Multidisciplinary approach to detect the seismogenic source of the Tortona 1828 earthquake.

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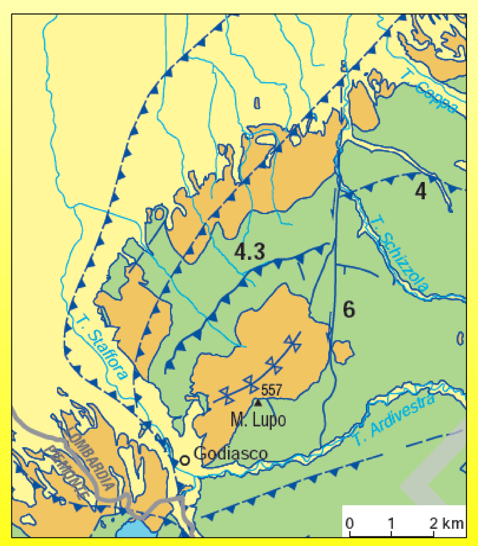
The seismic potential of the Piemonte Region is commonly associated with two main seismic districts: Northern Cottian Alps and Borbera-Grue (North-Western Apennines). This potential appears to be underestimated due i) to the lack of details in the available historical catalogs and ii) to the almost complete absence of information concerning the seismogenic sources responsible for the main events occurred in the two areas: the 1808 Pinerolo (Mw 5.64, Io VIII) and the Tortona 1828 (Mw 5.72, Io VIII) earthquakes. In particular, the Tortona 1828 earthquake caused several casualties and significant diffused damages. In order to obtain a more precise evaluation of the seismic potential in the area, we performed a revised collection of published and unpublished historical documentation. The processing of the collected data allowed to calculate the seismic effects on the urban and natural landscape and the consequent revision and updating of macroseismic catalogs. Moreover the evaluation of seismic intensity at the municipal and sub-municipal scale highlighted anomalies in the damages distribution due to "site effects". Starting from a morphometric analysis we detected some areas characterized by strong anomalous relief energy and sharp deviation of the river pattern. Field surveys allowed to verify the presence of tectonic, as well as lithological, influence on the drainage network distribution. In this way a sector crossing the Staffora River has been judged anomalous and we performed detailed geological, geomorphological and geophysical surveys to detect if Quaternary successions show presence of brittle deformations. The geophysical analysis revealed the possible presence of a fault surface affecting an alluvial deposit, Late Pleistocene in age. The analysis of the local microseismicity of the last 35 years shows a low frequency seismic activity in the area, concentrated within 20 km of depth, with the greatest energy released in the most shallow layers. Using Matlab we perform a Direct Linear Transformation (DLT) in order to estimate the plane that best fits the selected hypocenters; then plane orientation, expressed in terms of dip and dip direction, is calculated following the equations proposed by Ferrero et al. (2009). The results show a general presence of high angle surfaces east-west oriented, suggesting a possible expression of the Avolasca-Musigliano Fault (Festa et al., 2014), an E-W striking fault segment of the Villalvernia-Varzi Fault Zone.
Key words: seismogenic source, historical investigation, geomorphological survey, geophysics, modelling.

Geological Setting

Study area is located in south-eastern Piedmont (north-western Italy) where the seismic structure related to Tortona 1828 earthquake is placed.

