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RESULTS OF STUDIES ON THE MESO-CENOZOIC SUCCESSION IN THE MONTE OLIMPINO 2 TUNNEL. THE TECTONO-SEDIMENTARY SIGNIFICANCE OF THE "GONFOLITE LOMBARDA"

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Riassunto. La "Gonfolite Lombarda" è una successione di risedimenti, potente fino a 3000 m, depostasi in ambiente marino profondo al margine settentrionale dell'avanfossa padana. Tale successione è stata recentemente analizzata sulla scorta dei dati acquisiti durante la costruzione del traforo ferroviario Monte Olimpino 2 e di nuovi dati di affioramento provenienti dalle aree di Como e di Varese che ne hanno consentito la suddivisione in sequenze deposizionali.

La prima sequenza, costituita dalla Formazione di Chiasso (Rupeliano superiore - Cattiano), esprime un sistema di scarpata con sedimentazione terrigena. La deposizione avviene prevalentemente per correnti torbide diluite, ma sono rappresentati anche depositi emipelagici ed occasionali fenomeni di rimobilizzazione lungo pendio. La seconda sequenza (Cattiano superiore - Burdigaliano basale), alla quale sono riferiti i Conglomerati di Como e le formazioni arenacee e pelitiche ad essi eteropiche, consiste di un sistema canyon - argine naturale, prevalentemente conglomeratico, che si sovraimpone ai preesistenti depositi di scarpata tramite una netta superficie di erosione, profondamente incisa. Tale sistema è caratterizzato da una rapida progradazione iniziale e da una successiva graduale retrogradazione; quest'ultima è sottolineata da una progressiva diminuzione verso l'alto degli apporti clastici e da un aumento di diffusione delle facies pelitiche e delle faune pelagiche. La fase di retrogradazione del sistema raggiunge il culmine nella parte terminale della sequenza 2, con lo sviluppo di sedimenti arenacei di lobo ancora parzialmente confinati.

La terza sequenza (Burdigaliano - ?Langhiano) è rappresentata dai Conglomerati di Lucino con relative formazioni eteropiche. Essa esprime una ulteriore fase di progradazione del sistema canyon - argine, con il ritorno ad una sedimentazione prevalentemente conglomeratica. La progradazione alla base della sequenza è

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tuttavia meno rapida rispetto alla sequenza precedente; ad essa segue una graduale retrogradazione. La quarta sequenza, di età non determinata, ma riferibile per interpolazione al Miocene medio-superiore, è costituita dalle Arenarie di Gurone e dalle Peliti di Bizzozzero, affioranti solamente a sud di Varese. Questa sequenza è caratterizzata alla base da una netta discordanza angolare e da vistosi fenomeni di rimobilizzazione sinsedimentaria. La 4ª sequenza si distingue inoltre dalle precedenti per lo sviluppo di sistemi argine - canale con sedimentazione prevalentemente arenaceo-pelitica.

L'evoluzione deposizionale del Gruppo della Gonfolite (sequenze 2 - 4) evidenzia la persistenza di risedimentazione dovuta a flussi gravitativi ad alta densità e/o a correnti di torbida dall'Oligocene superiore fino almeno al Miocene inferiore-medio, in un ambiente che rimane sostanzialmente invariato dal punto di vista paleobatimetrico e riferibile al batiale superiore. Questa constatazione, unitamente alle scarse correlazioni esistenti tra le fasi di progradazione e retrogradazione del sistema deposizionale e le curve eustatiche, rivela la difficoltà di applicazione dei modelli deposizionali "classici" della stratigrafia sismica, sviluppati nell'ambito di margini passivi di tipo atlantico. I valori del tasso di accumulo e della velocità di subsidenza, calcolati in base ai dati biostratigrafici per ogni fase di evoluzione delle sequenze distinte, sono d'altro canto in accordo con l'ipotesi di un margine attivo. In alcuni casi è stato inoltre possibile evidenziare una velocità di subsidenza superiore in valore assoluto alla velocità di variazione del livello del mare, desunta dalle curve eustatiche.

In base a tali considerazioni le fasi di avanzamento e di arretramento del sistema deposizionale sono interpretate come espressione di fasi di acme e di rallentamento dell'attività tettonica nell'ambito della catena alpina, emergente al margine dell'avanfossa. Viene quindi proposto un modello che inserisce tentativamente la sedimentazione della "Gonfolite Lombarda" nel quadro dell'evoluzione strutturale del "thrust belt" sud-alpino, come risulta dai dati più recenti.

La presenza di una catena a falde, che si propaga rapidamente verso bacino, provoca il parziale retroscorrimento del cuneo clastico della "Gonfolite Lombarda" sopra il substrato pre-oligocenico, dando luogo ad una progressiva accentuazione dell'inclinazione dei termini più antichi rispetto ai più recenti ("discordanza progressiva") e a fenomeni di cannibalizzazione.

Viene qui inoltre descritta la successione mesozoica di età compresa tra il Lias medio ed il Cretaceo inferiore attraversata nella galleria Monte Olimpino 2. Tale successione è costituita, dal basso verso l'alto, da: Calcare di Moltrasio e Calcare del Domaro (Domeriano), Formazione di Sogno (Lias superiore - ?Dogger p.p.), Selcifero Lombardo (Dogger p.p. - Malm), Maiolica (Berriasiano - Barremiano) e Scaglia Variegata (Aptiano - Albiano). Essa, pur inquadrandosi sostanzialmente nel contesto deposizionale del Bacino del Monte Generoso, presenta un punto focale di interesse in corrispondenza del Lias superiore, ove litofacies pelitiche, riferibili alla Formazione di Sogno (Gaetani & Poliani, 1978), sostituiscono lateralmente il Rosso Ammonitico Lombardo s. str., affiorante nelle aree circostanti. La presenza della Formazione di Sogno, datata per mezzo del nannoplancton calcareo, indica una sedimentazione di tipo bacinale, più profonda rispetto alle facies di "Rosso Ammonitico". Un livello argilloso evidenziato alla base della Formazione di Sogno, inoltre, risulta correlabile con un evento di dissoluzione dei carbonati, registrato in tutta l'area mediterranea entro il Toarciano basale.

Abstract. The construction of the Monte Olimpino 2 railway tunnel connecting Chiasso (Switzerland) and Bernate (to the South of Como, Italy) allowed the continuous observation of the poorly outcropping Mesozoic to Cenozoic succession and the collection of new stratigraphic and structural data which are significant for the reconstruction of the South-alpine margin evolution.

The Mesozoic succession (lower Jurassic to lower Cretaceous) is strongly tectonized and thinned. The Selcifero Lombardo is represented by a sliver of radiolarites; the Maiolica is only 15 m thick and the Scaglia Variegata reaches a maximum local thickness of 1.5 m of cataclastic marls. From a stratigraphic point of view the presence of lithofacies referable to the lower lithozone of the Sogno Formation (upper Lias) is noteworthy. They occurr at the same stratigraphic position of the nearly outcropping Rosso Ammonitico Lombardo (Breggia river, Switzerland) and are indicative of relatively deeper sedimentation within the Generoso Basin. The overlying Oligocene to middle Miocene deep marine clastic succession, the "Gonfolite Lombarda", is separated from the Mesozoic succession by a North-vergent thrust.

Four depositional sequences have been recognized on the basis of major unconformities and of the progradation-retrogradation pattern of the depositional system. A gradual increase of the tectonic tilt from the bottom to the top ("progressive unconformity"), recurrent cannibalization phenomena and lateral shifting of the clastic buildups characterize the whole succession.

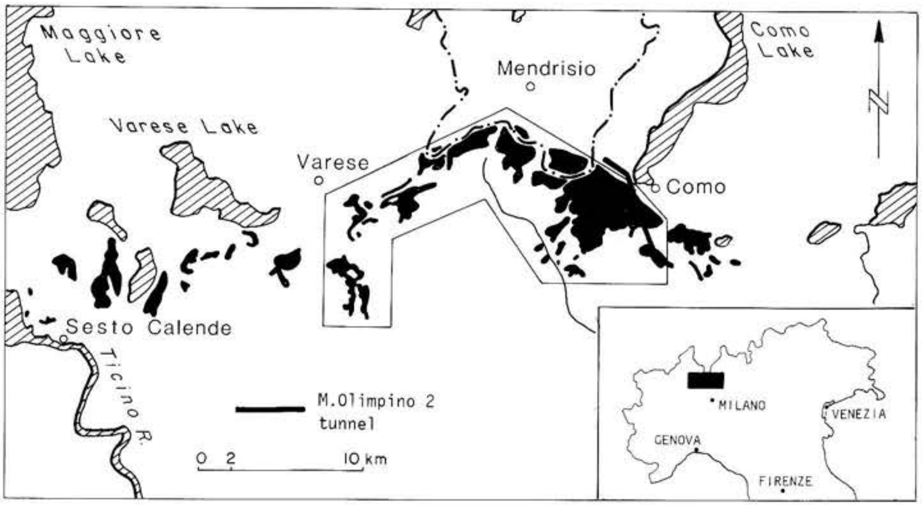

Fig. 1 - Location of the study area. Black: outcrops of the "Gonfolite Lombarda".

Introduction.

The Monte Olimpino 2 tunnel (7209 m long) is a new tract of the Milano - Chiasso railway which connects the present line near the village of Bernate with the border station of Chiasso (Fig. 1).

The tunnel excavation has been carried out starting from two opposite sides. On the southern, Bernate side, the tunnel was constructed by rock blasting on the entire profile. On the northern, Ponte Chiasso side, a pilot-tunnel has been drilled after the first 98 m.

On the Ponte Chiasso side the tunnel has crossed the following successions (Pl. 39):

a) A Mesozoic sequence, Jurassic to Early Cretaceous in age, including from bottom to top the following lithostratigraphic units: Moltrasio Limestone, Domaro Limestone, Sogno Formation, Selcifero Lombardo, Maiolica, Scaglia Variegata.

b) Sediments of the Oligo-Miocene "Gonfolite Lombarda" succession, including the Chiasso Formation (Early to Late Oligocene) followed by the Gonfolite Group s. str. (Late Oligocene to Early Miocene). The latter is composed of the following formations: Como Conglomerate, Prestino Mudstone and Val Grande Sandstone (lower part).

On the Bernate side the tunnel passed through the upper part of the Val Grande Sandstone and, beneath the Grandate area, alluvial deposits consisting of sands with rare pebbles and thin clayey layers.

The Tertiary succession forms a SW-dipping homocline laying with a major tectonic contact above the Mesozoic sequence. This contact is a reverse fault along which the southern block (Chiasso Formation) thrusted northward (Bernoulli et al., 1987; Bernoulli et al., 1989).

The Mesozoic succession is strongly tectonized, while deformation rapidly decreases in the lowermost part of the Chiasso Formation.

The Oligo-Miocene sequence is almost undisturbed; the dip gradually decreases from 70°-65° in the Chiasso Formation to 40°-35° in the Val Grande Sandstone. The contact between the Chiasso Formation and the Gonfolite Group is a regional unconformity truncating the upper part of the Chiasso Formation (Gelati et al., 1988).

In this paper we shall describe the stratigraphic characteristics of the Mesozoic and Cenozoic successions; we shall also discuss the tectono-sedimentary significance of the latters for the Oligocene-Miocene evolution of the South-Alpine margin.

The present work is based not only on the data collected in the Monte Olimpino 2 tunnel, but also on new field data from the Ponte Chiasso, Monte Olimpino and Villa Olmo areas.

Stratigraphy of the Mesozoic succession.

Moltrasio Limestone (between 45 m and 389 m from the N-entrance).

The oldest formation exposed in the Monte Olimpino 2 tunnel is the Moltrasio Limestone (Lombardischer Kieselkalk of Swiss authors). Of the 3500 to 4000 meters of this formation exposed in the Monte Generoso area to the North (Bernoulli, 1964), only the uppermost 35-40 m are exposed in the tunnel. As in outcrop, the formation consists of medium to thin-bedded, grey to pale brown, yellowish weathering siliceous limestones with interbedded dark-grey to black laminated marls.

