting of 50% to 80% of planktonic foraminifera *(Rotalipora* and *Heterohelicidae),* calcispheres and radiolarians. Silt-sized quartz grains and mica are common, benthonic foraminifera (mainly *Textularia*) occur only exceptionally. In the Brianza and in the western Bergamasco, the Sasso della Luna reaches a thickness of 300 m. The individual beds are up to 4 m thick. Here, the formation is overlain by the Scisti neri superiori. In the eastern part of the study area, the Sasso della Luna is thinner bedded and is similar to the Scaglia bianca. The unit is about 200 m thick and is grading upwards into Scaglia rossa.

Scaglia lombarda

In Lombardy the term "Scaglia lombarda" designates a heterochronous group of hemipelagic calcareous or clayey marls of Middle Cretaceous to Early Tertiary age. Locally it is subdivided into subunits according to the prevailing colors (Rossi 1975).

Scaglia rossa

In western Lombardy (Varesotto, Brianza, Bergamasco), the Scaglia rossa is restricted to the Cenomanian. In the Varesotto the Scaglia rossa overlies the Scaglia bianca (Lower Cenomanian, Luterbacher 1965) and is followed by the Varesotto Flysch dated as Upper Cenomanian (Luterbacher 1965, Sames 1970). In an abandoned quarry northeast of Gropello (northern Lago di Varese) the Scaglia rossa is well exposed. It mainly consists of knobby weathering red marls. Few cm-thick, dark and light-grey layers are intercalated. The single layers are of great lateral continuity. The carbonate content ranges from 27% to 77%. The carbonate-rich layers display structures of resedimentation in the silty to pelitic material. Sedimentary structures are largely obliterated by burrowing (e.g. *Chondrites*). The red marls contain a rich planktonic microfauna. The top is dated as Late Cenomanian by *Rotalipora greenhornensis* Morrow. In the Brianza and the Bergamasco the Scaglia rossa overlies the Sasso della Luna. It is followed by the Scisti neri superiori of Late Cenomanian age (Guillot 1967, Vicente 1966) in the Brianza and is directly overlain by the Sarnico Sandstone of Early Turonian age in the eastern Bergamasco.

Scaglia variegata and Scaglia rossa in the Bresciano

The Scaglia variegata in the Bresciano, partly the lateral equivalent of the more calcareous Sasso della Luna to the west, consists predominantly of green, grey and red marls with intercalations of black argillites and belongs to the Upper Barremian–Cenomanian p.p. time-interval (Rossi 1975, Boni et al. 1970). Up-section, the Scaglia variegata is gradational with the Scaglia rossa which starts in the Cenomanian p.p. indicated by *Rotalipora* sp. and *Praeglobotruncana stephani* (Gandolfi) (Boni et al. 1970). At the top of this unit, the microfossil content indicates a Maastrichtian age with *Globotruncana contusa* (Cushman) and *Globotruncana stuarti* (de Lapparent). The Scaglia rossa consists of thin-bedded red and white marls and marly limestones with intercalated thin layers of resedimented pelagic material. In the Campanian, dated by *Globotruncana stuartiformis* DALBIEZ and *Globotruncana elevata* (BROTZEN), the Scaglia rossa is sporadically interrupted by turbiditic sandstones and marls, which correspond lithologically to the Bergamo Flysch. The thickness of the Scaglia rossa, measured along a road near Gussago (section 58, p. 413, Fig. 1, L), amounts to about 200 m.

Scisti neri

The Scisti neri described here correspond to the Scisti neri superiori as defined by AUBOUIN et al. (1970), which were dated by these authors as Late Cenomanian by *Rotalipora cushmani* (MORROW). The Scisti neri are best exposed in a drainage ditch below the quarry of Cesana (section 11, p. 400; Fig. 1, D). Thin-bedded red and grey calcareous marls alternate with red and purple marls. The formation takes its name from occasional intercalations of black pelitic intervals. These bituminous layers range from a few to some ten centimeters in thickness. Deposition of the Scisti neri coincides with an oceanic anoxic event, which is reported worldwide during the Late Cenomanian-Early Turonian (ARTHUR & SCHLANGER 1979). The frequency of thin-bedded sandstone layers increases towards the top of the formation. These beds mark the transition to the overlying Flysch rosso. The only difference to the underlying Scaglia rossa are the intercalated bituminous shales. The red color of the marls is characteristic for all three formations.

Flysch rosso

The Flysch rosso is intercalated between the Scisti neri and the Pontida Formation. The sequence was first mentioned as Flysch rosso by VENZO (1954) and is synonymous with the Sommaschio Formation (FERNANDEZ 1962, GNACCOLINI 1968). This formation, with clear flysch characteristics, was considered of partly Cenomanian/partly Turonian age (AUBOUIN et al. 1970). Exposures of the Flysch rosso are delimited to the Brianza and the western Bergamasco (sections 11, p. 400; 23, p. 404; 30, p. 406). The formation reaches a total thickness up to 120 m. It shows a succession of reddish or green and purple marls alternating with thin turbiditic sandstone layers (T_b, T_c). The fine to medium grained sand consists of lithic fragments with a considerable amount of quartz and mica. In the lowermost portion the sand/shale ratio increases over 50 m from 1:10 to 1:1. The turbiditic layers are arranged acyclically. Neglecting the high sand/shale ratio, the predominant turbidite type corresponds to the facies D_2.

Varesotto Flysch

This formation was described by GNACCOLINI (1968) as “flysch conglomeratico ed arenaceo”. AUBOUIN et al. (1970) subdivided the formation into three levels: “flysch calcaro-pélitique”, “complexe à calcaires blancs”, “série flyschoïde à dominante calcaro-pélitique-gréseuse”. The lower limit of the Varesotto Flysch lies in the Upper Cenomanian, the upper boundary is not exposed. The age of the onset of the flysch sedimentation for the Breggia section (section 7, p.398; Fig. 1, C) is based on PREMOLI SILVA & LUTERBACHER (1965) and on our own data. The formation is composed by the following lithologies:

Near the base of the formation biocalcarenites alternate with grey calcareous marls. The biocalcarenites are light-colored turbiditic sandstones mainly composed of benthonic-neritic *(Orbitolina)* and planktonic foraminifera, fragments of red algae, echinoids and other biota. Furthermore they contain lithic fragments of older South-Alpine formations. The bioclastic sandstones occur as beds several tens of centimeters thick with an erosive base. They are characteristic for the base of the formation but are also found higher up.

Grey calcareous marls are the most frequent lithology in the Varesotto Flysch. The carbonate content ranges from 20% to 60%. A distinction between pelitic portions of turbidites and hemipelagic deposits cannot be made, because any former boundaries have been destroyed by bioturbation. Rare planktonic microfossils are poorly preserved. Higher up the calcareous marls alternate with lithic siltstones.

The lithic siltstones are dark-grey turbiditic beds, ranging from 5 to 50 cm in thickness. The single beds are parallel bedded and display exclusively T_d-Bouma intervals. The parallel lamination is accentuated by mica-rich dark layers. No microfossils are found in these layers. This facies is locally present in the basal flysch of the Breggia section (section 7, p.398, Fig. 1, C) but occurs sporadically at all levels of the Varesotto Flysch.

White-colored micritic limestones with even fracture planes are arranged in 5 to 20 cm thick parallel bedded layers alternating with grey marls. *Chondrites* and *Zoophycos* are abundant. The limestone layers are restricted to the lower third of the formation.

Lithic sandstones: Yellowish weathering, parallel bedded sandstone layers ranging in thickness from 5 to 70 cm. The sandstones represent T_{a-c}-Bouma intervals, overlain by shales. The sandstone consists mainly of fragments of chert, quartz, dolomite and limestone. Microfossils are not preserved. These lithic sandstones, alternating with grey shales, are the most common sandstone-type in the Varesotto Flysch.

Lithic conglomerates: In the area north of Varese (section 4, p.398; Fig. 1, B) at least two levels with closely packed, well sorted conglomerates can be recognized. The size of the well-rounded clasts ranges from 1 to 5 cm. The conglomerates are arranged into few m-thick channelized bodies. The components are dolomite (45%), cherts (13%), pelagic (17%), spiculithic (7%) and shallow water (6%) limestones, biogenic detritus occurs as fragments of red algae, echinoids and molluscs (9%), quartz and crystalline rock fragments (3%). All lithologies can be attributed to South-Alpine formations.

Pebbly mudstones form a distinct level in the middle part of the Varesotto Flysch, which was already mentioned by AUBOUIN et al. (1970) as "complexe à calcaires blancs". The matrix consists of light-colored contorted marly limestones containing angular quartz grains, lithic rock fragments and biogenic detritus, a mixture of reworked calpionellids, *Hedbergella, Rotalipora, Globotruncana* and other planktonic foraminifera. The size of the components ranges from well rounded granules up to 2 cm in diameter to rotated blocks of thin-bedded marly limestones of ten and more meters in diameter. The granules consist of lithic sandstone with reworked *Orbitolina,* or of foraminifera-bearing lime mudstones from the Scaglia or in most cases of calpionellid limestones from the Maiolica. The total thickness of the pebbly mudstone is estimated at 200 m. This facies is exposed in most outcrops in the Varesotto (e.g. sections 2, p. 397, and 5, p. 398, Fig. 1, B, C). In the reworked faunal association *Praeglobotruncana helvetica* (BOLLI) was determined as the youngest planktonic foraminifer by AUBOUIN et al. (1970) indicating a Middle Turonian age. The uppermost portions of the formation are again composed by facies D-sandstones (MUTTI & RICCI LUCCHI 1975) as in the lower part. The maximum thickness of the Varesotto Flysch is estimated at 600 m. The youngest species: *Marginotruncana renzi* GANDOLFI and *Dicarinella imbricata* (MORNOD) in the uppermost beds indicate a Turonian or even a Coniacian age.

Coldrerio Flysch

This 80 m thick sequence, formerly exposed along the highway near Coldrerio, Canton Ticino (section 10, p. 398, Fig. 1, C) could not be integrated into the Varesotto Flysch. We refer to this sequence informally as Coldrerio Flysch. It was first described by LONGO (1968), who attached the series to the Turonian similarly to the other flysch exposures in the area (Varesotto Flysch). Unpublished micropaleontological data by RUTISHAUSER (1977) indicate a Campanian age. Today this series is only documented by core samples from a borehole near Balerna (Canton Ticino). The core is stored at the Geological Institute of the ETH in Zürich. The sequence shows an acyclic alternation of lithic silt- and medium-grained sandstone layers with calcareous marls and light-colored marly limestones. Some of the beds show complete Bouma cycles with thicknesses from 5 to 50 cm. Beside quartz and mica, the sand is mainly composed by carbonate detritus. The sand/shale ratio is about 1:3. The marly limestones are interspersed with burrows which are filled with sand. These deposits correspond to the facies D_2. The whole sequence can be attributed to a basin-plain association.

Formazione di Pontida

The term Pontida Formation was first used by DE ROSA & RIZZINI (1967) for the succession of turbiditic sandstones and marls in the Pontida area (section 31, p. 406; Fig. 1, G). The expression "Flysch grigio", introduced by VENZO (1951) is a synonym.

The individual turbidites, mainly T_{b-e} and T_{c-e} Bouma sequences, ranging from 5 to 100 cm in thickness, have a wide lateral continuity and are bound by even and parallel surfaces. The sandstone/shale ratio is 1:3 (facies D). The turbidites are acyclically arranged; the Pontida Formation displays the diagnostic features of a basin-plain facies association (Fig. 3). The sandstones are grey, brown weathering, of fine to medium grain. Three main lithologic types can be distinguished: *Lithic arenites* are composed of siliciclastic fragments such as quartz, crystalline rocks, chert, feldspar and mica. *Bioclastic arenites* are mainly composed of detrital carbonate particles, such as fragments of echinoderms, molluscs (*Inoceramus* and rudists),

Fig. 3. Basin plain facies association. Formazione di Pontida, Turonian. Airuno section.

microfossils and lithoclasts derived from the Mesozoic formations of the southern Alps. *Foraminiferal arenites:* composed mainly of planktonic foraminifera (50–80%) together with silt-sized quartz grains and mica.

The grey, sometimes greenish marls contain a rich *Rhabdammina* fauna but are poor in planktonic foraminifera. A differentiation between hemipelagic (T_f) and turbiditic (T_e) mudstones cannot be made because of the lack of structural and compositional (e.g. $CaCO_3$-content) differences (cf. HESSE 1975). Paleocurrent directions show a general east–west transport in all sections examined.

The Pontida Formation is sporadically interrupted by so-called megabeds (RUPKE 1976a, b) (Fig. 4). These are turbidites up to 15 m thick consisting of a basal pebbly mudstone and/or conglomerate gradually passing into turbiditic sandstone and mudstone. The pebbly mudstone has a marly matrix. The pebbles are usually well rounded and range from 0.2 to 3 cm in diameter. The sandstone is composed mainly of planktonic foraminifera, quartz and mica. Although megabeds are particularly frequent in the Pontida basin plain deposits, they also occur in other depositional environments like the outer-fan facies association of the Bergamo Flysch. Their occurrence and extension seem to be independent from deep-sea fan systems (cf. RICCI LUCCHI 1975, 1978; RUPKE 1976a, b, BERNOULLI et al. 1981).