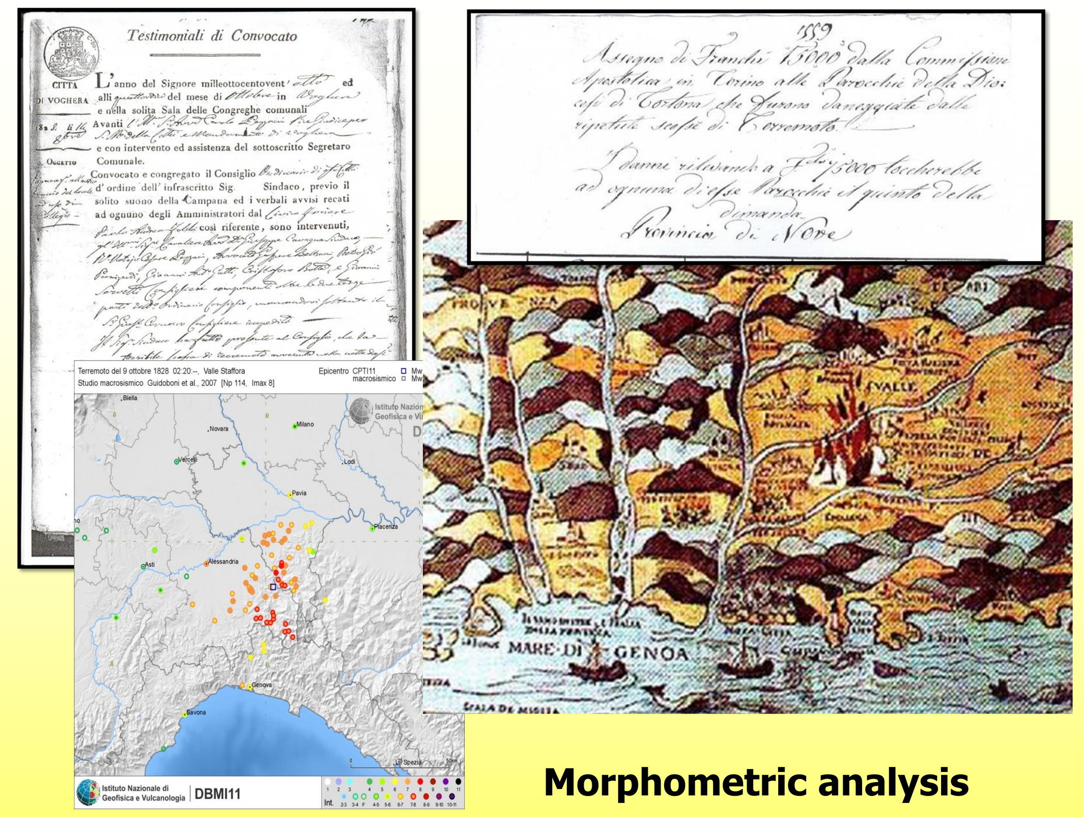
In this zone, the External Ligurian and Epiligurian Units of the Northern Apennines (green) are tectonically justaposed with the Tertiary Piedmont Basin units along the Villalvernia - Varzi Line, which represents an E-W striking, regional scale fault zone (Vercesi et al., 2014).

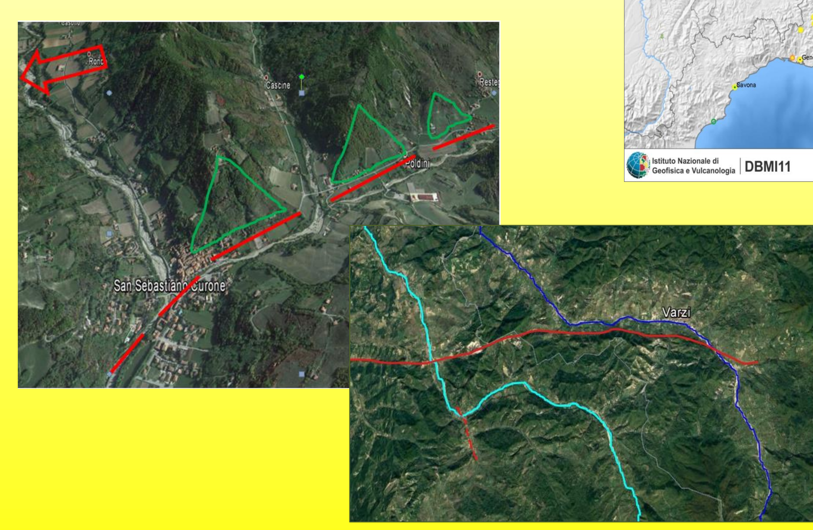


Messinian and Pliocene arched deposits (orange) outcrops only in south-eastern sector, showing a faster uplift than north-western one. Structural map highlights buried north-vergent compressive tectonic structures account for deformation in outcropping units. Furthermore Quaternary to Holocene fluvial deposits (yellow) mostly cover north-western flat area where the city of Tortona is built.

Historical data revision

To update macroseismic catalogs a consultation of historical archives in municipalities and parishes was performed. Several documents found in Voghera municipal archive reveals serious damages to the buildings and the inaccessibility of cathedral. In Voghera library an important text reports a total of 30 fatalities in Casteggio, Gamminella, San Paolo and Bagnaria villages, much more than it was documented before. Finally the State Archive of Turin allowed to get an impression of the costs incurred by dioceses.





