SEISMOTECTONIC ANALYSIS OF A COMPLEX FAULT SYSTEM IN ITALY: THE "GARFAGNANA-NORTH" (NORTHERN TUSCANY) LINE.

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We present the results obtained combining different techniques to determine the seismotectonic character of the Garfagnana region (northern Tuscany) where the existence of a rather complex fault system is acknowledged and somewhat mapped, but apart from the geological evidences, very little is known about its extension with depth and the regime.

The seismic potential of the area is also well known. In fact it was characterized, in the past, by destructive earthquakes; in particular a major event (Ms=6.4) struck the Lunigiana-Garfagnana area in September 1920, but several macroseismic catalogues index many other earthquakes. According to these catalogues, the majority of the events occurred along a NW-SE alignment, thus with an orientation similar to that of the principal fault systems of the area, namely the Garfagnana North and the Garfagnana South. The evidence for a correlation between major events and the Garfagnana (N and S) faults is also confirmed by instrumental data. In fact, the most significant earthquakes of the Garfagnana-Lunigiana area occurred when seismometry was already well developed. They have been recorded by several instruments, included in a phase–reading process and the corresponding data have been published in several bulletins. The seismograms of these recordings are sometimes still available, even in digital format. The availability of both interpreted and raw data, provided that a careful selection is made, renders the application of a Joint Hypocentral Determination technique possible. The methodology and results are described in Solarino et al. 1996, and Solarino, 2002; 2005. The method is based on the concept that it is possible to account for all systematic errors that may bias the location of an earthquake by computing corrective factors in conjunction with the velocity model used for locations; all non-systematic errors may instead be discarded by checking the single datum. The results show that 36% of the relocated events are in good agreement with the macroseismic location.

On the other hand, the recent seismicity of the area under study is known at both a global (Chiarabba et al., 2005) and local scale (Solarino et al., 2002), the latter aspect due to the establishment, since 1999, of a dense seismic network that monitors the area of Northern Tuscany.

Although the data acquired in the last decade contribute to increase the quality of the database and, as a consequence, the constraints on the seismic locations, nevertheless the application of methodologies to get the best performances from the data have been designed and applied in areas with similar characteristics (Waldhauser and Ellsworth, 2000) where they proved to be helpful in a more complete description of the sources.

The work hereby presented consists in seismic tomography experiments (1D and 3D velocity models), the application of precise location algorithms NonLinLoc and HypoDD (very constrained and reliable locations) and the computation of focal mechanisms (fault orientation and source), all combined and compared with the constraints provided by geological studies.

As known, the spatial and temporal distribution of earthquakes provide information on tectonic regime and material properties of an area, and on the depth of the brittle-ductile transition. Precise earthquake hypocentre locations are therefore the requirement to study structure and processes that trigger seismic activity. The accuracy of hypocentre locations must be of the same order of the size of the structures under study, and it depends on several factors. The most important are the number and type of available seismic phases recorded at the seismometers, the accuracy with which arrival times are measured, the network geometry , the knowledge of the crustal velocity structure and the linear approximation to a set of non-linear equations, which is assumed in the location process.

The existence of many data can account for the first three quoted requirements, that is number and quality of available seismic phases and network geometry. In fact, the seismicity of the study area is under constant monitoring by the national seismic network (RSNC – National Central Seismic Network) and by a pool of local stations, belonging to a regional network (RSLG – Regional Seismic network of Lunigiana and Garfagnana), able to record lower magnitude seismicity.

However, the location process and its results may be improved by adopting alternative algorithms. In particular, in this study the procedure applied to improve and constrain the locations consists in 1) Calculating a reference 1-D model 2) Calculating a tomographic 3-D model 3) Applying two precise location methods.

