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The Missaglia Megabed, a catastrophic deposit in the Upper Cretaceous Bergamo Flysch, northern Italy[1])

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ABSTRACT

Within the generally monotonous turbidite sequences of the Upper Cretaceous Lombardian Flysch, occasional thicker graded units, 4 to over 30 m thick, occur. They invariably overlie pebbly mud- to siltstones and grade from granule-bearing conglomerates into calcarenites and marlstones. They occur in basin plain (Pontida Formation) and outer-fan sequences (Bergamo Flysch) but cannot be integrated into the cyclic pattern of fan deposition.

The thickest of these intervals, the Missaglia Megabed, is intercalated into the Upper Santonian-Campanian Bergamo Flysch and can be traced over at least 12, presumably over 25 km. It overlies 6 m of pebbly mudstone with plastically deformed slabs of basinal marls of Aptian to Middle Cenomanian age, of turbiditic flysch sandstones and of cobbles and boulders of Liassic shallow-water and Cretaceous pelagic limestones set in a fluidally deformed silty matrix. The megabed itself consists of a 1 m thick basal conglomerate grading upwards into 25–30 m of coarse-tail graded calcarenite, calcisiltite and marlstone. In contrast to the terrigenous turbidites of the Lombardian Flysch, the Missaglia Megabed mainly contains along its base fragments of Upper Cretaceous pelagic limestones, of Jurassic shallow-water and pelagic limestones the same as in the sequence of the Trento Plateau, and, in the arenitic-pelitic interval, size-sorted tests of planktic foraminifera of Albian to Early Campanian age, quartz grains, bioclastic silt and redeposited coccolith ooze. The source area of the megabed is thus thought to have been a submerged high, possibly the Trento Plateau to the east and the emplacement of the catastrophic deposit is seen in connection with synsedimentary tectonics along the boundary faults which confined the Lombardian Basin during the Late Cretaceous. The sediment volume displaced by the Missaglia event must be larger than 4 km^3 and probably exceeds 20 km^3.

Palynomorphs (pollen, spores and dinocysts) from the underlying Bergamo Flysch are dated as Late Santonian–Early Campanian. The pollen assemblage shows close relationship to the contemporaneous Normapolles assemblages from Hungary.

RIASSUNTO

Tra le sequenze torbiditiche, generalmente monotone, del Flysch Cretacico superiore Lombardo, si trovano a volte unità gradate più potenti, di spessori compresi tra 4 e oltre 30 m. Esse ricoprono invariabilmente dei pebbly mudstones e passano gradualmente da conglomerati a calcareniti e a marne; si trovano in sequenze di piana di bacino (Formazione di Pontida) e di conoide esterna (Flysch di Bergamo), ma non possono essere integrate nel modello di deposizione ciclica di conoide.

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Il più potente di questi intervalli, il Megabed di Missaglia, è intercalato nel Flysch di Bergamo, di età santoniano superiore-campaniana, e può essere seguito per almeno 12, ma probabilmente anche 25 km. Esso ricopre 6 m di pebbly mudstone con placche plasticamente deformate di marne di bacino, di età aptiano-cenomaniana media, e di arenarie torbiditiche e con blocchi di Calcari Grigi liassici e di calcari pelagici del Cretacico superiore (Scaglia). Il megabed s. str. consiste di un conglomerato basale, dello spessore di un metro, che passa gradualmente verso l'alto a 25–30 m di calcarenite gradata, calcisiltite e marna. In contrasto rispetto alle torbiditi terrigene del Flysch Lombardo, il megabed, oltre ai minori frammenti litici che si trovano normalmente nei conglomerati e nelle arenarie del flysch, contiene suprattutto frammenti di calcari pelagici del Cretacico superiore, frammenti litici di calcari liassici di acqua poco profonda e di calcari pelagici come quelli contenuti nel Plateau di Trento; nell'intervallo arenitico-pelitico sono contenuti gusci, assortiti secondo le dimensioni, di foraminiferi planctonici di età aptiano-campaniana inferiore e inoltre, granuli di quarzo e silt bioclastico. La matrice è costituita da fango a coccoliti risedimentati.

Si ritiene quindi che la zona di origine del megabed sia stata un alto morfologico sottomarino, forse il Plateau di Trento a oriente, e che la messa in posto del deposito catastrofico sia connessa con la tettonica sinsedimentaria lungo le faglie di confine che delimitavano il Bacino Lombardo durante il Cretacico superiore. Il volume del sedimento rimosso dall'evento di Missaglia deve essere stato maggiore di 4 km^3 e probabilmente superava i 20 km^3.

Forme palinologiche (pollini, spore e dinocisti) provenienti dal Flysch di Bergamo sottostante sono state datate Santoniano superiore–Campaniano inferiore. L'associazione a pollini mostra chiaramente una stretta relazione con le coeve associazioni a Normapolles dell'Ungheria.

Introduction

In the Lombardian zone of the Southern Alps, Late Cretaceous terrigenous flysch sediments conformably overlie a deepening-upward pelagic to hemipelagic sedimentary sequence of Jurassic to Early Cretaceous age deposited on a submerged distal continental margin. The terrigenous sequence locally begins with Late Cenomanian fan fringe sediments (Flysch rosso, Varesotto Flysch p. p.), which overlie Aptian to Late Cenomanian hemipelagic marlstones and intrabasinal lime mud turbidites (Scaglia variegata, bianca, rossa and Sasso della Luna). From Turonian to Early Santonian, the westward progradation of a deep-sea fan system, including basin plain (Formazione di Pontida, Varesotto Flysch p. p.; Turonian-Coniacian), outer-fan to nonchannelized middle-fan (Arenaria di Sarnico, Turonian–Coniacian) and channelized middle-fan deposits (Piano di Sirone, Lower Santonian) is clearly documented by an overall thickening- and coarsening-upward trend (Bichsel & Häring 1981). In the Late Santonian, recession of the fan system led to deposition of outer-fan deposits (Flysch di Bergamo, Upper Santonian-Campanian) before hemipelagic and turbiditic carbonate sedimentation was resumed (Scaglia cinerea and rossa, Upper Campanian to Paleocene). The Cretaceous flysch sequence mainly contains lithic fragments of sediments and crystalline basement rocks of South-Alpine to Austroalpine facies; there is, however, no structural unconformity associated with this flysch in the Lombardian basin itself which remained a deep basin throughout the Cretaceous.

Massive layers, 4 to over 30 m thick, are occasionally found interlayered with the monotonous turbidite sequences of the Pontida Formation and of the Bergamo Flysch. The host turbidite sequence generally comprises sandstone beds from 30 to 50 cm thick, although some range from 10 to 200 cm. The megabeds (Rupke 1976a, b) are distinctly graded with calcirudites and calcarenites along their base, passing upward into calcisiltites and thick homogenous marlstones and invariably overlie pebbly mudstones.

The presence of thick-bedded marlstones was already noted by VENZO (1954) and AUBOUIN et al. (1970) who called them "intercalations of Sasso della Luna (facies)" without, however, discussing their origin. The close association with "breccias" was also observed by VENZO (1954) and SAMES (1970) who, following DE ROSA (1965), therefore related these deposits to submarine mass flow processes.

In contrast to the "normal" turbidite beds, megabeds can be followed over large distances. They also do not fit into the cyclic pattern of fan deposition and, although they are related to submarine mass flow processes, their textures, structures and lithologic composition are clearly distinct from those of the enclosing turbidite suite. Apparently, the deposition of the megabeds is related to unusual large-scale events superimposed onto the general submarine fan evolution.

Megabeds have been observed in the basin plain sequences of the Pontida Formation (BICHSEL & HÄRING 1981, Fig. 4) and of the Varesotto Flysch and in the outer-fan deposits of the Flysch di Bergamo (BICHSEL & HÄRING 1981). Their occurrences are set out in Table 1 (cf. BICHSEL & HÄRING 1981, Plate). In this paper

Table 1: *Occurrences of megabeds in the Pontida Formation and in the Bergamo Flysch. For exact location of sections see* BICHSEL & HÄRING (1981).

