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FIELD CONSTRAINTS TO THE MID-TERTIARY KINEMATICS OF THE LIGURIAN ALPS

Giovanni Capponi*, **Laura Crispini**, **Michele Piazza** and **Luciano Amandola**

Dipartimento per lo Studio del Territorio e delle sue Risorse, Corso Europa 26, 16132 Genova, Italy .
* *Corresponding author Tel.: +39 010 3538292; Fax: +39 010 352169; e-mail: capponi@dipteris.unige.it).*

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ABSTRACT

In the Ligurian Alps, Early Miocene folds and thrust faults involve both the metamorphic basement and its Tertiary sedimentary cover. Fold asymmetry and the Early Miocene deformations appear to be linked to the migration of the Ligurian Alps towards E-NE with the subsequent backthrusting onto the Apennine units; this stage was powered by the anticlockwise rotation of the Corsica-Sardinia block.

Tough the Ligurian Alps suggest a present-day N-S to SE-NW direction of shortening, which is not consistent with the kinematics of the Early Miocene deformations. We believe that these data are only apparently conflictual, in that they could consistently reflect a progressive rotation of the direction of shortening, during a continuous geodynamic evolution from Miocene to present, connected with the still active Europe-Africa convergence.

INTRODUCTION

The Middle Tertiary kinematics of the Ligurian Alps is best inferred from the deformations recorded in the sedimentary rocks of the Tertiary Piedmontese Basin (that we hereafter indicate as TPB), which is a late to post-orogenic basin spanning in age from the Late Eocene - Oligocene to the Late Miocene. The TPB has an inner position with respect to the arcuate belt of the western and Ligurian Alps, in northwestern Italy; it can be defined as an epi-Mesoalpine basin (Mutti et al., 1995), developed on the tectonic units already involved in the main alpine deformation phases. Despite the critical assumption that the deposition of the sedimentary rocks of the TPB sealed the major structures of the basement, and that the main alpine deformation events ceased at the end of the Eocene, the rocks of the TPB experienced both pervasive syn-sedimentary (Forcella and Rossi, 1980) and tectonic deformation, resulting in large-wavelength folds and thrust faults: this points to an ongoing tectonic activity during Oligocene and Miocene times. The major occurrences of contractional structures are at Santa Giustina (Pasquaré 1968; Capponi and Giammarino, 1982), Rossiglione (Forcella, 1976; Capponi et al., 1999a), and Bandita (d'Atri et al., 1997; Capponi et al., 1999b). In these areas (Fig. 1), metamorphic rocks are thrust onto Oligocene sedimentary rocks, which are locally folded and tilted to the vertical attitude. In places, these structures are accompanied by zeolite-facies re-crystallization. The Val Gorrini thrust, near Bandita (d'Atri et al., 1997), yields the best time constraint for these structures: the involvement of the Rocchetta Formation (Early-Late Oligocene) and the occurrence of the undeformed Burdigalian Visone Formation, onlapping the Val Gorrini thrust fault, shows that the timing of this deformation can be referred to the Early Miocene. On the regional scale this event is correlated (d'Atri et al., 1997; Piana et al., 1997; Capponi et al.,1999b) with the phase of tectonic uplift linked to the Monferrato culmination, described as "fase ligure III" by Mutti et al. (1995).

Even if the Early Miocene structures are more evident at the sites where they provide anomalous superposition of the metamorphic rocks onto the sedimentary rocks of the TPB, they also occur in the metamorphic basement (Capponi et al.,1999b), which includes several tectonic units, such as the Voltri Massif, the Sestri-Voltaggio Zone and the Montenotte Unit.

The aim of this paper is:

- to summarize the occurrences of thrusts and folds related to the Lower Miocene tectonic phase in the eastern sector of the Ligurian Alps;
- to describe the overall kinematics of these structures;
- to discuss the role of these contractional deformations in the geodynamic evolution of the eastern sector of the Ligurian Alps.