The Pontida Formation reaches its maximal thickness of 450 m in the eastern Brianza and western Bergamasco. Towards the east the unit is successively replaced by the Sarnico Sandstone (Fig. 2). The base of the Pontida Formation is dated with

Fig. 4. Megabeds in a basin plain facies association. Formazione di Pontida, Turonian. Lorentino superiore section.

Praeglobotruncana helvetica (BOLLI) as Early Turonian. In the middle part, *Marginotruncana marianosa* (DOUGLAS) indicates a Middle/Late Turonian age. In the western Bergamasco, the unit reaches probably the Lower Coniacian (BLANCHET 1965). The top of the Pontida Formation could be still younger in the Brianza region, if sedimentation conforms to the model of a prograding deep-sea fan.

Arenaria di Sarnico

The term "Pietra di Sarnico" was first mentioned by DE ALESSANDRI (1899). FERNANDEZ (1963) described massive sandstones in the Pontida area as "Formazione di Pratolungo". With reference to DE ALESSANDRI (1899), DE ROSA & RIZZINI (1967) adapted the term "Sarnico Sandstone" to all these massive sandstones in the Bergamasco and in the Brianza. The formation crops out from the Brianza (thickness of 500 m) to the Lago d'Iseo (Fig. 1, E–K), where the thickness can be estimated as only 300 m. The lower boundary of the Sarnico Sandstone in the eastern part is with the Scaglia rossa, everywhere else with the Pontida Formation. The upper boundary is with the Bergamo Flysch. The Sarnico Sandstone is poor in fossils. Besides agglutinating foraminifera *(Bathysiphon* and *Rhabdammina)*, there are only reworked faunal associations from the Albian and Cenomanian (e.g. *Ticinella, Planomalina, Rotalipora*). However, in several nannoplankton samples *Marthasterites furcatus* indicates a Coniacian age. Further stratigraphic control is given by the more precisely dated overlying and underlying formations: In the western Bergamasco, the Sarnico Sandstone lies on sediments dated as Upper Turonian to

Lower Coniacian. The onset of the Sarnico Sandstone deposition is obviously earlier in the east than in the west.

The bulk of the formation is composed of grey, massive or coarse-tail graded sandstones separated by thin shale layers. The sandstones consist of quartz (up to 50%), crystalline rock fragments (up to 20%), chert, feldspar, mica, chlorite, (Triassic) dolomite and limestone fragments from older formations. The sandstones have a scarce clayey matrix and a calcareous cement.

Coarse-tail graded, often amalgamated sandstone beds (facies C_1) build up large thickening (and coarsening) upward cycles attaining 100 m thickness. The individual beds, composed of medium to coarse-grained sandstone and between 50 and 300 cm thick, are bound by even, sometimes erosional surfaces and have a good lateral continuity. Low relief channels may occur. The sand/shale ratio is high to very high. Except for the western portion in the Brianza area, the Sarnico Sandstone corresponds well to a nonchannelized middle-fan facies association. In the central Brianza, the Sarnico Sandstone shows a decreased sandstone/shale ratio in the order of about 1:1. Here, the acyclic sequence of up to 80 cm thick parallel-bedded, base-missing turbidites displays an outer-fan facies association.

Piano di Sirone

We define the Sirone Conglomerate as a member of the Sarnico Sandstone. It is built up by several isolated conglomeratic bodies and is not developed as a continuous layer as described by de Cristoforis (1838). These deposits are concentrated in lenticularly shaped bodies, each 4–7 km wide and 80–200 m thick. Such bodies were recognized in the Sirone, the Pontida, the Bergamo and the Gandosso area

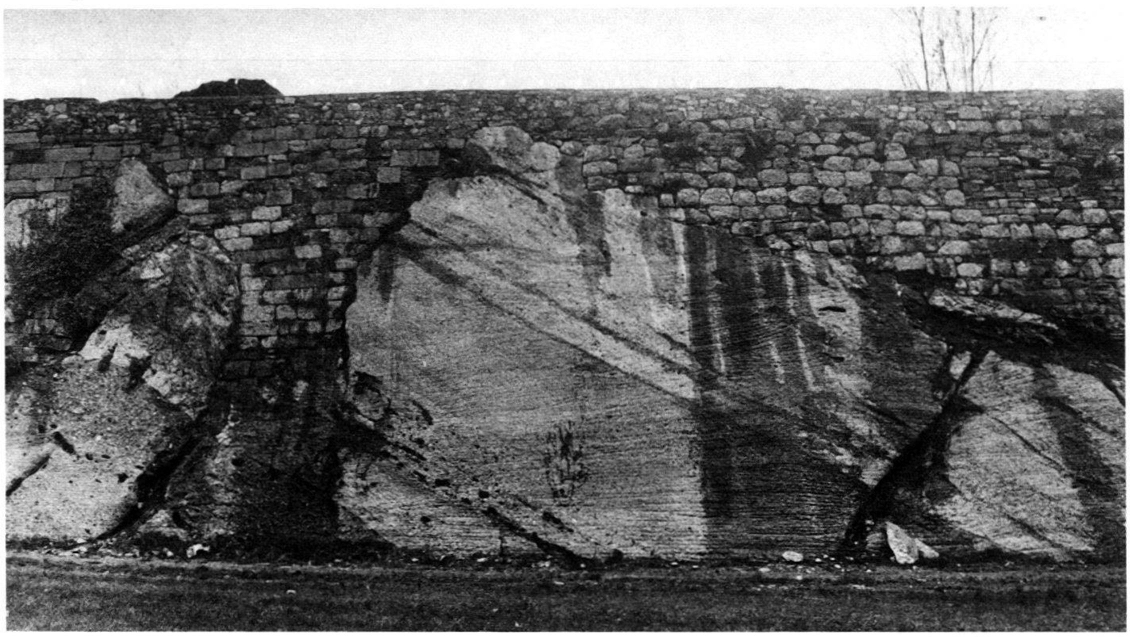

Fig. 5. Amalgamation of conglomeratic beds (facies A_1) representing channelized midfan facies association. Piano di Sirone member of the Arenaria di Sarnico, Lower Santonian. Bergamo, città alta.

respectively. At the Sirone type locality (section 21, p.401, Fig. 1, E, 11) the conglomerate is estimated to reach 150 m. The youngest planktonic microfossil *Dicarinella concavata* (BROTZEN) found in marly deposits of this member indicates a Late Coniacian to Early Santonian age and is consistent with earlier age determinations (DE ALESSANDRI 1899, VENZO 1951) based on ammonites. The Sirone Conglomerate consists of a polygenetic conglomerate of well rounded components with an average grain size of 3 cm and a maximum grain size of 20 cm. The pebbles consist of quartz and crystalline rock fragments (40%), dolomite (22%), chert (21%), pelagic limestone (4%), shallow-water limestone (6%), and coarse biogenic detritus (5%). All components can be attributed to formations of the South- to Austroalpine sequence. The conglomerates show little variation in composition. Massive conglomerate layers, over 20 m thick, with large clay chips, alternate with amalgamated and crossbedded sandstone layers (Fig. 5). Only thin marly intervals or wavy layer boundaries of amalgamated beds indicate stratification. Imbrication of clasts and inverse to normal grading at the base of the layers is common (Fig. 6). Sometimes, incised channels are cut into the underlying sandstone beds. The individual channel-fill sequences exhibit thinning- and fining-upward cycles (HÄRING 1978). The Piano di Sirone represents a classical channelized deposit within the general midfan association of the Sarnico Sandstone. Interchannel facies, mudstone dominated sediments with bundles of thin-bedded turbidites (facies D and E) are associated with the channelized bodies.

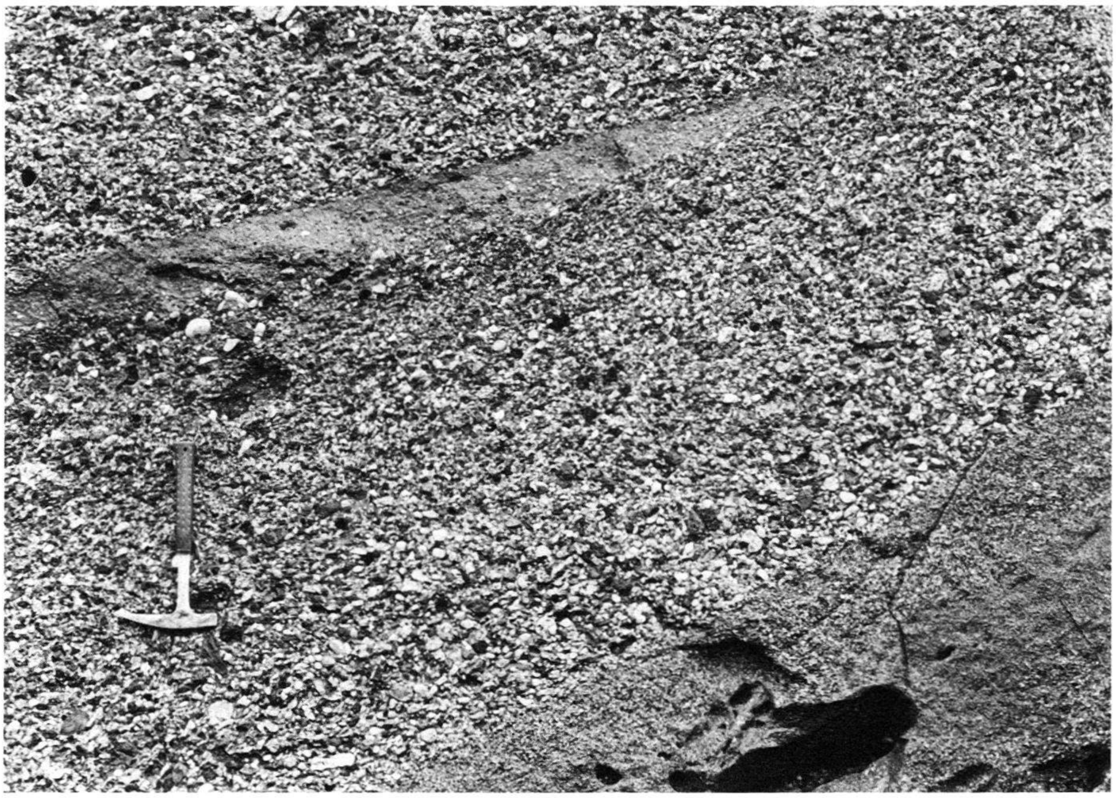

Fig. 6. Amalgamation of graded conglomerate layers (facies A_1), occasionally with inverse grading at the base (upper left) and shale clasts (lower right). Note imbrication of clasts. Piano di Sirone member of the Arenaria di Sarnico, Lower Santonian. Bergamo, città alta.

Flysch di Bergamo

The term Bergamo Flysch was introduced by GELATI & PASSERI (1967). The Bergamo Flysch is exposed mainly between the eastern Brianza and the river Oglio, with a thickness of about 1000 m in the Brianza and of at least 400 m in the Sarnico area. The lower boundary of the Bergamo Flysch is marked everywhere by the Sarnico Sandstone, or by the Piano di Sirone and is dated by *Dicarinella assymetrica* (SIGAL), *Globotruncana fornicata* PLUMMER and *Globotruncana lapparenti* BOLLI as Late Santonian. In the Bergamasco as well as in the central and eastern Brianza, the Bergamo Flysch is already succeeded in the Middle Campanian by marly Scaglia cinerea (Piano di Brenno) (KLEBOTH, in prep.).

In contrast to the siliciclastic sediments of the Sarnico Sandstone, the Bergamo Flysch contains abundant carbonate particles and displays a great variability in composition. The calcareous fraction consists mainly of carbonate fragments displaced from a (?)Late Cretaceous shallow-water area (echinoderms, red algae, bryozoa, miliolids, agglutinating foraminifera and pellet-like, strongly micritized red algal and shell fragments). The Bergamo Flysch is characterized by classical turbidites often with complete Bouma sequences, usually building up acyclic successions, but locally with huge negative cycles, up to 80 m thick.

The individual turbidite beds range from 20 to 200 cm in thickness representing mainly facies $D_{1,2}$ and $C_{1,2}$ and occasionally B_2. Locally, also symmetrical cycles (thickening and coarsening/thinning and fining upward) up to 30 m thick occur. The sandstones show a grain size variation from fine sand up to well rounded broadly channelized conglomerates (max. diameter 5 cm). The sand/shale ratio varies from 1:2 at the base and the top to 5:1 in the middle part of a cycle. On the whole, these features are consistent with the definition of the outer-fan facies association.

Scaglia cinerea

The term Scaglia cinerea (Piano di Brenno, VILLA & VILLA 1844) as used by GELATI & PASSERI (1967) stands for the ash-colored (cinerea) calcareous and sandy marls alternating with thin-bedded marly limestones of Late Campanian and Maastrichtian age, above the Flysch di Bergamo (KLEBOTH, in prep.). The thickness of the Scaglia cinerea is of about 150 m.

Description of sedimentary sequences

All observations from detailed measured sections (BICHSEL 1980, HÄRING 1980) have been integrated into composite sections for each outcrop area.

