Seismic Activity Preceding the 1983 Eruption of Mt. Etna

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ABSTRACT

The March-August, 1983 eruption of Mt. Etna can be considered as one of the most important in the last years.

The analysis of seismic activity during the three months immediately before the eruption showed interesting variations of the *b* coefficient, in the frequency-magnitude relationship, that have been linked to possible changes of the stress field in the Etnean region.

The eruption start was also preceded by a strong seismic crisis with epicenters mostly on the southern, eastern and southwestern flanks of the volcano, and characterized by the shallowness of most of the events ($h \leq 3$ km).

The data analysis has led to a hypothesis on the eruption occurrence based on a model of dynamic evolution of the stress field acting on Mt. Etna.

INTRODUCTION

The seismological approach is one of the best tools for the understanding of a volcano dynamics (SHIMOZURU, 1971) and a promising base for methods to be used in eruption prediction (TOKAREV, 1963; MINAKAMI, 1974; ZOBIN, 1979).

Seismic activity at Mt. Etna has been the subject of several recent studies (*e.g.*, GUERRA *et al.*, 1976; BARBANO *et al.*, 1979; COSENTINO *et al.*, 1979, 1981; SCARPA *et al.*, 1983), and the present state of seismological research at Mt. Etna is summarized in a recent work by COSENTINO *et al.* (1982).

This paper refers to the seismic activity that preceded the Etnean eruption of March 28-August 6, 1983 which can be considered as one of the most important of the last ten years both for its duration (132 days) and for volume of lava erupted (estimated between $60 \cdot 10^6$ m^3 (CRISTOFOLINI, pers. comm., 1984) and $150 \cdot 10^6$ m^3 (VILLARI, pers. comm., 1984). (For details on the eruption and its mechanism, see FRAZZETTA and ROMANO, this issue).

Data analysis has been performed following two lines:

a) Study of the seismic activity recorded during the three months before the eruption.

b) Analysis of the hypocentral distribution of the shocks during the seismic crisis (March 26-28) that preceded the opening of the eruptive vents.

A previous study on the seismic sequence that preceded the Etnean eruption of March, 1981 (GRESTA and PATANÈ, 1983*a*) showed interesting variations of the coefficient *b*, according to the GUTENBERG-RICHTER'S (1956) relationship, that have been related to possible changes in the local (and/or regional) stress field. A similar, even if less pronounced, pattern of *b* values had already been defined for earthquakes before the 1983 eruption (GRESTA and PATANÈ, 1983*b*).

No evidence of foci migration with time resulted from the analysis of the hypocentral locations of the earthquakes concerning the seismic crisis of March 26-28, 1983.

The shallowest events ($h \leq 3$ km) can be related to fracturing processes linked to the opening of eruptive fissures, while the deepest ones occurred mostly on a NE-SW trending vertical plane that can be indicated as a shear plane according to recent models of the stress field acting on the Mt. Etna (GHISETTI, 1979; LO GIUDICE *et al.*, 1982).

The results obtained by the two different approaches are in good agreement with each other and would confirm that tectonics play a very important role in the occurrence of a flank eruption at Mt. Etna.

DATA ANALYSIS

The configuration of the seismic network operating on Mt. Etna is sketched in Fig. 1.

Each station is equipped by a velocity seismometer for the vertical component.

Signals are telemetered to the Earth Science Institute of the Catania University and recorded both on magnetic tape and chart recorders (see BARBANO *et al.*, 1979, for a more detailed information on the monitoring system).

