Relations between faults and seismicity in the Cottian Alps (Central-Western Alps) by an integrated approach between structural analysis, morphotectonics and seismic data

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1. Introduction

In the most internal sector of Cottian Alps

Seismic activity characterized by low magnitude events (minor than 4 Richter's scale), though in the past some medium grade seismic events (up to MS=5,5) occurred.

For this part of the Alpine chain, an updated geological map and a seismotectonic model are still lacking.

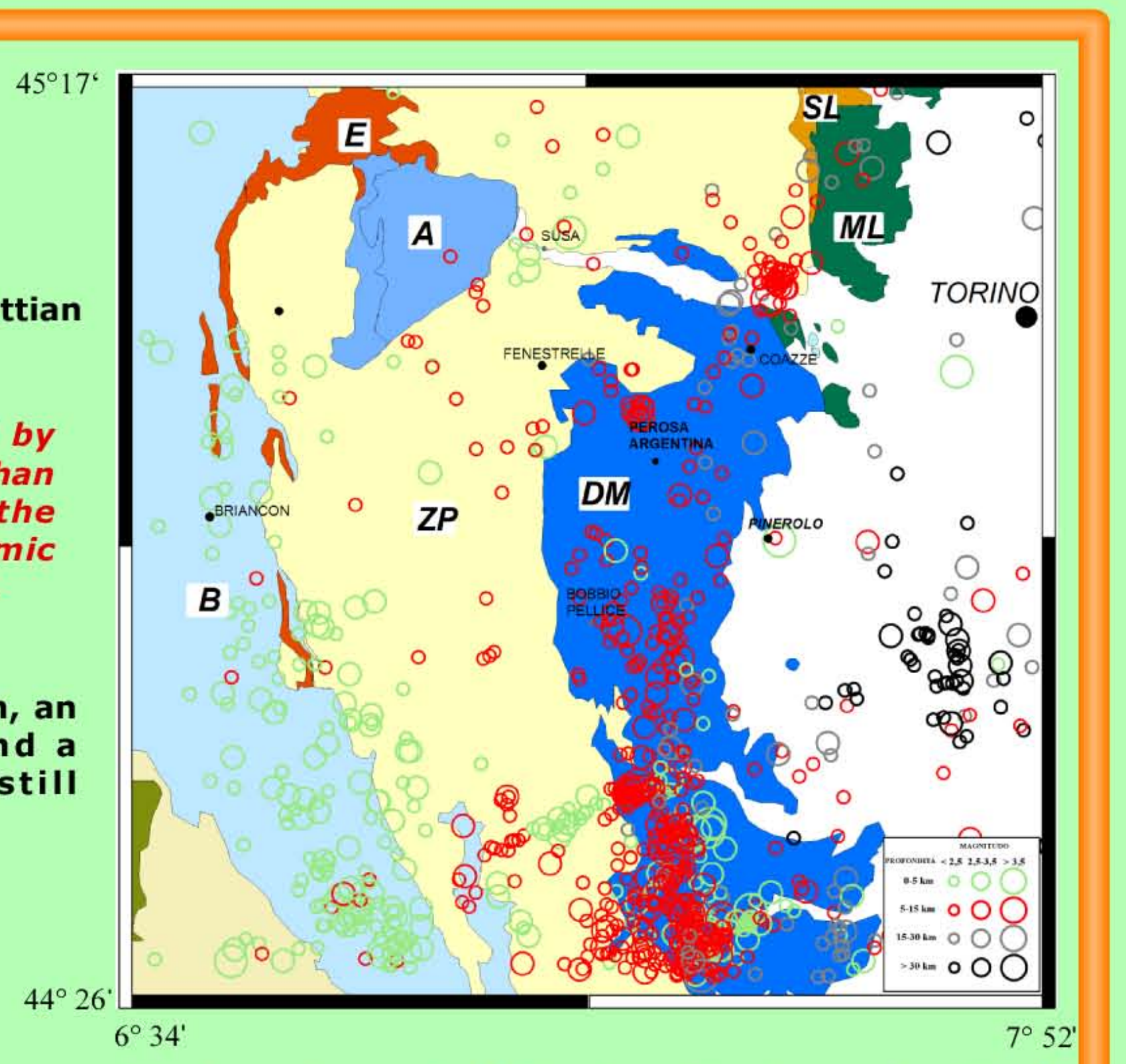


*Figure 1: map of seismicity of Cottian Alps with location error than 3 km. **A**: Ambin Unit; **B**: Briancoinnais zone; **DM**: Dora Maira Unit; **ML**: Lanzo Massif; **ZP**: "Zona Piemontese"auct.*

In this work structural analysis, morphotectonics and seismic data were coupled in order to:

- *work out a reference tectonic model*
- *reconstruct the post-metamorphic structural evolution*
- *understand genetic relations between faults and seismicity*