GEOLOGICAL FRAMEWORK

The SE sector of the Western Alps is commonly known as the Ligurian Alps (Fig. 1). The Lower Miocene structures described in this paper have been detected both in the metamorphic basement of this sector of the Ligurian Alps and in the overlying tertiary sedimentary cover sequences. The metamorphic basement encompasses the Ligurian-Piedmontese units and Trias-Lias carbonatic units

The Ligurian-Piedmontese units (Vanossi et al. 1984) consist of metaophiolitic rocks associated with metasediments which were involved in the Alpine tectonic events and suffered a complex and multiphase metamorphic and structural evolution (Capponi, 1991; Messiga and Scambelluri, 1991; Capponi and Crispini, 1997). In the Ligurian Alps they occur with different Alpine metamorphic imprint: the units re-equilibrated under eclogite facies metamorphic conditions, followed by a widespread retrogression under greenschist facies conditions, are usually referred to as the Voltri Group (Chiesa et al. 1975) or the Voltri Massif. The units re-equilibrated under blueschist facies conditions are known as the Montenotte Unit and the Cravasco - Voltaggio Unit, cropping out respectively west and east of the Voltri Group. In these units the retrogressive metamorphism is weak. Finally the Monte Figogna Unit experienced pumpellyite-actinolite facies Alpine metamorphic re-equilibration and a later retrogression under lower metamorphic conditions (Cortesogno and Haccard, 1984).