	Pebbly mudstone	Conglomerate	Calcarenite-marlstone	Age
Bergamo Flysch				
Maimoni	0.6 m	0.3 m	1.7 m	Upper Campanian
Montello	0.3 m	0.1 m	2.0 m	Lower Campanian
Missaglia Megabed (Missaglia, Predazzi)	6 - 8 m	0.5 m	25 - 31 m	Lower Campanian
Pontida Formation				
Vallone	0.6 m 0.8 m	0.5 m 0.4 m	9 m 11 m	Middle-Upper Turonian
Sala al Barro	0.5 m 0.3 m	0.2 m 0.2 m	6 m 5 m	Middle Turonian
Folla	0.7 m	0.1 m	8 m	Middle Turonian
Roncaletti	0.1 m	0.1 m	8 m	Lower Turonian
Lorentino	1.0 m 0.6 m	0.1 m 0.1 m	14 m 6 m	Turonian

we shall describe the general organization, the sedimentary structures, the clastic content and the biostratigraphy of the largest of the megabeds, the Missaglia Megabed, and discuss its paleotectonic significance.

Occurrence and location of sections

The Missaglia Megabed is intercalated into the lower part of the Bergamo Flysch (Lower Campanian), an outer-fan association comprising complexely overlapping depositional lobes (BICHSEL & HÄRING 1981). In this formation, sandstone beds range from 20 to 200 cm and show characteristics of facies $D_{1,2}$, $C_{1,2}$ and occasionally B_2 (MUTTI & RICCI LUCCHI 1975); locally symmetrical cycles (thickening- and coarsening-upward/thinning- and fining-upward) up to 30 m thick are observed. In contrast to the predominantly siliciclastic sandstones below, the Bergamo Flysch contains also abundant carbonate fragments derived from a Late Cretaceous shelf area. In the outcrop area of the Missaglia Megabed, the thickness of the Bergamo Flysch is about 800 m.

The Missaglia Megabed is best exposed in a complex of three now abandoned quarries 1 km north of the small town of Missaglia (748 150/064 800, Swiss topographic map 1:50000, sheet 297, Como; Fig. 1, 2). The features here described are best exposed in the southernmost of the three quarries facing towards Missaglia (Fig. 4). A north-facing second quarry abutts against the first, separated merely by a narrow ridge. In a third quarry some 150 m north of the second, only the upper part of the section is exposed but includes the contact of the massflow with the overlying fan deposits.

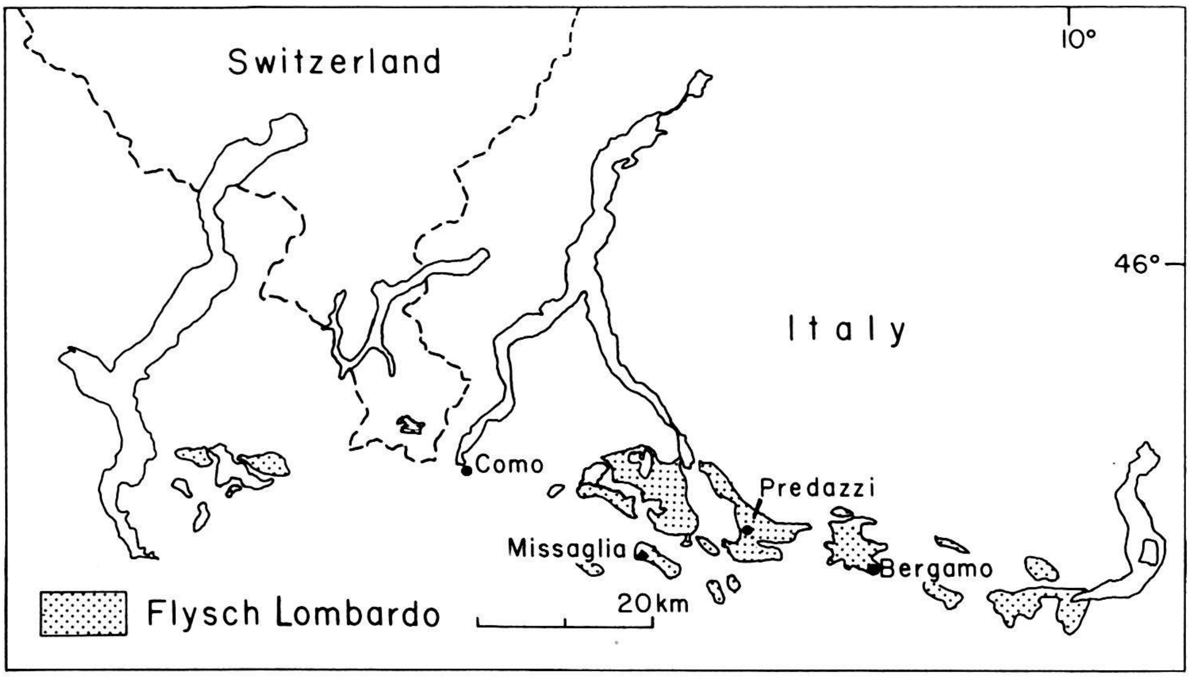


Fig. 1. Outcrop area of Lombardian Flysch (Upper Cretaceous) and location of Missaglia and Predazzi.

