BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA VOL. XXXVI, N. 141-144 - MARCH-DECEMBER 1994

G. DALLAGIOVANNA, A. LUALDI and M. VANOSSI

# THE LIGURIAN ALPS SEGMENT: A SHORT REVIEW

**Abstract.** The Ligurian Alps are composed of several tectonic units, firstly thrust and piled towards the foreland, then backfolded, and finally involved in Apenninic age and direction deformations. They include rock sequences derived from the paleo-European continent (from outer to inner domains: Dauphinois; Sub-Briançonnais), from its margin *s.s.* (Prepiemont *s.l.*) and from the Piemont-Ligurian ocean. In the Briançonnais domain, the pre-Namurian polymetamorphic basement is covered by a Permo-Carboniferous tegument composed of volcanites interbedded with continental deposits. The Meso-Cenozoic sequence follows upwards; it begins with uppermost Permian-Lower Triassic clastic sediments, covered by mainly Middle Triassic platform carbonates. A variable (Triassic-Jurassic) time-span gap corresponds to different amounts of erosion and non-deposition, and is in turn followed by Upper Jurassic-Paleocene basinal facies, and finally by Eocene turbidites. In the Prepiemont units, which generally lack pre-Triassic rocks, the Mesozoic sequence is typical of a passive continental margin. The Piemont-Ligurian domain contains portions of oceanic lithosphere ending with Cretaceous calcschists. It is highly probable that the main part of the Upper Cretaceous-Tertiary Helmintoid Flysch was deposited in the same domain. The main tectono-metamorphic Alpine phases in the different units, their temporal correlations and a supposed sequence of geodynamic events are shown in Fig. 5.

## INTRODUCTION

The Ligurian Alps (Fig. 1) are built up from groups of tectonic units (schematically outlined in Fig. 2), first thrust and piled toward the foreland, then backfolded and finally involved in more gentle deformations, among which a widespread phase of Apenninic age and direction is known.

In the framework of classical western Alpine paleogeography (though this is presently under criticism: Polino et al., 1990), they include rock sequences derived from the paleo-European continent (besides Dauphinois and Sub-Briançonnais domains, not treated here, they are outer, intermediate and inner Briançonnais), from its margin (Prepiemont *l.s.*) and from the Piemont-Ligurian ocean (represented by two main groups: pre-flysch ophiolitic and Helminthoid Flysch *l.s.* sequences). The presence of elements from the Adrian continent or from an hypothetical intra-oceanic microcontinent is highly doubtful.

## STRATIGRAPHY

### Briançonnais domain

#### *Pre-Namurian basement*

This crops out in two different tectonic positions (Fig. 2): *a)* allochtonous rootless bodies,



Manuscript received, December 23, 1992; accepted, September 10, 1993.

Dipartimento di Scienze della Terra, via Abbiategrasso 209, 27100 Pavia.

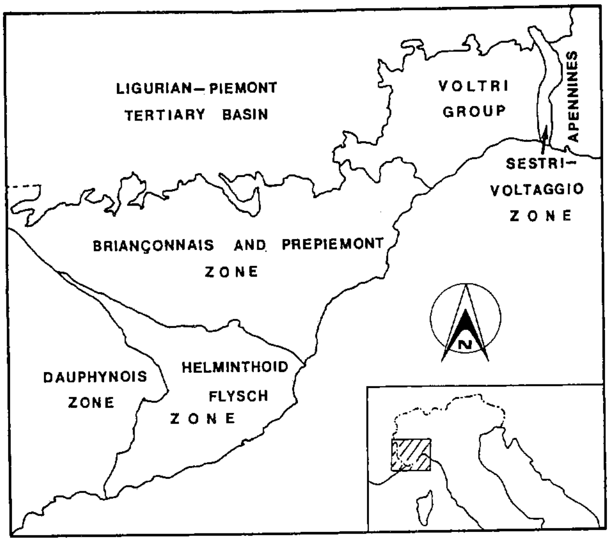



Fig. 1 — Schematic tectonic map of the Maritime Alps.

usually lacking late-Variscan tegument and post-Paleozoic cover, constituting the highest nappes from the Briançonnais domain (Savona, Calizzano, Pallare, Loano "massifs"; Bagnaschino Unit); *b)* stratigraphic basement of intermediate-inner Briançonnais lower units (Barbassiria, Nucetto, Lisio, Costa Dardella "massifs").

The first group (*a*) is mainly composed (Cortesogno et al., 1993) of orthogneisses I and II, paragneisses and micaschists, metabasites I (amphibolites and minor eclogites and granulites) and II (metagabbros), while the second (*b*) shows only orthogneisses II.

A possible sequence of events (Fig. 3) would begin (Cambrian-Ordovician?) with the deposition of fine detrital sediments (1, 1', 1" in Fig. 3), interfingered with both volcanic or subvolcanic rhyolites (2, 2', 2" in Fig. 3) and tholeiitic basalts (4, 4', 4" in Fig. 3) and intruded by granitic plutonic bodies or dikes (3, 3', 3" in Fig. 3). A first tectono-metamorphic phase, which might have started between Ordovician and Silurian times, developed following two different, contemporaneous trends (high grade amphibolitic and, subordinately, eclogitic conditions) and produced the paragneisses and micaschists, the metabasites I (amphibolites, eclogites and granulites) and the orthogneisses I (from both intrusive and effusive bodies). Afterwards (Upper Devonian? lowest Dinantian?), the sequence was intruded by anatectic monzogranitic melts (6,6' and 7,7' in Fig. 3; emplacement older than 327 Ma: Del Moro et al., 1981) and rare olivine gabbros, subsequently (Visean?) re-equilibrated under amphibolite facies conditions, with intermediate to high thermal gradient and comparatively low pressure. This second tectono-metamorphic phase transformed the anatexites and gabbros into the orthogneisses and metabasites II, respectively.

Studies on pebbles in the Upper Carboniferous coarse detrital deposits (Cortesogno et al., 1988b) have shown that at the end of the Sudetian phase the present polymetamorphic basement was covered by a rock-pile (5,5' in Fig. 3) at least 5 km thick. The lower part of this cover, eroded during Late Variscan progressive basement exhumation, was composed of still polymetamorphic sequences (essentially paraschists), while the upper, monometamorphic (Greenschist Facies) part was mostly formed by metasediments (pelites, sometimes graphitic; siltites; fine sandstones, cherts).

Depending on the still unknown age ("Caledonian" or pre-Cambrian) of the first pre-Variscan metamorphic event recorded in the polymetamorphic assemblages, the time-span covered by the monometamorphic sediments might be more or less extensive; in any case, it obviously corresponds at least to the Silurian-Visean interval.

