Characteristics of the seismicity of Vesuvius and Campi Flegrei during the year 2000

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Abstract
This paper describes the characteristics of the seismicity in the volcanic Neapolitan area during the year 2000 recorded by the monitoring seismic network of the Osservatorio Vesuviano. In particular, a detailed analysis of the seismicity of Vesuvius is presented. We compared the seismic velocity models available for the Vesuvius area locating the earthquakes recorded in the year 2000 and on the basis of the results, we introduce for routine earthquake location the new velocity model obtained by the seismic tomography experiments (TomoVes) performed in the area. We also determined the focal mechanisms and analysed the seismicity rate, comparing the results with those obtained for the past years. After the introduction of the new acquisition system at the Osservatorio Vesuviano, a re-calibration of the duration magnitude scale was necessary to avoid biases related to the different instrumental response. Consequently, we re-calibrated the magnitude relation used for the Vesuvius earthquakes, obtaining a new formula to be used for the earthquakes recorded by the new acquisition system. Finally, we give a description of the seismic activity in the Campi Flegrei area during the summer of 2000.

Key words *Vesuvius – Campi Flegrei – volcano – seismicity*

1. Introduction

Analysis of the earthquakes recorded by a seismic network located on a volcano is now the most useful tool to investigate the volcano structure and to understand the dynamics of active magmatic systems. Different kinds of seismic data, such as records of very distant earthquakes obtained by long period instruments, or records of local earthquakes or artificial sources performed by short period instruments, furnish different scale details on the velocity structure, attenuation and other physical properties of rocks that affect the propagation of the seismic waves in the volcano.

Moreover, the seismic activity is a significant indicator of the volcano dynamics because its variations may be related to changes in the physical state of the system. For this reason, the seismic monitoring of the volcanic areas is an important tool to forecast possible eruptions.

Vesuvius and the Campi Flegrei volcanic area have recently been investigated by different seismological techniques to improve our knowledge of the structure of the volcano edifices and magma chambers.

Auger *et al.* (2001), analysing data of two seismic active experiments performed in the area surrounding Vesuvius and in the Gulf of Naples, evidenced a magmatic sill under Vesuvius extending over a surface of at least 400 km^2. At Campi Flegrei, Ferrucci *et al.* (1992), studying seismograms produced by shots and regional

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earthquakes, hypothesised a shallow magma reservoir at a depth of four kilometers below sea level.

Studies of the local seismicity of Vesuvius and Campi Flegrei carried out using a precise three-dimensional location technique (Lomax *et al.*, 2001), high resolution seismic tomography (Aster *et al.*, 1992; De Natale *et al.*, 1998; Zollo *et al.*, 1998), coda wave attenuation (Bianco *et al.*, 1999a) and statistical analysis (Godano *et al.*, 1997; Zollo *et al.*, 2001) have made major contributions to the definition of the two volcano structures.

In this paper, we analyse the seismic activity in the Vesuvius and Campi Flegrei area during the year 2000. We show the results of the analyses routinely performed on these data, like earthquake locations, energy and time distributions and fault plane solutions. Moreover, we describe the recent modifications introduced at the Osservatorio Vesuviano in both the velocity model and the acquisition system and discuss the implications of these changes on earthquake location and the estimate of the magnitude, to give all researchers interested in using our data complete knowledge of the procedures they are dealt with.

2. The seismic data acquisition system

The Osservatorio Vesuviano, now a branch of INGV (Istituto Nazionale di Geofisica e Vulcanologia), set up a complex system of geophysical-geochemical surveillance for monitor-

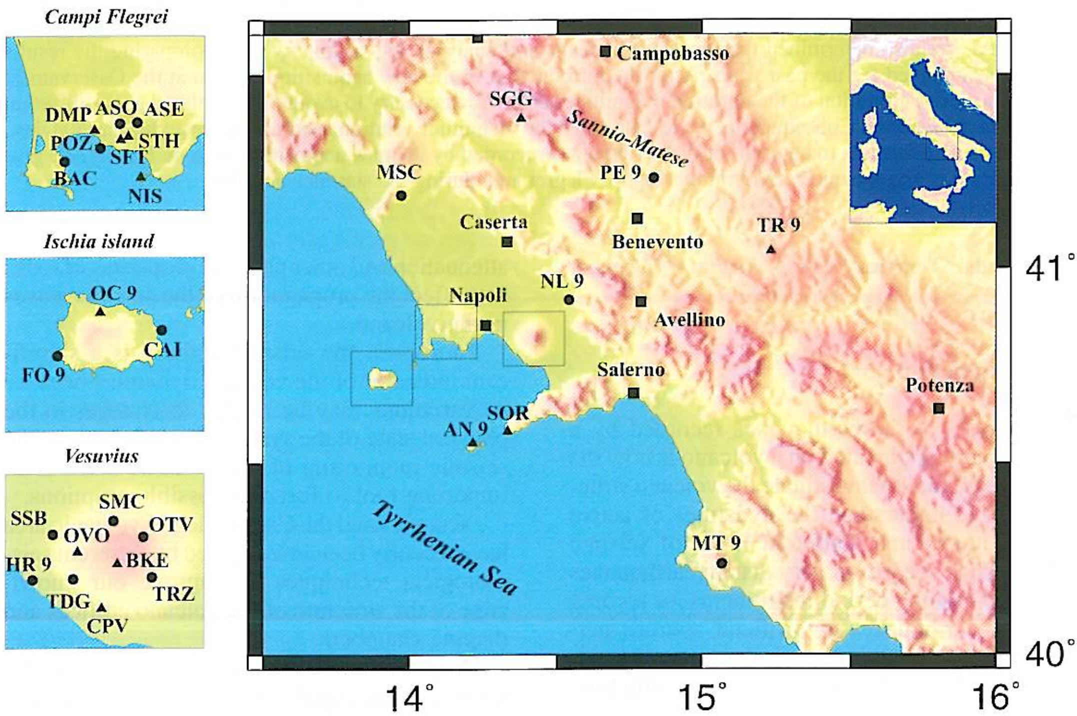

Fig. 1. Map of the Campania region and the volcanic areas (Vesuvius, Campi Flegrei, Ischia) showing the seismic surveillance network of the Osservatorio Vesuviano (solid circles = vertical component seismic stations; triangles = three component seismic stations). BKE and CPV were converted into three component stations during the year 2001.

ing the dynamic activity of the Campanian volcanic areas (Vesuvius, Campi Flegrei and Ischia Island).

