Ofioliti, 2001, 26 (2a), 161-164

TECTONIC EVOLUTION OF THE VOLTRI GROUP AND SESTRI VOLTAGGIO ZONE (SOUTHERN LIMIT OF THE NW ALPS): A REVIEW

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Keywords: *structural evolution, kinematics, folds, thrusts. Voltri Group, Sestri-Voltaggio Zone, NW Alps.*

EXTENDED ABSTRACT

INTRODUCTION

The present note summarizes the kinematics of the Voltri Group and the Sestri-Voltaggio Zone (Fig. 1) inferred from new structural data. These data have been collected during fieldworks performed by the authors since 1983 up to now in the Voltri Group and the Sestri-Voltaggio Zone.

The Voltri Group is a metaophiolitic massif with metasediments (Chiesa et al., 1975), cropping out in central Liguria (Italy). It encompasses several units, re-equilibrated up to different metamorphic P-T peak conditions, which afterwards suffered common deformation and folding. The units of the Voltri Group suffered eclogite to blueschist facies (HP-LT) peak conditions during a subduction event, followed by decompression down to greenschist facies conditions during the exhumation process (Messiga and Scambelluri, 1991; Capponi and Crispini, 1990; Cabella et al., 1994 and references therein). At present, greenschist facies assemblages prevail at a regional scale. The Sestri-Voltaggio Zone occurs at the eastern margin of the Voltri Group and encompasses three units: the Trias-Lias Unit, the Cravasco-Voltaggio Unit and the Monte Figogna Unit (Cortesogno and Haccard, 1984). Also these units were involved in the Alpine subduction-related tectonic events and underwent metamorphic re-equilibration up to different degrees characterized by blueschist facies (Trias-Lias and Cravasco-Voltaggio Units) and pumpellyite-actinolite facies (Monte Figogna Unit) peak metamorphic conditions, later re-equilibrated in lower metamorphic conditions (albite-chlorite-epidote mineralogical associations).

The tectonic limit between the Voltri Group and the Sestri-Voltaggio Zone is known as the Sestri-Voltaggio Line. Since the end of the last century it drew the attention of the geologists for its peculiar position among units with different metamorphic and structural characteristics. The Sestri-Voltaggio Line played different geodynamic roles in the