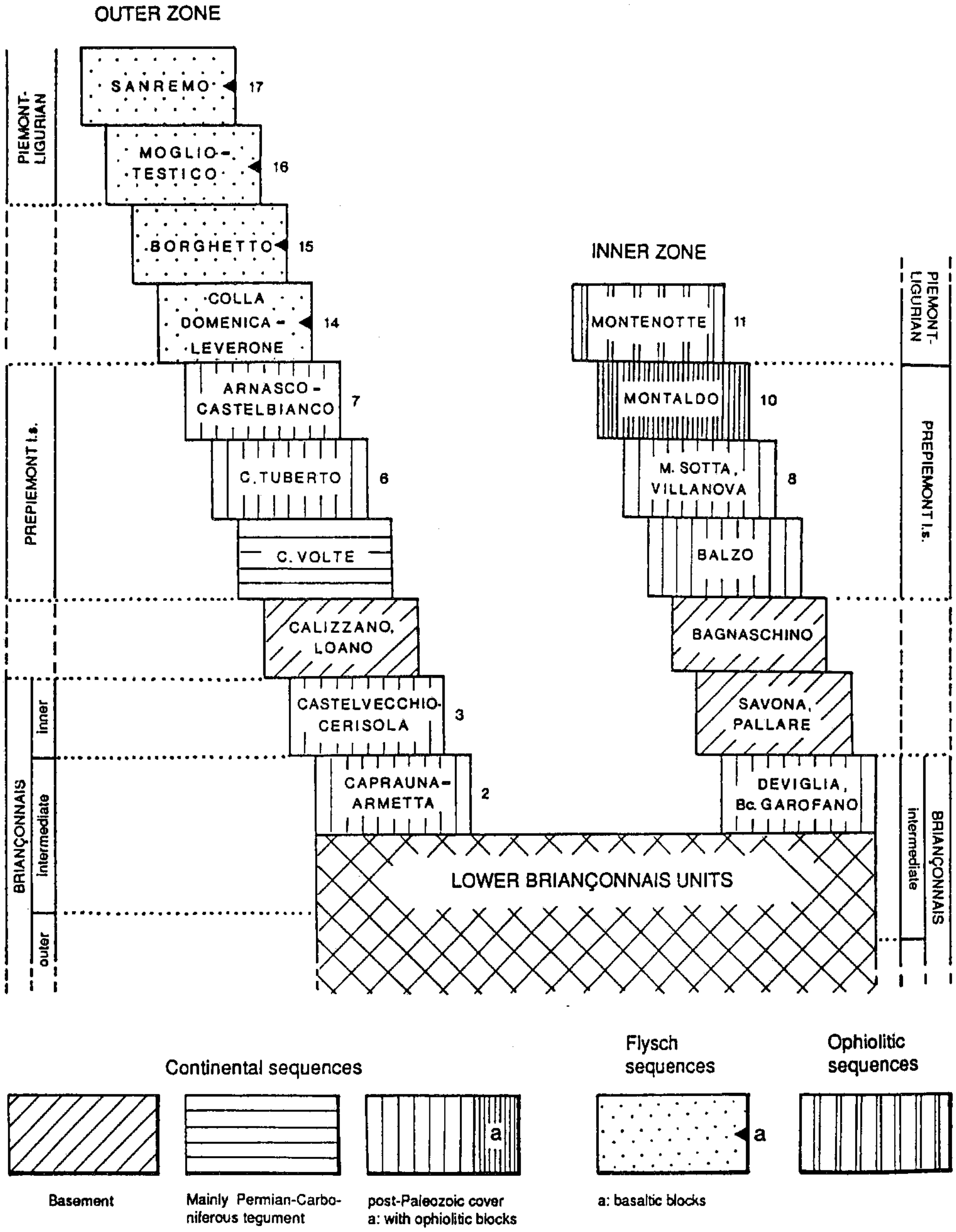



Fig. 2 — The pile of tectonic units in the outer (i.e., southwestern) and inner (i.e., northern) sectors in the Ligurian Alps has been schematically restored. This reconstruction shows that the higher the nappe location, the more internal is its paleogeographic supposed provenance. Both vertical sequences drawn in the figure may locally have in part been upset by the backthrusts that followed nappe emplacement. "Ophiolitic blocks" refers to reworked masses of variable, up to hectometric size, of peridotites, gabbros or basalts which display the same primary and metamorphic characteristics as the ophiolitic sequence in the Montenotte Unit; "basaltic blocks" indicates non-metamorphic olistolites from basalts whose chemical composition suggests a near-to-continental margin provenance (after Vanossi, 1991).

*Upper Carboniferous-Permian continental sequences*

Between Variscan metagranitoids and Scythian quartzites, a group of continental sediments and volcanics is found, ranging from Upper Carboniferous to Upper Permian, but very poorly dated in detail (there are rare Westphalian-Stephanian floras only in the Ollano Fm.).

It presently covers most of the Ligurian Briançonnais area and shows different sequences in the outer and inner sectors (Table, columns 1, 4 , 5; see also Fig. 3), thus affording a marked late-Variscan framework to the Mesozoic and Tertiary evolution of the whole domain.

In inner sectors (column 5) the lowermost detrital formation, unconformably resting on the orthogneisses II, is represented (Fig. 3) by arkosic products (*Lisio Fm.*), at whose top a first rhyolitic ignimbritic episode (*Lisetto Fm.*) is recorded. Mainly pelitic, sometimes graphitic, sediments follow (*Murialdo* and *Viola Fms.*), alternating with andesitic (exceptionally basaltic) fine ashes or lava flows (*Eze Fm.*). At the top, an unconformity usually separates the series from the overlying, Upper Permian (?) *Verrucano Fm.* (continental conglomerates, rich in quartzitic and rhyolitic pebbles), which in turn is conformably covered by Lower Triassic, at least partly marine quartzites. Sometimes, immediately below the Verrucano Fm., the uppermost part of the Lower Permian sequence, consisting of fine sandstones (*Gorra Fm.*) and of a new ignimbritic rhyolitic (*Melogno Fm.*) to dacitic (*Aimoni Member*) episode, is preserved.

Through a wide range of different occurrences, observable in the intermediate sectors (see, e.g., column 4, where the Melogno Fm. has been divided into different $A$, $B_1$, $B_2$, $C$, $C_1$ *lithozones*), the outer sector sequence evolves as follows (column 1):

the basement not being exposed, the series start with fluvial-lacustrine conglomeratic to coal bearing pelitic, often rhythmic, deposits (*Ollano Fm.*), intercalated with a first assemblage of rhyolitic volcanics (from coarse pyroclastic fall deposits to ignimbrites: *Bc. Crose* and Osiglia Fms., respectively); the intermediate, mostly andesitic event (*Eze Fm.*) and the associated fine deposits (*Viola Fm.*) form a thinner, but still present, upper segment of the series; this is completed at the top by the products of the third volcanic event, here represented by huge volumes of rhyolitic to dacitic ignimbritic (*Melogno Porphyroids*) and pyroclastic (*Aimoni* and *C. Pollaio Members*) rocks.

In all the sectors, the very last outpouring was represented by widespread, polychrome, often red, peculiar ignimbritic K-rhyolites (*D lithozone*); very often they have been completely eroded, but their pebbles are frequent in the overlying Verrucano.

Late Variscan plutonites are very poorly represented (Fig. 3) by some small granodioritic bodies and dikes (*Borda Granodiorites*) or, more often, by granophyric dikes (*Rio Castorello Granophyres*) crosscutting both the orthogneisses II and the Lisio Formation.

Chemically (Cortesogno et al., 1988a), the volcanic products are calc-alkaline (first and third event) or potassic sub-alkaline with shoshonitic affinity (second event and topmost K-rhyolites). The earliest rhyolites should derive from crustal anatexis; "shoshonitic" andesites and K-rhyolites would come from fractioning of a mantle partial melt, while calc-alkaline rhyolites to dacites of the third, principal, event might be due to fractioning of a hybrid magma.