The calcareous beds are spiculitic calcilutites or fine-grained calcarenites to calcsiltites, frequently showing parallel laminations and grading upward into homogeneous micrite or microsparite. Burrow structure are frequent, particularly in the upper portion of the beds. Nodules and lenses of grey to black diagenetic replacement chert truncating sedimentary structures are aligned parallel to the bedding.

In the Generoso Basin, the Moltrasio Limestone ranges in age from the Hettangian to the Early Domerian (Wiedenmayer, 1980).

In the tunnel, few diagnostic fossils were found within the uppermost part of the formation: badly preserved ammonites mainly referable to the genera *Fuciniceras* and *Phylloceras* s.l. The section of the Moltrasio Limestone exposed in the tunnel is thus of Late Pliensbachian (Early Domerian) age and can be correlated with the Molino Member of the Breggia section (Wiedenmayer, 1980).

Domaro Limestone (389 m to 460 m).

About 389 meters from the northern entrance, the Moltrasio Limestone passes upward into hazel-brown to light-greenish grey micritic limestone, in beds 10-20 cm thick without chert nodules and burrows, and with thin interbeds of grey argillaceous marl. Towards the top of the formation, red soft argillaceous interbeds a few centimeters thick appear, the uppermost of which is 20 cm thick.

This formation, which reaches a thickness of 15 m, can be referred to the Domaro Limestone of the Bergamasc Alps that is Early Domerian to earliest Toarcian (*tenuicostatum* Zone) in age (Gaetani, 1975).

The Domaro Limestone in the tunnel shows the same lithofacies as described in the Albenza area of the Bergamasc Alps (Gaetani & Poliani, 1978), where it reaches a thickness of 200-300 meters. The presence of a scarce nannoflora with the genera *Watznaueria, Parhabdolithus* and *Schizosphaerella* is consistent with this age. The Domaro Limestone is interpreted as a basinal deposit.

In the Breggia section (Wiedenmayer, 1980), immediately to the North of Chiasso, and in the Alta Brianza area (Gaetani & Fantini Sestini, 1978), to the East of Como, reddish-violet to green nodular ammonite-bearing limestones of typical "Rosso Ammonitico" facies occur at the same stratigraphical position (Morbio Limestone; Wiedenmayer, 1980). For these nodular limestone a more unstable submarine slope environment could be inferred.

Sogno Formation (460 to 510 m).

The Domaro Limestone is overlain by variegated, red and green spotted calcareous and argillaceous marls without defined bedding, 10-12 m thick. This formation, bounded at the base by a grey argillaceous layer about 5 cm thick, is truncated at its top by a fault and the last few meters are intensely tectonized. It can be correlated with the Sogno Formation of the Bergamasc Alps (Gaetani & Poliani, 1978).

No macrofossils were found, however, a fairly preserved calcareous nannoflora occurs. The assemblage yields abundant remains of *Schizosphaerella*, an "incertae sedis" taxon widespread in Tethyan deep-water limestones (Kälin & Bernoulli, 1984). Small sized (5 microns) coccoliths, mainly belonging to the genera *Watznaueria* s.l. and *Biscutum* also occur, together with *Parhabdolithus liasicus* Deflandre and *Ellipsagelosphaera britannica* (Stradner) (Pl. 40, fig. 5 to 9).

P. liasicus first appears in the earliest Sinemurian and occurs through most of the Liassic; its last occurrence is still matter of debate, however, recent data (Young et al., 1986; Gaetani & Erba, 1990) demonstrated its persistence up to the Early Toarcian. *E. britannica* makes its first appearance within the Toarcian (Perch-Nielsen, 1985). The Sogno Formation is thus essentially of Late Liassic (Toarcian) age, possibly extending into the Middle Jurassic.

The Sogno Formation occurs at the same stratigraphic position as the Rosso Ammonitico Lombardo in the Breggia section, 2 km to the Northwest (Bernoulli, 1964, 1980) and in the Alta Brianza to the East (Pelosio, 1968). From the ammonite-rich nodular marly limestones and marls of the Rosso Ammonitico Lombardo it is, however, clearly distinct by its bedding features and by the absence of fossils of original aragonitic composition.

The carbonate log recorded in the uppermost Domaro Limestone and in the Sogno Formation (Fig. 2) shows a distinct pattern which allows the identification of a marked minimum corresponding to the basal argillaceous layer of the Sogno Forma-

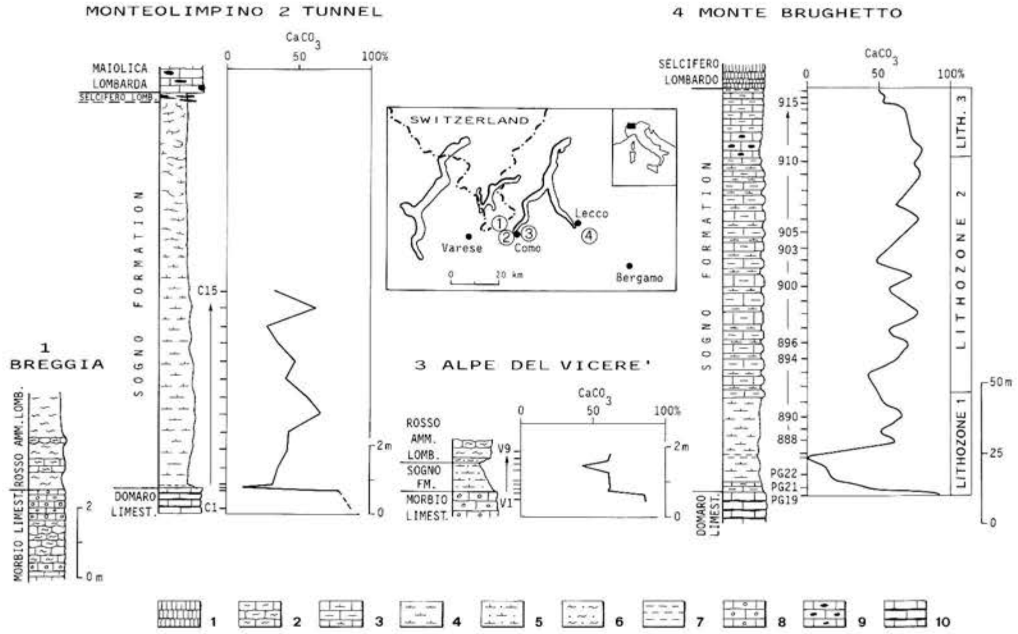

Fig. 2 - Sogno Formation: comparison between the Monte Olimpino 2 section and three classical sections in the Lombardian Southern Alps. Lithology: 1) radiolarian chert; 2) nodular marly limestone; 3) argillaceous limestone; 4) marl; 5) silty marl; 6) nodular silty marl; 7) shale; 8) nodular limestone; 9) cherty limestone; 10) limestone with thin argillaceous interbeds. Section 1 is after Wiedenmayer (1980): section 4 is after Gaetani & Poliani (1978).

tion (12% $CaCO_3$). It is followed by a gradual increase of the Calcium Carbonate percentage (33% to 62%) into the lowermost 2 meters of the marly sequence, and by a subsequent more irregular decreasing trend. The carbonate minimum of our section could be correlated with the dissolution interval present in the basal portion (Lithozone 1) of the Monte Brughetto section (Gaetani & Poliani, 1978), type section of the Sogno Formation in the Albenza Basin, Bergamasc Alps (Fig. 2). It is worth mentioning, however, that the $CaCO_3$ minimum of the Monte Brughetto section, is located 7 to 10 meters above the base of the Sogno Formation, and corresponds to an organic matter-rich layer of grey-greenish shales with iron and manganese impregnations and fish remains ("livello a Pesci"). This layer is connected with the depocentre of the basin and with anoxic conditions.

The comparison with the data of Gaetani & Poliani (1978) suggests that the dissolution episode is more condensed in the Monte Olimpino section than in the Monte Brughetto section, probably due to a lower sedimentation rate and/or to the presence of a hiatus in the basal part of the formation. The studied section is thus correlative with the lithozone 1 of the Sogno Formation, which lies within the Early Toarcian according to the age assigned by Gaetani & Poliani (1978), essentially based on scarce and badly preserved ammonite remains. This age assignment is consistent with the age inferred by us on the base of calcareous nannoplankton.

The abrupt decrease in carbonate at the boundary between the Domaro Limestone and the Sogno Formation in the tunnel section reflects a drastic change in sedimentation near the Middle to the Late Liassic boundary everywhere in the Lombardian Basin. This change coincides also with a general change in lithofacies in the whole Mediterranean area, as pointed out by many authors (Bernoulli & Jenkyns, 1974; Kälin & Trümpy, 1977; Gaetani & Poliani, 1978; Wiedenmayer, 1980; Jenkyns, 1988).

In the Generoso Trough, the lithofacies change can be placed within the earliest Toarcian (*tenuicostatum* Zone), according to the biostratigraphic data of Gaetani & Poliani (1978) and Wiedenmayer (1980); here the Sogno Formation is reduced to the Early Toarcian, and is overlain by the Rosso Ammonitico Lombardo. The classic Alpe del Vicerè section (Fig. 2), shows the occurrence of a decimetric layer of calcareous marls and marls rich in silt and mica which can be referred to the Sogno Formation. In the area between Chiasso and Mendrisio, a few kilometers to the West of Monte Olimpino, the Sogno Formation is absent (Breggia section; Fig. 2).

Selcifero Lombardo.

In the Monte Olimpino 2 tunnel, the Selcifero Lombardo is represented by a thin and discontinuous sliver of red radiolarian chert occurring along the fault contact between the Sogno Formation and the Maiolica formation. Red and variegated cherty limestones with aptychi outcrop near Chiasso, 80 m North-East of the Rio di Maiocca section and have been cut in the abandoned cement factory near Ponte Chiasso (Heim, 1906).

Maiolica.

The strongly tectonized Maiolica formation consists of thick beds of whitish micritic limestones in the lower part, getting thinner (50 to 10 cm) toward the top of the formation, where thin interbeds of black shale appear. Nodules and lenses of bluish to grey replacement chert are frequent.

The formation is bounded by two southwest-dipping faults and its thickness (about 15 m) is tectonically reduced, compared with the Breggia section (Weissert, 1979). The Maiolica is not well outcropping between Como and Chiasso, where Heim (1906) and Fiorentini (1957) mention a thickness between 15 and 40 meters. In the nearby Breggia section, a Berriasian to Barremian age has been established by coccoliths, calpionellids, radiolarians and ammonites (Weissert, 1979; Baumgartner, 1984; Renz & Habicht, 1985; Aita & Okada, 1986; Aita, 1987).

Scaglia Variegata.

Intensely deformed lenses of red clayey marls, from a few centimeters to 1.5 m thick, occur along the fault contact between the Maiolica and the Chiasso Formation (fig. 4, in Bernoulli et al., 1989). These marls are clearly distinct from the grey silty marls of the overlying Chiasso Formation and we correlate them with the Scaglia Variegata formation of the Breggia section, which consists of variegated, dark red to grey-greenish argillaceous marls and marlstones of Aptian to Albian age. The outcrops mentioned by Heim (1906) and Fiorentini (1957) in the Ponte Chiasso and Monte Olimpino area are now covered. The contact between the Mesozoic substratum and the Chiasso Formation, however, is visible in two collapse-cavings about 100 m to the West of the Monte Olimpino cemetery, above the trace of the tunnel; the Scaglia Variegata is represented by one meter of red and grey-to-bluish clayey marls with slivers of reddish marlstones and of grey-greenish silty marls derived from the Chiasso Formation.

The Cenozoic succession.