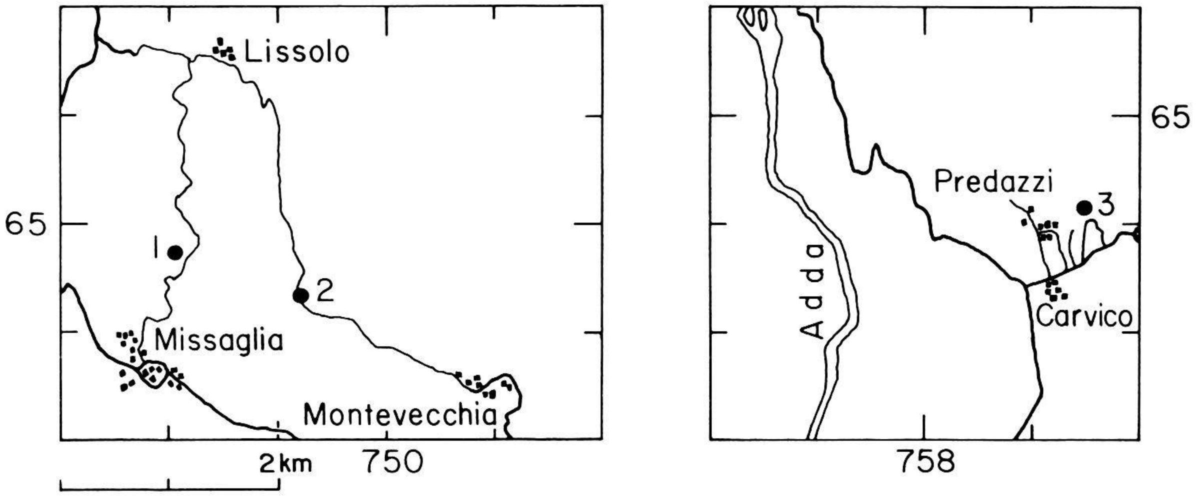


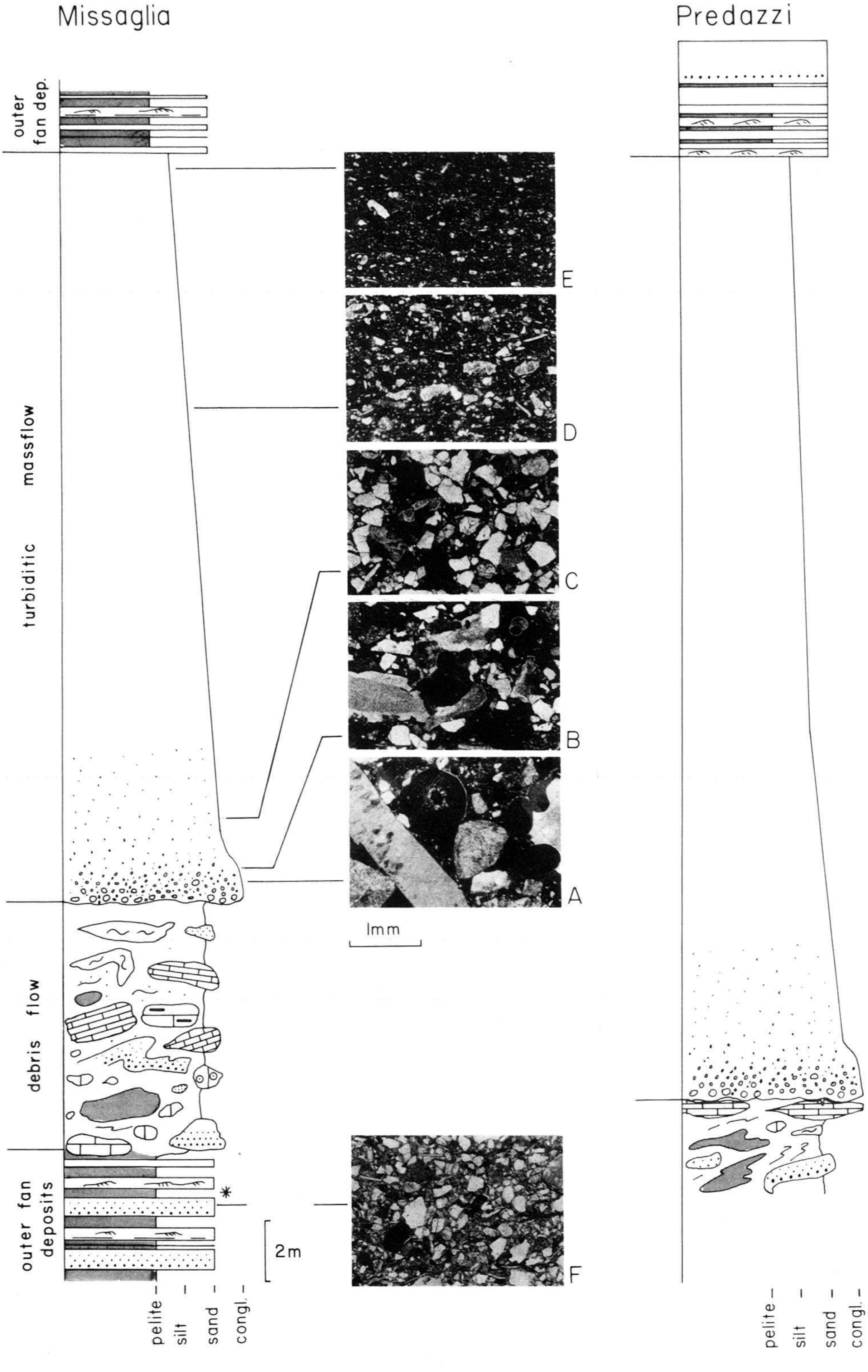
Fig. 2. Locations of sections north of Missaglia (1), along road from Montevecchia to Lissolo (2) and near Predazzi (3). Coordinates from Swiss National Map, 1:50000, sheet 297, Como.

Excavations in these quarries had already ceased long before our investigations were initiated in 1976 and 1977. A first sedimentological and paleontological description was subsequently presented in an unpublished ETH-diploma thesis on the Montevecchia area by MADELEINE STEINER (1977). Prior to those preliminary investigations the southernmost of the three quarries was extensively used as a refuse depository which not only made work unpleasant but increasingly buried the outcrops. To protect this unique and valuable geological locality from becoming completely filled and eventually lost, the "Gruppo Naturalistico della Brianza" was approached who in turn succeeded in preventing the Comune di Missaglia from further dumping of refuse. Subsequently the refuse already in the quarries was covered by a layer of earth and the quarries now are included in a protected area.

In the southern quarry the beds dip gently towards the northwest. Towards the south they are deformed into a east-west-trending south-vergent kinkfold, giving rise to differential movements and small overthrusts in the thinner bedded sandstones (cf. Fig. 4). About 1.5 km to the southeast, along strike, the pebbly mudstone and the calcarenite/marlstone member of the Missaglia Megabed are discontinuously exposed along the road from Montevecchia to Lissolo (749 150/064 400, Fig. 2). A complete section through the Missaglia Megabed is found again some 10 km to the southeast in an abandoned quarry (Lecchetto) east of Predazzi near Carvico (759 600/064 100; Fig. 2; VENZO 1954, Fig. 11). More than 10 m of massive, graded calcarenite to marlstone, exposed in the old city of Bergamo (Bergamo Alta, Piazza Luigi Angelini) most probably represent a continuation of the megabed further to the east (Fig. 1). In fact, the lithological composition and the faunal content of the megabed in Bergamo are the same as at Missaglia and Predazzi.

Sedimentology

The stratigraphic sequence of the Missaglia Megabed in the Missaglia quarry and near Predazzi is shown on Figure 3. The outcrop of Missaglia is further illustrated in Figures 4 and 5. The general sequence is identical at both locations and variations in thicknesses are minor. In both sections the enclosing Bergamo Flysch consists of lithic sandstones (Fig. 3, F) which are arranged in thickening-upward


Missaglia
Predazzi
outer fan dep.
turbiditic massflow
debris flow
outer fan deposits
2m
pelite
silt
sand
congl.
E
D
C
B
A
F
1mm
pelite
silt
sand
congl.

cycles of thin-bedded, base-missing turbidites (facies D_1, D_2 of MUTTI & RICCI-LUCCHI 1975) and thick-bedded, sometimes amalgamated sandstones (facies C_2, Fig. 3 and 4).

The megabed s. str. overlies a several meters thick pebbly mudstone with chaotic internal structure (Fig. 3–5). At Predazzi and Montevecchia, the base of this pebbly mudstone is not exposed, but at Missaglia, where a thickness of about 6 m can be determined, the base of the pebbly mudstone cuts into the underlying terrigenous turbidites. The pebbly mudstone contains here large slabs, up to several meters long, of marls and sandstones and pebbles, cobbles and blocks of limestones embedded in a matrix of fluidally structured, marly, mica-rich silt- to fine sandstone. Distorted turbiditic sandstone beds which are derived from the host formation are concentrated in the lower part of the pebbly mudstone, whereas larger slabs of dark green, gray or dark red marls and marly limestones (Scaglia variegata, Sc. bianca, Sasso della Luna) typically occur in the upper part (Fig. 5). Blocks and pebbles of limestones occur throughout the pebbly mudstone (Fig. 4); they are in general clearly distinct from the matrix, whereas the marls and sandstones locally merge with the latter.

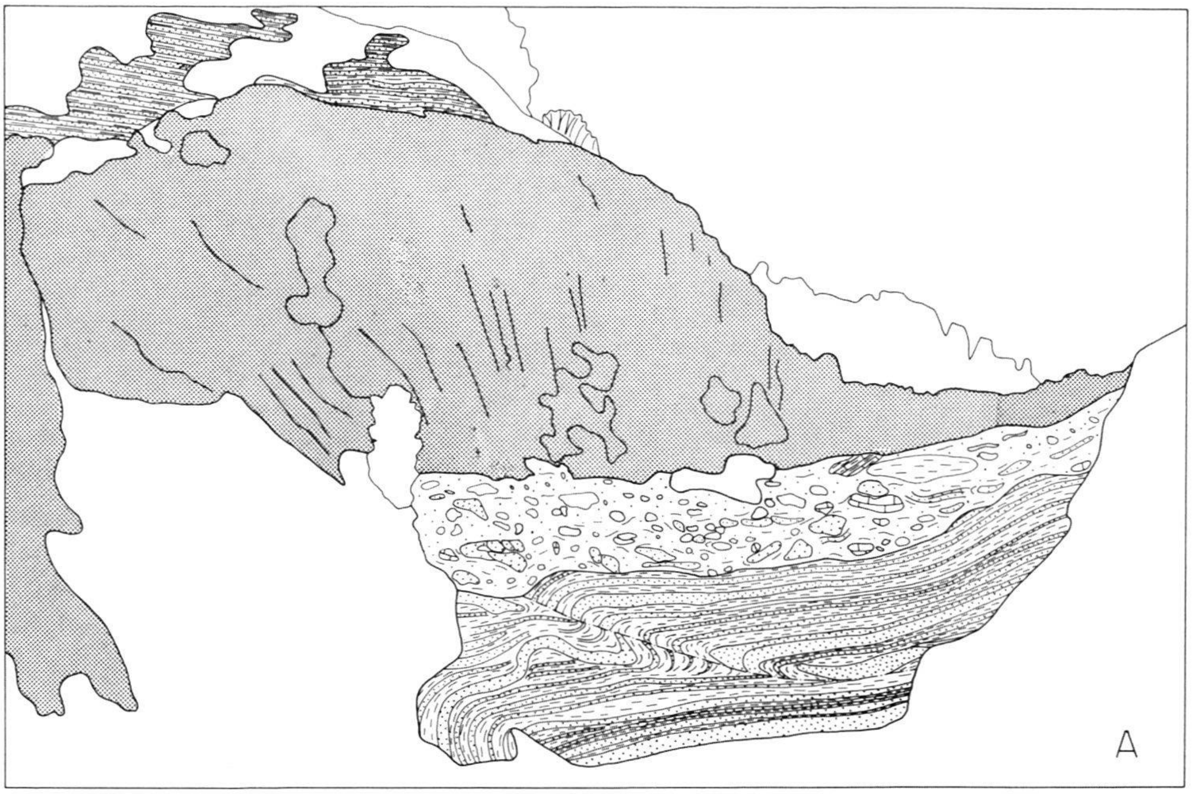


Fig. 4. A: View of Bergamo Flysch with intercalated pebbly mudstone and Missaglia Megabed. Note south-vergent "knee-fold" in megabed and south-vergent thrusts in underlying flysch. Quarry north of Missaglia, view from the south.

