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The significance of the Upper Cretaceous to Miocene clastic wedges in the deformation history of the Lombardian southern Alps

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ABSTRACT. — The Upper Cretaceous to Miocene turbidite systems of Southern Alps form two major clastic wedges, representing the infilling of synorogenic basins located at the southern border of the Alps.

The Upper Cretaceous and the Oligo-Miocene clastic wedges document and date the most important Cretaceous and late Tertiary thrusting events that involved basement and cover units and determined the syntectonic mobility of the basin margins. These two tectonic steps are separated by the well known emplacement of Eocene-Oligocene intrusive masses (Adamello, Val Gandino), and by the Late Eocene southwards propagation of thrust fronts, suggested by the clastic sediments of the Ternate Formation. The polyphase late Tertiary event substantially reshaped the older structural edifice, from the northern basement thrust sheets to the southernmost decolled cover units. A latest step is in fact proposed to be responsible for folding and thrusting along the southern reliefs of the "Flessura Frontale" and for the en-echelon imbrication of the Orobic Anticlines to the north.

The seismic picture provided by the CROP 88 experiment, confirms this interpretation and indicates that the present structural edifice lays above a decollement horizon connected with the sole thrust of the buried front of Southern Alps (Milano Belt), and is thus allochtonous.

KEY WORDS. — Alpine orogeny, Southern Alps, clastic wedges

Les prismes clastiques du Crétacé Supérieur - Miocène dans l'histoire des déformations des Alpes Méridionales en Lombardie

RÉSUMÉ. — Les systèmes turbiditiques du Crétacé supérieur et de l'Oligo-Miocène des Alpes Méridionales constituent deux prismes clastiques, qui représentent le remplissage des bassins synorogéniques à la bordure méridionale des Alpes.

Ces prismes documentent la mise en place et l'âge des chevauchements du Crétacé et de l'Oligo-Miocène, qui ont affecté les unités du socle et de la couverture sédimentaire, en produisant la mobilité synsédimentaire des marges des bassins. Les deux épisodes sont séparés par l'intrusion des corps magmatiques pendant l'Eocène et l'Oligocène (Adamello et Val Gandino). Avant les intrusions, la déformation Mésoalpine peut être documentée par la sédimentation des unités turbiditiques de l'Eocène supérieur (Formation de Ternate).

Les systèmes de déformation Néoalpin ont affecté profondément la structure plus ancienne, en la modifiant à partir des chevauchements de socle septentrionaux, vers les décollements des unités sédimentaires méridionales. La plus récente des mises en place des chevauchements peut avoir déterminé l'actuelle disposition en échelon des anticlinaux "orobiques" et le développement de la "Flessura Frontale" plus au sud.

Les données sismiques obtenues grâce aux profils CROP88, confirment cette interprétation et indiquent que l'édifice structural pré-Néoalpin a été recoupé par une zone de cisaillement profond, liée au décollement inférieur du front enseveli des Alpes Méridionales (ceinture de Milan), et se trouve donc en position allochtone.

MOTS CLÉS. — Alpes Méridionales, orogène alpin, prismes clastiques.

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Il significato dei cunei clastici Cretacico - Miocenici nella storia deformativa del Sudalpino Lombardo

RIASSUNTO. — I sistemi torbiditici cretacico-miocenici delle Alpi Meridionali, costituiscono, in Lombardia, due cunei clastici principali, che rappresentano il riempimento di bacini sinorogenici, collocati al margine meridionale delle Alpi.

I cunei clastici Cretacico superiore ed Oligo-Miocenico documentano e datano i principali episodi di sovrascorrimento, che coinvolsero unità di basamento e di copertura, determinando l'attività tettonica sinsedimentaria ai margini dei bacini. I due eventi tettonici sono separati dalla messa in posto delle masse intrusive Eocenico Oligoceniche (Adamello e Val Gandino), e dalla propagazione verso sud dei fronti di sovrascorrimento, documentata dai sedimenti clastici della Formazione di Ternate.

L'evento tettonico tardo terziario, polifasico, rielaborò sostanzialmente il precedente edificio strutturale, dai sovrascorrimenti più settentrionali, fino alle unità alloctone di copertura più meridionali. Un episodio tardivo può essere ritenuto responsabile del piegamento e dei sovrascorrimenti lungo i rilievi meridionali della Flessura Frontale, e dell'embricazione en-echelon delle Anticlinali Orobiche a nord.

Il quadro sismico fornito dal profilo CROP 88 conferma questa interpretazione ed indica che il presente edificio strutturale giace su una superficie di scollamento connessa con il fronte sepolto delle Alpi Meridionali (Milano Belt), ed è perciò alloctono.

PAROLE-CHIAVE. — Alpi Meridionali, cunei clastici, orogenesi alpina.

1. - INTRODUCTION

The Alpine deformation history of the Lombardian Southern Alps is constrained by the age of magmatic intrusions cutting across the older thrusts (e.g. Adamello and Val Gandino intrusive bodies, respectively 43-30 Ma and 62-50 Ma; Del Moro *et al.*, 1983; Zanchi *et al.*, 1990) and by the age and significance of syntectonic sedimentation during the Late Cretaceous - Miocene time span. The existing models are in agreement in recognizing pre- and syn-Adamello south-vergent thrusting of basement and cover units in the northern part of the Orobian Alps (Orobic arc after Castellarin 1984), followed by the post - Adamello foreland propagation of thrust fronts, the outer belt of which is presently buried in the Po plain subsurface (Pieri and Groppi, 1981; Cassano *et al.*, 1986; Milano belt, Laubscher, 1988). Major problems arise in contrast when trying to determine the age of the pre - Adamello structures and to correlate them with the sedimentary record (Cretaceous - Eocene), when attempting to clarify the late Tertiary tectonic steps and finally when looking for the link between the Eo- to Neoalpine evolution of the Central and Southern Alps.

This paper attempts to illustrate the significant information regarding these topics, provided by the stratigraphical and structural features of the Upper Cretaceous to Miocene syntectonic clastic wedges of the Southern Alps in Lombardy (Fig. 1). On the basis of these data, and taking into account the proposed reconstruction, an attempt to contribute to the geological interpretation of the present day seismic image of the Lombardian Southern Alps, provided at lithosphere scale by the CROP 88 experiment, is also presented.

2. - THE UPPER CRETACEOUS TO MIOCENE CLASTIC WEDGES

The Upper Cretaceous to Miocene turbidite systems of the Lombardian Southern Alps form two main composite clastic wedges representing the infilling of synorogenic basins at the southern border of the Alpine chain.

The Upper Cretaceous clastic wedge (UCw), up to 2,5 km thick, developed during the pre-collisional Eoalpine orogeny and was probably located on the back side of an active margin (Castellarin, 1976; Laubscher and Bernoulli, 1982; Polino *et al.*, 1990). Remnants of the Cretaceous basin are presently exposed in the southernmost outcrops, along the Flessura Frontale, which is part of the south-vergent fold and thrust belt (Fig. 1)(Upper Cretaceous Flysch, Venzo, 1954; Aubouin *et al.*, 1970; Castellarin, 1976; Bichsel and Haering, 1981; Gelati *et al.*, 1981). The Paleocene - Upper Eocene turbidite systems are poorly preserved in the western part of Lombardy (Laubscher and Bernoulli, 1982; Kleboth, 1982).

The Oligo-Miocene clastic wedge (OMcw), up to 3 km thick, was deposited close to the northern margin of the Padan foredeep (Chiasso Fm. and Gonfolite Group; Longo, 1968; Gunzenhauser, 1985; Gelati *et al.*, 1988). Syn - and post - depositional thrusting affected the wedge which presently crops out only in the western Lombardy (Fig. 1).

3. - THE UPPER CRETACEOUS TURBIDITE SYSTEMS

The Upper Cretaceous turbidite systems unconformably overlay the Upper Jurassic - Lower Cretaceous calcareous and marly pelagites of the