2. Regional geological setting

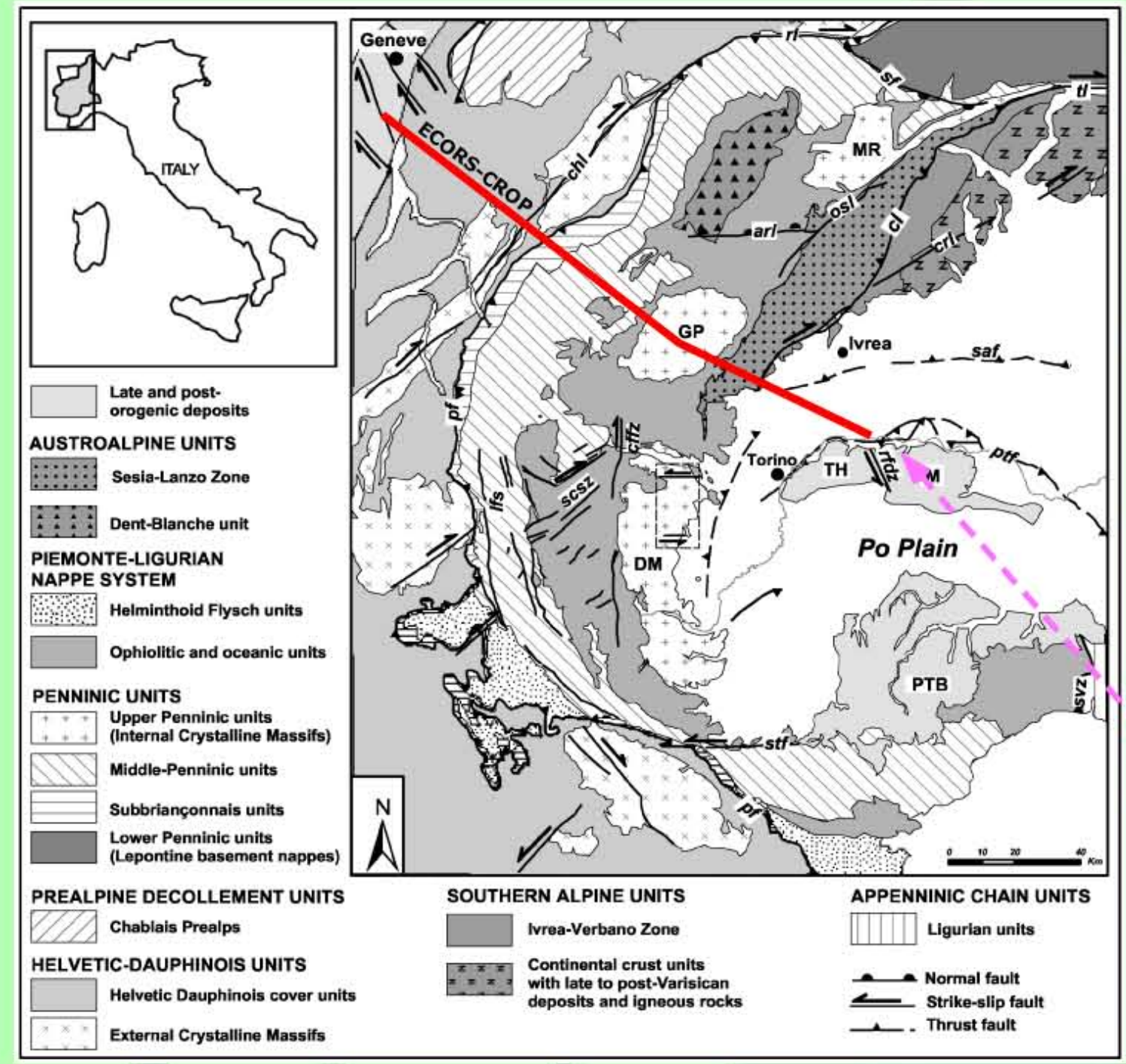
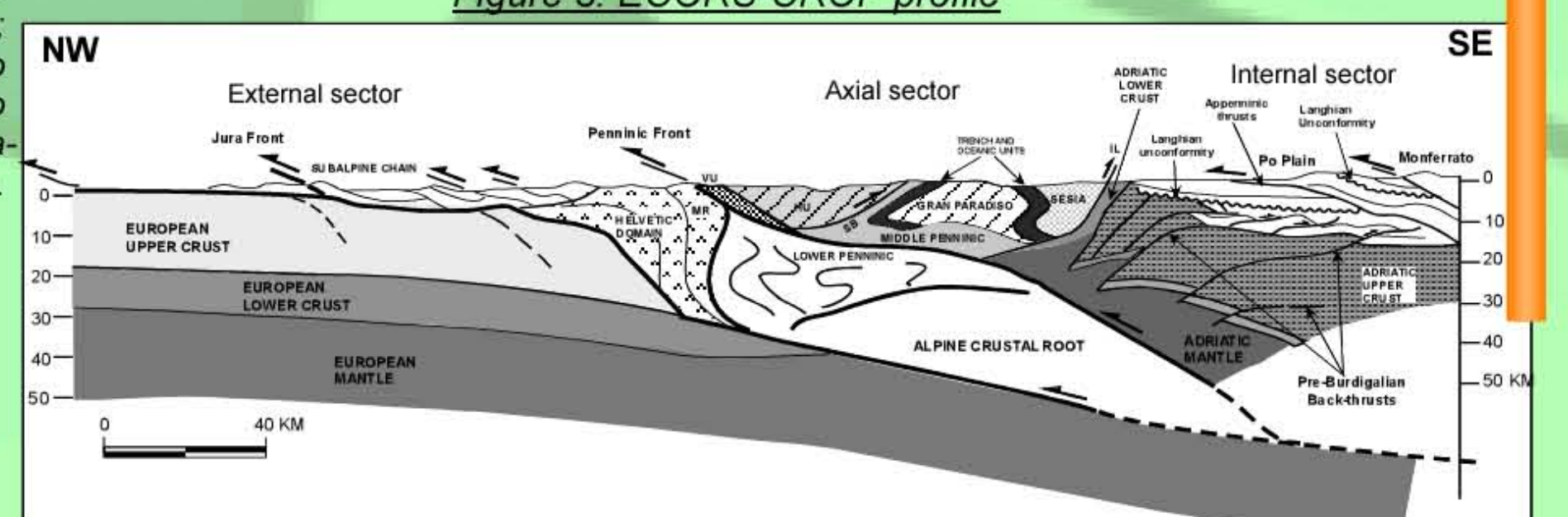


*Figure 2: Tectonic sketch map of Western Alps. **DM**: Dora-Maira Unit; **GP**: Gran Paradiso Unit; **MR**: Monte-Rosa Unit; **PTB**: Piedmont Tertiary Basin; **TH**: Torino Hill; **M**: Monferrato; **pf**: Penninic Front; **chl**: Chamonix Line; **cl**: Canavese Line; **crl**: Cremosina Line; **tl**: Tonale Line; **arl**: Aosta-Ranzola Line; **sf**: Simplon Fault; **rl**: Rodano Line; **stf**: Stura Fault; **rdfz**: Rio Freddo deformation Zone; **cffz**: colle delle Finestre Fault Zone; **svz**: Sestri-Voltaggio Zone; **ptf**: Padan Thrust Front; **saf**: South Alpine Thrust Front; **scsz**: Susa-Chisone shear zone; **osl**: Ospizio-Sottile Line; **lfs**: longitudinal fault system. The dashed rectangle shows the mapped area.*

The arc of Western Alps (fig.2) resulted from the convergence and subsequent collision between the Adria plate and the European margin of the Tethys since the Late Cretaceous.

Subduction of oceanic crust (Late Cret.-Paleocene)	Juxtaposition of nappes under HP/LT conditions (Polino et al., 1990)
Continental collision (Eocene-Oligocene)	***Axial sector*** Back-folding and back-thrusting of the Alpine units under greenschist facies metamorphic conditions ***External sector*** Thrusting of HP-LT metamorphic units of the Penninic Domain over the Helvetic units ***Internal sector*** Alpine metamorphic units back-thrusted over the non metamorphic Ligurian Units of the Adriatic foreland Formation of the Neogenic Padan foredeep, the Piedmont Tertiary Basin (PTB).

