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THE FOREDEEPS OF THE NORTHERN ADRIATIC MARGIN: EVIDENCE OF DIACHRONEITY IN DEFORMATION OF THE SOUTHERN ALPS

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Key-words: Neogene, Southern Alps, Foredeep, Diachronous thrusting, Insubric line, Oblique convergence, Anticlockwise shear.

Riassunto. L'evoluzione dei bacini di avampaese del margine Adriatico settentrionale ebbe luogo in un regime di convergenza obliqua. A partire dall'Oligocene superiore, gli effetti di compressione nelle Alpi Meridionali rappresentano prevalentemente la componente compressiva di un regime di transpressione destra lungo la Linea Insubrica, come si può desumere dalla disposizione *en-échelon* dei sovrascorrimenti neogenici rispetto alla Linea Insubrica. Diacronismo della deformazione nel Sudalpino, con accrezione laterale verso est del sistema di sovrascorrimenti, trova una corrispondenza nel diacronismo dei movimenti lungo il Lineamento Insubrico, dove gli effetti di transpressione e transtensione lungo il segmento orientale sembrano più tardivi rispetto ai movimenti lungo il segmento occidentale.

L'età dei movimenti sinistri lungo le Giudicarie è in buon accordo con quella richiesta per il trasferimento della deformazione dal blocco Sud-Alpino occidentale a quello orientale.

La migrazione verso est della deformazione nelle Alpi Meridionali a partire dall'Oligocene superiore trova una corrispondenza nella migrazione verso est: 1) dei depocentri delle avanfosse Sud-Alpine e 2) delle sorgenti principali di apporto clastico ai bacini torbiditici dell'Appennino. Inoltre è contemporanea alla traslazione verso est degli archi Appenninici. Si fa l'ipotesi che la migrazione della deformazione verso ovest nelle Alpi centro-occidentali (Coward & Dietrich, 1989) e verso est nelle Alpi Meridionali possa risultare da convergenza obliqua associata ad una componente di rotazione antioraria attorno ad un polo situato tra le Alpi Centrali e Occidentali, dove il raccorciamento è più elevato.

Abstract. The evolution of the foredeeps which developed on the northern Adriatic foreland took place in a regime of oblique convergence. From the Late Oligocene onwards much compression in the Southern Alps must have been the compressional component of dextral transpression along the Insubric Line, as suggested by the *en-échelon* arrangement of Neogene thrusts relative to the Insubric Line itself. Diachronous deformation within the Southern Alps, with eastward lateral accretion of the thrust belt, matches diachronous movements along the Insubric Line, where transpression and transtension along the eastern segment seem to outlast movements along the western segment.

The age of the Neogene sinistral displacement along the Giudicarie fault system is in good agreement with that required to accomodate continued thrusting in the eastern block after the termination of thrusting in the western block.

The eastward shifting of deformation in the Southern Alps from the Late Oligocene onwards is reflected by the eastward migration of 1) depocentres of the South-Alpine foredeeps and 2) entry-points of Alpine-

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sourced sediment gravity-flows feeding the Apenninic flyschs. In addition, it is coeval with the eastward migration of the Apenninic arcs. The shifting of deformation westwards in the Central-Western Alps (Coward & Dietrich, 1989) and eastwards in the Southern Alps may represent the effect of oblique plate convergence associated with anticlockwise shear around a rotation pole located between the Central and Western Alps, where the indenting Adria plate produced maximum shortening.

Introduction.

The evolution of the Mediterranean ranges, especially in the post-collisional stage, is characterized by a complex history dominated by large-scale horizontal movements of adjacent blocks, lateral tectonic escapes, and post-collisional back-arc extensional spreading; the latter was accomodated by ductile deformation in depth and strike-slip motion along major fault zones which acted as transform boundaries connecting areas of extension with areas of synchronous crustal shortening. Oblique convergence was accompanied by block rotation and changes in the nature of tectonic boundaries and block rheology with time.

This paper attempts a reconstruction of the evolution of the foredeeps which developed on the northern Adriatic foreland, mainly from a stratigraphic approach and an analysis of the age of the denudation products which accumulated in the foreland basins. Emphasis is placed on analysis of movements along the longitudinal and transverse strike-slip fault zones, which are thought to have played a primary role in this evolution.

Geologic setting.

The Southern Alps (Fig. 1) are a polyphase, mostly post-collisional, south-vergent fold-thrust belt. Indeed, after collision, the Alps assumed the bivergent wedge shape of an intracratonic compressional belt, notwithstanding its long prior history of N-vergent subduction and thrust imbrication (Roeder, 1989). Deformation in the South-Alpine domain mainly took place from the Late Oligocene onwards. However, a S-vergent orogen existed in the Late Cretaceous on the southern margin of the Tethys, accompanied by ophiolite obduction onto the Austroalpine margin and early erosion of Austroalpine crust (Laubscher, 1970; Laubscher & Bernoulli, 1982). This is documented by Upper Cretaceous flyschs deposited on the Adriatic margin, which are thought by Laubscher (1970) to have been deposited in the foredeep of the S-vergent Cretaceous orogen. Early compressional structures in the Lombardy area and Upper Cretaceous flysch partly related to an Austroalpine source have been interpreted by Doglioni & Bosellini (1987) as the expression of early foredeep development in the South-Alpine area, in a context of transpressive tectonics.

The relative motion between the European and Adriatic plates was largely right-lateral and directed essentially E-W during the Late Cretaceous (Waibel & Frisch, 1989). Coward & Dietrich (1989) suggest that early ophiolite obduction onto the southern continental margin was followed by a diachronous continent-continent collision which oc-

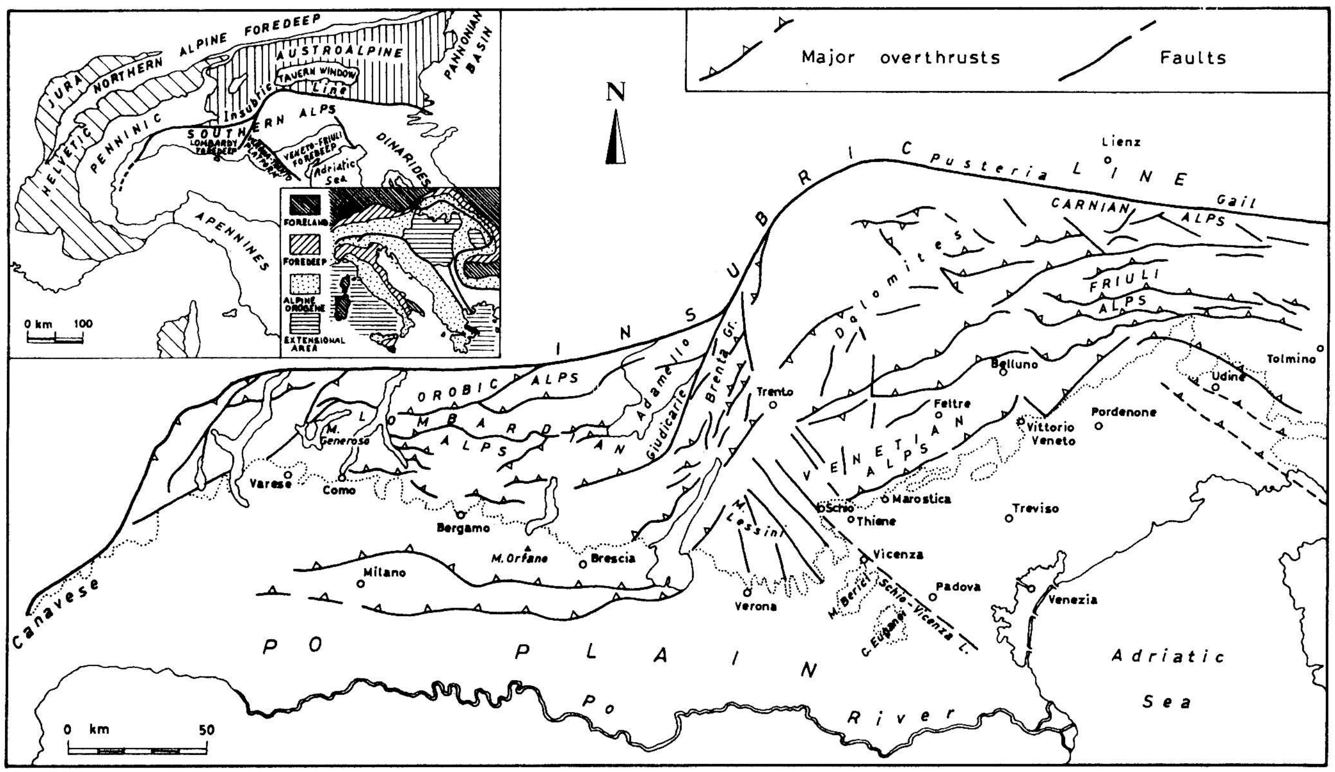

Fig. 1 - Simplified structural map of Southern Alps (Insets: main structural units of Alps and schematic tectonic map of Alpine, Periadriatic and Carpathian ranges). Lombardy and Veneto-Friuli Alps are characterized by tightly imbricate thrust sheets, whereas Trento-Verona platform in between is virtually undeformed and may be regarded as a sort of foreland wedge inserted in Southern Alps.

curred earlier in the Eastern Alps than in the Central and Western Alps. This diachronous deformation took place in a context of dextral transpression between the African Adriatic promontory and the southern margin of the European continent. Dextral transpression also played an important role during the Tertiary continental collision. Trümpy (1980) argued that the final closure of the ocean took place in Latest Eocene to Early Oligocene times. After this "Mesoalpine" phase, resumption of convergence accompanied by right-lateral transpression led to backthrusting of the Alps s.s. on the Southern Alps.

Laubscher & Bernoulli (1982) noted that obliqueness of convergence in the post-collisional stage caused both normal compression and strike-slip; they concluded that the South-Alpine thrusts and Insubric fault zone fit the division of roles often observed along obliquely convergent plate boundaries. In fact, from the Late Oligocene onwards, much compression in the Southern Alps must have been the compressional component of dextral transpression along this Line, which is a generally steep, E-W-trending fault zone with Neogene right-lateral offset, obliquely cutting through the nappe structure of the main part of the Alps (Laubscher, 1985a), the isogrades of the Lepontine metamorphism and the Oligocene plutons (Fig. 2). These relationships are especially clear in the Lombardy area, where a group of basement thrusts are apparently arranged as right-handed, *en-échelon* elements merging into the Insubric Line (Roeder, 1987) (Fig. 1). Peri-collisional shortening of the South-Alpine crust and dextral convergence created the thrust belt, which became the principal source for coeval clastic wedges of the foreland basins such as the Gonfolite Group.

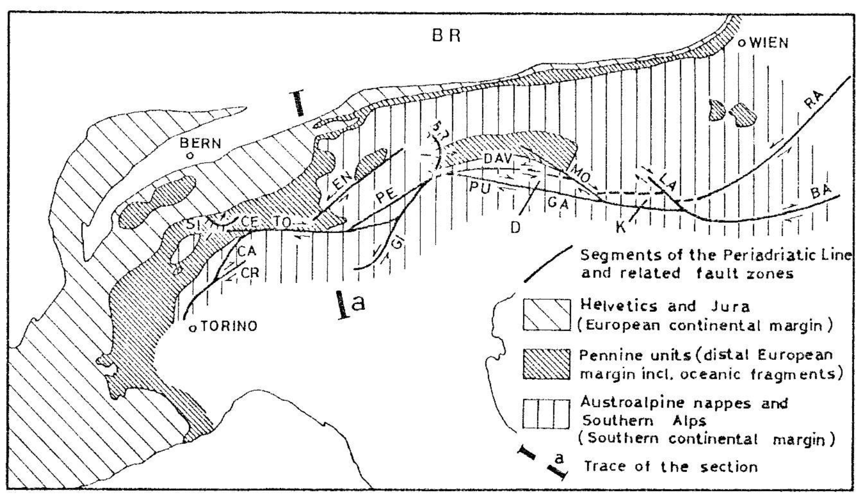

Fig. 2 - Segments of Insubric Line and related Late Alpine faults. From west: CR) Cremosina; CA) Canavese; CE) Centovalli; TO) Tonale; GI) Giudicarie: PU) Pusteria: DAV) Defereggental-Anterselva-Valles; GA) Gail. Related faults are, from W to E: SI) Simplon; EN) Engadine; PE) Pejo; BR) Brenner; MO) Mölltal; LA) Lavanttal; BA) Balaton; RA) Raba; D) Drauzug; K) Karawanken. After Schmid et al. (1989).