Composite section: Western Varesotto (Fig. 7, A on Fig. 1)

Detailed sections:

1. Gropello, abandoned quarry northeast of Gropello (Lago di Varese) (coord. 700.1/075.9, Swiss top. map).
2. Biandronno, along the shore of Lago di Varese (coord. 699.3/075.6, Swiss top. map).
3. Brebbia, Bregano, Fornace, scattered temporary exposures on building sites and small road cuts.

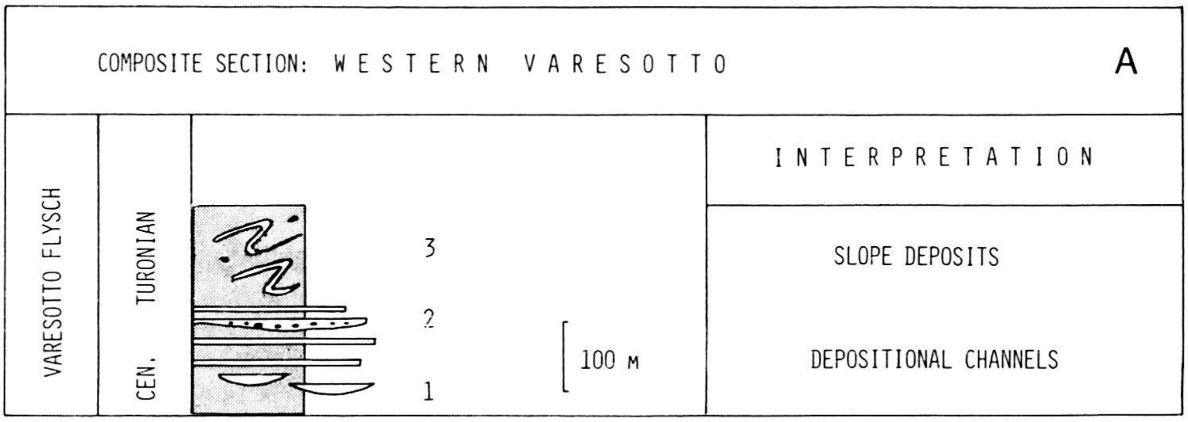

Fig. 7. Composite section: western Varesotto.

In this westernmost outcrop area of the Lombardian Flysch a total thickness of 300 m can be estimated for the Varesotto Flysch exposed. The predominantly hemipelagic deposits of the Scaglia rossa are interrupted by broadly channelized terrigenous turbidites derived from the north. These are overlain by facies D turbidites. The channelized deposits are interpreted as the result of suddenly advancing limbs of a locally restricted prograding fan system (WALKER 1978). The remarkable amount of neritic organisms (e.g. *Orbitolina*) in the coarser-grained turbidites point to a shallow-water source area. This sequence comprises about 50 m and is overlain by debris flow deposits of at least 200 m thickness. Beside the turbiditic deposits these sediments suggest deposition near a submarine slope.

Post-Turonian Cretaceous sediments are not exposed in the area. The next deposits in age are bioclastic submarine fan deposits of the Upper Eocene Ternate Formation (HERB 1976, BERNOULLI, in LAUBSCHER & BERNOULLI 1980, BERNOULLI & HERB, in prep.).

Composite section: North of Varese (Fig. 8, B on Fig. 1)

Detailed sections:

4. Molino grasso, brooklet near Molino grasso (coord. 707.2/078.0, Swiss top. map).
5. Poretti, Varese-Valganna road, next to the Poretti brewery (coord. 707.7/078.2, Swiss top. map).
6. Olona, Varese-Induno road, crossing the brook Olona (coord. 707.7/077.6, Swiss top. map).

In this area, a sequence with a total thickness of over 340 m of the Varesotto Flysch can be compiled from the various outcrops. The age of this sequence ranges from the very Late Cenomanian to Early Coniacian. The lower part shows about 40 m of acyclically arranged terrigenous turbidites of basin plain facies. The intercalated channelized beds of conglomerates are thought to belong to the same prograding system as the broadly channelized deposits in the western Varesotto. The lithic turbidite sequence is topped by debris flow deposits, for which a maximum thickness of 250 m can be reconstructed. Whereas in the western Varesotto only chaotic mudflows and pebbly mudstones with pebble-size particles occur, in this area slabs of thin-bedded calcareous marls of 10 m across and more are intercalated. These slabs had to be eroded subaqueously, because the Albian marls were only

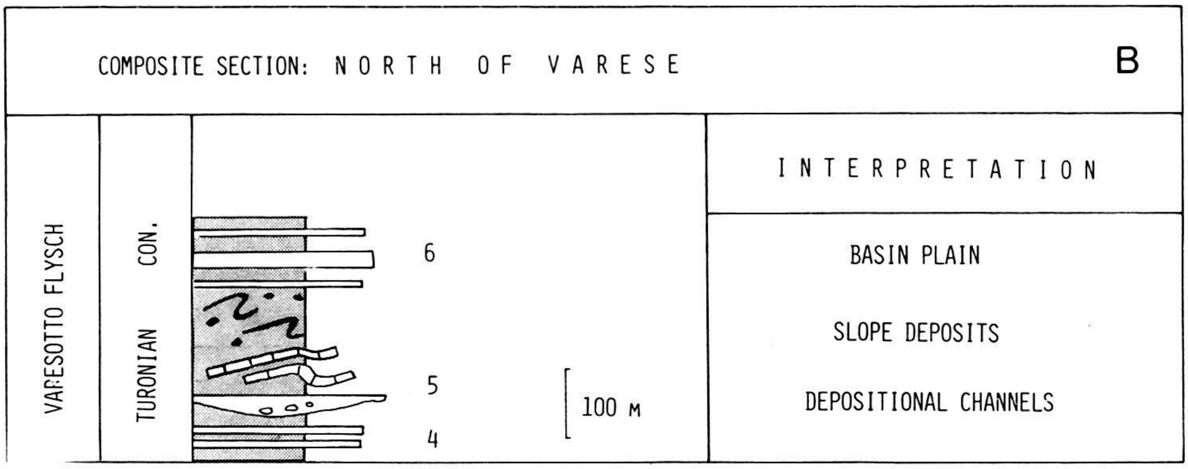

Fig. 8. Composite section: north of Varese.

poorly lithified and in part still plastic during redeposition. Beside lithic fragments of calpionellid-rich micrites isolated exhumed calpionellids occur in the matrix, proving submarine erosion of unconsolidated sediments of even Early Cretaceous age. On the other hand, usually well rounded pebbles of Triassic dolomites point to an exposed source area for the latter. The succeeding turbidite sequence again corresponds to a basin plain facies association. Thus, except for the few channelized beds and debris flow deposits, the Varesotto Flysch does not show a progradation from basin plain to more proximal deposits.

Composite section: Mendrisiotto (Fig. 9, C on Fig. 1)

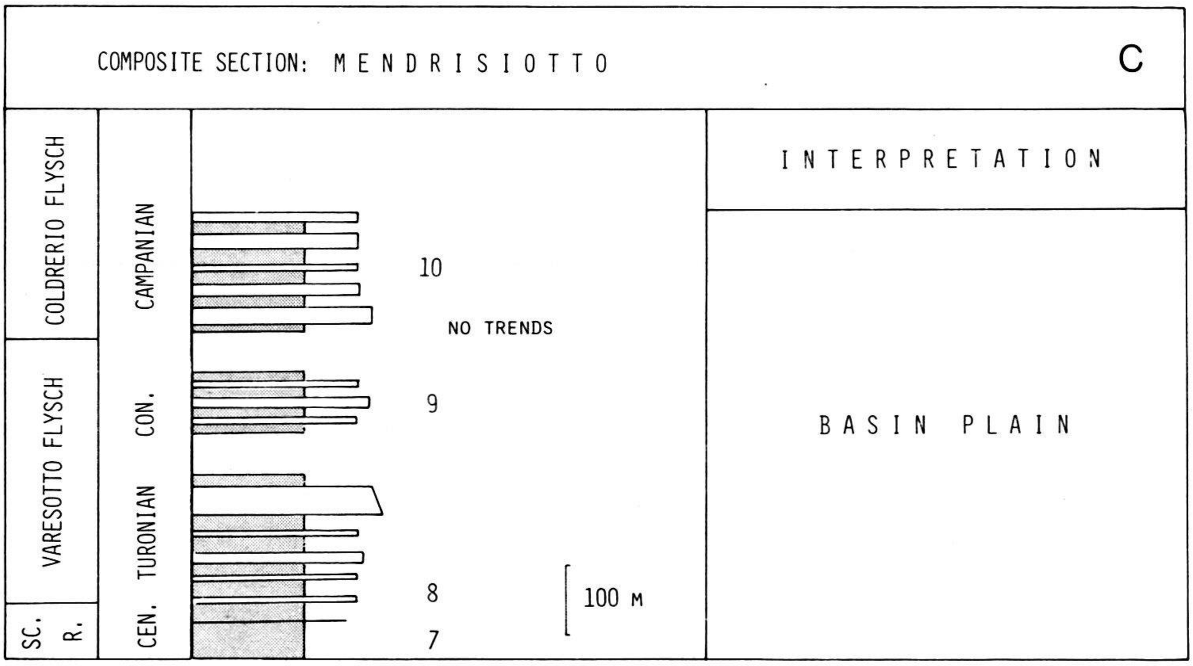

Fig. 9. Composite section: Mendrisiotto.

Detailed sections:

7. Breggia, Breggia river, north of Balerna (Ticino) (coord. 722.1/079.1, Swiss top. map).
8. San Pietro di Stabio, brooklet south of the church of San Pietro di Stabio (coord. 716.3/079.7, Swiss top. map).
9. Mercole, brook south of Mercole (coord. 721.5/078.8, Swiss top. map).
10. Coldrerio, parking place Coldrerio along the Chiasso-Lugano highway (coord. 720.1/078.8, Swiss top. map).

In this area the total thickness of the Upper Cretaceous Flysch cannot be established. The terrigenous sedimentation also started during the Late Cenomanian, but in contrast to the Varesotto, channelized conglomeratic deposits are lacking. The sequences all show parallel bedded and acyclically arranged turbidite beds. The sandstone/shale ratio remains far below 1. A basin plain facies is thus documented in the Mendrisiotto for the whole flysch sequence.

Composite section: Western Brianza (Fig. 10, D on Fig. 1)

Detailed sections:

11. Pusiano, drainage ditch below the quarry of Cesana (coord. 744.0/075.6, Swiss top. map).
12. Cesana, behind a garage along the Lecco-Erba main road in Cesana (coord. 744.7/075.6, Swiss top. map).
13. Bosisio, along the Cesana-Bosisio road along the east shore of the Lago di Pusiano (coord. 743.1/074.5, Swiss top. map).
14. Casletto, along the road opposite of the cemetery of Casletto (coord. 743.1/072.2, Swiss top. map).
15. Maggiolino, brooklet southwest of Maggiolino village (coord. 741.4/072.2, Swiss top. map).
16. Costa Masnaga, road cut east of the church of Costa Masnaga (coord. 743.3/070.0, Swiss top. map).

A vertical combination of all sections in the western Brianza gives a total thickness of about 1500 m for the flysch sequence. From top to bottom it comprises:

1.	Bergamo Flysch (Santonian-Campanian)	700 m
2.	Sarnico Sandstone (Piano di Sirone) (Lower Santonian)	100 m
3.	Pontida Formation (Turonian-Coniacian)	500 m
4.	Flysch rosso (Upper Cenomanian-Turonian)	150 m
5.	Scisti neri superiori (Upper Cenomanian)	50 m

The terrigenous sedimentation starts in the Late Cenomanian with thin-bedded turbidites of facies D_2. The first events are contemporaneous with episodes of anoxic conditions in the deepest parts of the Lombardian basin (Scisti neri, ARTHUR & SCHLANGER 1979, WEISSERT et al. 1979). A rapidly increasing sand/shale ratio in the Flysch rosso from 1:5 to 1:1 over about 50 m suggests a very active distant source area. With a thickness of about 150 m the Flysch rosso reaches its greatest thickness in the eastern Brianza. These sediments can be interpreted as fan fringe deposits (MUTTI 1977) even if typical thickening-upward cycles are lacking. The overlying Pontida Formation is again built up by classical basin plain deposits: acyclically arranged parallel bedded turbidites of varying thickness with a sand/shale ratio of about 1:2. This succession of base-missing turbidites displays a typical facies D. The Pontida Formation ranges up into the Coniacian and in its higher part consists of thin-bedded turbidites with a sand/shale ratio of 1:4 (facies D). Higher up, the Piano di Sirone is represented by thin to very thin (1-3 cm) turbiditic layers with slightly undulating surfaces and starved ripples intercalated into a shale dominated succession. This facies E (MUTTI 1977) is a diagnostic feature for an interchannel area.