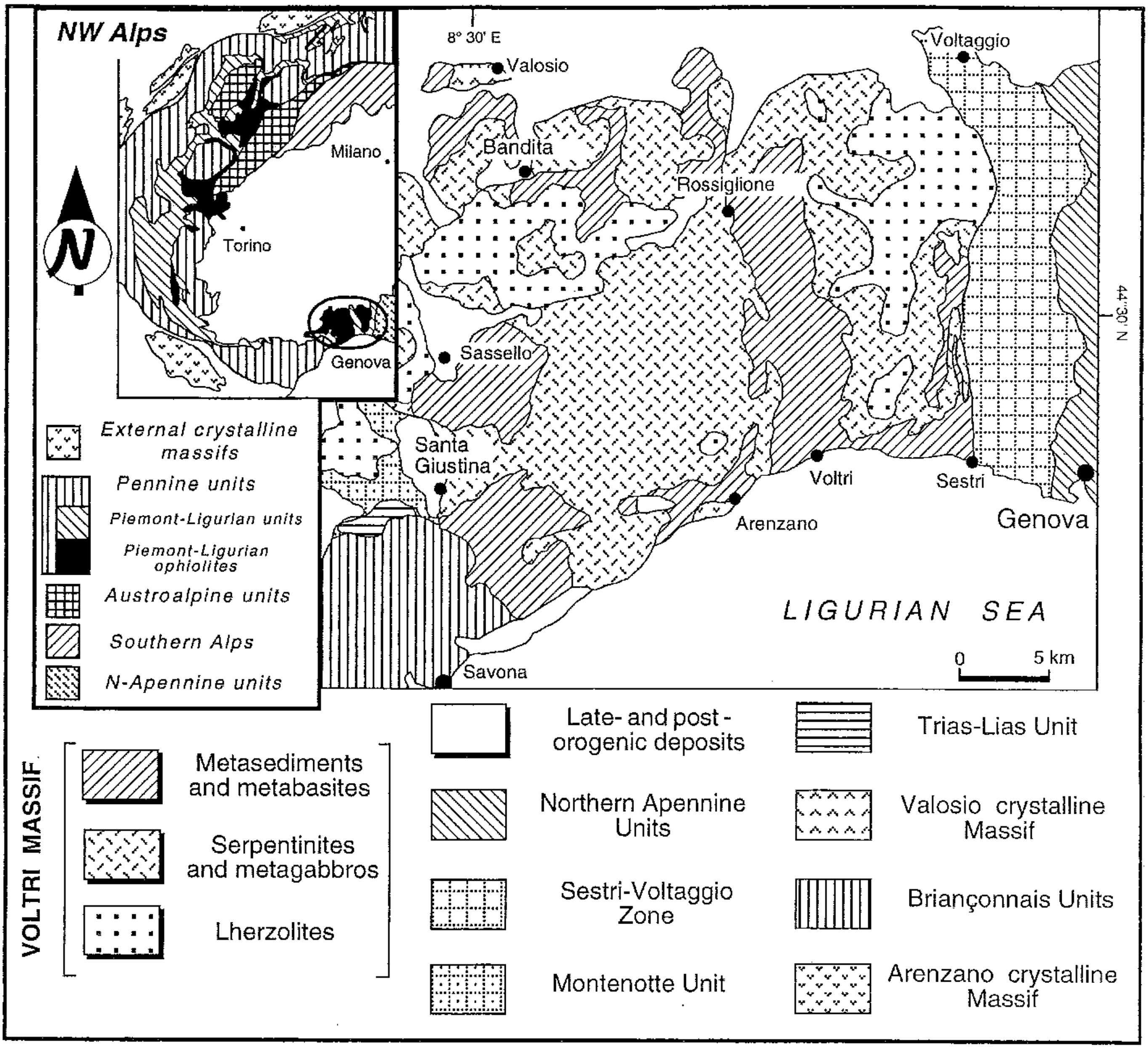

Fig. 1 - Structural sketch map of the eastern Ligurian Alps and adjoining units. In the top left inset structural sketch map of the Western Alps

The Trias-Lias units comprise carbonatic rocks and shales, that were deposited on a deepening shelf; they occur west and east of the Voltri Massif (Monte Gazzo-Isoverde Unit) and re-equilibrated under blueschist facies conditions.

In the regional literature the Cravasco - Voltaggio, the Monte Gazzo - Isoverde and the Monte Figogna units are usually referred to as the Sestri - Voltaggio Zone (Cortesogno and Haccard, 1984).

The metamorphic units are overlain by the sedimentary formations of Tertiary Piedmontese Basin, which is a late to post-orogenic basin (Lorenz, 1968; Gelati, 1974; Mutti et al., 1995), directly supplied by the erosion of the Alpine metamorphic basement. The TPB includes a siliciclastic sequence evolving from Upper Eocene breccias through Lower Oligocene conglomerate to Upper Oligocene - Miocene sandstones and marls.

The metamorphic units experienced several different superimposed deformation events, developed under different tectonic conditions, ranging from ductile to brittle regime (Capponi and Crispini, 1997; Capponi et al., 1999a; Crispini and Capponi, in press). The oldest structures testify the deformations attained during the eclogite stage of the tectonometamorphic evolution. Superimposed isoclinal folding and brittle-ductile folding and thrusting developed under greenschist facies conditions and are linked to the following steps of exhumation, uplift and nappe emplacement (Capponi and Crispini, in press). After the deposition of transgressive successions of the TPB, the Oligocene-Miocene deformations are shared by the metamorphic basement and the sedimentary formations.