The surveillance system includes geodetic, geochemical, hydrometric and seismic networks (Rendiconto sull'attività di sorveglianza - Osservatorio Vesuviano, 2001). In particular, the seismic network is composed of 28 analog stations: 9 located on the flanks of Vesuvius, 8 in the caldera of Campi Flegrei, 3 on the island of Ischia and 8 in the Campania region, as shown in fig. 1. Each seismic station is equipped with a vertical short period (1 Hz) seismometer (Mark L4-C or Geotech S13), 12 stations also have horizontal component sensors (fig. 1). All the seismic signals are frequency modulated and telemetered via phone line or UHF radio to the surveillance center in Naples where the signals are demodulated and digitized with a sampling rate of 100 sps. A clock controlled via radio by the DCF signal provides the absolute timing. The seismic signals recorded on 52 channels are stored in a SUDS-format file, 120 s long, on PC hard disks, where they are kept for about 70 days. The whole acquisition and data management software was developed by researchers of the Osservatorio Vesuviano (Giudicepietro *et al.*, 2000). The analog signals of some selected stations are also recorded on helicorder drums. A detailed description of the seismic network and the acquisition system is reported in Castellano *et al.* (2002) and Giudicepietro (2001).

The seismic data are analysed daily by the Seismological Laboratory staff who discriminate the signals, pick the main seismic phases and perform the routine analyses, extracting the channels containing the seismic traces and storing them on hard disk and CD-ROM. During the year 2000 about 3.5 Gb of data were stored. Periodically, data are inserted into the geophysical database of the Osservatorio Vesuviano.

3. The seismic data set

During the year 2000, over 3000 events were recorded by the Osservatorio Vesuviano seismic network: about 68% of these are natural events

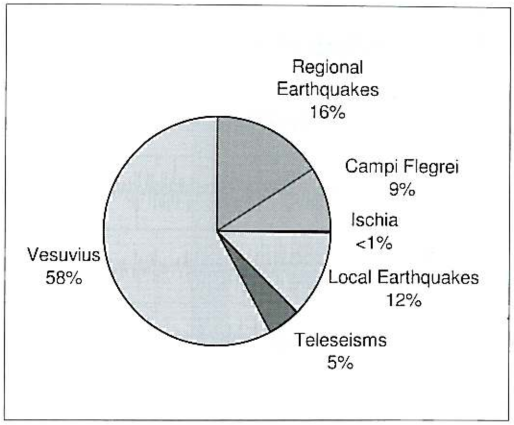

Fig. 2. Geographical distribution of the earthquakes recorded during the year 2000 by the seismic surveillance network of the Osservatorio Vesuviano.

and 17% are classified as blasts. In fig. 2 the recorded earthquakes are grouped according to geographical areas. Most recorded earthquakes are located in the Vesuvius area; an example of seismogram of a Vesuvius earthquake is shown in fig. 3.

About 16% of the recorded earthquakes are classified as regional (*i.e.* earthquakes occurring outside the Campania region, with epicentral distance less than 1000 km). Earthquakes recorded at our seismic stations with a difference in the *S*- and *P*-wave arrival time (T_s-T_p) less than five seconds are classified as local events (about 12% in fig. 2), mostly originated in the Sannio-Matese region (fig. 1).

Finally, at Ischia Island no significant earthquakes occurred during the year 2000. Only 6 local events and 6 blasts probably due to fishing activity were recorded at the seismic stations installed on the island.

Artificial events recorded by the seismic network are mainly related to the mining activities located at the border of the Campanian alluvial plane. The blasts generally occur in a limited time range as shown for the seismic station NL9 in fig. 4.

A different source of artificial events is represented by fishing activity in the Gulf of Poz-