In the Campanian the sediments of the Bergamo Flysch are also different from those of the type area. The shale dominated deposits show m-thick bundles of thin-bedded turbidites arranged into symmetrical cycles. With relation to the deposi-

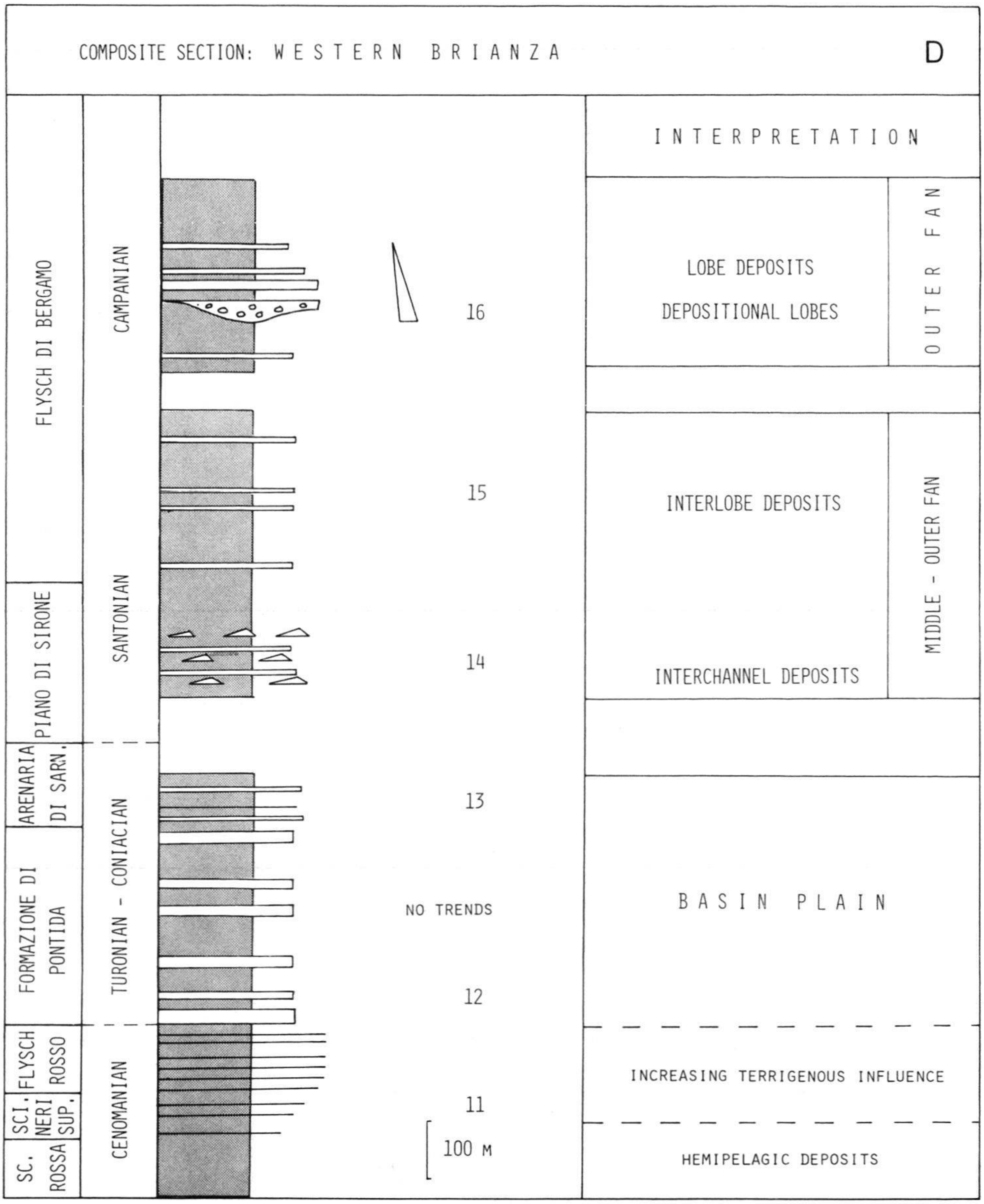

Fig. 10. Composite section: western Brianza.

tional lobes of the Bergamo Flysch further east, they are interpreted as their lateral pinch-out. The uppermost exposure of the Bergamo Flysch (section 16: Costa Masnaga) shows a thinning- and fining-upward cycle of carbonate-rich turbidites: the sequence starts with broadly-channelized conglomeratic layers up to 1.5 m thick. It is followed by rippled layers of facies E and thinner conglomeratic layers. These beds are thought to be deposits of braided channels on the top of depositional lobes (WALKER 1978), whereas the following thinning- and fining-upward sequence is the result of a decreasing supply or of a lateral shift of the lobe.

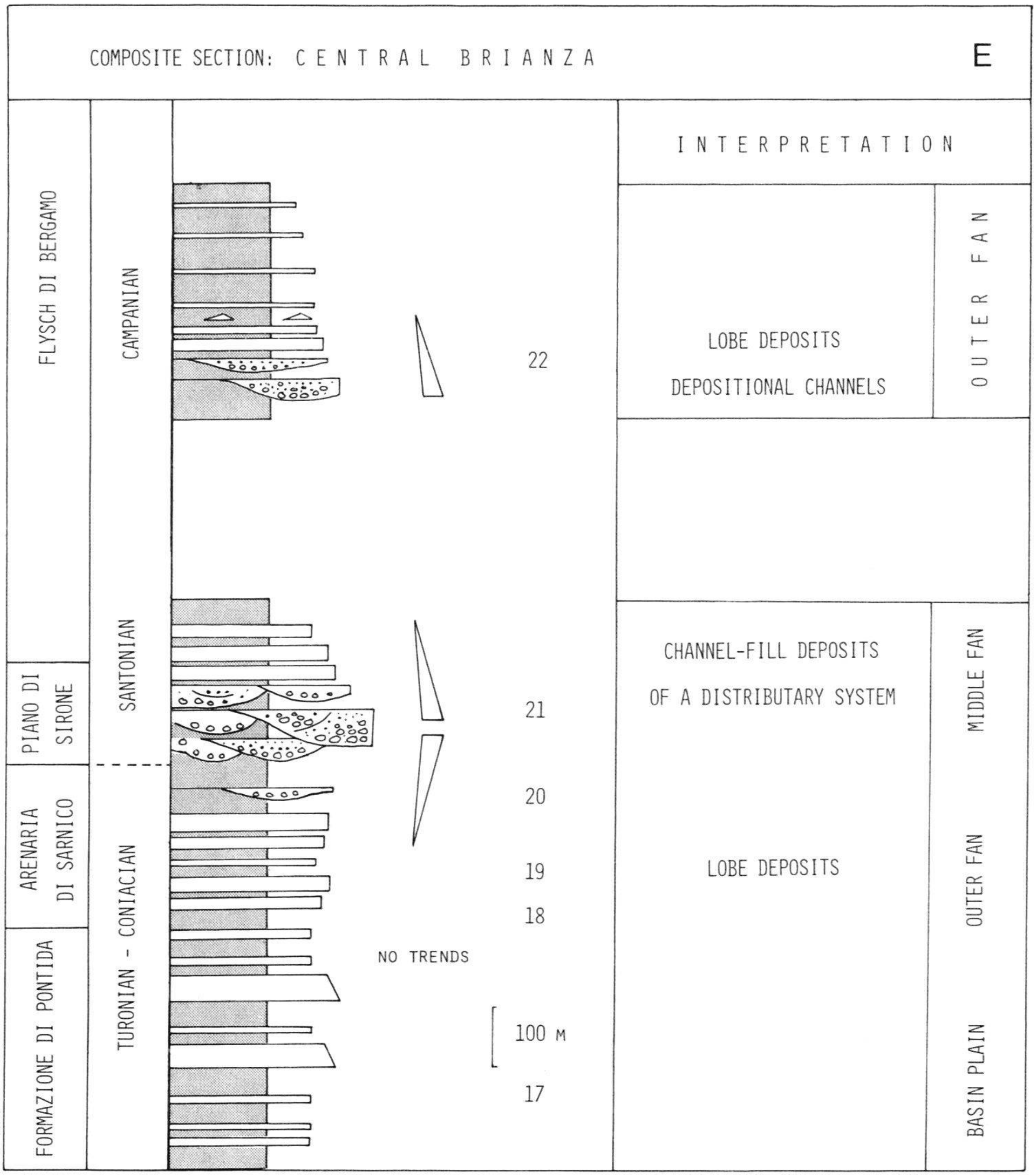

Fig. 11. Composite section: central Brianza.

Composite section: Central Brianza (Fig. 11, E on Fig. 1)

Detailed sections:

17. Sala al barro, road cut along the shore of the Lago d'Annone (coord. 749.3/075.4, Swiss top. map).
18. Oggiono village, at the street crossing to Olgiate (coord. 748.8/073.0, Swiss top. map).
19. Oggiono, opposite the railway station (coord. 747.5/072.5, Swiss top. map).
20. Colle Brianza, road cut along the Sta. Maria Hoè-Colle Brianza road (coord. 749.8/068.5, Swiss top. map).
21. Sirone, abandoned quarries to the north of Sirone.
22. Barzano, road cut along the Monticello-Dolzago road (coord. 746.2/066.1, Swiss top. map).

The thickness of the flysch in the central Brianza amounts to 800 m including the Pontida Formation and the Sarnico Sandstone with the Sirone member. In addition, 300 m of Bergamo Flysch occur at the western end of the Montevecchia. The Pontida Formation displays a classical basin plain facies association: It is composed of an acyclic sequence of generally base-missing, parallel-bedded turbidites. The sand/shale ratio is in the order of about 1:6. Beside lithic sandstones, some calcarenitic layers of reworked planktonic foraminifera are sporadically intercalated. They must be derived from a different source area, possibly a pelagic high bordering the basin (cf. BERNOULLI et al. 1981). Some of the lithic sandstone beds show bottom structures indicating a east-west transport direction. In section 17 (Sala al barro) two megabeds are exposed in the Pontida Formation. The Sarnico Sandstone differs from the Pontida Formation by an increased sand/shale ratio (1:1), still most

Fig. 12. Broadly channelized sandstone beds within thin-bedded overbank turbidites. Arenaria di Sarnico, Coniacian. Colle Brianza section.

turbidites are base-missing. All paleocurrent indicators show a clear east–west transport of the lithic turbidites. In relation to the massive sandstones of the Sarnico Sandstone further east they can be interpreted as outer-fan deposits. The upper part of the Sarnico Sandstone is not continuously exposed. The passage to the Sirone member consists of a sequence of alternating channel-fill sandstone bodies separated by thinner-bedded, muddier sediments (HÄRING 1978). The former are interpreted as infillings of turbidite channels within a deep-sea fan distributary system; the latter are thought to represent overbank deposits (Fig. 12). The broadly channelized sandstone units embedded in thin-bedded overbank deposits, are similar in many respects to the crevasse splay deposits described by MUTTI (1977) from the Eocene Hecho Group of Spain. The sequence includes a thick intercalation of pebbly mudstone deposits that were emplaced by a debris flow. Up-section, the sequence passes to massive conglomerates (Piano di Sirone) that could represent the fill of a fan channel within the distributary system. Conglomeratic channel fills have often been reported from similar depositional environments (MUTTI 1979, PIPER 1970, WALKER 1978).

The Bergamo Flysch shows a completely different character. The sandstones are generally of mica-rich calcarenitic composition but in coarse-grained deposits quartz, feldspar and crystalline rock fragments are dominant. In the central Brianza this formation is only represented by an isolated sequence that shows a thinning- and fining-upward cycle over 100 m, ranging from channelized conglomerates (facies A_1) to thin-bedded turbidites (facies D). Facies E and A_2 are also present. This facies association is interpreted as channel fill deposits of braided channels on depositional lobes.

Composite section: Eastern Brianza (Fig. 13, F on Fig. 1)

Detailed sections:

23. Airuno, brook between Airuno and Aizurro (coord. 754.0/069.4, Swiss top. map).
24. Cagliano, several isolated exposures along the Monticello-Cagliano road.
25. Monticello, road cut west of Monticello (coord. 751.7/066.7, Swiss top. map).
26. Missaglia, abandoned quarries north of Missaglia (coord. 747.9/064.6, Swiss top. map).
27. Montevecchia 1, road cut on the Montevecchia hill (coord. 749.1/064.8, Swiss top. map).
28. Montevecchia 2, road cut on the Montevecchia hill (coord. 749.1/064.8, Swiss top. map).
29. Montevecchia 3, road cut on the Montevecchia hill (coord. 749.0/065.2, Swiss top. map).

Because of structural complications in this area the total thickness of the whole flysch sequence cannot be estimated. The portion from the base of the Flysch rosso to the basal part of the Pontida Formation amounts to approximately 300 m. The equivalents of the Piano di Sirone and parts of the Bergamo Flysch reach 400 m, whereas the Campanian portion of the Bergamo Flysch exceeds 700 m.