Abrupt to progressive lateral and vertical changes in thickness, both of sediments and volcanics, point to the existence of grabens and half-grabens, bordered by two systems of active faults, presently trending N 30° and N 110° (Cabella et al., 1988).

*Meso-Cenozoic evolution (Table, columns 1 to 5)*

As an evolution from the coarse clastic continental deposits of the Verrucano Fm., the Tethys ingression begins in the Lower Triassic with beach quartzarenites (*Ponte di Nava Quartzites*), followed - after an upper Scythian phase of deposition in restricted pond and marsh environments (*Case Valmarenca Pelites*) - by the creation of the ubiquitous Middle Triassic shallow and subsiding carbonate shelf. It develops through three main cycles (Lualdi and Seno, 1986): growth of a peritidal shelf still subject to continental supply (Anisian; *Costa Losera Fm.*); spreading of cyclically arranged shallowing-upward sequences (Anisian-Ladinian); and open lagoon subtidal deposition locally rimmed by hypersaline highs (Upper Ladinian; *S. Pietro dei Monti Dolomites*; Fig. 4). Locally, Lower Carnian hypersaline facies (salt marsh, playa flat) seal the Triassic

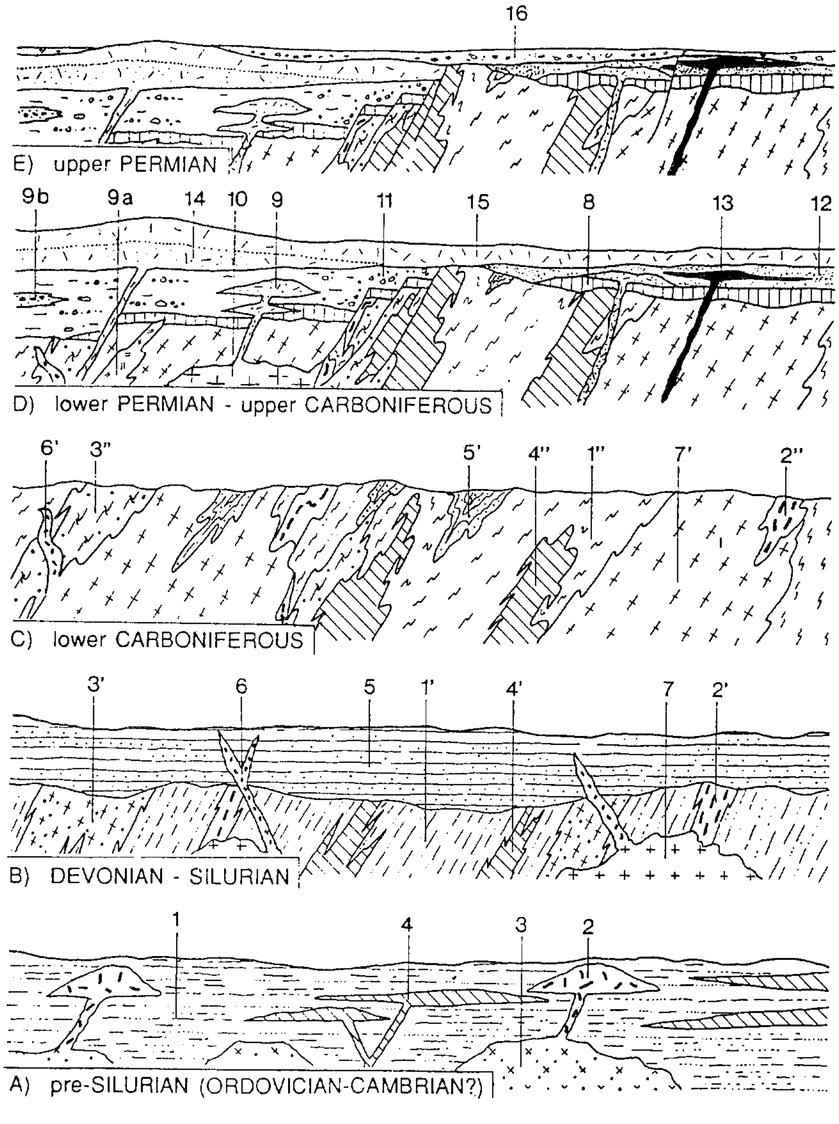
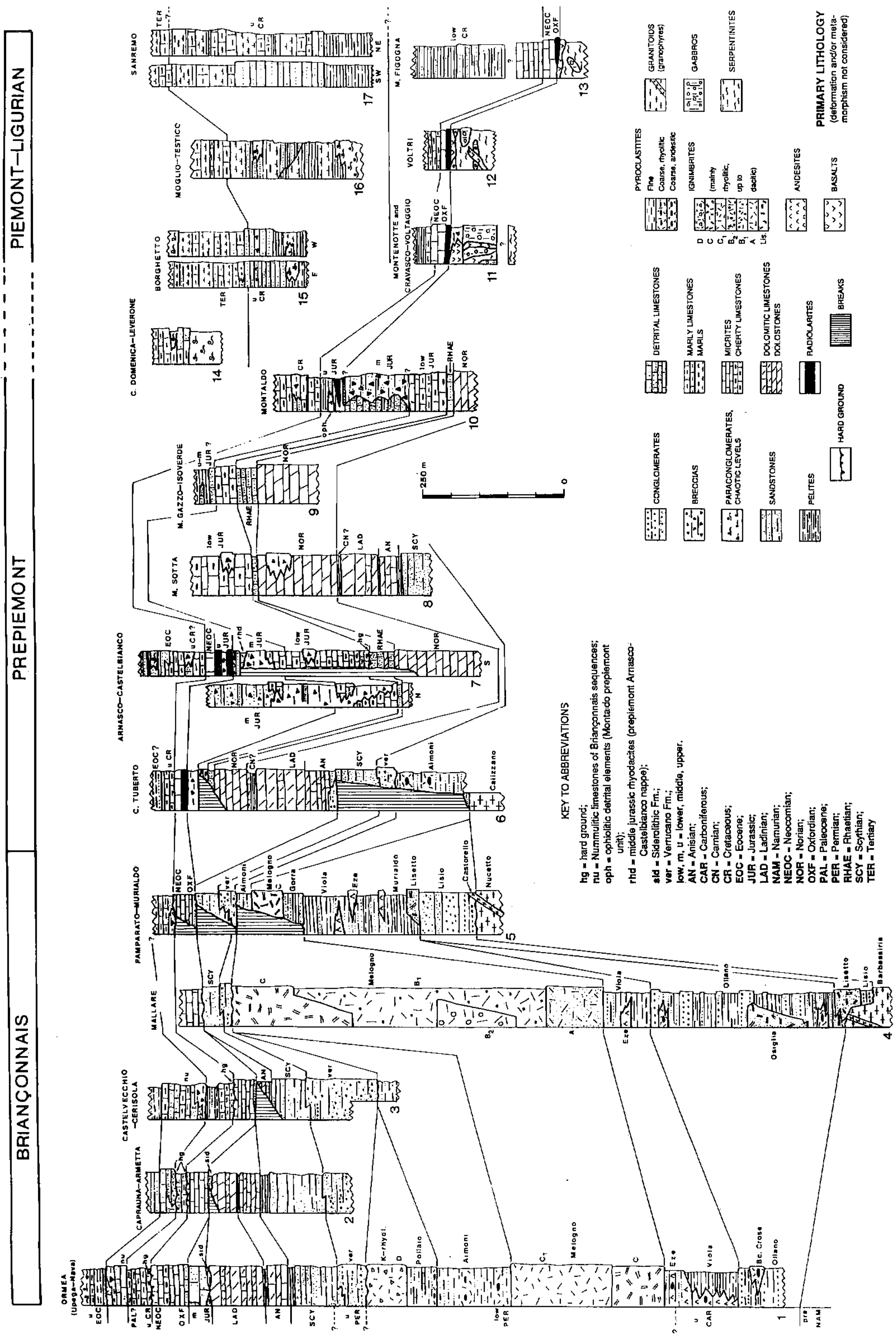