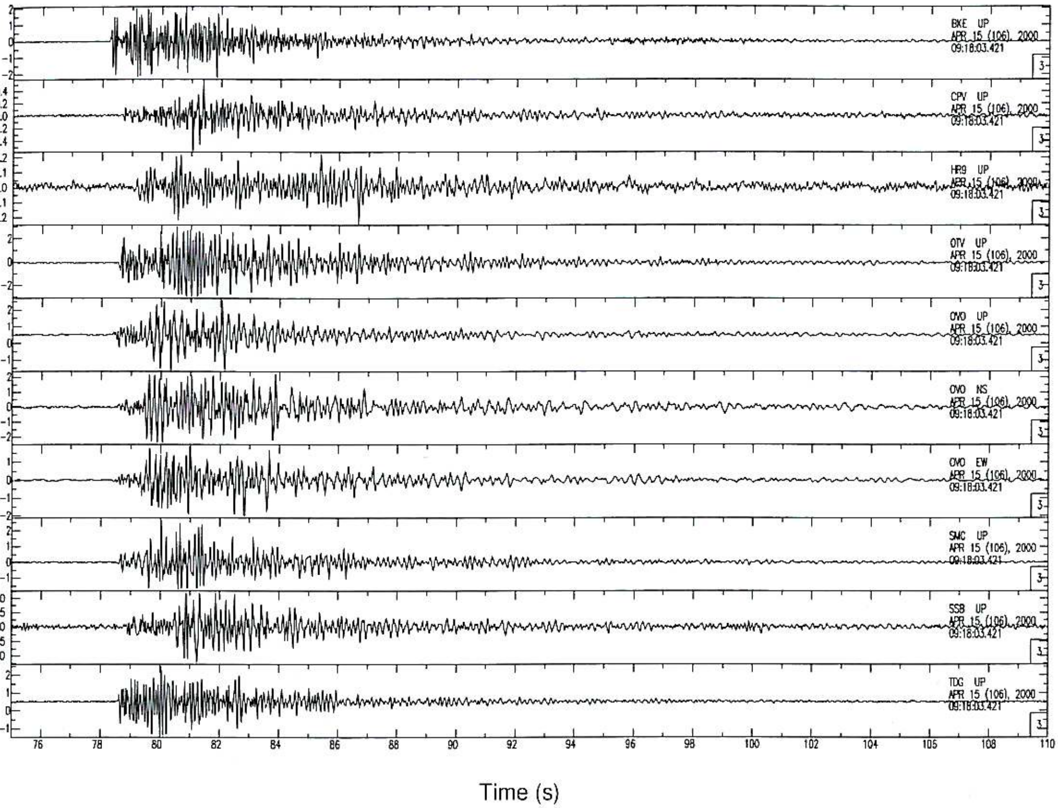

Fig. 3. Typical recording of a Vesuvius earthquake.

zuoli. The blasts related to this activity are characterized by:

– Seismogram shape showing the typical wave reverberation in the shallow water (see the example shown in fig. 5).

– Time distribution showing the occurrence of the events within a short period of time, generally during the night (fig. 6).

Generally, the low energy of the explosions prevents the observation of clear *P*-wave arrivals to be used for the analytic location of the events. However, the distribution of the arrival times at the different seismic stations indicates that the blasts are located along the coast-shoreline close to BAC station and Pozzuoli harbour. Moreover, the hypocentral locations (which can be performed for some of the most energetic events with clear *P* arrivals at several stations) indicate very shallow depths.

4. Analysis of Vesuvius seismicity

4.1. *Earthquake location*

Knowledge of a local seismic velocity model is essential for accurate hypocentral locations. Usually it is obtained using seismic wave arrival times from blasts or earthquakes. For the Vesuvius area the TomoVes tomographic experiment conducted during 1994 and 1996 has provided data for a reliable 3D velocity model. Lomax *et al.* (2001) obtained a three dimensional ve-

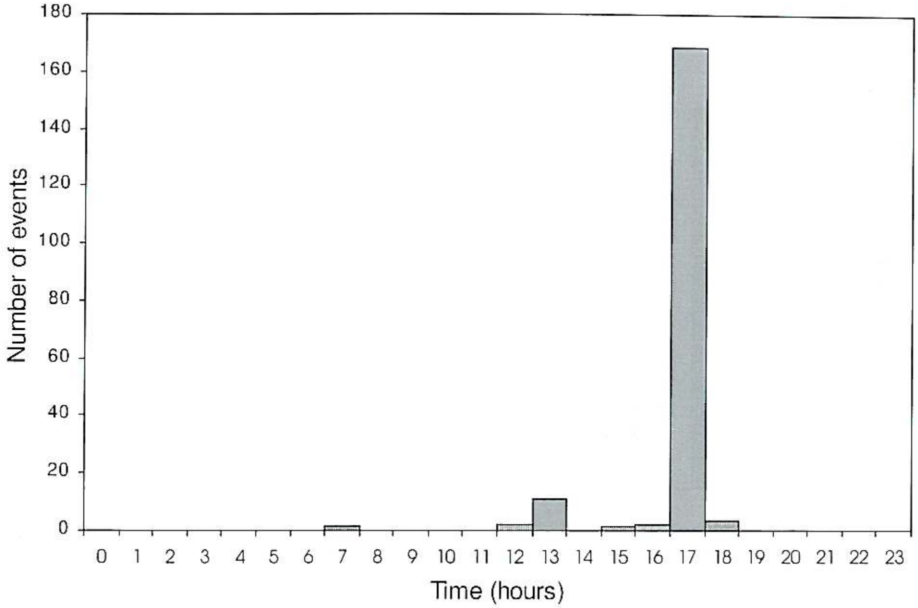

Fig. 4. Time distribution of the artificial events recorded by NL9 seismic station.