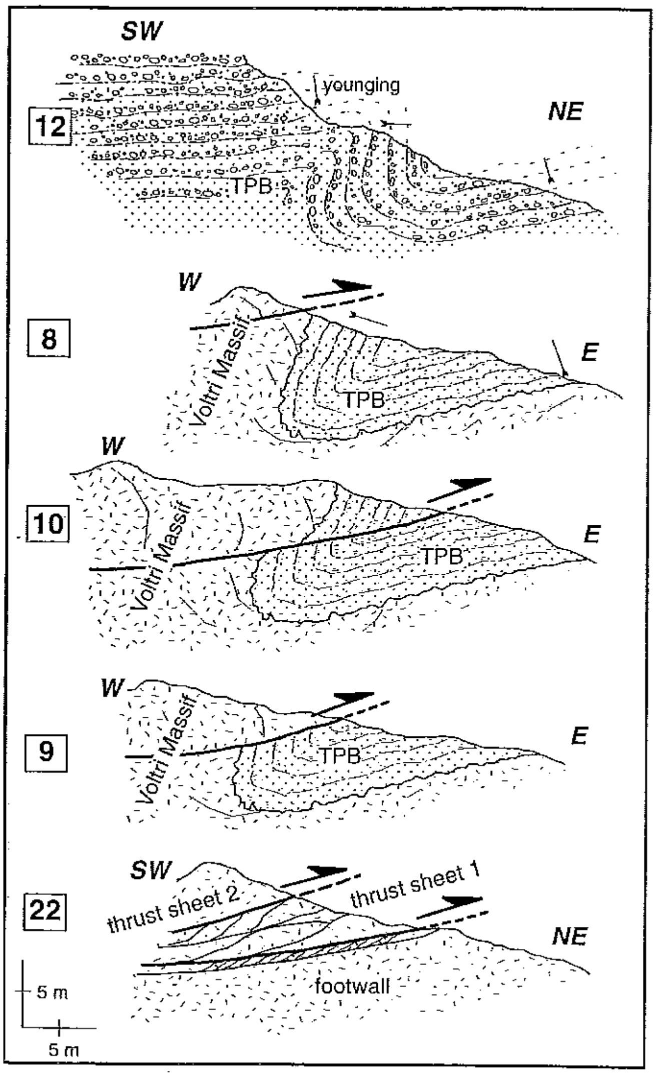

Fig. 2 - Cross-sections of some structures described in this paper. TPB is the Tertiary Piedmontese Basin conglomerate. Numbers refer to Fig. 5 and Table 1. Horizontal and vertical scale bar holds for all sections.

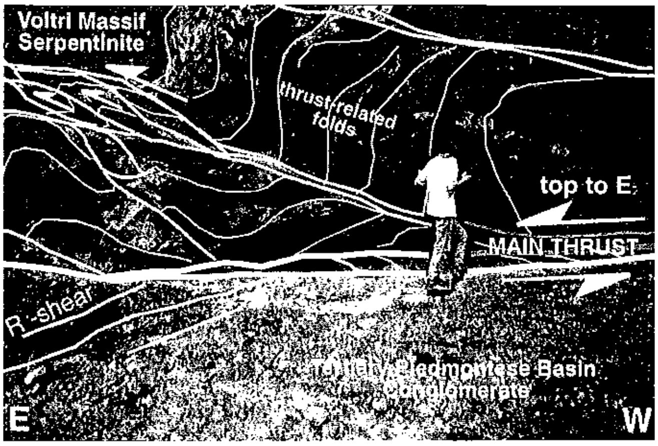

Fig. 3 - Structural features of the structure indicated with number 9 in Fig. 2 and Table 1.

FIELD DATA

Lower Miocene tectonic structures are folds and thrust faults. Folds are large-wavelength (up to several km) open folds, with moderately to steeply W-SW-dipping axial surfaces (Fig. 2); the sense of shear can be inferred from the strong fold asymmetry. Thrust faults have low-angle dips and fronts that are traced for several km; at most sites these structures are marked by fault rocks and m-scale horses (Fig. 3). Fault rocks are crush breccias (nomenclature of fault rocks after Sibson, 1977), with minor crush microbreccias, protocataclasites and cataclasites, rarely pseudotachylites (Fig. 4). The occurrence of crush breccias and cataclasites points to a deformation attained at shallow crustal levels. In places thrust planes are accompanied by zeolite recrystallization; the concurrent re-crystallization of chlorite and carbonates on the slickensides (Capponi et al., 1999b) suggests a temperature lower than 250°C, and very low pressure for this deformation. The direction of tectonic transport and the sense of shear can be inferred from the geometric arrangement of the horses, related to the attitude of the thrust surfaces, from the deflection of pre-existing schistosities of metamorphic rocks, stretching lineations, striae and other microstructures developed in fault rocks.