Fig. 3 — Hypothetical pre-Mesozoic evolution of the outer-intermediate (left) and inner (right) Ligurian Briançonnais sectors. The oldest steps (Figs. A, B, C) are described in the text.
After the main orogenic Variscan, probably Sudetian phase, arkosic sediments (Lisio Fm., 8) were first emplaced. During Late Westphalian-Stephanian times, a tensile - or transtensile - tectonic activity (Asturian phase) generated intracontinental grabens and, in inner sectors, also the emplacement of the first rhyolitic ignimbrites (C. Lisetto, 9), probably contemporaneously with granophyric dikes (Rio Castorello Granophyres, 9a) and rare granodioritic bodies (Borda Granodiorites, 10). In the outer-intermediate sectors, the subsiding grabens were progressively filled up by fine and coarse fluvial-lacustrine sediments (Ollano Fm., 11), with locally interfingered ignimbrites (Osiglia "Porphyres", 9) and pyroclastites (Bric Crose Tuffs, 9b). During Stephanian times, mostly fine, continental sediments (Viola, Gorra and Murialdo Fms., 12) were deposited. They are associated with andesitic lavas and pyroclastites (Eze Fm., 13), which are generally fine-grained, but display also very coarse textures (from lahars?) in the outermost sectors. In Early Permian times, a very thick sequence of volcanic products, mostly rhyolitic, with very poorly represented graphitic (marsh environments?) and carbonatic (of probable evaporitic origin) sediments, were erupted (Melogno Fm., 14). The only member of the Melogno Fm., which was probably poured out all over the Briançonnais and Prepiemont Zones, is the topmost D Lithozone (15), which is represented by characteristic K-rhyolites. At the end of Permian times, the last (Saalian) faulting phase, was not accompanied by volcanism, but produced suitable gradients for erosion and transport of mostly coarse Briançonnais Verrucano (16) clastic components (after Vanossi, 1991).

**Table — Schematic logs of the main tectonic units in the Ligurian Alps.**
The sequences are arranged in their hypothetic paleogeographic order, from outer (left) to inner (right) domains. On sides of the logs, both the formational and chronostratigraphic and/or the main lithologic names are indicated (after Vanossi, 1991).



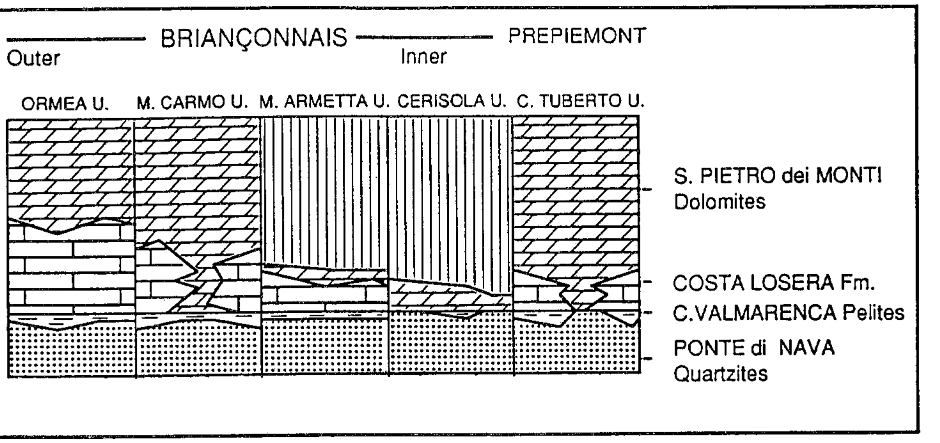



Fig. 4 — Sketch of the stratigraphic relationships among the Triassic sequences in the Ligurian Alps. Vertical hatching indicates breaks in the record (after Lualdi and Bianchi, 1990, modified).

deposition (*Capo Noli Fm.*; Lualdi, 1991).

In contrast with "classic" Briançonnais sequences, and perhaps as a consequence of a somewhat still obscure geodynamic event, during Upper Triassic times the Ligurian Briançonnais shelf stops subsiding and the sediments become very rare, thin, and diastemic. By the beginning of Jurassic (or possibly earlier) times, the domain is subject to full emersion and erosion, giving karsts and residual red soils (*"Siderolithic"*); and the regional uplift grows by steps towards the inner sectors (i.e. the future ocean side). Thus, while in the outer areas the Ladinian dolostones are still preserved (columns 1, 2), in the innermost regions the Upper Jurassic limestones may directly overlie pre-Verrucano tegument rocks (column 5).

Announced in the outer sectors by neritic limestones of Dogger age (*Rio di Nava Lms.*), the sea suddenly covers the whole domain during the Upper Jurassic; the spreading of the nearby Piemont-Ligurian ocean induces rapid sinking of the European continental passive margin: the land is driven back far to the west and the Malm sedimentation begins almost directly with pelagic limestones (*Val Tanarello Lms.*).

By the end of Lower Cretaceous, perhaps in connection with transition from passive to active behaviour of the paleo-European continental margin, pelagic sedimentation becomes highly condensed and a *hard ground* (Aptian-?Cenomanian) is laid down (Lualdi et al., 1989).

The following period, up to Paleocene, is dominated by hemipelagic calcareous deposits. Tectonic influences on sedimentation are different in external and internal sectors (breccias generated in transpressive fault zones and hard ground of a second generation: columns 2 and 3 respectively).

With no convincing proof of general emersion (but Lower Eocene deposits are poorly documented by fossils), sedimentation evolves to Middle Eocene *"nummulitic limestones"* and comes to an end during Priabonian times: hemipelagic and turbiditic sequences of this age, locally incorporating great volumes of breccias, are overlaid by olistostromes fed by the Helminthoid Flysch progressing nappes.

**Prepiemont l.s. domain and Triassic-Liassic sequences of uncertain provenance**

In the Ligurian Alps, klippen characterized by stratigraphic sequences more or less different from one another (Table, columns 6 to 10), but almost always lacking pre-Triassic basement, and all being marked by the presence of Triassic-Liassic carbonates (which display evolution from a shelf to basin environment), are found in three distinct tectonic positions: *I)* on the Briançonnais nappes, both at their external, south-western *(Ia)* and internal, northern *(Ib)* margins (Fig. 3); *II)* on the Piemont-Ligurian oceanic complexes ("Voltri Group"); and *III)* within the

"Sestri-Voltaggio Zone".