Figure 3: ECORS-CROP profile



3. Field mapping and structural analysis

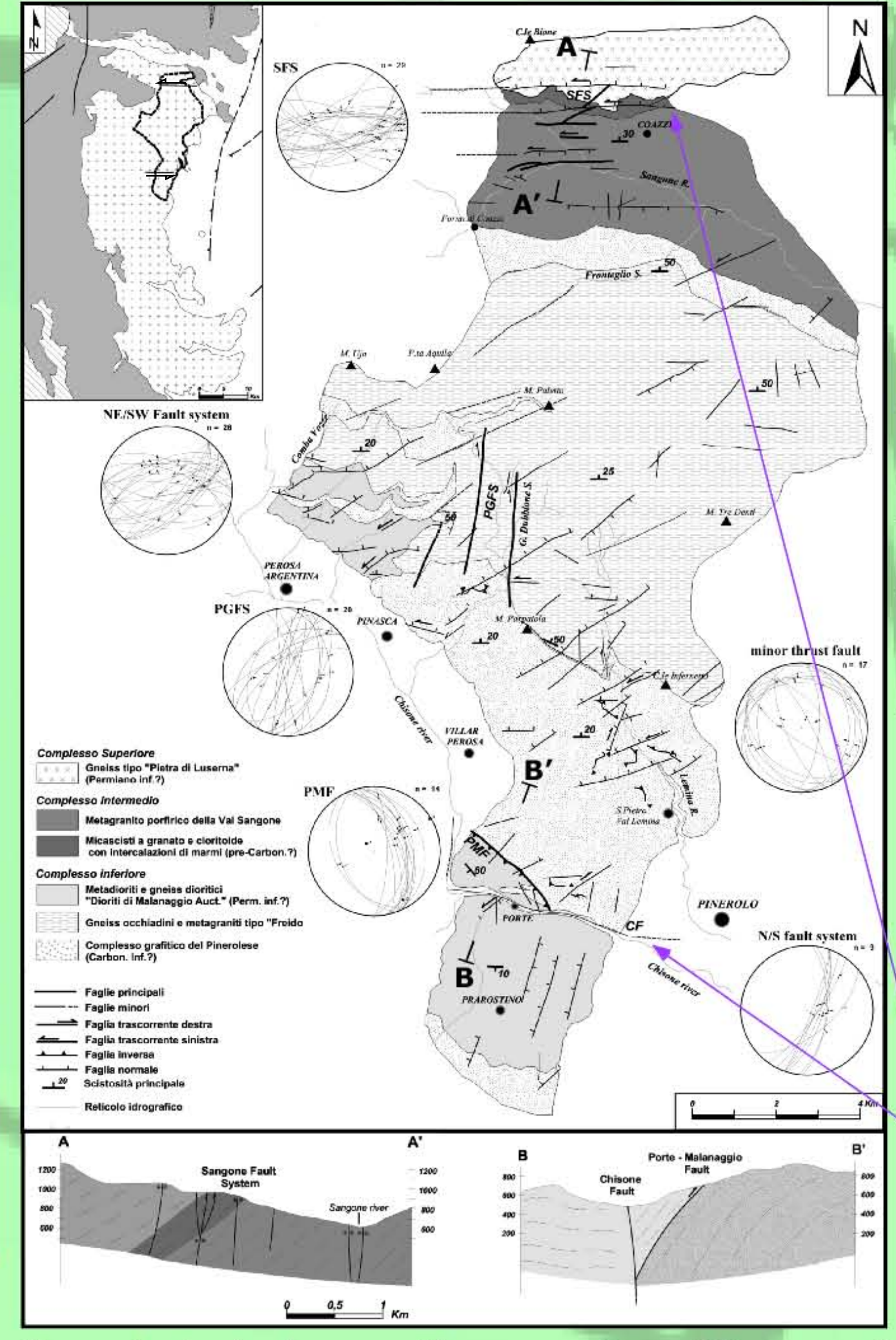


Figure 4: structural map with cross sections of the mapped area

Field mapping and mesostructural analysis of brittle shear zones have been carried out for the Northern sector of the Dora-Maira Unit, between Lower Sangone and Chisone Valley (fig.4).

STRUCTURAL SETTING

Three metamorphic complexes bounded by ductile tectonic contacts

SYN-METAMORPHIC STRUCTURAL EVOLUTION

Three deformation phases:

F1 → HP/LT metamorphic foliation (S1)

F2 → HP/LT metamorphic foliation (S2)
Isoclinal folds with E-W trending axes

F3 → N-verging E-W trending folds
Development of foliation (S3) in greenschist facies conditions

ANALYSIS OF LATE TO POST- METAMORPHIC STRUCTURES

Fault network poorly evolved

E-W STRIKING MASTER FAULTS:

Sangone Fault system (SFS)
Chisone Fault (CF)

MINOR FAULTS

NE-SW Fault system
Pinasca - Gran Dubbione fault system (PGFS)
N-S fault system
Porte-Malanaggio Fault (PMF)