Diachroneity in the deformation of the Southern Alps from the Late Oligocene onwards has been documented by Castellarin (1984), Castellarin & Vai (1986), Massari et al. (1986) and Castellarin et al. (1987). Castellarin & Vai (1986) and Castellarin et al. (1987) showed that the time-space structural evolution of the South-Alpine area is characterized by lateral accretion achieved by the addition of younger and younger branches in an ESE (SE) direction (Fig. 3). This diachroneity is reflected by the younging of the foredeep clastic wedges parallel to the chain front.

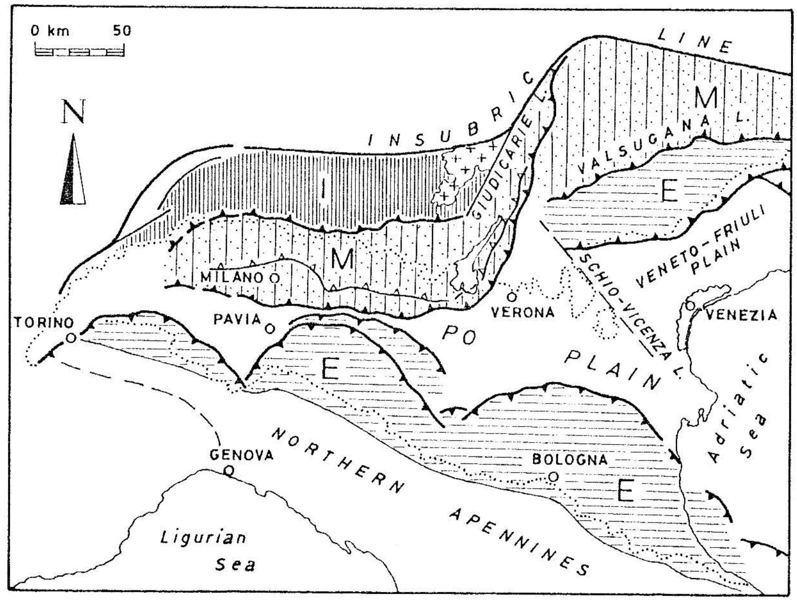

Fig. 3 - Main structural arcuate belts of Southern Alps and North Apenninic front, after Castellarin & Vai (1986), slightly modified. I) Internal (Cretaceous-Palaeogene) arc; M) intermediate (Mid Miocene - Tortonian) arc; E) external (Messinian-Quaternary) arc.

As reported by Castellarin & Vai (1981, 1982), the Southern Alps are not structurally homogeneous, being segmented by major transverse tectonic lines into blocks displaying significantly different and diachronous behaviour during both the Mesozoic rifting stage and the Cenozoic shortening stage. The transverse features, commonly identified as reactivated pre-existing intra-plate discontinuities, such as Mesozoic rifts, profoundly influenced the post-collisional evolution of the Southern Alps, by leading to separate kinematic development in the adjacent segments of the chain. The most important of these is the Giudicarie fault system, which separated segments of the chain with significantly different evolution and which may have played a fundamental role in the eastward shifting of deformation in the Late Miocene. The transverse features commonly functioned as different types of tectonic boundaries at different times. For example, the Giudicarie fault zone probably contains structures related to Jurassic extension, Late Cretaceous (and Eocene?) strike-slip movements, Oligocene extension and Late Miocene transpression.

The major transverse fault systems bound three main blocks with remarkably different characteristics. The western (Lombardy) and eastern (Veneto-Friuli) blocks were subjected to significant subsidence during Jurassic-Early Cretaceous times. They were subsequently the site of foredeep basins and were subjected to major crustal deformation during the Tertiary, with comparatively high shortening. The central element (Trento-Verona block), bounded by the Giudicarie fault system to the W and the Schio-Vicenza Line to the E, was characterized by relatively stable and rigid behaviour; indeed, it does not show any evidence of important thrusting on the surface (Fig. 1). Consequently, the South-Alpine thrust belt consists of two smaller arcs which developed in the Lombardy and Veneto-Friuli areas, whereas the Trento-Verona block is not thought to have been significantly incorporated into the South-Alpine chain, but represents a sort of foreland wedge inserted in the Southern Alps. This block behaved as a structural high during most of the Mesozoic, and was the site of volcanic activity (Lessini-Euganei area) during Eo-Oligocene times; this crustal element was also stable during the Miocene, unlike the adjacent basins which were subject to significant subsidence.

The Lombardy block displays two foredeeps of opposite polarity, overlapping in space and partly also in time (Pieri & Groppi, 1981; Roeder, 1985; Rossi & Rogledi, 1988), reflecting the fact that the S-vergent thrust belt of the Southern Alps and the N-vergent thrust belt of the Apennines accreted onto the same foreland (Pieri & Groppi, 1981). The older (South-Alpine) foredeep was not active in post-Tortonian times, as indicated by a widespread Messinian unconformity and the southward tilting of its clastic infill due to the tectonic loading of the later-emplaced Apenninic thrust sheets and foredeep sediments.

The Veneto-Friuli block displays two foreland basins of different ages and polarities but partly overlapping in space, i.e. a Dinaric Palaeogene to Middle Miocene foredeep with a NW-trending subsidence axis and a South-Alpine Middle Miocene to Quaternary foredeep with an ENE-trending subsidence axis.

The flysch stage.

A still unsolved problem concerns the age and structural context of the compressional tectonics which affected the Orobic area before the Adamello intrusion, producing ENE - to E-W-trending structures (De Sitter & De Sitter Koomans, 1949; Brack, 1981, 1985). According to Brack (1985), this tectonics produced a shortening of about 15 km and was fixed by the Adamello intrusion, which was emplaced with northward progression from 42 to 29 Ma (Del Moro et al., 1985).

S-vergent thrusts affecting the southern plate margin during the Late Cretaceous are generally admitted (Trümpy, 1980; Janoschek & Matura, 1980; Winkler, 1988; Polino et al., in press). Winkler (1988) argued that continued compression and subduction during the Late Cretaceous resulted in the formation of a S-vergent fold-thrust belt in the Austroalpine continental margin, supplying coarse-grained detritus to oceanic basins to the north and continental foreland basins to the south. Several points of evidence indicate that the deformation affected also the South-Alpine domain. The basement of the Orobic Alps displays an overlapping low-grade metamorphism for which mixed ages ranging between 134 and 43 Ma have been determined by Mottana et al. (1985). The Cenomanian to Campanian flysch deposits of the Lombardian area document Late Cretaceous deformation in the South- and Austroalpine realms (Bernoulli et al., 1989). In the Lombardian flysch Bersezio & Fornaciari (1989) have described a Cenomanian sequence which apparently filled an E-W-trending depression with a steeper northern flank, suggesting incipient folding of the Orobic substrate during the early Late Cretaceous. A Late Cretaceous age of the pre-Adamello compressional tectonics was assumed by De Sitter & De Sitter Koomans (1949), Doglioni & Bosellini (1987), Schmid et al. (1989) and Laubscher (1985b). Doglioni & Bosellini (1987) assumed that this tectonics must have been transformed into sinistral transpression along a proto-Giudicarie Line. This interpretation seems to be indirectly confirmed by palaeomagnetic directions determined in Permo-Triassic beds metamorphosed in the contact aureole of the Adamello intrusions, which indicate that this area underwent anticlockwise rotation before the emplacement of the Adamello intrusions (Heller et al., 1989). Evidence of synsedimentary faulting in the Giudicarie belt during the Late Cretaceous is undeniable (Castellarin, 1972; Bosellini et al., 1978; Bernoulli et al., 1981; Castellarin et al., 1987), as indicated by megabreccia bodies, large sedimentary dykes and widespread unconformities. However, the assumption of transpressive tectonics is opposed by Castellarin (1972) and Castellarin et al. (1987), who documented the presence of extensional features in this belt, such as widespread clastic dykes and a half-graben (E of the Brenta Group) bounded by a normal listric fault, both infilled with Scaglia Rossa pelagites. This evidence may be interpreted as the expression of at least locally developed transtensional regimes. Schmid et al. (1989) regarded the rise of the Cretaceous Oetztal thermal dome and eastward thrusting of the Oetztal nappe during the Late Cretaceous as elements suggesting strike-slip movements along forerunners of the Insubric or nearby lines, such as the northern Giudicarie Line. Several points of evidence suggest that the relative motion between Adria and Europe was mostly lateral and directed essentially E-W during the Cretaceous (Waibel & Frisch, 1989). According to Coward & Dietrich (1989), a generalized strike-slip setting for the Cretaceous flysch sedimentation may be regarded as the result of SE motion of the southern part of the European plate, induced by the opening of the North Atlantic. After the S-vergent thrusting of ophiolite nappes in the Eastern Alps, the Middle Cretaceous continental collision produced NW-directed overthrusts of the Austroalpine units, suggesting dextral transpressive deformation between the colliding margins (Coward & Dietrich, 1989; Ratschbacher & Neubauer, 1989). As a result of this geologic setting, both internal and external Cretaceous flysch belts were probably bounded by zones of lateral motion.

The Upper Cretaceous Lombardy ("Insubric") flysch may have been connected with the Dinaric flysch through the Austroalpine domain, where the Albian flysch of

Lienz may represent a remnant of an originally continuous belt (Aubouin et al., 1970) primarily fed by Austroalpine units which had just been emplaced. Shortening was probably transferred from the eastern part of the Eastern Alps to the northern part of the Dinarids, partly by a broad system of dextral strike-slip faults (Royden & Baldi, 1988).

The Giudicarie zone therefore seems to represent only a segment of an extensive strike-slip fault belt bounding the Insubric and Dinaric flyschs towards the Adriatic foreland. Repeated tectonic activity along this belt is documented by widespread unconformities, large-volume gravity-flow deposits (megabreccias, megabeds and submarine slides) originating from the unstable margin and emplaced into the adjacent basins; it was particularly intense during the Turonian and Coniacian-Campanian in the Giudicarie belt (Castellarin, 1972) and from Late Campanian to Middle Cuisian in the Tolmino trough, which is bounded by the NW-trending eastern border of the Friuli Ridge (Tunis & Venturini, 1987). In the Tolmino trough several distinctive breccia horizons have been recognized by Cousin (1981) also in the Upper Aptian-Albian, Vraconian-Lower Cenomanian, and Upper Coniacian-Santonian. The repeated large-volume gravity displacements seem to be consistent with the assumption of high-frequency fault reactivations in a strike-slip regime. In addition, Upper Cretaceous and Lower Eocene basins in the Giudicarie zone are elongated with a clearly Giudicarian trend and may well represent strike-slip basins (Bosellini & Luciani, 1985; Luciani, 1988).

The south-westward migration of flysch basins in the Dinaric domain from the Slovenian (Maastrichtian) to Dalmatian zone (Lutetian) is proof of a definite polarity linked with the Dinaric orogeny (Cousin, 1981). The easternmost branch of the Dinaric flysch belt was the Belluno basin, infilled with Lower to Middle Eocene turbidites (Grandesso, 1976). In the Feltre area the flysch deposits onlap on the eastern flank of the Trento-Verona platform, which survived as a relative high from the Mesozoic through the Tertiary.

The Friuli, Carnian and Dolomitic areas were strongly involved in the Dinaric orogeny during the Late Eocene (Doglioni, 1987). The Dinaric front is thought to have extended into the Dolomites, where the age of deformation is constrained by the Upper Oligocene-Lower Miocene Parei Conglomerate which overlies strongly deformed Liassic limestones displaying Dinaric-trending folds (Cros, 1978; Doglioni, 1985; Doglioni & Bosellini, 1987).