The succession above the Mesozoic substratum, from 473 to 1864 m and from 3233 m to the S entrance, belongs to the Oligo-Miocene clastic deposits traditionally named "Gonfolite Lombarda". Between 1864 and 3233 m Quaternary fluvio-glacial deposits were encountered.

This succession can be splitted in at least two main segments: the lower one (about 170 m thick) is represented by the Chiasso Formation and the upper one (about 2800 m thick) by the Gonfolite Group s. str. The Gonfolite Group is composed of several formations distinguished in the different outcropping areas (see Gunzenhauser, 1985; Gelati et al., 1988). In the Como area it includes from bottom to top six lithostratigraphic units which are partly heteropic: Como Conglomerate, Prestino Mudstone, Val Grande Sandstone, Lucino Conglomerate, Lucinasco Mudstone and Lurate Caccivio Mudstone. Only the former three have been cut by the tunnel.

Chiasso Formation (473 m to 685 m).

The Chiasso Formation has been transversed by the Monte Olimpino 2 tunnel for a stratigraphic thickness of about 80 meters. Elsewhere the formation covers a time span from Rupelian to Early Chattian, but only the Rupelian is represented in the tunnel (Gelati et al., 1988).

- 473 m to 529 m.

This part of the formation consists of folded and tectonized gray mudstones.

- 529 m to 571 m.

Interbedded laminated mudstone to siltstone without bioturbation and thin beds of sandstone (up to 10 cm thick), which in cases are lens-shaped and grade upward through a laminated interval into pelite. Toward the top of this interval the sandstone beds are more frequent, but the sandstone/mudstone ratio is always less than 1 (Fig. 3).

- 571 m to 685 m.

Grey mudstone to silty mudstone with sporadic thin sandstone layers.

Outside the tunnel the outcropping thickness of the Chiasso Formation ranges from about 50 m in the Chiasso area to about 120 m in the Villa Olmo area. Since the formation is bounded above by an erosional surface and below by a fault, its total

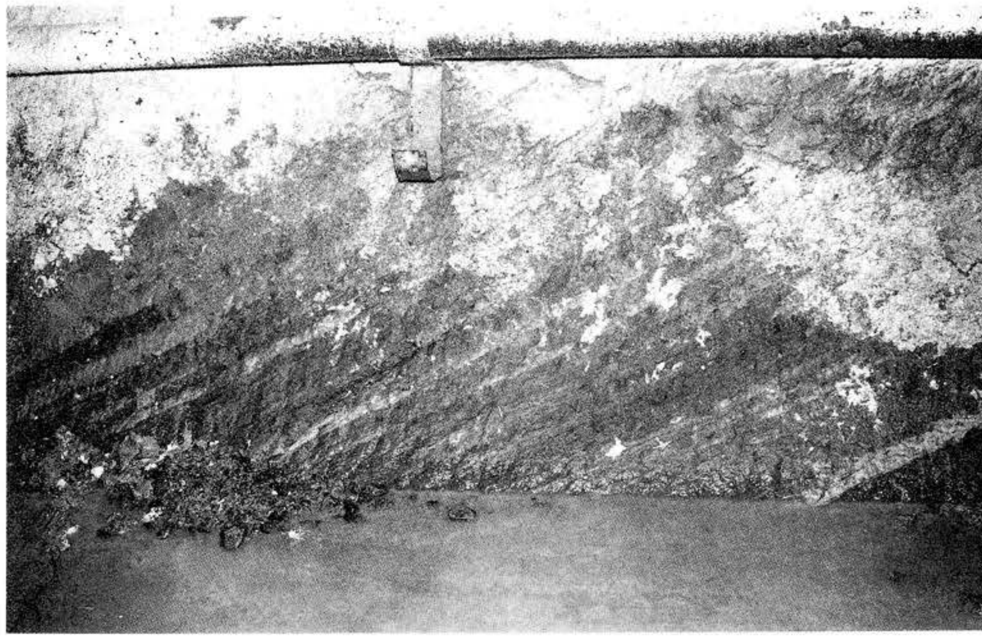

Fig. 3 - Monte Olimpino 2 tunnel: thin bedded turbidites within the Chiasso Formation (courtesy of E. Jäger).

stratigraphic thickness is hard to extimate; however the maximum thickness is at least 170 m taking into account the biostratigraphical data.

The angular unconformity between the Chiasso Formation and the Como Conglomerate visible in the tunnel is about 5°, but can vary from 0° to about 10° in outcrop (Fig. 4). The erosional nature of the contact is confirmed by the varying age of the underlying strata. In the Ponte Chiasso - Monte Olimpino area the top of the Chiasso Formation is considerably older than in the Chiasso area, due to the marked erosional truncation. New data from samples collected in the outcrops between Monte Olimpino and Villa Olmo confirm a Rupelian age for the top of the formation. The age is documented by a fairly preserved planktic microfauna characterized by the occurrence of *Chiloguembelina cubensis, Turborotalia ampliapertura, Turborotalia increbescens* (Pl. 40, fig. 1-4) and *Subbotina angiporoides.*

Gonfolite Group.

Como Conglomerate (685 m to 3160 m).

This formation, about 870 m thick, consists of coarse to medium grained conglomerates in beds of one to few meters of thickness and subordinately of massive or pebbly sandstones. Locally mudstone layers are present. The clasts are mainly composed of igneous and metamorphic rock fragments.

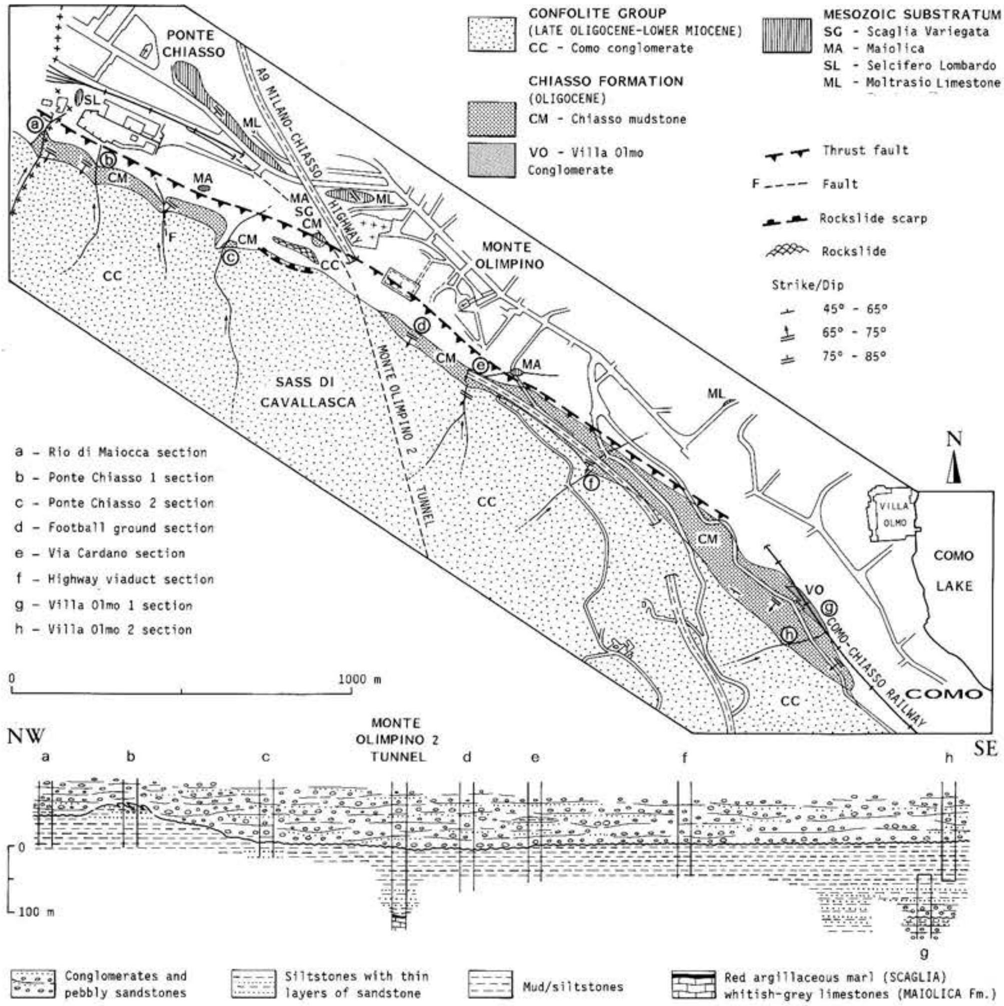

Fig. 4 - Monte Olimpino area: geological sketch-map and schematic cross-section of the unconformity between the Chiasso Formation and the Como Conglomerate.

- 685 m to 1920 m.

Lithozone 1: medium to coarse grained clast-supported conglomerates and conglomeratic sandstones 650 m thick; locally mudstone layers occur. Clast-supported conglomerates are coarse to very coarse with pebbles and cobbles ranging from 5-6 cm to 40 cm of diameter (occasionally more than one meter) or medium grained with particles a few centimeters across (occasionally clasts may be up to 30-40 cm). The individual beds, from 30 cm to about 4 m thick, always show a sharp base and the lower bounding surface is locally erosive. Clast supported conglomerates are internally disorganized (Fig. 5) or inversely graded (Conglomerate type A of Gunzenhauser, 1985); inverse-normally (type B of the same Author) or normally graded conglomerates are less common.

- 1920 m to 2800 m and 2945 m to 3160 m.

Lithozone 2: clast-supported conglomerates with an abundant sandy matrix; sandy, matrix supported conglo-

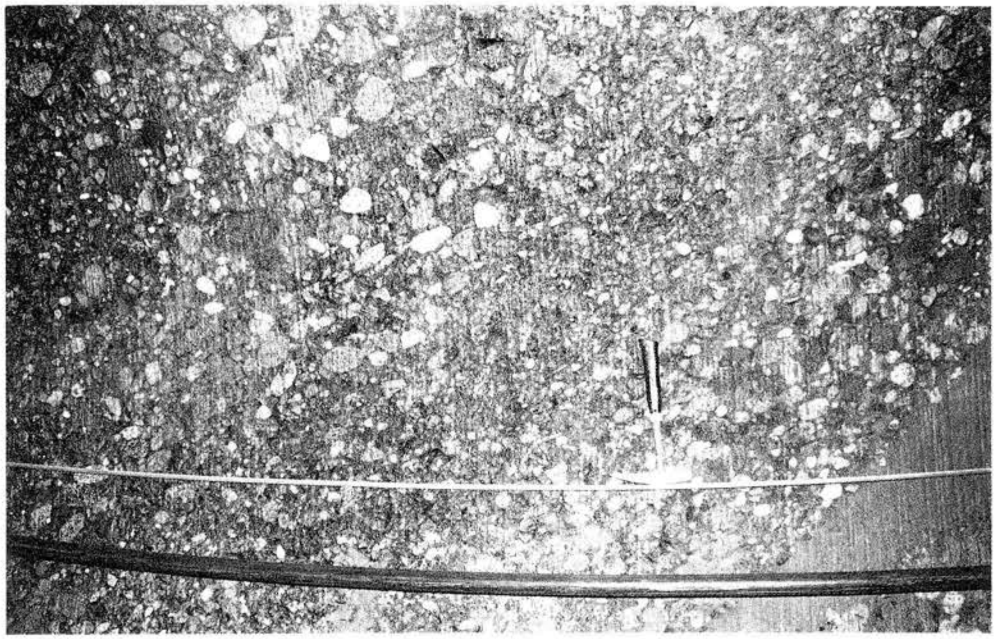

Fig. 5 - Monte Olimpino 2 tunnel (lowermost part of the Como Conglomerate): medium to coarse grained disorganized clast-supported conglomerate.