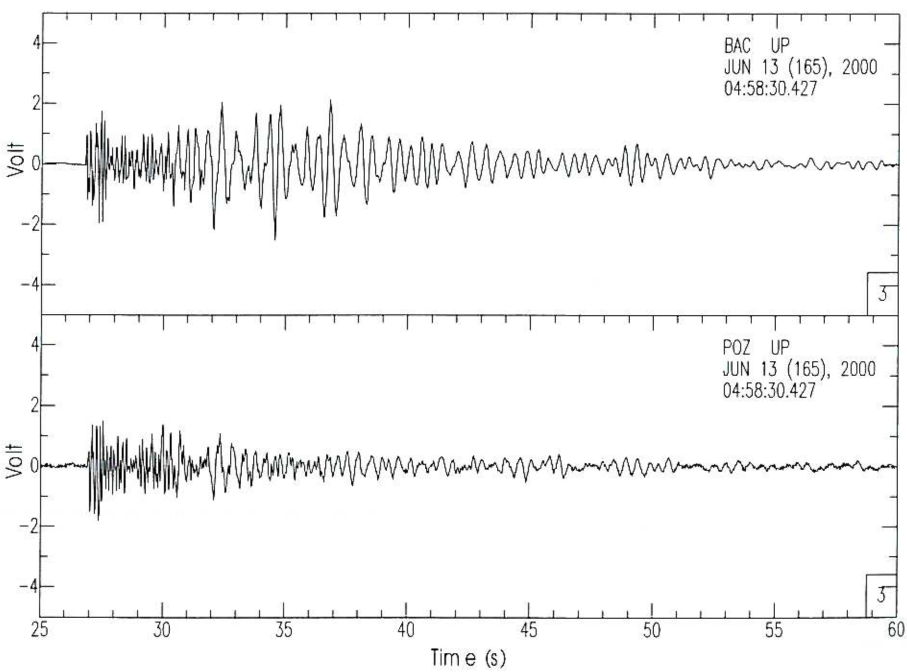

Fig. 5. Vertical component recording of an underwater explosion in the Gulf of Pozzuoli recorded at BAC station.

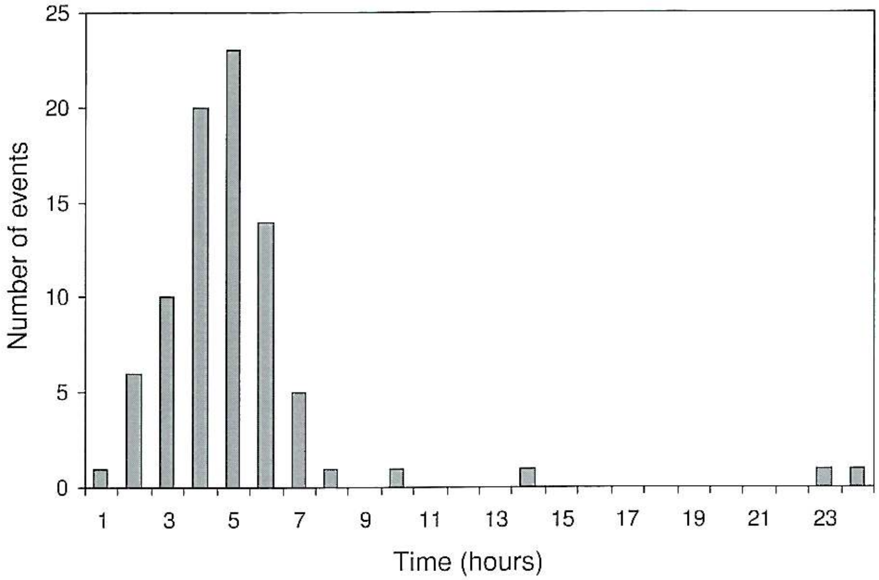

Fig. 6. Time distribution of the artificial events (underwater explosions) occurring in the Gulf of Pozzuoli.

locity model of Vesuvius by interpolating smooth 2D velocity sections. These sections were inferred by the inversion of the seismic refraction profiles carried out during the TomoVes experiment. Starting from this 3D model, Lomax *et al.* (2001) also proposed a representative 1D layered model. Obviously the strong topographic variation of the volcanic edifice cannot be modelled by a 1D layered model which produces a less satisfactory fit of the observed travel times. In any case, by fitting by trial and error the observed travel-times produced by the TomoVes experiment, these authors obtained a simple 1D velocity model with a 2-km thick layer, with V_p = 3.0 km/s over a half space with V_p = 6 km/s. Since the TomoVes data have provided information on the *P*-wave velocity structure, the V_p/V_s ratio was obtained by Lomax *et al.* (2001) comparing the results of earthquake locations using different V_p/V_s values. The best location results with smaller hypocentral errors were obtained with a relatively high V_p/V_s ratio of 1.90.

At the Osservatorio Vesuviano earthquake locations are routinely performed using the

Table I. Velocity model used for routine location at the Osservatorio Vesuviano.

Depth	Velocity
Topography	V_p = 3.0 km/s
0-2.5 km	V_p = 3.0 km/s
2.5-4 km	V_p = 3.5 km/s
4-10 km	V_p = 4.0 km/s
10-23 km	V_p = 6.2 km/s
23-30 km	V_p = 6.7 km/s
> 30 km	V_p = 8.2 km/s
V_p/V_s = 1.8	

Table II. 1D velocity model proposed by Lomax *et al.* (2001).

Depth	Velocity
Topography	V_p = 2.0 km/s
0-2 km	V_p = 3.0 km/s
> 2 km	V_p = 6.0 km/s
V_p/V_s = 1.9	