The sequence of the Flysch rosso and of the lower Pontida Formation show the same evolution of the facies associations as in the western Brianza. The level corresponding to the Piano di Sirone contains only minor conglomeratic deposits; scattered outcrops (section 24, Cagliano) show an alternance of thin-bedded turbidites, arranged into a 5 m thickening upward sequence (facies D), some shale intervals, pebbly mudstones (facies A_2) and shales with occasionally rippled sandstone layers or starved ripples (facies E). This facies association represents an

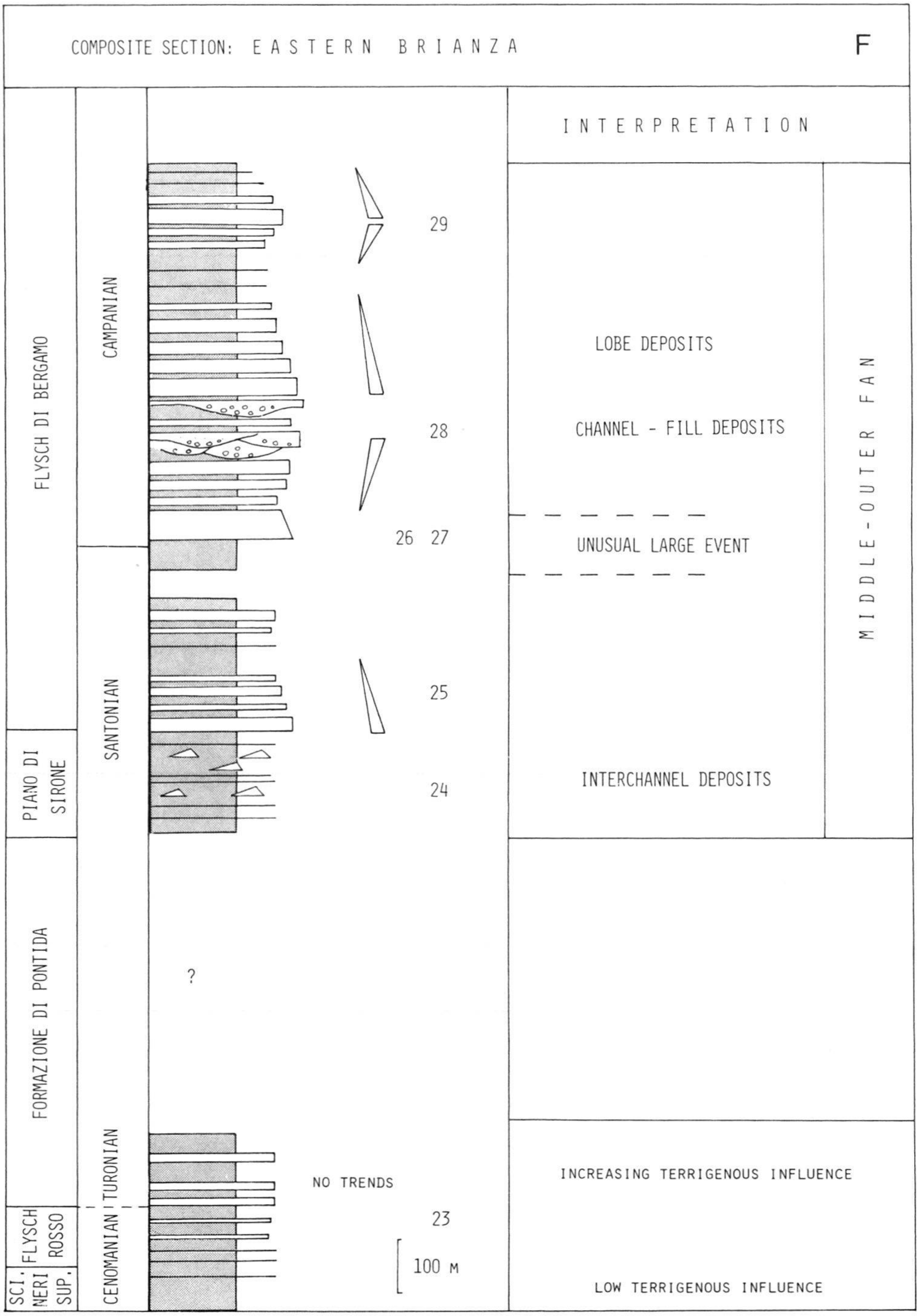

Fig. 13. Composite section: eastern Brianza.

interchannel depositional environment that can be laterally related with the Sirone Conglomerate.

The lower part of the Bergamo Flysch (Santonian) is represented by the facies C_2, D_1, D_2 and A_2. The quartz- and mica-rich sandstone beds, arranged into thickening-upward cycles, are outer-fan deposits. The Campanian part of the Bergamo Flysch shows at the base a megabed of about 30 m thickness (Missaglia Megabed, Bernoulli et al. 1981). Upsection several symmetrical thickening- and thinning-upward cycles are recognized. The average grain size is medium sand. Facies A and facies C beds show slight incision into the underlying sediment. Parallel to the thickening and thinning of the beds, the sand/shale ratio varies from 1:4 to 5:1. The sediments are interpreted as accumulations of depositional lobes in the outer fan. The oscillating supply could have been caused by lateral shifting of the deposition center.

Composite section: Pontida area (Fig. 14, G on Fig. 1)

Detailed sections:

30. Roncaletti, in the Torrente Sommaschio, near Caprino Bergamasco (coord. 759.9/067.8, Swiss top. map).
31. Vallone, brook on the northern flank of the Monte Canto basso near Pontida (coord. 758.9/066.2, Swiss top. map).
32. Mapello, behind the church of Mapello (coord. 5062.3/542.6, Carta d'Italia).
33. Pratolungo, abandoned quarry near Pratolungo (coord. 5062.3/539.6, Carta d'Italia).
34. Tassodine, footpath on the northern flank of the Monte Canto basso, near Villa d'Adda (coord. 758.4/065.3, Swiss top. map).
35. Corna, along a footpath north of "Sotto il Monte" (coord. 5062.6/538.6, Carta d'Italia).
36. Roncarro, along a footpath near Roncarro (coord. 5062.3/539.6, Carta d'Italia).
37. Predazzi, abandoned quarry near Carvico (coord. 5062.0/537.5, Carta d'Italia).
38. Monte Giglio, middle level of the Italcementi quarry "Monte Giglio" (coord. 5061.0/536.9, Carta d'Italia).

In the Pontida area, the Lombardian Flysch reaches its greatest thickness. Although only parts of the whole succession are exposed, we could determine the following values for each formation:

Scaglia cinerea (Uppermost Campanian-Maastrichtian)	150 m
Bergamo Flysch (Upper Santonian-Campanian)	1000 m
Sarnico Sandstone (Lower Coniacian-Lower Santonian)	600 m
Pontida Formation (Turonian-Lower Coniacian)	400 m

The sediments of the Pontida Formation show the salient features of a typical basin plain, here summarized as follows: regular, acyclic succession of parallel-bedded, fine-grained turbidites (i.e. absence of obvious megasequences sensu Ricci Lucchi 1975); superposition of turbidites with variable lithologic compositions probably indicating different source areas (cf. Ricci Lucchi & Valmori 1980); sandstone/shale ratio is about 1:3 to 1:5; classical facies type D (Mutti & Ricci Lucchi 1975); opposite paleocurrent directions along the basin axis (generally east to west, exceptionally west to east).

The transition to the Sarnico Sandstone is exposed only in a few small outcrops, which do not allow a detailed facies analysis. Compared with the Pontida Formation, the base of the Sarnico Sandstone has a clearly increased sandstone/shale ratio resembling an outer-fan facies association.

In the Middle Coniacian, fairly coarse-grained, thick-bedded an often amalgamated sandstones (mainly facies C) form large thickening- (and coarsening-)upward

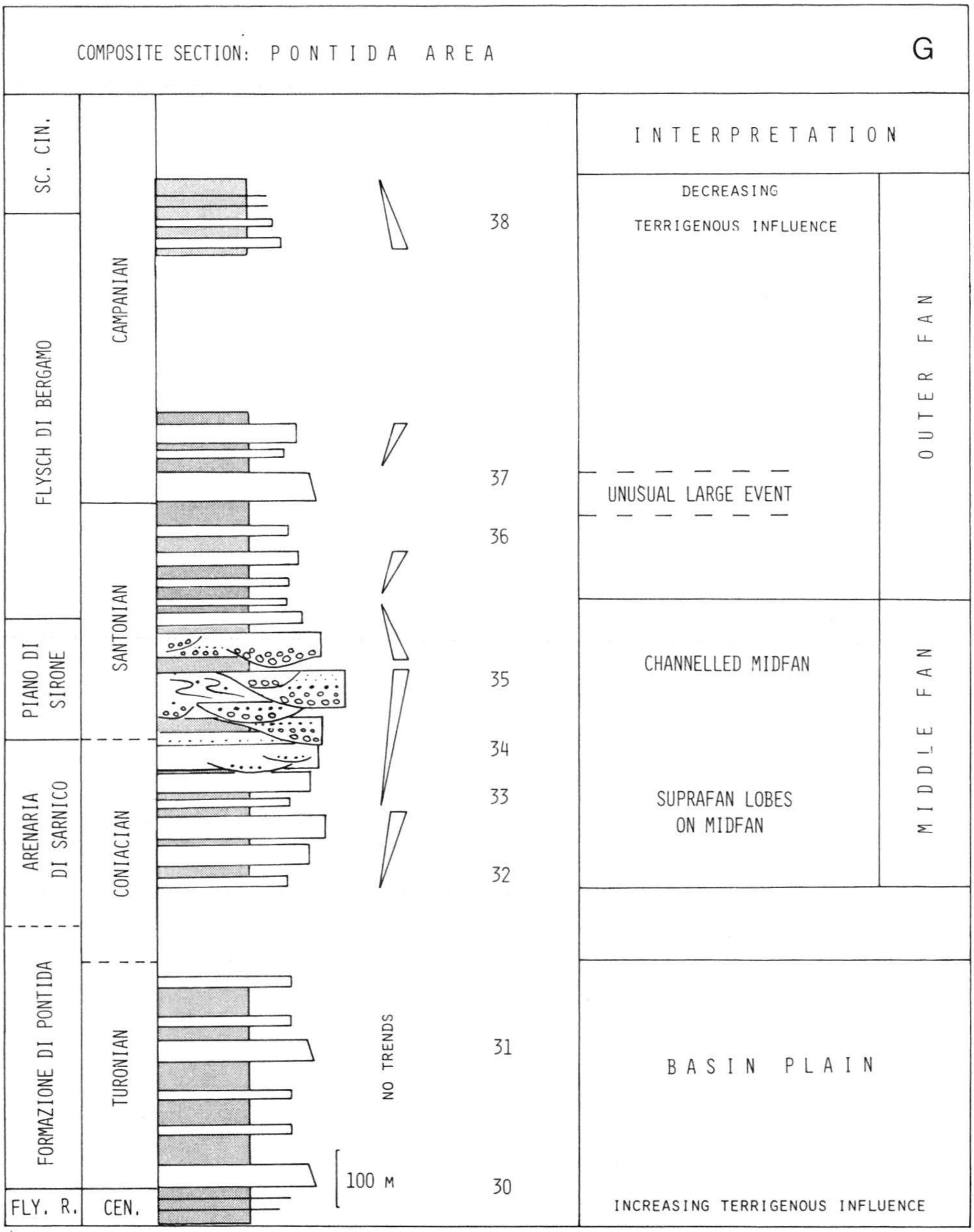

Fig. 14. Composite section: Pontida area.

cycles up to 50 m thick. We interprete them as suprafan lobes of the nonchannelized middle fan (WALKER 1978, NORMARK 1978). The erosional surfaces in the Upper Coniacian can be interpreted as channels on suprafan lobes (WALKER 1978) or as broad and shallow scours made by individual flows (NORMARK et al. 1979, RICCI LUCCHI & VALMORI 1980). In the Lower Santonian, deeply erosive, lens-shaped conglomeratic bodies are embedded in the surrounding sandstones (Piano di Sirone). These conglomerates display thinning- and fining-upward sequences in the order of 5 to 15 m thick and represent the channelized middle fan (WALKER 1978, NORMARK 1978). The succession from the Turonian to the Lower Santonian can be interpreted as a classical progradation of a deep-sea fan (progradational turbidite suite; RICCI LUCCHI 1975).

In the Upper Santonian, with the onset of sedimentation of the Bergamo Flysch, the channel system was inactivated. It is overlain by usually acyclically arranged, thick calcareous turbidites. Subordinate negative cycles are sometimes intercalated. They represent small prograding sandstone lobes. Features like these are described by numerous authors as an outer-fan facies association (e.g. WALKER 1978, MUTTI & RICCI LUCCHI 1972).

The megabed in the lowermost Campanian (section 37, Predazzi), an unusually large turbidite, can be correlated with the Missaglia Megabed in the eastern Brianza (section 26, Missaglia). It is superposed on the development of the deep-sea fan and must be related to an unusual catastrophic event (BERNOULLI et al. 1981). In the Pontida area, the middle part of the Bergamo Flysch is covered by Quaternary deposits. In the uppermost Campanian (*Globotruncana calcarata*-zone), the flysch sedimentation wanes: the sandstone-dominated turbidites are successively replaced by ash-colored clays and marls. The succession from the Lower Santonian to the Upper Campanian can be considered as a recessional turbidite suite in a broad sense (RICCI LUCCHI 1975).