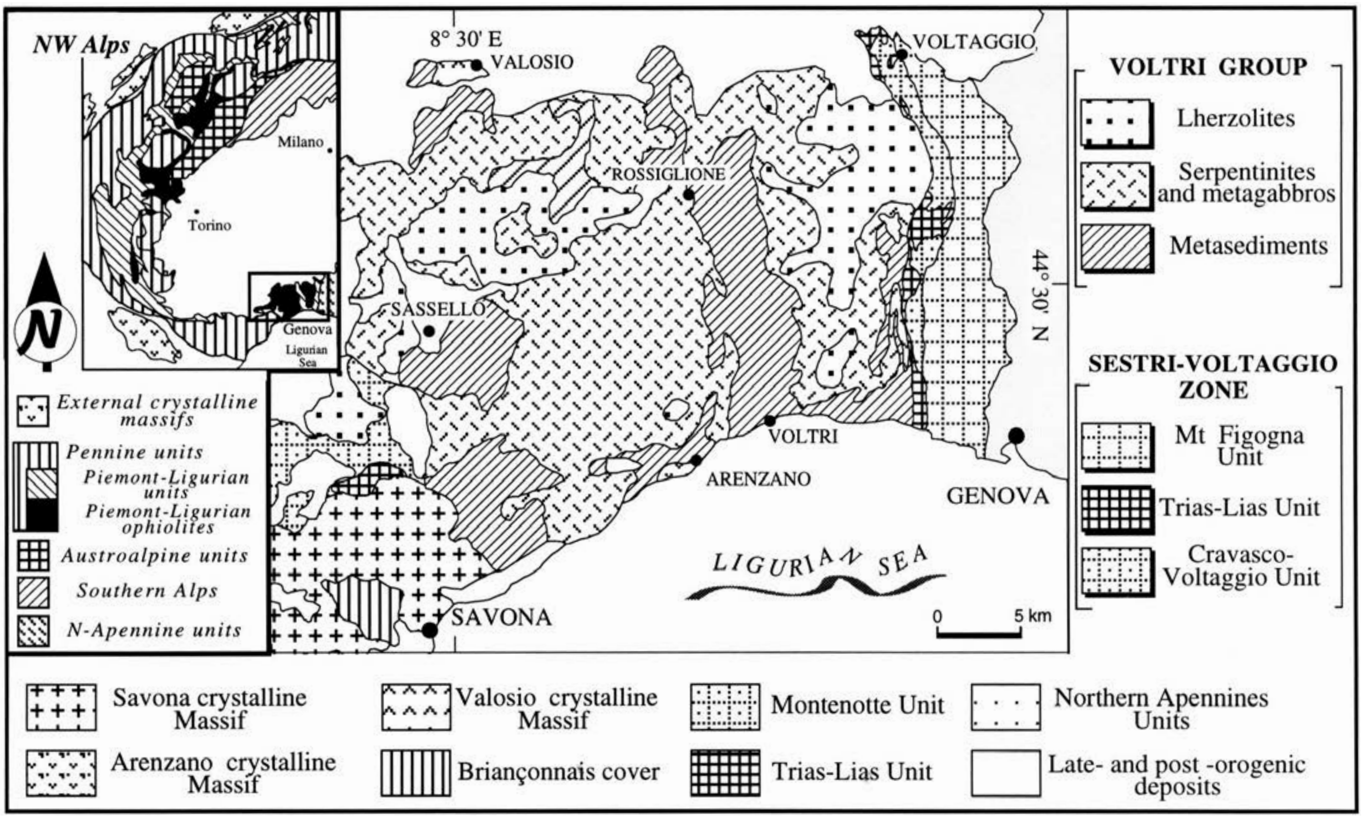

Fig. 1 - Tectonic sketch map of the Voltri Group and the Sestri-Voltaggio Zone.

models proposed by the authors; it was interpreted as a stratigraphic boundary, for example the limit between the “falda delle Pietre Verdi” and the “falda ligure-toscana” by Rovereto (1939), or it was interpreted as a tectonic boundary, for example as a “trasformante” (= transform) fault by Elter and Perusati (1973), a thrust contact in Cortesogno and Haccard (1984) and, more recently, as an extensional fault by Hoogerduijn Strating (1994).

STRUCTURAL EVOLUTION, TECTONIC SETTING AND KINEMATICS OF THE VOLTRI GROUP

The analysis of the Voltri Group metasediments (where deformations are better recorded) reveals a complex structural evolution developed in a rotational shear strain regime (Hoogerduijn Strating, 1991; Crispini, 1996). The folding evolution can be summarized with five distinct superimposed folding events (from pre-$D1_{VG}$ to $D4_{VG}$) recognized in all the Voltri Group units. In general, the structures related to the high-pressure metamorphic stages (pre-$D1_{VG}$ structures) are preserved as micro- to mesoscopic unrooted folds in relic boudins (Capponi, 1991; Crispini, 1996), whereas the main folding events ($D1_{VG}$ -$D2_{VG}$ -$D3_{VG}$) are coeval with the decompressive evolution down to greenschist facies metamorphism. $D1_{VG}$ and $D2_{VG}$ folds occur from mm- to km-scale; they are tight to isoclinal in shape, with schistosity parallel to the axial plane which represents the main foliation at the regional scale. In the sector of the Voltri Group close to the Sestri-Voltaggio Zone this foliation is N-S striking and steeply dipping to the E. In most cases $D1_{VG}$ folds are severely transposed by $D2_{VG}$ schistosity; only in places type 3 and rarely type 2 interference patterns (Ramsay, 1967) due to the superposition of the $D2_{VG}$ onto the $D1_{VG}$ folds have been observed. $D1_{VG}$ and $D2_{VG}$ folds are strongly non-cylindrical with axes nearly parallel to $D2_{VG}$ stretching lineations. $D1_{VG}$ -$D2_{VG}$ related meso- and microstructures (such as asymmetric δ- and σ-type mantled porphyroclasts) are characteristic of non-coaxial progressive deformation and suggest a shear strain regime characterized by minimum values of $\gamma \approx 10$, calculated from shear zones and inclusion patterns in rotated porphyroblasts (Crispini, 1996; Crispini and Capponi, 1997). Due to the multiple repetitions of the stratigraphic sequence by the early folding and transposition events and the complexity added by the later deformations, no information about the vergence of the $D1_{VG}$ - $D2_{VG}$ folds can be derived with confidence.

