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Changes in *b* Values before the Etnean Eruption of March–August 1983

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Abstract—The Etnean eruption of March–August 1983 can be considered among the most important in the last years. The associated seismic activity was carefully studied in order to detect possible changes of the *b* coefficient in the equation relating frequency to magnitude of the seismic events. The analysis of 1056 B-type earthquakes, which occurred during the three months before the eruption, was carried out according to the maximum-likelihood method. A significant increase of the *b* value was noticed, followed by an almost linear decrease (from a mean value of 1.7 to 0.8) starting three weeks before the eruption. The observed pattern of *b* values has been compared with that related to the Etnean eruption of March 1981, and some considerations on the volcano dynamics have been made.

Key words: Seismology; Frequency-magnitude relationship; Volcanic eruption; Mt. Etna.

Introduction

Studies of seismic activity are a very interesting tool for understanding volcano dynamics. The daily frequency of earthquakes (MINAKAMI, 1974a), the seismic energy release (TOKAREV, 1963), and the variation of source parameters (ZOBIN, 1979) are considered promising for prediction of eruption.

The coefficient *b* of the frequency–magnitude relationship (GUTENBERG and RICHTER, 1956):

$$\log N = a - bM \tag{1}$$

represents an important parameter for studying the seismicity in a certain area (MOGI, 1967; KARNIK, 1969) and for understanding the mechanism of earthquake sequences (GIBOWICZ, 1973; UDIAS, 1977).

The *b* value normally ranges from 0.5 to 1.0 for tectonic earthquakes, while for volcanic events it can be even higher than 2.0 (MINAKAMI, 1974b).

On Mt. Etna, GUERRA *et al.* (1976) found a *b* value of 1.01 for the seismic sequence accompanying the 1974 lateral eruption.

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A mean b value of 3.03 and an interesting time evolution of b have been noticed for the earthquake sequence preceding the March 1981 eruption (GRESTA and PATANÈ, 1983).

In this paper we analyze 1056 seismic events of the B-type (PATANÈ, 1982) that occurred at Mt. Etna during the three months before the March–August 1983 eruption.

The mean b value was obtained according to the maximum-likelihood method (UTSU, 1965); b variations with time were also calculated, and a gradual increase (from a mean value of 1.1 to 1.7), followed by a significant decrease (from 1.7 to 0.8) starting three weeks before the eruption, was noticed.

The observed variations with time of the b values have been related to possible changes in the local stress field.

From the comparison between the results obtained and those related to the March 1981 eruption some considerations on the volcano dynamics before an eruption have been made.

Seismic and volcanic activity before the eruption

The analyzed data have been obtained from recordings of the seismic network operating at Mt. Etna. A sketch map with the distribution of the seismic stations, which are equipped with short-period vertical seismometers, is shown in Figure 1.

In this study we analyzed all B-type events (PATANÈ, 1982) recorded at the MVT station (Monte Vetore, 1660 m a.s.l.) from January 1st to March 26th 1983, two days before the eruption start. The length of the time interval considered and the number of events analyzed are large enough to assure a reasonable statistical analysis. The daily number of events considered is shown in Figure 2a; the epicenters are mostly concentrated over an area covering the summit of the volcano (Figure 1). The hypocentral depths probably vary within a range of 0 to 5 km. (Their extremely shallow focal depth is confirmed by the recording of the weakest events at one or two stations only.)

The volcanic activity at Mt. Etna during the three months before the eruption was characterized by a strong and continuous emission of vapor from the summit craters (see Figure 3).

Only around January 15th, during a seismically quiet period (see Figure 2a), some explosions with ash emission from the Chasm were noticed. A strong fumarolic activity from the Northeast crater was also noticed around February 15th. In the late evening of March 26th a strong seismic crisis involving the southern and the southwestern sides of the volcano started. The crisis lasted for 30 hours. On March 28th, at about 06.45 (GMT), an eruptive fracture opened on the southern flank

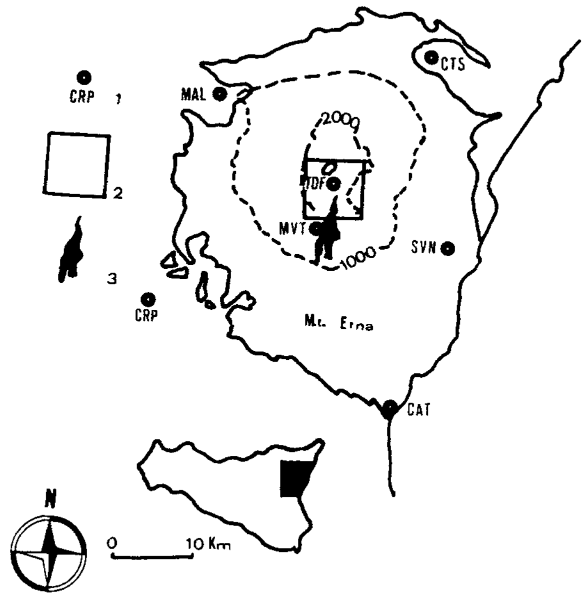

Figure 1. Sketch map of Mt. Etna. *1*, stations of the seismic network; *2*, area where most of the events analyzed in this paper were located; *3*, lava flows of March–August 1983.