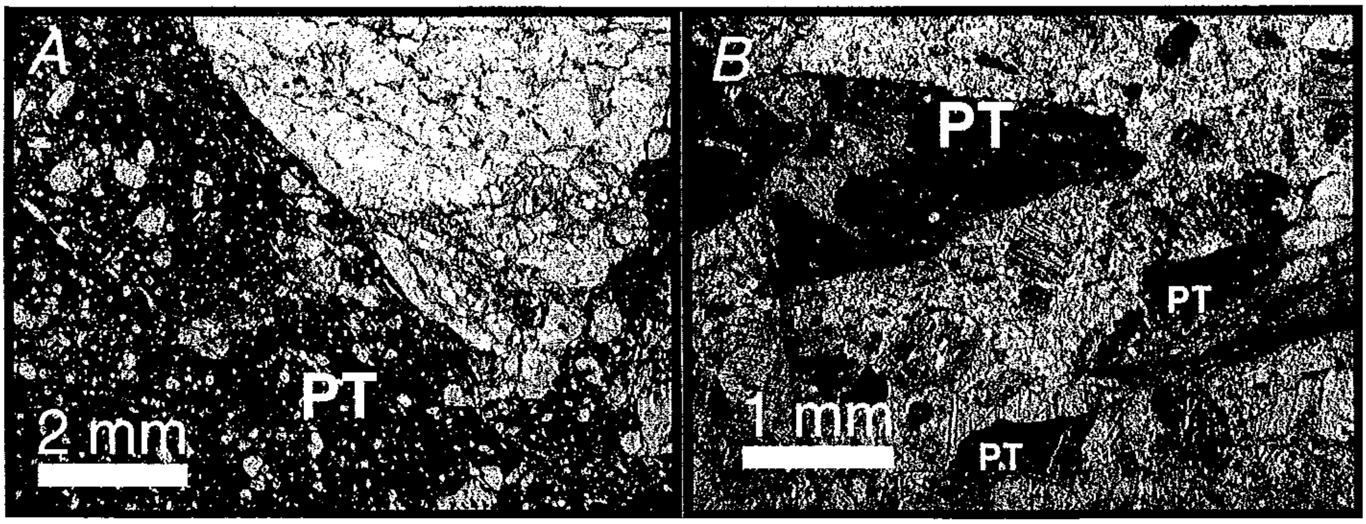

Fig. 4 - A. Photomicrograph of a pseudotachylite (PT) vein in a metabasite of the Voltri Massif. The dark matrix of the pseudotachylite include fragments of different size of the host rock. PPL. B. Photomicrograph of a cataclasite composed of angular fragments from different metamorphic rocks of the Voltri Massif. Dark fragments (PT) are mylonitized pseudotachylyte . PPL.

In Fig. 5 original data on the direction of tectonic transport inferred from several structures are shown together with data obtained from the literature. Fig. 6 shows the main tectonic transport direction from all the structures of Fig. 5 and the axes of folds in the sedimentary sequences of the Tertiary Piedmontese Basin. On large structures a lot of observations were possible; in these sites the direction is an average among measured point data (Fig. 7). At the sites where sedimentary rocks are involved and a time constraint is available, the age or the minimum age of each structure is given. The major features of each structure are summarized in Table 1.