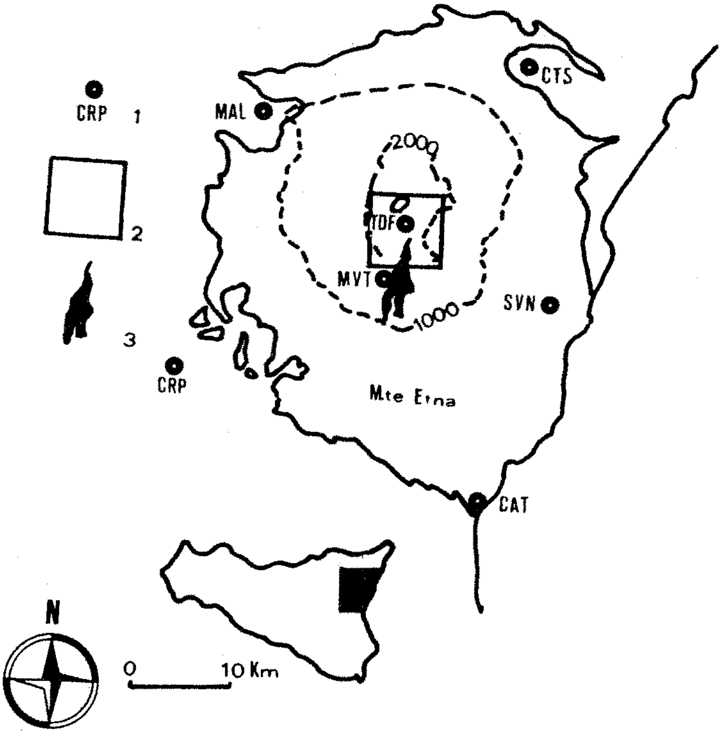

FIG. 1 – Sketch map of Mt. Etna. 1 = stations of the seismic network; 2 = area where occurred most of the seismic events of the sequence Jan 1st - Mar 26th; 3 = lava flows of the 1983 eruption (from GRESTA and PATANÈ, 1983 *b*).

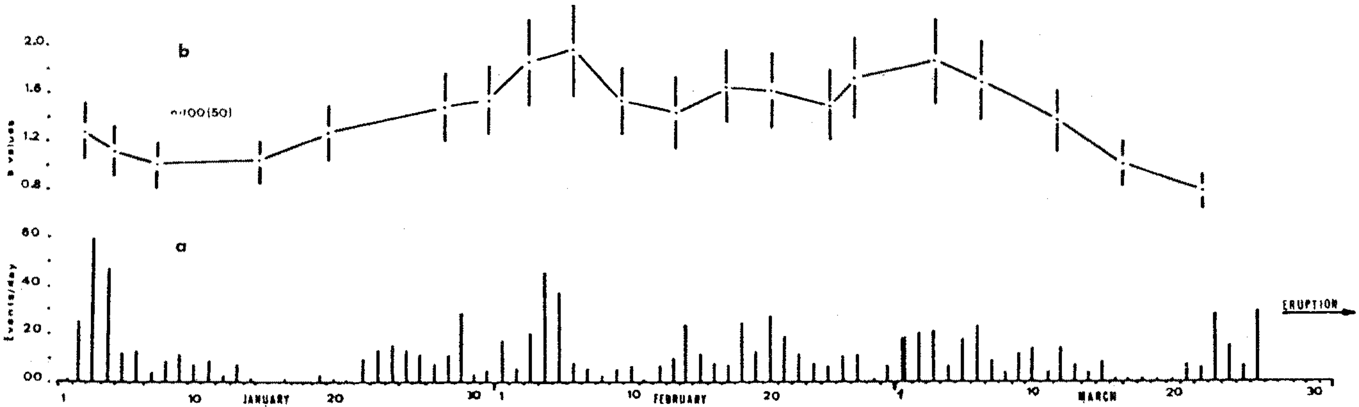

FIG. 2 – a) Daily distribution of the earthquakes occurred before the 1983 eruption, recorded at MVT station. The arrow indicates the eruption start.
b) Time variations of b before the eruption (from GRESTA and PATANÈ, 1983 b).