The knowledge of both 1-D and 3-D velocity reference models is of paramount importance in the location process. A as-close-to-real-as-possible parametrization of the distribution of seismic velocity under surface is in fact needed to reconstruct the exact path of a seismic ray and then its origin. The a-priori or geological information about the earth's structure of a given area are relative to the shallow layers, and do not account for the seismic ray paths at depth. On the other hand, the seismic velocities as provided, for example, by the DSS experiments indeed give information on deeper layers but are relative only to the shooting line, and cannot expanded to the whole area. Ellsworth (1977) and Kissling (1988) proposed to use the coupled velocity-hypocentre problem to get information on the seismic velocity structure of a volume. The process consists in an iterative routine that starts from known a priori information and expands them to deeper layer by minimizing the travel time residuals of the data used in input. The model that best fits with the known information and minimizes best the residuals is then used as a reference for the location process. Thurber (1983) proposed a similar methodology in a 3-D volume: the resulting model not only provides better and more constrained information on the velocity model but also gives an "image" of the structure (velocity, density, temperature) of the deeper earth.

The location algorithms used in this study are the probabilistic , non-linear earthquake location method (NonLinLoc, Lomax and Curtis, 2001) and the double difference relocation technique (HypoDD hereinafter) of Waldhauser and Ellsworth, 2000.

The first methodology is based on a global search algorithm that can be performed in three different ways; in fact instead of a grid-search algorithm using successively finer, nested grids, the Metropolis-Gibbs or the Oct-Tree Importance sampling algorithms can be applied. The approach provides a complete description of location uncertainty estimates and can be used with any available velocity model (1-D or 3-D) and method of traveltime calculation.

In the second method (HypoDD) the residuals between observed and theoretical traveltime differences are minimized for pairs of earthquakes at each station and the spatial offset between these events can be computed with high accuracy. The location method incorporates ordinary absolute traveltime measurements and/or cross correlation P and S wave differential traveltime measurements. This method is apparently independent from the velocity model, that must be mono-dimensional.

953 earthquakes have been merged, picked and relocated first with a standard technique and then with improved location algorithms. 1-D and 3-D velocity propagation models have been computed and properly used.

Figure 1 and 2 show a comparison between the NonLinLoc and HypoDD locations, in plane and depth view respectively. The star and square symbols show the position of the 1920 (macroseismic and instrumental) and 1995 events. The likely position of the Garfagnana North and South faults is also reported. The analysis of figure 1 reveals that the main trend of seismicity is oriented in a NW-SE direction, that is parallel to the most important faults of the area. In particular, the recent seismicity occurs at the northern edge of the Garfagnana North fault, while the Garfagnana South fault results quasi aseismic. The seismic line (C-D) crossing this seismicity cluster show a plane dipping 30° NE. A similar trend is confirmed by the tomographic cross sections.

Since all earthquakes (figure 3) of the area have a transtensive character (Eva et al., 2005), it is reasonable to attribute such a character to the fault, conversely to what proposed in DISS and in agreement with the findings of Ameri, 2005.

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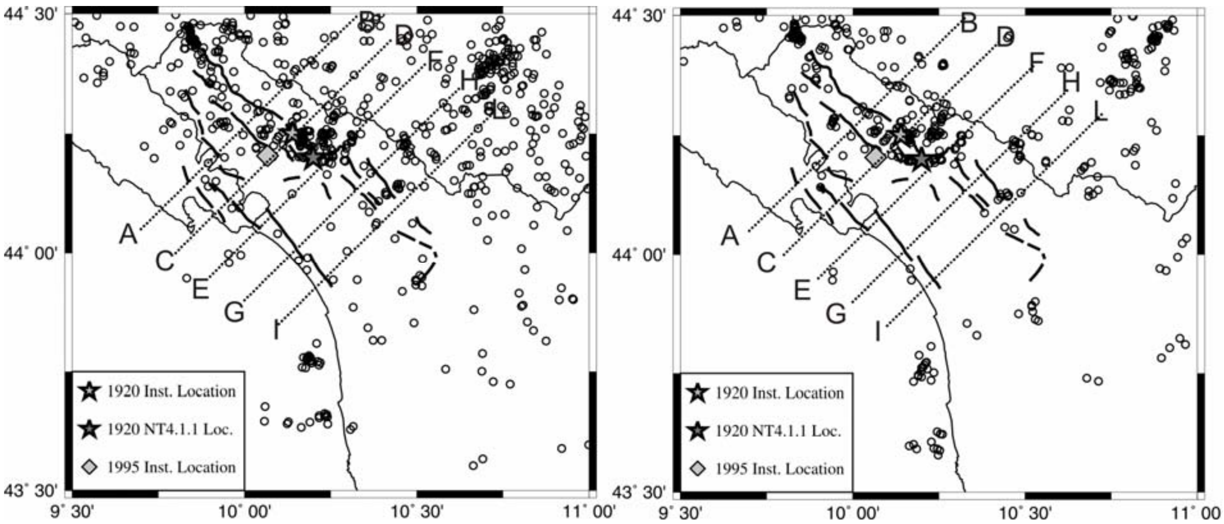