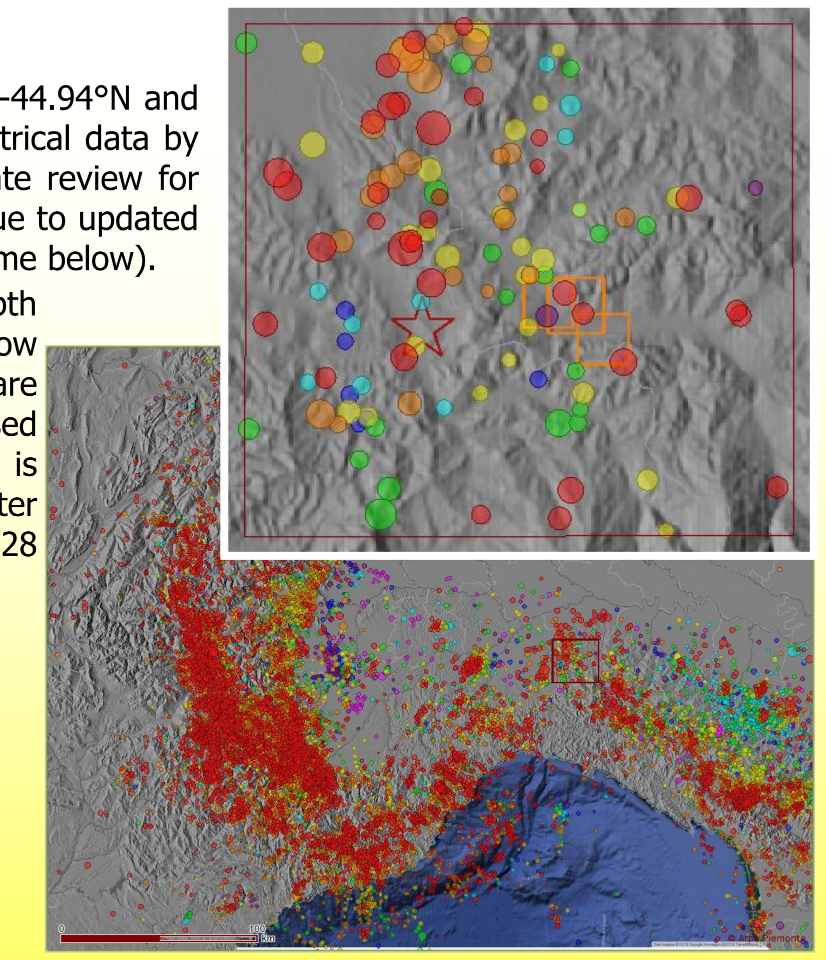
Morphometric analysis

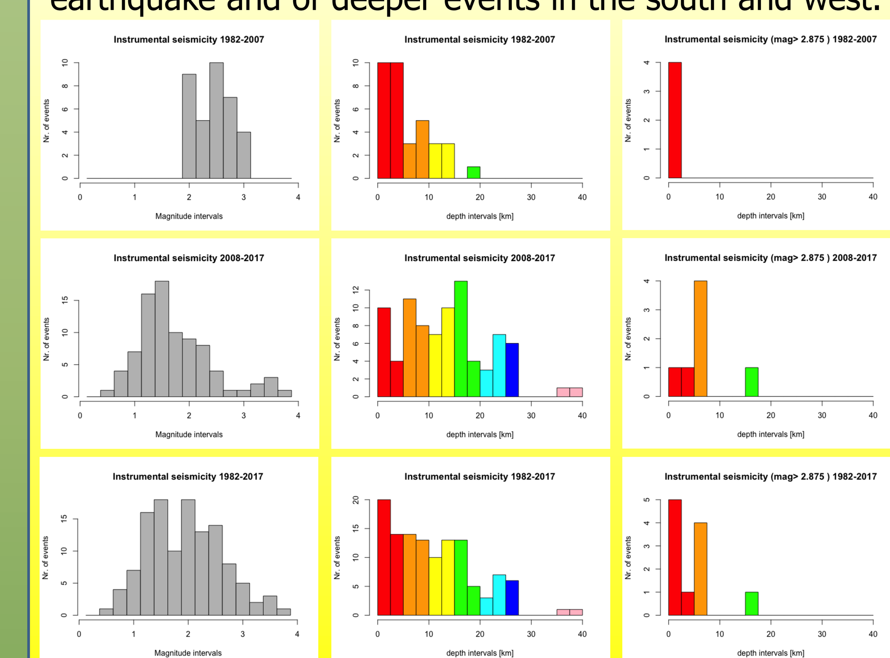
Active tectonic could induce drainage network adjustments: in particular the Staffora and Curone rivers change their S-N directions to E-W with anomalous 90 degree angles. It could be associated with the well-known Avolasca-Musigliano strike-slip structure and with a N-S hyphotetic fault near San Sebastiano Curone village.