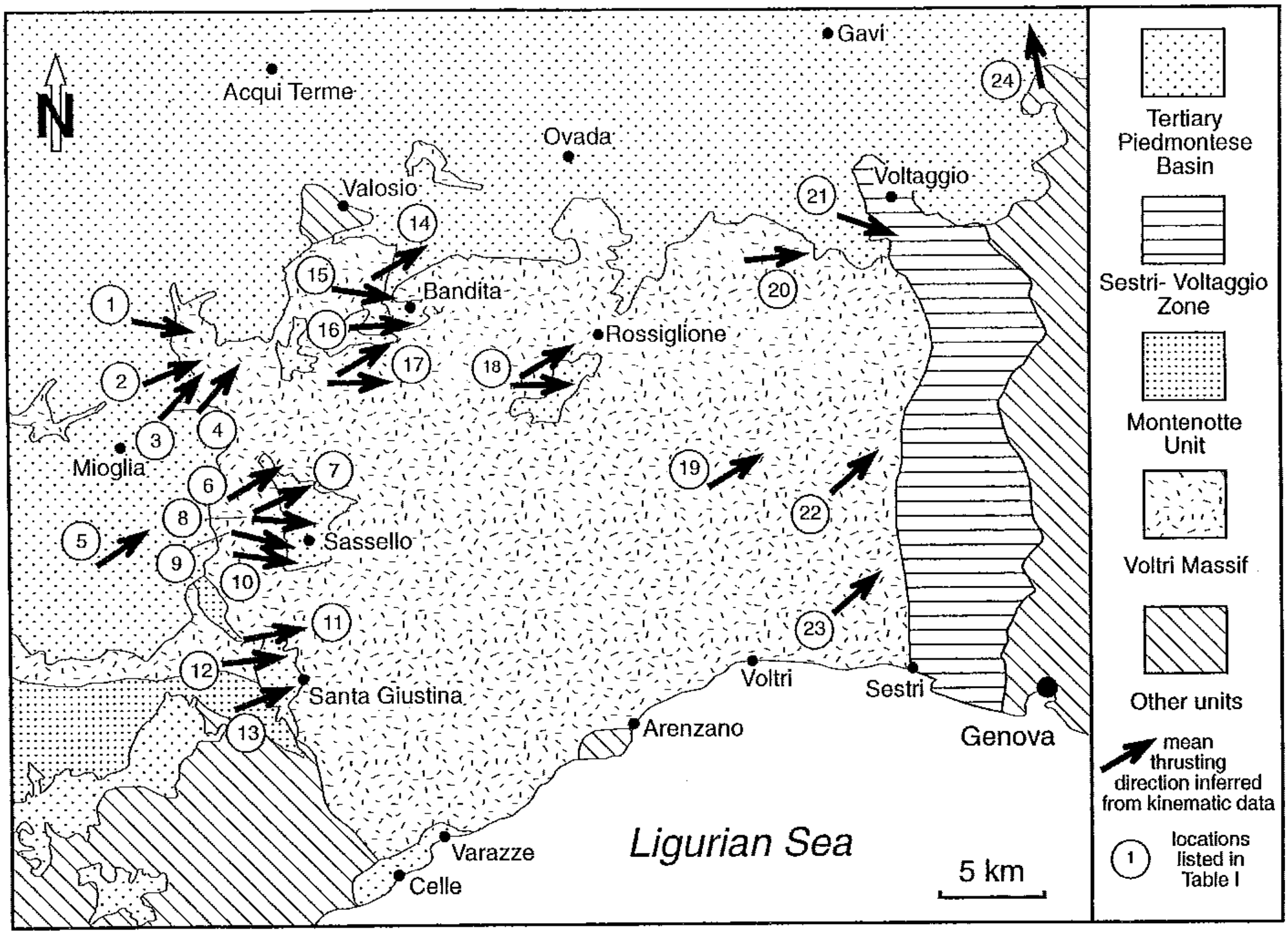

Fig. 5 - Sketch map showing the location of the early Miocene folds and thrust faults. Arrows indicate the direction and the top of tectonic transport. Numbers refer to Table 1.

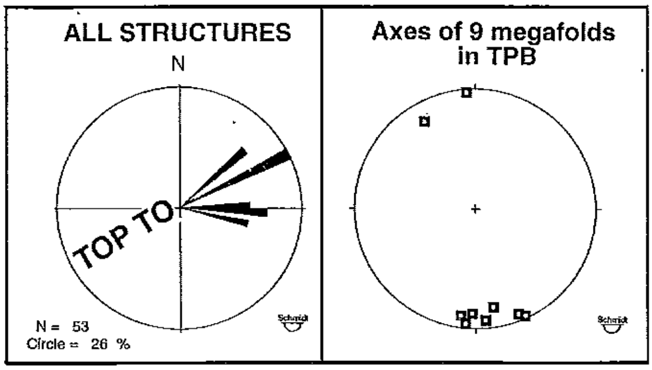

Fig. 6 - A. Rose diagram of the main tectonic transport direction from all the structures of Fig. 5. B. Stereographic projections (Schmidt net, lower hemisphere) of the axes of folds in the sedimentary sequences of the Tertiary Piedmontese Basin.

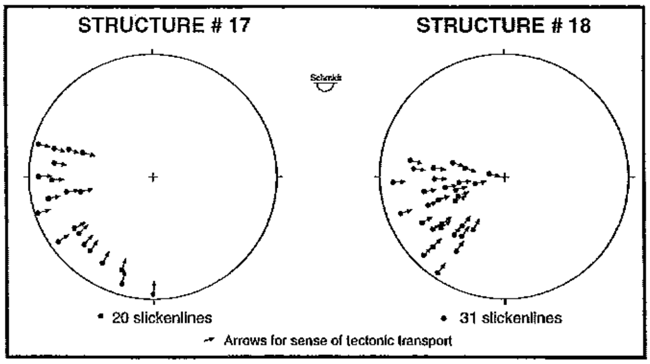

Fig. 7 - Stereographic projections (Schmidt net, lower hemisphere) of slickenlines and striae from the structures of Rossiglione and Bandita areas. Numbers refer to Fig. 5 and Table 1. (data from Capponi et al., 1999a; Capponi et al., 1999b).

Table 1 - Summary of the Early Miocene structures.