There is general agreement on attaching klippen *Ia* to the Prepiemont domain; this same paleogeographic attribution seems highly probable for klippen *Ib*; discussion is still open (European, Adrian, or "mid-way" microcontinent provenance) for klippen *II* and *III*, though some arguments (Vanossi et al., 1986) point to a paleo-European solution.

Putting together all the data from the various klippen *Ia* (columns 6 and 7), one gets the following *ideal* stratigraphic sequence, well depicting the passive behaviour of the paleo-European continental margin from Triassic to Lower Cretaceous times: coarse to fine clastic lower Triassic deposits directly rest on their Variscan basement (this condition is exceptionally still preserved at the southern edge of the Calizzano "massif": Dallagiovanna, 1988), without any interposed Permian-Carboniferous tegument, thus indicating that during this time-span the future Prepiemont domain was the source-area for the Briançonnais continental deposits.

A Middle Triassic carbonate sequence of subsiding shelf facies, similar to that of the Briançonnais , follows; it ends with Carnian (?) evaporites, in turn overlain by a second Norian carbonate deposition (first tidal flat, then open shelf facies; *M. Arena Dolomites, Veravo Lms.*), rapidly evolving (after a short period of rest, leaving a Hettangian hard ground: Lualdi, 1986) to cherty limestones of basinal environment (*Rocca Livernà Lms.*).

The sinking of the continental margin is accompanied (Upper Lias-Dogger) by the production of megabreccias (*M. Galero Breccias*), whose huge volumes (column 7) strongly suggest important strike-slip components of movement along marginal faults (transtensile system). Volcanic activity is locally recorded near the top of the breccias (Cortesogno et al., 1981). By the beginning of Upper Jurassic, the domain reaches the depth of the adjoining oceanic areas and receives the same sedimentation: radiolarites (Malm: *Arnasco Radiolarites*), then pelagic *Calpionella* limestones (Lower Cretaceous: *Menosio Lms.*). Ophiolitic detrital supply - known at this stage in the klippen *Ib* only (Montaldo unit: see colums 10, after Dallagiovanna and Vanossi, 1991) - is completely lacking.

Upper Cretaceous sediments are unknown (condensation as a consequence of change from passive to active margin?), though foraminifera of this age appear reworked in Eocene turbidites, forming the top of the Prepiemont sequence. As happens in the Briançonnais domain, this is stopped by olistostromes from Helminthoid Flysch nappes (column 7, right).

## Piemont-Ligurian (oceanic) sequences

Nappes believed to derive from the oceanic basin belong in two main groups: *1)* ophiolitic bodies with their sedimentary pre-flysch cover, forming Alpine polyphase metamorphic units, all over printed by an early (eo-Alpine?) high pressure event; *2)* substantially non-metamorphic Helminthoid Flysch units, always detached from their original unknown basement.

### *Pre-flysch ophiolitic sequences (Table, numbers 11 to 13)*

These form a number of tectonic units (Units of the "Voltri Group"; Cravasco-Voltaggio and Montenotte Units), issued from more or less complete sections of oceanic lithosphere (Piccardo, 1986).

The upper mantle peridotites are most commonly represented, both in the Voltri Group and in the Montenotte Unit, by antigoritic serpentinites (columns 11 and 12); these derive from tectonitic lherzolites coming from a partially depleted mantle. The serpentinites show primary association, locally still preserved, with metagabbros (from fractional crystallization of N-MORB tholeiitic melts); they both underwent eclogitic (Voltri Group) or blueschist (Montenotte Unit) conditions, probably eo-Alpine in age, which later evolved through polyphase retrograde metamorphism to Greenschist Facies (see also Fig. 5).

A somewhat peculiar and comparatively rare type of mantle rock is represented by the tectonitic lherzolites of the Erro-Tobbio unit of the Voltri Group: they show only partial serpentinization, but their Alpine metamorphic history appears to be marked by complex prograde and retrograde evolution similar to that affecting Voltri and Montenotte peridotites (Scambelluri and Piccardo, 1989).

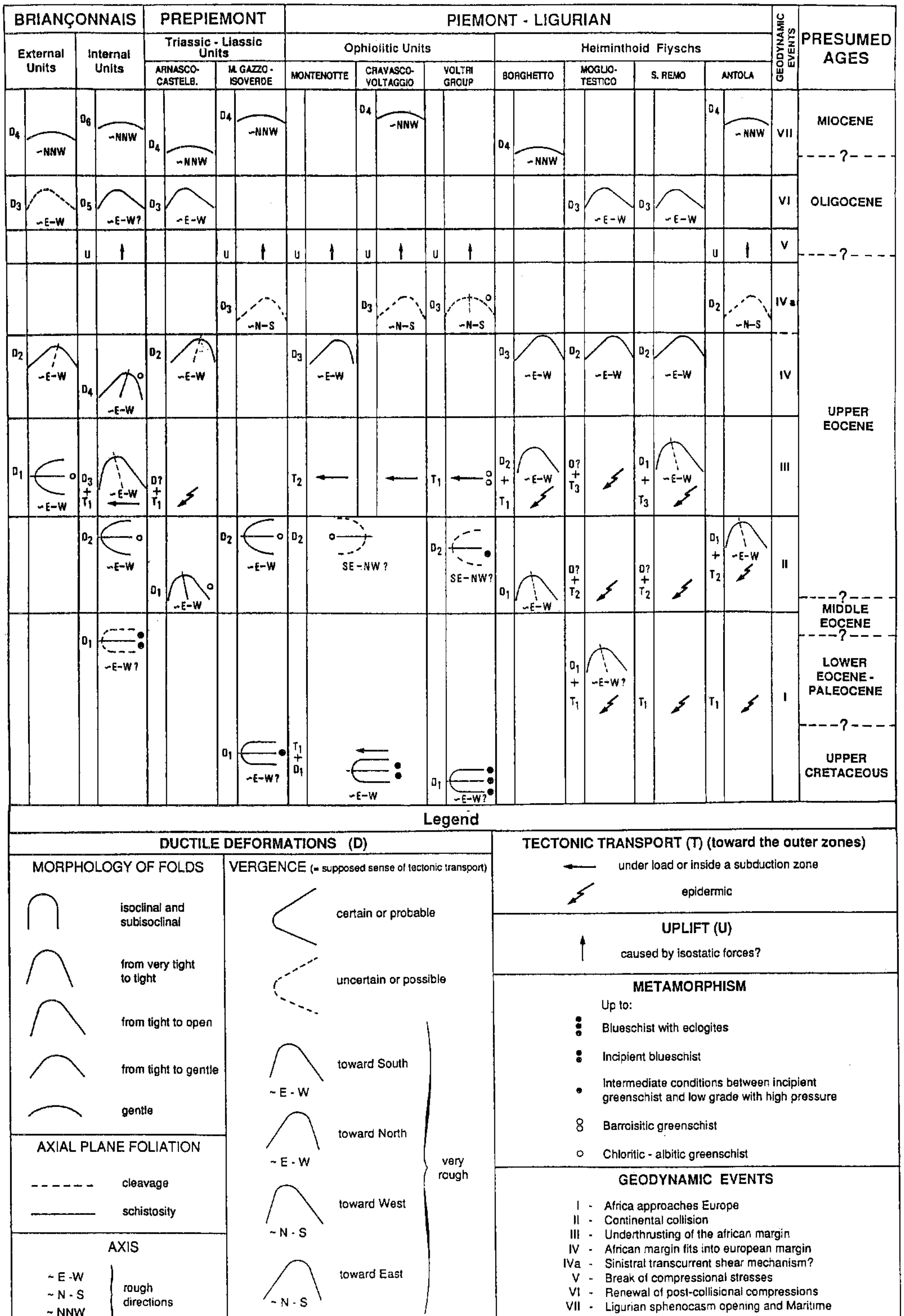



Fig. 5 — Alpine tectonic-metamorphic evolution in the Ligurian Alps, tentative time-correlation of phases in the different domains and suggested corresponding geodynamic events (after Vanossi et al., 1986, slightly modified).