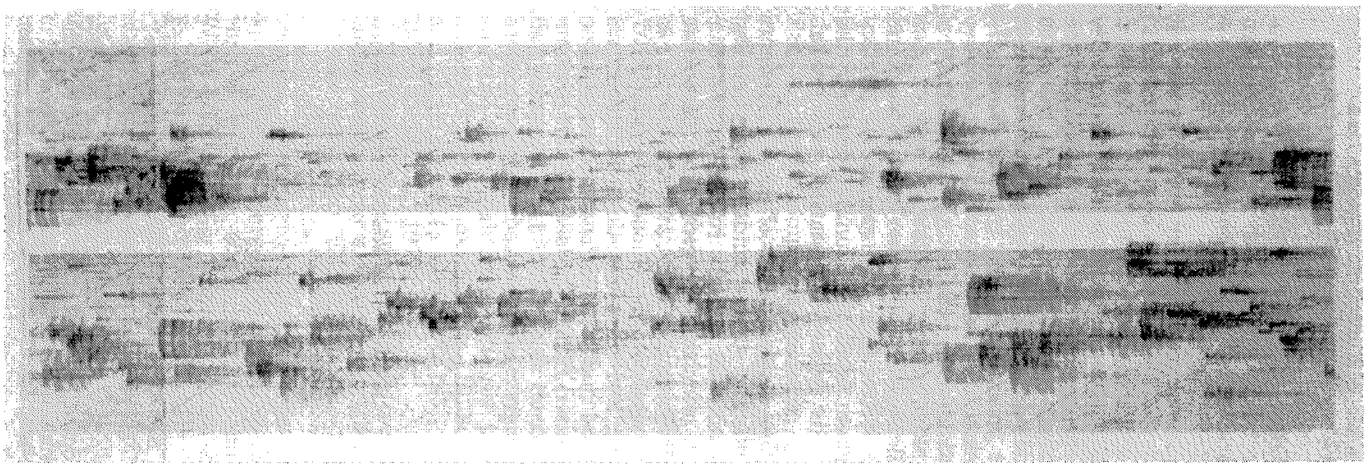

FIG. 3 – Seismograms of the seismic crisis of March 26-28, 1983.

Seismic Activity from Jan. 1st to March 26th, 1983

Seismic activity at Mt. Etna from January 1st to March 26th has mostly been characterized by B-type earthquakes (see PATANÈ, 1982).

An average S-P delay less than 1 sec at both MVT (Monte Vetore, 1660 m a.s.l.) and TDF (Torre del Filosofo, 2919 m a.s.l.) stations indicates that the majority of the considered events occurred in the summit area (Fig. 1) next to these stations. A correct hypocentral location is not possible because most of the earthquakes have been recorded at one or two stations only, indicating that their foci were extremely shallow.

Because of the higher tremor level and the occurrence of sporadic explosion-quakes from the summit craters, the records from MVT station were considered more reliable.

The daily number of analyzed events resulted as almost randomly varying (Fig. 2a) with not definite rule. *b* values have been calculated for groups of 100 events (GRESTA and PATANÈ, 1983*b*) according to the maximum likelihood method (UTSU, 1965), and their variations with time are plotted in Fig. 2b. It is clear that *b* value increased during the second half of January from 1.1-1.2 to 1.6-1.7; during all February no marked changes were observed. Conversely, since the first days of March *b* value begun to decrease down to 0.8 when the seismic crisis of March 26-28 started.

The too high concentration of earthquakes during the seismic crisis did not allow further computations of *b* value to be made.

The mean value of *b* for all the 1056 events of the sequence Jan 1st-March 26th, 1983 resulted to be 1.45 ± 0.09 (GRESTA and PATANÈ, 1983*b*), while magnitude values were ranging between about 0.8 and 3.2.

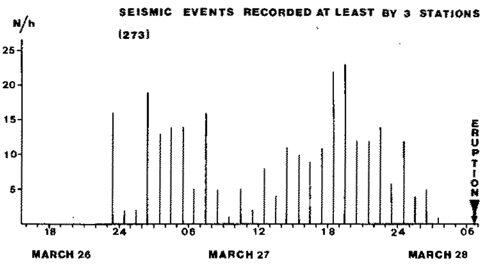

FIG. 4 – Hourly frequency of the earthquakes recorded by at least three stations during the seismic crisis that preceded the beginning of the eruption. The arrow indicates the eruption start.

The Seismic Crisis of March 26-28, 1983

A strong seismic crisis started in the night of March 26 and stopped on the early morning of March 28, few hours before the opening of effusive vents (Fig. 3). The hourly frequency of the seismic events recorded at least by three stations of the seismic network is shown in Fig. 4.

On March 27 a relative decrease of seismic activity occurred from 08.00 a.m. to 14.00 p.m. (Fig. 4), while at the same time an increase of the tremor amplitude was recorded.

Earthquake location has been performed by a revised version of Hypo 71 program adopting the velocity model proposed by LOMBARDO *et al.* (1983) for the Etnean region (see Fig. 5).

The epicentral locations of all the earthquakes recorded at three stations are shown in Fig. 6. It can be seen that most of the events are concentrated in an area along and on the east of the eruptive fissure.

If we consider the earthquakes recorded by four or more stations (mean error on the hypocentral coordinates of about 1.5 km and mean RMS less than 0.4 s), it can be seen (Fig. 7) that the higher energy activity was mostly concentrated at Valle del Bove and only few of the events occurred along the eruptive fracture.

This fact would indicate that only small earthquakes are linked to the actual opening of shallow eruptive cracks.

