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Northward thrusting of the Gonfolite Lombarda ("South-Alpine Molasse") onto the Mesozoic sequence of the Lombardian Alps: Implications for the deformation history of the Southern Alps

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ABSTRACT

Between 1984 and 1987, the construction of the new Monteolimpino railway tunnel between Ponte Chiasso and Grandate provided a continuous exposure of the Mesozoic succession, the Chiasso Formation and the Gonfolite Lombarda s.str. The contact between the Oligocene Chiasso Formation and the underlying Maiolica Formation (Berriasian to Barremian) is clearly tectonic. Palaeo-stress determinations based on fault plane and striae measurements and on shear sense determinations, indicate a subvertical σ_3 and a subhorizontal σ_1 directed ca. N 0–20°. The steeply SSW-dipping contact, therefore, has accommodated a North-vergent thrust bringing the younger Chiasso Formation above the older Lower Cretaceous Maiolica Formation. Of the Scaglia Variegata Formation only thin lenses, up to one meter across, are preserved along the contact. Deformation is most intense in the Mesozoic sequence below the thrust and decreases rapidly in the hanging wall. The contact between the Upper Rupelian to Lower Chattian Chiasso Formation and the overlying Como Formation is a major unconformity cutting across the upper part of the Chiasso Formation.

The thrust observed in the Monteolimpino tunnel is not a local phenomenon, but is part of a regional North-vergent thrust separating Chiasso Formation and Gonfolite Lombarda Group from the underlying Mesozoic and Lower Tertiary sequence. The age of the thrusting is not precisely constrained. It could be Burdigalian in age or belong to the Late Miocene deformation observed below the Po Plain. This thrusting of younger formations onto older ones is part of a larger "wedge into split apart"-system as they have been described also from the external margins of the Northern Alps and of other orogenic belts. The implications of the thrust are discussed in the context of the sedimentary record of the Southern Alps.

RIASSUNTO

I lavori di scavo del nuovo tunnel ferroviario Monteolimpino 2 hanno permesso, tra il 1984 e il 1987, l'osservazione dei contatti tra la successione mesozoica e la Formazione di Chiasso e tra quest'ultima e la Gonfolite Lombarda s.str. Il contatto della Formazione di Chiasso (Oligocene medio-superiore) con la sottostante Maiolica (Berriasiano-Barremiano) è chiaramente tettonico. L'analisi strutturale di faglie e strie ha evidenziato un campo di paleostress con σ_3 (stress principale distensivo) verticale e σ_1 (stress principale compressivo) sub-orizzontale a direzione N 0–20°. Il contatto tettonico, che immerge a SSW, è quindi un sovrascorrimento con la Formazione di Chiasso portata sulla successione del Giurassico-Cretaceo inferiore. Delle varie centinaia di metri che costituiscono nel Mendrisiotto lo spessore tipico della successione compresa tra il Cretaceo medio e il Paleogene (Scaglia Lombarda, Flysch Lombardo, Formazione di Ternate), non restano lungo il contatto che alcune lenti di Scaglia per uno spessore totale di 1 m. La deformazione è assai intensa nella successione mesozoica al di sotto del contatto tettonico, mentre tende a diminuire rapidamente nel blocco superiore. Il contatto tra la Formazione di Chiasso (Oligocene inferiore-medio)

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e la sovrastante Formazione di Como è un'importante discordanza che attraversa la parte superiore della Formazione di Chiasso. Il contatto tettonico osservato nel tunnel non è un fenomeno locale ma è parte di un sovrascorrimento N-vergente di importanza regionale che separa la Formazione di Chiasso e la Gonfolite Lombarda dalla sottostante successione mesozoica. L'età del sovrascorrimento non è esattamente definibile; potrebbe essere burdigaliana o essere correlabile alla deformazione tardo-miocenica osservata nel sottosuolo della Pianura Padana. Il sovrascorrimento di formazioni più recenti su formazioni più antiche (retroscorrimenti, «wedge into split apart») è un fenomeno che è stato descritto in altri settori delle Alpi esterne e di altri orogeni. Vengono poi esaminate le implicazioni del sovrascorrimento sulla storia sedimentaria delle Alpi Meridionali.

Introduction

The Southern Alps are a fold- and thrust-belt in which Variscan basement, Late Paleozoic sediments and volcanics and Mesozoic to Late Tertiary sediments are involved (e.g. LAUBSCHER 1985). Vergence of thrusting and overfolding is generally towards the South and different levels of decollement are present within the sedimentary sequence – the Lower Triassic Carniola di Bovegno, the Upper Triassic Raibl Beds, the Rhaetian Argillite di Riva di Solto, the marls of the Scaglia Lombarda Group (middle Cretaceous) and the Oligocene Chiasso Formation. The present-day structure of the Southern Alps is the product of different "phases" of deformation. Of these, the older, Late Cretaceous to Paleogene ones are documented in the Orobic zone by thrusts and folds cut by the Early Tertiary Adamello intrusion (BRACK 1981) and by synorogenic clastic sediments which, however, are only preserved in border areas and which are involved in Late Miocene thrusting and folding.

Authors of the late 19th and early 20th century compared the coarse clastic deposits of the Oligo-Miocene Gonfolite Lombarda Group (Fig. 1) to the coeval molasse deposits to the North of the Alps (e.g. STOPPANI 1857, SCHMIDT & STEINMANN 1890, HEIM 1906). Both, North- and South-Alpine "molasse" deposits were and still are regarded as the debris derived from early and middle Tertiary Alpine orogeny, uplift and erosion. Whereas the North-Alpine molasse conglomerates are mainly subaerial fan or fan delta deposits interfingering to the North with the alluvial plain or shallow-marine sediments of a narrow fore-deep (MATTER & HOMEWOOD 1980), recent biostratigraphical and sedimentological investigations have shown that the conglomerates and sandstones of the Gonfolite Lombarda were deposited essentially by mass movement processes operating along the slopes of a deep basin (RÖGL et al. 1975, GUNZENHAUSER 1985, NAPOLITANO 1985, GELATI et al. 1988).