#	Structure	Top-to	Units involved	Minimum age	Source
1	Thrust	ESE	TPB - VM	Late Rupelian	This paper
2	Fold	NE	TPB - VM	Late Rupelian	This paper
3	Fold	NE	TPB - VM	Late Rupelian	Lorenz 1968
4	Thrust	NE	TPB - VM	Late Rupelian	This paper
5	Fold - Thrust	NE	TPB	Early Chattian	Bernini and Zecca, 1990
6	Fold	NE	TPB - VM	Early Chattian	This paper
7	Fold	NE	TPB - VM	Early Chattian	This paper
8	Fold	E	TPB - VM	Late Chattian	This paper
9	Thrust	ESE	TPB - VM	Late Chattian	This paper
10	Fold	ESE	TPB - VM	Late Chattian	This paper
11	Fold	ENE	TPB	Middle Chattian	This paper
12	Fold	ENE	TPB	Early Chattian	This paper
13	Thrust	NE	TPB Montenotte Unit	Late Chattian	Pasquarè, 1968 Capponi and Giammarino, 1982
14	Thrust	NE	TPB - VM	Late Aquitanian	d'Atri et al., 1997
15	Fold	ESE	TPB - VM	Middle Rupelian	This paper
16	Fold	E	TPB - VM	Middle Rupelian	This paper
17	Thrust	E - NE	VM	No age constraint	Capponi et al. 1999b
18	Thrust	E-NE	TPB - VM	Late Oligocene	Capponi et al., 1999a
19	Thrust	NE	VM	No age constraint	Capponi et al., 1986
20	Thrust	ENE	VM	No age constraint	This paper
21	Thrust	ESE	BTP	Late Rupelian	This paper
22	Thrust	NE	VM	No age constraint	This paper
23	Thrust	NE	VM	No age constraint	This paper
24	Fold Thrust	N	TPB	Late Oligocene	Fossati et al., 1988 This paper

TPB stands for Tertiary Piedmontese Basin; VM stands for Voltri Massif. The definition of minimum age is based on the age of younger beds involved. The structure 14 has also a Burdigalian upper time limit.

DISCUSSION

Field data indicate consistent directions of tectonic transport; most of the analyzed structures show a top-to-E, or top-to-NE sense of displacement. This coincides with the kinematics outlined by most data derived from the literature, except for some top-to-NW data reported by Hoogerduijn Strating et al. (1991). At two of the investigated sites, Val Gargassino, near Rossiglione (Capponi et al., 1999a) and Bandita -Val Gorrini (d'Atri et al., 1997; Capponi et al., 1999b), detailed field mapping and structural analysis provided ample evidence that the sense of displacement was top to E-NE. Nevertheless, minor occurrence of top-to-NW structures could be possibly interpreted as backthrusting.

At the regional scale the Oligocene-Miocene kinematics of the Ligurian Alps is usually interpreted in the frame of the anticlockwise rotation of the Corsica-Sardinia block (Castellarin, 1992; Laubscher et al., 1992; Vanossi et al., 1994; Giglia et al., 1996), combined with the NW motion of the "Adriatic indenter" (Platt et al., 1989; Laubscher, 1991) and the subsequent backthrusting of the Ligurian Alps onto the Apennine units. The result is a complex indentation of the European and Adriatic crust, with the development of several imbrications of tertiary sedimentary rocks and basement sheets.

In the Alpine system, a N-NW motion of the Adriatic indenter and a subsequent N-S to SE-NW direction of shortening is proposed by several authors (Platt et al., 1989; Hoogerduijn Strating et al., 1991, with references), since Eocene time to present. Nevertheless this NW motion does not match the direction of shortening indicated by the Lower Miocene surface structures. Top-to-N structures occur only at one site (top right corner of Fig. 5; Fossati et al., 1988; this paper) and this poses the question of its tectonic significance. Moreover the lacking of data with intermediate orientation does not support the hypothesis of a gradual sweep from E-W to N-S direction of shortening.