Composite section: Bergamo area (Fig. 15, H on Fig. 1)

Detailed sections:

39. Santa Anna, northwest of Azzonica, along a footpath (coord. 5066.1/550.6, Carta d'Italia).
40. Castagnola, in a narrow valley north of Bastia near Bergamo alto (coord. 5063.0/550.7, Carta d'Italia).
41. Bergamo alto, part of the town wall of the old City of Bergamo (coord. 5061.9/551.9, Carta d'Italia).
42. Bosco, road cut 300 m west of the church Madonna del Bosco (coord. 5061.5/548.8, Carta d'Italia).

In the Bergamo area, a determination of the thickness of each formation is very difficult. We estimate the Pontida Formation to about 400 m thick, and the Sarnico Sandstone about 600 m.

The vertical evolution is almost the same as in the Pontida area: The basin plain deposits, equally developed as in the west, are followed, although separated by a considerable gap in outcrop, by thick, mostly coarse-tail graded sandstones of the Sarnico Sandstone, building thickening-upward cycles. They represent, together with the overlying channelized conglomerates, pebbly sand- and mudstones (Piano di Sirone), the inner and outer middle fan. The progradation of the deep-sea fan is also clearly documented here. The conglomerates of the Piano di Sirone are distinct-

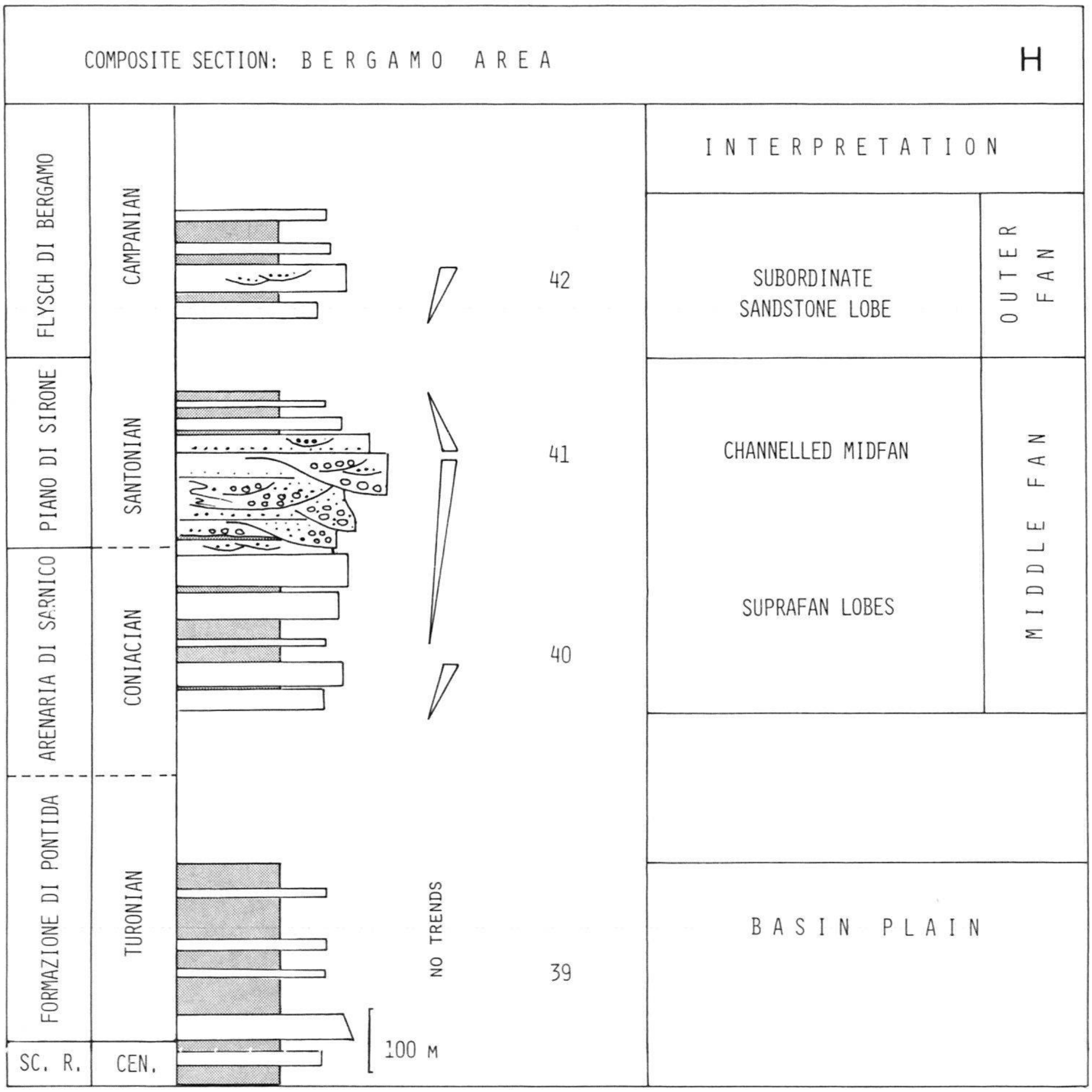

Fig. 15. Composite section: Bergamo area.

ly separated from those of the Pontida area by sandstone deposits. They thus represent different channel systems acting at about the same time. Such relationships are also well-known from proximal suprafan areas of modern deep-sea fans (Piper 1978, Normark et al. 1979). The poor outcrop conditions of the Bergamo Flysch do not allow a more precise facies interpretation.

Composite section: Rocca del Colle (Fig. 16, I on Fig. 1)

Detailed sections:

43. Tomenone, along a footpath on the northern flank of the Monte Tomenone (coord. 5058.4/560.7, Carta d'Italia).
44. Fontanelli, abandoned quarries, 800 m north of Brusaporte (coord. 5058.8/559.6, Carta d'Italia).
45. Montello, abandoned quarries, 600 m of Costa di Mezzate (coord. 5075.5/561.5, Carta d'Italia).

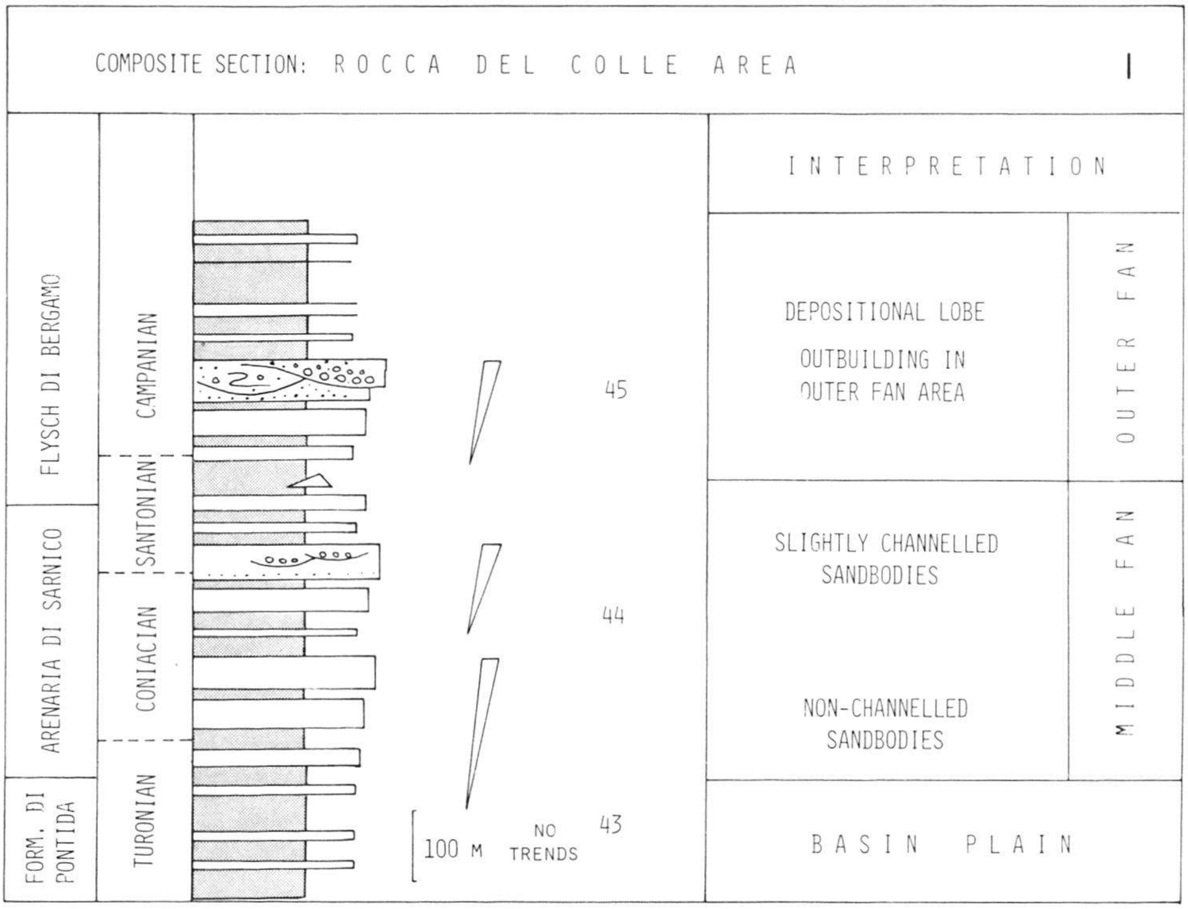

Fig. 16. Composite section: Rocca del Colle area.

In this area VENZO (1954) indicates a thickness of 300 to 350 m for the whole Pontida Formation, but today only about 50 m can be really measured. Both, the lower and the upper boundary of the Sarnico Sandstone is exposed. The calculated thickness of 300 m is clearly less than in the Brianza and in the western Bergamasco. The Bergamo Flysch reaches a thickness of about 400 m.

As in the Brianza and in the western Bergamasco, the Turonian sediments (Pontida Formation) are developed as basin-plain deposits. The Sarnico Sandstone starts directly with massive, sometimes coarse-tail graded sandstones (facies C) organized into negative cycles. Contrary to other areas, the conglomerates at the top are missing and only some slightly channelized fine conglomerates 50–80 cm thick occur; however, a progradation of the more proximal deposits is clearly visible.

The overlying Bergamo Flysch displays an acyclic, monotonous succession of relatively thick sandstones and marls (sandstone/shale ratio is about 1:1), often interrupted by "complex thickening- and coarsening-upward cycles" (RICCI LUCCHI 1975) representing depositional lobes in the outer-fan area.

Composite section: Gandosso area (Fig. 17, J on Fig. 1)

Detailed sections:

46. San Pantaleone, along the San Pantaleone–Gandosso road (coord. 5055.9/568.3, Carta d'Italia).

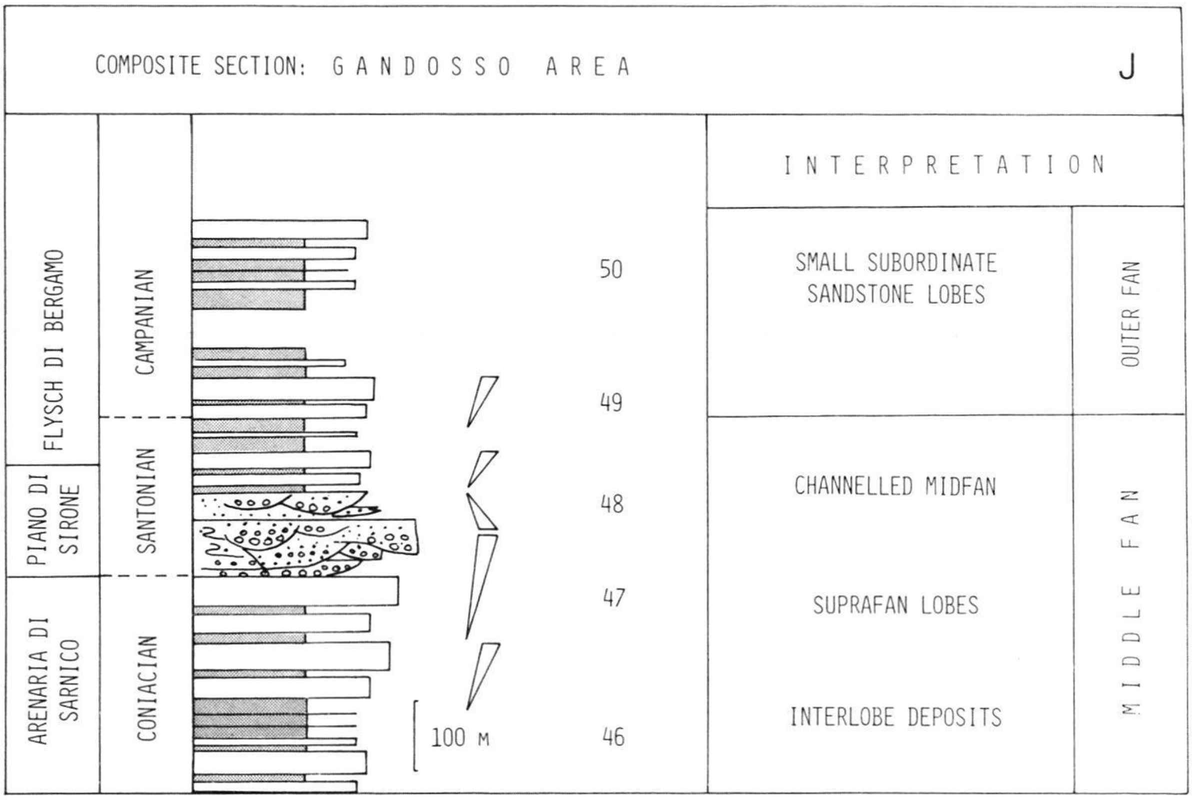

Fig. 17. Composite section: Gandosso area.