Fig. 3. Lithostratigraphic section of pebbly mudstone, Missaglia Megabed and enclosing Flysch di Bergamo and sequence of microfacies in the Missaglia Megabed (A–E) and in the Bergamo Flysch (F). Asterisk is location of palynological assemblage (sample HMB 77/12). Quarries north of Missaglia and near Predazzi.

Fig. 4. B (Detail of 4A): The flysch sequence at the base of the outcrop shows 1-2 m thick thinning- and fining-upward cycles of turbiditic sandstones (facies C_2, D_1, D_2). It is overlain by about 6 m of pebbly mudstone which in a fluidally structured marly to silty matrix contains large deformed slabs of turbiditic sandstones from the Bergamo Flysch and, in the higher part, of hemipelagic marls (Scaglia). The light colored limestone blocks are predominantly pelagic limestones of Late Cretaceous age or Calcari Grigi (Lower to Middle Liassic). The overlying megabed rests with a basal conglomerate on the pebbly mudstone.

In the quarry of Predazzi, the top of the pebbly mudstone largely consists of yellowish, fine-grained biomicrites. These have been described by VENZO (1954) and GELATI & PASSERI (1967) as continuous beds lithologically similar to the pelagic limestones of the Maiolica Formation. However, detailed observations show that these limestones are elongated slabs, up to 80 cm thick and 5-10 m long, of fine-grained biomicrites with a rich fauna of planktic foraminifera of Late Santonian-Early Campanian age (Table 2). The micrites must have been transported while still plastic: their boundary with the overlying conglomerate shows impressions by pebbles and cracks and small fissures filled by the calcarenitic matrix of the conglomerate (Fig. 3).

The boundary between the pebbly mudstone and the overlying megabed s. str. usually is sharp but at places the conglomerate at the base of the megabed is gradational with the rubble along the top of the pebbly mudstone. Irregularities in the top of the pebbly mudstone are infilled by the conglomerate (Fig. 3). The conglomerate is about 1 m thick and grades upward into calcarenite-calcisiltite and finally marlstone which together constitute the bulk of the megabed. The conglomerate consists of loosely packed subrounded to angular lithoclasts set in a matrix of

Fig. 5. Pebbly mudstone with large slab of dark red marl (Scaglia variegata), slabs of thin-bedded turbidites and blocks of various limestones. Note overlying conglomerate infilling irregularities along the top of the pebbly mudstone. Southern quarry north of Missaglia.

calcarenite and shows coarse-tail grading with an upward increase of matrix. Above the conglomerate the sequence grades within a few meters from packed calcarenite rich in quartz (up 40%), dolomite fragments and planktic foraminifera into sparse calcarenites and calcisiltites with scattered planktic foraminifera (see Fig. 3, A–E). The uppermost part of the megabed also shows distinct coarse-tail grading with a decrease in grain-size of the bioclasts from globotruncanids in the lower part of the bed to small planktic forms such as small globigerinids, radiolaria and indeterminable fragments.

Lithological and faunal composition

Lithology, fauna and flora, source formation and age of the lithic fragments recognized in the pebbly mudstone and in the basal conglomerate of the Missaglia Megabed are set out in Table 2. Table 3 presents the quantitative lithologic composition of the basal conglomerate based on point counting of the 1–5-mm fraction.

Pebbly mudstone

At Missaglia the matrix of the pebbly mudstone contains a well preserved but displaced fauna of planktic foraminifera:

Table 2: *Lithic components of Missaglia pebbly mudstone and megabed. Quarries of Missaglia and Predazzi.*

Lithology	Formation	Age
Biomicrite with		
Dicarinella asymmetrica (SIGAL)	Scaglia	Passage Campanian-
Globotruncana elevata (BROTZEN)		Santonian
G. stuartiformis DALBIEZ		
Marly biomicrite with		
Dicarinella carinata (DALBIEZ)	Scaglia	Santonian
Globotruncana bulloides VOGLER		
G. fornicata PLUMMER		
G. lapparenti (BROTZEN)		
G. linneiana (D'ORBIGNY)		
Marginotruncana coronata (BOLLI)		
Heterohelix sp., globigerinids		
Marly biomicrite with		
Heterohelix sp., globigerinids, radiolaria, sponge spicules	Scaglia	Coniacian
Biomicrite with		
Heterohelix sp.	Scaglia	Turonian
Pithonella ovalis (KAUFMANN)		
Lithic arenites, siltstones, shales unfossiliferous	Lombardian Flysch	Late Cretaceous
Biomicrite with		
Biticinella breggiensis (GANDOLFI)	Scaglia bianca	Late Albian
Globigerinelloides bentonensis (MORROW)	Sasso della Luna	
Rotalipora appenninica (RENZ)		
Rotalipora subticinensis (GANDOLFI)		
Rotalipora ticinensis (GANDOLFI)		
Ticinella roberti (GANDOLFI)		
Marly biomicrite with		
Hedbergella simplex (MORROW)	Scaglia variegata	Middle Albian
Hedbergella trochoidea (GANDOLFI)		
Ticinella primula LUTERBACHER		
Ticinella roberti (GANDOLFI)		
Globigerinelloides sp.		
Biomicrites with calpionellids, aptychi, radiolaria	Maiolica	Late Tithonian-Barremian
Marly biomicrites with radiolaria, Radiolarian Chert	Rosso ad Aptici Selcifero Lombardo	Late Jurassic
Crinoidal limestone with pebbles of biomicrite with *Protoglobigerina*	Rosso Ammonitico Veneto	Middle-Late Jurassic
Cherty limestone with sponge spicules	Lombardian Siliceous Limestones	Liassic
Oolitic and other shallow-water limestones	Calcari Grigi, Ooliti di S. Vigilio	Liassic
Crystalline dolomites		Triassic
Quartz arenites		Lower Triassic?
Porphyrites, quartzporphyries		Permian
Crystalline basement rocks (micaschists, quartzites, hornblende schists, gneiss)		pre-Permian

Table 3: *Composition of basal conglomerates of Missaglia Megabed from point counting of 1-5-mm fraction.*

	Missaglia	Predazzi
Echinoderm fragments	10 %	4 %
Other biogenic fragments		11 %
Sandstones	2 %	
Biomicrites with planktonic foraminifera	23 %	7 %
Biomicrites with calpionellids		1 %
Biomicrites with radiolaria		4 %
Cherts in general	10 %	6 %
Cherts with radiolaria		1 %
Cherts with sponge spicules		1 %
Cherty limestones		1 %
Shallow-water limestones	6 %	14 %
Oolitic limestones		5 %
Ooids	4 %	7 %
Dolomites	18 %	14 %
Quartz	8 %	7 %
Crystalline basement rocks	19 %	11 %

Marginotruncana angusticarinata (GANDOLFI)	Late Turonian-Coniacian
M. coronata (BOLLI)	Middle Turonian-Santonian
M. cf. *paraconcavata* PORTHAULT	Coniacian
M. pseudolinneiana PESSAGNO	Turonian
M. undulata (LEHMANN)	Coniacian
Globotruncana fornicata PLUMMER	Middle Santonian-Middle Maastrichtian

The ranges of these species are in part mutually exclusive and show that at least the older forms must be reworked and not only displaced. In this context, the occurrence of large slabs of green, gray, red and variegated marls which, according to their faunal content are allocated to the formations of the Scaglia variegata (Aptian-Middle Albian) and to the Scaglia bianca or the Sasso della Luna (Upper Albian-Middle Cenomanian) is of particular interest. These marls were strongly deformed during emplacement of the pebbly mudstone and locally merge with the silty-marly matrix. Turbiditic arenites are also severely deformed and indicate that marls and sandstones were not lithified at the time of redeposition. The same holds true for the large slabs of pelagic limestones of Late Santonian-Early Campanian age which must have been displaced very shortly after their initial deposition. Whereas the Middle Cretaceous marls and the Upper Cretaceous turbiditic sandstones are typical for the facies of the Lombardian Basin, pelagic limestones of Turonian to Early Campanian age do not occur in the Lombardian Basin west of Lake Iseo but must be derived from elsewhere. By far the most abundant limestone fragments are white to light grey shallow-water limestones, white pelagic limestones with black or bluish chert bands and lenses (Maiolica) and light grey to pink pelagic limestones with planktic foraminifera of Late Cretaceous age. The shallow-water limestones are all angular and comprise oolithic grainstones with *Valvulinidae, Trochamminidae, Thaumatoporella, Cayeuxia* and other algae; pelletal grainstones, pelletal-onkoidal grainstones with cryptalgal laminae, fenestral limestones (loferites) and other shallow-water limestones. The facies of these limestones is identical with that of the Lower to Middle Liassic Calcari Grigi of the Trento Zone to the east (cf. CITA 1965). Crinoidal limestones with fragments of pelagic limestones containing *Protoglobigerina* (Fig. 6A) also occur in angular blocks and cobbles. These lithologies are also known from the Trento Plateau.