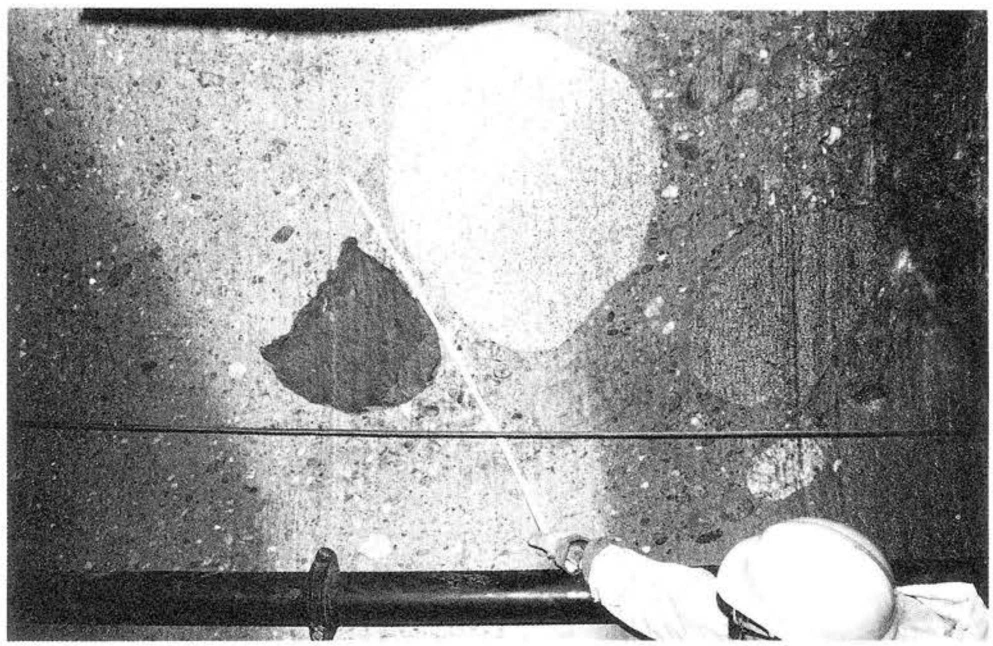

Fig. 6 - Monte Olimpino 2 tunnel (upper part of the Como Conglomerate): disorganized, sandy, matrix supported conglomerate with a mud clast derived from the Prestino Mudstone.

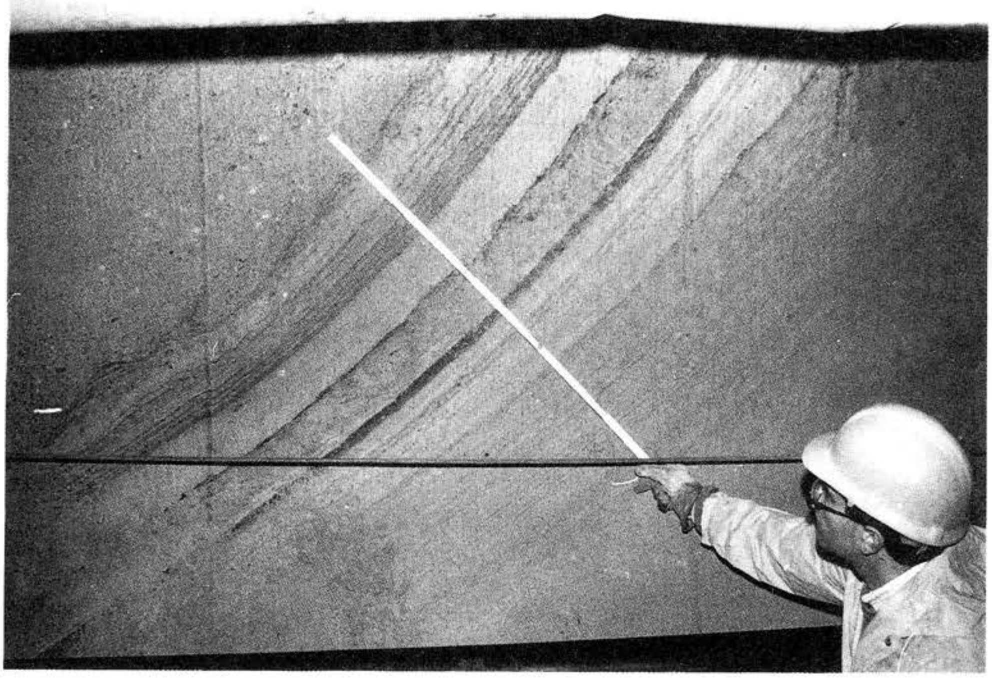

Fig. 7 - Monte Olimpino 2 tunnel (upper part of the Como Conglomerate): horizontal laminations in a coarse grained sandstone bed.

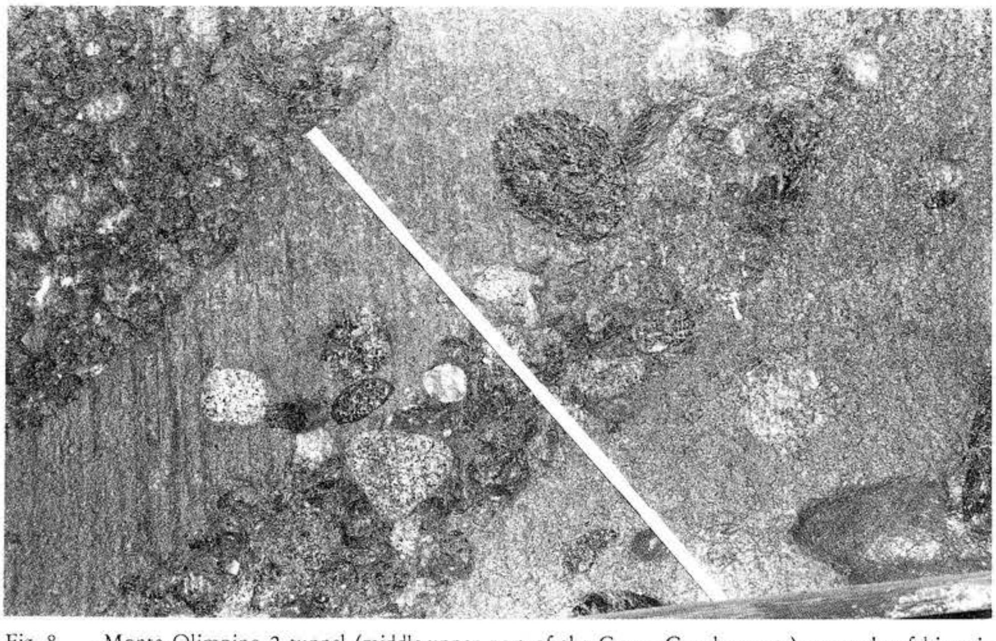

Fig. 8 - Monte Olimpino 2 tunnel (middle-upper part of the Como Conglomerate): example of bipartite conglomerate.

merates, pebbly sandstones and massive sandstones 220 m thick. Mud clasts are common. Toward the top interbedded sandstones and mudstones are prevailing. Disorganized, sandy, matrix supported conglomerates (type D of Gunzenhauser, 1985) in beds 0.4 to 2 m thick contain cobbles and boulders (commonly 40 to 100 cm across) and sometimes mud clasts with sharp edges (Fig. 6).

Laterally continuous or lensing coarse grained sandstones, massive or rarely with crude horizontal or low angle cross laminations, are also present (Fig. 7). Very frequently they develop at the top of individual beds of conglomerate (bipartite conglomerate) (Fig. 8). In the transition zone between the lithozones 1 and 2 tripartite conglomerate beds are observable, with, from the bottom: clast-supported conglomerate, disorganized or graded; disorganized matrix-rich conglomerate with larger clasts; coarse grained sandstone.

(Como Conglomerate / Prestino Mudstone transition).

Lithozone 3: in the upper part of the succession (2800 m to 2945 m) an interval referable to the Prestino Mudstone is intercalated; immediately below and above this interval a third lithozone is characterized by the interfingering of conglomerates and mudstones and by mud pebble breccias. The latter consists of mud clasts and fragments with sharp edges floating in a sand-sized matrix (see Gelati et al., 1988, p. 297, fig. 9). The fragments usually appear to be part of a mud layer or a group of mud layers broken and remobilized, but still recognizable. Sporadically pebbly mudstones are present; they are disorganized matrix-supported conglomerates with a clayey-silty matrix.

Prestino Mudstone (2800 m to 2945 m and 3160 m to 4160 m).

This formation about 460 m thick, Late Chattian - Aquitanian in age, mainly consists of gray silty mudstones with poorly developed laminations. Thin laterally discontinuous sandstone layers showing parallel or cross-laminations are locally present. The sandstone/mudstone ratio is always less than 0.1. Toward the top of the succession interbedded mudstone and sandstone layers 4-6 cm thick prevail and the sandstone/mudstone ratio gets higher (from 1 to 0.5); the sandstones show grading, parallel laminations and ripples (Tab, Tac, Tbc sequences). A slump involving mudstone and sandstone layers up to 15 cm thick is present at 3660 meters.

At the surface the Prestino Mudstone appears as a lenticular body extending in a NW-SE direction, partly interfingering with and partly overlying the Como Conglomerate. In outcrop the Prestino Mudstone is less monotonous than in the tunnel. In the northern outcrop area near Cavallasca the formation is characterized by higher sandstone/mudstone ratio, by the occurrence of massive or graded medium to coarse grained sandstone beds 10 to 40 cm thick and also by a clast-supported conglomeratic intercalation. The succession observed along the tunnel is most similar to that one outcropping near Prestino. Toward SE the succession gets progressively more homogeneous, consisting only of mudstones and siltstones. Hemipelagic layers characterized by a well-developed autochthonous macrofauna are interbedded with layers deposited by dilute turbidity currents.

The passage to the overlying unit (Val Grande Sandstone) is transitional and characterized by a gradual increase of the sandstone-mudstone ratio.

Val Grande Sandstone (4160 m to 4380 m of the pilot tunnel; 1864 m to 3223 m of the plan layout).

The Monte Olimpino 2 tunnel cuts the Val Grande Sandstone (upper Aquitanian - Burdigalian) in two intervals lying to the North and to the South of the Quaternary deposits infilling a deeply incised paleocanyon (Bini et al., 1978) in the Grandate area; the total thickness of the Val Grande Sandstone is calculated at about 700 meters. The observed stratigraphic thickness is 135 m in the northern and 170 m in the southern interval. Because of its orientation the tunnel failed to meet the overlying Lucino Conglomerate.

The Val Grande Sandstone consists essentially of interbedded sandstones and mudstones; the former are sometimes associated with fine to medium grained clast-supported conglomerates.

Five lithologic associations can be distinguished:

1) Hemipelagic mudstone layers up to 40-50 cm thick with silt-sand laminations, characterized by an autochthonous macrofauna consisting of molluscs and echinoids, occuring only in the southern tract of the tunnel.
2) Interbedded sandstone and mudstone layers 10-20 cm thick with a sandstone/mudstone ratio ranging from 1.25 to 2. The sandstone layers show sharp bases, locally erosive and normal grading. Internal laminations are frequently deformed or obliterated by bioturbation in both the lithologies. Within the lower portion of the Val Grande Sandstone (northern tract of the tunnel) this association is often organized in fining and thinning upward sequences. The interbedded mudstones sometimes contain an autochthonous macrofauna (Gelati et al., 1988).
3) Coarse grained sandstones, massive or normally graded, 20-30 cm to 3 m thick, with horizontal or low angle laminations often present, erosional bases and amalgamation very common. Thin interbedded mudstone layers, when present, show loading deformation. In the northern tract of the tunnel the sandstone beds are sometimes organized in thickening upward sequences or compensation cycles, in the southern tract (upper Val Grande Sandstone) thinning and fining upward sequences appear. The association 3), that represents the main portion of the succession, rapidly grades upward into associations 1) and 2) or locally is incised into them.
4) Fine to medium grained clast-supported conglomerates (mainly in the northern tract of the tunnel); they are disorganized, normally graded or inverse-to-normally graded, and always associated with thick sandstone beds of the association 3). Matrix-supported conglomerates laterally evolving into pebbly or massive sandstones are sporadically present.
5) At the 4225 m of the pilot tunnel a pebbly mudstone bed about 20 m thick, with pebbles of 6-7 cm of diameter and fragments of the associated sandstone beds occur. The same deposit is visible also in outcrop (see Gunzenhauser, 1985, fig. 58) and it is followed by several thickening upward sequences.

