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Fault plane orientations of microearthquakes at Mt. Etna from the inversion of P-wave rise times

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ABSTRACT

A crucial point in the analysis of tectonic earthquakes occurring in a volcanic area is the inference of the orientation of the structures along which the ruptures occur. These structures represent zones of weakness which could favor the migration of melt toward the surface and the assessment of their geometry is a fundamental step toward efficient evaluation of volcanic risk. We analyzed a high-quality dataset of 171 low-magnitude, tectonic earthquakes that occurred at Mt. Etna during the 2002–2003 eruption. We applied a recently developed technique aimed at inferring the source parameters (source size, dip and strike fault) and the intrinsic quality factor Q_p of P waves from the inversion of rise times. The technique is based on numerically calibrated relationships among the rise time of first P waves and the source parameters for a circular crack rupturing at a constant velocity. For the most of the events the directivity source effect did not allow us to constrain the fault plane orientation. For a subset of 45 events with well constrained focal mechanisms we were able to constrain the "true" fault plane orientation. The level of resolution of the fault planes was assessed through a non linear analysis based on the random deviates technique. The significance of the retrieved fault plane solutions and the fit of the assumed source model to data were assessed through a χ-square test. Most of the retrieved fault plane solutions agree with the geometrical trend of known surface faults. The inferred source parameters and Q_p are in agreement with the results of previous studies.

1. Introduction

The knowledge of the focal mechanism of an earthquake is a fundamental step for understanding geometry and dynamics of the seismogenic fault. Its determination is usually performed from the inversion of P-wave polarity (Reasenberg and Oppheneimer, 1985). Once the fault mechanism is computed, the next problem is deciding which of the two nodal planes corresponds to the true fault plane, except when the fault has clear surface morphological evidence which is confirmed by the hypocenter distribution at depth.

Several studies (Mori, 1996; de Lorenzo and Zollo, 2003; Filippucci et al., 2006; Warren and Shearer, 2006 among the others) have shown that the fault plane orientation of an earthquake can be inferred by modelling the directivity effect of the seismic source, i.e. the variation of the pulse widths of first P and/or S waves as a function of the angle between the normal to the fault plane and the seismic ray. However, the possibility to assess the "true" fault plane is strongly dependent on several factors such as the number of available data, the exploration of the range of takeoff angles, the error on the data and the ability of the theoretical source model to predict the data. Moreover, the equations governing the rise time variations with varying the model parameters are non linear. Therefore a statistical approach aimed at determining how data errors map onto the model parameter space is needed in order to assess the reliability of the results.

In this article, we present the results of a study aimed at inferring the fault plane orientation of events with well constrained focal mechanisms (Barberi et al., 2006) that occurred at Mt. Etna during the 2002–2003 eruption. We used a recently developed pulse width technique (Filippucci et al., 2006). The source parameters of the events and the average intrinsic Q_p are also provided and compared with results of previous studies.

2. Tectonic setting

At Mt. Etna, signs of active tectonic processes are mainly recognised on the eastern flank of the volcano, as it is well demonstrated by the Timpe fault zone (Fig. 1), which is characterized by both frequent shallow seismic activity and localized aseismic creep. The Timpe