The fragments of pelagic limestones with chert contain abundant calpionellids and are derived from the Maiolica Formation; like the Upper Cretaceous pelagic limestones they show internal plastic deformation prior to final lithification. Beside these lithologies which may be derived from outside the Lombardian Basin, angular fragments of cherts and cherty limestones with sponge spicules and of radiolarian cherts of presumably Late Jurassic age are found. Triassic dolomites and fragments of crystalline basement rocks occur only in the granule- and sand-size fraction.

Megabed

The components in the basal conglomerate are pebbles of pelagic micrite with planktic foraminifera and lithic fragments of older sediments, with minor fragments of crystalline basement rocks. They are loosely packed and set in a matrix of pelagic micrite with sand-sized quartz and bioclastic grains (planktic foraminifera, inoceram and echinoderm fragments); sometimes they are closely packed and welded by late diagenetic pressure solution (Fig. 6B). Whereas the pelagic micrite pebbles are rounded and were probably redeposited while still plastic, the angular to subangular lithic fragments of chert, of spongolithic or cemented shallow-water limestones are clearly reworked from older formations. Some of these reworked lithologies in the basal conglomerate of the Missaglia Megabed are also found in the terrigenous deposits of the Lombardian Flysch (Table 2, Fig. 6B, cf. BICHSEL & HÄRING 1981). In fact, granules of Triassic dolomites and of crystalline basement rocks appear to be better rounded; they could thus be exhumed from Late Cretaceous flysch conglomerates.

Beside the frequent fragments of Calcari Grigi (oolithes, Fig. 6D, pelletal limestones), isolated ooids are particularly common (Table 3, Fig. 6C). In cases they are surrounded by a fringe of cement A, and may be derived from loosely cemented oolithes of the Calcari Grigi Formation or the San Vigilio Oolithe of the Trento Zone. In fact, isolated ooids occur together with fragments of Calcari Grigi in somewhat older Upper Cretaceous debris flow deposits intercalated with pelagic Scaglia limestones which are found immediately west of the boundary faults separating the Lombardian Basin from the Trento Zone (Ponte Pia near Ponte Arche [Trentino], CASTELLARIN 1970, and personal observations by D. Bernoulli).

Up-section the lithic fragments give way to larger bioclastic fragments, quartz grains, some rounded dolomite fragments and larger planktic foraminifera of upward decreasing grain size and finally to finer bioclastic hash and smaller planktic

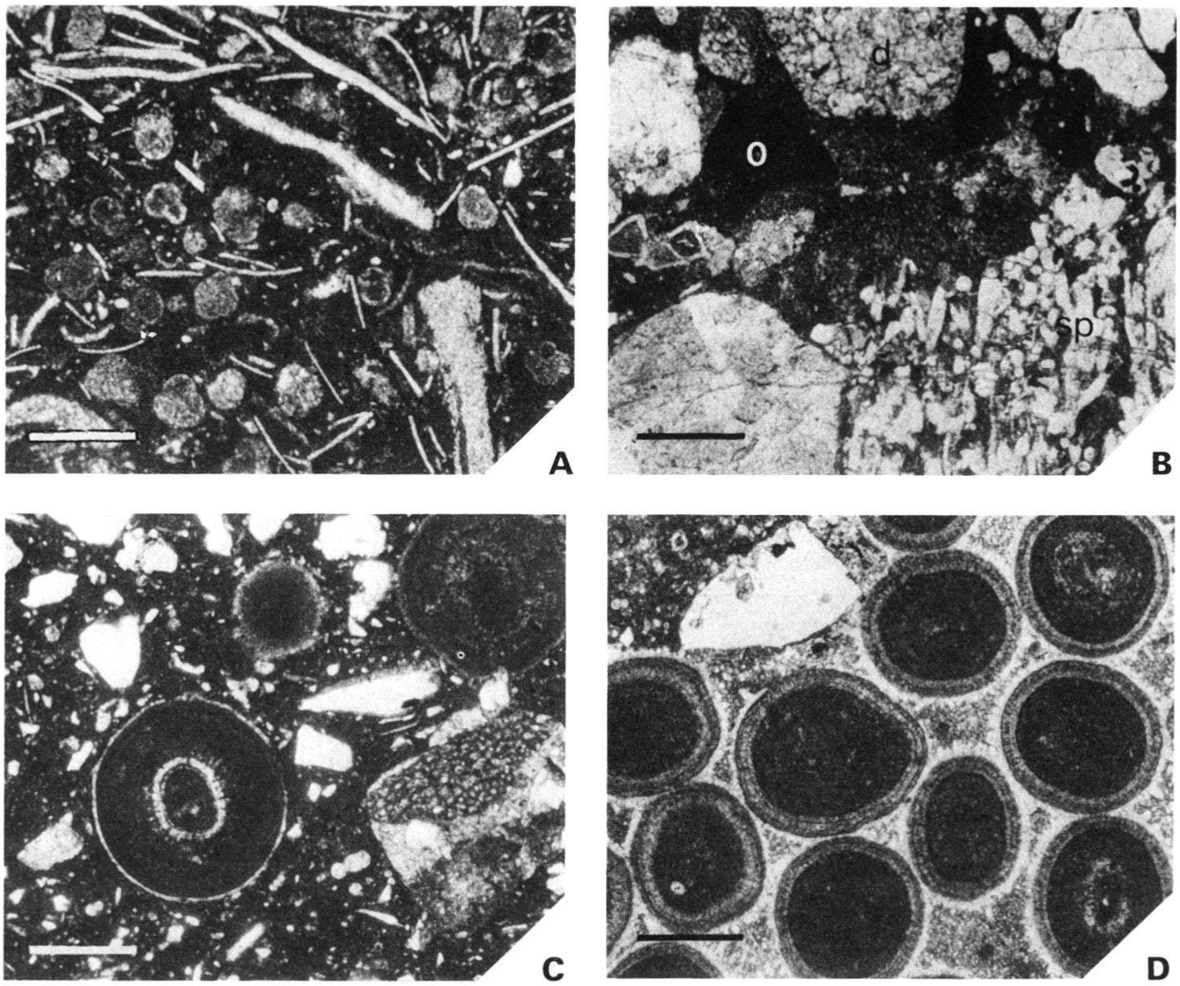


Fig. 6. Microfacies of various components of pebbly mudstone and basal conglomerate of Missaglia Megabed.

A: Pelagic limestone with remains of (?pelagic) bivalves, crinoids and *Protoglobigerina* (Middle to Upper Jurassic). This lithology is a component of a larger pebble of crinoidal limestone similar to those found on the Trento Plateau. From pebbly mudstone, quarry north of Missaglia. MH 346.

B: Basal conglomerate of Missaglia Megabed with components of spiculitic cherty limestone (sp, Liassic), crystalline dolomite (d, Triassic), quartz, micritized ooids (o, Calcari Grigi, Lower to Middle Liassic) and displaced planktic foraminifera (*Globotruncana elevata* BROTZEN). The shape of the components is modified by late-diagenetic pressure solution. Quarry Lecchetto near Predazzi, MB 428.

C: Basal conglomerate of Missaglia Megabed with isolated ooids, sometimes fringed with early cement A (lower left), quartz, mica, small planktic foraminifera in a matrix of displaced pelagic lime mud. Fragment at lower right is a calcareous sandstone with a test of an orbitolinid foraminifer, probably exhumed from the Lombardian Flysch. Quarry north of Missaglia, MH 352.