The northernmost portion of the Val Grande Sandstone, heteropic with the Como Conglomerate, has not been met by the tunnel. In outcrop it is characterized by a sequence of amalgamated thick graded sandstones or fine conglomerates with irregular and frequently erosional bases. The sediments are associated with fine to medium grained clast-supported conglomerates, that can be disorganized or normally graded. Graded stratified conglomerates are also present.

Cenozoic depositional sequences.

The characteristics of the described cenozoic succession confirms that it is probably part of an inner deep-sea fan complex superimposed to a slope or slope-base system (Gunzenhauser, 1985). The succession consists of at least four depositional sequences (Fig. 9) which are close to "allogroups" sensu Mutti et al. (1988).

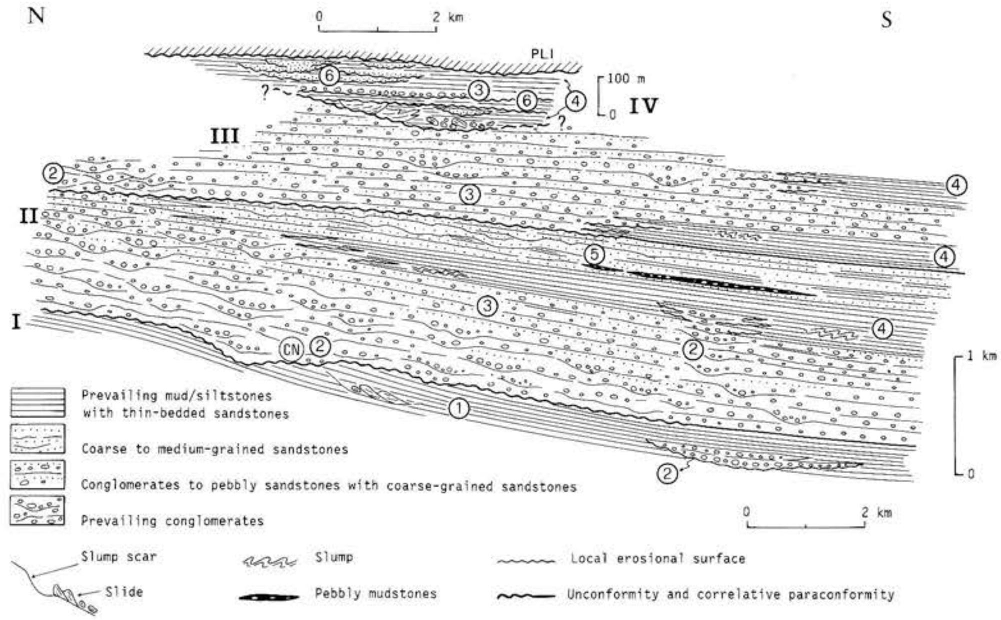

Fig. 9 - Depositional sequences in the "Gonfolite Lombarda" (I-IV) and facies distribution on a generalized N-S section. Facies associations and related depositional mechanisms: 1) slope to slope-base complex (hemipelagic deposition and low density turbidity currents); 2) proximal conglomeratic channel-fill (prevailing density modified grain flow to high density turbidity currents); 3) distal conglomeratic channel-fill (density modified grain flow/sandy debris flows and high density turbidity currents); 4) levee and intercanyon complexes (low density turbidity currents to hemipelagic deposition with local fluidized flows); 5) sandy lobe, partly channelized (high to low density turbidity currents with local sandy debris flows); 6) sandy channel-fill (prevailing low density turbidity currents). CN) canyon-fill. PLI) Pliocene.

Sequence I.

The first depositional sequence is represented by the Chiasso Formation bounded at its base by a tectonic contact and at its top by a marked truncation surface. Its deposition is documented at least from Late Rupelian (zone P19/P20) to Early Chattian (zone P21b, probably extending into earliest zone P22) (Gelati et al., 1988).

The hemipelagic mudstones and thin bedded turbidites of this sequence can be referred to a slope to slope-base complex (Gunzenhauser, 1985). They were deposited within the upper bathyal zone (from about 500 m to about 1000 m of depth) as indicated by the benthonic fauna (Rögl et al., 1975; Gelati et al., 1988). Locally, conglomeratic clast-supported deposits associated with coarse to medium grained sandstones, massive or with parallel laminae (Villa Olmo Conglomerate), record an increase of the clastic supply; they may represent gravity flow sediments infilling submarine channels. Slides, mud-breccias and slide-scars infilled by muddy hemipelagic deposits are recorded from the area to the West of Varese (Bernate section) and from the Brianza area (Gunzenhauser, 1985). These features only locally visible due to the poor exposure outline the complexity of the Chiasso Formation. A further internal subdivision could be matter of discussion.

Pelagic microfaunas (planktonic foraminifera) and deep water benthonic foraminifera occur throughout the sequence. They seem to be richer and more diversified in its medium to lower part, where pelitic (hemipelagic) facies more frequently occur. A one meter thick layer of clay to marly clay very rich in planktonic foraminifera of the zone P21a (plankton/benthos ratio more than 0.95) occurs near Brusata (Switzerland) in the lowermost outcrop of the sequence.

The subsequent depositional history of the sequence reflects a gentle increase of the terrigenous input.

The average sedimentation rate for the documented time span is estimated to be no more than 3 cm/1000 years for compacted sediment (170 m deposited in 6 MA).

Sequence II.

The beginning of the sedimentation of the Gonfolite Group s.str. in the Late Oligocene (Chattian) marks a sudden change in the sedimentation conditions recorded over the whole outcrop area of the "Gonfolite Lombarda". The Gonfolite Group is the result of the evolution of a submarine canyon system whose proximal tract (i.e. the lower part of the Como Conglomerate) is deeply incised into the slope complex (Fig. 10).

Fig. 10 - Ponte Chiasso 1 section (b in Fig. 4): the erosional truncation bounding the Chiasso Formation at its top representing the boundary from the sequences I and II. Some clastic intrusions of the overlying Como Conglomerate can be observed.

The Sequence II consists of the Como Conglomerate and its heteropic units.

Conglomerates, pebbly sandstones and coarse grained sandstones deposited by density modified grain flows and high density turbidity currents mainly characterize the lower part of the sequence. They are interpreted as part of a "proximal" canyon-fill complex. The rough lenticular bedding of the conglomerates, which are arranged in laterally discontinuous bodies with a sharp non-erosive base, and the mutual geometric compensation (Fig. 11) indicate their origin by rapidly migrating high density flows.

The depositional system gradually evolved during the very Late Chattian into relatively downcurrent conglomeratic-arenaceous facies associations, which represent the distal portion of the submarine canyon complex. During the Early Miocene (Aquitanian to very Early Burdigalian) a natural levee complex (Prestino Mudstone) confining arenaceous - conglomeratic channel-fill facies associations developed. A remarkable reduction of the clastic supply in the western Como area occurred during this two-step evolution, pointing to a partial abandonment of the feeding system, possibly due to a relative sea level rise. The sudden development of sandy lobe facies associations (Val Grande Sandstone) characterizes the final evolution of the second sequence.

The hemipelagic and low density turbiditic deposits of the Prestino Mudstone rapidly evolve into the prevailing low to high density turbidity current derived sandy deposits of the Val Grande Sandstone. The facies association (Napolitano, in prep.)

Fig. 11 - Ponte Chiasso 1 section (lowermost part of Como Conglomerate); lenticular conglomerate bodies showing mutual geometric compensation.

and their mutual geometrical relationships in outcrop indicate that there is a lateral grading between the distal canyon-fill associations of the uppermost Como Conglomerate and the sandy lobe associations of the Val Grande Sandstone. These features, together with the sandstone beds geometry, lead us to consider this formation as a lobe complex still partly confined by a major fan valley. This stage of evolution of the Sequence II is characterized by the rapid but not abrupt transition from relatively upcurrent (canyon-fill and levee) to relatively downcurrent (confined sandy lobe) facies associations. This implies a retrogressive stage of the depositional system.

The subsequent stratigraphic and sequential evolution of the Gonfolite Group is not recorded in the Monte Olimpino 2 tunnel. The reconstruction of the depositional history is based upon outcrop data both from the Como and Varese areas.

Sequence III.

This sequence poorly crops out both in the Como and in the Varese area. Its lower boundary is marked by a sudden increase of the coarse clastic supply and is marked by truncation surface visible where it overlies arenaceous or pelitic facies associations. The Lucino Conglomerate (and heteropic units) which overlies both the Val Grande Sandstone and the Como Conglomerate represent a new progradation phase of the depositional system that can be referred to the Early Burdigalian.

This progradation seems to be less abrupt than that recorded at the base of Sequence II since levee or intercanyon facies associations (Lucinasco Mudstone) developed as early as the sedimentation of the lowermost Lucino Conglomerate. Moreover, the conglomeratic-arenaceous facies associations of the lower Lucino Conglomerate show an upward trend from relatively "downcurrent" to relatively "upcurrent". The upper part of Sequence III is characterized by an opposite trend, which is pointed out also by the occurrence of levee facies associations (Lurate Caccivio Mudstone) (Napolitano, 1985). The Lucino Conglomerate, besides, contains reworked pebbles of Chiasso Formation (Bernoulli et al., 1989).

The age of this sequence probably extends up to the Late Burdigalian (Gelati et al., 1988). Recent data based on palynology (D. Bernoulli, pers. comm. 1990) suggest a possible Middle Miocene (Langhian) age for the uppermost outcropping part of Sequence III (Lurate Caccivio Mudstone).

Sequence IV.

This sequence crops out only in the Varese area (Gurone Sandstone and Bizzozzero Mudstone). Its base is characterized by a marked erosional truncation which cuts the underlying Lucino Conglomerate and by an angular unconformity.

The lowermost Gurone Sandstone, interpreted as a levee complex incised by sand-bearing channels, is partially involved in slides up to several meters thick. Boulders of intraformational origin, consisting of massive or laminated sandstones and mudstones, also occur. An intraformational angular unconformity separating pelitic deposits occurs within the upper part of this succession (Fig. 9). The middle to upper part of the Gurone Sandstone reflects a two-step evolution: the instauration of a conglomeratic canyon system passing upward into a levee complex confining a sandy channel-fill association dominated by low density turbidity current deposits. The poor continuity of the outcrops and the lack of biostratigraphic control do not allow to discriminate further sequence boundaries within Sequence IV.

Sequence IV is unconformably overlain by turbiditic, slump and sand-flow deposits Early Pliocene in age, followed by glacio-marine deposits (Corselli et al., 1985). Since its uppermost part is characterized by intense weathering of Late Miocene age (Corselli et al., 1985) a post-Burdigalian and pre-Messinian age can be assigned to the sequence. Taking into account the data of Rizzini & Dondi (1978), according to whom the uplift of the Lombardian homocline above the sea-level took place within the Tortonian, the age of Sequence IV may be restricted to pre-Tortonian.

Discussion.