47. Molere, abandoned quarry, 1 km northwest of Gandosso (coord. 5057.6/569.6, Carta d'Italia).
48. Carobbio, road cut near Carobbio degli Angeli (coord. 5058.2/565.8, Carta d'Italia).
49. Gandosso, abandoned quarry in Gandosso (coord. 5070.1/569.2, Carta d'Italia).
50. Maimoni, abandoned quarry 200 m west of San Pantaleone (coord. 5055.7/567.6, Carta d'Italia).

In this area, only the Sarnico Sandstone and the Bergamo Flysch, each at least 300 m thick, are exposed. The whole Sarnico Sandstone displays one huge thickening- and coarsening-upward cycle, representing the nonchannelized middle fan. The conglomerates at the top are again interpreted as channel-fill sequences of the proximal middle fan.

The calcareous turbidites of the Bergamo Flysch exhibit the well-known features of the outer-fan facies association. The conglomerates at the base of the formation document the transition from the middle to the outer fan.

Composite section: Sarnico area (Fig. 18, K on Fig. 1)

Detailed sections:

51. Valdone, abandoned quarry, 1.5 km northwest of Capriolo (coord. 5055.4/578.8, Carta d'Italia).
52. Adrara, along the Adrara–Foresto Sparso road (coord. 5060.8/573.4, Carta d'Italia).
53. Paratico, quarries underneath the "Castello di Paratico" (coord. 5056.4/574.3, Carta d'Italia).
54. San Giuseppe, abandoned quarries south of Foresto Sparso (coord. 5059.5/571.9, Carta d'Italia).
55. Tremellini, along the Foresto Sparso–Tremellini road (coord. 5060.0/571.6, Carta d'Italia).
56. Credaro, quarry west of Credaro (coord. 5056.9/572.1, Carta d'Italia).
57. Castelrampino, quarry near Castelrampino west of Credaro (coord. 5056.3/571.6, Carta d'Italia).

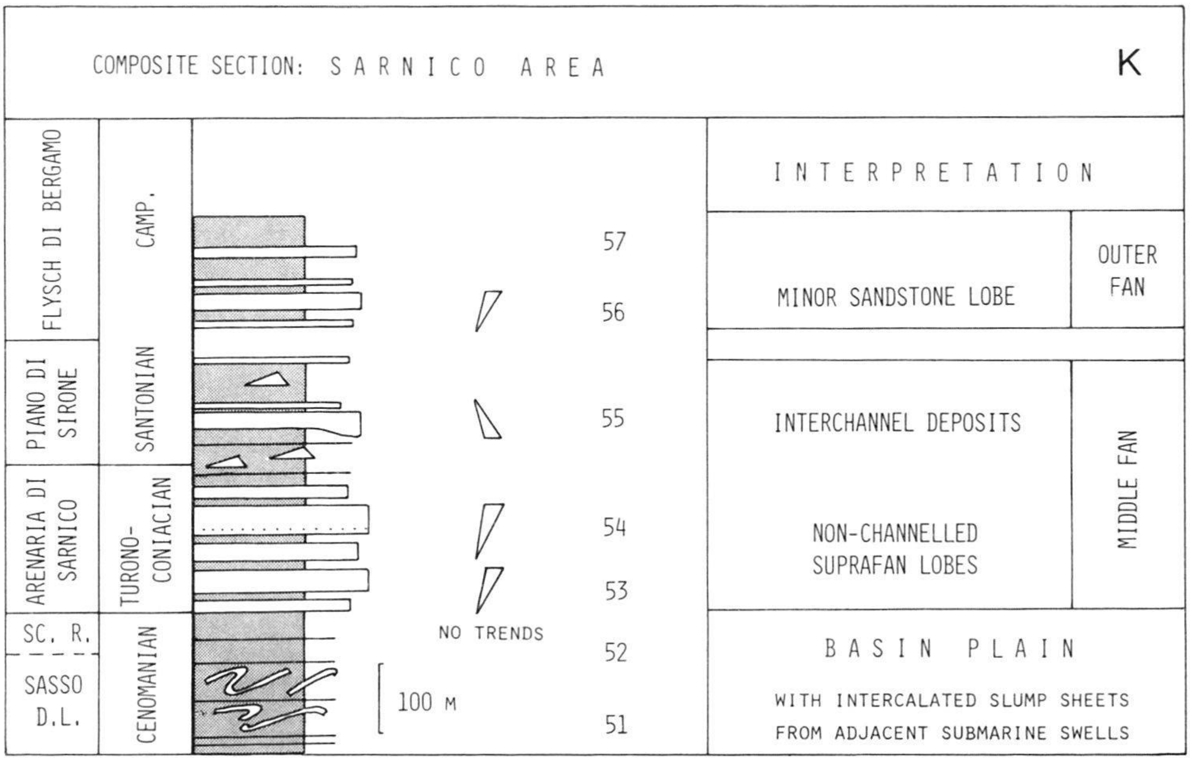

Fig. 18. Composite section: Sarnico area.

Fig. 19. Very thin turbidites with flat base and rippled surfaces (facies E), and minor channelized turbidites, representing an interchannel facies association. Piano di Sirone member of the Arenaria di Sarnico, Lower Santonian. Tremellini section.

The Sasso della Luna (up to the Middle Cenomanian) and the Scaglia rossa together measure 250 m. The thickness of the Sarnico Sandstone and the Bergamo Flysch is estimated as 300 m each.

The Sasso della Luna as well as the Scaglia rossa are both classical basin plain deposits, built up by turbidity currents carrying pelagic sediment. Submarine slumping, as observed south of Sarnico and near Foresto Sparso, indicates variations in the submarine morphology within the Lombardian basin. It is also possible, that some of these slumps originated from submarine scarps along the western boundary faults of the Trento Plateau (CASTELLARIN 1970). Terrigenous flysch sedimentation starts in the Turonian directly with massive and coarse-tail graded sandstones belonging to the Sarnico Sandstone. Over the whole formation a clear thickening- and coarsening-upward trend is observable. In the Lower Santonian, a mudstone-dominated succession interrupted by repetitive bundles of turbiditic sandstones organized in symmetric cycles (equivalent of the Piano di Sirone) is present. MUTTI (1977) describes such features as diagnostic for interchannel areas (Fig. 19). This interpretation is supported by the nearby occurrence of channelized conglomerates of the same age.

As usual, the Bergamo Flysch is built up by normally acyclically arranged calcareous turbidites often interrupted by negative cycles comprising 3–10 single beds (Fig. 20).

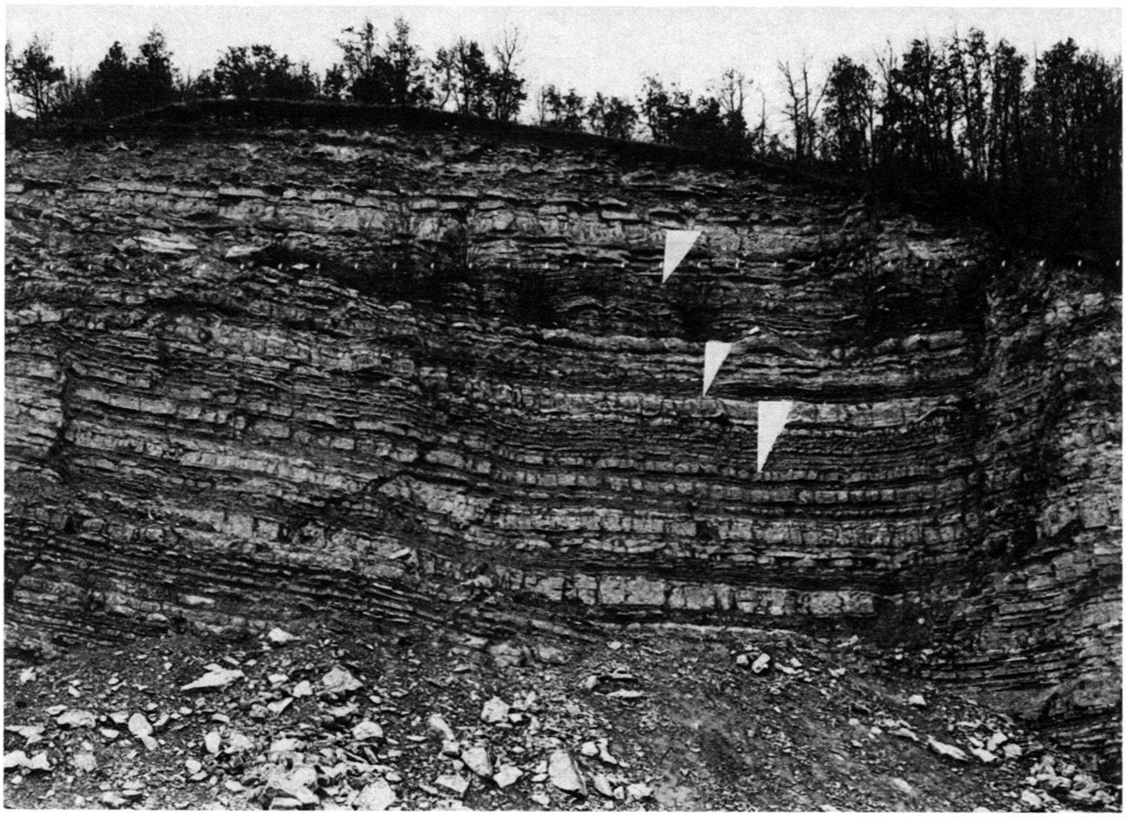

Fig. 20. Superposition of thickening-upward sequences (▽) of depositional lobes in an outer-fan facies association. Flysch di Bergamo, Campanian. Castelrampino section.

Composite section: Gussago area (Fig. 21, L on Fig. 1)

Detailed sections:

58. Polaveno, along the Iseo–Polaveno road (coord. 5061.8/588.2, Carta d'Italia).
59. Madonna della Stella, along the path leading to the church "Madonna della Stella", 1.5 km northeast of Gussago (coord. 5050.2/591.9, Carta d'Italia).

Whereas in the Varesotto, the Brianza and the Bergamasco a flysch sequence over 1500 m thick was accumulated from the Turonian to the Santonian, in the Gussago area, only about 100 m of Scaglia rossa were deposited during the same time interval. The Scaglia rossa consists mainly of hemipelagic marls and marly limestones with intercalated pelagic turbidites, probably derived from the Trento Plateau. Terrigenous material is absent. We therefore interpret this facies as deposited on a relative high, probably a fault block, marginal to the Trento Plateau in the east. In the Campanian, calcareous turbiditic sandstones and marls, which are identical to the Bergamo Flysch, indicate that the flysch trough was filled up and that the most voluminous turbidity currents episodically invaded the marginal fault block. The whole succession up to the Maastrichtian has a thickness of 220 m.

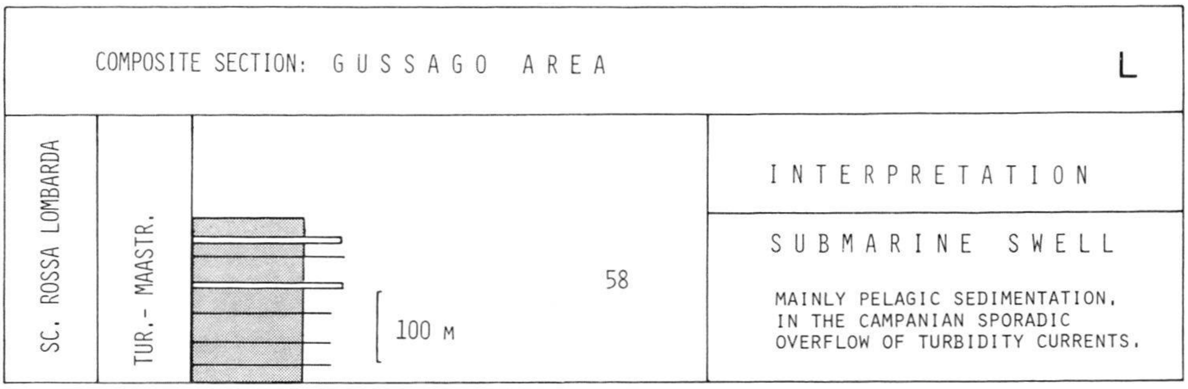

Fig. 21. Composite section: Gussago area.

Sedimentary and paleogeographic evolution

Our reconstruction of the sedimentary and paleogeographic evolution of the Lombardian Basin during the Late Cretaceous (Fig. 22 and Plate) is based on the correlation of the composite sections (Fig. 7–11, 13–18, 21).