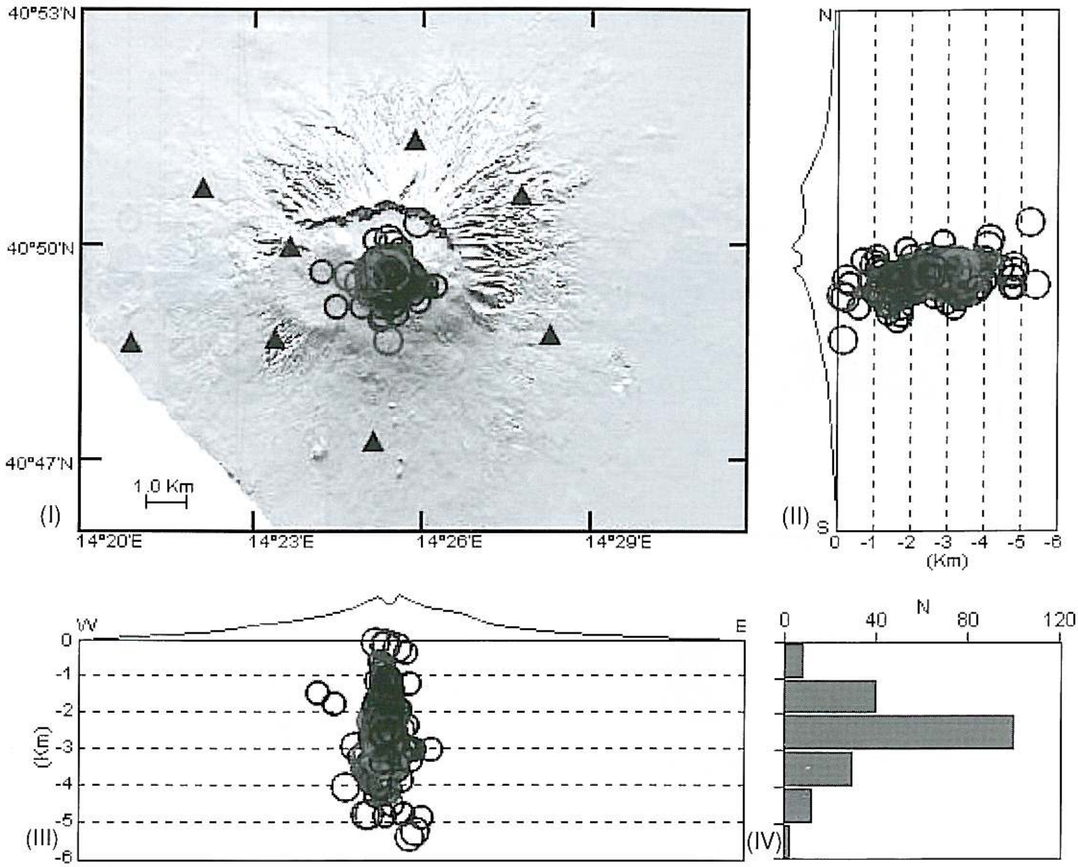

Fig. 7a. Location of 185 selected earthquakes at Vesuvius during the year 2000, obtained using the velocity model reported in table I. Figures (I) report the epicenters with the seismic stations operating on Vesuvius (black triangles). Figures (II) and (III) represent two sections oriented N-S and W-E respectively. Figures (IV) show the depth distribution of the hypocenters.

HYPO71 computer program with a velocity model composed of 5 layers over a half space (table I). In order to compare the locations (fig. 7a) obtained using this velocity model with those determined applying the new model (table II) proposed by Lomax *et al.* (2001), we selected 185 earthquakes with a minimum number of *P* readings equal to six. We performed two run with the HYPO71 computer program for locating the earthquakes with the two velocity models using in both cases the same trial depth (3 km). The result of the locations is shown in fig. 7b, together with two cross sections striking east-west and north-south and a histogram showing the depth distribution of the located events.

Figures 7a,b show that the epicentral locations are very similar, but the new 1D velocity model produces a stronger clustering of the hypocenters compared to that obtained using the 5-layer model. This result is supported by the plot of the T_s-T_p times obtained from the

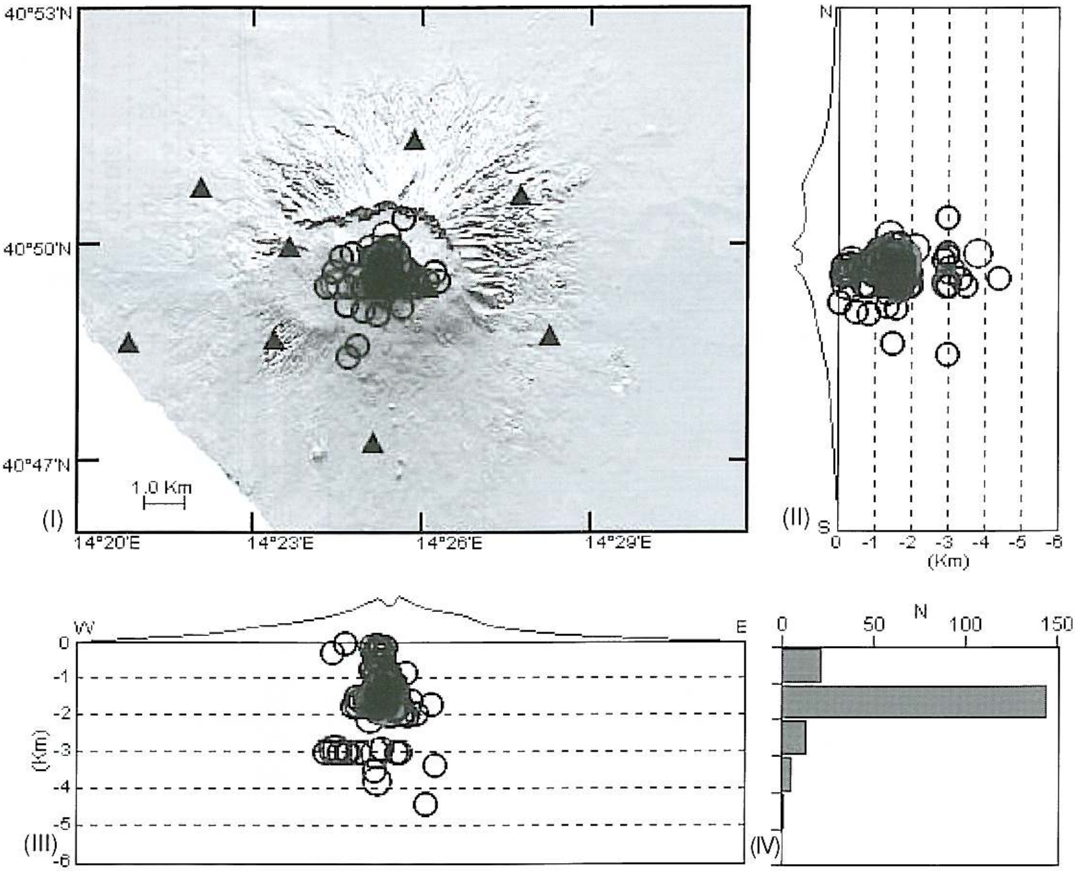

Fig. 7b. Location of 185 selected earthquakes at Vesuvius during the year 2000, obtained using the velocity model reported in table II. Figures (I) report the epicenters with the seismic stations operating on Vesuvius (black triangles). Figures (II) and (III) represent two sections oriented N-S and W-E respectively. Figures (IV) show the depth distribution of the hypocenters.