Flysch sedimentation in the Lombardian area was interrupted by a pelagic interval during the Late Campanian to Early Palaeocene, but was resumed in the Eocene. According to Bernoulli (1988), a scenario of S-vergent thrusts and imbricate slices affecting the South-Alpine sedimentary cover at the inner margin of the Lombardy flysch basin during the Late Eocene is suggested by the occurrence of pebbles of Liassic to Cretaceous South-Alpine formations in the gravity-flow deposits of the Ternate Formation, an Upper Eocene prograding submarine fan. The abundance of coeval bioclastic debris suggests that the basin was rimmed by an active carbonate platform.

The Oligocene extensional phase.

The continental collision ended at about 30-40 Ma (Latest Eocene to Early Oligocene) (Trümpy, 1980) and led to the development of Alpine nappes within the Austroalpine and Pennine regions, displaying essentially N, NW or W vergence (Mesoalpine collisional event). The continuity of convergence in the Alpine belt was interrupted by an Oligocene extensional phase, which separates two distinct groups of events respectively of Cretaceous to Early Tertiary and Late Oligocene to Miocene age. A similar time separation of convergent trends can be recognized in the Apenninic and Carpathian belts (Royden & Burchfiel, 1989).

As suggested in 1976 by Dal Piaz and outlined by Laubscher (1985a), the Oligocene extensional regime which followed the overthrusting of the Austroalpine and Penninic nappes onto the North-European craton affected not only the perialpine area and the European craton, but also the Alpine collisional chain itself. The system of grabens of the European foreland probably developed in the early phases of large-scale reorganization of plate boundary configurations. This generalized extensional regime may actually have resulted from changes in sea-floor spreading rates in the different segments of the North Atlantic-Iceland Sea, and reorganization of sea-floor spreading axes (Ziegler, 1987). In western Europe the extension was maximum in the South, where the Balearic rift came into existence between Spain and the Corso-Sardinian block, and progressively decreased northwards along the Rhône, Bresse and Rhine grabens. According to Tapponnier (1977), the graben system was certainly bounded at its southern end by an important sinistral strike-slip fault system. The Insubric fault zone may have acted as a transtensional branch of this system, which would imply inversion of the previous dextral motion. That the periadriatic plutons are intruded into sinistral extensional gashes as a response to an inversion of the shear direction along the Insubric Lineament is regarded as possible by Laubscher (1988). Sinistral strike-slip in a context of high thermal gradients associated with crustal stretching is suggested by the fact that some intrusions (e.g. Bergell pluton) are located on NE-striking branches of the Insubric system (Laubscher, 1988); furthermore, according to Gatto et al. (1976), Oligocene dykes crossing the Austroalpine nappes between the Giudicarie Line and Engadine Window commonly show a NE-striking orientation and are thought by Beccaluva et al. (1985) to be related to a transtensional regime along the Insubric zone.

According to Del Moro et al. (1985) the northward shift in time of the Adamello intrusions from 42 to 29 Ma may reflect the northward migration of the fracture zones through which the magma ascended. This migration of extensional effects through time may again be regarded as a consequence of a transtensional regime. Widening of the opening, along with concurrent infilling by magma, may have developed synchronously with an approximately E-W-trending large sinistral shear zone. The crustal opening may simply have acted as a collecting structure for an underlying "layer" of magma from under-crustal sources thermally active since the Eocene (or earlier) (Dal Piaz & Venturelli, 1985; Dal Piaz et al., 1988; see also Guineberteau et al., 1987).

The Oligocene extension on the southern side of the Alps promoted both the opening of intramontane basins in episutural position, such as the Piedmont Tertiary basin, and the onset of basaltic effusive activity in foreland areas, e.g. the Thiene-Marostica region near Vicenza. The Lower Oligocene sediments in most of the Padan areas are represented by deep-water marls and mudstones, probably related to the Rupelian major sea-level highstand, but partly also reflecting this extensional phase.

The presence of minerals of presumably ophiolitic provenance in the molasse deposits since the Chattian (glaucophane in the Venetian molasse and barroisitic hornblende in the Austrian North-Alpine molasse; Massari et al., 1986; Füchtbauer, 1967) attests to the early unroofing and erosion of the Tauern Window. These findings are consistent with the conclusions of Selverstone & Hodges (1987), according to whom low-angle normal faulting under ductile conditions led to W-directed removal of the Austroalpine nappe pile and unroofing of the western Tauern Window, soon after the cessation of "Mesoalpine" deformation and prior to the thermal metamorphic peak (i.e. by about 30-40 Ma). Total displacement may have been of the order of several to tens of kilometres, leading to removal of at least 10 vertical kilometres of section (Selverstone, 1988). These statements are consistent with Genser & Neubauer's (1989) conclusions concerning the uplift of the metamorphic dome of the Penninic core nappes in the Tauern Window, which is probably linked to orogen-parallel sinistral wrenching and related low-angle normal faults leading to tectonic unroofing.

The Insubric phase (Late Oligocene-Early Miocene).

The Insubric phase was responsible for the westward translation of the Insubric indenter, shortening in the Western Alps, and backthrusting of the Central Alps toward the Southern Alps (Laubscher, 1988). The wedging of the Ivrea body into the Western Alps is thought by Laubscher (1988) to have occurred during this phase, whereas Schmid et al. (1989) argue that it started earlier, as suggested by the arcuate shape of the westernmost segment of the Insubric Line which may have been predetermined by the already emplaced body acting as a rigid buttress during the Insubric phase.

The westward motion of the Insubric indenter requires that Adria has been moving independently of both Africa and Europe. Independent kinematics is inferred by Platt et al. (1989) to have been active at least since the end of the Eocene, and is implied by palaeomagnetic data which suggest the counterclockwise rotation of Adria by about 15 degrees with respect to Africa during the Tertiary (Lowrie, 1986).

Schmid et al. (1989) observed that the present-day topography of the Moho is closely related to and caused by post-collisional shortening during the Insubric phase. They also stressed that the Moho trough no longer follows the direction of the Insubric Line east of the Tonale Line, and its topography seems to be unrelated to and unaffected by the Giudicarie, Pusteria and Gailtal Lines. According to the above Authors, this would indicate that segments of the Insubric Line accomodated different displacements at different times.

Resumption of convergence and dextral transpression after the Oligocene extensional phase was very rapid (Laubscher, 1988). In the Early Miocene the Central Alps were uplifted more than 9 km by southward thrusting along the Insubric Line (Hurford et al., 1989). Southward thrusting also strongly affected the basement and sedimentary cover of the western Southern Alps (Heitzmann, 1987). Rapid cooling identified in the Lepontine area and Bergell granite (Wagner et al., 1977; Hurford, 1986; Hunziker & Martinotti, 1987; Hurford et al., 1989) may reflect rapid uplift and formation of structural domes due to backthrusting and dextral transpression, but may also result from thermal uplift combined with tectonic unroofing (Laubscher, 1988; Selverstone, 1988). Backthrusting and dextral strike-slip faulting under ductile conditions lasted from 25 to 20 Ma and produced a horizontal offset along the Insubric Line of about 60 km, as indicated by the distance of the Bergell intrusion in relation to the Gonfolite Group containing Bergell boulders (Fumasoli, 1974; Heitzmann, 1987). According to Schmid et al. (1989) it is possible that the mylonite belt, which takes up most of the 60 km dextral shear, continues along the Pejo Line; in this case the latter would have been involved in the transfer of the dextral motion from the western to the eastern segments of the Insubric Line.

The synchroneity of backfolding and backthrusting with major components of folding and/or thrusting of the Helvetic units to the north is taken by Schmid et al.

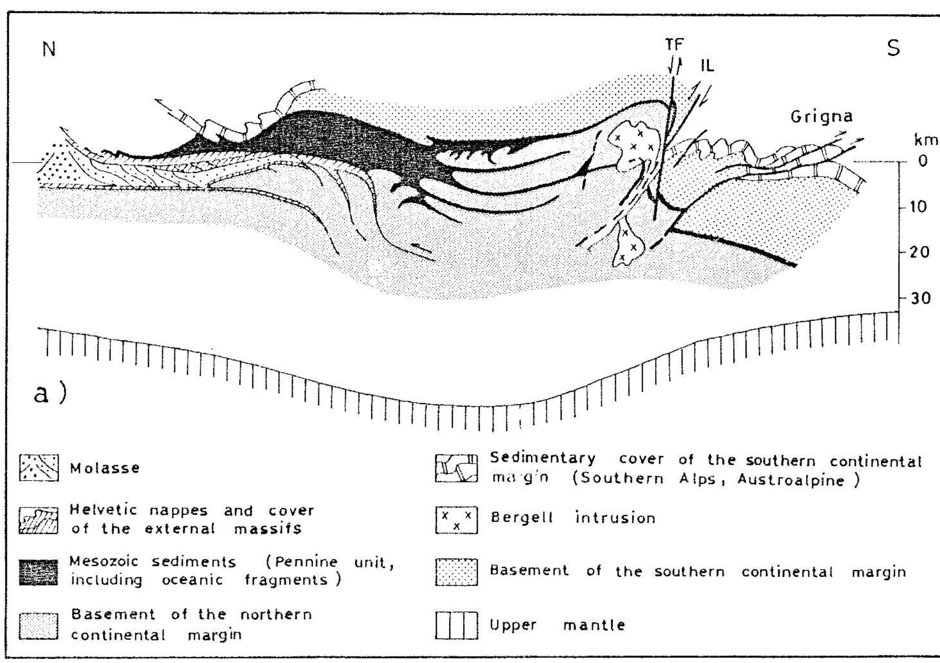

Fig. 4 - Simplified geological profile through Alps, from eastern Switzerland to Lombardy (trace a in Fig. 2). IL) Insubric Line; TF) Tonale fault. After Schmid et al. (1989).

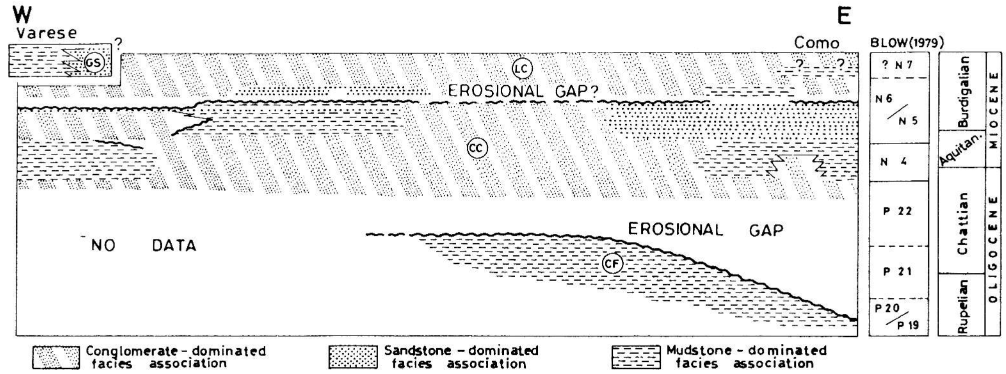

Fig. 5 - Bio- and chronostratigraphic framework of Gonfolite Group in area between Varese and Como. CF) Chiasso Formation; CC) Como Conglomerate; LC) Lucino Conglomerate; GS) Gurone Sandstone. Simplified after fig. 15 of Gelati et al. (1988).

(1987) to indicate that the mobile crust of the Central Alps seeks to escape upwards and laterally onto the foreland, thereby inducing N-directed thrusting within the Helvetic nappes and S-vergent transport within large portions of the Central and Southern Alps (Fig. 4). The component of backthrusting and transpression along the Insubric Line rapidly decreased eastwards in favour of simple dextral strike-slip. Vertical displacements and uplift were consequently much more pronounced along the western segment of the lineament, associated with northward thrusting (Helvetic nappes) and southward backthrusting. This would probably result in decreasing eastward elevation of the Alps, as suggested by the eastward axial dispersion of clastic sediments in the North-Alpine molasse basin during this time (Füchtbauer, 1967; Lemcke, 1984).