Fig.1 Comparison between high precision locations obtained with the NonLinLoc method (left panel) and HypoDD (right panel). The stars and the square show the location of the 1920 and 1995 events respectively. The lines with dot show the orientation of the cross sections of fig. 2.

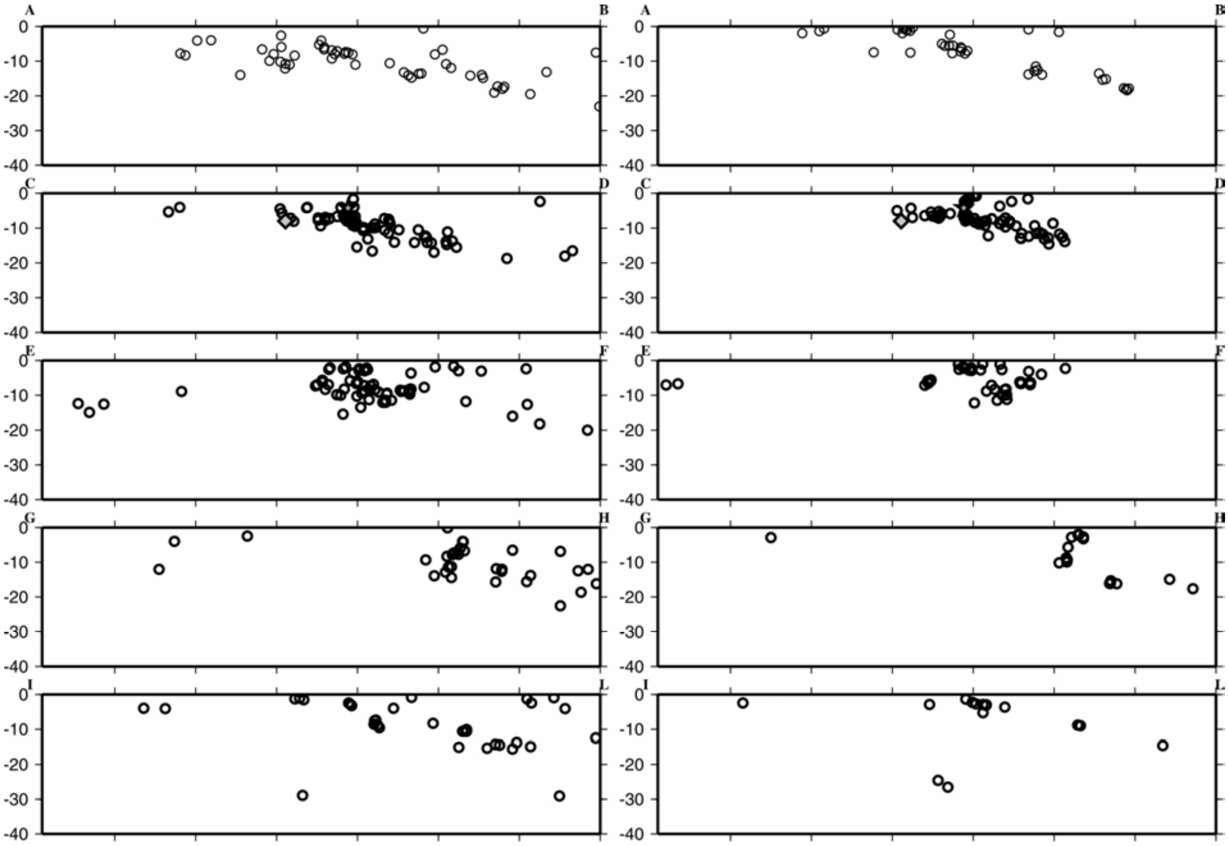

Fig. 2 Cross sections along the lines of fig. 1; those on the left panels are based on the location obtained with the NonLinLoc technique. On the right: HypoDD.