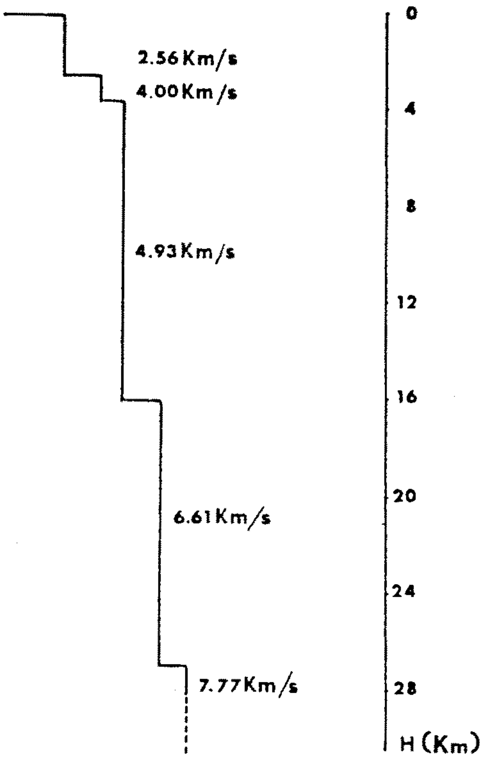

FIG. 5 – The velocity model adopted for hypocentral locations (after LOMBARDO *et al.*, 1983).

Most of the stronger events occurred within a 15 km long and 6 km wide zone trending about ENE-WSW (Fig. 8).

Hypocentral distributions have been projected on two planes trending NE-SW (Fig. 9) and NW-SE (Fig. 10) respectively, and crossing at the summit of the volcano. Shallowest events ($h \leq 3$ km) are more scattered on the NW-SE cross-section plane, while scattering of deepest shocks is higher on the NE-SW cross-section. This may be related to a different behaviour of the shallower and deeper layers subjected to the same stress field.

There is no evidence of a temporal migration of foci with time which would imply that activity in both shallow and deep structures inside the volcano was simultaneous.

DISCUSSION AND CONCLUSION

The epicentral distribution of the earthquakes occurred during the seismic crisis before the Etnean eruption of March-August 1983 suggests that these earthquakes are connected with the regional stress field acting on north-eastern Sicily.

Focal mechanisms related to the seismic events located in the areas on the north and north-west of Mt. Etna show a predominance of either normal or left transcurrent movements (RIUSCETTI and SCHICK, 1974). These mechanisms may depend on a stress field having a NNE-SSW-trending compression axis σ_1, an intermediate vertical axis σ_2, and a tensional axis σ_3 directed ESE-WNW (GHISETTI, 1979); such a stress field would originate shear movements along two planes trending NNW-SSE and ENE-WSW, respectively. Nevertheless normal faulting along these two directions is also present, while purely shear mechanisms were expected (GHISETTI, 1979). This fact can be explained with the high degree of heterogeneity of the crust hindering shear stress to accumulate and giving rise to the observed normal movements (RIUSCETTI and SCHICK, 1974; CRISTOFOLINI *et al.*, 1977; GHISETTI, 1979).

Statistical distributions of both tectonic and volcanic linear elements in the whole Etnean area (LO GIUDICE *et al.*, 1982) match with a stress field with NNE-SSW-trending compressive principal stress axis σ_1 that is the largest, an intermediate vertical principal stress axis σ_2 and a WNW-ESE trending principal stress axis σ_3 which is the smallest (Fig. 11).

A temporary interchange between σ_1 and σ_2 has also been proposed to explain locally or generally the recent structural conditions (LO GIUDICE *et al.*, 1982).

Seismic activity during the three months before the eruption was characterized by very shallow earthquakes in the