Another matter is the tectonic position of the "molasse" deposits. To the North it was recognized at a very early stage that the clastic wedge of the North-Alpine molasse was involved in Tertiary decollement tectonics and was overthrusted in the South by the Helvetic and certain flysch nappes. Contrary to this, the South-Alpine "molasse" was traditionally regarded as an essentially autochthonous post-orogenic deposit, unconformably overlying the Mesozoic and Lower Tertiary sequences of the Southern Alps (HEIM 1906, CADISCH 1932). Indeed, HEIM (1906, plate 1, cf. our Fig. 2) observed an unconformable sedimentary contact between the conglomerates of the "molasse" (now known as the Como Formation) and the underlying marls (now the Chiasso Formation) and interpreted this contact as due to the "transgression" of the South-Alpine "molasse" onto the Mesozoic to possibly Lower Tertiary sequence of the Southern Alps (Scaglia of Late Cretaceous to possibly Eocene age in his interpretation). He also carefully illustrated the tectonic deformation he observed along the con-

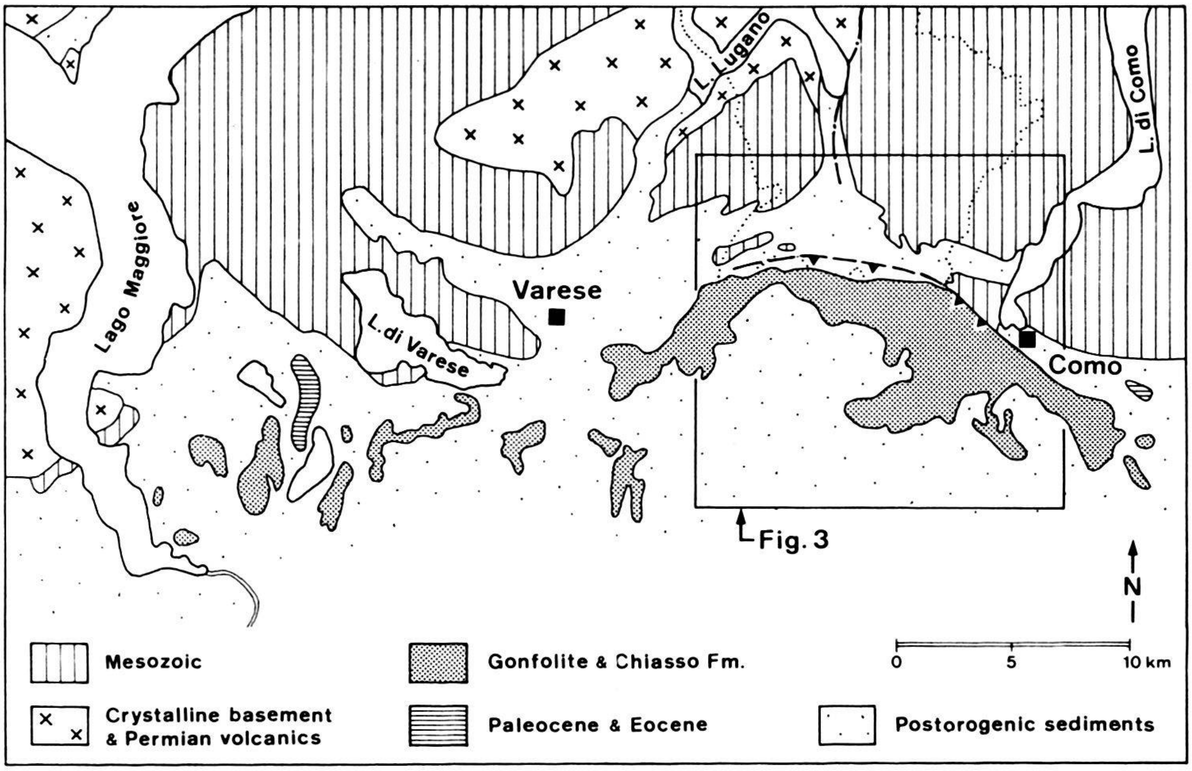


Fig. 1. Occurences of the Gonfolite Lombarda Group.

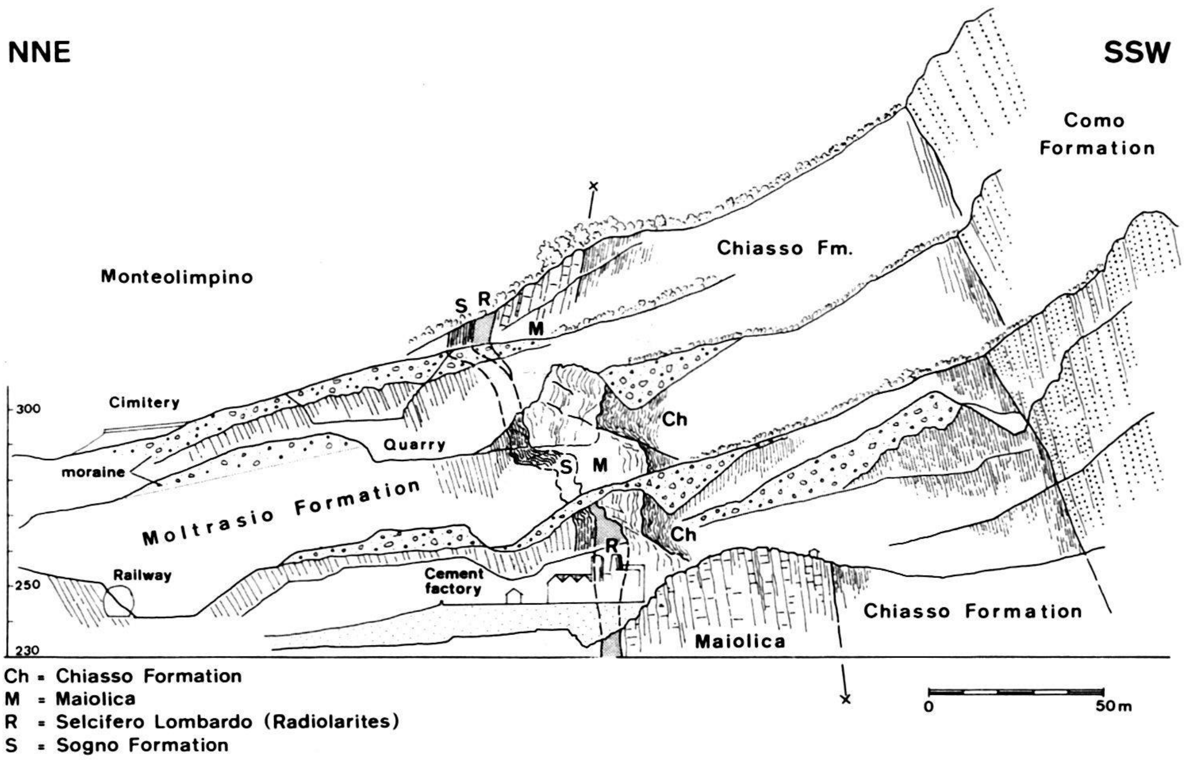


Fig. 2. Geological cross-section across the abandoned cement factory at Ponte Chiasso. Redrafted after HEIM (1906) and reinterpreted according to the new stratigraphic data.