of the volcano between 2450 m a.s.l. and 2250 m a.s.l., and an eruption started that would end of August 6th, covering an area of about 6 km^2 (see Figure 1) and pouring out about $100 \cdot 10^6$ m^3 of lava (SEAN BULLETIN, 1983).

Frequency-magnitude variation

The frequency-magnitude relationship is usually expressed by

$$\log N = a - bM \qquad (1)$$

where N represents the number of events of a given magnitude M, and a and b are constants (GUTENBERG and RICHTER, 1956). The constant a depends on the magnitude range considered and on the b value (DUDA, 1965). The coefficient b has a clear physical meaning. It depends upon the ratio between large and small earthquakes in a given set of events. Changes in b also provide informations about the nature of seismic energy release.

GIBOWICZ (1973) noticed a gradual increase of b during some aftershock sequences. In foreshock sequences, conversely, the b values were significantly smaller than those of the aftershock (SUYEHIRO and

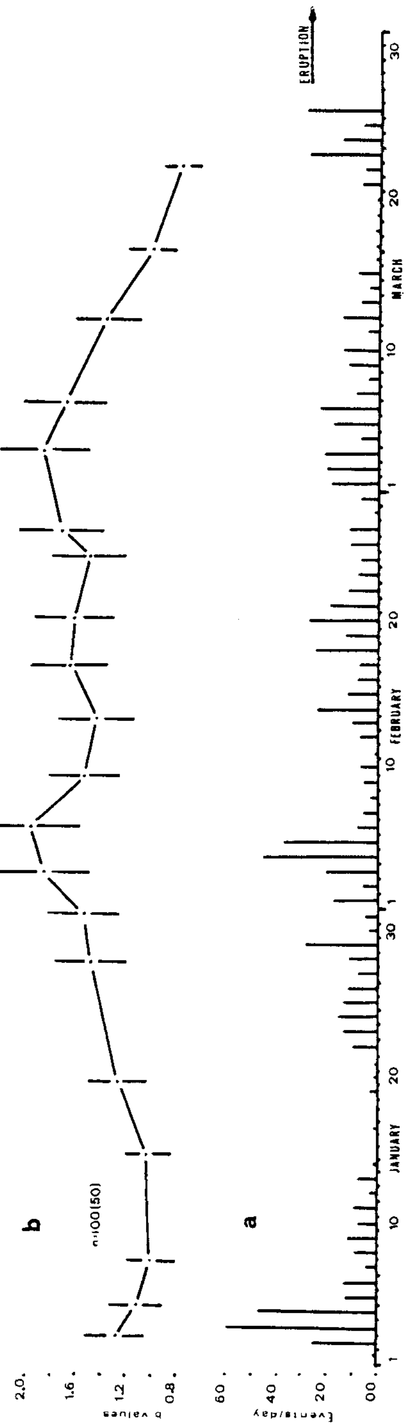

Figure 2. (a) Distribution of the daily earthquake number before the 1983 eruption, recorded at MVT station. The arrow indicates the eruption start. (b) Time variations of b calculated for $n = 100$ ($\Delta n = 50$).