D: Lithic fragment of loosely cemented ooidal grainstone probably derived from the Calcari Grigi Formation (Lower to Middle Liassic). Cement A has been formed before displacement of the fragment, whereas the microsparitic groundmass which contains silt-sized quartz and mica formed after deposition of the megabed. Basal conglomerate of the Missaglia Megabed, Quarry Lecchetto near Predazzi. MB 428. Thin sections, scale bars: 0.5 mm.

foraminifera (Fig. 3) set in a matrix of marly coccolith ooze (Fig. 7). The fauna of the calcarenite to marlstone section at Missaglia yielded the following forms, all determined as isolated specimens:

Globotruncana arca (CUSHMAN)	Late Santonian–Late Maastrichtian
G. fornicata PLUMMER	Late Santonian–Middle Maastrichtian
G. lapparenti (BROTZEN)	Late Santonian–Middle Maastrichtian
G. linneiana (D'ORBIGNY)	Early Campanian–Middle Maastrichtian
G. tricarinata (QUEREAU)	Campanian–Middle Maastrichtian
G. stuartiformis DALBIEZ	Early Campanian–Late Maastrichtian
Dicarinella carinata (DALBIEZ)	Santonian
D. concavata (BROTZEN)	Middle Coniacian–Middle Santonian
D. primitiva (DALBIEZ)	Coniacian
Globotruncanella havenensis (VOORWIJK)	Campanian–Maastrichtian
Heterohelix reussi (CUSHMAN)	Middle Turonian–Santonian
Planoglobulina glabrata (CUSHMAN)	Late Santonian–Maastrichtian
Loeblichella coaractata (BOLLI)	Late Cenomanian–basal Maastrichtian
Rotalipora cf. *cushmani* (MORROW)	Late Cenomanian

In the section northwest of Montevecchia the following forms were determined (sample HMB 77/100):

Globotruncana elevata (BROTZEN)	Campanian–Maastrichtian
G. bulloides VOGLER	Late Santonian–Early Maastrichtian
Archaeoglobigerina blowi PESSAGNO	Middle Coniacian–Early Maastrichtian
Pseudotextularia elegans (RZEHAK)	Campanian–Maastrichtian
Rotalipora appenninica (RENZ)	Late Albian–Early Cenomanian
Hedbergella flandrini PORTHAULT	Late Turonian–Coniacian

In the calcarenite to marlstone section of the Missaglia Megabed at Predazzi the following forms were observed:

Globotruncana arca (CUSHMAN)	Late Santonian–Late Maastrichtian
G. fornicata PLUMMER	Late Santonian–Middle Maastrichtian
G. elevata (BROTZEN)	Campanian–Maastrichtian
G. stuartiformis DALBIEZ	Early Campanian–Late Maastrichtian
G. lapparenti (BROTZEN)	Late Santonian–Middle Maastrichtian
Marginotruncana coronata (BOLLI)	Middle Turonian–Late Santonian

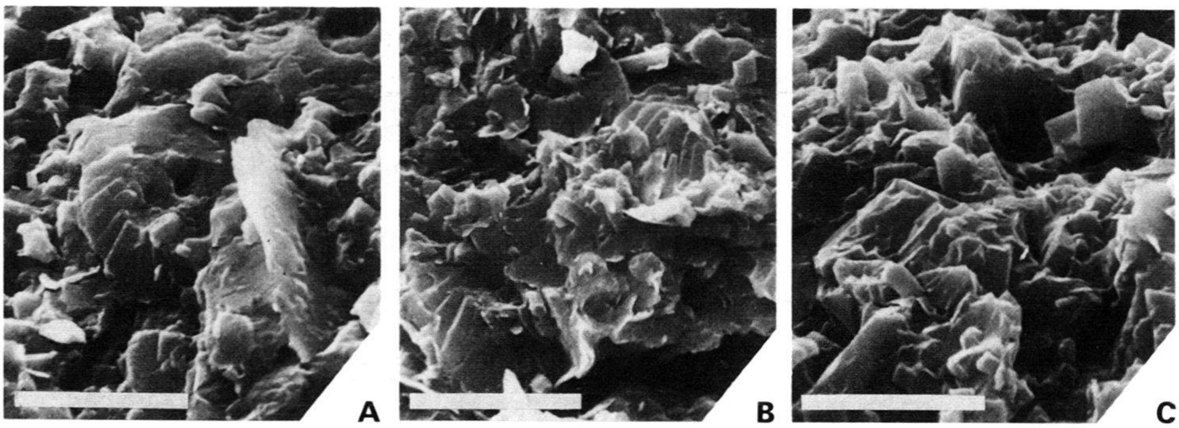


Fig. 7. Stereoscan electron micrographs of marlstones in the upper part of the Missaglia Megabed, showing that the fine redeposited sediment consists of argillaceous, slightly recrystallized coccolith ooze. Quarry north of Missaglia. Scale bars: 5 microns.

Combined these taxa range from Late Albian to Maastrichtian; their combined individual ranges, however, are in part mutually exclusive and show that the older forms are not only displaced but also reworked.

Palynology

Two shale samples (HMB 76/11, HMB 76/12) of the Bergamo Flysch from the middle Missaglia quarry (Fig. 3) were investigated for organic remains. Sample HMB 76/11 yielded only fragments of strongly coalified organic matter, but sample 76/12 contains much organic detritus in which wood structures are still recognizable. Palynomorphs are rare and their finer structures have been heavily affected by pyritization. A floral list is presented in Table 4 and the most important forms are illustrated in Figure 8.

Sporomorphs are much more common than marine forms. Nevertheless the poorly diversified dinoflagellate association allows bracketing the age of sample HMB 77/12 to between the Early Santonian and the Campanian: The occurrence of *Dinogymnium microgranulosum* and of *D. undulosum* places the sample in the very late Cretaceous (Santonian or younger), whereas *Palaeohystrichophora infusorioides* which is common in the sample ranges from the late Early Cretaceous up to the Early Campanian. *Odontochitina porifera*, documented in our material by a few specimens, does not range higher than up to the Campanian (cf. WILLIAMS 1977).

The bulk of the sporomorph association is constituted by the gymnosperm genera *Classopollis* and *Araucariacites;* vesiculate gymnosperm pollen are absent. The angiosperm pollen of the Normapolles group are of stratigraphic importance. *Hungaropollis, Krutzschipollis* and *Longanulipollis,* typical forms of the very late Cretaceous, are present in our material. The pollen spectrum can be interpreted stratigraphically by using of the palynostratigraphic zonation based on the evolution of the Normapolles group. This zonation was proposed by GÓCZÁN (1964) for the Upper Cretaceous of Hungary. A large part of the forms identified, such as *Longanulipollis lenneri, L. elegans, L. bajtayi, Krutzschipollis spatiosus, Hungaropollis krutzschi, H. ajkanus* and *Hungaropollis* fsp. appear within zones C and D of GÓCZÁN et al. (1967), i.e. Middle Santonian to Early Campanian. One of the most frequent forms belongs to the genus *Capipollis* which appears in the Middle Santonian and disappears at the Campanian-Maastrichtian boundary. Another datum is given by the occurrence of *Complexiopollis tabernacularis* which disappears in the Early Campanian. In the boreal realm, the last occurrence of this genus is recorded from the "Aachener Bild" (KRUTZSCH 1966) and also corresponds to the Early Campanian. Relying on the correlation with floral association C and D of GÓCZÁN (1964), the palynomorph association of sample HMB 77/12 is referred to the time span between the Middle Santonian and the Early Campanian.

The pollen spectrum from Missaglia resembles those of the associations described from Hungary both in qualitative and in quantitative respect. The Hungarian associations are typical for the Mediterranean realm of the Normapolles province. During the Late Cretaceous, occurrence of the Normapolles form group extended from southern Scandinavia to Southwest Europe (Spain, Portugal) and occasional occurrences of the Normapolles group in Upper Cretaceous sediments of