tact between the Lower Cretaceous Maiolica Formation and his Scaglia-marls in the now covered outcrops of the former cement factory at Ponte Chiasso. However, not knowing the Oligocene age of the marls between the Maiolica and the conglomerates of the Como Formation, he did not recognize the importance of this tectonic contact. Later workers (VONDERSCHMITT 1940, SANTINI, 1956) recognized the marls as Oligocene in age (SANTINI's Chiasso Series). However, after the outcrops at Ponte Chiasso were covered, the tectonic contact observed by HEIM (1906) could no longer be observed and an erosional unconformity at the base of the South-Alpine "molasse", including now the Chiasso Formation, was generally assumed (FIORENTINI 1957, LONGO 1968). In Figure 2, HEIM's section across the quarries of Ponte Chiasso has been re-interpreted according to the new stratigraphical data and the findings in the new Monteolimpino railway tunnel.

Between 1984 and 1987, the construction of the new Monteolimpino railway tunnel between Ponte Chiasso and Grandate (Fig. 3) exposed a strongly tectonized Mesozoic section, a major tectonic contact between Mesozoic sequence and Chiasso Formation, an unconformity between the Chiasso Formation and the Gonfolite Lombarda Group s.str. and a stratigraphic section of the Gonfolite from the Como to the Val Grande Formation. In this paper we shall describe the overthrust of the Tertiary onto the Mesozoic sequence and discuss it in the light of the tectono-sedimentary evolution of the Southern Alps. The stratigraphy and sedimentology of the Gonfolite Group as observed in the tunnel has been summarized by GELATI et al. (1988).

Geological situation

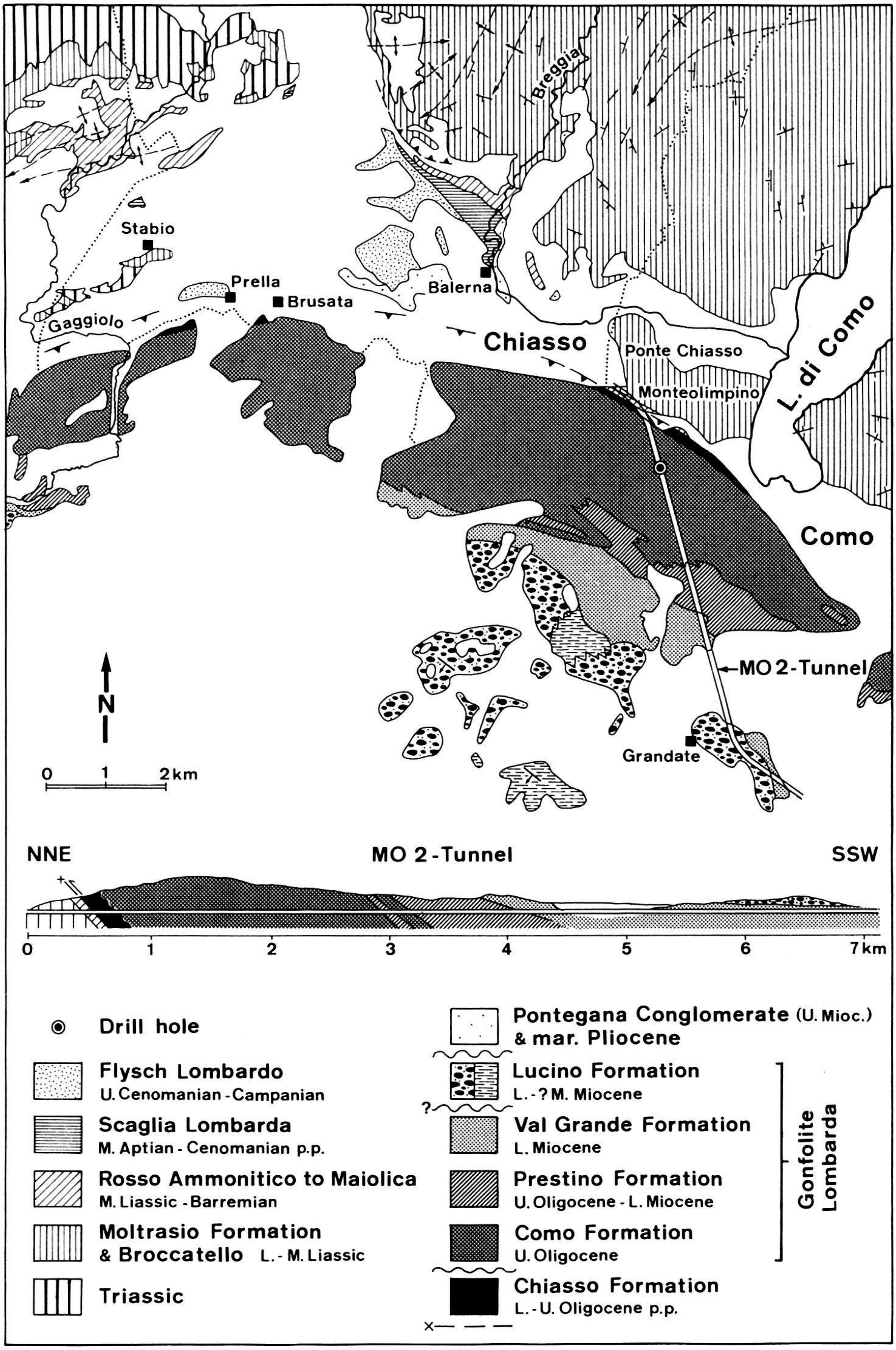
The Mesozoic succession

In the Monteolimpino tunnel, part of the Jurassic-Cretaceous succession of the Generoso-Basin (BERNOULLI, 1964) is exposed between 45 and 570 m from the N-entrance. The beds dip typically to the SSW by 50–70° (Fig. 6).