The above scenario of backthrusting in the Southern Alps related to transpressive movements along the Insubric Line is consistent with the stratigraphy of the western South-Alpine foredeep (Fig. 5). A widespread unconformity of regional importance marks the base of the Gonfolite clastic wedge in the Lombardy foredeep. The contact between the Rupelian to Chattian Chiasso Formation, mainly consisting of slope mudstones with thin-bedded turbidites, and the lowermost Upper Chattian portion of the

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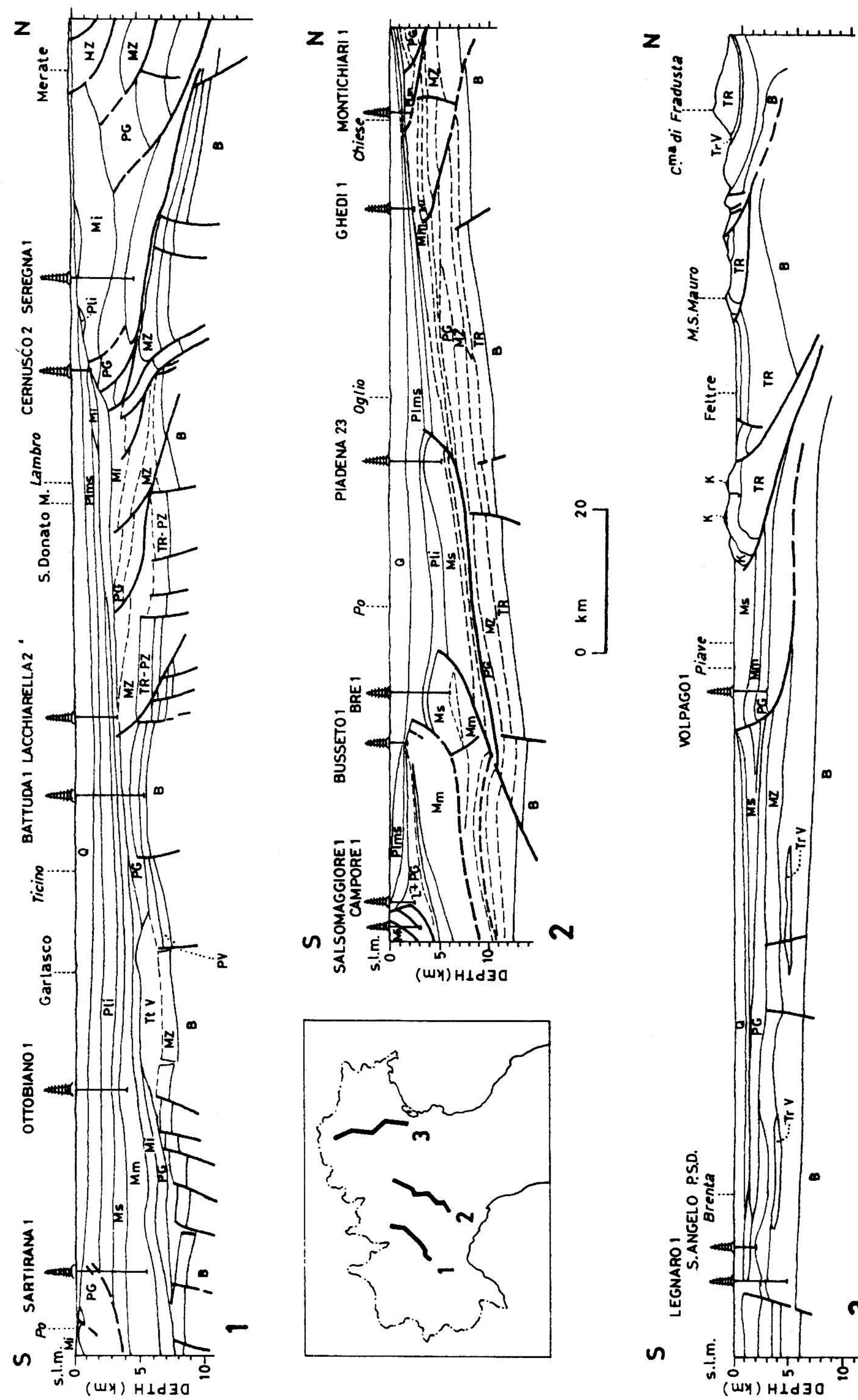
Fig. 6 - Geological sections through frontal South-Alpine and Apenninic thrust-belts and related foredeeps (traces in inset). Migration of foredeep depocentres can be recognized by eastward progressive younging of clastic wedges. Sections 1 and 2 show two foredeeps of opposite polarity, overlapping in space and partly also in time. Inactivation of western South-Alpine foredeep in post-Tortonian times is indicated by widespread Messinian unconformity and southward tilting of clastic infill due to tectonic loading of later emplaced Apenninic thrust-belts and foredeep sediments. Q) Quaternary; Pli) Pliocene; Plms) Middle/Upper Pliocene; Ms) Upper Miocene; Mm) Middle Miocene; Mi) Lower Miocene; PG) Palaeogene; MZ) Mesozoic; K) Cretaceous; J) Jurassic; TR) Triassic; PZ) Palaeozoic; TtV) Tertiary volcanite; TrV) Triassic volcanite; PV) Permian volcanite; L) Liguride Complex; B) Magnetic basement. After Cassano et al. (1986), slightly modified.


S
N
SARTIRANA 1
OTTOBIANO 1
Garlasco
Ticino
BATTUDA 1
LACCHIARELLA 2
S. Donato M.
Lambro
CERNUSCO 2
SEREGNA 1
Merate
SALSOMAGGIORE 1
CAMPORE 1
BUSSETO 1
BRE 1
Po
PIADENA 23
Oglio
GHEDI 1
Chiese
MONTICHIARI 1
LEGNARO 1
S. ANGELO P.S.D.
Brenta
VOLPAGO 1
Piave
Feltre
M. S. Mauro
DEPTH (km)
s.l.m.
0 km 20
1
2
3

overlying Gonfolite Group, mostly made up of deep-sea fan conglomerates, is marked by a hiatus ranging from 2-3 to 8 Ma and represents an erosional discontinuity of regional importance, locally accompanied by a slight angular discordance (Gelati et al., 1988).

The Gonfolite Group may be regarded as a clastic wedge infilling a deep foreland basin flanking a S-vergent thrust-belt evidently growing during sedimentation (Fig. 6). The sudden onset and high rate of subsidence strongly suggest a flexural origin for the basin (Gelati et al., 1988; Roure et al., 1989). According to the latter authors, the Ecors-Crop seismic profile clearly illustrates S-verging Oligocene-Aquitanian thrusts involving the Adriatic basement beneath the Po plain. Furthermore, this profile outlines a major Burdigalian unconformity, which postdates the main Alpine deformation. Bernoulli et al. (1989) describe a regional N-vergent thrust separating Chiasso Formation and Gonfolite Group from the underlying Mesozoic and Lower Tertiary sequence. This northward thrusting in an overall S-vergent thrust belt resembles the "triangle zones" which have been recognized in external parts of orogenic belts, and could be either Burdigalian (as the youngest formation involved in the thrust is of Aquitanian to Lower Burdigalian age) or Late Miocene in age. The Gonfolite Group includes clasts of Austroalpine, Penninic and South-Alpine provenance and consists of a number of deep-sea fan systems which in their proximal area infilled deeply incised canyons. The Gonfolite Group has been subdivided by Gelati et al. (1988) into three depositional sequences, which probably correspond to distinct clastic wedges: 1) Upper-Chattian-Lower Burdigalian Como Conglomerate (with some heteropic formations), 800-1500 m thick, containing Bergell boulders from the lowermost horizons, 2) Burdigalian Lucino Conglomerate (including some heteropic formations), 800-1000 m thick, and separated by an erosional truncation

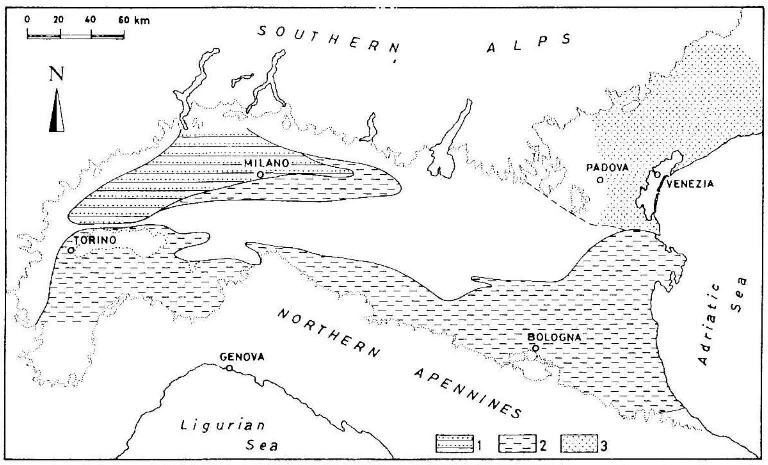


Fig. 7 - Facies distribution in subsurface of Po plain and Veneto-Friuli plain during Aquitanian (22.5-18 Ma). 1) Deep-sea fan deposits; 2) slope mudstones; 3) platform sandstones. Simplified after Dondi & D'Andrea (1987).

from Como Conglomerate, and 3) Gurone Sandstone, a poorly outcropping turbidite unit, 120 m thick, of pre-Tortonian age. According to Rögl et al. (1975), the youngest exposed strata belong to the Langhian. The outcropping Gonfolite Group may be correlated to the Upper Oligocene to Langhian turbiditic succession existing in the subsurface of the Po plain west of Lake Garda (Dondi & D'Andrea, 1987), so that on the whole the deposits of the Gonfolite Group appear to extend over a distance of about 40 km in a N-S direction and at least 200 km parallel to the South-Alpine front (Fig. 7).

In addition to the S-vergent thrusts, the westward motion of the Insubric indenter probably also produced (or accentuated) some W-vergent thrusts in the Lombardian Alps by inversion of Jurassic listric faults (e.g. Generoso thrust) (Schmid et al., 1989).

Due to the transpressive character of the Insubric movements, the strike-slip fault motions created mainly sedimentary source areas rather than subsiding basins and, if any sediments accumulated along the strike-slip faults, they were probably eroded soon after their deposition due to the uplift of thickened crust. As a result, most of the detritus which was eroded from the convergent oblique fault zones ended up in the pericollisional foreland basins.

It should also be noted that the Insubric movements correspond in age to rifting in the Balearic basin, leading to the counterclockwise rotation of the Corso-Sardinian block, and cover a time-span from the beginning of the Apennine orogeny to the collision of the Corso-Sardinian block with the Adria plate at about 18 Ma (Dewey et al., 1989).

The Pannonian sideways escape.

According to Sengör et al. (1985), the strike-slip basins forming along the boundaries of laterally escaping fragments as a result of complex strains connected to sideways expulsion of lithosphere wedges from zones of convergence are perhaps the most important escape-related structures because they commonly preserve the only stratigraphic record of events associated with escape. As the Pannonian "fragment" began its easterly movement, it also started to be disrupted internally (Royden et al., 1982), with normal faults bounding graben complexes. Between the compressional and extensional areas, a series of disconnected basins of similar age are lined up, marking the course of strike-slip faults (Sengör et al., 1985). This kind of role may have been played by the Klagenfurt, Lavanttal, Noric and Vienna basins (Fuchs, 1980), which have been interpreted as pull-apart basins linked to dextral transtensional stresses occurring along the eastern segment of the Insubric Line and its Riedel shears (Steininger et al., 1987).