$D1_{VG}$ - $D2_{VG}$ folds and structures are then overprinted by mylonitic structures (Dml_{VG}) such as asymmetric foliation boudinage and shear bands (Capponi and Crispini, 1997), at low angle with respect to $D1_{VG}$ - $D2_{VG}$ schistosity. Dml_{VG} can be interpreted as the result of a continuous and progressive deformational event developed under decreasing pressure conditions, from Na-amphibole greenschist to greenschist s.s. facies (Crispini and Frezzotti, 1998).

Two main thrust systems ($Sth2_{VG}$) deform and cut $D1_{VG}$ - $D2_{VG}$ folds and Dml_{VG} and are pre-syn $D3_{VG}$ folds. They are characterized by greenschist to low greenschist facies mylonites; the kinematic analysis of these mylonites gives respectively top to NNW and top to SW directions of tectonic transport.

$D3_{VG}$ is characterized by m- to 10 m-scale parallel and chevron folds, gentle to open in shape, in places with a rough spaced cleavage, rarely with schistosity. $D3_{VG}$ fold axes are gently to moderately plunging to both NNW and SSE.

As no radiometric dating is available, the time constraints for these deformations are rather poor; they obviously post-date the age of the deformed rocks (i.e. Late Cretaceous) and are predated by the Late Eocene (?) - Oligocene transgression of the Tertiary “Piemontese” Basin (TPB).

$D4_{VG}$ folds are open in shape and have wavelength up to 10 km; axes are nearly horizontal and are N-S trending. $D4_{VG}$ folds are occasionally characterized by a cleavage with zeolite facies minerals and involve also the Oligocene formations of the TPB. They evolve in top to E-NE thrusts ($Sth3_{VG}$) linked to the overthrusting of the “Alpine” units onto the “Ligurian” units of N-Apennine. A Chattian minimum age is given by the TPB formations affected by this deformation.

Tectonic juxtaposition among the units of the Voltri Group can be linked to pre-$D1_{VG}$ deformations as their contacts ($Sth1_{VG}$) are deformed by $D1_{VG}$ and $D2_{VG}$ and partially reworked by later deformations.

The scattering of kinematic indicators (Crispini, 1996) and stretching lineations linked to early metamorphic conditions testify to the complexity of the kinematics of nappe juxtaposition which is characterized by changes in direction of movement. Field data are clear only for the kinematic of the last part of the evolution (Crispini, 1996), evidence that is not in agree with previous work showing a constant WNW vergence for all pre and syn - collisional deformations (Hoogerduijn Strating, 1994). Present orientation of $D1_{VG}$ -$D2_{VG}$ related schistosity (see fig. 2 in Capponi and Crispini, 1997) and the main direction of $D1_{VG}$ -$D2_{VG}$ fold axes-stretching lineations are easily explained by a $D4_{VG}$ E-vergent km-scale fold which involve all Voltri Group units as proposed in Capponi (1991) and Crispini (1996).

STRUCTURAL EVOLUTION, TECTONIC SETTING AND KINEMATICS OF THE SESTRI-VOLTAGGIO ZONE

The Trias-Lias and the Cravasco-Voltaggio units shared a common deformation history. $D1_{SVZ}$ and $D2_{SVZ}$ developed under blueschist facies metamorphic conditions and are characterized by high shear strain; shear zones and calcite mylonites-ultramylonites layers are common in limestones nevertheless strain partitioning prevented portions of rocks where S0 is still recognizable from extensive deformation. $D1_{SVZ}$ and $D2_{SVZ}$ folds occur from mm- to km-scale and have tight similar shapes, with a penetrative axial surface schistosity which represents the main foliation at the regional scale (S2 in Fig. 2). They are highly non-cylindrical with axes subparallel to stretching lineations that show two maxima for NW-SE and E-W trend with plunge either to the north and to the south. $D2_{SVZ}$ folding event is followed by thrusting ($Sth2_{SVZ}$) that developed at the limit greenschist/pumpellyite-actinolite facies metamorphism. The prevailing tectonic transport inferred from the analysis of the mylonites (Crispini, 1996) is towards S-SW. $Sth2_{SVZ}$ are deformed by $D3_{SVZ}$ open to close subcylindrical folds, with NE-SW axes and SE dipping axial surfaces, during low-pressure decompressive metamorphism (albite + chlorite + epidote assemblages).

Adequate absolute time constraints for the SVZ deformational events are still lacking; as seen for the Voltri Group they occur between the Late Cretaceous and the Late Eocene ?- Oligocene.