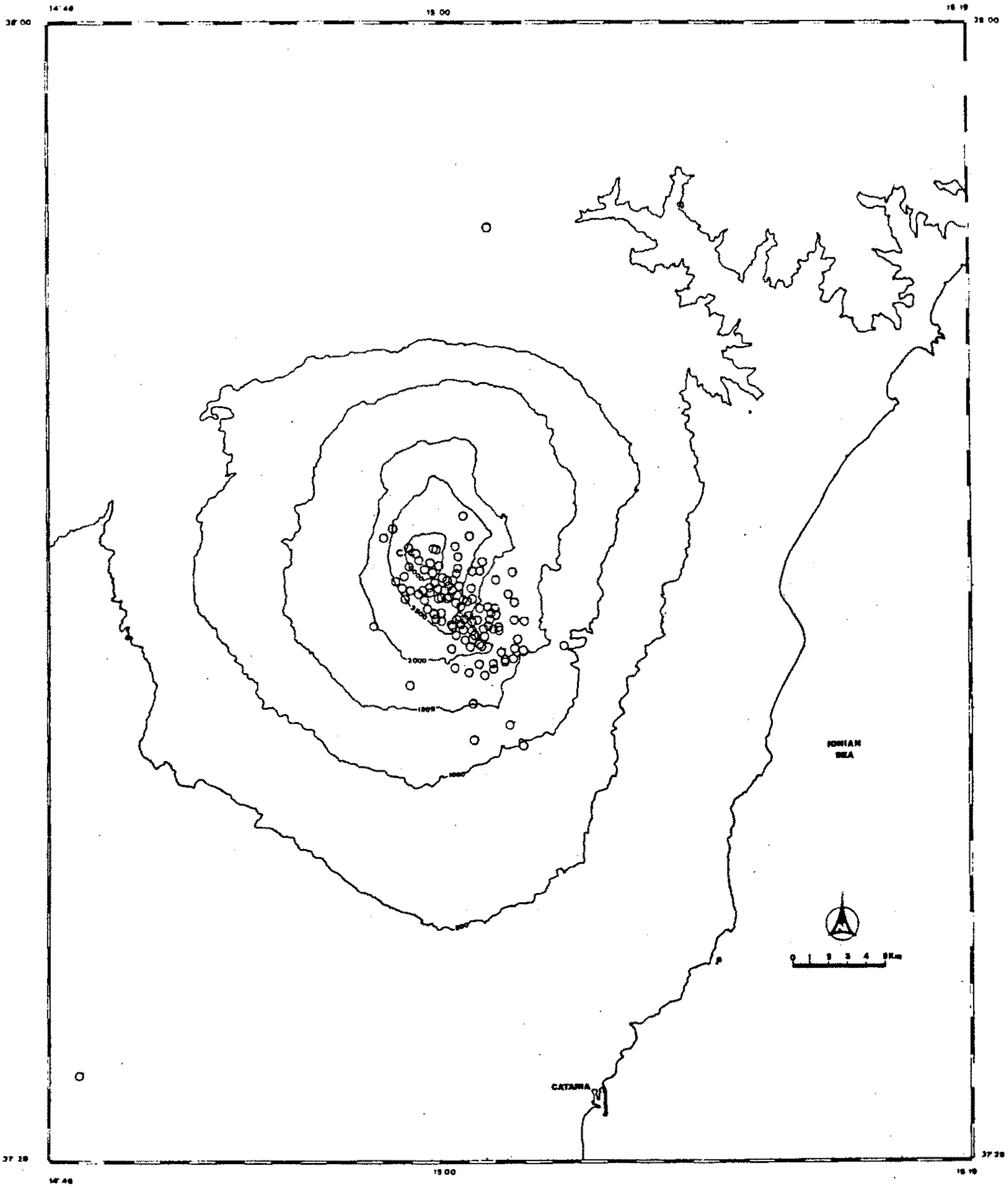

FIG. 6 - Epicentral distribution of the earthquakes of the March 26-28 seismic crisis recorded at three stations only.