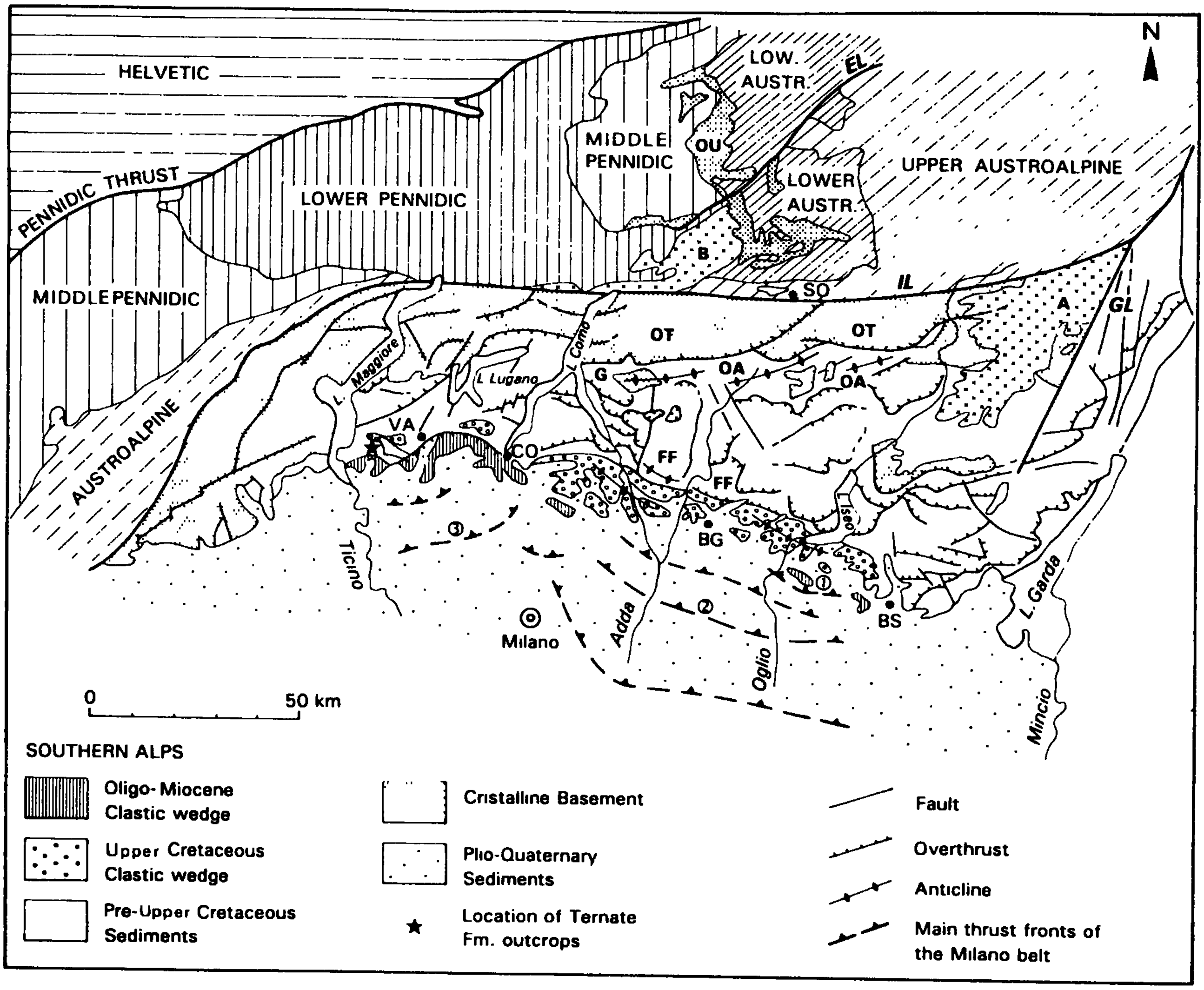


FIG. 1. Geological scheme of the Lombardian Southern Alps and neighbouring areas. A: Adamello batholith; B: Bregaglia intrusive body; EL: Engadina Line; FF: "Flessura Frontale"; GL: Giudicarie Line; IL. Insubric Line; OA: Orobic Anticlines; OT. Orobic Thrust; OU: ophiolitic units; 1: M. Orfano anticline; 2: Malossa area; 3: Romentino thrust. Towns' identification: BG, Bergamo; BS, Brescia, CO, Como; SO, Sondrio; VA: Varese.

FIG. 1. Schéma géologique des Alpes Méridionales en Lombardie et des régions voisines. A: Adamello massif; B: Bregaglia massif; EL: Ligne de l'Engadine ; FF: "Flessura Frontale"; GL: Ligne Judicarienne; IL: Ligne Insubrienne; OA: Anticlinaux Orobiques; OT: Chevauchement Orobique; OU: unités ophiolitiques; 1: anticlinal du M Orfano, 2: Malossa; 3: Chevauchement de Romentino. Identification des villes: BG, Bergamo; BS, Brescia; CO, Como; SO, Sondrio; VA: Varese.

Maiolica and Scaglia formations. The transition between carbonate and terrigenous sedimentation occurred during the Aptian in a pelagic environment at bathyal depth (Arthur and Premoli Silva, 1982). Close to the Aptian/Albian boundary, fine grained siliciclastic turbidite sedimentation set on, and lasted up to the Middle Albian, while the development of syntectonic terrigenous turbidite systems began during the Late Cenomanian.

The Upper Cretaceous turbidite units (Cenomanian - Campanian), are organized in four sequences bounded by marginal unconformities and the correlative basinward conformities (Fig. 2). Every sequence consists of one or more turbidite system interfingering with pelagic-hemipelagic marlstones and/or redeposited slope sediments and chaotic deposits.

The Cenomanian Sequence consists of an Upper Cenomanian fine grained turbidite sandstone wedge (0-70 m thick), with an E-W elongated shape, embedded between two main calcareous chaotic megabeds, consisting of slide and slump facies, passing to calcareous turbidites basinwards. The turbidite body progressively wedges out towards the N and NE, lapping out above the lower chaotic body; the latter overlays the lower bounding unconformity, that corresponds to an Early - Middle Cenomanian hiatus (marginal sector) (Fig. 2). Towards the S and W the turbidite lithosome thins more progressively and the chaotic megabeds are replaced by a succession of pelagic turbidites and hemipelagites conformably

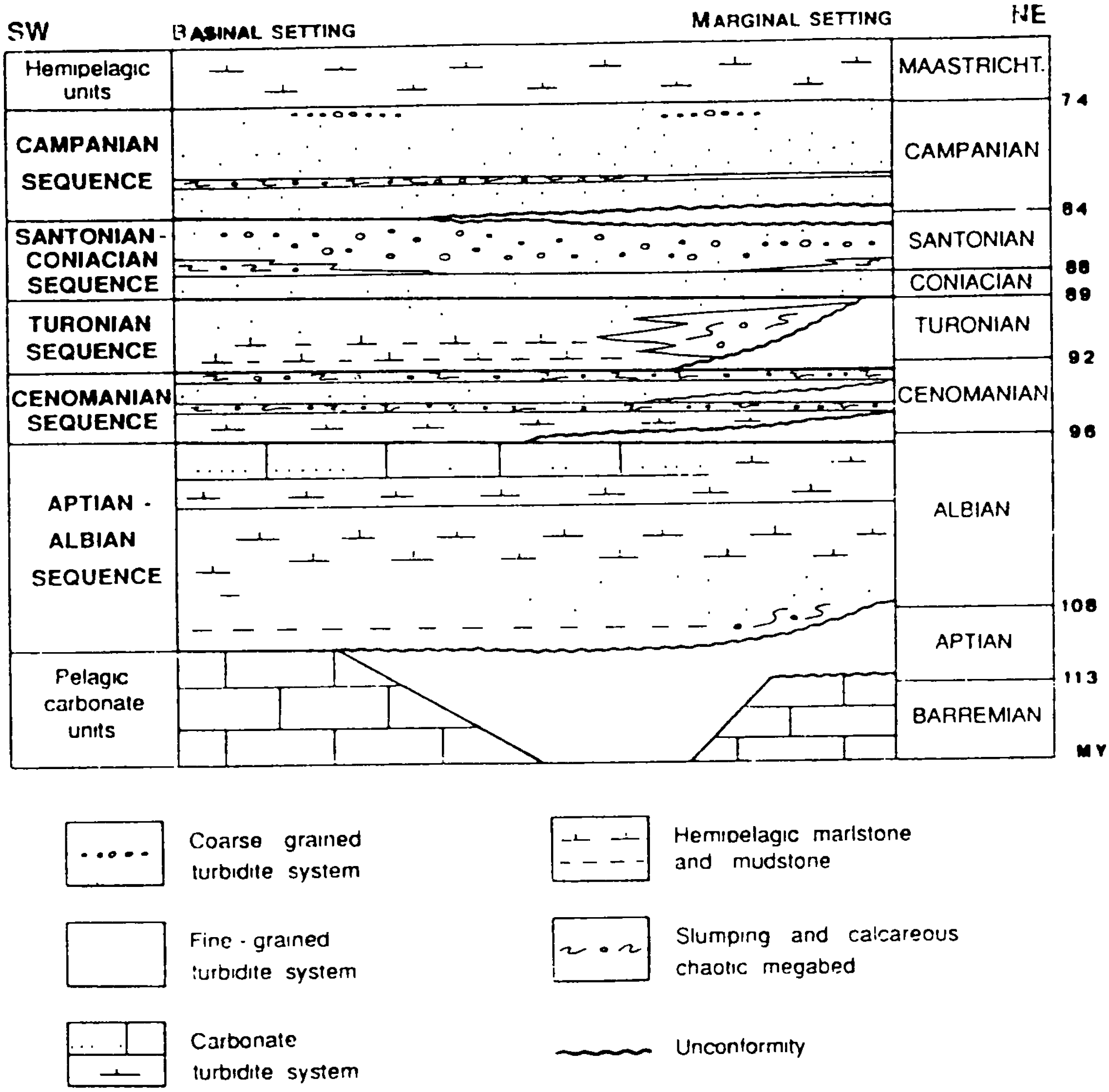


FIG. 2. - Chronostratigraphic scheme of the syntectonic sequences building the UCw (redrawn and modified after Bersezio *et al.*, 1990).

FIG. 2. - *Schéma chronostratigraphique des séquences syntectoniques composant le UCw (modifié d'après Bersezio* et al., *1990).*

overlaying the older basinal units (basinal sector) (Bersezio and Fornaciari, 1988).

The Turonian Sequence is characterized by the 600 m thick Peliti Rosse and Flysch di Pontida turbidite systems, Mid - Late Turonian in age, that interfinger eastwards and northwards with a 200 m thick lenticular body of massive turbidites, pebbly mudstones and slumps (Flysch di Colle Cedrina) and with a third chaotic megabed (Bersezio *et al.*, 1990). In the southern complete and conformable sections the uppermost Cenomanian to Lower Turonian is represented by a basinal pelagic unit with black shales (Peliti Nere). This conformable lower boundary is progressively replaced eastwards and northwards by an unconformity corresponding to progressive wedging out of the Turonian lithosomes, documenting a hiatus that spans the latest Cenomanian and Turonian (Fig. 2). In a northern setting, presently thrust over the described successions, the lower unconformity deeply dissects the underlying units, down to the Barremian Maiolica (Bersezio *et al.*, 1989), cutting across the Cenomanian marginal unconformity and succession.

A comparison of thickness and facies variations between the Cenomanian and Turonian sequences indicates that the depocenters slightly shifted southwards after the Late Cenomanian.