The upper oceanic crust is presently represented by prasinites coupled with calcschists, usually forming independent units, separated by detachment planes from serpentinites and metagabbros. The prasinites derive from N-MORB tholeiitic basalts; the calcschists were their original sedimentary cover, sometimes beginning with metaquartzites and marbles, respectively comparable with Upper Jurassic radiolarites and lowermost Cretaceous *Calpionella* limestones resting on the ophiolitic, practically non-metamorphic sequences of the Ligurian units in the Northern Apennines.

The lithologic and stratigraphic comparability of calcschists with Lower and Middle Cretaceous Apenninic sediments, and the assumption that the high pressure metamorphic event - though undated in the Ligurian Alps - falls in the eo-Alpine phase, lead to the belief that the top of the pre-flysch sequence should not be younger than the base of the Upper Cretaceous.

*Helminthoid Flyschs (Table, columns 14 to 17)*

These consist of three main distinct tectonic units, namely the "Borghetto d'Arroscia-Alassio", the "Moglio-Testico", and the "S. Remo-M. Saccarello".

Though characterized by some distinguishing features, they all represent thick turbiditic series, beginning with a "basal complex" formed by manganesiferous, thin arenitic-pelitic rhythms. In Borghetto and S. Remo Units, these are frequently covered by massive sandstones and conglomerates deposited in proximal deep-sea fans (Galbiati, 1986; Sagri, 1986). In all the units, the top is mainly represented by calcareous turbidites typical of basin-plain deposition.

As is usual in flysch deposits, fossils are rare and frequently reworked; hence, some uncertainties exist about the exact time-span covered by each of the three series. Most probably, their base is always Upper Cretaceous (Cenomanian-Turonian?); Lower Eocene faunas have been found only in the upper part of the Borghetto sequence and in the Colla Domenica-Leverone sub-Unit; the top of the Moglio-Testico and S. Remo series might well reach the lowermost Tertiary, or be confined in the Uppermost Cretaceous.

Because the original basement of the flysch series is presently lacking, their oceanic provenance cannot be directly demonstrated. This is nevertheless supported by a good number of independent arguments (Vanossi et al., 1986): the highest geometric position in the nappe building, coupled with evidence of tectonic transport towards the foreland; no available room for flysch sedimentation in the Briançonnais and Prepiemont domains; supply of terrigenous materials from paleo-European continent; local findings of ophiolitic olistolites; etc.

## GENERAL STRUCTURE

For the sake of simplicity, the Ligurian Alps can be divided into five main sectors (Fig. 1), roughly corresponding to outcrops of different groups of units (see also Vanossi et al., 1986; Vanossi, 1991).

From SW to NE, i.e., approximately from present-day outer to inner zones, these are: 1) the "Autochtonous" Dauphinois Zone; 2) the Helminthoid Flysch Zone; 3) the Briançonnais and Prepiemont Zone; 4) the Voltri Group; and 5) the Sestri-Voltaggio Zone.

The Dauphinois Zone - whose structure is not treated here - forms in its south-eastern sector the tectonic base of the S. Remo Helminthoid Flysch nappe. The contact comprises a more or less wide belt, composed of olistostromes fed by the S. Remo Unit and, expecially towards NW, of "Sub-Briançonnais" tectonic slices, made up mainly of Eocene Flysch deposits.

### Helminthoid Flysch Zone

The geometric relationships among the three main already mentioned units are best seen in south-eastern sectors, where they have not been completely upset by late deformations and where, from geometric top to bottom, the superposition order is "S. Remo"-"Moglio-Testico"-"Borghetto". By the interposition of a small tectonic element ("Colla Domenica-Leverone" sub-Unit, n. 14 in the Table), accompanied by olistostromes, the Borghetto Unit covers in turn the Prepiemont Arnasco-Castelbianco and C. Tuberto klippen.

Contacts between the different flysch units are characteristically marked by olistostromes.

In particular, in Borghetto and Moglio-Testico Units, these deposits - forming the top of each series - are almost only formed by elements of the basal complexes, and are in turn covered by the overlying flysch nappe, whose base begins with chaotic horizons, mostly composed of crumpled beds from the same basal complexes.

This peculiar setting, coupled with the absence of unquestionable datings, has given rise to different interpretations, among which that of a unique stratigraphic flysch sequence.

Nevertheless, in most authors' opinion, three main tectonic flysch units do exist; their present relationships might be explained, for instance (Di Giulio, 1988), as at least partially deriving from mud diapirism phenomena and mud ridge development in the basal complexes during the early stages of the progressive superposition of flysch nappes over each other, within an accretionary prism.

**Briançonnais and Prepiemont Zone**

The general structure of this zone, forming the central part of the chain, may be briefly outlined as follows:

the widest part of the Zone is built up from the lower Briançonnais units, partially overriding each other and, at some depth, probably thrust onto Dauphinois domain. During the orogenesis, their original contiguity seems to have been preserved. Their stratigraphic series may locally begin with pre-Namurian metamorphic basement; the upper Carboniferous-Permian tegument, though characterized by different facies and thickness, follows everywhere, and is in turn overlain by the Meso-Cenozoic cover, which appears more and more reduced from outer (and lower: Table, column 1) to inner (and higher: Table, columns 2 to 5) units.

Two main groups of rootless upper tectonic units, from different paleogeographic domains, rest on the lower Briançonnais units. Many of them form isolated klippen of small width, so that nowhere is the entire pile of units visible. Correlations - sometimes open to different interpretations - among separate klippen are based on the identity of a) the relative geometric position; b) the stratigraphic series; and c) the tectonic and metamorphic Alpine evolution.

The first group, settled in a more or less external (south-western) position, comprises, from geometric bottom to top (Fig. 2):

- Briançonnais cover (Permian-Triassic to Eocene) nappes, from intermediate (Caprauna-Armetta Unit: Table, column 2) or inner (Castelvecchio-Cerisola Unit: column 3) paleogeographic sectors;

- innermost Briançonnais and/or Prepiemont basement nappes (Calizzano, Loano "massifs");

- Prepiemont covers (C. Volte, C. Tuberto and Arnasco-Castelbianco Units: columns 6 and 7), ranging from Triassic to Eocene terrains.