The chronostratigraphic restoration of the Oligocene-Miocene succession allows a sequence analysis in order to discriminate between the influence of global changes of sea level and of tectonic events on the sedimentation along the southern border of the

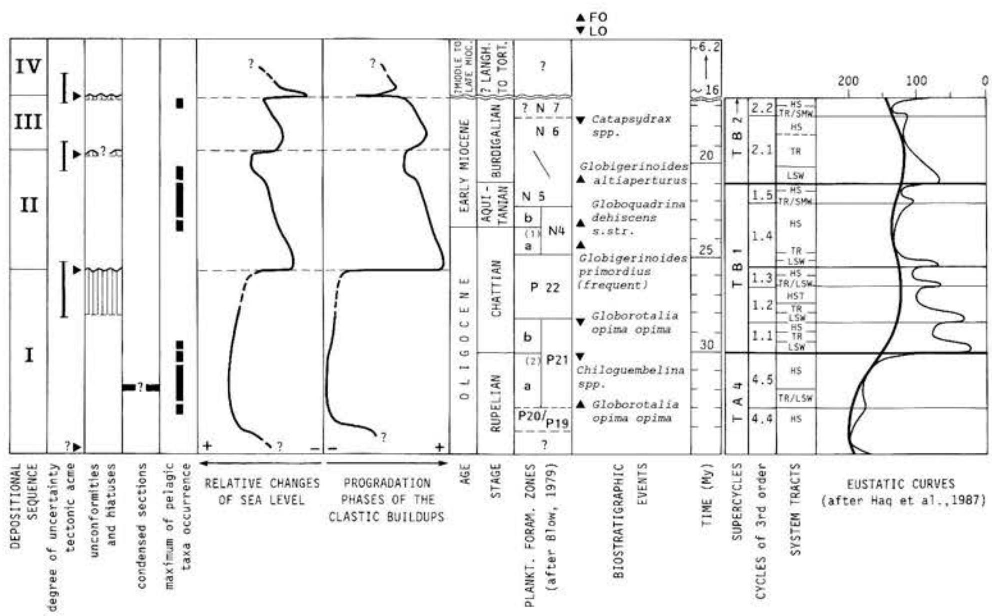

Fig. 12 - Sequence stratigraphic analysis of the "Gonfolite Lombarda".

emerging mobile Alpine thrust belt (Fig. 12). The tectonic nature of the contact with the Mesozoic sequence does not allow the interpretation of the basal part of the succession, represented by the Chiasso Formation. The outcropping portion of this formation, however, covers a time span corresponding at least to the third order cycles TA 4.4, TA 4.5 and TB 1.1 of Haq et al. (1987). It is, however, not easy to discriminate the individual cycles probably because of the deep marine nature of the examined deposits and of their poor exposure.

The Villa Olmo Conglomerate, deposited by sediment gravity flows and locally present at the base of the pelitic succession, probably is comprised in the upper part of the TA 4.4 cycle characterized by a phase of global sea level rise (Fig. 12). Therefore this clastic input in the Rupelian is probably tectonically controlled. In our opinion the meter thick layer rich in planktonic foraminifera occurring at Brusata may represent a condensed section which points out the transition from a transgressive to an highstand phase of the sea level characterized by a strong decrease of terrigenous supply. It could be placed within the third order cycle TA 4.5 recorded by Haq et al. (1987).

The erosional truncation that characterizes the base of the Como Conglomerate represents a sequence boundary. This can be placed in the lower part of the TB 1 second order supercycle. Note that this boundary is not related to the major sequence boundary indicated at the Rupelian-Chattian boundary (30 MA). On the basis of our biostratigraphical data it could be related to the medium sequence boundary indicated at the very Late Chattian (25.5 MA). This would imply a very high rate of sedimentation in a deep marine environment during the deposition of the lowermost Como Conglomerate: about 90 cm/1000 years of compacted sediment (870 m of conglomerates deposited between 25.5 MA and about 24.5 MA - base of the Prestino Mudstone). Assuming an unchanged depositional bathymetry (upper bathyal zone, 500-1000 m of depth) we could obtain for the lower Como Conglomerate a high subsidence rate (more than about 35 cm/1000 years, minimum value). Even assuming at 28 MA the beginning of the coarse clastic sedimentation (Fig. 12), we will obtain a subsidence rate of about 10 cm/1000 years (minimum possible value) and an accumulation rate of 25 cm/1000 years. The inferred subsidence rates are in any case typical of active margins (Stow et al., 1985).

According to Bernoulli et al. (1989) and to Bernoulli et al. (1990) the massive terrigenous influx is probably related to a rapid phase of uplift and erosion North of the Insubric Line reflected in the Como Conglomerate by deformed and recrystallized Tertiary Tonalite boulders derived from the Val Masino - Val Bregaglia Massif (Giger & Hurford, 1989; Giger, 1991).

Angular unconformities associated with erosional truncation of probable Late Oligocene age are recorded in the central-eastern South Alpine belt: in the Garda Lake area (Luciani, 1989) and in Veneto - Friuli (Massari et al., 1986).

During the Late Oligocene a strong tectonic activity is recorded by the occurrence of unconformities also in the satellite basins of the Northern Apennine thrust

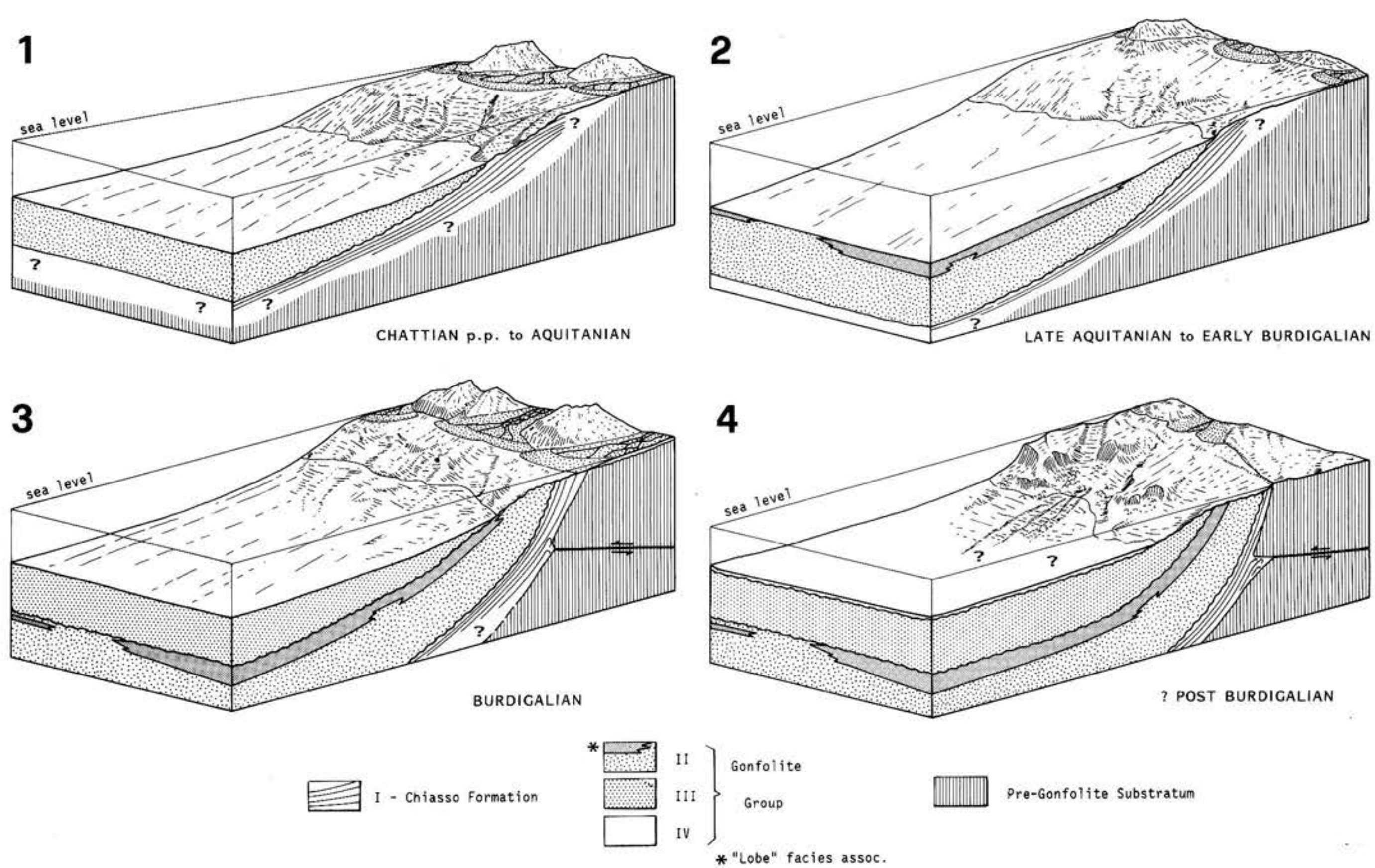

Fig. 13 - Block diagrams not to scale showing the tectono-sedimentary evolution at the inner margin of the "Gonfolite Lombarda" basin. The upper shelf could be exposed in blocks 1 and 3; it could be flooded in block 2. The tectonic of the substratum is only indicative.

belt (Gasperi et al., 1986); this is particularly clear in the Piedmont Tertiary Basin which is developed behind the thrust front of the north-western sector of the Apennine belt (Gnaccolini et al., in press). Therefore the inferred tectonic control could also reflect a contemporaneous tectonic acme involving the Southern Alpine thrust belt and the surrounding regions.

As mentioned, the widespread presence of pelitic associations partly of hemipelagic origin (e.g. Prestino Mudstone) in the upper portion of the second depositional sequence, i.e. above the conglomeratic associations, may reflect a relative sea level rise leading to a partial abandonment of the feeding system (Fig. 13). The sudden increase of the turbiditic deposition (Val Grande Sandstone) at the ending of Sequence II apparently matches the type I major sequence boundary located between the second order supercycles TB 1 and TB 2 (21 MA). The recorded depositional evolution however doesn't agree with a major relative sea level fall. A rapid drop of the sea level, infact, would have caused the general deposition of more proximal facies associations with a marked progradation phase of the depositional system. The distal nature of the examined facies associations in an upper deep sea fan context and the abandonment of the eastern sector of the Como area suggest on the contrary a relative sea level rise, whose cause has therefore a local origin.

The Val Grande Sandstone deposition could be tentatively linked to a developing thrusts system migrating southward determining a tectonic loading and consequently high subsidence rate in the foredeep (Fig. 13). Eustatic sea level drops that can be considered as minor if compared to the total amount of relative deepening of the sea bottom, can easily escape documentation on a rapidly subsiding deep marine slope.

An age of 21 MA for the base of the Val Grande Sandstone (700 m thick) implies, assuming an end of the sequence at 19-20 MA, a minimum rate of subsidence ranging from 10 to 20 cm/1000 years because of the persistence of an upper bathyal environment. These values are higher than the sea level lowering that can be estimated on the eustatic curve (up to about 5 cm/1000 years) of Haq et al. (1987). Furthermore, even though the accumulation rate of the Prestino M.- Val Grande S. time span (21 to 25 cm/1000 years resulting from 1150 m of thickness in 4.5 - 5.5 MA) is probably lower than in the basal Como Conglomerate, the subsidence rate shows comparable minima values (12 to 14 cm/KA). The progradation - retrogradation trend deduced from the facies distribution is in line with this.

The stratigraphic and sequential evolution of the remaining succession of the Gonfolite Group, not observable in the Monte Olimpino 2 tunnel, reveals a renewed tectonic control (Fig. 12) on the sedimentation from the Burdigalian to the Middle Miocene (sequences III and IV).

The new progradation phase which characterizes the initial deposition of the Lucino Conglomerate, even though considering the degree of uncertainty of the biostratigraphic data, appears to be younger than the cited low stand phase marked by the TB1-TB2 supercycles boundary.

The nature of the boundary between the Lucino Conglomerate and the Gurone Sandstone and the features of the immediately overlying deposits suggest a sudden renovation of tectonic activity in a pre-Tortonian time. It caused a submarine erosion of Sequence III and initial sedimentation of Sequence IV under conditions of slope unstability, which allowed the mobilization of semiconsolidated and unconsolidated deposits.