Instrumental seismicity

Preliminar analysis performed over selection within 44.74-44.94°N and 8.95-9.25°E box from regional seismic database. Parametrical data by seismic surveillance bulletins, so they need more accurate review for seismotectonic purposes. Dataset splitted in 2 subsets, due to updated configuration of monitoring systems since 2008 (see scheme below).

In particular 2nd set is better constrained in terms of depth and of general accuracy of focal parameters. In this low frequency seismicity area, the most number of events are observed within 27 km depth, with higher energy released in the shallower layers (<7km). No strong trend is highlighted in map view, except for a slightly greater concentration of shallow events north of the 1828 earthquake and of deeper events in the south and west.

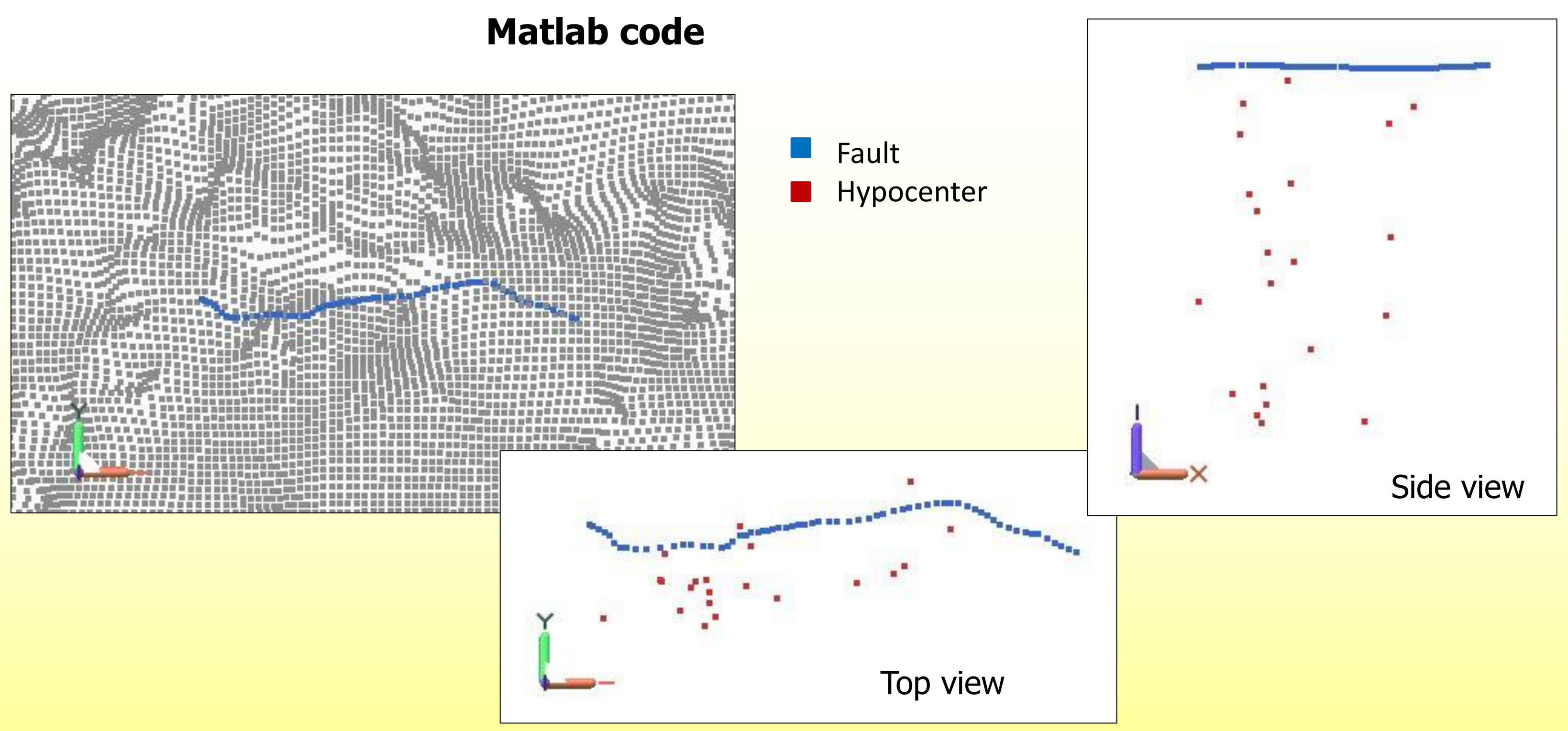




Regional seismic network main improvements

1982-2007	2008+
Short period	Broadband
1 component	3 components
analog	digital w/ high dynamic
P + (S)	P + S
Md	ML, (Mw)

Matlab code



Direct Linear Transformation (DLT) was implemented in Matlab code in order to estimate the plane that best fits the selected hypocenters. Equation must be expressed in a reference system with y-axis oriented toward North.

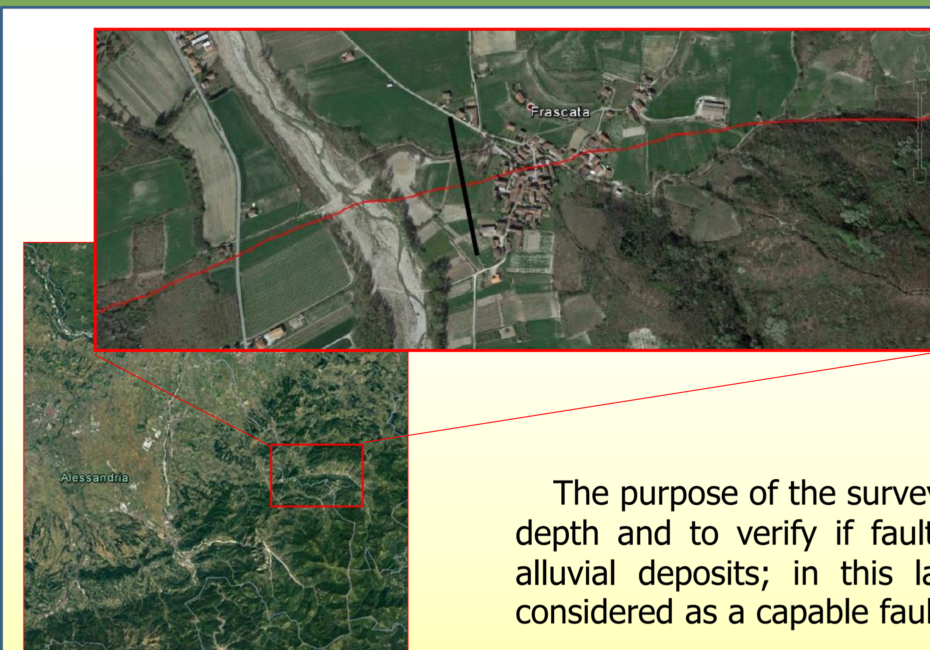
$$ax + by + cz + d = 0$$

Since normalized a, b, c are the direction cosines of the normal n to the plane, Dip and dip direction can be calculated as (Ferrero et al., 2009):