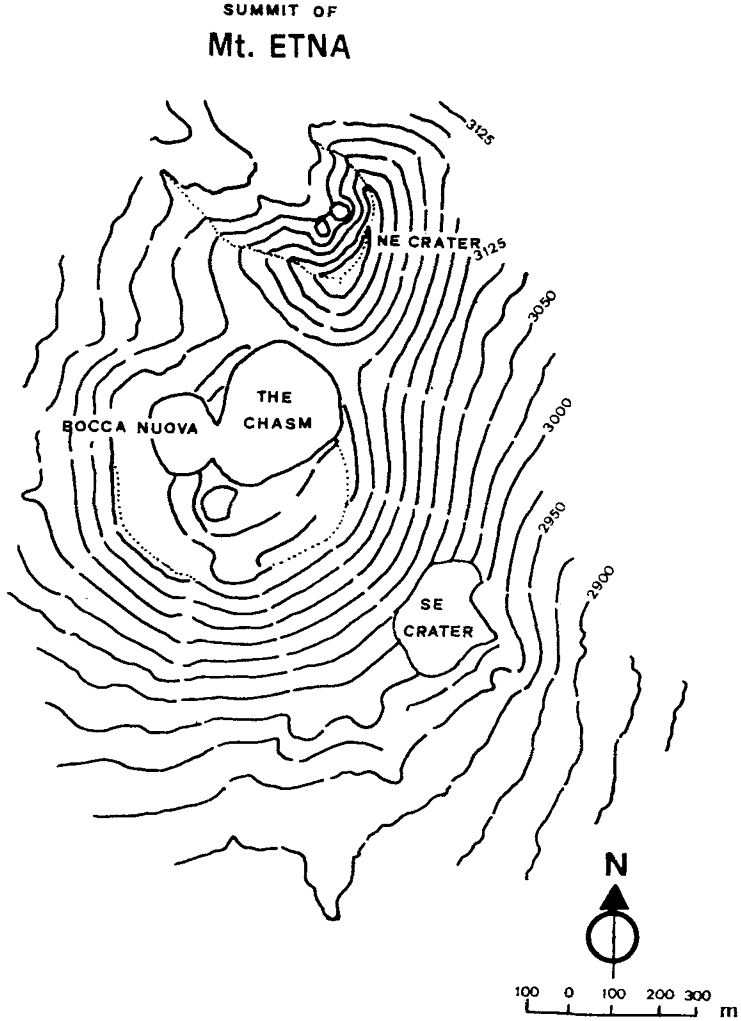

Figure 3. Schematic map with location of summit craters of Mt. Etna. (From Gresta and Patanè, 1983.)

SEKIYA, 1972). Laboratory tests of rock samples (SCHOLZ, 1968; WEEKS *et al.*, 1978) have showed b values decreasing with increasing stress. This could mean that the stress state plays a very important rôle in controlling the value of b. The b value can be found by the least-squares method, but it is better to calculate it by the method of maximum likelihood, according to UTSU (1965):

$$b = \frac{0.4343}{\bar{M} - M_o} \quad (2)$$

where M_0 is the smallest magnitude considered and $\bar{M}$ is the average magnitude for the analyzed events. Unfortunately the formula cannot be used for our data, because the MVT station is not calibrated to give the magnitude of events; we have therefore applied a relationship equivalent to Equation (2):

$$b = \frac{0.4343}{(\Sigma_i \log A_i)/n - \log A_0} \tag{2'}$$

Here A_0 is the lowest amplitude for a well-detected shock, and n is the number of events with A_i larger than A_0 (WEEKS *et al.*, 1978). This method implies that no events should saturate the amplitude scale of the seismograph during the time interval considered; this limited the data analysis until the seismic crisis started on March 26th, when the first events saturating seismograms occurred. The error in b value is

$$b = \frac{1.96 \cdot b}{\sqrt{n}} \tag{3}$$

at 95% confidence limits for a normal distribution (AKI, 1965).

Following BUFE (1970), we use the relationship (2′) to compute the b value for a fixed earthquake number n, scanning the whole sequence at steps of Δn events. In Figure 2b time variations of b for $n = 100$ ($\Delta n = 50$) are reported. The b values are drawn with their respective error bars. The abscissa of every point is the middle of each time interval. It is clear that since the second half of January (see Figure 2b) the b value gradually increased from 1.1–1.2 to 1.6–1.7; during all February the b values were nearly constant (about 1.7); conversely, since the first days of March the value of b began decreasing almost linearly to 0.8. The mean b value for all the events of the sequence was 1.45 ± 0.09.

Discussion and conclusion

Variations of the b coefficient in the frequency–magnitude relationship for the earthquake occurred during three months before the Etnean eruption of March–August 1983 were noticed. Comparison of the observed pattern with that observed before the Etnean eruption of March 1981 (GRESTA and PATANÈ, 1983) suggests some differences in the dynamics of the volcano before the two eruptions (see Figure 4). The 1981 seismic sequence was relatively short (about 36 days), had a large number of events (about 4000), and a high mean b value (3.03 ± 0.09). Conversely, the earthquake sequence before the eruption of March–August 1983 was longer (more than 75 days), had fewer earthquakes