Of the Moltrasio Formation (Lombardischer Kieselkalk of the Swiss authors, Lower to Middle Liassic, BERNOULLI 1964) which also constitutes the hills N of Ponte Chiasso and Monteolimpino (Fig. 3) only the uppermost 60 m are encountered. The Moltrasio Limestone passes upward into hazel-brown to light greenish gray micritic limestones without chert. Lithologically, these limestones can be compared to the Domaro Limestone of the western Bergamasc Alps which is of Early Domerian to earliest Toarcian age (GAETANI 1975).

From 450 to 510 m, red and green spotted calcareous marls are encountered. This formation can be correlated to the Sogno Formation of the western Bergamasc Alps (GAETANI & POLIANI 1978); a fairly well preserved nannofossil assemblage indicates a Toarcian to possibly Middle Jurassic age (personal communication, R. Gelati and A. Valdisturlo 1988). The thickness of the formation is estimated at 10 to 12 m. The upper boundary is a fault and the uppermost few meters of the formation are intensely tectonized. In outcrop, HEIM (1906) attributed the sediments of the Sogno Formation

Fig. 3. Geological sketch map of the Monteolimpino area (after BERNOULLI 1964 and LONGO 1968), and generalized section of the Monteolimpino 2 tunnel (from GELATI et al. 1988).



Breggia
Stabio
Prella
Brusata
Balerna
Gaggiolo
Chiasso
Ponte Chiasso
Monteolimpino
L. di Como
Como
MO 2-Tunnel
Grandate
N
0 1 2km
NNE
MO 2-Tunnel
SSW
0 1 2 3 4 5 6 7km
Drill hole
Flysch Lombardo
U. Cenomanian - Campanian
Scaglia Lombarda
M. Aptian - Cenomanian p.p.
Rosso Ammonitico to Maiolica
M. Liassic - Barremian
Moltrasio Formation & Broccatello L.- M. Liassic
Triassic
Pontegana Conglomerate (U. Mioc.) & mar. Pliocene
Lucino Formation
L.-? M. Miocene
Val Grande Formation
L. Miocene
Prestino Formation
U. Oligocene - L. Miocene
Como Formation
U. Oligocene
Chiasso Formation
L.- U. Oligocene p.p.
Gonfolite Lombarda

to the Rosso Ammonitico Lombardo Formation, however, the Domaro Limestone and the Sogno Formation are lithologically clearly distinct from the coeval ammonite-rich nodular limestones and marls of the Morbio (Domerian p.p. to lowermost Toarcian) and the Rosso Ammonitico Lombardo (Toarcian to Middle Jurassic) Formations occurring only a few km to the NW (Breggia Gorge, BERNOULLI 1964, WIEDENMAYER 1980) and E (Alpe Turati, BERNOULLI 1964, GAETANI & FANTINI SESTINI 1978). Like GAETANI & POLIANI (1978) we interpret the Domaro Limestone and the Sogno Formation to represent a deeper and more basinal depositional environment in comparison with the ammonite-rich lithologies.

In the tunnel, the Sogno Formation is in tectonic contact with the Maiolica Lombarda Formation (Berriasian to middle Barremian, WEISSERT 1979). The Selcifero Lombardo Formation (Radiolarite Formation, Upper Jurassic) is reduced to a small tectonic sliver of a few decimeters of red radiolarian chert along the fault contact. In outcrop, thin-bedded red marly limestones with *Aptychus* occur near Ponte Chiasso at the Swiss-Italian border. From the abandoned quarries of Ponte Chiasso, HEIM (1906) mentiones 10 m of thin-bedded red cherts. The overlying Maiolica Lombarda Formation which reaches a thickness of 130 m in the Breggia Gorge is tectonically thinned to about 20 m both in the tunnel and in the outcrops between Chiasso and Monteolimpino (see also Figs. 2 and 3).

In the tunnel, the Scaglia Variegata Formation (Aptian-Albian p.p.) is reduced to a few small slivers of dark red and variegated marls along the tectonic contact between the Maiolica and the Chiasso Formation (Lower to Upper Oligocene p.p.). In the quarries of Ponte Chiasso, HEIM (1906) did not separate them from the marls and thin-bedded sand- and siltstones of the Chiasso Formation. Further to the SE, near Monteolimpino, FIORENTINI (1957) mentions 8 m of Scaglia Variegata.

Chiasso Formation and Gonfolite Lombarda Group

Traditionally, the Oligo-Miocene clastic formations of the Lombardian foothills and subsurface habe been assembled in the Gonfolite Lombarda Group (e.g. CITA 1962). However, GELATI et al. (1988) have separated the basal Chiasso Formation from the overlying Gonfolite Lombarda Group s.str., as it is separated from the latter by a major regional unconformity. This unconformity is of a deeper marine erosional origin and the eroded sequence locally spans several millions of years. The Chiasso Formation can thus be considered as a distinct depositional sequence in the sense of VAIL (1987). Lithologically, the Chiasso Formation is composed of thin-bedded, grey mud- and siltstones and thin-bedded sandstone turbidites. The overlying Como Formation is the result of rapid deposition in a submarine canyon system (GUNZENHAUSER 1985). In the area of the Monteolimpino tunnel, the Chiasso Formation crops out along a narrow strip between Chiasso and Como (Fig. 3). In the tunnel it occurs from m 570 to 782 (from the N-entrance) for a total thickness of about 80 m.

The Chiasso Formation is bound at its top by an angular unconformity. The importance of the erosional truncation is demonstrated by the age of the Chiasso Formation below the unconformity: Chattian (Zone P 21 of BLOW 1969) near Chiasso (Rio della Maiocca, RÖGL et al. 1975) and to the west (Brusata), Rupelian (P 19/20) between Ponte Chiasso and Como and in the Monteolimpino tunnel (GELATI et al.

1988). The overlying Como Formation predominantly consists of clast- or matrix-supported conglomerates, and of lesser pebbly or massive sandstones. The lithologies encountered in the tunnel match very well the descriptions from outcrop sections (GUNZENHAUSER 1985).