The above-outlined stress field seems to predominate from Latest Burdigalian or base of Langhian to Early Serravallian, and corresponds to the opening, maximum subsidence and infilling of the above-mentioned intra-alpine and intra-carpathian basins. Extension was accomodated by strike-slip motion along the major fault zones. The involved strike-slip fault systems may be defined as transform boundaries connecting a zone of extension with one of synchronous compression, as the opening and extension of the Insubric and intra-carpathian basins seem to be closely related to shortening and thrusting within the Eastern Carpathians (Royden et al., 1983).

The relief of the Alpine chain was considerable, as indicated by the thick, extensive conglomeratic fans of the Upper Freshwater molasse in the North-Alpine foredeep and by persisting conglomeratic sedimentation in the Gonfolite basin (Dondi & D'Andrea, 1987; Rossi & Rogledi, 1988). The continuing growth of compressional structures at the periphery of the chain indicates that extension or transtension in the core of the chain are synchronous with persisting compression in the pericollisional basins.

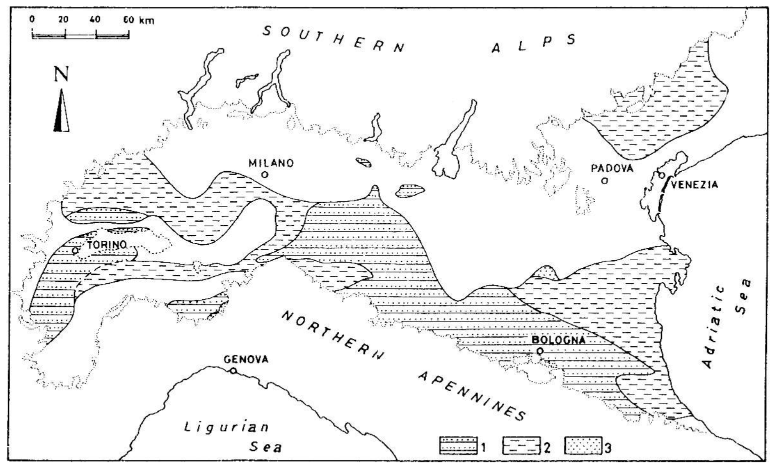


Fig. 8 - Facies distribution in subsurface of Po plain and Veneto-Friuli plain during Serravallian (14.7-12 Ma). 1) Deep-sea fan deposits; 2) slope mudstones; 3) platform sandstones. Simplified after Dondi & D'Andrea (1987).

In the Lombardy area the depocentre of synorogenic sedimentation seems to have shifted eastwards with respect to the Gonfolite depocentre (Fig. 8). The M. Orfano Conglomerate, outcropping in the Prealpine area between Brescia and the Oglio river is a deltaic formation up to 800 m thick, locally unconformably resting on Mesozoic limestones and consisting of pebbles of South-Alpine Mesozoic formations. It contains terrestrial gastropods, vegetal remains and scarce microfauna of littoral foraminifera which allowed its attribution to the Early-Middle Miocene (Cita, 1954; Vecchia, 1954).

The Late Miocene Giudicarie phase.

From about 14 to 8 Ma the effects of N-S convergence are widespread throughout the Alps (Laubscher, 1985a). A rapid change from transtensional to again transpressive conditions took place along the Insubric belt. Miocene basins associated with the eastern segment of the Insubric Line and its Riedel shears were everted as a result of strong transpression (Laubscher, 1985a). Along the eastern segment of the Insubric Line the infill of the Klagenfurt basin was deformed by transpressive movements which gave rise to the Karawanken flower structure (Laubscher, 1985a). North-South convergence activated (or reactivated) a system of conjugate strike-slip faults, commonly with transpressive effects, including the sinistral NE-trending Engadine and Giudicarie Lines and dextral NW-trending Mölltal and Lavanttal faults (Riedel shears of the Insubric Line). The Serravallian-Tortonian Giudicarie phase is regarded as the expression of the northward motion of the eastern South-Alpine indenter, bounded at the western side by the sinistral Giudicarie fault and at the northern and eastern sides by the dextral Pusteria-Gail-Vardar fault system (Ogniben, 1986). Laubscher (1988) argued that the offset along the Giudicarie fault system was probably accomodated by strong shortening, partly in the area of the Tauern Window, partly in the northern part of the Veneto-Friuli block, and partly in the Milan belt, where the structures are mostly hidden under the Po plain. Shortening in the Tauern Window area is indirectly confirmed by white mica and biotite cooling ages and apatite fission track ages, which suggest that the western portion of the Tauern Window underwent acceleration of uplift from 10 Ma onwards (Grundmann & Morteani, 1985).

The left slip along the Giudicarie fault zone may have involved shifting of thrusting from the western South-Alpine block to the eastern one. The age of the displacement along this fault system is in good agreement with that required to accomodate continued thrusting in the eastern block after the termination of thrusting in the western one. A similar role was played by the sinistral NE-SW fault system bounding the Vienna Basin (Royden, 1985) accomodating part of the displacement between the active and inactive parts of the thrust belt in the western Carpathians.

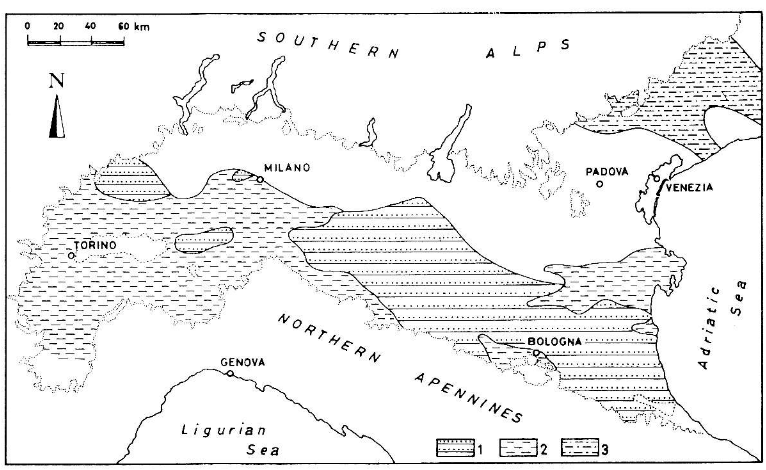


Fig. 9 - Facies distribution in subsurface of Po plain and Veneto-Friuli plain during Tortonian (12-6.4 Ma). 1) Deep-sea fan deposits; 2) slope mudstones; 3) prodelta mudstones. Simplified after Dondi & D'Andrea (1987).

Some evidence of eastward displacement of deformation and uplift is also apparent in the North-Alpine molasse basin, where the inversion of axial drainage in the Serravallian (Füchtbauer, 1967; Lemcke, 1984) may reflect accelerated uplift in the Eastern Alps.

AGIP subsurface data (Rizzini & Dondi, 1978; Pieri & Groppi, 1981; Cassano et al., 1986; Dondi & D'Andrea, 1987) indicate the presence of a clastic wedge along the southern margin of the Bergamasc Alps, i.e., in the eastern portion of the Lombardian foredeep, during the Serravallian and Tortonian. This clastic wedge is in close connection with the Marnoso-arenacea basin (Dondi & D'Andrea, 1987) (Fig. 9) and this relationship suggests that the Giudicarie zone represented a preferential transport path of the Marnoso-arenacea feeding system. An eastward time-shift of entry points may be documented, with terrigenous influx coming from NW in the Serravallian and from NNW or N in the Tortonian (Ricci Lucchi, 1975).

The development of the Veneto-Friuli thrust belt.

During post-Tortonian times the Lombardian area was no longer affected by major thrusting. Its folded and eroded clastic successions of Late Oligocene to Middle Miocene age are unconformably overlain by virtually undisturbed Messinian and younger sediments. Only weak compression is recorded in the central area of the Po plain, where the southernmost arc collided with Apenninic N-vergent thrusts (Pieri & Groppi, 1981).

Within the Southern Alps major thrusting in post-Tortonian times seems to be virtually confined to the eastern block. The Friuli area shows the most severe shortening, with very tightly imbricate thrust sheets superimposed on the older Dinaric structures and an estimated reduction to one third of the pre-Cretaceous depositional N-S extent (Castellarin & Vai, 1986). The amount of shortening within the eastern South-Alpine block gradually decreases westwards toward the central Dolomites and Venetian Alps, where most shortening (about 20%) is apparently related to the important Val Sugana basement thrust (Castellarin & Vai, 1986; Bosellini & Doglioni, 1986). More to the west the Verona-Trento high, including the M. Lessini and the Berici-Euganei hills, behaved as a comparatively more rigid unit and shows geophysical features typical of a foreland crust (high magnetic anomalies coupled with a gravimetric high) (Cassano et al., 1986). The NW-trending Schio-Vicenza Line (Fig. 1), which bounds this block to the east, has been regarded by some authors as an important transcurrent fault, but actually horizontal movements seem to be of limited importance and the field and geophysical evidence are primarily those of a dip-slip fault displaying a basement offset which is maximum in the Schio area, lateral to the front of the eastern South-Alpine thrust belt (coinciding with maximum subsidence in the Veneto foredeep), and significantly decreases from this area both NW-wards and SE-wards.

As a result of continuing convergence during post-Tortonian times, the deformation apparently propagated towards the interior of the eastern South-Alpine block from its boundaries, *i.e.*, eastwards from the Giudicarie fault system (where ESE-vergent thrusting probably continued into the Messinian, according to Castellarin et al., 1987, and possibly also the Pliocene and (?) Pleistocene, according to Ogniben, 1986), southwards from the Insubric Line and westwards from the old Dinaric thrust belt, reactivated in dextral transpression as a result of NNW-directed maximum strain. The Valsugana and Belluno thrusts are probably of Late Miocene age, whereas south of these structures the deformation is essentially of Plio-Quaternary age. The youngest structures are those lining the front of the eastern South-Alpine chain towards the Veneto-Friuli plain, where a number of blind thrusts also exist (Slejko et al., 1986). It should be noted that the age of deformation in the eastern Southern Alps is the same as that of the outermost Apenninic arcs occurring in the subsurface of the Po plain.

The Veneto-Friuli area shows peculiar evolution due to the interference of two foreland basins of different ages and polarities (Fig. 10) (Massari et al., 1986). In an earlier stage, from Late Campanian to Middle Cuisian it was the site of flysch deposition in Dinaric-trending basins, probably developing in a context of transpressive tectonics. As outlined above, shortening was probably transferred from the eastern part of the Eastern Alps to the northern part of the Dinaric domain, partly by a broad system of strike-slip faults (Royden & Baldi, 1988). A system of thrusts displaying a SW polarity developed, with shortening climaxing in post-Lutetian/pre-Late Oligocene times (Cousin, 1981). A regional unconformity exists at the base of the molasse sequence of the Dinaric foredeep in the Veneto-Friuli area, where Chattian to Aquitanian shallow-

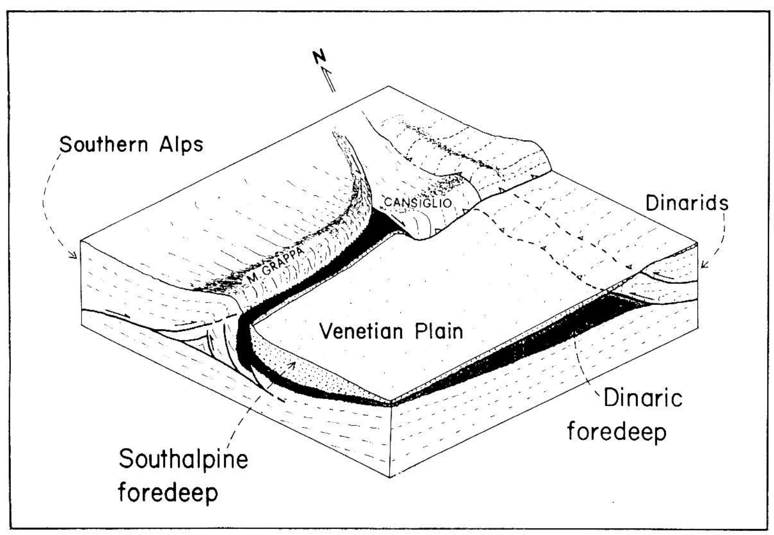


Fig. 10 - Schematic block diagram showing how Veneto-Friuli foreland basin underwent influences first of Dinaric thrusting during Palaeogene to Middle Miocene, and then of South-Alpine thrusting during Middle Miocene to Quaternary. After Massari, Mellere & Doglioni (in press), slightly modified.

water deposits are generally underlain by the Lower Eocene flysch, with a contact conformable to the west and increasingly unconformable to the east, where it is commonly accompanied by angular discordance (Cousin, 1981). A weak continuation of Dinaric thrusting and foreland basin subsidence is recorded by Upper Oligocene to Middle Miocene clastic wedges that thicken towards the front of the Dinaric thrusts, as shown by seismic profiles (Amato et al., 1976) (Fig. 10). Ramp-basin infills are not particularly thick, indicating that thrusting in the most external units was of relatively minor importance during the Miocene in the NW segment of the Dinaric chain and probably represents the weak final stage of Tertiary convergence.