The Coniacian-Santonian Sequence consists of a lower turbidite system, which built a sandstone lithosome, up to 400 m thick (Arenarie di Sarnico, Coniacian; Venzo, 1954), followed upsection by a 150 m thick conglomeratic body, Santonian in age (Conglomerati di Sirone). In the southernmost outcrops, the Arenarie di Sarnico conformably overlay the Flysch di Pontida, with a transitional boundary

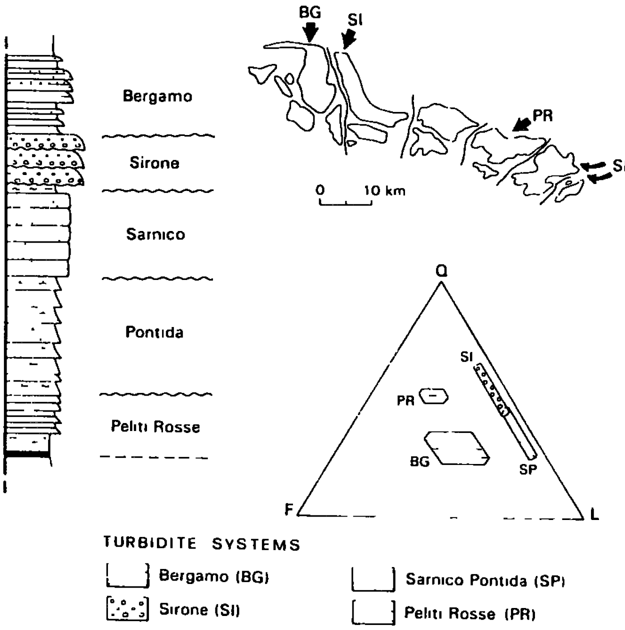


FIG. 3 Sandstone composition vs. paleocurrent trends of the Turonian - Campanian turbidite systems in the Bergamasc Prealps.

FIG. 3. *Composition des arénites et directions des paléocourants des systèmes turbiditiques du Turonien Campanien dans les Préalpes bergamasques.*

(Fig. 2). This basinal conformity is replaced by an erosional truncation that is visible today only in the eastern outcrops, around Lake Iseo. The truncation cuts across the Turonian and Cenomanian sequences and their relative bounding unconformities. Angular unconformities between the Cenomanian units and the Arenarie di Sarnico can be observed in the Val Adrara-Capriolo area, south of Lake Iseo (Fig. 1).

The Campanian Sequence is represented by the interfingering Flysch di Bergamo and Pietra di Credaro turbidite system, whose thickness can hardly be established due to scattered exposure, but should exceed 600 m. A huge calcareous megabed is present in the lower half of the Flysch di Bergamo (Missaglia Megabed, Bernoulli *et al.*, 1982). A lower bounding unconformity has been detected in the SE areas, between the Campanian turbidites and the Conglomerati di Sirone. The documented hiatus comprises the Late Santonian - Early Campanian time span (Fig. 2).

Sandstone petrography shows that the extrabasinal turbidites were fed by erosion of metamorphic and sedimentary units similar to those presently exposed in the Southern Alps (Bersezio and Fornaciari, 1987; Bernoulli and Winkler, 1990). Variations in the compositional modes of arenites indicate that erosion of low grade metamorphites and sedimentary units prevailed during Late Turonian to Santonian, while high grade metamorphic clasts are more typical of the

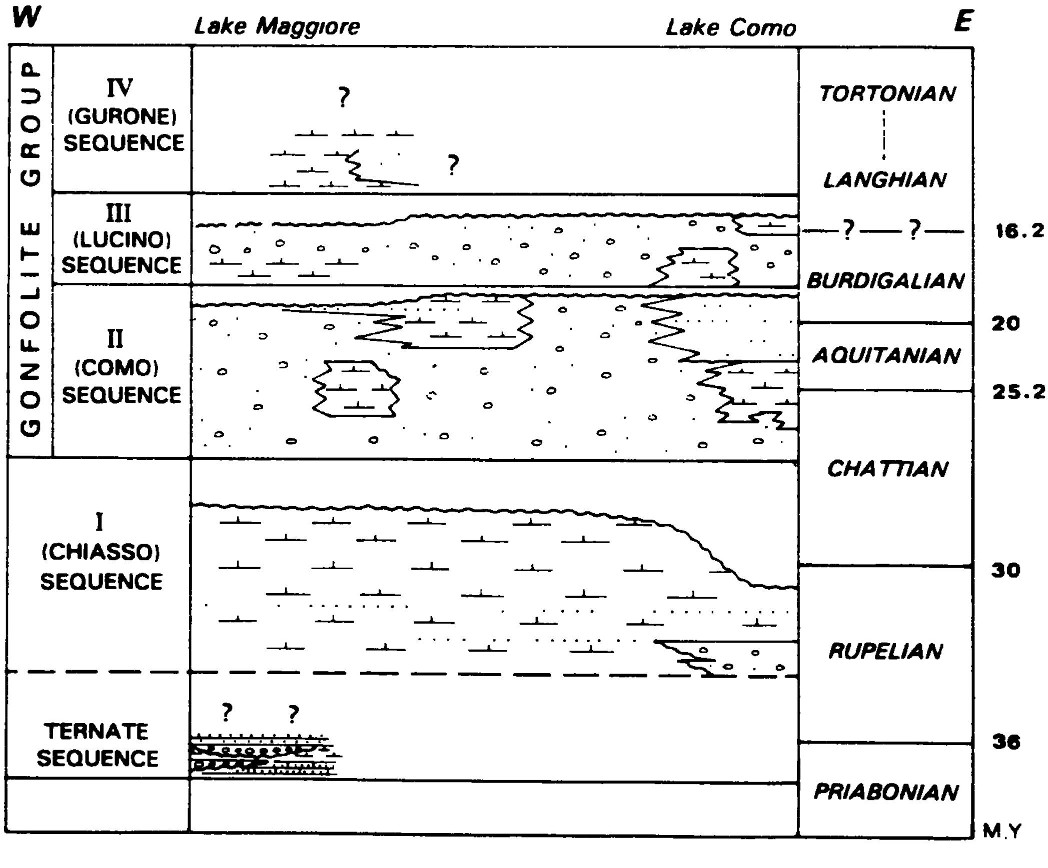


FIG. 4. - Chronostratigraphic scheme of the syntectonic sequences building the OMcw.

FIG 4 *Schéma chronostratigraphique des séquences syntectoniques constituant le OMcw.*

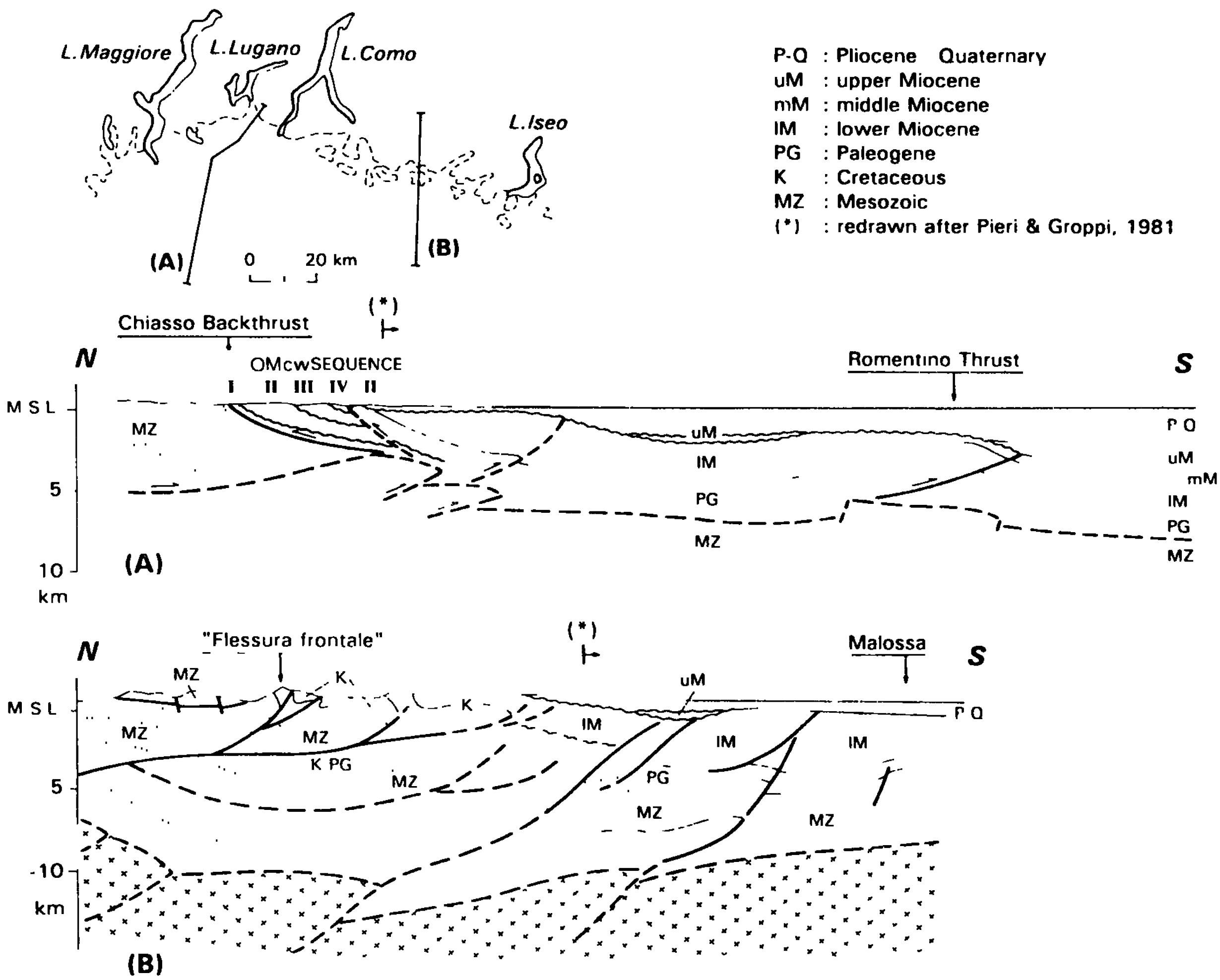


FIG. 5. - Interpretative geological cross-sections of the frontal southalpine sector in Lombardy, based on field data, seismic interpretation (Pieri and Groppi, 1981) and CROP88 data (southern end of Morbegno Dalmine transect), after CROP88 Working Group, in press.