records of the three component OVO seismic station reported in fig. 8. In fact, the nearly constant values of T_s-T_p around 1 s indicate a strong clustering of the hypocenters. Moreover, the locations obtained with the new 1D velocity model show rms values and errors on the depth that are lower than those obtained using the old velocity model (fig. 9). The new velocity model reported in table II is now routinely used for the earthquake locations in the Vesuvius area.

4.2. *The magnitude scale*

The magnitude of the earthquakes occurring in the Vesuvius area is routinely computed from the time length of the seismograms recorded at OVO station using the following relation introduced in the early eighties (Gruppo di lavoro sismometria terremoto del 23/11/1980; 1981):

$$M_D = 2.75 * \log \tau - 2.35$$

where τ is the total signal duration in seconds.

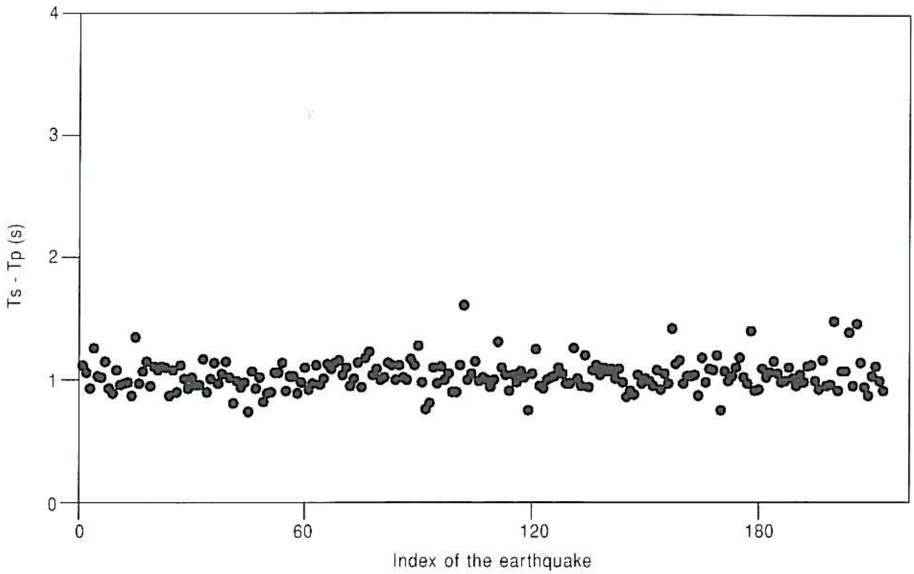

Fig. 8. T_s-T_p time of the Vesuvius earthquakes recorded at OVO seismic station in the year 2000.

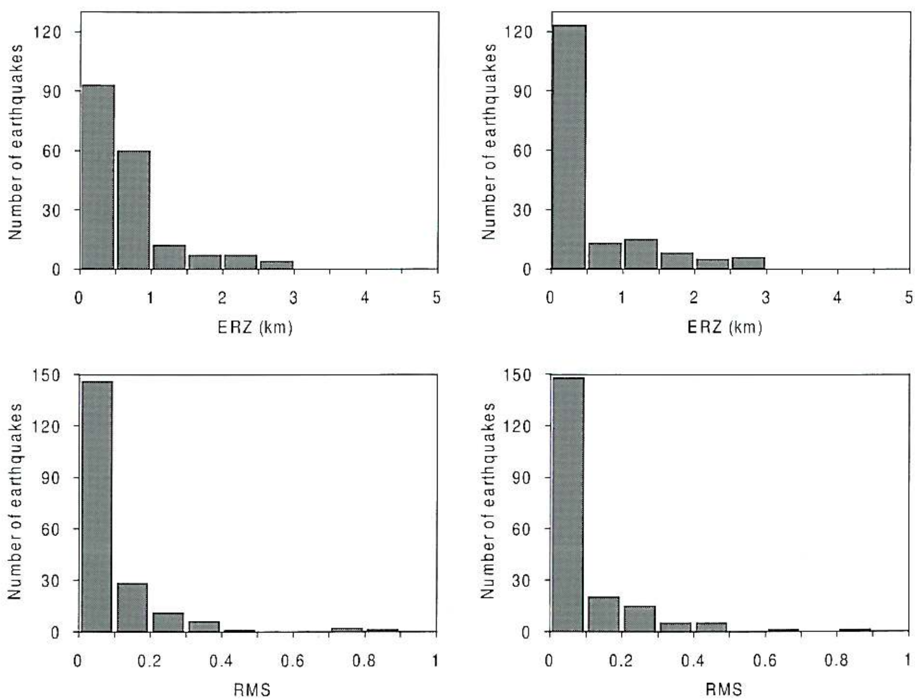

Fig. 9. Distributions of the errors on the depth and RMS values for the locations obtained using the velocity model reported in table I (on the left) and table II (on the right).