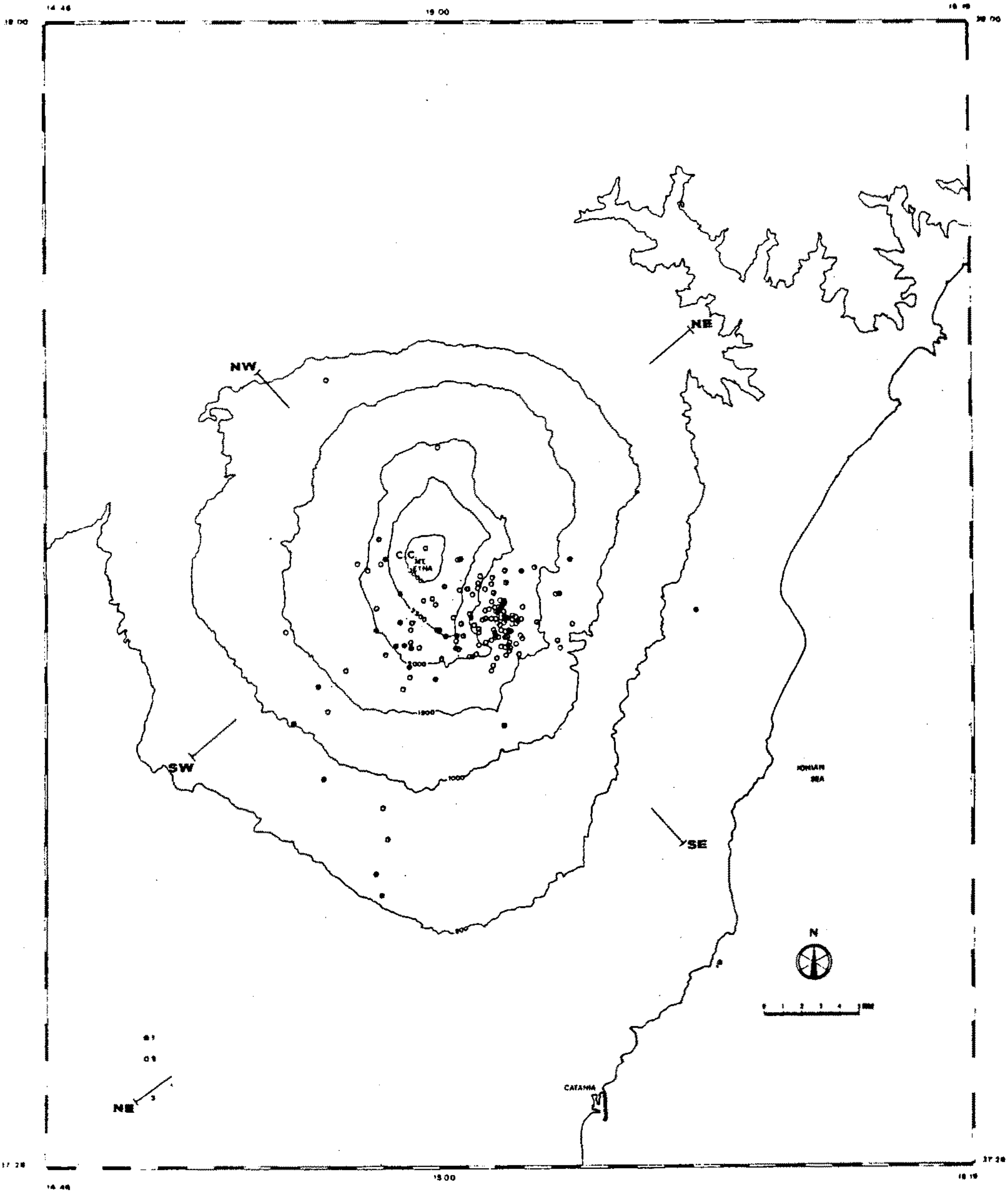

FIG. 7 – Epicentral distribution of the earthquakes of the March 26-28 seismic crisis recorded by at least four stations. (Black dots represent the events with foci deeper than 4 km).

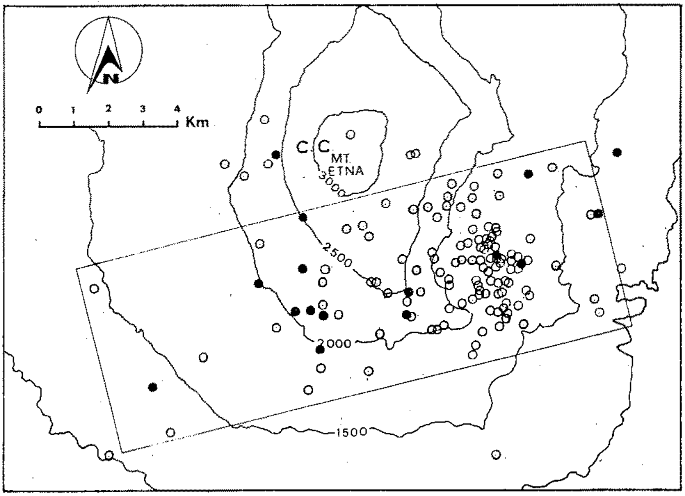

FIG. 8 - Particular of the epicentral distribution of Fig. 7.