Last fold system ($D4_{SVZ}$) shows no evident metamorphic

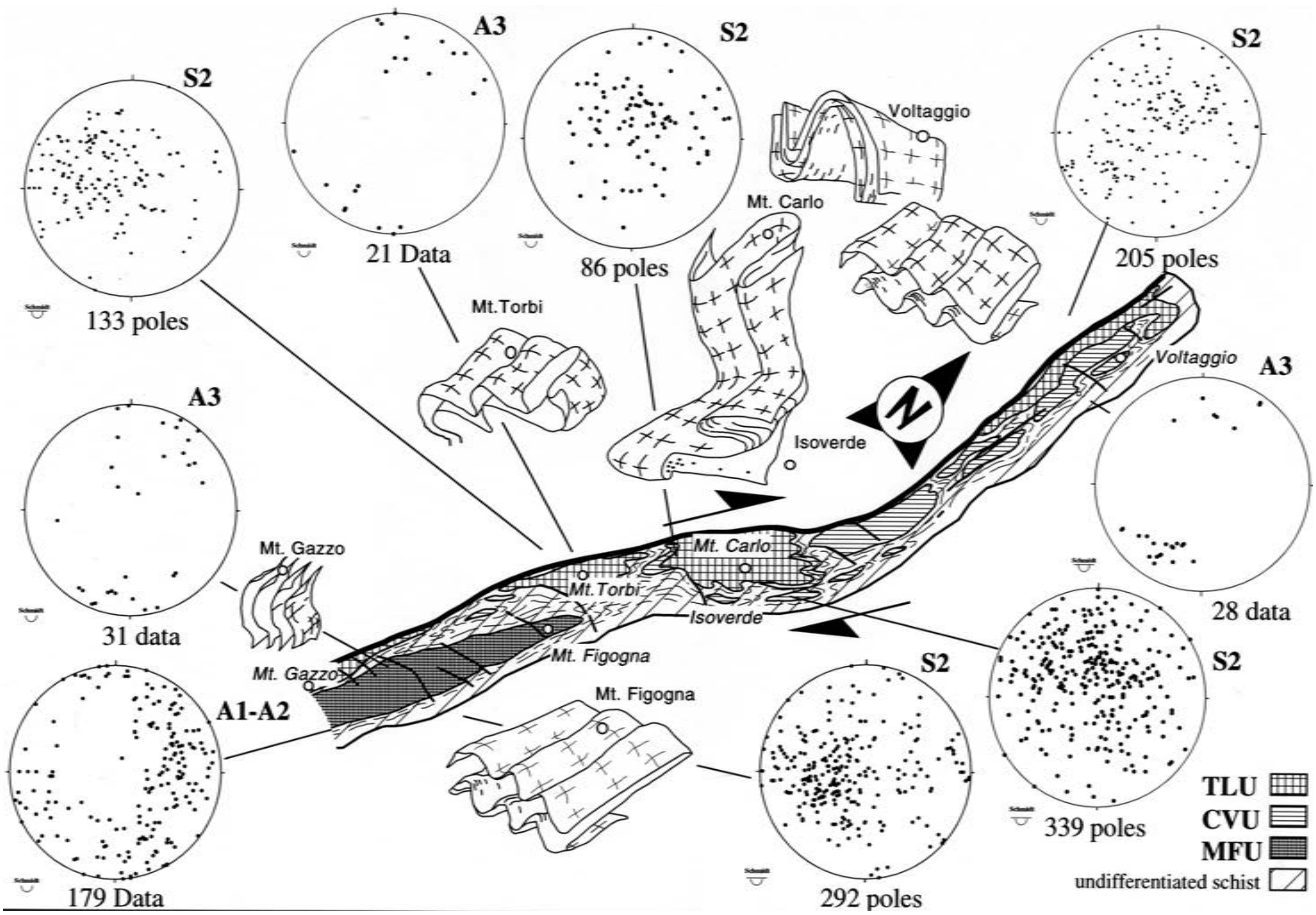

Fig. 2 - Simplified reconstruction of the structures that characterize the main outcrops of the three units in the Sestri-Voltaggio Zone. Stereoplots summarize the principal structural elements of the Zone. 3D-cartoon are not to scale. Arrows show the inferred sense of late movement along the Sestri-Voltaggio Line. TLU stands for Trias-Lias Unit; CVU for Cravasco-Voltaggio Unit; MFU for Monte Figogna Unit.

recrystallization (rarely zeolites or calcite and quartz). $D4_{SVZ}$ folds are linked to E-NE vergent thrust system that involve also the Chattian formations of the Tertiary “Piemontese” Basin (TPB). These late events cause the tilting of the regional foliation up to steep angle of dip in most of the Sestri-Voltaggio Zone.