$$\text{Dip} = \arccos(c)$$

$$\text{Dip Direction} = k \pm \arctan(a,b)$$

Geophysical Surveys

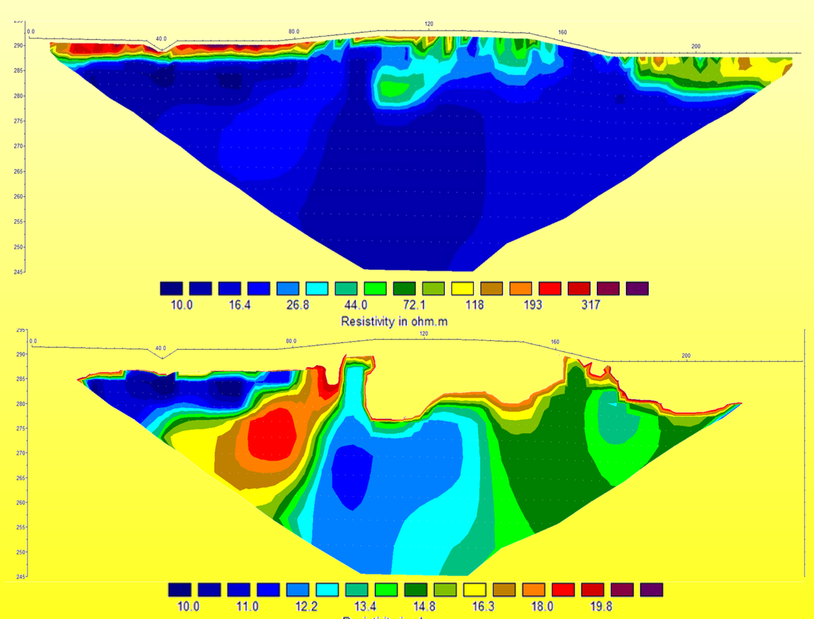


An Electric Resistivity Tomography has been executed along a 235 m, N-S transect with 48 electrodes at 5 m interelectrode spacing and Wenner-Schulumberger acquisition sequence. The survey line (black) was placed over alluvial deposits, with an evident morphological terrace in correspondence of the Avolasca-Musigliano Fault (red).

The purpose of the survey was to better understand fault geometry with depth and to verify if fault movements may have altered the overlying alluvial deposits; in this last case the Villalvernia-Varzi fault could be considered as a capable fault with respect to possible future earthquakes.

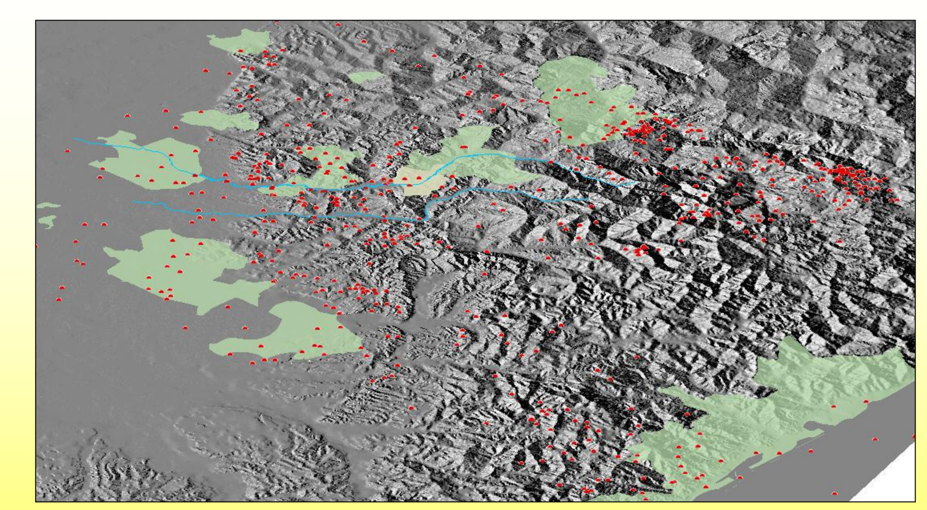
Results of the survey evidenced (top figure): 1. A shallow (5 m thick) layer of alluvial conglomeratic deposits with a basal "strat" type erosional surface; 2. A sandy clayey alluvial fan 8-9 m thick; 3. An interaction zone in the center of the tomography in correspondence of the terrace.

Below these shallow deposits a clear damage zone, with high angle north dipping shape, can be evidenced in the bottom figure (color scale calibration of the same tomography). This damage zone which is the expression of the Avolasca-Musigliano Fault is however at the contact between mainly pelitic formations partially complicating the interpretation.



Conclusions

This multidisciplinary approach sets out the guidelines to follow to add new data and observations to poor research on seismogenetic source in North-western Italy. Research on this issue, then, in addition to having a great scientific interest, is particularly important because it can provide an essential support for Administrations to identify areas with highest seismic risk, intervene on resistance of buildings and set civil protection plans. The ultimate aim is avoiding, or at least mitigating the heavy economic and social impact we saw in the past.



Last 30 years hypocentres map in relation to 1828 earthquake damaged zones.

The main result is the identification of the location of the fault systems responsible of the Tortona earthquake, its direction and geometry. The fault system shows a high angle surfaces east-west oriented, suggesting a possible relation and surface expression with the Avolasca-Musigliano Fault, an E-W striking fault segment of the Villalvernia-Varzi Fault Zone.

References

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