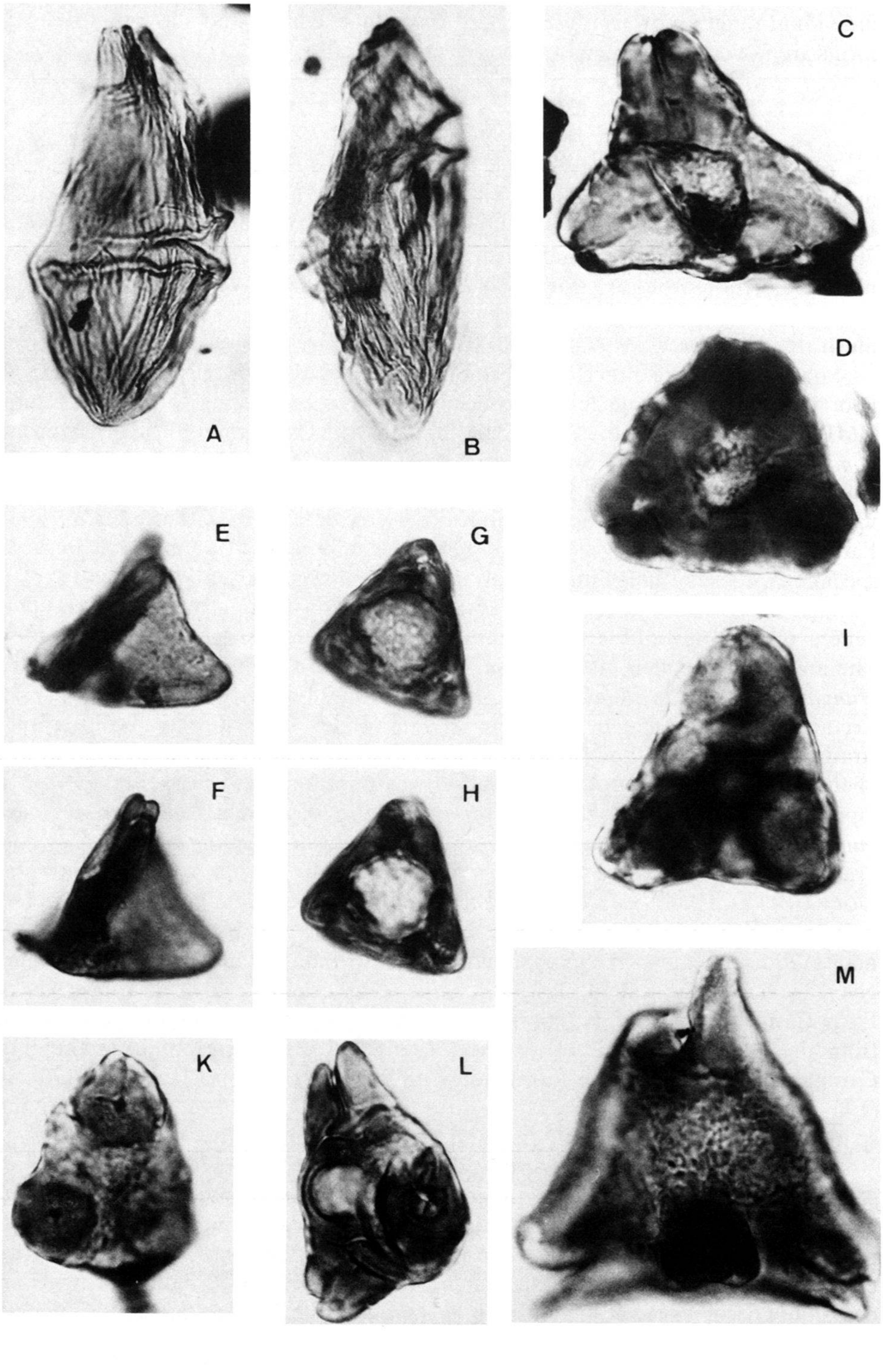

A
B
C
D
E
G
I
F
H
M
K
L

Table 4: *Floral list of sample HMB 77/12, Bergamo Flysch, Lower Campanian, north of Missaglia.*

Dinoflagellate cysts
Achomosphaera ramulifera (DEFLANDRE) EVITT 1963
Dinogymnium microgranulosum CLARKE & VERDIER 1967
D. undulosum COOKSON & EISENACK 1970
Odontochitina porifera COOKSON 1956
Palaeohystrichophora infusorioides DEFLANDRE 1935
Spiniferites ramosus (EHRENBERG) LOEBLICH & LOEBLICH 1966
Sp. cingulatus (O. WETZEL) SARJEANT 1970
Xenikoon australis COOKSON & EISENACK 1960a

Spores
Appendicisporites spinosus POCOCK 1964
Baldurnisporites fsp.
Cibotiumspora fsp.
Cicatricosisporites paradorogensis group (sensu KRUTZSCH 1957)
Corrugatisporites toratus WEYLAND & KRIEGER 1953
Costaperforosporites cf. *foveolatus* DEAK 1962
Leiotriletes fsp.
Matonisporites fsp.
Polypodiaceoisporites fsp.
Toroisporis fsp.
Trilites fsp.
Vadaszisporites urcuticus (DEAK) DEAK & COMBAZ 1967
Zlivisporites fsp.

Pollen
Gymnosperms
Araucariacites australis COOKSON ex COUPER 1953
Classopollis fsp.

Angiosperms
Capipollis oculis GÓCZÁN 1967
Capipollis fsp.
Complexiopollis cf. *praeatumescens* KRUTZSCH 1959c
C. tabernacularis (GÓCZÁN) GÓCZÁN & KRUTZSCH 1967
Hungaropollis cf. *ajkanus* GÓCZÁN 1964
H. krutzschi GÓCZÁN 1964
Hungaropollis fsp.
Interporopollenites proporus WEYLAND & KRIEGER 1953
Krutzschipollis magnoporus GÓCZÁN 1967
K. spatiosus GÓCZÁN 1967
Krutzschipollis fsp.
Longanulipollis elegans (GÓCZÁN) GÓCZÁN 1967
L. bajtayi (GÓCZÁN) GÓCZÁN 1967
L. lenneri (GÓCZÁN) GÓCZÁN 1967
Oculopollis fsp.
Tricolporopollenites fsp.

the Rif mountains document the extension of this province to Northwest Africa (Hochuli, unpublished). The adjacent province to the south is characterized by a totally different evolution of angiosperms which is clearly reflected in the pollen spectrums. No representative of this southern province has been found in our material.

Age

The Middle Santonian to Early Campanian age of the palynomorph association found in the Bergamo Flysch fits well with the age of the youngest planktic foraminifera found in the Missaglia Megabed which ranges from Campanian to Maas-

Fig. 8. Dinoflagellate cysts and Normapolles from sample HMB 77/12, Bergamo Flysch, Lower Campanian, quarry north of Missaglia.
A: *Dinogymnium microgranulosum* CLARKE & VERDIER 1967; B: *Dinogymnium undulosum* COOKSON & EISENACK 1970; C: *Hungaropollis* cf. *ajkanus* GÓCZÁN 1964; D: *Hungaropollis* fsp. (GÓCZÁN et al. 1967); E, F: *Complexiopollis tabernacularis* (GÓCZÁN) GÓCZÁN & W. KR. 1967; G, H: *Interporopollenites proporus* WEYL. & KRG. 1953; I: *Capipollis oculis* GÓCZÁN 1967; K: *Oculopollis* fsp.; L: *Longanulipollis elegans* (GÓCZÁN) GÓCZÁN 1967; M: *Krutzschipollis magnoporus* GÓCZÁN 1967
Enlargements: A, B × 750, C to M × 1000.

trichtian. Based on these data an Early Campanian age is inferred for the emplacement of the Missaglia Megabed. This is in agreement with the general stratigraphy of the Lombardian Flysch. A large part of the redeposited pelagic coccolith ooze constituting the bulk of the Missaglia Megabed may thus have been displaced penecontemporaneously; however, the occurrence of older planktic foraminifera in the finer grades of the megabed suggests that a considerable fraction of the redeposited coccolith ooze may be older than Early Campanian.

Origin of the megabed and paleotectonic significance

The ubiquitous close association of the megabeds of the Lombardian Flysch with their underlying pebbly mudstones points to a genetic relationship of the two lithologies. In fact, nowhere have pelagic or hemipelagic deposits been found between the pebbly mudstones and the overlying megabeds. The pebbly mudstones are interpreted as submarine debris flow deposits (Middleton & Hampton 1973), whereas the overlying coarse-tail graded megabeds are thought to have been deposited by a turbidity current mechanism. The close association of slumped beds or pebbly mudstones and thick-bedded graded units has been frequently noted both in pelagic (Bernoulli 1964, 1971) and in terrigenous resediments (Rupke 1976a, b; Johns et al. 1981), and the triggering of turbidity currents by submarine slumping or debris flow has been demonstrated experimentally (Hampton 1972).