FIG. 5. - *Section géologique interprétative du secteur sud des Alpes Méridionales de Lombardie, d'après les données superficielles, l'interprétation sismique de Pieri et Groppi (1981) et du CROP88 (partie méridionale du transect Morbegno - Dalmine) (CROP88 Working Group, sous presse).*

Middle Turonian and Campanian (Fig. 3). These data are in agreement with the heavy mineral associations described by Bernoulli and Winkler (1990). Considering the present-day distribution of outcrops, paleocurrent trends indicate westward funneling of clastics for the Cenomanian, Upper Turonian and Coniacian turbidite systems, while a northern provenance can be assessed for the Middle Turonian, Santonian and Campanian units (Fig. 3). Intrabasinal redeposition from local slope and marginal areas is documented by the composition of the chaotic megabeds, massive turbidites and pebbly mudstones of Cenomanian-Turonian age. The northern and north-eastern location of the source areas, with respect to the present-day position of the depocentral and basinal sections, is documented by the southward trend of thickness and facies variations of the mass gravity deposits, by the geometry of the marginal unconformities and by their relationships with the chaotic deposits.

4. - THE MAASTRICHTIAN-EOCENE TURBIDITE UNITS

The Maastrichtian to Eocene turbidite units, (Piano di Brenno Fm., Tabiago Fm., Ternate Fm.) crop out in scattered exposures in the western part of Lombardy (Brianza, Varesotto, Fig. 1).

The Maastrichtian Piano di Brenno Fm. consists of up to 200 m of red and grey, thin and parallel-bedded, marly limestones with pelagic microfossils ("Scaglia" facies), including resedimented calcarenites and calcirudites. This unit conformably overlays the Flysch di Bergamo (Fig. 4) in the few available exposures.

The Tabiago Fm. consists of more than 100 m of turbidite calcarenites associated with pebbly mudstones and calcirudites, embedded in Scaglia - like hemipelagic marlstones of Paleocene - Middle Eocene age (Kleboth, 1982). In the easternmost outcrops the lower boundary is represented by a paraconformity, with a lowermost Paleocene hiatus (Premoli Silva and

Luterbacher, 1966), while westwards a slightly angular unconformity of local extension is present, and the related hiatus spans the Lower - Middle Paleocene (Beckmann *et al.*, 1982). The calciclastic bodies are sealed in the eastern sector (Adda valley) by pelagic calcilutites, late Middle Eocene in age, but the upper boundary of the unit is never exposed.

The clastic resediments within the two formations mostly consist of Mesozoic carbonate lithoclast of local south-Alpine provenance mixed with platform and outer shelf biota, penecontemporaneously redeposited intraclasts and fossils (Kleboth, 1982). A deep water setting at bathyal depth of some 1500-2000 m has been recognized on the basis of benthic foraminifers and facies association. Channelized turbidites were fed by an emergent platform and structural high in the north (Kleboth, 1982).

The Upper Eocene Ternate Formation consists of at least 150 m of redeposited bio-lithoclastic limestones, with channelized conglomerates and pebbly mudstones, associated with subordinate hemipelagic marlstones (Braghieri and Montanari, 1976; Herb, 1976; Bernoulli, 1980). The bottom and top boundaries of the unit are not known. Facies association and benthic Foraminifers indicate turbidite and mass gravity flow sedimentation within a channel-interchannel environment at upper bathyal depth (Bernoulli *et al.*, 1988). Sediment composition points to a provenance from erosion of local south-Alpine Variscan basement and sedimentary units up to the Campanian Flysch (Braghieri and Montanari, 1976; Herb, 1976), of slightly older slope and basinal sediments originally laid down in a deeper environment than the Ternate Formation, and of a penecontemporaneous carbonate platform and shelf environment in the north (Bernoulli *et al.*, 1988).

5. - Structural setting of the UCw at the front of the Bergamasc Prealps

The Upper Cretaceous clastic units have been involved by post depositional tectonism at least since Late Eocene, because clasts of the Campanian deep sea turbidites have been found in the Ternate Fm. (Herb, 1976; Braghieri and Montanari, 1976). Redeposition of deeper sediments in an upper bathyal environment indicates that pre-Late Eocene uplift and possibly upfolding affected the Cretaceous wedge at least in the western area, where the Ternate Fm. has been preserved in outcrops (Bernoulli *et al.*, 1988).

Deformation in the Late Tertiary fold and thrust belt of Lombardy affected the Upper Cretaceous clastic units, which are presently exposed in a WNW-ESE trending strip of south-vergent faulted folds along the southernmost reliefs bordering the Po plain (Fig. 1). The Cretaceous deep-sea sediments are also involved in thrusts and folds of the Milano Belt (Pieri and Groppi, 1981) whose S-vergent thrusts face the younger external arc of the N-vergent Apennines (Pieri and Groppi, 1981; Cassano *et al.*, 1986). AGIP and CROP seismic data (Errico *et al.*, 1980; Pieri and Groppi, 1981; Pieri *in* Bally, 1983; Dalla *et al.*, in press; Montrasio *et al.*, 1992) allow to link the buried and outcropping thrust belts (Fig. 5).

Considering the outcropping strip, the following outstanding features can be summarized :

- the Cretaceous clastic units are mostly preserved in outcrops in the area E of Como; westwards they are truncated by north-vergent thrusting of tertiary sediments (see a later paragraph) or they are stratigraphically covered by the same units (Fig. 1 and Fig. 5);

- the Upper Cretaceous clastic wedge (UCw) is often decolled from the Mesozoic substratum and cut into several thrust slices. Two main WNW-ESE striking en-echelon anticlines characterize the southern exposures (Fig. 1). These folds are due to ramping of thrust surfaces that climb up cutting the Rhaetian-Jurassic section (as can be seen in the Zandobbio area, close to Lake Iseo) and probably reach a decollement horizon in the Carnian evaporites below the Norian Dolomia Principale. In contrast, the complex pattern of thrust slices that are stacked in the northern outcrop area, consists of Middle-Upper Cretaceous units, decolled along the Aptian-Albian mudstones. Between Como and the Lake Iseo (Fig. 1) these units are overthrust by the Jurassic succession belonging to the southern limb of the so called "Flessura Frontale" ("steep rand zone" of De Sitter and De Sitter Koomans, 1949). In the Albenza area only, between the Adda and Brembo valleys, the decolled Cretaceous succession is thrust N-wards over the southern limb of the "Flessura Frontale" (Bersezio and Fornaciari, 1988). These backthrusts are presently sub-vertical, due to oversteepening by progressive ramp folding along the "Flessura" itself;

- the "Flessura Frontale" is a belt of south-vergent knee and overturned folds linked to emergent or blind thrust surfaces that ramp through the Dolomia Principale and the Rhaetian-Jurassic units, reaching the shallower decollement horizon represented by the Aptian-Albian mudstones. The average E-W strike of the "Flessura" is turned to WNW-ESE in correspondance of transverse strike-slip faults and of transfer zones consisting of fold belts (Fig. 1) (Gaetani and Jadoul, 1986; Laubscher, 1988; Bersezio and Fornaciari, 1988; Zanchi *et al.*, 1988; Schonborn, 1991; 1992).The overall en-echelon pattern of the "Flessura Frontale" segments is identical to that shown by the southern anticlines;

- the southernmost thrust linked with the "Flessura Frontale" is shown to cut the older thrust stack near Lecco (Schonborn, 1992). The homologous thrust-splay, east of the Serio river, involve some Aptian - Turonian successions that are typical of an internal marginal domain (Bersezio *et al.*, 1989). They override a quite different coeval succession, that was deposited much more basinward;

- vitrinite reflectance data, the thermal alteration index of palynomorphs, illite cristallinity values and clay mineral assemblages indicate very low to low diagenetic grade for the Upper Cretaceous units east of Como (Bersezio *et al.*, 1990). Clay mineralogy data indicate that the same is true west of Como, in the Chiasso area (Deconinck and Bernoulli, 1991). A higher diagenetic stage has been reached only by the Upper Cretaceous sediments directly underlying the frontal thrust of the "Flessura Frontale", at its present-day southern border east of the Brembo river.

Timing of the Late Tertiary deformation in this area is constrained by cross-cutting relationships between thrusts and by Upper Eocene porphyrite dikes intruded along extensional joints in the middle Serio valley, north of the "Flessura Frontale" (Zanchi *et al.*, 1990). The minimum age for deformation is indicated by the presence of undeformed or only gently tilted marine Pliocene units cropping out at the southern margin of the prealpine hills. Moreover the Middle Miocene M. Orfano Conglomerates (possibly Langhian in age; Cita, 1954) are exposed along the southern limb of the southernmost outcropping anticline south of Lake Iseo (Fig. 1). Subsurface data by Pieri and Groppi (1981) indicate a Late Miocene age for the emplacement of the buried frontal thrusts of the Milano belt (Fig. 1).

6. - The Oligo-Miocene turbidite sequences

During the Early Oligocene-Middle/Late Miocene time span a deep water clastic complex commonly referred to as Gonfolite Lombarda was deposited in the Southalpine foredeep.

The present outcrop area (Fig. 1 and Fig. 6) extends discontinuously between Lake Maggiore and the eastern branch of Lake Como (Brianza area); the isolated outcrops of conglomerates present further east (Montorfano Bresciano) belong to a comparable succession. The Gonfolite Lombarda is widely present also in the subsurface of the northern Po plain, of eastern Piedmont and of Lombardy (Dondi and D'Andrea, 1986). The present areal distribution is about 200 km in an E-W and about 40 km in a N-S direction.

This thick succession (thickness in outcrops is almost 3 km) consists of clastic systems fed by the erosion of the Southalpine basement and cover and of the central Alpine nappes and intrusive bodies.