4. Post- metamorphic structural evolution

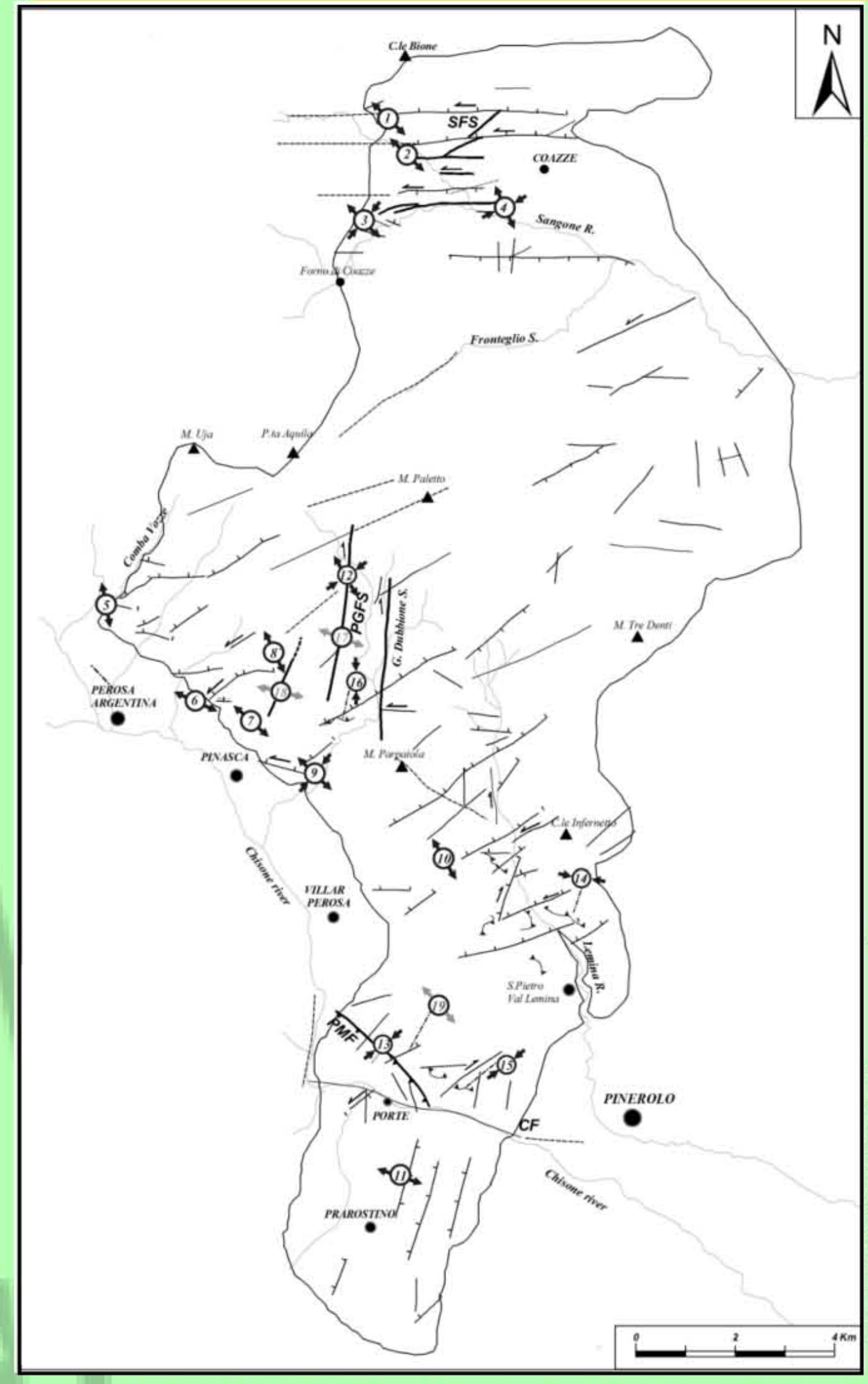


Figure 5: structural sketch of the analyzed area. Black and grey circle indicate the structural stations related to F4 and F5 deformation phases respectively. The arrows indicate the direction of shortening and extension axes.

Two deformation phases:

F4 →
- E-W sinistral fault zone formed in brittle-ductile conditions
- quartz, chlorite and albite mineralizations of striae on fault surfaces (fig.7c)
- fault rocks constituted mainly by foliated cataclasites
- kinematics and geometry of structures consist with a roughly NE-SW shortening direction (fig. 6)

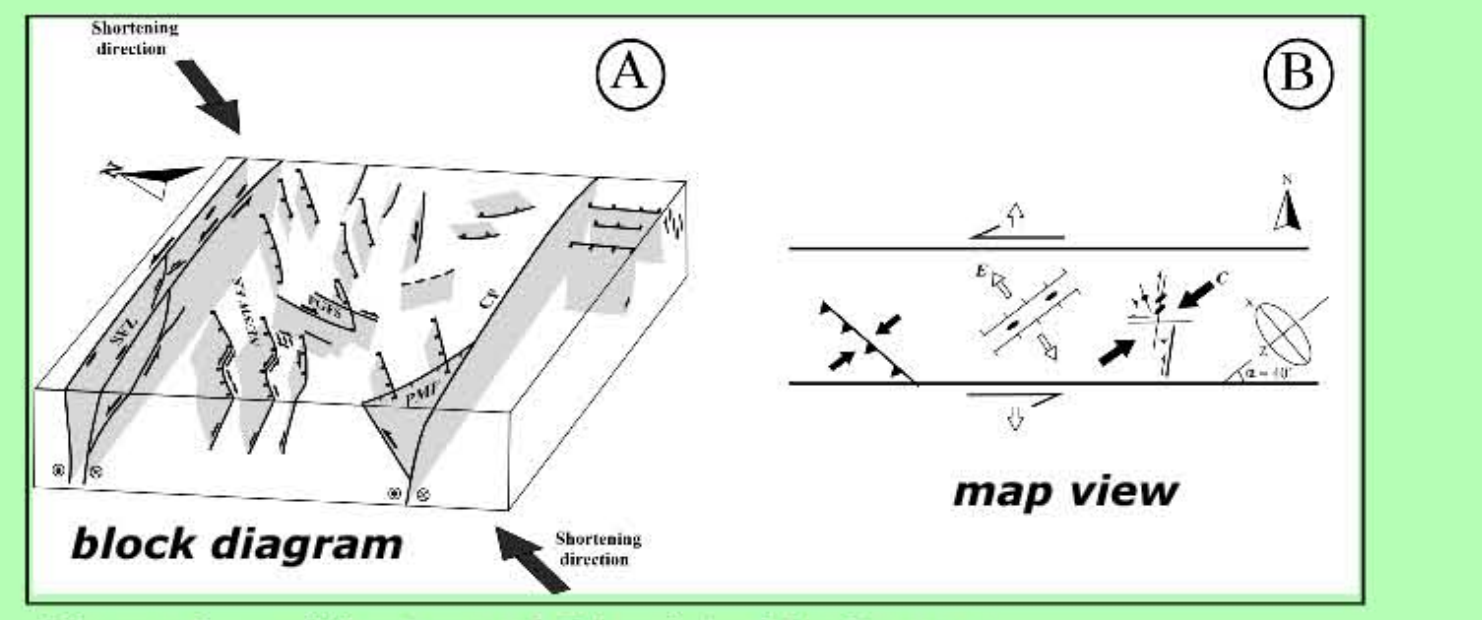


Figure 6: architecture of F4-related fault zone

F5 →
- development and reactivation of N-S fault as extensional structures
- fault rocks constituted by tectonic breccias and microbreccias (fig. 7a)