Late Cenomanian

In the Late Cenomanian terrigenous turbidites began to replace the hemipelagic sedimentation over most parts of the Lombardian Basin. Different facies associations can be distinguished over the whole area. In the west, the Varesotto Flysch starts with channelized deposits containing large amounts of Upper Cretaceous shallow-water debris, probably derived from a shoal or shelf edge positioned in the north, whereas more distal deposits derived from the same source area were laid

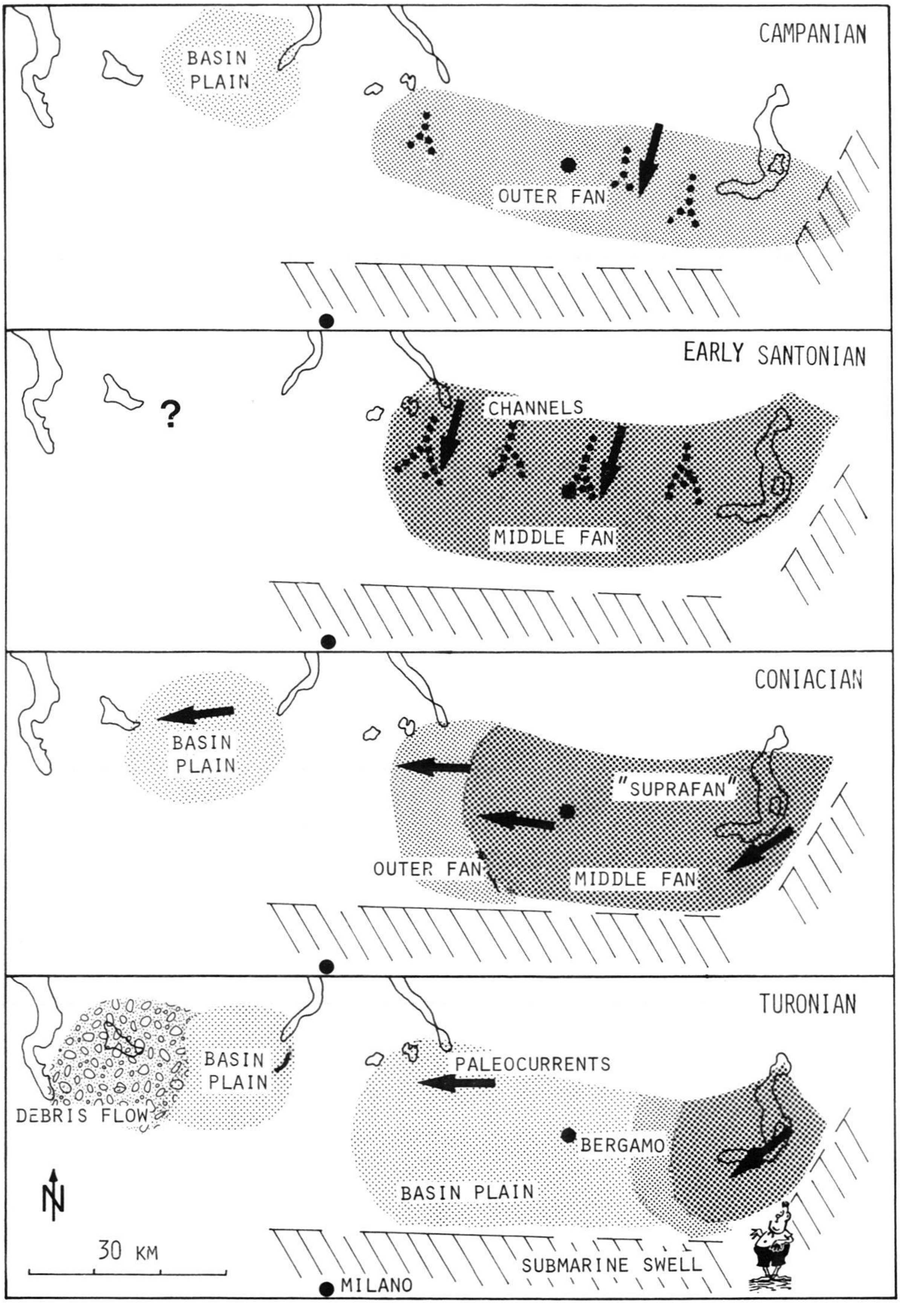

Fig. 22. Facies distribution and evolution of the deep-sea fan systems in the Lombardian Basin.

down in the Mendrisiotto. The terrigenous sediments of the Flysch rosso are restricted to the Brianza and the western Bergamasco. They are associated with black shales, recording anoxic episodes in the deepest parts of the Lombardian Basin, that obviously acted as a trap during the earliest phase of flysch sedimentation. In the Sarnico area the hemipelagic marls with intercalated pelagic turbidites of the Scaglia rossa replace the white colored Sasso della Luna. This monotonous succession is occasionally interrupted by submarine slumps, which are probably derived from fault scarps along the eastern margin of the Lombardian Basin (CASTELLARIN 1970).

Turonian

In the eastern Bergamasco, the coarse-grained and thick-bedded Sarnico Sandstone started to build up a suprafan. Towards the west these sediments lose their proximal character and pass gradually through a weakly developed outer fan into the basin plain deposits of the Pontida Formation in the western Bergamasco and the Brianza. The Pontida Formation represents the distal part of the submarine fan system. Progradation of this system from east to west is confirmed by the paleocurrent data.

During the Late Turonian, the suprafan reached the central Bergamasco (Rocca del Colle area). This is documented in the composite sections by overall thickening- and coarsening-upward cycles.

In the central Bresciano an only 30 m thick succession of hemipelagic Scaglia marls and limestones was deposited. This sequence is, compared with the at least 400 m thick Turonian flysch, extremely thin and must have been deposited in areas sheltered from coarse terrigenous influx, probably on a elevated fault block between the Trento Plateau and the deep Lombardian Basin. In western Lombardy, the pebbly mudstone and the lithologically different basin plain deposits of the Varesotto Flysch underline a separate evolution of the western basin, lasting throughout the Late Cretaceous. Sediment transport was probably from north to south as in the underlying channel-fill deposits of Late Cenomanian age.

Coniacian

In the Coniacian the Sarnico Sandstone reached the Brianza, where it exhibits an outer-fan facies association. Over the whole Bergamasco region the Sarnico Sandstone is developed as nonchannelized middle fan. It is characterized by coalescent sandstone lobes documented by negative cycles ranging from 10 to 50 m thickness and by ephemeral depositional channels (sensu NELSON & KULM 1973). During the Coniacian the Sarnico Sandstone gets coarser and thicker bedded: the middle fan enlarges. In the central Bresciano the sedimentation of the Scaglia rossa continues.

Santonian

In the Early Santonian, the progradation of the Sarnico fan reaches its greatest extension. Conglomeratic channel-fill deposits, embedded in the surrounding Sarnico Sandstone, occur at the same time at different locations (Sirone, Pontida, Bergamo, Gandosso). Laterally the conglomerates are replaced by shale-rich interchannel deposits. The clastic content of the conglomerates is almost identical at all localities and suggests a common source area and close relation between the different channel-fill deposits. Paleocurrent indicators (imbrication, channel geometry) within the conglomerates, also of variable orientation, are consistent with a general pattern of sediment dispersal from the north.

In the Late Santonian, with the isochronous onset of the Bergamo Flysch, the lithologic composition changes abruptly. The sandstone/shale ratio decreases continuously up-section. Individual turbidites get thinner and the average grain size shifts towards the sand-silt range. The beds are in general acyclically arranged, but are often interrupted by negative cycles comprising 3–10 individual layers. This evolution occurs simultaneously in the whole study area and announces the recession of the middle fan. The remarkable amount of shallow-water material (red algae, benthonic foraminifera and fragments of echinoids and shells) points to the erosion of a neritic domain. The concomitant occurring facies change (in grain size as well as in lithological composition) could be related to either global or orogeny-induced relative sea-level changes.

Campanian

The Bergamo Flysch accumulates as a monotonous outer fan association all over the Bergamasco and the western Brianza. The lateral migrating depositional lobes indicate neither progradation nor recession of the fan system during the Campanian (Ricci Lucchi & Valmori 1980). During the latest Campanian (*Globotruncana calcarata*-zone), the terrigenous influence decreased and the fan system was inactivated. The Campanian flysch sequence that exceeds 700 m at Montevecchia undergoes a rapid facies change over 6 km towards the west, where in the Merone area, it is replaced by a mudstone dominated sequence only 300 m thick. We think that this rapid facies change is caused by a submarine swell or at least a local elevation which probably existed in earlier times. The independent evolution of the flysch in the Varesotto and Mendrisiotto also suggests a morphological differentiation of the basin. In the Early Campanian, the marginal fault block in the Bresciano was episodically affected by the overflow of voluminous turbidites.

Basin configuration

The lack of information in the adjacent northern Bergamasc Alps – Upper Cretaceous deposits occur only along the Giudicaria line and Lake Garda – does not allow a reconstruction of the northern limit of the flysch trough. To the south, thick Tertiary and Quaternary deposits cover the Mesozoic sediments. The only information available is from well-data of the Malossa oil field. In the Malossa field, the Upper Cretaceous is developed as a thin, sandstone-free Scaglia, which is interpreted as deposited on a submarine swell (Groppi et al. 1976). Whether this swell was of only local significance or was regionally connected to the Trento plateau remains unclear. In this paper we use the term "Malossa-swell" for this submarine high.

A further basin-confining element has already been mentioned in the Bresciano by AUBOUIN et al. (1970). They suggest a number of intermediate zones between the Lombardian Basin and the Trento Plateau which was characterized by pelagic sediments throughout the Cretaceous. CASTELLARIN (1970) demonstrated a similar situation north of Lake Garda: Here the Lombardian Basin repeatedly subsided from the beginning of the Jurassic, along a NNE-SSW striking fault zone that was active at least up to the Maastrichtian. A parallel fault zone between Sarnico and Brescia is likewise postulated from the sedimentary record.

Towards the west the outcrops of the Upper Cretaceous flysch are limited by Quaternary cover. The only suggestion for a basin margin is given by the slope facies of the Turonian. Progradation of the western basin margin towards the east, as suggested by AUBOUIN et al. (1970) is not compatible with the occurrence of Campanian basin plain deposits in the Mendrisiotto. The basin margin postulated in the south and east is in line with the paleocurrent pattern. The available data show that the clastic flow entered the basin from the north (CASTELLARIN 1976) and was deflected along an east-west trending basin axis. A rich *Rhabdammina* fauna, which is considered usually as indicator for a deep marine environment, populated the seafloor. However, the lack of carbonate-free hemipelagites indicates that the turbidite sequence accumulated everywhere, and at all times, above the calcite compensation depth. The flysch sedimentation, even with a maximum thickness of 2000 m does not lead to a shallowing of the basin, and after withdrawal of the terrigenous influx the basin was dominated again by hemipelagic sedimentation (Scaglia).

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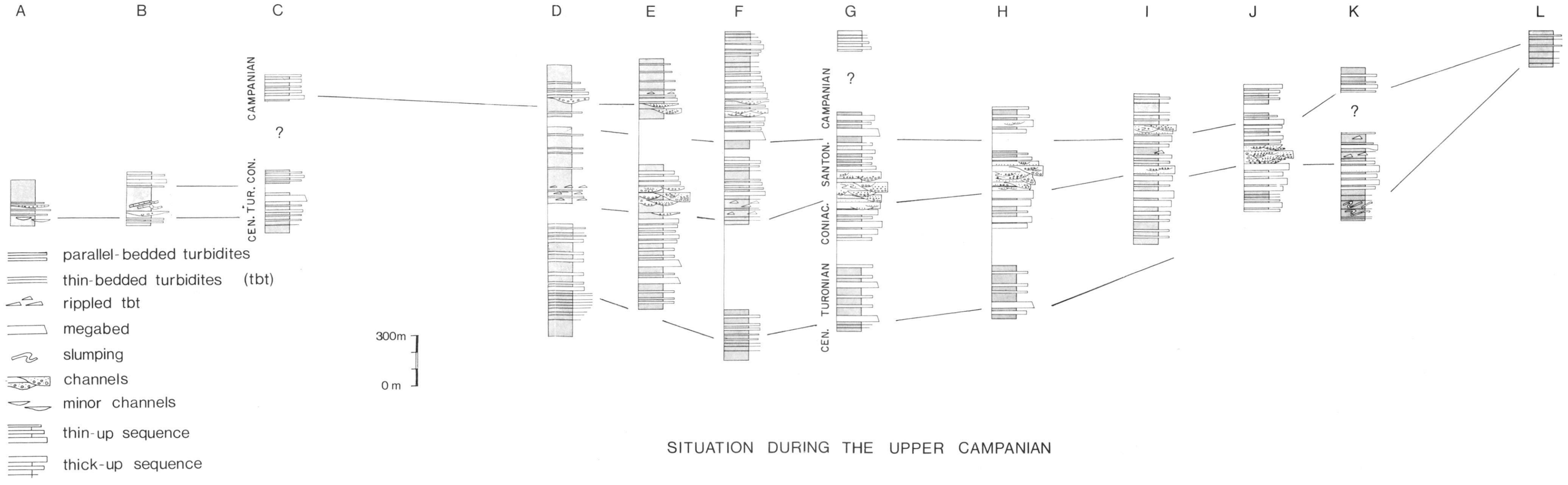
LATE CRETACEOUS FLYSCH IN LOMBARDY



SITUATION DURING THE UPPER CAMPANIAN