The presence of at least three major unconformities (Fig. 4) with a submarine erosional truncation can be recognized in the outcrop areas between Varese and Como on the basis of their geometric features; the unconformities are accompanied by a sudden increase of the coarse clastic material. The biostratigaphic analysis based on planktonic foraminifera (zonal scheme after Blow, 1979) allowed to place them respectively into the Late Oligocene, Early Burdigalian and latest Burdigalian/ Langhian (Gelati *et al.*, 1988; 1991). The recognized unconformities represent the boundaries of four syntectonic depositional sequences (Fig. 4).

Sequence I, Upper Rupelian to Lower Chattian

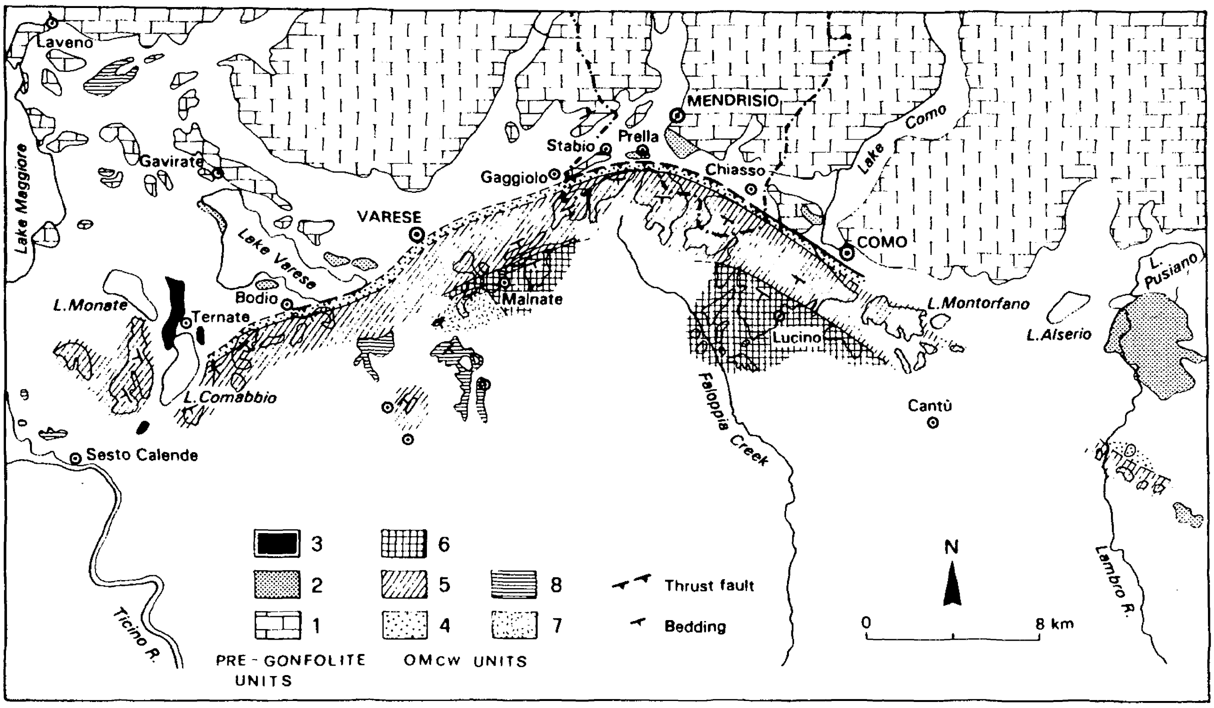


FIG. 6. - Geological sketch map of the Chiasso backthrust area. 1 : undifferentiated Mesozoic units; 2 : Upper Cretaceous units; 3 : Ternate Fm., 4 : Sequence I; 5 : Sequence II; 6 : Sequence III; 7 : Sequence IV; 8 : undated Gonfolite units.

FIG. 6. - *Schéma géologique de la région du chevauchement rétro-vergent de Chiasso. 1 : unitées Mésozoïques ; 2 : unités du Crétacé supérieur; 3 : Formation de Ternate; 4 : Séquence I; 5 : Séquence II; 6 : Séquence III; 7 : Séquence IV; 8 : unité d'âge inconnue (Gonfolite).*

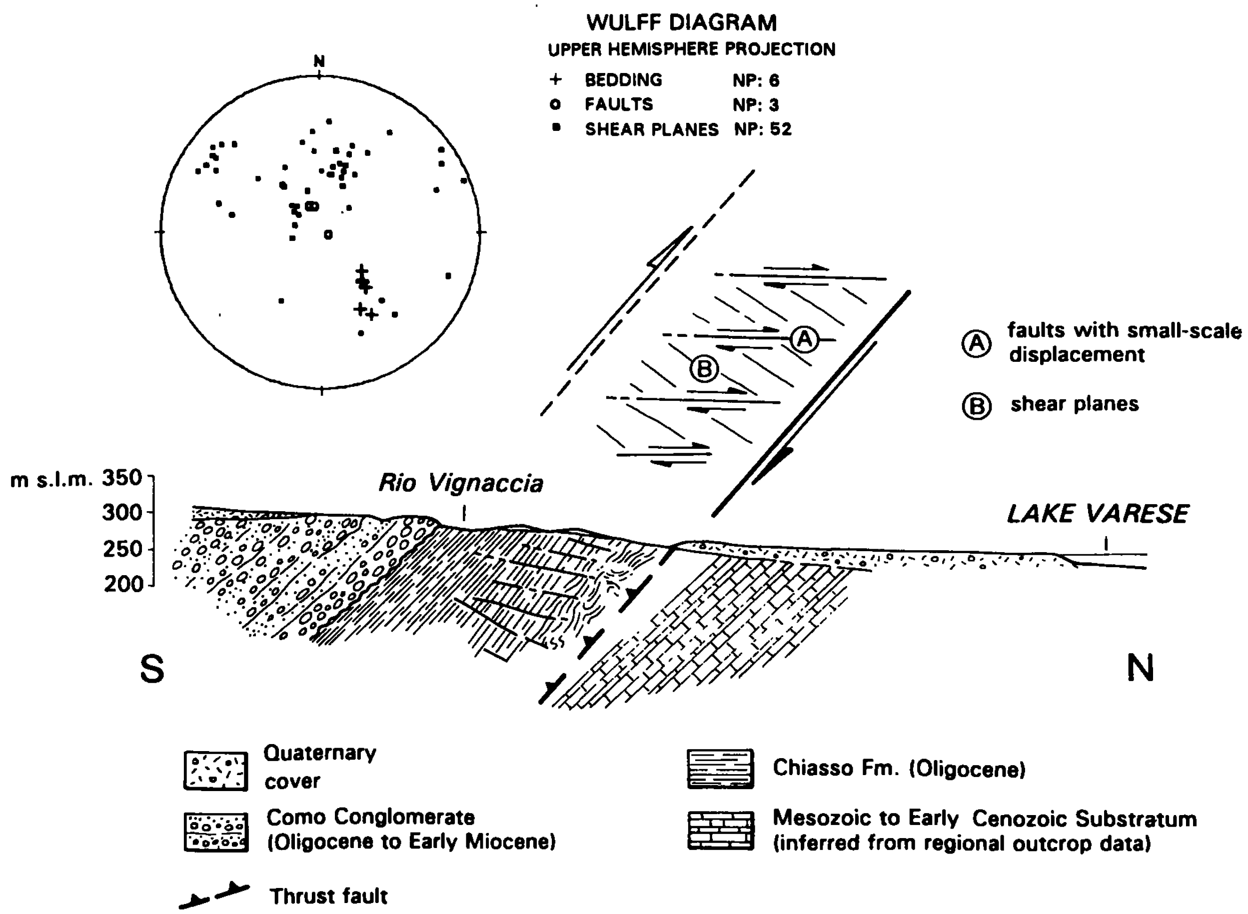


FIG.. 7. - Geological cross-section, structural data and interpretation of the lower contact between the OMcw and the Mesozoic substratum near Varese.

FIG.. 7. - *Section géologique, données stucturales et intérprétation du contact inférieur entre le OMcw et les unitées Mésozoïques sous-jacentes, à proximité de Varese.*

(P19/P20 and P21 zones) is represented by hemipelagic mudstone and thin-bedded turbidites (Chiasso Fm.) with local coarse clastic deposits (Villa Olmo Conglomerates) referred to a slope to slope-base complex (Gunzenhauser, 1985). It is bounded at its base by a tectonic contact interpreted as a N-vergent thrust (see following chapter)(Bernoulli *et al.*, 1989), and at its top by a marked truncation surface, corresponding to an angular unconformity.

Sequence II is mostly represented by the Como Conglomerate and its heteropic units, comprising the Upper Chattian to Lower Burdigalian (late P22 to N5/N6 zones). This sequence mostly consists of conglomerates, pebbly sandstones and coarse-grained sandstones gradually upwards fining, interpreted as a canyon-fill complex, representing the inner portion of a deep - sea fan depositional system. Its uppermost part is characterized by the development of levee and interchannel deposits and finally by sandy lobes facies associations. The lower sequence boundary is represented by the Upper Oligocene unconformity (Fig. 4). The Como Conglomerate contain basement and sedimentary lithoclasts from both the Southern and Central Alps. Tonalite boulders attributed to the Bregaglia intrusion (Giger and Hurford, 1989; Giger, 1991) are also present, as well as mudstone and conglomerate clasts of Sequence II itself.

Sequence III (Burdigalian in age) is defined by the sudden development of coarse arenaceous to conglomeratic deposits (Lucino Conglomerates) which point out a new progradational phase of the depositional system (Gelati *et al.*, 1991). They are associated with pelitic levee or interchannel facies associations, already present in the lower part of the sequence. The sequence boundary is represented by the Lower Burdigalian unconformity (Fig. 4).