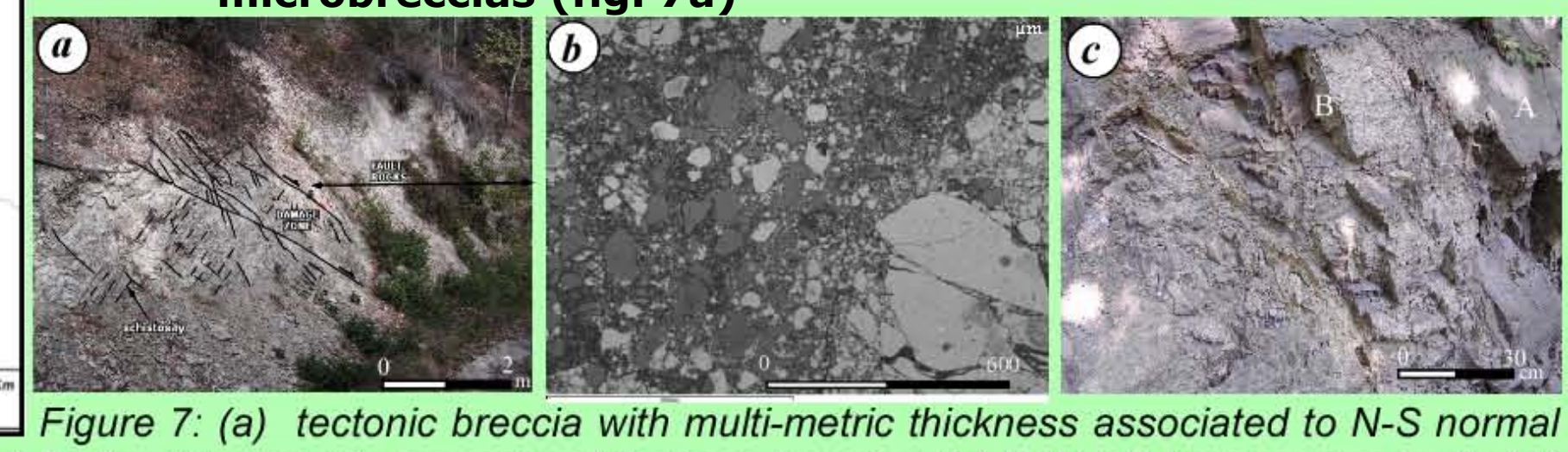


Figure 7: (a) tectonic breccia with multi-metric thickness associated to N-S normal faults; (b) microphotography of tectonic breccia; (c) E/W left-transtensive faults (A) with chlorite slickenfibers crosscut by N/S faults (B).

5. Post-Oligocene tectonic evolution

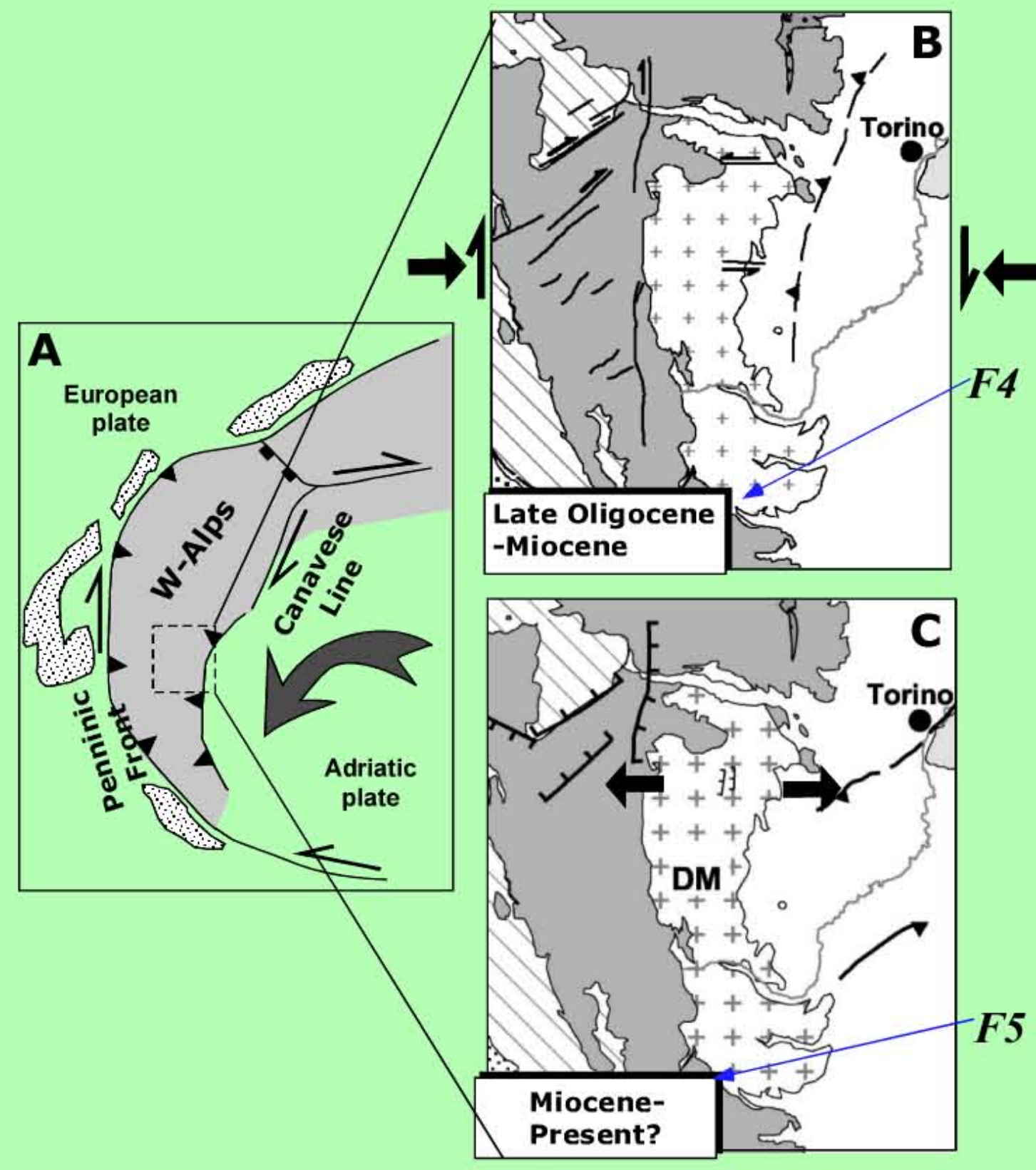


Figure 7: (a) structural sketch of W-Alps. (b) Kinematics of structures of the Cottian Alps In Late Oligocene-Miocene and in (c) Miocene to Present.

No geological-stratigraphic marker allow the dating of post-metamorphic structural evolution

Apatite fission track data indicate that this sector of W-Alps reached a depth of about 4-5 km of in the Oligocene

Based on these data:

F4 → *Late Oligocene-Miocene (fig. 7B)*

E-W sinistral fault zone in the study area considered as a tear zone of E-vergent back-thrusts

coeval with rigth-lateral movements on the Canavese Line and rigth transpressive movements of the Penninic Front

↓

Dextral transpression at regional scale due to the anticlockwise rotation of the Adriatic plate

F5 → *Miocene-Present? (fig. 7C)*

Extension at the scale of the Cottian Alps, as indicated also by Tallone et al. (2002) and Perello et al. (2004)

↓

Uplift and isostatic readjustment of a fractionated litosphere induced by the regional dextral transpression