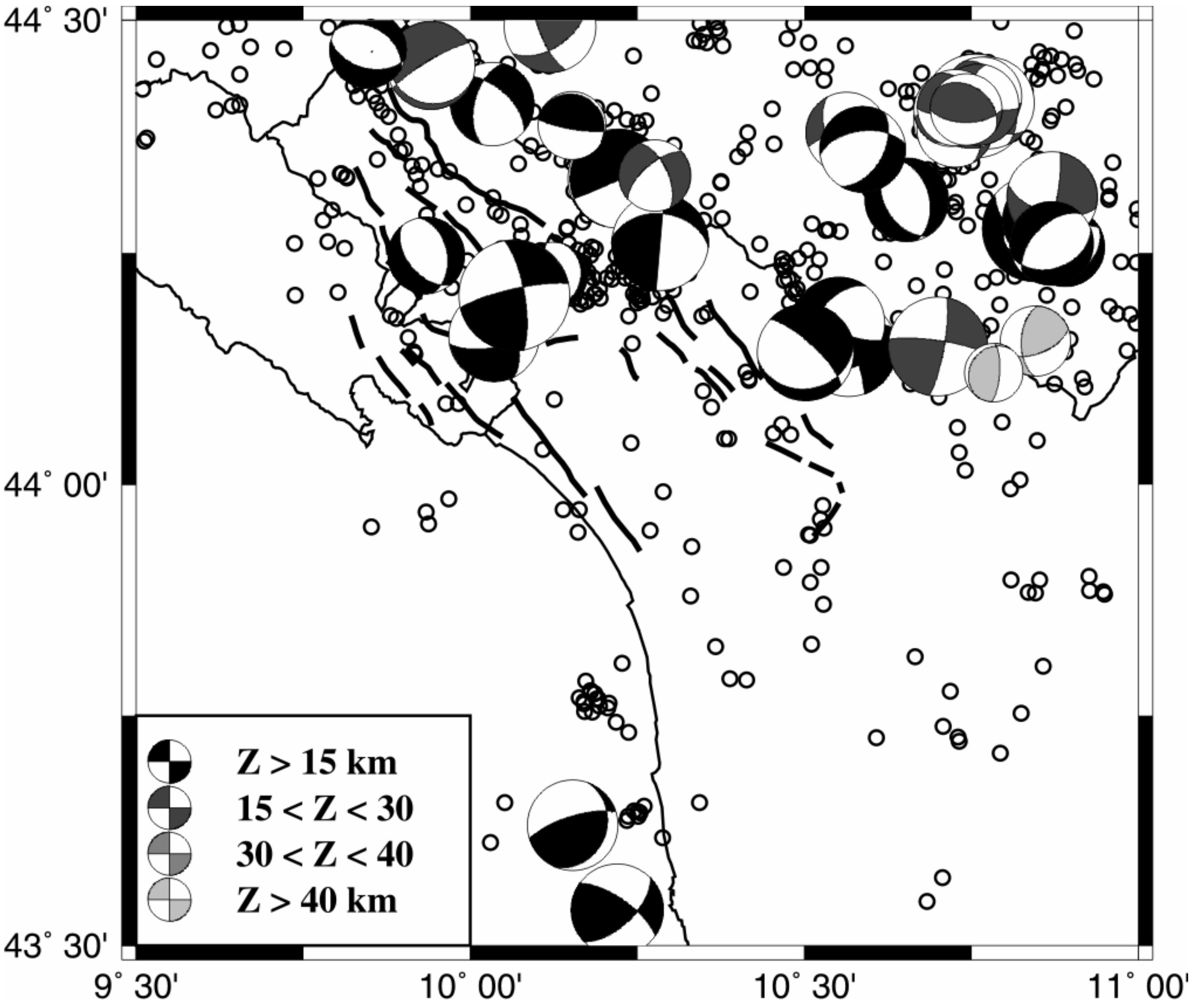

Fig.3 Focal mechanisms computed with the first onset method. The majority of solutions have a transtensive character.