Sequence IV is represented by the Gurone Sandstone and the Bizzozzero Mudstone, outcropping in the Varese area only. This sequence is bounded at the base by an erosional truncation surface with a clear angular unconformity (uppermost Burdigalian/ Langhian unconformity). The lower part of the sequence is characterized by the presence of intra-formational unconformities associated with sliding phenomena, probably of syndepositional tectonic origin. Channel and levee facies associations prevail throughout the succession.

As reported in Fig. 5, a tentative correlation between the OMcw sequences and the units reported in Pieri and Groppi (1981) suggests that :

FIG.. 8. - Planktonic Foraminifera in the pelite unit of Castronno. 1, *Globigerinelloides trilobus* Reuss : 1A, umbilical view; 1B, spiral view; 2, *Catapsydrax dissimilis* (Blow and Banner). Umbilical view; 3, *Globigerinelloides primordius*, Blow and Banner. Spiral view; 4, *Globorotalia acrostoma* Wezel. Umbilical view; 5, *Globorotalia siakensis* (Le Roy). Umbilical view.

FIG.. 8. - *Foraminifères planctoniques dans les pélites de Castronno. 1,* Globigerinelloides trilobus *Reuss : 1A, vue ombilicale; 1B, vue spirale;* 2, Catapsydrax dissimilis *(Blow and Banner), vue ombilicale; 3,* Globigerinelloides primordius, *Blow and Banner, Vue spirale; 4,* Globorotalia acrostoma *Wezel, Vue ombilicale; 5,* Globorotalia siakensis *(Le Roy), Vue ombilicale.*

- sequences I and II could correspond to the PG (Palaeogene) unit of the Authors;

- sequence III could correspond to their lM (Lower Miocene) unit, and

- sequence IV could correspond to their mM (Middle Miocene) unit.

This correlation documents the southward thinning of the sequences, towards a belt of structural highs, that are identified by the AGIP subsurface data (Valle Salimbene and Battuda highs; Pieri and Groppi, 1981; Cassano *et al.*, 1986).

7.- Structural setting of the OMcw in the Como-Varese area

The Oligo - Miocene clastic wedge has been involved by folding and thrusting in outcrop as well as in the subsurface. The outcropping part of the wedge is tilted up to a subvertical attitude in the northernmost exposures. From north to south the dip value gradually decreases to 15-20°. Locally the Gonfolite is detached from the Mesozoic substratum along the Chiasso Formation, and thrust towards the north (Bernoulli *et al.*, 1989).

8. - Geometry of the Chiasso north-vergent thrust

According to Bernoulli *et al.* (1989) the tectonic contact between the Chiasso Fm. and the underlying Mesozoic succession recorded in the Monte Olimpino 2 tunnel is part of a regional north - vergent thrust. The thrust can be traced toward NW in the Mendrisio area (Fig. 6), where the Upper Cretaceous Prella series (Bernoulli *et al.*, 1987) is tectonically overturned. As suggested by these authors the proximity of the Upper Triassic and Liassic units between Stabio and Gaggiolo (Fig 6) to the Gonfolite outcrops points to a westward continuation of the thrust.

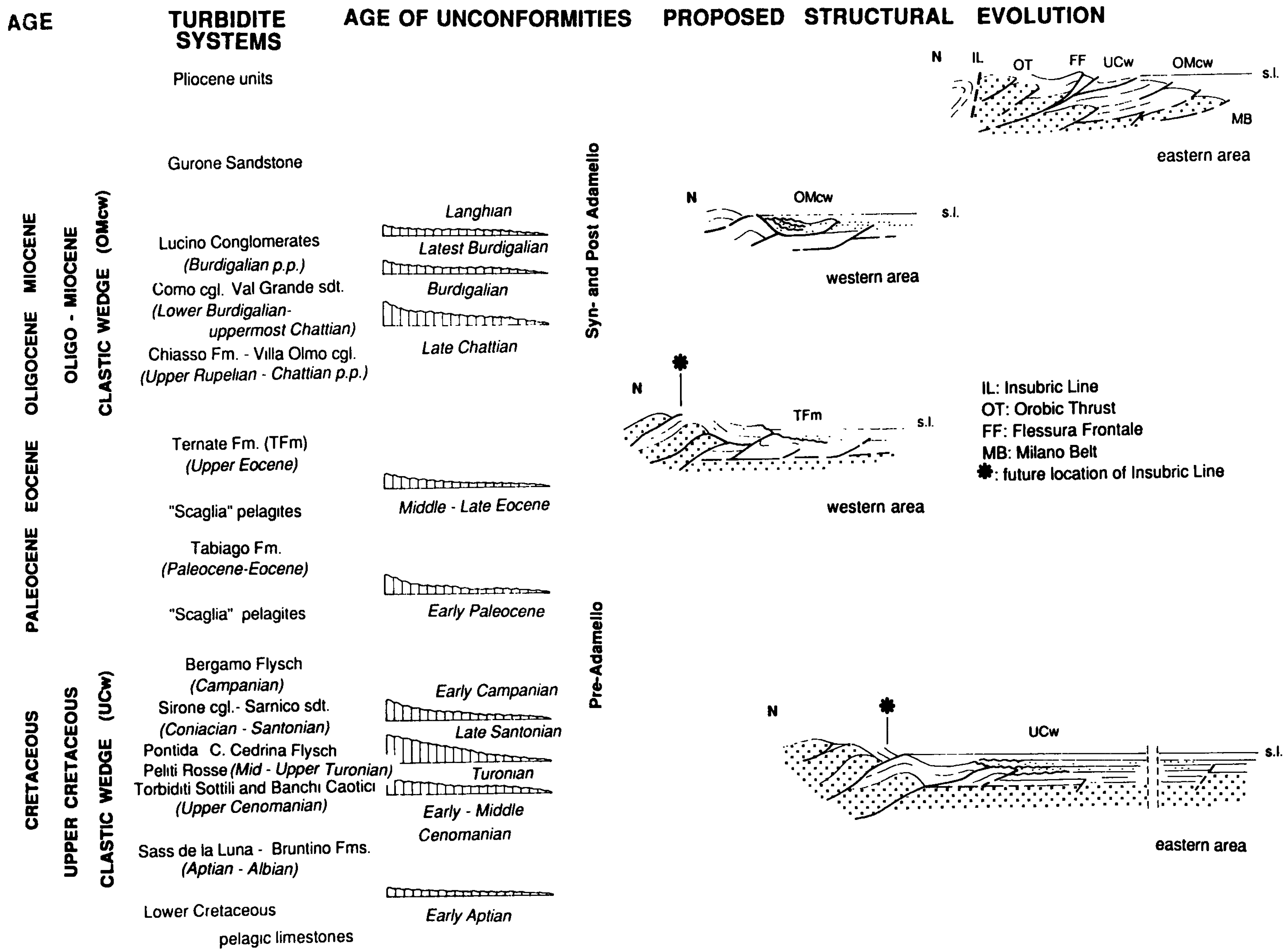
In the Varese area a large gap in outcrops separates the Gonfolite and Mesozoic units, obscuring the trend and nature of the contact. The oldest stratigraphic unit belonging to the Gonfolite Group near Varese is the Belforte Mudstone (Late Oligocene - Early Miocene, P22 - N4 zones after Blow, 1979) (Gelati *et al.*, 1988). Therefore the Belforte Mudstone belongs to Sequence 2 and cannot obviously correlate with the Chiasso Fm. cropping out near Prella. As a consequence, the trend of the contact between the Gonfolite and the older units is not represented by the present-day northern margin of the Gonfolite outcrops in that area. Since in the gap of exposures there is room enough to accomodate the thickness of the remaining Gonfolite succession, its lower contact could be traced parallel to the regional bedding, from Bizzarone to Varese (Fig. 6). About the nature of this contact some information can be collected in the Bodio area, south of Lake Varese (Fig. 6), where the Chiasso Fm. is exposed with a thickness of at least 100 m in the Rio Vignaccia section. The lowermost part of the outcrops is affected by strong deformation, gradually decreasing upsection; the upper 50 m of the formation are tectonically undisturbed (Fig. 7). Several sub-horizontal faults, with northwards small-scale displacement and well developed shear planes can be observed there. The fault and shear planes attitudes have been measured in order to assess the sense of displacement. Most of the shear planes are distributed between WNW and NNE, opposite to the bedding, with a dip variable between 40° and 80° (Fig.7). This distribution can be explained by northwards thrusting of the Gonfolite over the Lower Cenozoic and Mesozoic carbonates. This allowed the development of shear zones in the relatively incompetent Chiasso Formation.

The movement along the backthrust has been interpreted as of Burdigalian to Tortonian age (Bernoulli *et al.*, 1989; Gelati et *al.*, 1991). A possible Burdigalian age for upfolding is suggested by the inferred presence of an erosional truncation to the north, during the deposition of Sequence III, documented by the redeposition of pelitic pebbles of the Chiasso Formation in the Lucino conglomerates (Bernoulli *et al.*, 1989). Moreover the progradation of the depositional system at the base of Sequence III (sharp transition from sandy lobe to canyon facies associations) is in line with the hypothesis of increasing tectonic activity during the Early Burdigalian.

In the subsurface, the pre-Upper Miocene sediments are incorporated into south-vergent thrust sheets or form independent slices, detached from the Mesozoic units (Pieri and Groppi, 1981; Cassano *et al.*, 1986; Dalla *et al.*, in press). According to Pieri and Groppi (1981), the Paleogene to Upper Miocene succession is involved by a south-vergent thrust (Romentino thrust) (Fig. 5). The stratigraphic relationships among the Tertiary units change from north to south of the thrust front; while northwards the sequence is mostly Paleogene to Lower Miocene in age, south of the Romentino thrust Middle to Upper Miocene deposits are well developed. The structure is unconformably overlain both by Upper Miocene and Pliocene sediments. The sudden change in thickness proportion of the different segments of the Tertiary succession, as well as the geometries reported by Pieri and Groppi (1981), suggest that the movement along the thrust is at least younger than Early Miocene. The Romentino structure is linked to the southalpine foothill area by a wide and open syncline, which is affected along its northern flank by a loosely defined minor thrust (Fig. 5).