The pebbly mudstones and their associated megabeds are "exceptional depositional events" (Ricci Lucchi 1978) and cannot be integrated into the cyclic evolution of fan deposits. Their thickness exceeds that of the terrigenous turbidite beds, sometimes by one order of magnitude or more. Estimates of the volumes of sediment transported by unusually large debris flows and turbidity currents are given in recent literature. For the "Contessa"-like layers, marker beds in the Miocene Formazione Marnoso-arenacea of the northern Apennines which can be followed over more than 120 km, volumes between 1.5 and 35 km^3 have been estimated for the different individual turbidite beds (Ricci Lucchi 1978); for the Roncal Unit in the Eocene flysch of the southern Pyrenees a volume of even 100 km^3 is calculated by Johns et al. (1981). These volumes are comparable to those transported by large-scale submarine sediment slides and slumps along continental margins (slide off Spanish Sahara, 600 km^3, Embley & Jacobi 1977). In the case of the Missaglia event, an estimate of the volume of transported sediment is very difficult in view of the limited outcrops. However, a few minimum figures can be given: If the Missaglia Megabed had a north-south extension of only 10 km in a narrow, east-west trending flysch basin (Bichsel & Häring 1981), calculation for the area between Missaglia and Predazzi alone leads to a minimum figure of nearly 4 km^3 for the compacted sediment assuming a more or less constant thickness of the deposit. If the outcrop in Bergamo Alta is the continuation of the Missaglia Megabed, a minimum figure of 8 km^3 is derived, and if the flow came from an eastern basin margin in the area of Brescia, a volume of 20 km^3 or more is likely. As the basin certainly continued for some distance towards the west, these figures are minimum figures and it might well be that the volume of the Missaglia debris flow and turbidite even exceeds this figure.

The pebbly mudstones and megabeds of the Lombardian Flysch differ not only by their volumes, but also by their composition from the associated terrigenous turbidites. Paleocurrent data and clastic content suggest that the turbidity currents carrying terrigenous detritus entered the basin from the north and northeast (CASTELLARIN 1976) and were deflected by the confining submarine fault scarps of the Trento Plateau and the Malossa High (cf. GROPPI et al. 1976) into a longitudinal western direction (BICHSEL & HÄRING 1981, our Fig. 9). In contrast to the terrigenous turbidites which mainly contain fragments of lithified sediments or crystalline basement rocks of South-Alpine to Austroalpine facies, the Missaglia pebbly mudstone and megabed additionally contain a large portion of previously unlithified sediments and penecontemporaneously displaced pelagic coccolith ooze of Scaglia facies: In the pebbly mudstone, there are many deformed slabs of hemipelagic marls derived from the Scaglia variegata, Scaglia bianca and Sasso della Luna formations, of deformed pelagic limestones of Late Cretaceous age (Scaglia) and of turbiditic sandstones, particularly of Bergamo Flysch. The overlying megabed is dominated in its conglomeratic part by rounded pebbles of *Upper Cretaceous* (post-Cenomanian) *Globotruncana*-bearing Scaglia limestones and by angular lithic fragments, among which ooidal limestones, some dated as Liassic and probably derived from the Calcari Grigi Formation, are particularly frequent. Both these lithologies do not occur in the Lombardian Basin, but are typical for the Trento Plateau, as are limestones with *Protoglobigerina* of the Middle/Upper Jurassic and phosphatized limestones with planktic foraminifera (hardgrounds of the Santonian-Campanian boundary on the Trento Plateau, MASSARI & MEDIZZA 1973; NOVBAKHT 1973).

In the sand-sized fraction of the megabed planktic foraminifera (*Globotruncana, Dicarinella, Marginotruncana,* 40–70%) and quartz grains prevail; the silt- and mud-sized fraction finally consists of fine planktic tests and marly coccolith ooze. The source area of the fine sediment of the megabed must therefore have been located on a submarine high or plateau outside or along the margins of the Lombardian Basin where pelagic to hemipelagic sedimentation of coccolith ooze took place during the Late Cretaceous. Such highs bordering the Lombardian Basin during the Late Cretaceous are referred both to the east (Trento Plateau, CASTELLARIN 1970; and a submerged fault block between the Lombardian flysch trough and the Trento Plateau in the Bresciano, AUBOUIN et al. 1970; BICHSEL & HÄRING 1981) and to the south (Malossa High, GROPPI et al. 1976) (Fig. 9).

Whereas the Cretaceous history of the (subsurface) Malossa High and particularly of its northern margin is only poorly known, that of the western margin of the Trento Plateau is well explored (CASTELLARIN 1970). There, along the boundary faults that separate the Trento Plateau from the marginal fault blocks of the Lombardian Basin, large slide scars occur in the Early Jurassic (Calcari Grigi) to Early Cretaceous (Maiolica Veneta) sequence (CASTELLARIN 1970, Pl. 4 and 5). Obviously the slide scars are related to large debris flows that were repeatedly emplaced to the west during the Late Cretaceous, and which include abundant fragments derived from the Trento Plateau, but also some from the Lombardian Basin itself. Slope instability during the Late Cretaceous was related to active synsedimentary normal faulting along the NNE-trending fault system (CASTEL-

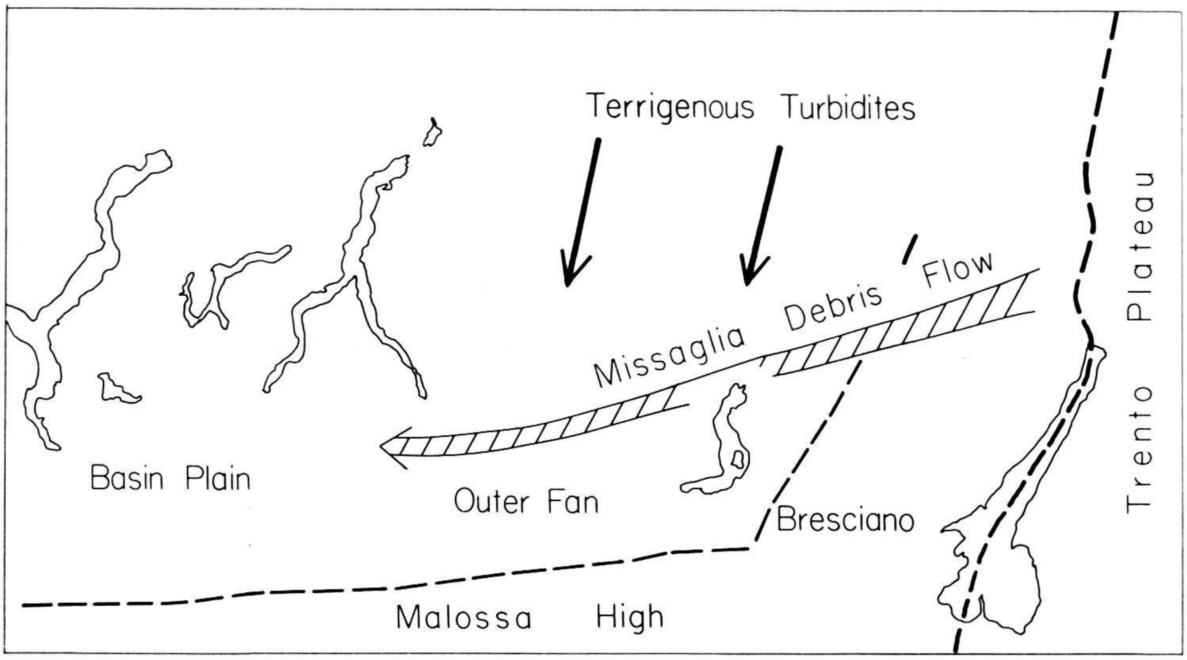


Fig. 9. Paleogeographic map of the Lombardian Basin during the Early Campanian with inferred provenance of terrigenous turbidites and of Missaglia debris flow.

LARIN 1970), and earthquakes related to this faulting activity may have triggered the debris flows and slumps observed. Although no direct connection between the Missaglia Megabed and the debris flows along the western margin of the Trento Plateau can be proven, a similar source area situated along the same margin is possible. This would explain the abundance of angular blocks and pebbles of Early Jurassic shallow-water limestones, the isolated ooids exhumed from ooidal sands that were only loosely cemented by early diagenesis, the fragments of pelagic rocks of Trento facies, and the unconsolidated foraminiferal coccolith ooze. The large plastically deformed fragments of turbiditic sandstones and basinal hemipelagic marls of Middle Cretaceous age could have been reworked during the passage of the debris flow across marginal fault blocks with thin sediment cover (Bresciano). Finally, granules of Triassic dolomites together with crystalline basement rocks and detrital quartz could be reworked from the Lombardian flysch. Although the region to the south of the Lombardian Alps was a relative high during the Late Cretaceous (Malossa High, GROPPI et al. 1976), this region is a less likely source area for the Missaglia Megabed. There the Jurassic to Early Cretaceous sequence does not differ much from that of the Lombardian Zone and is mainly composed of basinal deposits from the Lower Liassic up to the Middle Cretaceous (GROPPI et al. 1976). This does not exclude the Malossa High as a possible source area for other megabeds in the Lombardian Flysch.

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