The later stage of evolution, as outlined above, is strongly influenced by the South-Alpine deformation. The axis of the foredeep changed from a Dinaric to South-Alpine trend. This change may be placed in the Serravallian, and marks the onset of deposition of a new thick clastic wedge of Serravallian to Quaternary age, clearly pinching out southwards from the South-Alpine front (Fig. 10). The Serravallian to Messinian sequence consists of outer shelf to epibathyal prodelta mudstones with sparse thin-bedded turbidites and locally (Vittorio Veneto area) channelized conglomeratic bodies, grading upwards into delta-front, fan-delta and alluvial fan conglomerates and sandstones. Synsedimentary angular unconformities linked to the growth of thrust-cored anticlines coupled with local transpressive effects along transverse faults have been recognized in the Tortonian-Messinian sequence (Massari et al., 1986; Massari et al., in press). The facies belt is not isochronous along-strike, as fan-delta progradation took place earlier in the Friuli area; this suggests some revival of the Dinaric polarity, probably due to the reactivation of the NW-trending Dinaric faults and thrust faults in a transpressive regime.

A deeply incised erosional surface separates the Messinian conglomerates from the fine-grained Pliocene sediments, and is interpreted as the record of the strong lowstand known to have occurred in the Mediterranean area in the Late Messinian (Ryan & Cita, 1978; Rizzini & Dondi, 1978) followed by the sudden Pliocene transgression. Seismic profiles show that the foredeep infill continues with a Pliocene progradational wedge and a Quaternary sequence, the latter displaying weak uplift near the front of the chain. A subsurface high near the Adriatic coast may represent the peripheral bulge of the Neogene South-Alpine loading (Roeder, 1989).

Slejko et al. (1986) showed that the eastern block of the Southern Alps is the area displaying the highest seismicity within the whole Alpine chain. Shortening and crustal thickening are still active and the most intense seismic activity has been recorded along the southern margin of the eastern Southern Alps, and especially near their eastern and western boundaries (Friuli and Lake Garda areas). The Friuli seismic activity is almost exclusively given by compressional mechanisms, with main compression directed NNW-SSE, and subordinate transcurrent mechanisms (dextral transpression along the NW-SE Dinaric faults and thrust faults). The highest seismic activity occurs in the area east of Pordenone and may be related to the interference between the South-Alpine and

Dinaric systems. In the Garda area the focal mechanisms are differentiated, including those related to transcurrent movements along E-W striking faults and to ESE-vergent thrusts.

The high neotectonic and seismic activity at the southern margin of the eastern Southern Alps, and the northward deepening of the Moho may be the result of underthrusting of the Adriatic lithosphere beneath the Alps (Castellarin & Vai, 1981), although a deep seismicity is apparently missing.

Conclusions.

Relative movements between the plates in the Alpine chain were mostly obliquely compressive due to the anticlockwise rotation of the southern plate in collision. During the Cretaceous-Palaeogene this led to a diachronous collision, which took place earlier in the Eastern Alps than in the Central-Western Alps, and in a dextrally transpressive deformation regime (Coward & Dietrich, 1989). Oblique convergence continued into the Late Oligocene and Miocene, during which the strike-slip component of movement was concentrated along the Insubric fault zone, while the compressive component was largely taken up in the outer belt of the chain. As stressed by Laubscher (1988), the Miocene Alps can be considered as a dextrally transpressive intracontinental mountain belt. In addition, the Insubric fault zone was the site of discontinuous transtension, possibly related to back-arc spreading processes. Two main transtensional phases are apparent, respectively in the Oligocene and Middle Miocene, after the main phases of convergence (Mesoalpine and Neoalpine of Trümpy, 1973). As pointed out by Laubscher (1988), compression (transpression) and extension (transtension) seem to alternate in the evolution of the Alpine chain, following poorly understood patterns.

The space and time patterns of thrusting in the Southern Alps from the Late Oligocene onwards seem to be closely related to movements along the Insubric Line. As pointed out by Schmid et al. (1989), the history of the Insubric Line was very complex, with segments accomodating different displacements at different times. In particular, along the eastern segment of the Insubric Line, transpression and transtension seem to outlast movements along the western segment. Within the South-Alpine belt thrusts ended diachronously, becoming progressively younger from west to east (Fig. 11), as indicated by the eastward shifting of ramp-basin depocentres. Thrust propagation probably took place with an eastward-progressing right-handed *en-échelon* pattern combined with "progradation" toward the foreland. The western block of the Southern Alps was approximately locked into its present position relative to the Padan foreland by Middle Miocene times. Activation of the sinistral transpression along the Giudicarie fault zone during the Serravallian-Tortonian coincides with the time-shift of deformation from the western to the eastern block of the Southern Alps. In other words, during the Tortonian the Giudicarie probably played the role of a transfer fault system that separated one region of active thrusting from another where thrusting was becoming inactive. The quasi-inactivation of the western South-Alpine (Lombardian) thrust belt is proved by the dip reversal of the western South-Alpine foreland starting from the Early Pliocene due to Pliocene to Recent Apennine thrusting (Pieri & Groppi, 1981); instead, the eastern (Veneto-Friuli) foredeep does not show any reversal, partly due to the easterly increasing distance to the Apennine load, and partly because of the continuation of thrusting into the Pliocene.

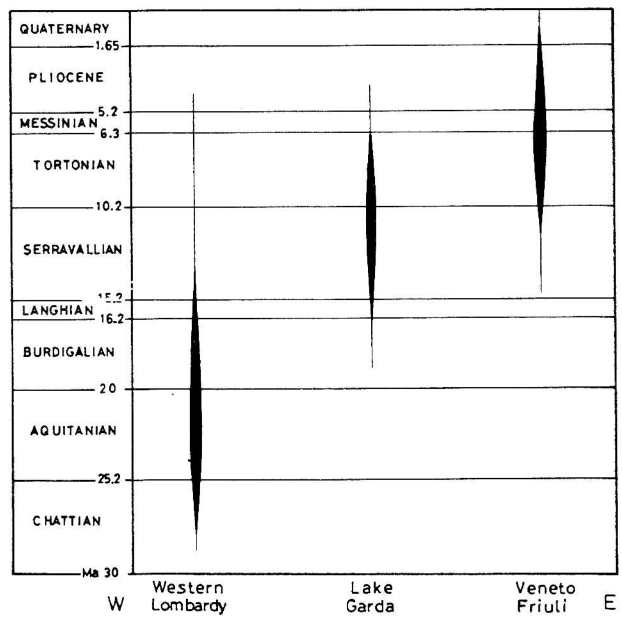


Fig. 11 - Eastward younging of post-Late Oligocene thrusting and folding within Southern Alps, as inferred from stratigraphy of foredeep deposits of three representative areas.

Correspondence between the well-known eastward shifting of the Apenninic arcs and the similar eastward displacement of deformation and ramp-basin depocentres in the South-Alpine domain should be noted. This migration is shared by the eastward shifting of entry-points of the Alpine-sourced sediment gravity-flows feeding the Apenninic flysch basins from the Late Oligocene to the Tortonian (Fig. 7, 8, 9). A detailed petrographic analysis of Apennine flyschs led Cipriani et al. (1985) to the conclusion that the source area for these flyschs is clearly broadening eastwards in time, being restricted to the Western Alps during Late Oligocene (Macigno), including the Central-Western Alps during the Early Miocene (Modino-Cervarola), and extending to the Central-Eastern Alps during the Middle-Late Miocene (Marnoso-arenacea).

Dextral shear movements along the Insubric Line are thought to result from the Tertiary anticlockwise rotation of Adria relative to Europe (Lowrie, 1986), leading to plate convergence associated with dextral shear. Coward & Dietrich (1989) argue that dextral transpressive movements interfered with sinistral strike-slip movements in the Western Alps, and that an anticlockwise rotation of the direction of the overthrust shear in the zone of interference produced a migration of deformation from east to west. This rotational deformation sequence is of regional importance in the Central-Western Alps and apparently persisted throughout the Miocene and Pliocene, as it has been recognized not only in the Pennine zone (Merle et al., 1989) but also in the external zones of the Alps, the Helvetic zone and the Chaînes Subalpines, with younger increments of deformation occurring in progressively western areas (Gratier et al., 1989). The westward shifting of deformation in the Central-Western Alps and eastward migration of thrusting in the Southern Alps may both represent the expression of oblique plate convergence associated with anticlockwise shear around a rotation pole located between the Central and Western Alps, where the indenting Adria plate produced maximum shortening.

The geodynamic setting on a Mediterranean scale was characterized by obliquity of convergence and by the successive opening first of the Balearic basin and then of the Tyrrhenian basin in the rear of the Apennines. It does not seem to be a pure coincidence that the first event approximately corresponds to the Insubric phase and the second to the shift of deformation from the western to the eastern block of the southern Alps. A diachronous end of thrusting also occurred in the West and East Carpathians during the Middle-Late Miocene (Royden & Burchfiel, 1989). Neogene thrusting in this belt was space- and time-linked to the back-arc extension of the Pannonian basin, as convergence seems to have been compensated by east-west extension and crustal thinning in the back-arc basin and heating of its mantle lithosphere. A similar mechanism was also active in the case of Apenninic belt, where thrusting was linked to the back-arc spreading of the Tyrrhenian basin. The effect of the eastward displacement in time of the Apenninic arcs seems to be matched by the diachronous history of movements along the Insubric fault system and the eastward shift of deformation in the Southern Alps.

It may be concluded that large-scale horizontal movements, rotations of adjacent blocks, lateral tectonic escapes, alternation of transpression and transtension, and time-shifting of deformation along the strike of the arcuate fold-thrust belt, may represent different aspects of the same structural context, dominated by oblique plate convergence.

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REFERENCES

Amato A., Barnaba P. F., Finetti I., Groppi G., Martinis B. & Muzzin A. (1976) - Geodynamic outline and seismicity of Friuli-Venetia Julia region. *Boll. Geof. Teor. Appl.*, v. 72, pp. 217-256, Trieste.

Aubouin J., Sigal J., Berland J., Blanchet R., Bonneau M., Cadet J. P., Guillot P. M., Lacour A., Piat B. & Vicente J. C. (1970) - Sur un bassin de Flysch: stratigraphie et paléogéographie des flyschs crétacés de la Lombardie (versant sud des Alpes Orientales, Italie). *Bull. Soc. Géol. France*, s. 7, v. 12, n. 4, pp. 612-658, 1 fig., Paris.

Beccaluva L., Bigioggero B., Chiesa S., Colombo A., Fanti G., Gatto G. O., Gregnanin A., Montrasio A., Piccirillo E. M. & Tunesi A. (1985) - Post collisional orogenic dyke magmatism in the Alps. *Mem. Soc. Geol. Ital.*, v. 26 (1983), pp. 341-359, 10 fig., Roma.

Bernoulli D. (1988) - The Ternate Formation, a Late Eocene bioclastic submarine fan of the Lombardian Basin (Southern Alps). *Amer. Ass. Petr. Geol.*, Mediterranean Basins Conference, Nice, September 1988, Poster Session.