9. - A possible southernmost backthrust

New field data collected in the Varese area, SW of Castiglione Olona (Fig. 1 and Fig. 6), allow to complete the cross-section of Pieri and Groppi (1981), and to link it with the Varese and Como classical outcrop areas (Fig. 5 and Fig. 6).


AGE
TURBIDITE SYSTEMS
AGE OF UNCONFORMITIES
PROPOSED STRUCTURAL EVOLUTION
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
OLIGO - MIOCENE
CLASTIC WEDGE (OMcw)
UPPER CRETACEOUS
CLASTIC WEDGE (UCw)
Pliocene units
Gurone Sandstone
Lucino Conglomerates
(Burdigalian p.p.)
Como cgl. Val Grande sdt.
(Lower Burdigalian-
uppermost Chattian)
Chiasso Fm. - Villa Olmo cgl.
(Upper Rupelian - Chattian p.p.)
Ternate Fm. (TFm)
(Upper Eocene)
"Scaglia" pelagites
Tabiago Fm.
(Paleocene-Eocene)
"Scaglia" pelagites
Bergamo Flysch
(Campanian)
Sirone cgl.- Sarnico sdt.
(Coniacian - Santonian)
Pontida C. Cedrina Flysch
Peliti Rosse (Mid - Upper Turonian)
Torbiditi Sottili and Banchi Caotici
(Upper Cenomanian)
Sass de la Luna - Bruntino Fms.
(Aptian - Albian)
Lower Cretaceous
pelagic limestones
Langhian
Latest Burdigalian
Burdigalian
Late Chattian
Middle - Late Eocene
Early Paleocene
Early Campanian
Late Santonian
Turonian
Early - Middle
Cenomanian
Early Aptian
Syn- and Post Adamello
Pre-Adamello
N
IL
OT
FF
UCw
OMcw
s.l.
MB
eastern area
N
OMcw
s.l.
western area
N
TFm
s.l.
western area
IL: Insubric Line
OT: Orobic Thrust
FF: Flessura Frontale
MB: Milano Belt
: future location of Insubric Line
N
UCw
s.l.
eastern area

A pelitic succession poorly outcropping between the villages of Caronno and Castronno (Fig. 6) gave age-diagnostic planktonic foraminiferal association, characterized by the following taxa (Fig. 8) : *Catapsidrax dissimilis* (frequent), *C. unicavus*, *Globorotaloides suteri* (frequent), *Globigerina* gr. *praebulloides*, *Globigerinoides primordius*, *G. trilobus* (frequent), *Globorotalia acrostoma*, *G. siakensis*, *G. semivera*, *G. pseudocontinuosa*, *Globoquadrina* cf. gr. *dehiscens*. This association can be referred to a latest Chattian age (upper zone P22 to lowermost zone N4). Therefore this pelite succession must belong to Sequence II, being time-equivalent of the Belforte Mudstone and the lower Prestino Mudstone (Fig. 4). The regional trend of bedding does not permit to directly link the Castronno and the Belforte outcrops; moreover, the gap in outcrops south of Varese exceeds the space necessary to accomodate thickness of Sequence II. The presence of an Upper Oligocene unit near Castronno can be therefore tentatively linked to a tectonic uplift, probably due to a buried thrust. Taking into account the regional bedding, always south-eastwards dipping, the most plausible structure seems a north-vergent thrust. The age of this structure is constrained by Sequence III (Burdigalian to possibly Early Langhian), which is necessarily involved in the deformation. Some sedimentary features of Sequence IV (slides, intra-formational pebbles) document synsedimentary tectonic instability, possibly due to the development of this structure. This interpretation, leading to at least a Middle Miocene age for the inferred backthrust, does not prevent, as an alternative, a possible younger age for inception of thrusting, after a previous synsedimentary upfolding.

10. - Implications for the Late Cretaceous to Miocene evolution of Southern Alps in Lombardy

The present-day structure of Southern Alps is the result of a long and polyphase Alpine history, strongly controlled by the older (Permo-Jurassic) extensional tectonic framework (Gaetani and Jadoul, 1979; Cassinis, 1983; Laubscher, 1985; Gaetani and Jadoul, 1986; Roeder, 1985; 1988; 1990; Castellarin, 1984; Castellarin *et al.*, 1992, among the others).

The pre-Adamello deformation in the Orobic Alps (Brack, 1983) has been considered almost indifferently of Late Cretaceous to Eocene age (Doglioni and Bosellini, 1987; Bernoulli *et al.*, 1990; Forcella and Jadoul, 1990; Schumacher, 1990; Schonborn, 1990; Siletto, 1990; Castellarin *et al.*, 1992). Pre-Adamello structures are known in the present area of the Orobic anticlines, but also southwards, in the central Orobic region, where the Presolana antiformal stack is cut by dike swarms as old as 50 MA (Zanchi *et al.*, 1990).

A possibility to link the pre-Eocene structures with the Late Cretaceous stage is provided by the stratigraphic reconstruction of the Upper Cretaceous clastic wedge (UCw). It has been already suggested on the basis of its stratigraphic features that this wedge could represent the infilling of a flexural basin, developed in front o a Cretaceous "Orobian" fold and thrust belt (Doglioni and Bosellini, 1987; Bersezio and Fornaciari, 1987; 1988). The apparent contradiction between this framework and the evidence of Cretaceous synsedimentary extension in the South-Giudicaric area (Castellarin, 1972; Castellarin *et al.*, 1987), can be resolved taking into account that the Late Cretaceous belt could have developed west and north of this latter area, close to the present North-Giudicarie region (Castellarin *et al.*, 1987; 1992; Laubscher, 1990a).

The stratigraphic reconstruction indicates that a tectonically active margin at the north and east side of the Cretaceous basin began to exist in the Late Cenomanian. Unconformities associated with slump-scouring and emplacement of chaotic bodies (that involved uppermost Albian basinal units identical to the one underlying the Upper Cretaceous turbidite systems), and the cross-cutting relationships between the marginal unconformities point to upfolding of this marginal sector. This can be tentatively attributed to the development of frontal folds at the southern termination of the inferred Upper Cretaceous thrust belt, that propagated from the northern Orobic sector to the more southern decolled Mesozoic units (e.g. Presolana) and further southwards (Fig. 9).

Considering that during this initial stage the basement of the Orobic thrust sheet most probably was still buried, the source area for the Cenomanian-Campanian turbidites could have been partly represented by the exposed Strona-Ceneri type basement (Bernoulli and Winkler, 1990) of some northern tectonic units, that have been subsequently separated from the Orobic thrust sheet after dextral strike-slip along the Insubric Line (Schmid *et al.*, 1987; Laubscher, 1988). Variations in paleocurrent trends and sandstone modes suggest that derivation from this south-Alpine source prevailed during Middle Turonian and Campanian times. The westward progradation of the Upper Cenomanian and Upper Turonian-Coniacian turbidite systems was more probably linked to erosion of the Austroalpine units that were actively deformed in the north and east (Bernoulli and Winkler, 1990).

The deposition of the uppermost Cretaceous-Paleocene deep water formations indicates that the Cretaceous basin was never filled up. Parts of the UCw were uplifted and eroded during a Late Eocene

FIG. 9 - Synthesis of stratigraphic data and tentative structural interpretation of the Late Cretaceous to Late Miocene evolution of the Lombardian Southern Alps.

FIG. 9. *Synthèse des données stratigraphiques et essai d'interprétation de l'évolution tectonique des Alpes Méridionales de Lombardie du Crétacé supérieur jusqu'au Miocène supérieur.*

deformation stage, and clasts were redeposited within the Upper Eocene Ternate basin (Braghieri and Montanari, 1976; Herb, 1976; Bernoulli *et al.*, 1988)(Fig. 9). If the age determinations of the dikes cutting across the thrusts, provided by Zanchi *et al.* (1990) are reliable, the pre-Middle Eocene deformation in the Bergamasc Alps and the thrusting episode witnessed by the Ternate Fm. (Bernoulli *et al.*, 1988, Fig. 1) are separated by the N-S extensional phase during which the dikes were emplaced. This would suggest a separation of the Late Cretaceous (Eoalpine) and Late Eocene (Mesoalpine?) compressional events, which were followed by the later southward propagation of thrusts fronts.

As it has been discussed by Gelati *et al.* (1988; 1991) and Bernoulli *et al.* (1989) the Late Tertiary deformation of the Southern Alps is recorded by the Oligo-Miocene clastic wedge (OMcw) sediments. The regional scenario is that of collision and lithospheric indentation between the European and Adriatic crusts (Bernoulli *et al.*, 1990; Roure *et al.*, 1990; Laubscher, 1990b; Schmid, 1992). Several late Tertiary tectonic events have been proposed in the border region between the Southern and Central Alps : rapid uplift of the Central Alpine sector with respect to the Southern Alps accompanied by synkinematic intrusion of the Bregaglia batolith (Early to Late Oligocene)(Hurford, 1986; Werner, 1987; Giger and Hurford, 1989; Schmid, 1992); Insubric backthrusting and dextral transcurrence (Late Oligocene - Early Miocene) (Heitzmann, 1987; Schmid *et al.*, 1987; Zingg *et al.*, 1990; Schmid, 1992); dextral strike-slip in brittle conditions (Heitzmann, 1987). The crustal indentation between the European and Adriatic blocks has been attributed to a later step (Middle-Late Miocene) connected with southwards thrusting in Southern Alps, by Schmid (1992).