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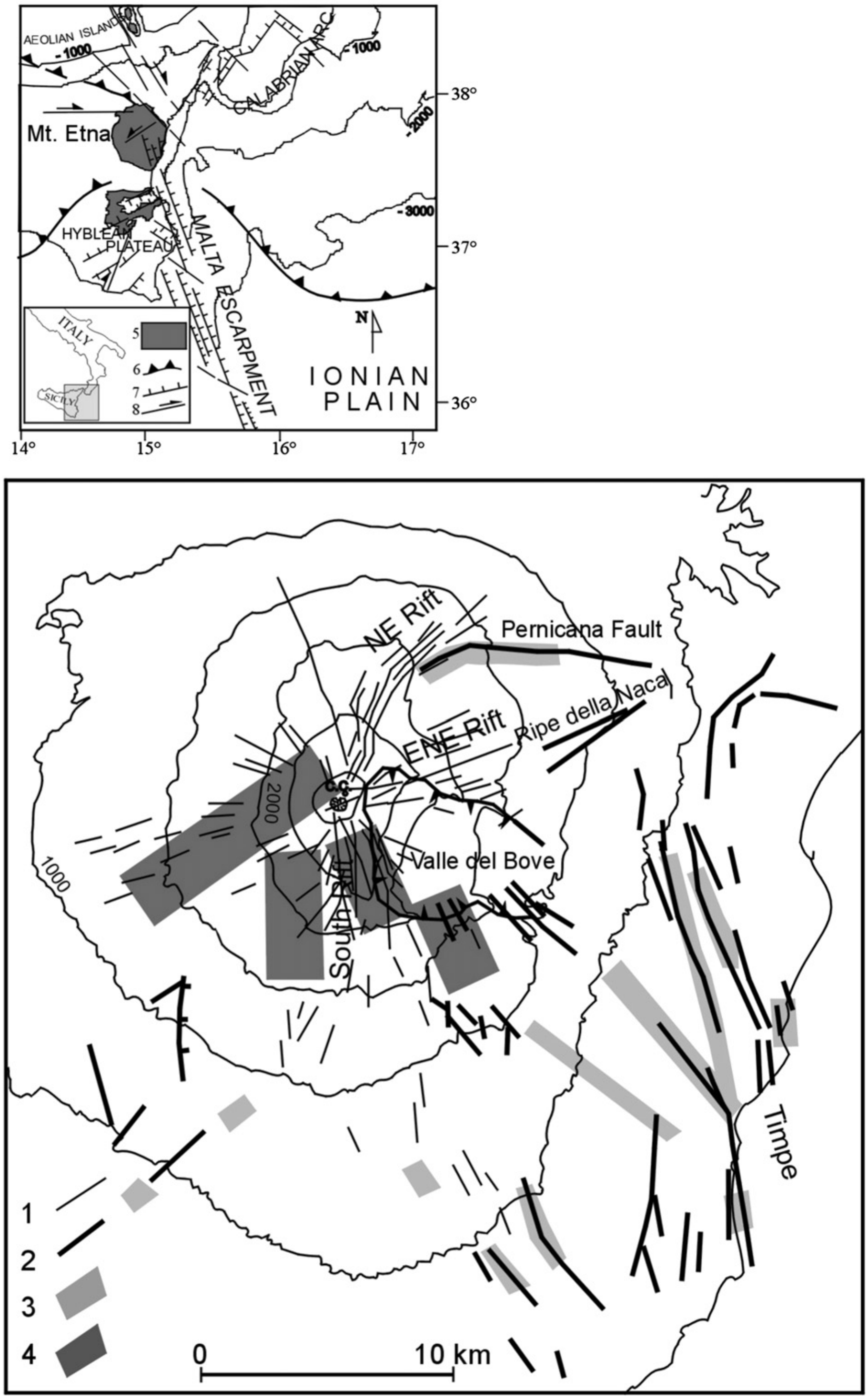

Fig. 1. Structural map of Mt. Etna (after Azzaro, 1999). 1. eruptive fractures; 2. main faults; 3. coseismic surface faulting zones; 4. zones where seismicity is mainly clusterized.

fault zone represents the northernmost prolongation of the NNW–SSE trending Malta Escarpment and is characterized by several individual faults with the same general strike of the escarpment. These fault segments are roughly parallel and of considerable length (8–10 km) with vertical offset (up to 200 m) that down-throw toward the sea.

It is worth noting that, while the Timpe faults mainly dominate the southern part of the eastern flank of Mt. Etna, other seismogenic structures, with predominantly ca. NE–SW Messina fault zone affinity, are recognisable in the northern part of the volcanic edifice (e.g., Lanzafame et al., 1996; and Azzaro, 1999). In fact, to the north the NNW–SSE fault system is interrupted by the E–W Pernicana fault, which cuts a large part of the volcanic edifice, and by the NE–SW Ripe della Naca system (Fig. 1).

It is noteworthy that both the NNW–SSE and NE–SW structural trends are largely comparable to the main directions of the volcanic activity and the eruptive fractures on the upper flank of the volcano.

By a new detailed re-examination of historical sources and recent surface ruptures at Mt. Etna, Azzaro (1999) indicated that the kinematics of the two main seismogenic structures reported above is essentially associated with ruptures at shallow and very-shallow