The above relationship was developed by comparing amplitudes from Wood-Anderson seismograms recorded at RMP station close to Rome with the signal durations measured from the vertical short period records obtained at OVO station. The associated standard error on the magnitude value is 0.30 (Gruppo di lavoro sismometria terremoto del 23/11/1980; 1981). This formula was applied to seismograms recorded since 1972, when a vertical and two horizontal Geotech S13 seismometers and the Helicorder recording system were introduced at the Osservatorio Vesuviano. The time duration of seismic events was estimated on the paper recording of the vertical component seismometer, the drum rotation speed being 1 mm/s. Using these data, a catalogue of Vesuvius seismicity over the last 30 years was compiled.

With the introduction of the new acquisition system, seismic data are recorded in digital form and the seismic traces are displayed on monitors (20″ high resolution flat screen) where all the analyses are performed (Giudicepietro *et al.*, 2000; Giudicepietro, 2001). However, some selected stations are still recorded also by the Helicorder system. The magnitude is still esti-

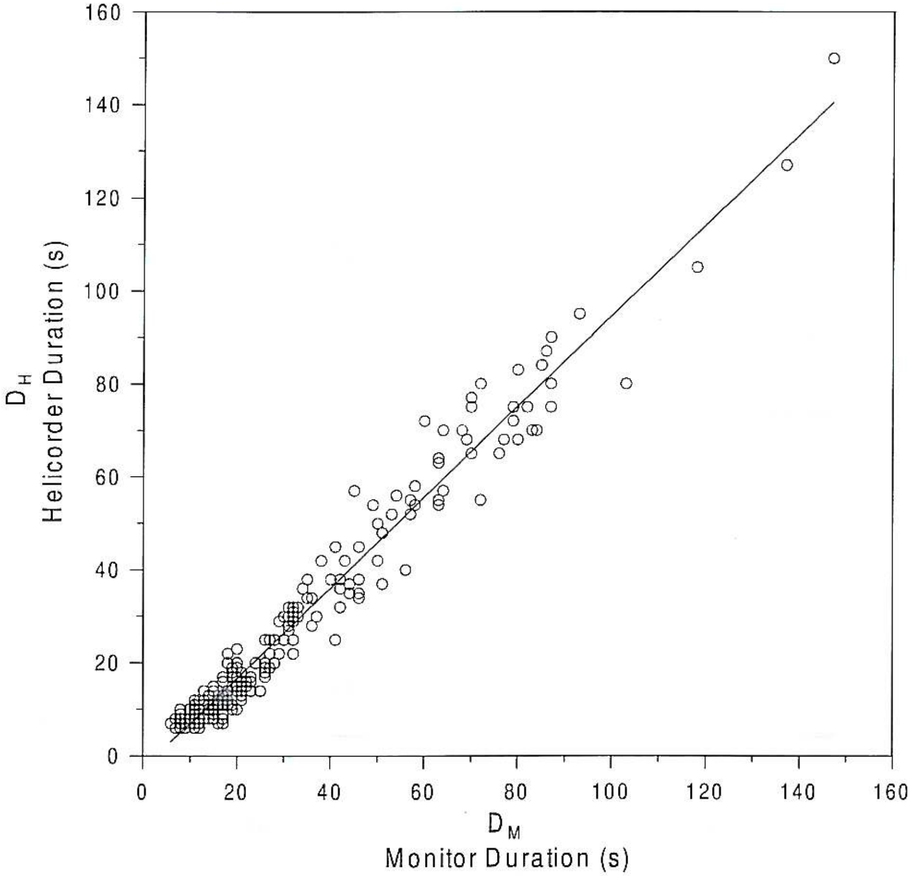

Fig. 10. Comparison of time duration of 204 selected earthquakes recorded at OVO station and determined both on Helicorder recording system (D_H) and monitor of the new acquisition system (D_M).

mated using the earthquake time length but now retrieved on the monitors. As a consequence of the different instrumental response, differences in time duration between paper and video-recordings could be expected, hence different magnitude values can be estimated.

To ensure validity in time of the magnitude catalogue, we calibrated the magnitude-duration formula according to the new acquisition system. We selected 204 earthquakes recorded by both the systems and to reduce personal biases in reading seismograms, the time length of each earthquake was estimated on both the recording systems by the same operator. Data are reported in fig. 10. The relationship obtained between the time durations estimated from the Helicorder paper recordings (D_H) and those estimated from monitor (D_M), is

$$D_H = (0.97 \pm 0.01)\, D_M - (2.9 \pm 0.5). \quad (4.1)$$

This relation indicates that the time duration of the earthquakes is systematically overestimated compared to that from the Helicorder system. This effect could be expected because the Helicorder, being a mechanical system, has a more limited frequency response than that of the new digital acquisition system. Taking into account the time duration differences quantified through the expression (4.1), we re-calibrated the magnitude scale. At present, this relation is routinely used for the magnitude estimation of earthquakes occurring in the Vesuvius area.

4.3. *Time distribution*

The catalogue of the Vesuvius earthquakes reports about 9000 events since 1972. As evidenced by many authors (Luongo *et al.*, 1996; Vilardo *et al.*, 1999; Zollo *et al.*, 2001), the completeness of this catalogue can be assumed starting from 1.9 as the minimum value of magnitude. Accordingly, for the following analysis we only will consider data with this magnitude threshold. It means that out of a total number of 383 earthquakes detected by the OVO station during the year 2000, we selected 44 events with a magnitude value greater than 1.8. The maximum observed magnitude in this period was $M_D = 3.0$ for the two earthquakes on January 22 and September 27. Only five more events had a magnitude greater than or equal to 2.5 and three events were also felt in the Vesuvian area. The hypocenter parameters of the $M_D \geq 2.5$ earthquakes are reported in table III.