Therefore the main phases of northward thrusting of the "Gonfolite Lombarda" onto the Mesozoic could be indicated by the sequence boundaries II/III and III/IV, respectively corresponding to Lower Burdigalian and Upper Burdigalian/pre-Tortonian.

The probably continuous movement of the underlying thrusts system is recorded by the progressive variation of bed dip values ("progressive unconformities") visible in the outcropping homocline of the "Gonfolite Lombarda". The persistence of the same depositional mechanisms indicates almost constant depositional gradients. This implies a progressive deformation of the slope morphology along the inner basin margin. Periods of highly increased rate of deformation are recorded by the tectonically induced unconformities limiting each depositional sequence (Fig. 14, 15).

Regional unconformities are present in the Burdigalian - Langhian also in the Veneto - Friuli Southern Alps (Massari et al., 1986). A tectonic control was also active in the Piedmont Tertiary Basin during the Aquitanian-Burdigalian and at the Langhian-Burdigalian (Gelati & Gnaccolini, 1988; Gnaccolini et al., in press) as indicated by increased clastic input. In the Northern Apennine tectonic "crisis" are recorded between the Langhian and the Serravallian and within the Early Tortonian (Gasperi et al., 1986).

The observed stratigraphy and the comparison with the global cycle charts, shows the poor adaptability of the classical depositional models (see Mitchum et al., 1977 inter alias) to active margins (Mutti et al., 1988; Mutti, 1990) characterized by a rapidly evolving foredeep basin like the South-Alpine border.

In the Rupelian to Burdigalian time span several worldwide "lowstand system tract" intervals follow one another (Haq et al., 1987). They are separated by "transgressive" and "high stand system tract" often comprising long time spans (1-3 MA) (Fig. 12).

In the Gonfolite Group this alternation is not obvious. In fact we see a persistent deep-sea system in which the clastic deposits and the areal distribution of the hemipelagic sediments are not necessarily related to the global sea level changes. Moreover the persistence of the turbiditic sedimentation in the "Gonfolite Lombarda" is not easily correlatable with eustatic low stand phases.

Because of the impossibility to use the coastal onlap along the inner and not preserved margin of the foredeep basin, the relative sea level changes have to be analyzed from the variations in the internal organization and geometry of the depositional system or analyzing the transition to the foreland. The foreland of the Southern Alps (central Po Plain) is also the foreland of the Northern Apennines and was, during

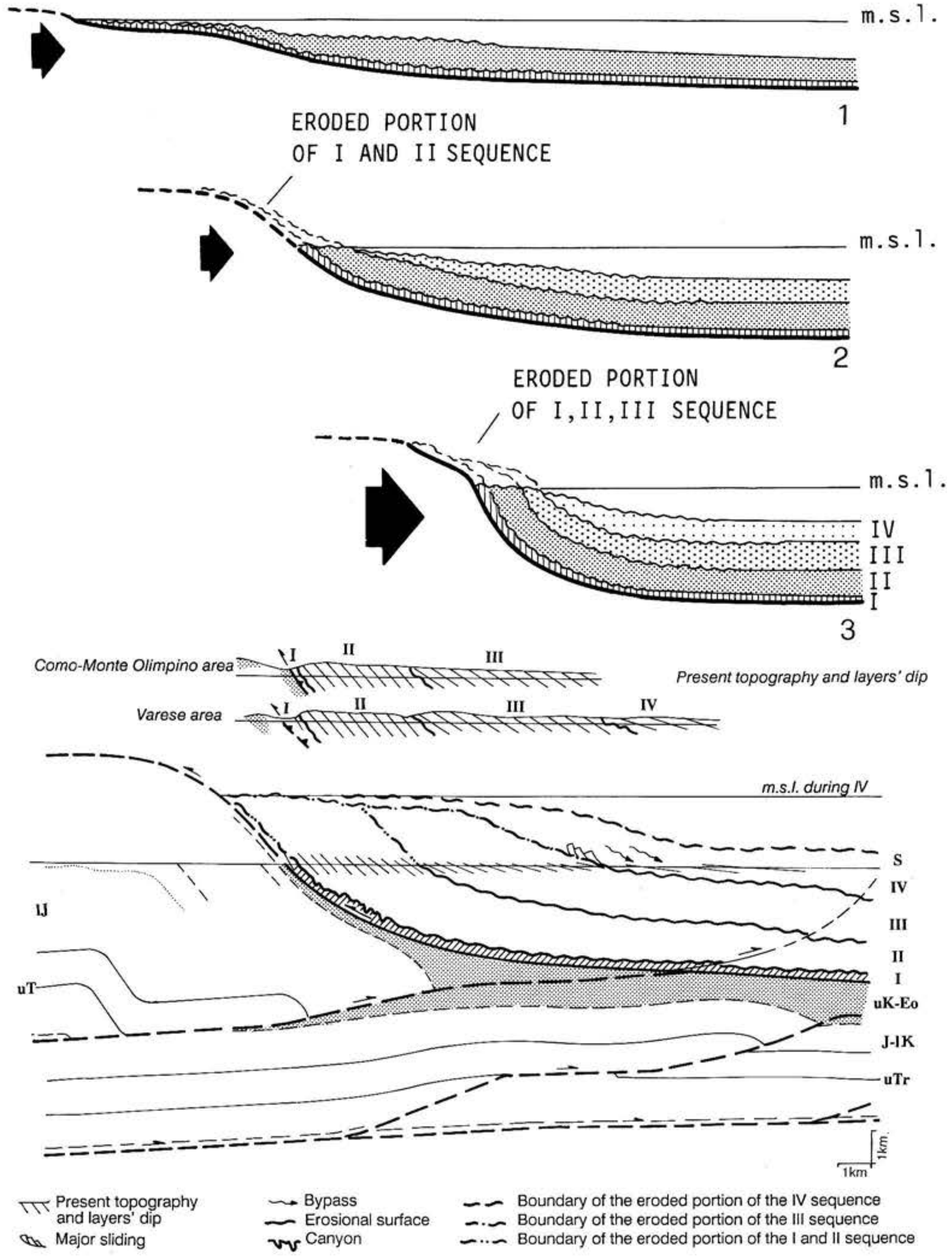

Fig. 14, 15 - Depositional evolution of the "Gonfolite Lombarda" clastic wedge related to the thrust belt propagation at the northern margin of the Padan Foredeep along a generalized north (on the left)-south (on the right) section. The geometry of the embricated substratum is only indicative of the possible scenario (see i.a. Pieri & Groppi, 1981; Laubscher, 1985, 1991; Bernoulli et al., 1990).

the Oligocene and the Miocene, characterized by open marine pelitic sedimentation. In this context it is not only difficult to recognize relative sea level changes, but also to separate tectonic and eustatic influence.

Depositional models utilizable for this purpose and pertinent to deepsea fans infilling elongate basins confined by a more progressively deformed thrust belt were developed by Mutti (1985). All other things being equal, the sedimentation in this kind of basins is essentially function of the volume of gravity flows and then of the relative sea level position. There are several factors influencing the general internal organization of deep sea clastic complexes. As summarized by Stow et al. (1985), these factors can be grouped into sedimentary, tectonic and sea level controls each of them with primary and secondary factors. But in the examined geodynamic context some of them seem to assume a prevailing influence on the deep marine sedimentation:

- the presence of an emerging thrust belt and the high rates of uplift, denudation (Giger & Hurford, 1989; Giger, 1991), tectonic shortening (Roeder, 1990; Laubscher, 1991) and subsidence. They affect shelf width, continental margin gradients, gross sediment budgets, morphology of the receiving basin and local sea level changes (Stow et al., 1985);

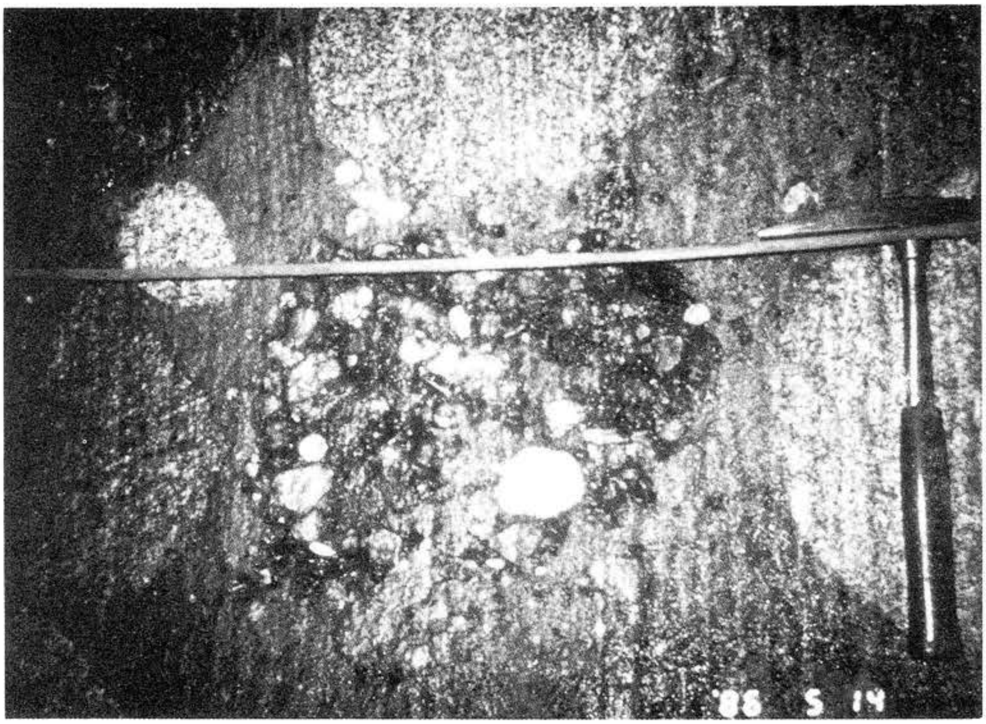

Fig. 16 - Monte Olimpino 2 tunnel (middle part of the Como Conglomerate): reworked boulder of conglomerate (courtesy of E. Jäger).

- the shape and the confinement of the basin, related to the geodynamic context;

- the volume and the type of the transported sediments. They affect the process and the distance of transport and hence the geometry of the deposit (Stow et al., 1985).

The sum of these factors in the presence of a high deformation rate can determine apparent sea level changes of an order of magnitude higher than eustatic ones (Mutti & Sgavetti, 1987; Mutti, 1990). This can be the case of a rapidly emerging thrust belt with a high degree of shortening as in the "Gonfolite Lombarda" depositional basin.

In such a context high gradients at the thrust belt front and rapid subsidence of the foreland basin floor can be expected. The southward weak confinement of the basin prevents the basin infilling as shown by the facies distribution in the subsurface of the Po Plain (Dondi & D'Andrea, 1986) at least until the Middle Miocene. The almost continuous input of clastic sediment can be explained by the persistence of uplift movements in the inner part of the thrust belt (see Giger & Hurford, 1989).

The growth of the thrust system probably determined a progressive basinward tilting of the inner basin margin (Fig. 14 and 15) testified by partial cannibalization of the previous sediments (Fig. 16; see also Bernoulli et al., 1989) and progressive unconformities. As recognized by Mutti et al. (1988), the basinward tilting of the basin margin in a tectonically mobile setting is a critical factor controlling turbidite and mass-flow deposition because it simultaneously provides the space for sedimentation and the sediment with which this space is partly filled in. The tectonic loading and the basinward tilting cause a high subsidence rate of the basin floor. Therefore a retrogressive phase of the depositional system during a period of eustatic sea level lowering (e.g. Val Grande Sandstone) can be explained. The forward propagation of the thrust system front can determine a partial backthrusting of the clastic wedge onto the older moving substratum (see Bernoulli et al., 1987; Bernoulli et al., 1989). Cannibalization, internal unconformities and relative sea level changes are then expected.