The tectonic contact between the Mesozoic sequence and the Chiasso Formation

Nature of the contact

The contact between the Mesozoic sequence and the Chiasso Formation is well exposed in the Monteolimpino tunnel. The slighly bent contact surface strikes 120° and has a dip of 60° towards the SW. Its tectonic character is quite clear. There is no sign of sedimentary continuity. The Scaglia Variegata Formation (Upper Aptian to Albian p.p.) is reduced to a few decimeters of shattered marls and slivers of Maiolica (Lower Cretaceous p.p.) have been ripped off and now float within the tectonized Scaglia (Fig. 4). The limestones and marls of the Mesozoic sequence are strongly tectonized. They show cracks and shear fractures often filled by fibrous calcite. Above the contact, only the first few meters of the Chiasso Formation are severely deformed. Here most of the shear fractures are calcite-free. The intensity of the deformation decreases rapidly up-section and in the main part of the Chiasso Formation the shale-silt alternations are virtually undisturbed. The erosional unconformity between the Chiasso Formation and the Como Formation is cut by a small fault. Deformation in the Como Formation is restricted to a few discrete fracture zones with no signs of major displacements. Both sections and surface mapping by LONGO (1968) and NAPOLITANO (1985) indicate a continuous stratigraphic sequence with no tectonic repetitions.

However, siliceous limestones from the Moltrasio Formation habe been reported from a well above the tunnel at a depth of 280 meters above sea-level (180 meters beneath the surface, Sasso di Cavallasca, coordinates of Swiss topographic map: 725 070/075 500, for approximate location see Fig. 3). This report is in contradiction with all the observations made in the tunnel and at the surface and cannot be explained by us.

Structural analysis of the contact

To assess the sense of displacement along the contact, fault planes and striae have been measured and their shear sense determined in the Monteolimpino tunnel (Fig. 5). Most of the fault planes are oriented subparallel to bedding (Fig. 6), i.e. their orientation is strongly dependent on the pre-existing rock anisotropy and therefore not directly representative of the stress field. To derive the principle strain- and stress-axes in spite of the anisotropy, the data were treated after the methods of ARTHAUD (1969) and ANGELIER & MECHELER (1977).

With ARTHAUD's (1969) method the orientation of the principle strain axes ($X \geq Y \geq Z$) is obtained based on the following consideration: the striae on a fault plane represent the direction of relative movement along that surface. This implies that one strain axis must lie on the so-called *movement plane*, which is defined as the plane perpendicular to the fault and containing the striae. The intersection of the movement planes constructed for two faults defines a strain axis compatible with the faults considered. For a set of faults, the poles of the movement planes, plotted on a stereographic projection, will tend to define great circles (three in the ideal case, usually two). The poles of these great circles correspond to the principle strain axes. Shear sense determinations then enable to define which of these axes is the lengthening one, which one the intermediate and which one the shortening.

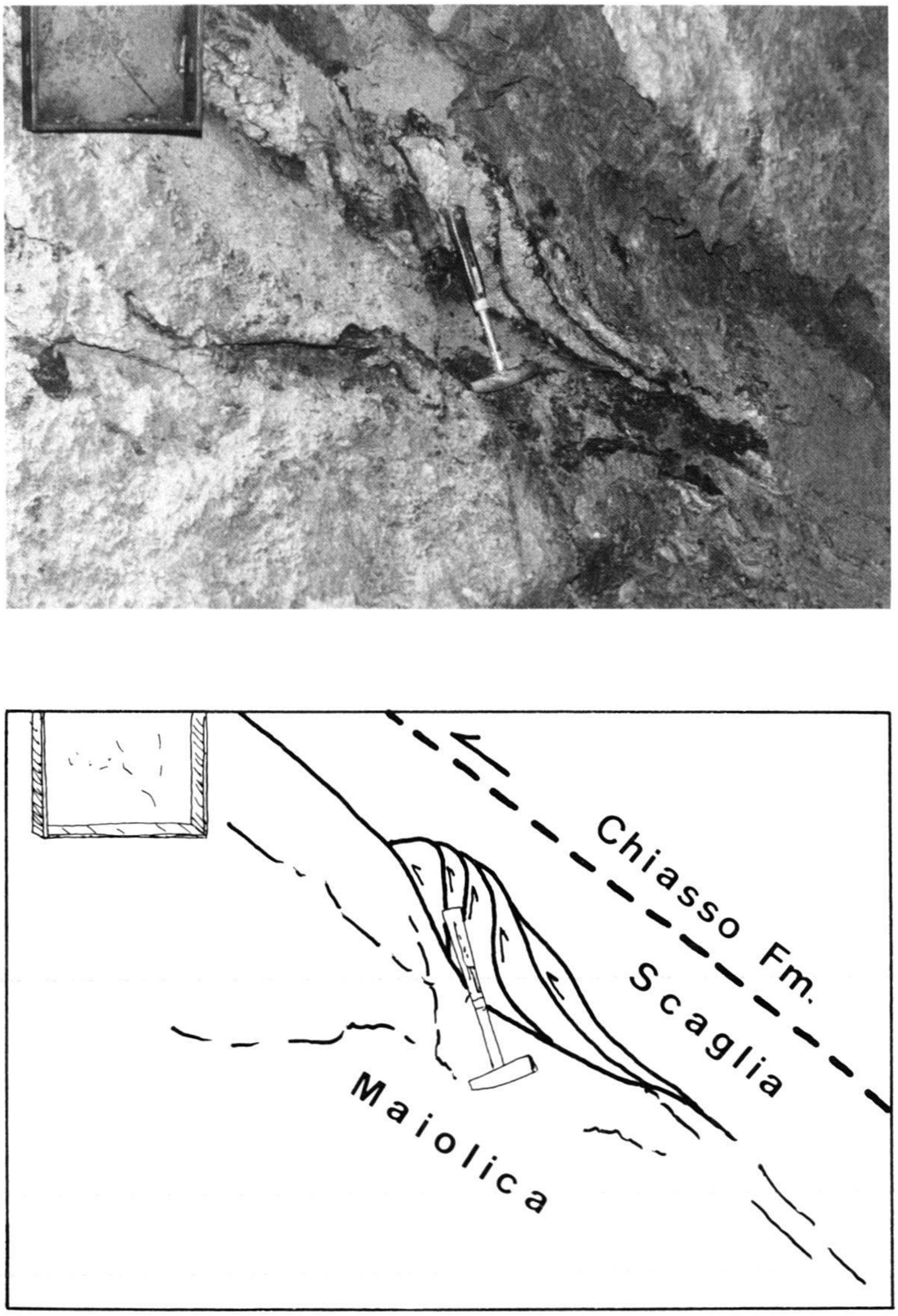


Fig. 4. Photograph and interpretative sketch of the tectonic contact between Maiolica and Chiasso Formation in the new Monteolimpino tunnel. Note imbrication structures indicating a thrust of the hanging wall (Chiasso Formation) from the right (South) to the left (North).