The second group, cropping out at the internal (northern) Briançonnais margin, shows, from geometric bottom to top, the following ideal pile (Fig. 2):

- small decollement klippen formed from inner Briançonnais reduced cover (Deviglia; Bc. Garofano);

- innermost Briançonnais and/or Prepiemont basement nappes (top: Bagnaschino Unit, with Alpine blueschist metamorphism: Cabella et al., 1991; bottom: Pallare, Savona "massifs", with Alpine Na-amphibole greenschist metamorphism);

- Prepiemont Triassic-Liassic klippen (Balzo; Monte Sotta: column 8 of Table; Villanova) and Jurassic-Cretaceous units (e.g. Montaldo: column 10). Most probably, these latter represent the original stratigraphic cover of the Triassic-Liassic sequences (Dallagiovanna and Vanossi, 1991; Dallagiovanna, unpublished data); they are characterized by rare Jurassic ophiolitic olistolites; Middle Jurassic heterometric and heterogeneous breccias (up to 100 m thick), underlying the Upper Jurassic radiolarites, and Lower Cretaceous mostly carbonate breccia levels;

- Piemont-Ligurian ophiolitic unit (Montenotte nappe: column 11).

### Voltri Group

This group is essentially made up of a pile of Piemont-Ligurian ophiolitic units. Presently, as a result of late deformations, it appears to be marginally overthrust by the Savona "massif" along the Celle-Sanda line in the SW, and by the Sestri-Voltaggio Zone along the homonymous line in the E.

Studies being still in progress, the general structure, as outlined below (mainly after Messiga and Piccardo, 1980) cannot be considered definitive.

The present Voltri Group seems to derive from a polyphase deformation of an eo-Alpine (?) mega-anticline, with an originally nearly horizontal axial plane. The core of the fold would be occupied by serpentinites and eclogites, while the units composed of prasinites and calcschists should form the limbs.

This structure is overthrust onto the basement of the Valosio "massif", thought to belong in the Prepiemont domain, and is in turn discontinuously covered by the Erro-Tobbio lherzolites. On this ensemble, small klippen of the Piemont-Ligurian Montenotte Unit are found, locally supported by remnants of an unnamed Triassic-Liassic tectonic unit.

### Sestri-Voltaggio Zone

This narrow N-S trending belt, cropping out in the far east of the Ligurian Alps, is composed (Cortesogno and Haccard, 1986), from geometric bottom to top, of the following three main tectonic units:

- Triassic-Liassic sequence (M. Gazzo-Isoverde Unit: Table, n. 9), of presumed Prepiemont origin (see discussion in Vanossi et al., 1986);

- Piemont-Ligurian ophiolitic unit (Cravasco-Voltaggio: Table, n. 11), believed to be the eastern equivalent of the Montenotte Unit, with which it shares stratigraphic sequence and Alpine tectono-metamorphic evolution;

- M. Figogna Unit (Table, n. 13), displaying a sequence (from ophiolitic base up to Middle Cretaceous flysch formations) well comparable with Ligurian Northern Apenninic series; its early metamorphic imprint is somewhat intermediate between blueschist conditions affecting the underlying Cravasco-Voltaggio Unit and very low grade metamorphism attained by the overlying first Apenninic units.

## ALPINE TECTONO-METAMORPHIC EVOLUTION

### Data

Fig. 5 shows a greatly simplified scheme of the principal structural and metamorphic data as far as they are known today. It deserves some comments.

- The paleogeographic order, from external (left) towards internal domains, is obviously not respected, for graphic reasons, for the whole set of flysch units, which should probably be placed somewhere over the set of ophiolitic units (cfr. stratigraphic columns of Table). Of course, inside each of these two sets, units are arranged from presumed outer (left) to inner paleogeographic sector.

- The arrows indicating tectonic transport or uplift have been drawn on the basis of indirect evidence or tectogenetic assumptions.

- While in each vertical column the chronologic order of folding and metamorphism phases follow from field and microscope direct evidence, the horizontal time-correlations should be regarded only as probable (or, in some cases, as merely possible).

- Time-correlations between each folding and metamorphic phase inside each unit are simplified: in fact, metamorphic climax may sometimes just precede or follow the folding event.

- In general, the first deformation events are only documented by folds or foliations visible at the meso-or micro-scale of observation, while the corresponding megastructures are unknown. The question whether they were generated as complete overturned folds or as thrust sheets in between shear zones is open.

- On the contrary, the late ductile deformation events have generally left poor evidence at the meso-scale, while their influence on previous folds clearly appears as interference patterns at the macro-scale.

**Chronologic constraints and speculations**

The presumed ages indicated on the right side of Fig. 5 derive from the following considerations.

No important unconformities having been observed inside the stratigraphic sequences of the different domains, in general the first compressional event has obviously been considered slightly younger than the top of the corresponding deformed series; yet, datings of this are generally imprecise.

The first event affecting the pre-flysch ophiolitic sequences was considered eo-Alpine (Upper Cretaceous) without proof, just because this age has been proposed or documented for similar units in other western Alpine regions (see, e.g., Polino et al., 1990 and references therein).

One of the clearest chronologic constraints is represented by the regional unconformity which separates the nappe system of the Ligurian Alps, already backfolded and uplifted, from the overlying terrains, on the whole only slightly deformed, forming the well known marine sequence of the "Ligurian-Piemont Tertiary Basin" (Fig. 1). Its base falls mainly in the Oligocene and becomes somewhat younger towards the west. But intramontane continental deposits of Lower Oligocene age locally (S. Giustina, Sassello, Bagnasco) preceded the marine transgression, thus indicating that the last important tectonic event in the inner (presently northern) side of the Ligurian Alps was already over.

In the outer sectors the same relationship is documented by the transgressive "Pietra di Finale", whose base falls in Lower Oligocene times.

At the far south-western side, the top of the Dauphinois Ventimiglia flysch, covered by the S. Remo Helminthoid Flysch nappe, has probably an uppermost Eocene age.

Lastly, the NNW-trending phase has tentatively been given a Miocene age because of its possible connection with the Northern Apennines Langhian event.

**Tectogenetic model**

Within the framework of data and interpretations listed in the preceding pages, a highly conjectural tectogenetic model (see Vanossi 1991, for details and graphic presentation) would provide the following principal stages:

- Upper Cretaceous: subduction, mainly intra-oceanic, event, coeval with Helminthoid flysch deposition, progressively involving - along a complex shear zone, where some tectonic superpositions are already in act - Voltri Group Units, the Montenotte Unit, part of the Prepiemont basement (Valosio) and cover: innermost Triassic-Liassic (M. Gazzo-Isoverde; Villanova) and Jurassic-Cretaceous (Montaldo) Units.

- Lower-Middle Eocene: Europe continues to approach Adria and, in some way connected with the stress field, the exhumation of the Voltri Group begins, along the contact plane between Prepiemont basement and its cover; contemporary deformations and intrabasinal superpositions of flysch units occur; tectono-metamorphic phenomena prograde towards outer sectors, accompanied by the development of an ensialic underthrust zone within inner Briançonnais.

- Middle-Upper Eocene: continental collision and "intercutaneous" exhumation of the Voltri Group and Erro-Tobbio Unit, beneath their tectonic cover, represented by Montenotte and Triassic-Liassic Units; progressive piling and transport towards the external sectors of Flysch and Prepiemont Units, dragging at their base inner Briançonnais rootless units, whose exhumation is in progress.