The same chronology and characteristics of structures can be described for the Monte Figogna Unit, but in it $D1_{SVZ}$ and $D2_{SVZ}$ developed under lower metamorphic conditions (pumpellyite-actinolite facies). The juxtaposition of the three units of the Sestri-Voltaggio Zone occurred at different structural levels. The mylonitic contacts between the Cravasco-Voltaggio e the Triassic-Liassic units ($Sth1_{SVZ}$) are deformed by all the folding events (from $D1_{SVZ}$ to $D4_{SVZ}$) whereas the contact between the Triassic-Liassic + Cravasco-Voltaggio units and the Monte Figogna Unit is post-$D2_{SVZ}$ and can be linked to the thrusting with a top to SW main tectonic transport. In all units stretching lineations linked to early metamorphic conditions are re-orientated by $D3_{SVZ}$ and $D4_{SVZ}$ folding. The cartoon of Fig. 2 shows a three-dimensional reconstruction of the main structures that characterize main outcrops of the three units in the Sestri-Voltaggio Zone. The megastructures result from $D1_{SVZ}$ to $D3_{SVZ}$ evolution and from the dissection caused by the later effect of two main systems of faults: N-S transcurrent steep faults and WSW-ENE normal faults.

RELATIONSHIP BETWEEN VOLTRI GROUP AND SESTRI-VOLTAGGIO ZONE

Structural correlations (such as deformation of the Sestri-Voltaggio line and correlation between structures and metamorphism in the different domains) suggest that the juxtaposition between the Voltri Group and the Sestri-Voltaggio Zone was possibly established syn- to post- $Sth2_{SVZ}$ deformations. At present the Voltri Group and the Sestri-Voltaggio Zone are separated by a steep N-S fault mainly developed in along the boundary between the more competent carbonatic Trias-Lias Unit and the metasediments and serpentinoschists of the Voltri Group. This N-S fault coincides with the Sestri-Voltaggio Line described in literature, it cuts the $D3_{VG}$ and $D3_{SVZ}$ structures and its main activity ceased prior to the deposition of Oligocene formations of the TPB (Cortesogno and Haccard, 1984); it is partially reworked by the $D4_{VG}$ and $D4_{SVZ}$ deformations which interest also the Oligocene formations of the TPB. Kinematic indicators and related antithetic WSW-ENE normal faults point to a dextral strike-slip movement (Crispini, 1996 and Crispini and Capponi, unpublished data). A Paleogene extensional role for this tectonic contact was hypothesized (Hoogerduijn Strating, 1994) in order to explain differences in P-T metamorphic conditions between the Voltri Group and the Sestri-Voltaggio Zone units. An extensional tectonics can explain the present Voltri Group-Sestri-Voltaggio Zone stacking, but there are no field evidences for an extensional tectonics. The P gap in the peak metamorphic conditions between Sestri-Voltaggio Zone and Voltri Group it can be as well explained by an early telescoping of the metamorphic units during the collision and the emplacement of the nappes. The complexity of Voltri Group-Sestri-Voltaggio Zone structural evolution and uncertainty in restoring early kinematics give no precise constraints and we can fit the different models on the basis of the different data we take in consideration.

CONCLUDING REMARKS

At regional scale the structural setting of this sector of the north-western Alps is controlled essentially by a km-scale fold (that can be linked to $D4_{VG} = D4_{SVZ}$) which involve both Sestri-Voltaggio Zone and Voltri Group (partially in accordance with the hypotheses of Cortesogno and Haccard, 1984; Capponi, 1991 and Crispini, 1996) and can be related to the overthrusting of the "Alpine" units onto the "Ligurian" units of N-Apennine. The Sestri-Voltaggio Line is an early nappe contact reworked at different tectonic levels during late stages of the "Alpine evolution s.s." and allocthonized during early stages of the "Apenninic evolution s.s.". The pre-Oligocene role as dextral transcurrent system in the Alpine framework, has been already outlined in Giglia et al. (1996). $D4_{VG}$ and $D4_{SVZ}$ structures are linked to a E-NE vergent regional deformation that at crustal scale causes the allochthony of the whole TPB with its substratum onto the Insubric crust (Biella et al., 1988; Polino et al., 1995).

Acknowledgements

This work benefited of "Ateneo" funds from the University of Genova, Italy.