6. Morphotectonics

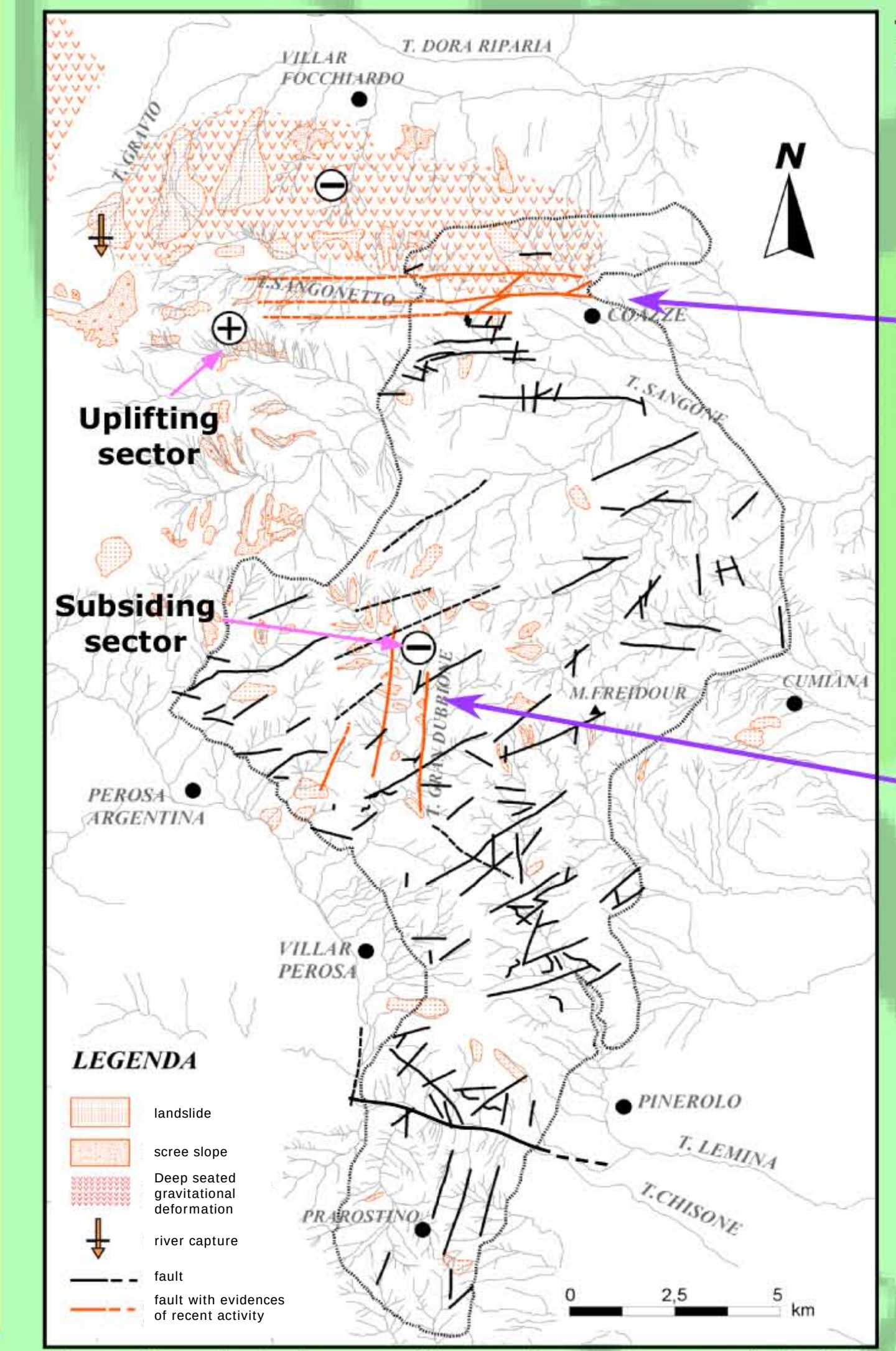


Figure 8: neotectonic map of the analyzed area. + and - indicate uplifting and subsiding sectors.

The analysis of geomorphological elements possibly linked to the recent tectonic activity of faults suggest that (fig.8):

Two structures show evidences of possible recent tectonic activity

SANGONE FAULT SYSTEM

Evidences:

- strong influence on the hydrographyc network
- bound a Deep seated gravitational deformation and numerous active landslides
- occurrence of a head capture in correspondence of these faults

PINASCA-GRAN DUBBIONE FAULT SYSTEM

Evidences:

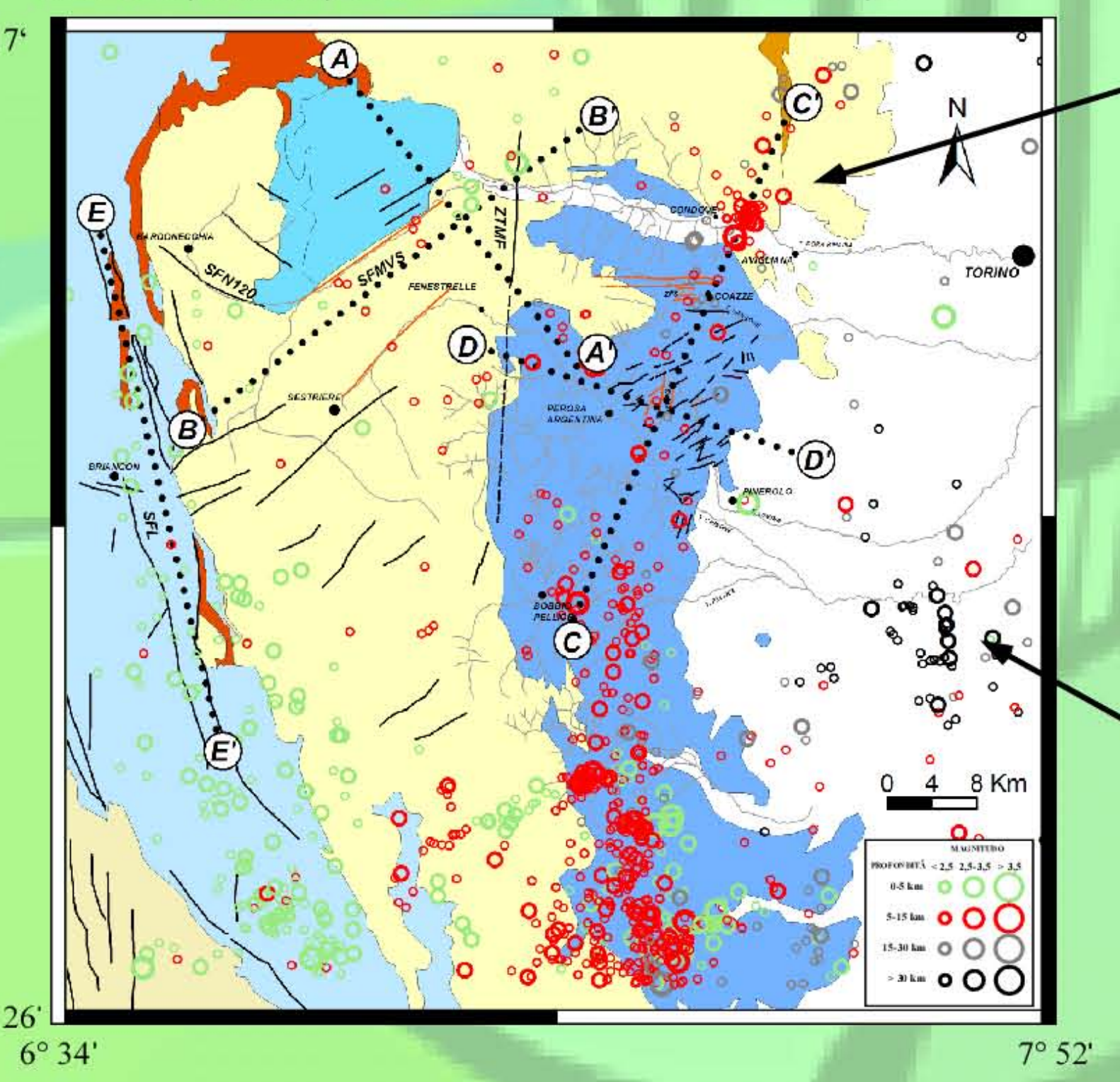
- anomalous concentration of landslides, debris deposits and scarps lined up to a N-S direction
- straigth and strongly asymmetric sub-parallel N-S valleys
- strong widening of the hydrographic basin of the Gran Dubbione river in respect to the adjoining basins