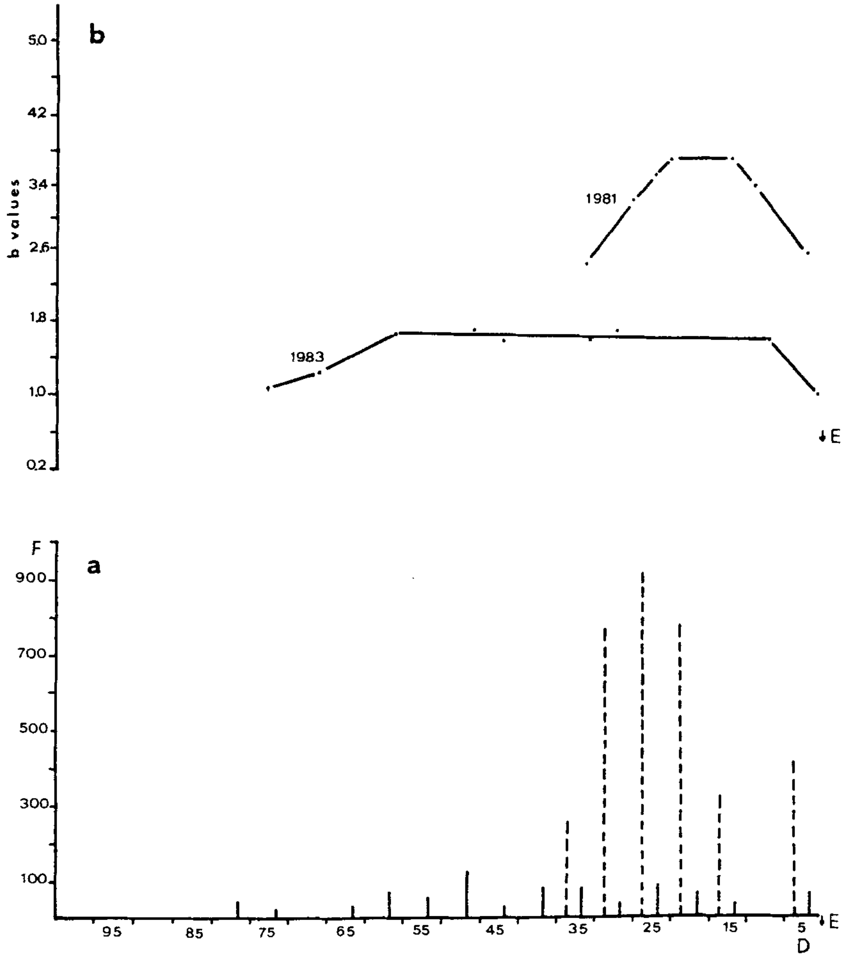

Figure 4. Graph comparing the data related to Etnean eruptions of March 1981 and of March–August 1983. (a) D = days before the eruption starts (E): F = five-day frequency of B-type earthquakes before both eruptions: the dashed line, events preceding the 1981 eruption; continuous line, seismic events preceding the 1983 eruption. (b) Time variations of n before both eruptions.

(1056 events from January 1st to March 26th), and a lower mean b value (1.45 ± 0.09). Such differences could be attributed to different mechanisms in the two eruptions.

The eruption of March 1981 can be defined, according to RITTMANN's (1973) classification, as a radial lateral with subsequent opening downslope of various eruptive fissures and with a relatively high effusion rate (about $4 \cdot 10^6$ m^3/day).

The eruption of March–August 1983 can also be defined as radial lateral, but with only one shorter eruptive fracture and a lower effusion rate (less than $1 \cdot 10^6$ m^3/day). Also on the basis of the seismic activity it can be defined as a radial eruption; nevertheless, studies on the volcanic tremor behaviors (PATANÈ and GRESTA, 1984) suggest that the connection of the feeding dyke with the central conduit system was shallower than in the March 1981 eruption.

Nevertheless it is remarkable that in both patterns of *b* values three distinct subsequent behaviours (see Figure 4) can be seen:

(a) gradual increase
(b) steady values
(c) almost linear decrease

GIBOWICZ *et al.* (1974) have related changes in *b* values observed during a seismic swarm associated with a submarine eruption with possible variations of the local stress field.

Space and time variations of the stress field acting at Mt. Etna were recently suggested by SCARPA *et al.* (1983) on the basis of studies on focal mechanisms, and changes in the stress field have already been proposed as controlling variations of *b* before the Etnean eruption of March 1981 (GRESTA and PATANÈ, 1983). In that paper an alternative suggestion was given to explain changes in *b* values: differences of heterogeneity and rigidity among crustal layers. But, according to this hypothesis, it should be not possible to understand why the *b* values related to the two seismic sequences analyzed, both occurring in the same depth range (from 0 to 5 km), are so different (3.03 and 1.45, respectively). Changes in the stress field probably cause the observed *b* value patterns. In such case, the three distinct behaviors in both patterns could be associated with the following proposed dynamic evolution of the stress field:

(a) gradual decrease of intensity (and/or beginning of a reorientation of the axes) of the stress field
(b) period characterized by a steady state
(c) more or less sharp increase of the intensity (and/or continuing of the reorientation of the axes) of the stress field up to the start of a strong seismic crisis and to the opening of eruptive fractures.

The proposed behaviors could be related to sudden changes in the stress field acting at Mt. Etna due to the mechanism of dynamic evolution of the crust in the middle Mediterranean area, but more probably the observed variations of *b* values are due to extremely local stress field changes caused by magma injection, as already suggested by YAMASHINA and NAKAMURA (1978), which usually precede a volcanic eruption.

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