REFERENCES

Biella G.C., Gelati R., Lozej A., Rossi P.M. and Tabacco I., 1988. Sezioni geologiche nella zona limite Alpi Occidentali - Appennino settentrionale ottenute da dati geofisici. Rend. Soc. Geol. It., 11: 287-292.

Cabella R., Cortesogno L., Gaggero L. and Lucchetti G., 1994. Clinopyroxenes through the blueschist facies metamorphism of the Liguria Alps: compositional variability and miscibility gaps. Atti Ticinesi. Sci. Terra, Ser. Spec., 1: 55-63.

Capponi G., 1991. Megastructure of the South-eastern part of the Voltri Group (Ligurian Alps): a tentative interpretation. Boll. Soc. Geol. It., 110: 391-403.

Capponi G. and Crispini L., 1990. Chloritoid bearing assemblages in metagabbros from the Erro-Tobbio Unit (Voltri Massif, Ligurian Alps): preliminary data. Ofioliti, 15 (2): 327-332.

Capponi G. and Crispini L., 1997. Progressive shear deformation in the metasediments of the Voltri Group (Ligurian Alps, Italy): occurrence of structures recording extension parallel to the regional foliation. Boll. Soc. Geol. It., 116 (2): 267-346

Chiesa S., Cortesogno L., Forcella F., Galli M., Messiga B., Pasquarè G., Pedemonte G.M., Piccardo G.B. and Rossi P.M., 1975. Assetto strutturale ed interpretazione geodinamica del Gruppo di Voltri. Boll. Soc. Geol. It., 94: 555-582

Cortesogno L. and Haccard D., 1984. Note illustrative alla carta geologica della zona Sestri-Voltaggio. Mem. Soc. Geol. It., 28: 115-150.

Crispini L., 1996. Evoluzione strutturale dei metasedimenti del Gruppo di Voltri e della Zona Sestri-Voltaggio: implicazioni nell'evoluzione tettonica e geodinamica alpina. Ph.D Thesis, E.R.S.U., Università di Genova, 129 pp.

Crispini L. and Capponi G., 1997. Quartz fabric and strain partitioning in sheath folds: an example from the Voltri Group (Western Alps, Italy). J. Struct. Geol., 19 (9): 1149-1157.

Crispini L. and Frezzotti M.L., 1998. Fluid inclusion evidence for progressive folding during decompression in metasediments of the Voltri Group (Western Alps, Italy). J. Struct. Geol., 20 (12): 1149-1157.

Elter P. and Pertusati P., 1973. Considerazioni sul limite Alpi-Appennino e sulle sue relazioni con l'arco delle Alpi Occidentali. Mem. Soc. Geol. It., 12 (4): 359-376.

Giglia G., Piazza M., Capponi G. and Crispini L., 1996. Seysmotectonic model of NW Italy. Tectonophysics, 267: 143-175.

Hoogerduijn Strating, E.H., 1991. The evolution of the Piemonte-Ligurian ocean. A structural study of ophiolite complexes in Liguria (NW Italy). Geol. Ultraiect., 74, 145 pp.

Hoogerduijn Strating E.H., 1994. Extensional faulting in an intraoceanic subduction complex - working hypothesis for the Palaeogene of the Alps-Apennine system. Tectonophysics, 238: 255-273.

Messiga B. and Scambelluri M.,1991. Retrograde P-T-t path for the Voltri Massif eclogites (Ligurian Alps, Italy): some tectonic implications. J. Metam. Geol., 9: 93-109.

Polino R., Clari P., Crispini L., D'Atri A., Dela Pierre F., Novaretti A., Piana F., Ruffini R. and Timpanelli M., 1995. Relazioni tra zone di taglio crostali e bacini sedimentari: l'esempio della giunzione alpino-appenninica durante il Terziario. Guida all'escursione in Monferrato e nella Zona Sestri-Voltaggio. Atti Convegno "Rapporti Alpi-Appennino" e guide alle escursioni. Acc. Naz. Sci. Scritti e Documenti, 14: 531-593.

Ramsay J.G., 1967. Folding and fracturing of rocks. Mc Graw - Hill, New York, 568 pp.

Rovereto G., 1939. Liguria geologica. Mem. Soc. Geol. It., 2, 743 pp.

Vanossi M., Cortesogno L., Galbiati B., Messiga B., Piccardo G.B. and Vannucci R., 1984. Geologia delle Alpi Liguri: dati, problemi, ipotesi. Mem. Soc. Geol. It., 28: 5-75.

Received, January 28, 1998
Accepted, September 1, 1999