It is reasonable to hypothesize that no wide shelves and large delta complexes developed (Fig. 13) because of the probable steep gradients and large amount of extratopography (Roeder, 1990); thick and highly unstable suspended small deltas on a narrow shelf (Gunzenhauser, 1985) seem to be more probable. The sediments thus would have been carried down into a deep sea environment with an almost complete bypassing of the narrow or non-existing neritic area even during periods of high sea level.

The resulting total travel of a single pebble (or boulder) from the source point to the bathyal area is therefore very rapid since the intermediate stage of standstill in a delta complex is eliminated or shortened. In this way the relatively short time occurring between the emplacement and cooling of the Bregaglia granitoids and the deposition of the Gonfolite Group (tonalite pebbles of about 31 MA of radiometric age in the Villa Olmo Conglomerate and basal part of Como Conglomerate; Giger & Hurford, 1989) can be more easily explained.

The "Gonfolite Lombarda" succession therefore suggests some concluding remarks concerning basins flanking a rapidly emerging and forward propagating thrust belt:

- the different depositional phases of coarse clastic sedimentation in a deep basin are not necessarily related to eustatic changes;
- high stand system tracts could be not recorded in the inner part of the deep marine depositional system;
- high stand type deposits can be not related to eustatic sea level rises.

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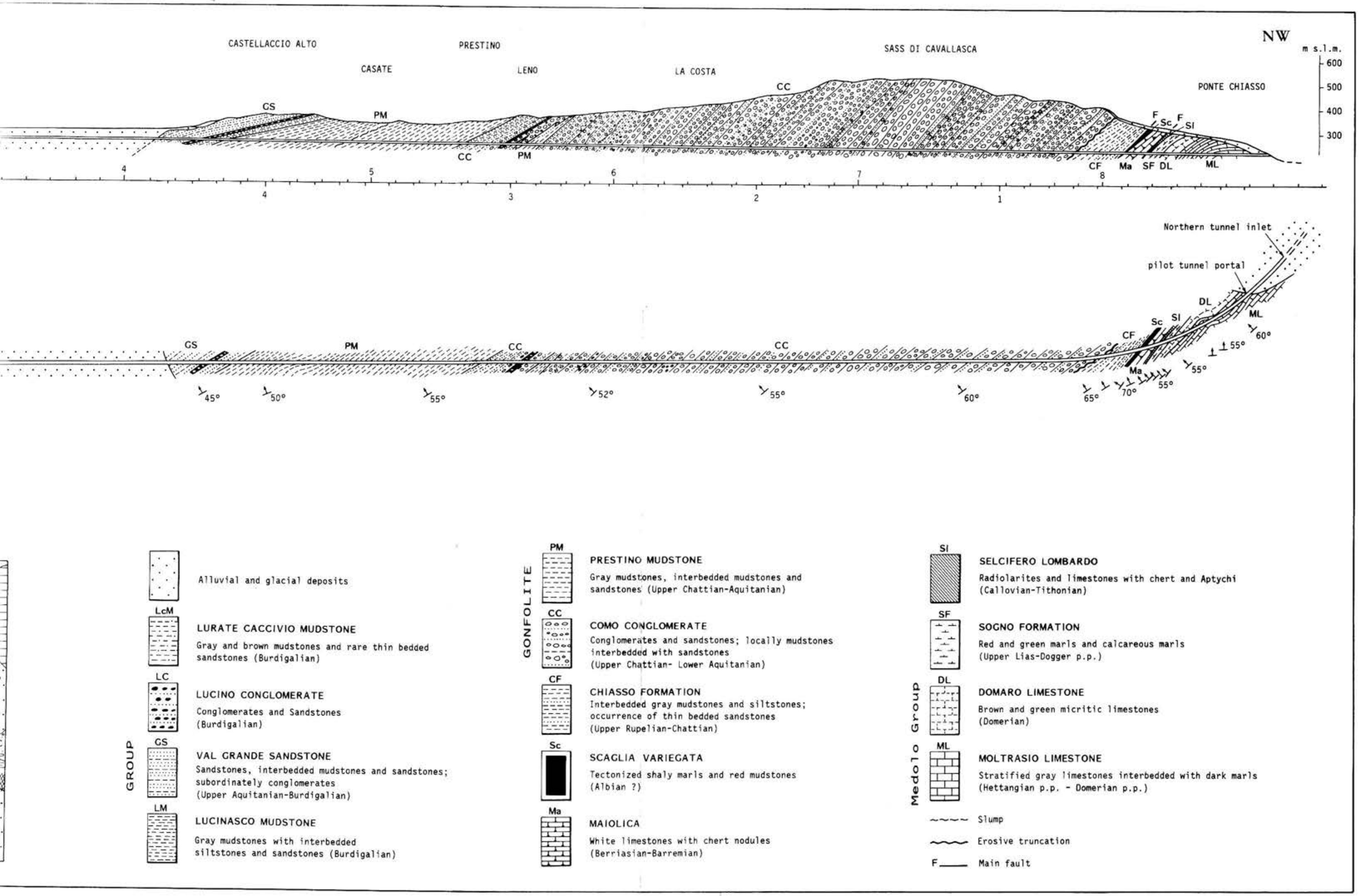
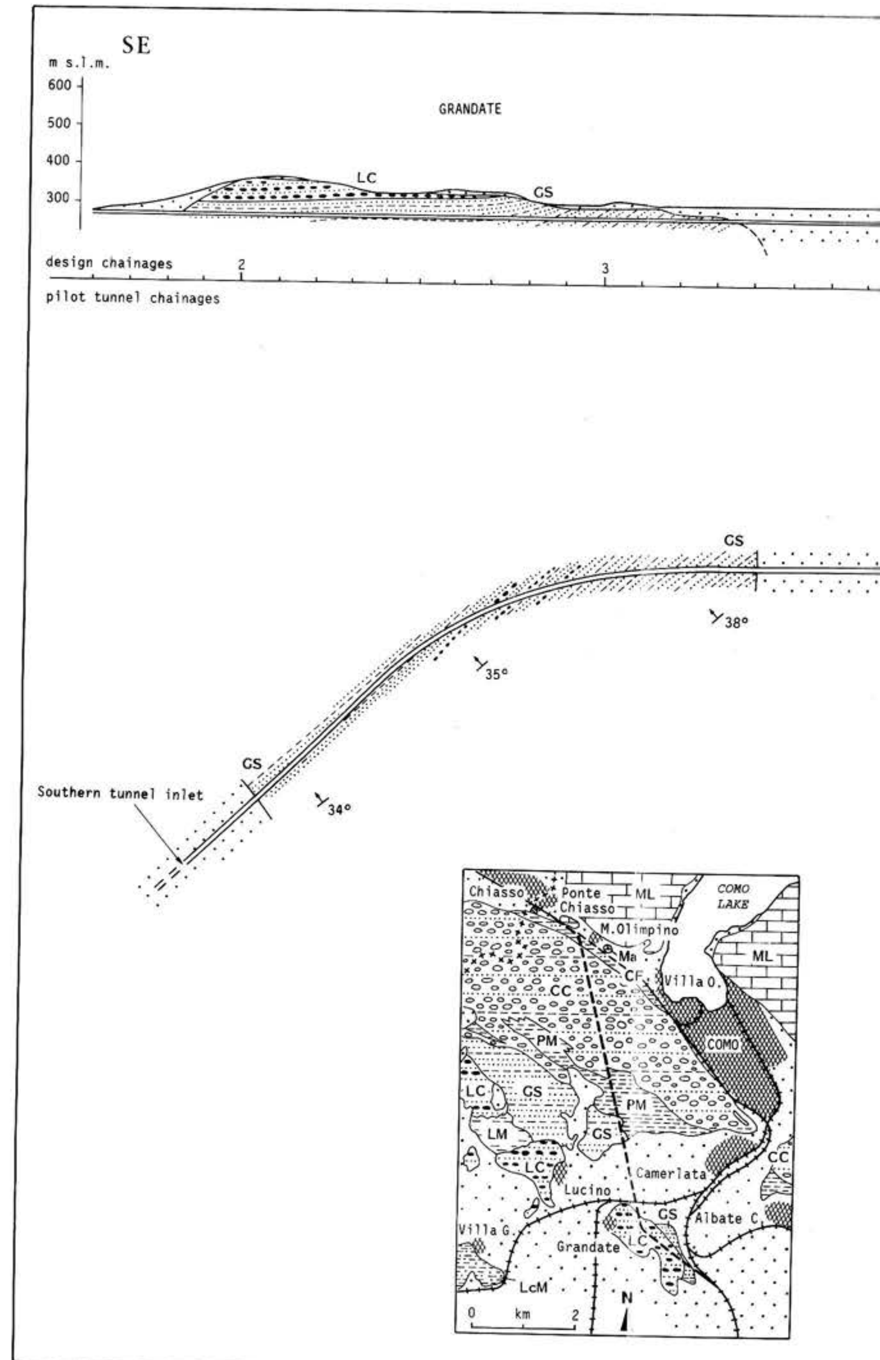
PLATE 39

Fig. 1 - Geological cross-section along the Monte Olimpino 2 tunnel.

PLATE 40

Fig. 1, 2 - *Chiloguembelina cubensis* (Palmer). Chiasso Formation, Monte Olimpino, Football ground section.


NW
m s.l.m.
600
500
400
300
CASTELLACCIO ALTO
CASATE
PRESTINO
LENO
LA COSTA
SASS DI CAVALLASCA
PONTE CHIASSO
GS
PM
CC
PM
CC
F
Sc
F
SI
CF
Ma
SF
DL
ML
4
5
6
7
8
4
3
2
1
Northern tunnel inlet
pilot tunnel portal
GS
PM
CC
CC
CF
Sc
SI
DL
ML
Ma
45°
50°
55°
52°
55°
60°
65°
70°
55°
55°
55°
60°
Alluvial and glacial deposits
GROUP
LcM
LURATE CACCIVIO MUDSTONE
Gray and brown mudstones and rare thin bedded sandstones (Burdigalian)
LC
LUCINO CONGLOMERATE
Conglomerates and Sandstones (Burdigalian)
GS
VAL GRANDE SANDSTONE
Sandstones, interbedded mudstones and sandstones; subordinately conglomerates (Upper Aquitanian-Burdigalian)
LM
LUCINASCO MUDSTONE
Gray mudstones with interbedded siltstones and sandstones (Burdigalian)
GONFOLITE
PM
PRESTINO MUDSTONE
Gray mudstones, interbedded mudstones and sandstones (Upper Chattian-Aquitanian)
CC
COMO CONGLOMERATE
Conglomerates and sandstones; locally mudstones interbedded with sandstones (Upper Chattian- Lower Aquitanian)
CF
CHIASSO FORMATION
Interbedded gray mudstones and siltstones; occurrence of thin bedded sandstones (Upper Rupelian-Chattian)
Sc
SCAGLIA VARIEGATA
Tectonized shaly marls and red mudstones (Albian ?)
Ma
MAIOLICA
White limestones with chert nodules (Berriasian-Barremian)
SI
SELCIFERO LOMBARDO
Radiolarites and limestones with chert and Aptychi (Callovian-Tithonian)
SF
SOGNO FORMATION
Red and green marls and calcareous marls (Upper Lias-Dogger p.p.)
Medolo Group
DL
DOMARO LIMESTONE
Brown and green micritic limestones (Domerian)
ML
MOLTRASIO LIMESTONE
Stratified gray limestones interbedded with dark marls (Hettangian p.p. - Domerian p.p.)
Slump
Erosive truncation
F
Main fault


SE
m s.l.m.
600
500
400
300
GRANDATE
LC
GS
design chainages
2
3
pilot tunnel chainages
GS
38°
35°
GS
Southern tunnel inlet
34°
COMO LAKE
Chiasso
Ponte Chiasso
ML
M.Olimpino
Ma
CF
Villa O.
CC
COMO
PM
LC
GS
LM
Camerlata
Lucino
Albate C.
Villa G.
Grandate
LcM
0 km 2
N

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