The syntectonic sediments of the OMcw in Lombardy document uplift and erosion of the Central Alpine block, at least starting from the Rupelian (Sequence I) (Fig. 9). The 32-30 MA cooling ages of the tonalite pebbles that have been found in the Villa Olmo and Como conglomerates (Giger and Hurford, 1989; Giger, 1991), compared with the biostratigraphically established age of the host sediments, indicate that a very short time lag existed between uplift, cooling, erosion and redeposition of the pebbles. Whatever their source area (there is not an obvious need for a present-day Bregaglia source of these clasts), they indicate that a highly mobile relief area existed on the southern side of the chain, and long-lived intermediate depositional systems could not develop and survive between the sites of erosion and final deposition. The tectonic activity affected also the marginal slope environment of the Gonfolite *s.s.* basin, as far as cannibalization of clastic materials occurred since the latest Oligocene (Sequence II). Moreover the progressive oversteepening of unconformities and the development of intraformational truncations associated with slumping of unconsolidated sediments, points to deformation of the OMcw during the Burdigalian (sequence boundary II/III, III/IV and the related sequences)(Gelati *et al.*, 1991). On the basis of these data, the initiation of northwards thrusting (Chiasso and Castiglione Olona backthrusts) could be placed in the Early Burdigalian, and could be contemporaneous with a southwards propagation of the same structures. As an alternative, a possible northwards propagation of the two thrusts, related to wedging of the Mesozoic units with the Tertiary sediments, could be considered. In this hypothesis, as far as sequence III and possibly sequence IV are involved in deformation, a plausible Middle - Late Miocene age could be proposed for the initiation of movement along the Castiglione Olona thrust, and an even slightly younger age should be assigned to the Chiasso backthrust (Bernoulli *et al.*, 1989).

The previous discussion gives indirect evidence that Oligo - Miocene tectonics affected not only the thrust belt of the Southern Alps, but also reached the OMcw foredeep to the south. This is in agreement with the proposed late Tertiary tectonic evolution of the Lepontine Alps, the Ivrea zone and the Canavese zone (Werner, 1987; Schmid *et al.*, 1987; Zingg et *al.*, 1990; Roure *et al.*, 1990). Even taking into account the dextral offset along the Insubric Line, evidence for coeval deformation in the areas around the OMcw basin are provided by structural data (e.g. the Proman antiform in the northern Ivrea zone; Schmid, 1967; Schmid *et al.*, 1987; the deformation belts in the south-Alpine area between lakes Maggiore and Como, Schumacher, 1990). Moreover, east of Lake Como, structural evidences of polyphase Alpine folding and thrusting, with post-Adamello events, have been shown in the basement of the Orobic Alps by Brack (1981; 1986), Milano *et al.* (1988), Siletto (1990), Albini *et al.* (1992). In particular in the Orobic Alps near Sondrio (Fig. 1), Milano *et al.* (1988) identified south-vergent thrusting followed by folding with NE-SW striking axes; the latter direction parallels the strike of the en-echelon Orobic anticlines (Fig. 1). Siletto (1990) determined a dextral strike-slip component of movement along the Orobic thrust, which is suggested to be superimposed on a previous thrusting episode.

On the basis of morphological and structural considerations, supported by the findings of several probably neogenic intramontane breccia bodies in the Bergamasc Prealps, Forcella and Jadoul (1990) proposed that late Tertiary tectonics affected the Orobic Alps. Otherwise, in the area east of Lake Como, the sedimentary record of the late Tertiary evolution is scanty in outcrops, being represented by the Langhian (?) M. Orfano Conglomerates, cropping out on the emergent limb of a mostly buried ramp fold (Pieri and Groppi, 1981). The thrusts of the buried Milano Belt (Laubscher, 1988), sealed by uppermost Miocene sediments (Pieri and Groppi, 1981), represent the souhernmost structural front of Southern Alps.

Based on the previous discussion it can be proposed that Oligo-Miocene deformation involved the south-Alpine block, reshaping the previously built structural edifice, starting from the northern Orobic Alps and reaching to the south the Upper Miocene Milano Belt (Laubscher, 1988). In this view, the classical in-sequence propagation of the Upper Cretaceous to Miocene thrust fronts towards the south was not respected. Moreover the late, Miocene, emplacement of a regional thrust responsible for the development of the "Flessura Frontale" and for the allochtony of the UCw remnants (Fig. 1 and Fig. 5), has to be considered (Schonborn, 1991; 1992). The eventual link between this stage of thrusting and the late development of the en-echelon Orobic Anticlines has been suggested by several authors (see discussion in Forcella and Jadoul, 1990). It seems plausible to infer a kinematic link between the structuration of the Orobic Anticlines and the structures related to the "Flessura Frontale", considering their symmetrical en-echelon patterns (Fig. 1). If this inference is correct, the late event during which deep crustal wedging occurred (Schmid, 1992), is expressed in the surface by a dextral transpressive regime.

In the area west of Como the displacement linked with the latest Tertiary event recorded in the Bergamasc Prealps, could have been partly accomodated by the Chiasso and Castiglione Olona backthrust system due to frontal wedging of the Mesozoic units with those of the Cenozoic (Fig. 5).

The proposed interpretations can be tested by comparison with the geometries resulting from the deep seismic image of the Southern Alps provided by the CROP88 experiments (Montrasio *et al.*, 1992), and gives some suggestions for the interpretation of its pellicular part.

11. - Bearing on the interpretation of the CROP88 seismic image

The features of the Southalpine segment of the CROP88 seismic lines, more relevant for this discussion, are here briefly summarized. The data and some alternative interpretations are in press by the CROP88 Working Group led by A. Montrasio (CNR - Milano). The picture of the seismic line can be found in the Final Report of the CNR - CROP88 Working Group (in progress).

- At the Southern Alps/Northern Alps border a north-dipping belt of reflectors represents a steep zone north of the emerging Insubric Line; the latter is transparent on the contrary;

- a complex pattern of north- and south-dipping reflections cutting some almost horizontal or arcuated events, is present in the uppermost few seconds (TWT) of the line;

- a prominent alignement of north-dipping to horizontal reflectors underlies the upper complex zone, from the Insubric region to the Po plain subsurface; there it reaches the sole thrust of the Milano Belt (Pieri and Groppi, 1981; Laubscher, 1988). More steeply inclined and north-dipping reflectors splay upwards from this alignement; one prominent reflector crosses it and reaches the subsurface of the "Flessura Frontale" region, cutting the whole overlying edifice.

The interpretation of some reflectors reaching the neighbourhoods of the topographic surface is suggested by field geology; there south of the Insubric region and within the complex pattern of reflectors of the upper part of the seismic line, shot in the Brembo Valley, the downward prolongations of the Orobic Thrusts and of theValtorta and Antea south-dipping fault zones have been recognized (CROP88 Working Group, in press).

The prominent alignement of events underlying the whole edifice at shallow depth is clearly linked with the Middle-Late Miocene emplacement of the Milano belt. The reflectors (thrusts) splaying from this zone affect the whole investigated area, from the Insubric region to the Po plain subsurface. As a consequence this feature could represent the lower decollement surface of a Miocene deformation system. The upwards propagating thrust, that is responsible for the development of the "Flessura Frontale" and of the southernmost outcropping structures, represents a later step, in keeping with the recent interpretation proposed by Schonborn (1991; 1992). The emplacement of this late thrust sheet, in a dextral transpressive framework, could have been responsible for the en-echelon embrication of the Orobic as well as the southern frontal anticlines, as it has been previously proposed.

Therefore the complicate stack of basement and cover thrust sheets that is portrayed by the seismic experiment (and well known in the field) and that results from the pre- and syn- to post-Adamello events, is presently allochtonous with respect to the lower decollement, representing a Milano Belt-related Miocene event (compare with Laubscher, 1988; 1990; Roeder, 1988; 1990). Within this framework, the presently outcropping remnants of the UCw always remained in a shallow structural position, as it is documented by their very low diagenetic grade; in contrast the more internal Cretaceous units brought into their present position along the "Flessura Frontale" by the latest thrust, show a more pronounced diagenetic overprint due to the previously suffered tectonic load.

12. - Conclusions

The present south-Alpine fold and thrust belt of Lombardy lays above a Miocene decollement, that extends at least from the Insubric area to the frontal Milano Belt (Pieri and Groppi, 1981; Laubscher, 1988), as revealed by the CROP88 seismic image. The previously formed structural edifice is thus allochtonous.

The older structural framework was impressively modified by the late Miocene event, that is proposed to be responsible for the imbrication of the Orobic anticlines, the development of the "Flessura Frontale" and of the southern belt of anticlines.

The previous Tertiary tectonic evolution of both Central and Southern Alps is documented by the development of the Upper Oligocene, Lower Burdigalian and Upper Burdigalian/Langhian unconformities, and by the sedimentary and compositional features of the four sequences building the OMcw. All these data, as well as the structural documentation of polyphase Alpine tectonic in the Orobic basement and cover (e.g., Milano *et al.*, 1988 and various others) point to folding and thrusting, uplift and erosion in the northern part of Southern Alps, as well as to synsedimentary tectonics affecting the foredeep marginal slopes during the Late Oligocene - Middle Miocene.

Late Cretaceous and Early tertiary synsedimentary tectonics, of pre- and syn-Adamello age, are documented by the UCw and by the poorly preserved Upper Eocene turbidite units (Bernoulli *et al.*, 1988). The deformation recorded at the northern and eastern margins of the Cretaceous basin can be attributed to the termination of thrust fronts that propagated southwards from the (presently) northernmost Orobic thrust. Clastic material, eroded from the South Alpine and Austroalpine basement and sediments built the Cenomanian - Campanian clastic units of the Lombardy flexural basin.

Timing of the movement of individual thrust sheets or of the propagation of arcuate thrust belts (Ménard, 1988; Castellarin, 1992 with references) towards the southern foreland area is still uncertain, but important structural reshaping during the late Tertiary can be documented. Out-of-sequence propagation of thrusts, from the Orobian Alps and southwards, is suggested by several lines of evidence, but more structural analysis is necessary in some key areas (e.g. Orobian basement-cover relationships, backthrusts of the Bergamo Prealps, structure of the "Flessura Frontale").

This very complex Alpine evolution leads to sometimes puzzled structural geometries and kinematic solutions, arising problems on the paleogeographic reconstruction and modelling of the pre-Cretaceous south-Alpine rifted margin in Lombardy.

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