↓

These features suggest that this sector is subsiding

7. Seismological data

Figure 9: map of seismicity (location error of seismic events minor than 3 km) with major tectonic features of the Cottian Alps



Seismicity lines up to a NNE-SSW direction in the analysed area

Hypocentres mainly located at depth of 10-15 km (sections C-C' and D-D')

Hypocentres located at depth major than 30 km in the W- Po Plain

Figure 10: seismic sections

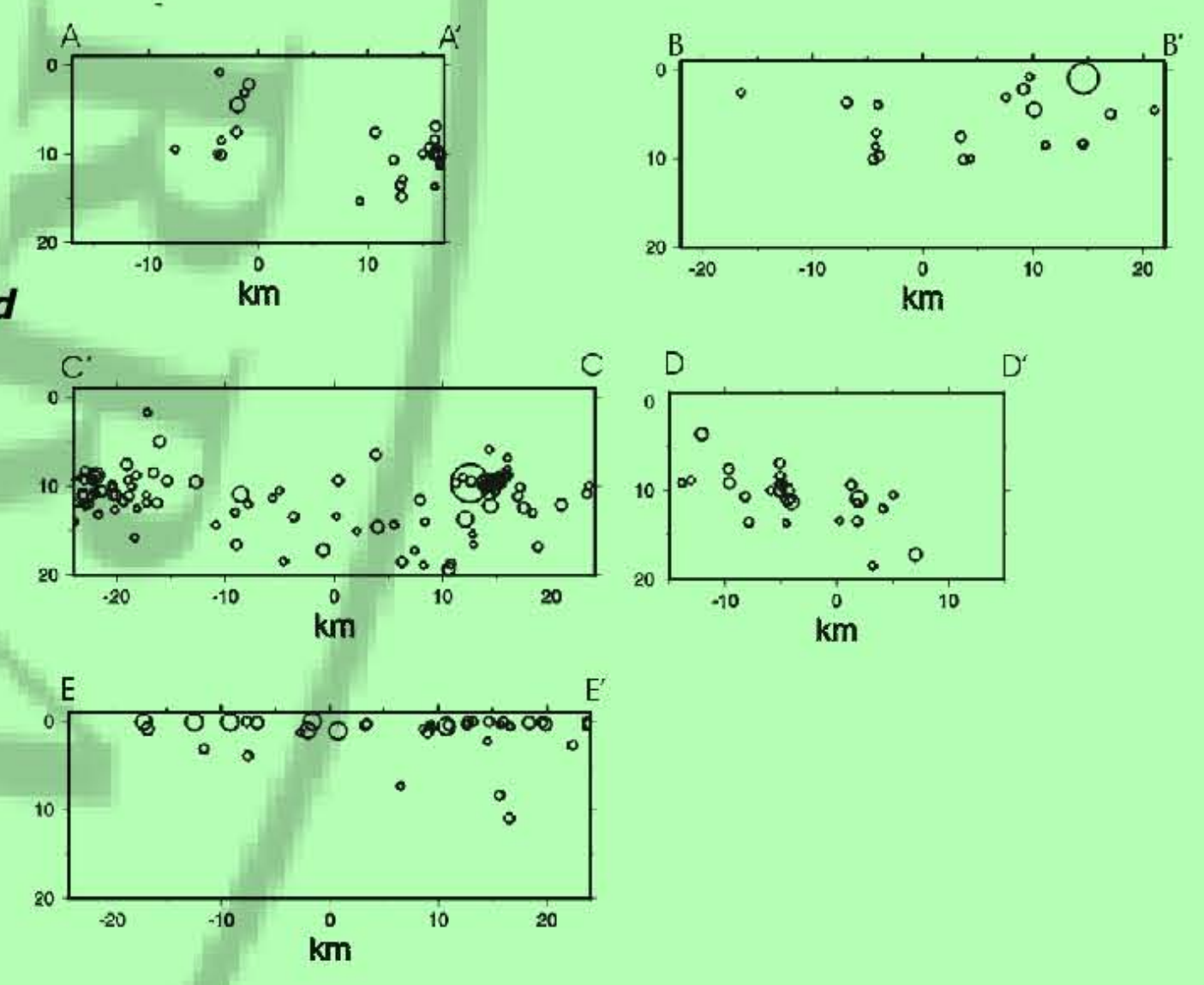
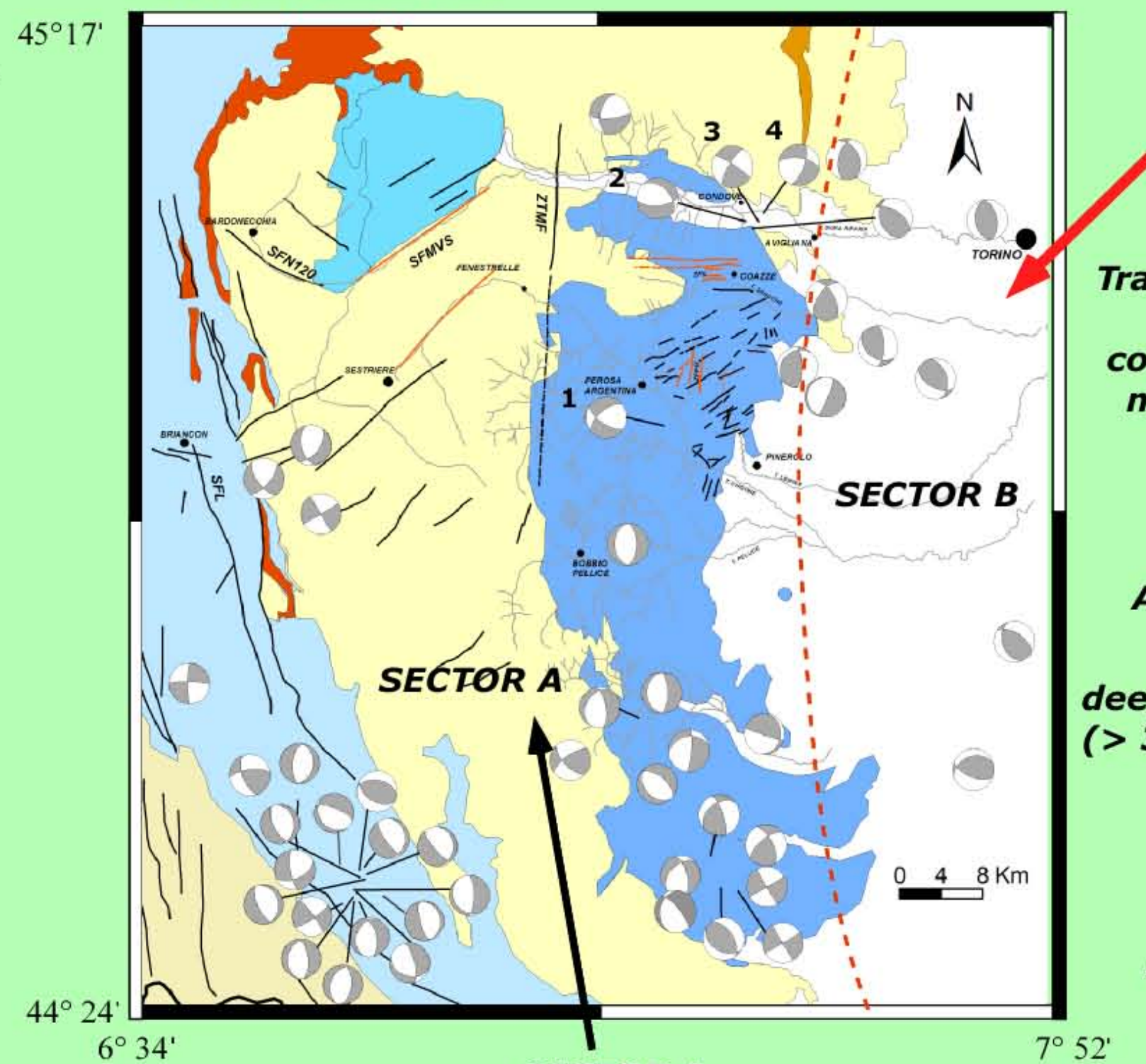