- Uppermost Eocene: underthrusting and subsequent indenting of the Adrian north-western margin into the European one, first accompanied by further outward transport of rootless units, then by backfolding of previous Europe-verging structures.

Oligocene: tectonic progradation of the already sutured Adrian-Briançonnais wedge on the outer Dauphinois belt, accompanied by a gentle folding phase of the migrating block, more pronounced in the sectors nearer to its front.

- Lower Miocene: sinistral rotation of the Ligurian Alps, along sub-horizontal deep-seated shear planes, connected with the Ligurian sphenocasm opening and, consequently, birth of roughly Apenninic-oriented deformations (see also Perotti et al., 1994).

**Acknowledgements.** The research was supported by the Consiglio Nazionale delle Ricerche (project "Mobilità tettonica neogenica e recente nelle Alpi e nelle aree peripadane") and by M.U.R.S.T. 40% grant.

## REFERENCES

Cabella R., Cortesogno L., Dallagiovanna G., Gaggero L. e Luchetti G.; 1991: *Metamorfismo alpino a giadeite+quarzo in crosta continentale nel Brianzonese ligure*. Atti Tic. Sc. Terra, **34**, 43-54.

Cabella R., Cortesogno L., Dallagiovanna G., Vannucci R. e Vanossi M.; 1988: *Vulcanismo, sedimentazione e tettonica nel Brianzonese ligure esterno durante il Permo-Carbonifero*. Atti Tic. Sc. Terra, **31**, 269-326.

Cortesogno L., Dallagiovanna G., Gaggero L. and Vanossi M.; 1993: *Elements of the Paleozoic history of the Ligurian Alps*. In: von Raumer J.F. and Neubauer F. (eds), Pre-Mesozoic Geology in the Alps, Springer-Verlag, 257-277.

Cortesogno L., Dallagiovanna G., Vannucci R. et Vanossi M.; 1988a: *Volcanisme, sédimentation et tectonique pendant le Permo-Carbonifère en Briançonnais ligure: Une revue*. Ecl. geol. Helv., **81**, 487-510.

Cortesogno L., Dallagiovanna G. et Vanossi M.; 1988b: *Paléogéographie du Briançonnais ligure d'après les lithoclastes des formations permo-carbonifères*. Géol. Alpine, Mém. h.-série, **14**, 9-28.

Cortesogno L. e Haccard D.; 1986: *Note illustrative alla Carta Geologica della Zona Sestri-Voltaggio*. Mem. Soc. Geol. It., **28**, 115-150.

Cortesogno L., Oxilia M., Royant G., Vanossi M. et Vivier G.; 1981: *Témoins d'un volcanisme rhyodacitique du Dogger dans le domain prépiémontais des Alpes ligures*. Ecl. geol. Helv., **74**, 569-585.

Dallagiovanna G.; 1989: *Testimonianze e significato di una trasgressione permo-triassica sul basamento cristallino del Brianzonese ligure interno*. Boll. Soc. Geol. It., **107**, 445-451.

Dallagiovanna G. e Vanossi M.; 1991: *Itinerario n. 7*. In: Vanossi M. (ed), Guide Geologiche Regionali, Alpi Liguri, BE-MA, Milano, pp. 163-185.

Del Moro A., Pardini G., Messiga B. e Poggio M.; 1981: *Dati petrologici e radiometrici preliminari sui Massicci cristallini della Liguria Occidentale*. Rend. S.I.M.P., **38**, 73-87.

Di Giulio A.; 1988: *Possibile interpretazione attualistica delle facies caotiche dei flysch della Liguria Occidentale*. Atti Tic. Sc. Terra, **31**, 156-164.

Galbiati B.; 1986: *L'Unità di Borghetto d'Arroscia-Alassio*. Mem. Soc. Geol. It., **28**, 181-210.

Lualdi A.; 1986: *Early Sinemurian hardgrounds in the Ligurian Alps, Northwestern Italy (Prepiemontese domain, Arnasco-Castelbianco unit)*. Ecl. geol. Helv., **79**, 365-384.

Lualdi A.; 1991: *Aggiornamenti alla stratigrafia triassica nelle Alpi liguri (Brianzonese e Prepiemontese)*. Rend. Soc. Geol. It., **14**, 75-78.

Lualdi A. e Bianchi U.; 1990: *La formazione di Costa Losera: una nuova unità stratigrafica dell'Anisico delle Alpi Liguri (Brianzonese e Prepiemontese)* Atti Tic. Sc. Terra, **33**, 33-62.

Lualdi A., Menardi Noguera A. and Mosna S.; 1989: *Poliphase hardgrounds from the Aptian-?Cenomanian of the Maritime Alps, NW Italy. (Ligurian Briançonnais domain, Marguareis-Besimauda and Ormea units)*. Boll. Soc. Geol. It., **108**, 41-57.

Lualdi A. e Seno S.; 1986: *Osservazioni stratigrafiche e tettoniche nella zona del Rio di Nava (Brianzonese ligure esterno, unità di Ormea)*. Mem. Soc. Geol. It., **28**, 493-503.

Messiga B. and Piccardo G.B.; 1980: *Metamorphic ophiolites of the Voltri Massif and the Montenotte Nappe, Western Liguria. Field Excursion Guide-book*. VIth Ophiolite Field Conference.

Perotti C.R., Seno S. and Vanossi M.; 1994: *The crust-mantle boundary in the Ligurian area: geological and geodynamic implications*. Boll. Geof. Teor. Appl, **36**, 63-75.

Piccardo G.B.; 1986: *Le ofioliti metamorfiche del Gruppo di Voltri, Alpi liguri: caratteri primari ed interpretazione geodinamica*. Mem. Soc. Geol. It., **28**, 95-114.

Polino R., Dal Piaz G.V. and Gosso G.; 1990: *Tectonic erosion at the Adria margin and accretionary processes for the Cretaceous orogeny of the Alps*. In: Roure F., Heitzmann P. and Polino (eds), Deep structure of the Alps. Mém. S. G. F., **156**; Mém. Soc. géol. Suisse, **1**; Vol. spec. Soc. Geol. It., **1**, 345-367.

Sagri M.; 1986: *Litologia, stratimetria e sedimentologia delle torbiditi di piana di bacino del flysch di San Remo (Cretaceo superiore, Liguria occidentale)*. Mem. Soc. Geol. It., **28**, 577-586.

Scambelluri M. and Piccardo G.B.; 1989: *The Alpine metamorphic evolution of the Erro-Tobbio peridotite in the framework of the alpine history of the Voltri Massif*. In: Piccardo G.B. and Vissers R.L.M. (eds), Excursion guide-book on Erro-Tobbio peridotite, June 26-28.

Vanossi M. (ed); 1991: *Guide Geologiche Regionali. Alpi Liguri*. BE-MA, Milano, 295 pp.

Vanossi M., Cortesogno L., Galbiati B., Messiga B., Piccardo G. e Vannucci R.; 1986: *Geologia delle Alpi liguri: dati, problemi, ipotesi*. Mem. Soc. Geol. It., **28**, 5-75.