The contrasting evidence about different directions of shortening appears as a major discrepancy, but this can be reconciled if these directions are correctly related to the various sectors of the Alpine belt, that display different kinematic behaviours. In the Late Eocene - Early Oligocene time, the overall geodynamic regime was dominated by a general NW-SE directed shortening, powered by the displacement of the Adriatic indenter against Eurasia. This indentation caused the detachment of the Corsica-Sardinia block with respect to Eurasia and its anticlockwise rotation (Tapponnier, 1977; Laubscher et al., 1992). The process involved also the Ligurian Alps: the rotation of the Corsica-Sardinia block and the related opening of the Ligurian-Provençal basin forced the branch of the Ligurian Alps to migrate towards E-NE (Fig. 8). Accordingly, the resulting

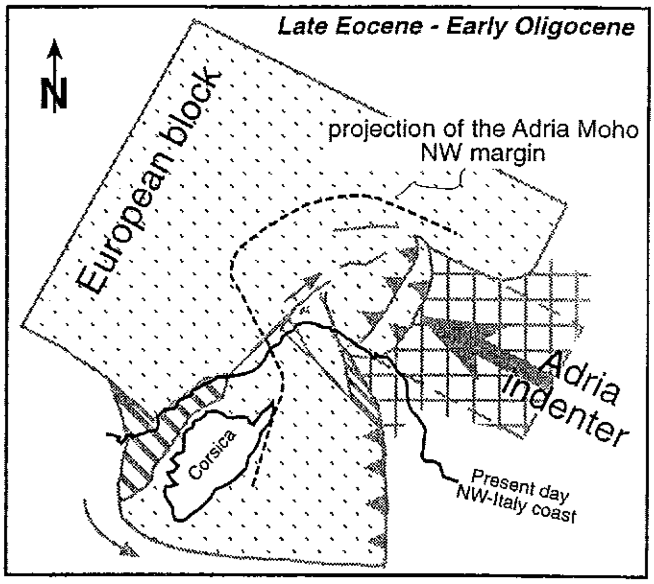

Fig. 8 - Simplified model for the Late Eocene - Early Oligocene time. The overall geodynamic regime was dominated by a NW-SE shortening, powered by the displacement of the Adriatic indenter against Eurasia. For detail see text. Redrawn and modified from Peltzer and Tapponnier (1988) and Vanossi et al. (1994).

tectonics displayed E-W to SW-NE direction of shortening.

Another mismatching point arises from geophysical data; seismic cross sections (Cassano et al., 1986; Biella et al., 1988, Laubscher et al., 1992) through the Ligurian Alps suggest a N-S direction of shortening, which does not match the early Miocene NE-SW data. Nevertheless this discrepancy can be also solved if located in time; the E-W to SW-NE direction of shortening is obtained from Lower Miocene fossil field structures, whereas the N-S to SE-NW direction is largely based on the seismic data, which reflect the present-day structural arrangement. This points to a kinematic evolution of the Ligurian Alps characterized by a rotation of the predominant direction of shortening from Miocene time to present. The present-day stage can be considered the ultimate step in a continuos geodynamic evolution, powered by the still active Europe-Africa convergence (Ziegler, 1990; Giglia et al., 1996).

CONCLUSIONS

In the eastern sector of the Ligurian Alps folds and thrust faults involve both the metamorphic basement and the overlying Tertiary sedimentary cover. At many sites their age is constrained to the Early Miocene. The asymmetry of the folds and sense of movement inferred from the thrust faults indicate a consistent top-to-E-NE sense of shear. Top-to-N sense of shear occurs at one site only and it could be consistent with a more general top-to NE tectonic transport direction.

The Lower Miocene E-W to NE-SW direction of shortening appears to be linked to the back-thrusting of the Ligurian Alps onto the Apennine units; this stage was powered by the anticlockwise rotation of the Corsica-Sardinia block. The rotation of the Corsica-Sardinia block and the connected opening of the Ligurian-Provençal basin were caused by the NW displacement of the Adriatic indenter against Eurasia, in a geodynamic regime dominated by an overall SE-NW direction of shortening. As a local feature of a wider structural framework, the Lower Miocene SW-NE direction of shortening does not necessarily represent a mismatching point in the geodynamic evolution of the Western Alps - Northern Apennines system. Seismic data support a present-day N-S to SE-NW direction of shortening for the Ligurian Alps, which is only apparently conflictual with the Lower Miocene kinematics. These data in fact, are consistent with a progressive rotation of the direction of shortening, during a continuos geodynamic evolution from Miocene to present, powered by the still active Europe-Africa convergence.

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