Figure 11: map of focal mechanisms with major tectonic features of the Cottian Alps.



SECTOR B

Transpressional and compressional mechanisms

↓

At the margin of the chain

deep crustal levels (> 30 km of depth)

↓

Roughly E-W shortening direction

SECTOR A

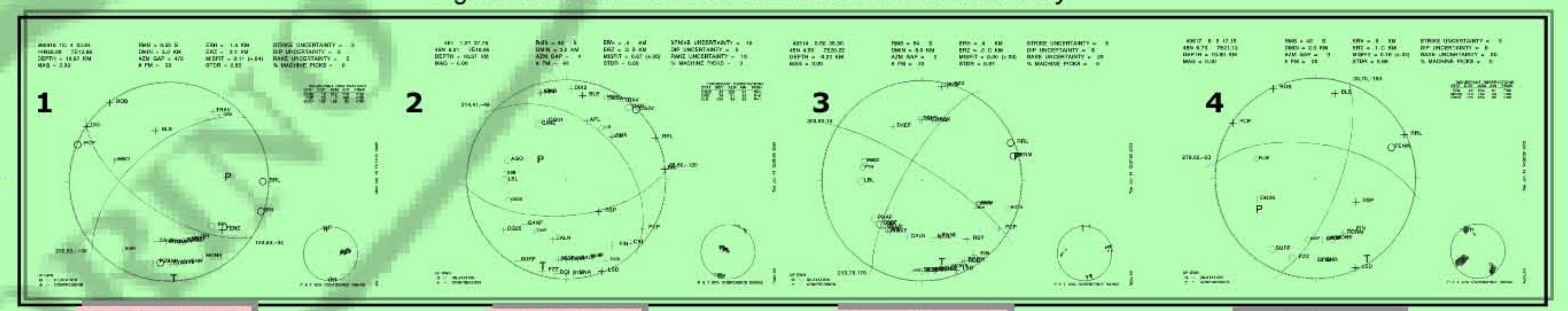
Extensional and transtensional mechanisms

↓

Crustal levels of about 10 km of depth → ***In mountainous areas***

Figure 12: focal mechanisms calculated in this study

Four new focal mechanisms were calculated to increase the seismotectonic data of this part of W-Alps →



18/4/1999 ***1/4/2000*** ***14/5/2004*** ***17/5/2004***

8. Conclusions

Structural data collected in the internal sector of the Cottian Alps indicate a polyphasic post-Oligocenic tectonic evolution :

Oligocene - Mioc. Inf. → ***Development of an E-W sinistral fault zone*** → ***interpreted as a tear zone of E-vergent back-thrusts***

Mioc. Inf. - Present? → ***Extension related to development and reactivation of N-S faults***

At the scale of W-Alps this tectonic evolution could be related to the dextral transpression induced by anticlockwise rotation of Adria plate

At present → ***Shortening concentrated at deep crustal levels*** → ***at the margin of the chain***
Extension at shallow crustal levels → ***in the mountainous areas*** → ***still on-going dextral transpression?***

Geomorphological analysis suggest that in the analyzed area N-S and E-W faults show evidences of recent tectonic activity

Seismicity lined up to a NNE-SSW direction and widespread at about 10-15 km of depth suggest that such an extension may be accomodated by the reactivation of steep N-S faults and by the tectonic inversion of Miocenic thrust faults → ***In agreement with the model proposed by Eva et al. (1997) and with geodetic data***

References

EVA E., SOLARINO S., EVA C. & NERI G., (1997) - *Stress tensor orientation derived from fault plane solution in the Southwestern* Alps. J. Geophys. Res., 102, 8171-8185.

PERELLO P., DELLE PIANE L., PIANA F., MORELLI M., DAMIANO A., VENTURINI G., ET AL. (2004a) - *New constraints on late to post-Oligocene deformation history of the Western Alps: data from middle Susa valley and high Maurienne valley*. Abstract, 32° IGC - Firenze, 247.

TALLONE S., CADOPPI P., BALESTRO G., DELLE PIANE L., PERELLO P. & RICCIO I., (2002) - *Ductile-to-brittle tectonic evolution at the structural knot between the lower and middle Susa Valley (province of Turin)*. In: Cinematiche collisionale: tra esumazione e sedimentazione- Riassunti dell'81a Riunione estiva della Società Geologica Italiana, Torino 10-12 Settembre 2002, 310-311.