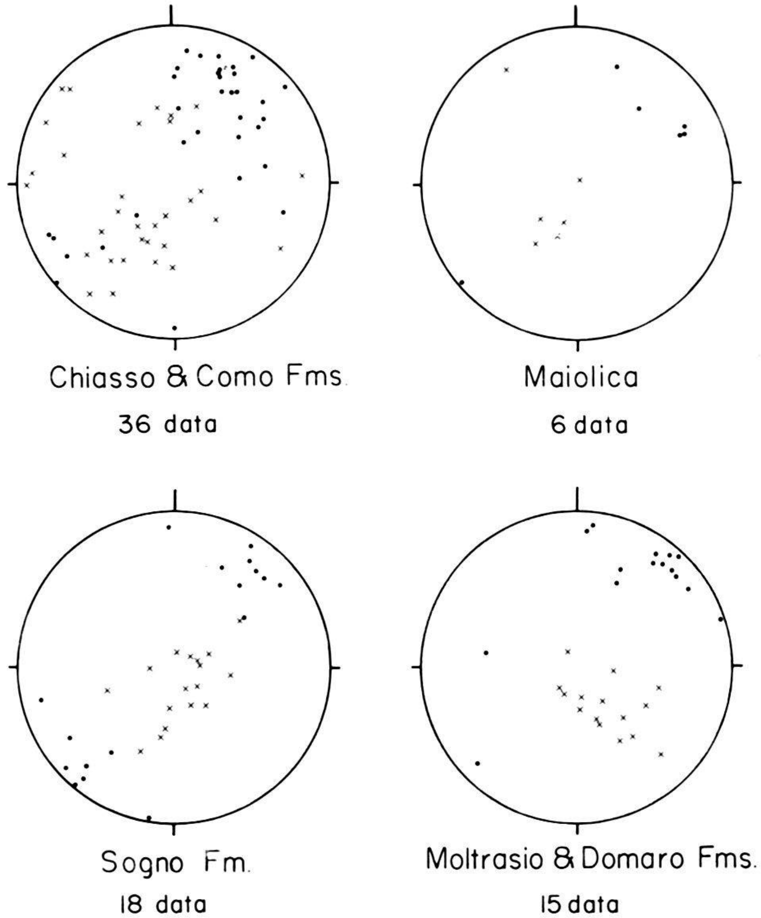


Fig. 5. Distribution of fault planes and of striae. Dots: poles of fault planes; crosses: striae. Lower hemisphere, equal-area stereographic projection.

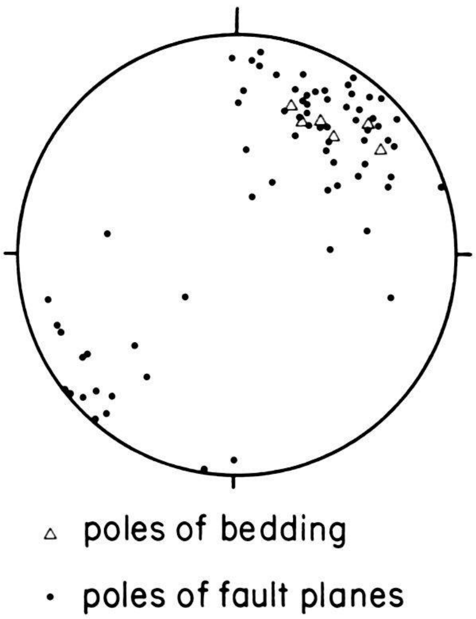


Fig. 6. Distribution of bedding and fault planes in the Monteolimpino tunnel. Lower hemisphere, equal-area stereographic projection.

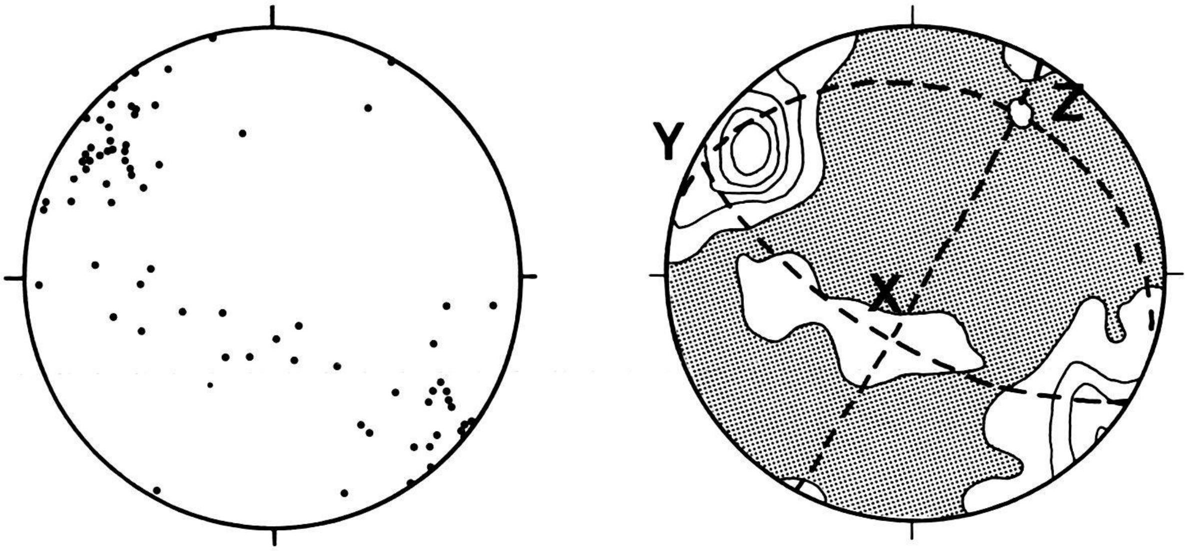


Fig. 7. Directions of strain axes determined with ARTHAUD's (1969) method. Lower hemisphere, equal-area stereographic projection, contoured at 1.0, 3.0, 5.0, 7.0, 9.0, 11.0, 13.0, times uniform (number of points per 1.35% area).

As most of our data refer to faults subparallel to bedding anisotropy, the resulting plot from ARTHAUD's (1969) method (Fig. 7) shows one strong maximum of the poles of movement planes and two modestly constrained great circles. Thus the orientation of the principle strain axes can only crudely be fixed with X:219/68, Y:300/02 and Z:032/23. This correspond roughly to a NNE-SSW directed shortening direction.