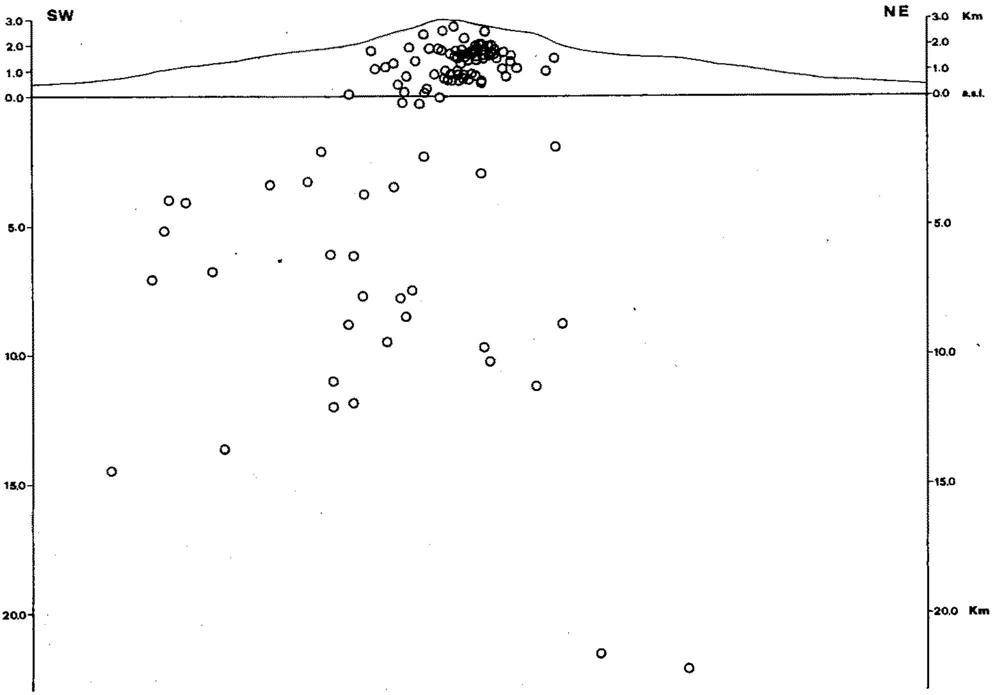

FIG. 9 - Hypocentral distribution of the earthquakes recorded by at least four stations in a NE-SW cross-section.

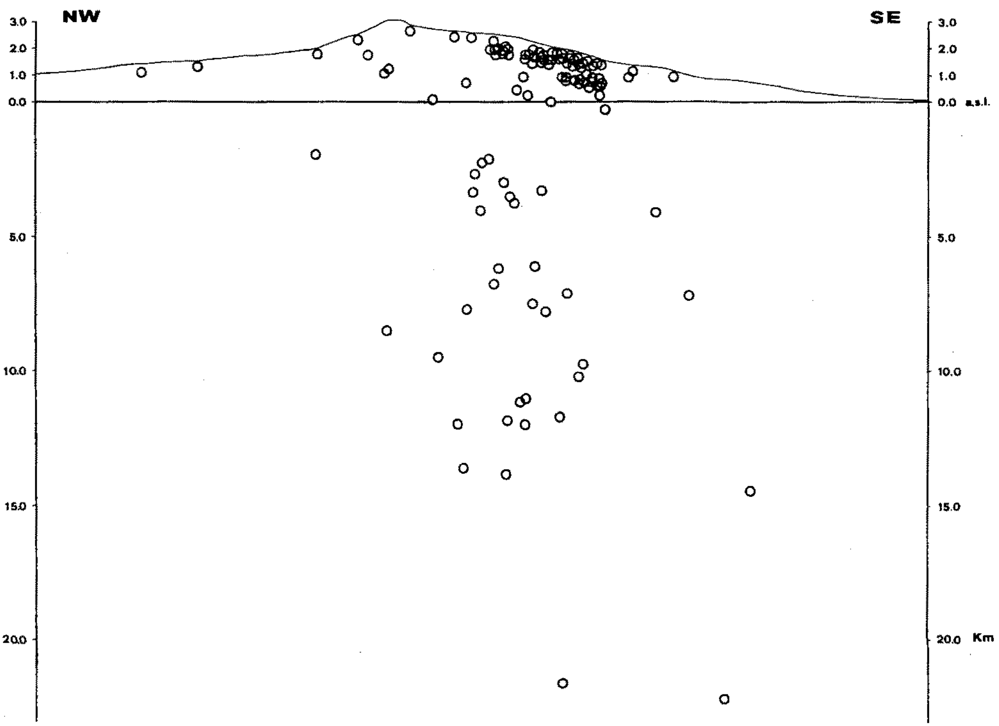

FIG. 10 – Hypocentral distribution of the earthquakes recorded by at least four stations in a NW-SE cross-section.

summit area only, and the temporal pattern of the related *b* values has been interpreted as depending on changes in the stress field acting on the volcano (GRESTA and PATANÈ, 1983*b*).

More particularly, the succession: increase – steady values – decrease of *b* in Fig. 2b may indicate respective evolution of the local stress field intensity as decreasing – steady – increasing until the beginning of the strong seismic crisis of March, 26-28 (GRESTA and PATANÈ, 1983*b*).

The occurrence of the seismic crisis can be explained by the sudden release of strain energy that occurred through a great number of small events in the shallower layers because their high heterogeneity and low rigidity had not permitted a high stress to cumulate.

