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The alignment of shear-wave polarization eigendirection at Mt. Etna: implications on the volcanic activity?

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Introduction

A temporary digital seismic network installed on Mt. Etna volcano recorded local seismicity in three different periods: in 1988 when no eruption occurred, in 1989 during an effusive eruption, and since 1994, after the 1991-1993 eruption. From the seismic point of view, the existence of an anisotropic volume can be better revealed by shear wave splitting (birefringence) observations. When a shear-wave enters into an anisotropic region, it splits into two phases which can propagate having different polarizations and different velocities. These two phases, commonly named qS1 and qS2 waves, arrive at the exit interface at different times, and upon re-entering an isotropic region the original waveform cannot be reconstructed. Therefore the measured splitting parameters are

- time-delay between qS1 and qS2 phases (hereafter TD)
- polarization anomalies of the S-wavetrains
- polarization direction of qS1 waves

Moreover, in an anisotropic medium, splitting parameters are theoretically well related to the stress field features so that changes in splitting parameters could be used to monitor changes in the stress field acting on the volcanic area.

Data analysis

Polarization anomalies have been evidenced by analysing the time behaviour of the polarization eigenvector in the horizontal plane on a very selected data-set recorded during the three periods, according to shear wave window (35°). This is rather similar to what Aster et al. (1990) suggested, and has the advantage of computing the eigenvector using the 3D signal even if the representation is 2D. This could lead to more stable results in a very heterogeneous medium (Aster et al., 1990). The diagonalization of the covariance matrix was calculated using an analytical time-moving window across the entire S-phases contained in the recorded signal. We evaluated the duration of the window after estimating the mean value of the linearity interval (the time in which the qS1 phase is the only wave recorded) choosing, then, the length of the moving window greater than this value, resulting generally 0.5 seconds.

To have a quantitative information on the degree of the polarization anomalies, we have defined an empirical *chaoticity* parameter, that we have called R(x), as: the mean value of the number of rotations of the polarization eigenvectors around the x-axis in the time-unity, each value being normalised respect to the greatest number of rotations in the entire distribution of data-set. The behaviour of the polarization eigenvectors' *chaoticity* suggested us that the anisotropic volume has different characteristics and is not homogeneously distributed on the eastern slope of Mt. Etna volcano.

Polarization of the leading split wave has been deduced by diagonalization of covariance matrix too. The leading shear

wave polarization eigendirections agree with the direction of the regional maximum compressive stress-field ($\sigma_1 \approx$ NS; Lo Giudice *et al.*, 1982), but do not show any variation between the uneruptive period and the eruptive one. The alignment between polarization eigendirections of the leading split waves and the direction of the regional maximum compressive stress-field, could be interpreted as due to the presence of an anisotropic fluid filled cracked volume (Booth *et al.*, 1986) Stations located on active faults, however, show qS1 polarization eigendirections compatible with faults direction.

Weighted mean-values of TD vary station-to-station from 0.04 to 0.09 seconds during the uneruptive periods, and from 0.05 to 0.23 seconds during the eruptive one (Bianco *et al.*, 1994). In a crack model the splitting parameter TD is directly related to cracks dimensions and/or density. Correlation between TD and event depth is not clear in suggesting the presence of a pervasive anisotropy that, according to both the qS1 polarization eigendirections and the spatial pattern of the polarization anomalies, is probably due to fluid filled crack not homogeneously distributed on the eastern slope of Mt. Etna volcano. The results of travel time differences analysis suggest that this volume might be concentrated in the upper 15 - 20 km of the crust.

Correlations between delays and events depth for 1988 data-set vary between 0.42 and 0.79 station-to-station; for 1989 data-set between 0.33 and 0.99. From these data the pervasive nature of the anisotropic volume is very debatable, but they seem to confirm the not homogeneous distribution of the anisotropic region.

Moreover the irregular topography, even if have only a secondary effect on the recorded polarization, could be taken into account to explain much of the scatter which is apparent in the polarizations distribution.

CONCLUSIONS

Both polarization and time-delay analyses show clear evidences of shear wave splitting that seems to be caused by the presence of an anisotropic volume with different characteristics and not homogeneously distributed on the eastern slope of Mt. Etna volcano.

The selected data show a preferred eigendirection of qS1 waves in agreement with regional compressive stress field acting in the area.

These observations suggest that the anisotropic volume should be composed by vertical NS aligned fluid filled cracks. However at present we do not have enough data to completely rule out the possibility that observed anisotropy is due to the presence of intrusive body composed of minerals like olivine and clinopyroxene, clearly observed on Mt. Etna. Moreover it could be possible that both causes generate anisotropy at the same time.

The result of a travel time differences analysis suggests that the presence of the seismic anisotropy might be concentrated in the upper 15-20 Km of the crust.

The local volcanic stress-field was probably able to change cracks dimensions and/or density, but was not able to change cracks direction.

At this point we want to stress that the severe constraints adopted to obtain the best events to analyse have dramatically reduced the number of statistically significant earthquakes. Consequently our results are not unique and definitive, but certainly preliminary. Much more data over a wide period of different volcanic activity are needed to know more precisely the correlation that seem to exist between shear wave splitting and stress field on such a complex volcano.

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