Bernoulli D., Bertotti G. & Zingg A. (1989) - 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. *Ecl. Geol. Helv.*, v. 82, pp. 841-856, 8 fig., Basel.

Bernoulli D., Bichsel M., Bolli H. M., Häring M. O., Hochuli P. A. & Kleboth P. (1981) - The Missaglia Megabed, a catastrophic deposit in the Upper Cretaceous Bergamo Flysch, northern Italy. *Ecl. Geol. Helv.*, v. 74, pp. 421-442, 9 fig., Basel.

Bersezio R. & Fornaciari M. (1989) - Geometria e caratteri stratigrafici della Sequenza Cenomaniana nel Bacino Lombardo (Alpi Meridionali). *Riv. Ital. Paleont. Strat.*, v. 94 (1988), n. 3, pp. 425-454, 15 fig., Milano.

Blow W. H. (1979) - The Cainozoic *Globigerinida*: a study of the morphology, taxonomy, evolutionary relationship and the stratigraphic distribution of some *Globigerinida* (mainly *Globigerinacea*). Pt. 1. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. V. of 222 pp., 88 fig., E. J. Brill, Leyden.

Bosellini A., Broglio Loriga C. & Busetto C. (1978) - I bacini Cretacei del Trentino. *Riv. Ital. Paleont. Strat.*, v. 84, n. 4, pp. 897-946, 15 fig., Milano.

Bosellini A. & Doglioni C. (1986) - Inherited structures in the hangingwall of the Valsugana overthrust (Southern Alps, Northern Italy). *Journ. Struct. Geol.*, v. 8, pp. 581-583, Elmsford, NY.

Bosellini A. & Luciani V. (1985) - Contributo alla conoscenza dell'hard ground di Nago. *Rend. Soc. Geol. Ital.*, v. 8, pp. 61-64, 2 fig., Roma.

Brack P. (1981) - Structures in the southwestern border of the Adamello intrusion (Alpi Bresciane, Italy). *Schweiz. Mineral. Petrogr. Mitt.*, v. 61, pp. 37-50, Zürich.

Brack P. (1985) - Multiple intrusions - Examples from the Adamello batholith (Italy) and their significance on the mechanisms of intrusion. *Mem. Soc. Geol. Ital.*, v. 26 (1983), pp. 145-157, 14 fig., Roma.

Cassano E., Anelli L., Fichera R. & Capelli V. (1986) - Pianura Padana. Interpretazione integrata di dati geofisici e geologici. *AGIP (73° Congr. Soc. Geol. Ital.*, Roma, 1986), 27 pp., 35 fig., Milano.

Castellarin A. (1972) - Evoluzione paleotettonica sinsedimentaria del limite tra "piattaforma veneta" e "bacino lombardo" a Nord di Riva del Garda. *Giorn. Geol.*, s. 2, v. 38, n. 1, pp. 11-212, Bologna.

Castellarin A. (1984) - Schema delle deformazioni tettoniche sudalpine. *Boll. Ocean. Teor. Appl.*, v. 2, pp. 105-114, Trieste.

Castellarin A., Fesce A. M., Picotti V., Pini G. A., Prosser G., Sartori R., Selli L., Cantelli L. & Ricci R. (1987) - Structural and kinematic analysis of the Giudicarie deformation belt. Implications for compressional tectonics of Southern Alps. *Miner. Petrogr. Acta*, v. 30, pp. 287-310, Bologna.

Castellarin A. & Vai G. B. (1981) - Importance of Hercynian tectonics within the framework of the Southern Alps. *Journ. Struct. Geol.*, v. 3, pp. 477-486, Elmsford, NY.

Castellarin A. & Vai G. B. (1982) - Introduzione alla geologia strutturale del Sudalpino. In Castellarin A. & Vai G. B. (Eds.) - Guida alla geologia del Sudalpino centro-orientale. *Guide Geol. Reg. Soc. Geol. Ital.*, pp. 1-22, Bologna.

Castellarin A. & Vai G. B. (1986) - Southalpine versus Po Plain Apenninic arcs. In Wezel F. C. (Ed.) - The origin of arcs. *Developments in Geotectonics*, n. 21, pp. 253-280, Elsevier, Amsterdam.

Cipriani N., Malesani P. & Vannucci S. (1985) - Distribuzione e rapporti dei sedimenti oligocenici e miocenici nell'Appennino settentrionale. *Miner. Petrogr. Acta*, v. 29, pp. 191-210, Bologna.

Cita M. B. (1954) - Studi stratigrafici sul Terziario subalpino lombardo. Pt. II. Osservazioni micropaleontologiche su alcuni campioni raccolti nei conglomerati terziari del Bresciano. *Riv. Ital. Paleont. Strat.*, v. 60, n. 4, pp. 213-219, Milano.

Cousin M. (1981) - Les rapports Alpes-Dinarides - Les confins de l'Italie et de la Yougoslavie. *Soc. Géol. Nord*, publ. n. 5, v. I, pp. 1-521; v. II, pp. 1-521, Villeneuve d'Ascq.

Coward M. & Dietrich D. (1989) - Alpine tectonics - An overview. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 1-29, London.

Cros P. (1978) - Interprétation des relations entre sédiments continentaux intrakarstiques et molasses littorales Oligo-Miocènes des Dolomites Centrales Italiennes. *Atti Congr. "Processi paleocarsici e neocarsici"*, Napoli.

Dal Piaz G. V. (1976) - Alcune riflessioni sulla evoluzione geodinamica alpina delle Alpi. *Rend. Soc. Ital. Miner. Petrogr.*, v. 32, n. 1, pp. 380-385, Milano.

Dal Piaz G. V., Del Moro A., Martin S. & Venturelli G. (1988) - Post-collisional magmatism in the Ortler-Cevedale Massif (Northern Italy). *Jb. Geol. Bundesanst.*, v. 131, n. 4, pp. 533-551, 9 fig., Wien.

Dal Piaz G. V. & Venturelli G. (1985) - Brevi riflessioni sul magmatismo post-ofiolitico nel quadro dell'evoluzione spazio-temporale delle Alpi. *Mem. Soc. Geol. Ital.*, v. 26 (1983), pp. 5-19, 1 fig., Roma.

Del Moro A., Pardini G., Quercioli C., Villa I. M. & Callegari E. (1985) - Rb/Sr and K/Ar chronology of Adamello granitoids, Southern Alps. *Mem. Soc. Geol. Ital.*, v. 26 (1983), pp. 285-299, 6 fig., 9 tab., Roma.

De Sitter L. U. & De Sitter Koomans C. M. (1949) - The geology of the Bergamasc Alps, Lombardia, Italy. *Leid. Geol. Meded.*, v. 14, pp. 1-257, geol. maps, Leiden.

Dewey J. F., Helman M. L., Turco E., Hutton D. H. W. & Knott S. D. (1989) - Kinematics of the western Mediterranean. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 265-283, London.

Doglioni C. (1985) - The overthrusts in the Dolomites: ramp-flat systems. *Ecl. Geol. Helv.*, v. 78, pp. 335-350, 13 fig., Basel.

Doglioni C. (1987) - Tectonics of the Dolomites (Southern Alps - Northern Italy). *Journ. Struct. Geol.*, v. 9, pp. 181-193, Elmsford, NY.

Doglioni C. & Bosellini A. (1987) - Eoalpine and mesoalpine tectonics in the Southern Alps. *Geol. Rund.*, v. 76, n. 3, pp. 735-754, 16 fig., Stuttgart.

Dondi L. & D'Andrea M. G. (1987) - La Pianura Padana e Veneta dall'Oligocene superiore al Pleistocene. Proc. Interim Colloq. Paleog. Geodyn. Peritуrr. Area (1984), *Giorn. Geol.*, s. 3, v. 48, n. 1-2, pp. 197-225, 23 fig., Bologna.

Frey M. (1986) - Very low-grade metamorphism of the Alps - an introduction. *Schweiz. Miner. Petrogr. Mitt.*, v. 66, pp. 13-27, Zürich.

Fuchs W. (1980) - Die Molasse und ihr nichthelvetischer Vorland- anteil am Untergrund einschliesslich der Sedimente auf der Böhmischen Masse. In Oberhauser R. (Ed.) - Der geologische Aufbau Österreichs, pp. 144-176, Springer, Wien.

Füchtbauer H. (1967) - Die Sandsteine in der Molasse nördlich der Alpen. *Geol. Rund.*, v. 56, n. 1, pp. 266- 300, 12 fig., Stuttgart.

Fumasoli M. W. (1974) - Geologie des Gebietes nördlich und südlich der Jorio-Tonale Linie im Westen von Gravedona (Como, Italia). *Mitt. Geol. Inst. Eidgen. Techn. Hochsch. Univers. Zürich.*, n. 194, 230 pp., Zürich.

Gatto G. O., Gregnanin A., Molin G. M., Piccirillo E. M. & Scolari A. (1976) - Le manifestazioni "andesitiche" polifasiche dell'Alto Adige occidentale nel quadro geodinamico alpino. *St. Trentini Sc. Nat.*, v. 53, n. 5A, pp. 21-47, 9 fig., Trento.

Gelati R., Napolitano A. & Valdisturlo A. (1988) - La "Gonfolite Lombarda": stratigrafia e significato nell'evoluzione del margine Sudalpino. *Riv. Ital. Paleont. Strat.*, v. 94, n. 2, pp. 285- 332, 5 pl., 16 fig., 2 tab., Milano.

Genser J. & Neubauer F. (1989) - The uplift of pull-apart metamorphic domes by tectonic unroofing as a consequence of orogen-parallel crustal wrenching. *Terra abstr.*, n. 1, p. 256.

Grandesso P. (1976) - Biostratigrafia delle formazioni terziarie del Vallone Bellunese. *Boll. Soc. Geol. Ital.*, v. 94 (1975), n. 5, pp. 1323-1348, 16 fig., Roma.

Gratier J.-P., Ménard G. & Arpin R. (1989) - Strain-displacement compatibility and restoration of the Chaînes Subalpines of the western Alps. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 65-81, London.

Grundmann G. & Morteani G. (1985) - The young uplift and thermal history of the central Eastern Alps (Austria/Italy), evidence from apatite fission track ages. *Jb. Geol. Bundesanst.*, v. 128, n. 2, pp. 197-216, 13 fig., Wien.

Guineberteau B., Bouchez J-L. & Vigneresse J.-L. (1987) - The Mortagne granite pluton (France) emplaced by pull-apart along a shear zone: structural and gravimetric arguments and regional implication. *Geol. Soc. Amer. Bull.*, v. 99, n. 6, pp. 763- 770, 6 fig., Boulder.

Heitzmann P. (1987) - Evidence of Late Oligocene/Early Miocene backthrusting in the Central Alpine "root zone". *Geodyn. Acta*, v. 1, n. 3, pp. 183-192, 7 fig., Paris.

Heller F., Lowrie W. & Hirt A. M. (1989) - A review of palaeomagnetic and magnetic anisotropy results from the Alps. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 399-420, London.

Hunziker J. C. & Martinotti G. (1987) - Geochronology and evolution of the Western Alps: a review. *Mem. Soc. Geol. Ital.*, v. 29 (1984), pp. 43-56, 6 fig., 2 tab., Roma.

Hurford A. J. (1986) - Cooling and uplift patterns in the Lepontine Alps, South Central Switzerland and an age of vertical movement on the Insubric fault line. *Contrib. Mineral. Petrol.*, v. 92, pp. 413-427, New York.

Hurford A. J., Flisch M. & Jäger E. (1989) - Unravelling the thermo-tectonic evolution of the Alps: a contribution from fission track analysis and mica dating. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 369-398, London.

Janoschek W. R. & Matura A. (1980) - Outline of the geology of Austria. *Abh. Geol. Bundesanst.*, v. 34, pp. 7-98, 20 fig., 1 geol. map, Wien.

Laubscher H. P. (1970) - Bewegung und Wärme in der Alpine Orogenese. *Schweiz. Miner. Petrogr. Mitt.*, v. 50, pp. 565- 596, Zürich.