The epicentral distribution of shallower events ($h \leq 3$ km) covers the upper southern and southeastern sides of Mt. Etna and does not coincide with eruptive fractures whose opening must have required a very small release of seismic energy.

Deeper earthquakes ($h \geq 4$ km), conversely, may be due to a higher stress accumulation, favoured by the higher rigidity and homogeneity of the medium strain release thus occurring through fewer events of larger magnitudes.

The hypocentral distribution of deeper events showed a scattering along NE-SW and NW-SE cross-sections (Figg. 9 and 10) suggesting that deeper seismic activity is related to movements occurring along shear planes trending ENE-WSW and

NNW-SSE according to the above mentioned stress field model (LO GIUDICE *et al.*, 1982).

The higher scattering shown in the NE-SW cross section suggests the hypothesis that during the seismic crisis before the eruption start the ENE-WSW structural trends were the most active.

Conversely, the hypocenters of the most important swarm of deep earthquakes occurred during the eruption (June, 3-4) resulted highly scattered along

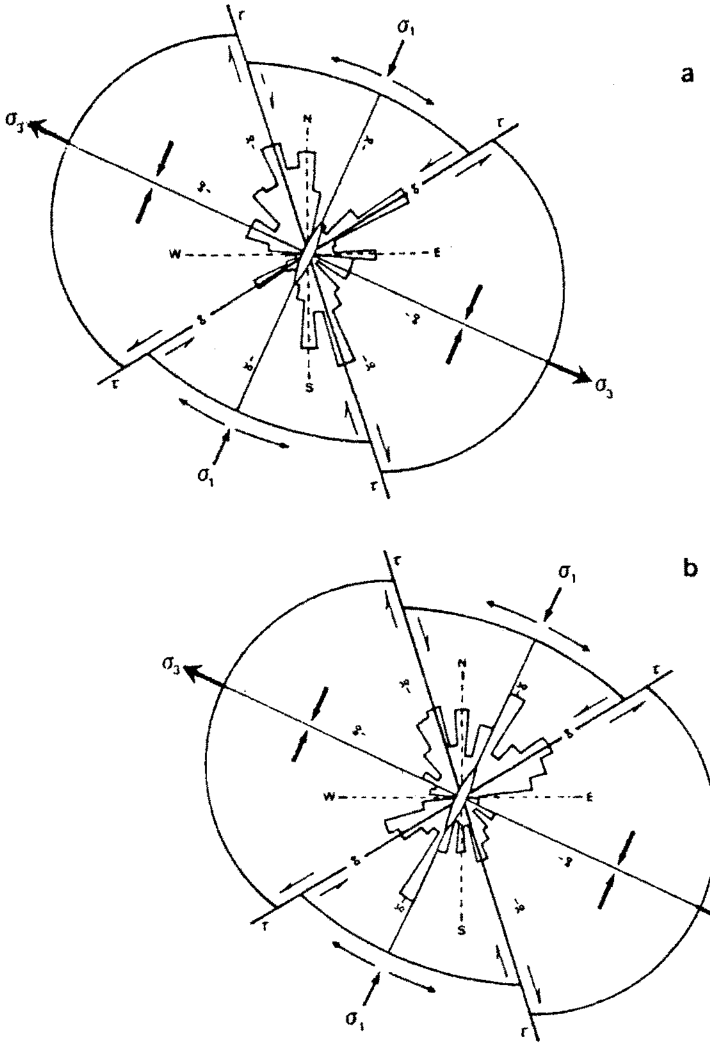

FIG. 11 – Strain ellipse related to: a) distribution of tectonic linear elements in the volcanic area; b) distribution of volcanic linear elements in the Etnean area. σ_1 is the largest principal stress; σ_3 is the smallest principal stress; τ are shearing stresses. (From LO GIUDICE *et al.*, 1982).

the NW-SE cross-section (GLOT *et al.*, this issue). This could indicate a higher activity of the NNW-SSE structural trends at that stage of the eruption.

We attribute these two different behaviours of seismic activity before and during the eruption to very small but sufficient variations with time of the intensity and/or orientation of the stress field acting on the volcano.

From the data analysis it is evident that only small and shallow earthquakes were related to the opening of eruptive fractures at the surface, also because the magma uprise did not occur from a deep magma chamber, but from a shallow feeder dyke, probably connected with the main pipe of the NE Crater (COSENTINO *et al.*, this issue).

Nevertheless modalities of deeper seismic activity suggest that possibly tectonics play a very important role on the occurrence of flank eruptions at Mt. Etna.

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