With the second method (ANGELIER 1975, ANGELIER & MECHELER 1977, PFIFFNER & BURKHARD 1987), stress instead of strain axes are considered. For each fault plane an auxiliary plane is constructed which is perpendicular both to the striae and to the fault plane. Similarly to earthquake focal mechanisms, fault plane and auxiliary plane will define four dihedra. The sense of shear associated with the striae allows to define the two dihedra containing the compressional axis and those containing the tensional one. For a set of faults the area common to the dihedra of same sign contains the stress axis compatible with the faults considered. The percentage of faults represented in the common area gives an indication of the reliability of the determination obtained (MAX value of PFIFFNER & BURKHARD 1987).

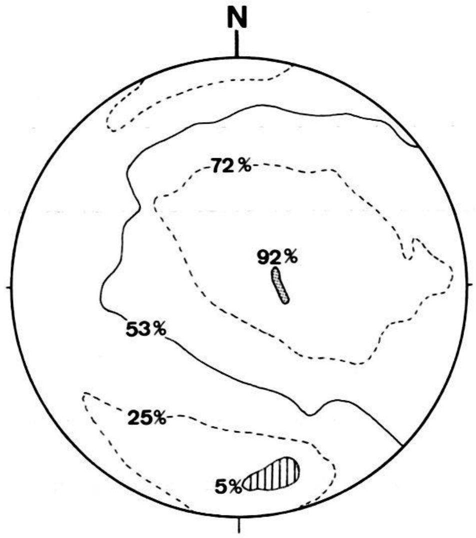


Fig. 8. Direction of stress axes determined with ANGELIER's (1975) method. 29 data. Lower hemisphere, equal-area stereographic projection. Countouring gives the percentage of faults having extensional dihedra in that area. Stippled area represents therefore the possible directions of σ_3, and the ruled area possible directions of σ_1.

The results obtained for the 29 faults for which a shear determination was possible are shown in Fig. 8. The areas of likeliest directions for the stress axes are fairly well constrained; the compressional axis is subhorizontal, the tensional one is subvertical and the intermediate one is subhorizontal and roughly E-W directed.

The structural analysis demonstrates that the faults along the contact between the Chiasso Formation and the Mesozoic sequence result from a compressive regime with a subhorizontal, N-S directed σ_1. The contact is thus an inverse fault with the southern hanging-wall block being thrusted upon the northern, foot-wall block.

This interpretation is supported by the geometry of the dm-sized slivers of Maiolica limestone found at the contact in the tunnel (Fig. 4). The observed imbrication is indicative of an upward displacement of the hanging wall. Minor N-vergent thrusts were already observed by Heim (1906, plate II, our Fig. 2).

Regional extent and age of the thrust

The thrust observed in the Monteolimpino tunnel is not a local phenomenon, but is part of a regional North-vergent thrust separating Chiasso Formation and Gonfolite Lombarda from the underlying Mesozoic and Lower Tertiary succession. Near Brusata (Fig. 3), a continuation of the thrust can be postulated between the steeply (ca. 60°) S-dipping Chiasso Formation and the equally S-dipping, but tectonically overturned Upper Campanian Prella Series (Bernoulli et al. 1987). South of Stabio (Fig. 3), a further continuation of the thrust is suggested by the vicinity of the Liassic outcrops of the Stabio structure (Senn 1924) and those of the Gonfolite to the South (Longo 1968); obviously there is not enough space to accomodate the remaining Mesozoic-Tertiary succession in between.

In map view the contact has a curved shape and is clearly oblique with respect to the regional bedding of the underlying Mesozoic sequence both E (bedding striking more or less NW-SE) and W (ENE-WSW directions) of Mendrisio (Bernoulli 1964, Plate 1). The Chiasso Formation is in contact with the Maiolica Formation in the Monteoliompino tunnel and E of it, with the Campanian Prella Series SE of Stabio whereas SW of Stabio part of the Mesozoic to ?Early Tertiary sequence must be missing. Whether this discordance is due only to the geometry of the post-Gonfolite thrust (lateral ramps) or whether the tectonic contact follows an old unconformity (pre-Oligocene folding), remains open to discussion. In any case the Gonfolite Lombarda Group and its basal contact appear not to be affected by the Lugano fault. This means that the Alpine reactivation of the Lugano fault (Bernoulli 1964) is older than the thrust of the Gonfolite or that we deal with a very complex kinematic system or both.

The lower age bracket of the thrusting of the Chiasso Formation and the Gonfolite Lombarda Group onto the Mesozoic sequence is constrained by the Val Grande Formation (Aquitanian p.p. to Lower Burdigalian), which is the youngest formation obviously involved in the thrusting (profile of Fig. 3).

The younger age bracket of the thrust is weakly constrained: it must be older than the Messinian Pontegana Conglomerate. The Upper Burdigalian to possibly Middle Miocene Lucino Formation is separated from the Val Grande Formation by a sequence boundary, most probably an erosional truncation. As its conglomerates contain pebbles derived from the Chiasso Formation dated as Oligocene (personal communication by B. Mohr 1989), there must be an important erosional truncation to the North. Therefore, the thrust could be Burdigalian in age. Alternatively, the thrust could be part of the Late Miocene (Tortonian) thrust system which is well documented under the Po Plain (Pieri & Groppi 1981).

The sedimentary record and the deformation history of the Lombardian Alps

Pre-Oligocene (pre-Gonfolite) deformation in the South- and Austroalpine realm is documented by Cenomanian to Campanian flysch deposits (Castellarin 1976, Bichsel & Häring 1981, Gelati et al. 1982) and by clastic intercalations in Maastrichtian to Upper Eocene base of slope and submarine fan deposits (Piano di Brenno and Tabiago Formations, Kleboth 1982, Ternate Formation, Bernoulli et al. 1988). The associated structures are, however, largely unknown. Unconformities and chaotic deposits in the Cenomanian of the Bergamasc Alps point to submarine erosion and mass-wasting, possibly in connection with minor decollement and foreland deformation in the sedimentary cover of the Southern Alps (Bersezio & Fornaciari 1989). However, the bulk of the siliciclastic detritus in the Lombardian Flysch is derived from an emergent area situated in the present-day Orobic zone or, possibly, in the adjacent Austroalpine realm still further North (Castellarin 1976, Winkler & Bernoulli 1989). The clastic material admixed in the resediments of the small bioclastic fans of Maastrichtian to Late Eocene age seems to be of more local provenance and partly exhumed from older clastic sediments exposed along the basin slope or in submarine valleys (Bernoulli et al. 1988). In any case, Pre-Late Eocene deformation in the Adamello area is documented by folds and overthrusts predating the intrusion of the Adamello batholith (Brack 1981, Cassinis & Castellarin 1988).