Laubscher H. P. (1985a) - The late Alpine (Periadriatic) intrusions and the Insubric Line. *Mem. Soc. Geol. Ital.*, v. 26 (1983), pp. 21-30, 3 fig., Roma.

Laubscher H. P. (1985b) - Large-scale, thin-skinned thrusting in the Southern Alps: kinematic models. *Geol. Soc. Amer. Bull.*, v. 96, n. 6, pp. 710-718, 8 fig., Boulder.

Laubscher H. P. (1988) - Material balance in Alpine orogeny. *Geol. Soc. Amer. Bull.*, v. 100, n. 9, pp. 1313-1328, 12 fig., Boulder.

Laubscher H. P. & Bernoulli D. (1982) - History and deformation of the Alps. In Hsü K. J. (Ed.) - Mountain building processes. Acad. Press, pp. 169-180, London.

Lemcke K. (1984) - Geologische Vorgänge in den Alpen ab Obereozän im Spiegel vor allem der deutschen Molasse. *Geol. Rund.*, v. 73, n. 1, pp. 371-397, 14 fig., Stuttgart.

Lowrie W. (1986) - Paleomagnetism and the Adriatic promontory. *Tectonics*, v. 5, n. 5, pp. 797-807, 3 fig., Washington.

Luciani V. (1988) - La Dorsale Paleogenica M. Baldo - M. Bondone (Trentino meridionale): significato paleogeografico e paleotettonico. *Riv. Ital. Paleont. Strat.*, v. 93 (1987), n. 4, pp. 507-520, 2 fig., Milano.

Massari F., Grandesso P., Stefani C. & Jobstraibizer P. G. (1986) - A small polyhistory foreland basin evolving in a context of oblique convergence: the Venetian basin (Chattian to Recent, Southern Alps, Italy). In Allen P. A. & Homewood P. (Eds.) - Foreland basins. *Spec. Publ. Int. Ass. Sediment.*, n. 8, pp. 141-168, 16 fig., Blackwell Scientific Publ., Oxford.

Massari F., Mellere D. & Doglioni C. (presentato alla Fourth International Conference on Fluvial Sedimentology, Sitges, 1989) - Cyclicity in nonmarine foreland-basin sedimentary infill: the Messinian conglomerate-bearing succession of the eastern Southern Alps (Italy).

Merle O., Cobbold P. R. & Schmid S. (1989) - Tertiary kinematics in the Lepontine dome. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 113-134, London.

Mottana A., Nicoletti M., Petrucciani C., Liborio G., De Capitani L. & Bocchio R. (1985) - Pre-alpine and alpine evolution of the South-alpine basement of the Orobic Alps. *Geol. Rund.*, v. 74, n. 2, pp. 353-366, 3 fig., Stuttgart.

Ogniben L. (1986) - Modello geodinamico della regione trentina ed aree circostanti. *St. Trentini Sc. Nat.*, v. 63 (Acta Geol.), pp. 1-165, 76 fig., Trento.

Pieri M. & Groppi G. (1981) - Subsurface geological structure of the Po plain, Italy. *CNR, Prog. Fin. Geodin.*, Publ. n. 414, 13 pp., 7 pl., 19 fig., Roma.

Platt J. P., Behrmann J. H., Cunningham P. C., Dewey J. F., Helman M., Parish M., Shepley M. G., Wallis S. & Weston P. J. (1989) - Kinematics of the Alpine arc and the motion history of Adria. *Nature*, v. 337, pp. 158-161, 3 fig., Basingstoke.

Polino R., Dal Piaz G. V. & Gosso G. (submitted to *Mém. Soc. Géol. France*) - An accretionary wedge model for the pre-collisional Cretaceous orogeny in the Alps.

Ratschbacher L. & Neubauer F. (1989) - West-directed decollement of Austro-Alpine cover nappes in the eastern Alps: geometrical and rheological considerations. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 243-262, London.

Ricci Lucchi F. (1975) - Miocene palaeogeography and basin analysis in the Periadriatic Apennines. In Squyres C. (Ed.) - Geology of Italy. V. 2, pp. 129-236, PESL, Castelfranco Veneto-Tripoli.

Rizzini A. & Dondi L. (1978) - Erosional surface of Messinian age in the subsurface of the Lombardian Plain (Italy). *Mar. Geol.*, v. 27, n. 3-4, pp. 303-325, 14 fig., Amsterdam.

Roeder D. (1985) - Geodynamics of Southern Alps. Seminar paper given at University of Milan, November 28. *Anschutz Corp. Expl. Res. Div.*, 22 pp., Denver, Colorado.

Roeder D. (1987) - South-Alpine Neogene fold-thrust belt. *Terra Cognita.* (abstr.), v. 7, p. 87, Strasbourg.

Roeder D. (1989) - South-Alpine thrusting and trans-Alpine convergence. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 211-227, London.

Rögl F., Cita M. B., Müller C. & Hochuli P. (1975) - Biochronology of conglomerate-bearing Molasse sediments near Como (Italy). *Riv. Ital. Paleont. Strat.*, v. 81, n. 1, pp. 57-88, 4 pl., 4 fig., Milano.

Rossi M. & Rogledi S. (1988) - Relative sea-level changes, local tectonic settings and basin margin sedimentation in the interference zone between two orogenic belts: seismic stratigraphic examples from Padan foreland basin, northern Italy. In Nemec W. & Steel R. J. (Eds.) - Fan deltas: sedimentology and tectonic settings, pp. 368- 384, Blackie and Son, Glasgow.

Roure F., Polino R. & Nicolich R. (1989) - Poinçonnement, rétrocharriages et chevauchements post-basculement dans les Alpes occidentales: évolution intracontinentale d'une chaîne de collision. *C. R. Acad. Sc. Paris*, v. 309, s. 2, pp. 283-290, Paris.

Royden L. H. (1985) - The Vienna Basin: a thin-skinned pull-apart basin. In Biddle K. T. & Blick N.-C. (Eds.) - Strike-slip deformation, basin formation and sedimentation. *Soc. Econ. Paleont. Miner.*, Spec. Publ. 37, pp. 227-264, 18 fig., Tulsa.

Royden L. H. & Baldi T. (1988) - Early Cenozoic tectonics and paleogeography of the Carpathian-Pannonian region. In Royden L. H. & Horváth F. (Eds.) - The Pannonian basin: a study in basin evolution. *Mem. Amer. Ass. Petr. Geol.*, n. 45, pp. 1-16, Tulsa.

Royden L. H. & Burchfiel B. C. (1989) - Are systematic variations in thrust belt style related to plate boundary processes? (the Western Alps versus the Carpathians). *Tectonics*, v. 8, n. 1, pp. 51- 61, 6 fig., Washington.

Royden L. H., Horváth F. & Burchfiel B. C. (1982) - Transform faulting, extension, and subduction in the Carpathian region. *Geol. Soc. Amer. Bull.*, v. 93, n. 8, pp. 717-725, 7 fig., Boulder.

Royden L. H., Horváth F. & Rumpler J. (1983) - Evolution of the Pannonian basin system. 1. Tectonics. *Tectonics*, v. 2, n. 1, pp. 63-90, 10 fig., Washington.

Ryan W.B.F., & Cita M. B. (1978) - The nature and distribution of Messinian erosional surfaces - Indicators of a several-kilometer-deep Mediterranean in the Miocene. *Mar. Geol.*, v. 27, n. 3-4, pp. 193-230, 19 fig., Amsterdam.

Schmid S. M., Aebli H. R., Heller F. & Zingg A. (1989) - The role of the Periadriatic Line in the tectonic evolution of the Alps. In Coward M. P., Dietrich D. & Park R. G. (Eds.) - Alpine tectonics. *Geol. Soc.*, Spec. Publ. n. 45, pp. 153-171, London.

Schmid S. M., Zingg A. & Handy M. (1987) - The kinematics of movements along the Insubric Line and the emplacement of the Ivrea Zone. *Tectonophys.*, v. 135, n. 1-3, pp. 47-66, 10 fig., Amsterdam.

Selverstone J. (1988) - Evidence for east-west crustal extension in the Eastern Alps: implications for the unroofing history of the Tauern Window. *Tectonics*, v. 7, n. 1, pp. 87-105, 10 fig., Washington.

Selverstone J. & Hodges K. V. (1987) - Unroofing history of the western Tauern Window: evidence for west-directed removal of the Austroalpine nappe sequence. *Terra Cognita* (Abstr.), v. 7, p. 89, Strasbourg.

Sengör A. M. C., Görür N. & Sarõglu F. (1985) - Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In Biddle K. T. & Blick N.-C (Eds.) - Strike-slip deformation, basin formation and sedimentation. *Soc. Econ. Paleont. Miner.*, Spec. Publ. 37, pp. 227-264, 20 fig., Tulsa.

Slejko D., Carraro F., Carulli G. B., Castaldini D., Cavallin A., Doglioni C., Nicolich R., Rebez A., Semenza E. & Zanferrari A. (1986) - Seismotectonic model of northeastern Italy: an approach. Int. Symp. "Engineering geology problems in seismic areas". *Geol. Appl. Idrogeol.*, v. 21, pp. 153-165, 3 pl., 2 fig., Bari.

Steininger F. F., Wesselly G., Rögl F. & Wagner L. (1987) - Tertiary sedimentary history and tectonic evolution of the Eastern Alpine foredeep. *Giorn. Geol.*, s. 3, v. 48, n. 1-2, pp. 285-297, 10 fig., Bologna.

Tapponnier P. (1977) - Évolution tectonique du système alpin en Méditerranée: poinçonnement et écrasement rigide-plastique. *Bull. Soc. Géol. France*, s. 7, v. 19, n. 3, pp. 437-460, 5 fig., Paris.

Trümpy R. (1973) - The timing of orogenic events in the Central Alps. In De Jong K. A. & Scholten R. (Eds.) - Gravity and tectonics, pp. 229-251, J. Wiley & Sons, Chichester, Sussex.

Trümpy R. (1980) - Geology of Switzerland. A guide book. Part A. An outline of the geology of Switzerland. *Schweiz. Geol. Kommiss.*, 104 pp., Wepf & Co. Publ., Basel.

Tunis G. & Venturini S. (1987) - Megabeds and turbidite sequence of eastern Friuli (the Italcementi quarry of Vernasso). In Int. Symp. "Evolution of the karstic carbonate platform: relation with other periadriatic carbonate platforms" (5 June 1987). Guidebook of the excursion: Eastern Friuli, karst of Gorizia and western Slovenia, pp. 1-12.

Vecchia O. (1954) - Studi stratigrafici sul Terziario subalpino lombardo. Pt. I. Nuove osservazioni sui conglomerati terziari dei colli tra Brescia e l'Oglio. *Riv. Ital. Paleont. Strat.*, v. 60, n. 4, pp. 205-212, 1 fig., Milano.

Wagner G. A., Reimer G. M. & Jaeger E. (1977) - Cooling ages derived by apatite fission track, mica Rb-Sr and K-Ar dating: the uplift and cooling history of the central Alps. *Mem. Ist. Geol. Min. Univ. Padova*, v. 30, pp. 1-27, 9 fig., 2 maps, Padova.

Waibel A. F. & Frisch W. (1989) - The Lower Engadine Window: sediment deposition and accretion in relation to the plate-tectonic evolution of the Eastern Alps. *Tectonophys.*, v. 162, n. 3-4, pp. 229-241, 7 fig., Amsterdam.

Winkler W. (1988) - Mid- to Early Cretaceous flysch and melange formations in the western part of the Eastern Alps. Palaeotectonic implications. *Jb. Geol. Bundesanst.*, v. 131, n. 2, pp. 341-389, 20 fig., Wien.

Ziegler P. A. (1987) - Late Cretaceous and Cenozoic intra-plate compressional deformations in the Alpine foreland - a geodynamic model. *Tectonophys.*, v. 137, n. 1-4, pp. 389-420, 11 fig., Amsterdam.