The re-installation of a siliciclastic source area to the North is indicated by turbiditic sandstones and deep-water conglomerates in the Chiasso Formation. The stratigraphic relationship between the latter and its original substrate is still unknown. The marls and thin-bedded turbidites of the Chiasso Formation have been deposited in a deeper marine upper bathyal environment (Rögl et al. 1975); intraformational unconformities and large submarine slumps suggest a slope or base of slope setting (Gunzenhauser 1985). In the subsurface of the Po Plain of Lombardy, there seems to be more or less continuous sedimentation from the hemipelagic marls of the Scaglia Group into the Upper Eocene to Oligocene Gallare Marl Group which northwards also interfingers with the clastics of the Gonfolite Lombarda Group (Errico et al. 1980, Dondi & D'Andrea 1986). In the conglomerates of the Chiasso Formation (Villa Olmo Conglomerate, Longo 1968), well-rounded limestone pebbles derived from the Upper Eocene Ternate Formation (Bernoulli et al. 1988) occur, already showing the typical diagenetic features of that formation, i.e. welding of the calcitic bioclastic fragments by intense pressure solution. This means that the bioclastic deep-water limestones of the Ternate Formation were subject to lithification, uplift and erosion prior to the Early Oligocene demonstrating deformation of the South-Alpine margin after the Late Eocene but before the Late Rupelian. In the type-area of the Ternate Formation, a large gap in outcrop separates the Ternate from the Chiasso Formation and it cannot be discerned whether an unconformity is present or not.

The contact between the Chiasso Formation and the overlying Como Formation is a major unconformity cutting across the Chiasso Formation. This unconformity is of deeper marine erosional origin and the missing interval locally spans several millions of years (Gelati et al. 1988). Thus, this erosional truncation marks an important sequence boundary. We agree with Gelati et al. (1988) that the Chiasso Formation should be separated from the Gonfolite Lombarda Group s.str. in which it was hitherto included.

The Gonfolite Lombarda Group is composed of at least two major depositional sequences (Gelati et al. 1988) that are generally thinning and fining upward. The Como Formation is mainly composed by gravity displaced conglomerates deposited in a submarine canyon proximally incised into the underlying Chiasso Formation. According to the biostratigraphical data, the erosional profile of the canyon could have been as broad as 2.5 km and as deep as 50 to 60 m (Gelati et al. 1988, Fig. 5). Distally and upward the conglomerates of the Como Formation are overlain by thick-bedded sandstones (Val Grande Sandstones) arranged in thickening and coarsening upward lobes (Gunzenhauser 1985). However, the relative sea level drop associated with the incision of a canyon is younger than the large scale eustatic sea level drop postulated for the Rupelian-Chattian boundary (Haq et al. 1987). It rather seems to reflect a phase of rapid uplift and erosion during the Late Oligocene and the Early Miocene North of the Insubric Line from where most of the pebbles of the Como Formation are derived (Pfister 1921, Longo 1968, Giger & Hurford 1989). This uplift postdates the emplacement of the Bregaglia granitoids (Wagner et al. 1979) and is coeval with transpressional movements along the Insubric Line (Hurford 1986, Heitzmann 1987, Schmid et al. 1987, 1989, Laubscher in press).

The second depositional sequence (Lucino Formation) is separated by an erosional truncation from the first one (Gelati et al. 1988). It may be linked to repeated uplift during the Early to possibly Middle Miocene; however, radiometric data do not allow to distinguish between two distinct phases of increased uplift in the Early Miocene in the Central Alps (Hurford 1986). Alternatively, the second depositional sequence of the Gonfolite Lombarda Group could record tectonic movements and uplift in the Southern Alps. In this context, it is interesting to note, that in the westernmost part of the Southern Alps, along the ECORS-CROP seismic line, Roure et al. (in press) identified a Burdigalian unconformity above a South-vergent nappe edifice in which the Oligocene to Aquitanian Gonfolite Lombarda Group is involved. The possibility of a Burdigalian age also for the Monteolimpino thrust was mentioned in the previous chapter.

Sedimentation history and structures document the Alpine polyphase tectonics of the Southern Alps with pre-Adamello, pre-Oligocene and Miocene deformations. However, several of the major South-Alpine structures cannot be attributed with certainty to one of these phases as dating is possible only in border regions. In addition, reactivation of older structures by approximately coaxial deformations is expected. The thrusting age of the Chiasso Formation and Gonfolite Lombarda Group onto the Mesozoic sequence is not precisely constrained and a Burdigalian or Tortonian age must be considered. This Northward thrusting of younger onto older series in an overall S-vergent thrust belt resembles geometrically the "triangle zones" which have been recognized in external parts of orogenic belts. Such features have been described e.g. from the N-Alpine molasse (Habicht 1945), from the eastern foothills of the Canadian

Rocky Mountains (Price 1981) and are also postulated for the contact between frontal parts of the basement nappes and the sedimentary cover in more internal parts of the Southern Alps (Laubscher 1985). Thus the thrust near Chiasso is interpreted as part of an indentation between Mesozoic and the Oligo-Miocene sequences.

Deformation in the western segment of the Southern Alps can thus be summarized as follows: In Late Cretaceous (Doglioni & Bosellini 1987) or Eocene times, the Orobic thrust system was initiated in the northern Bergamasc Alps. At depth this system of thrusts clearly involved crystalline basement rocks and Mesozoic sediments. Thrusts of this system, emerging to the South and exposing the sedimentary cover, might be responsible for the clastic content of the latest Cretaceous to Eocene resediments (Pian di Brenno to Ternate Formation). In the Late Oligocene to Early Miocene dextral transpressive movements along the Insubric Line separated the Orobic thrusts from their backward parts, juxtaposing the Alpine-metamorphic Lepontine area and what is now the northern part of the Southern Alps. During the Miocene, the deformation front obviously migrated to the South. The age of the deformation in the Mendrisio-Como area is weakly constrained, the latest phases in the allochthon may be Burdigalian or Late Miocene (Tortonian) in age. In Late Miocene times finally the decollement nappes of the "Milano belt" formed.

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