To compare the seismicity in the year 2000 with that of the previous years, we evaluated the time and energy distribution of the earthquakes occurring in the past twenty years. The magnitude values were converted into energy by the Gutenberg-Richter relationship

$$\log E = 9.9 + 1.9\, M_D$$

where E is the energy in erg and M_D the magnitude.

Table III. Location parameters for the earthquakes with $M_D \geq 2.5$ in 2000.

Day	Time	Lat. N	Long. E	Depth (km s.l.m.)	M_D	RMS (s)	ERH (km)	ERZ (km)	Q
2000/01/22	04:09	40-49.28	14-25.35	3.27	2.5	0.08	0.3	0.6	A
2000/01/22	04:34	40-49.21	14-25.52	3.68	3.0	0.06	0.3	0.4	A
2000/05/20	10:11	40-49.45	14-25.71	3.34	2.5	0.09	0.4	0.6	B
2000/07/10	03:05	40-49.36	14-25.42	2.28	2.8	0.05	0.2	0.3	A
2000/08/07	01:32	40-49.24	14-25.62	2.91	2.8	0.07	0.2	0.4	A
2000/09/27	09:01	40-49.41	14-25.56	3.00	3.0	0.03	0.1	0.2	A
2000/12/11	22:15	40-49.40	14-25.59	3.28	2.9	0.08	0.2	0.4	A

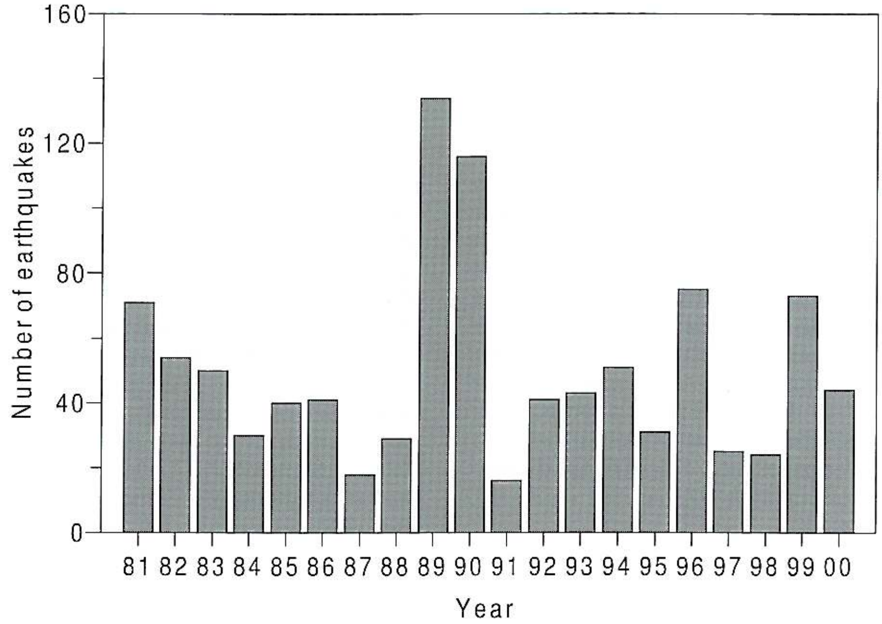

Fig. 11. Number of earthquakes with $M_D \geq 1.9$ at Vesuvius in the past 20 years.

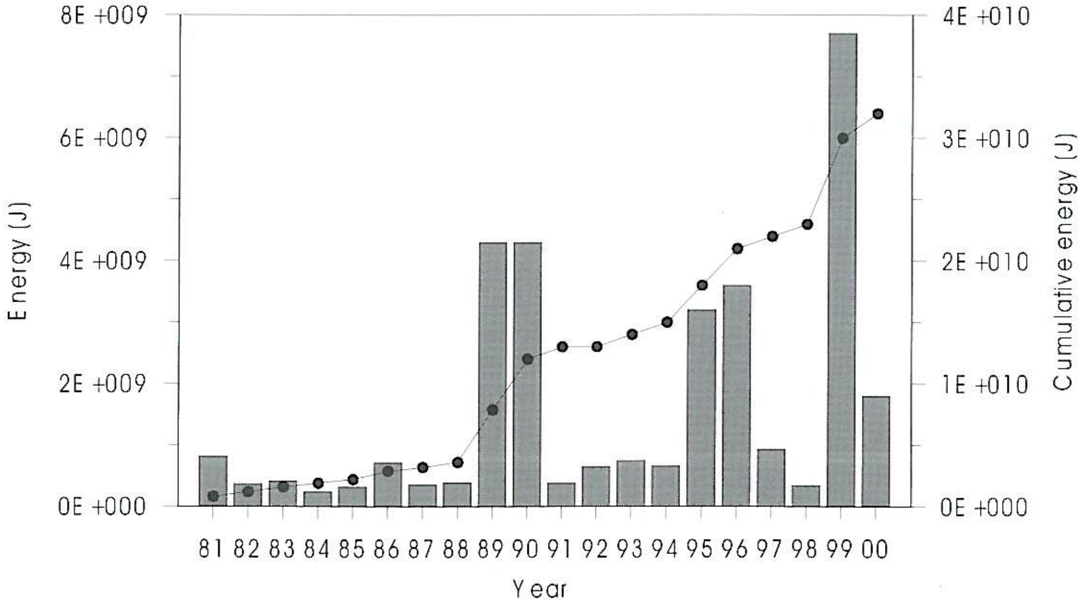

Fig. 12. Time distribution of the energy (histogram) and cumulative energy (solid circles) of the earthquakes with $M_D \geq 1.9$ at Vesuvius in the past 20 years.

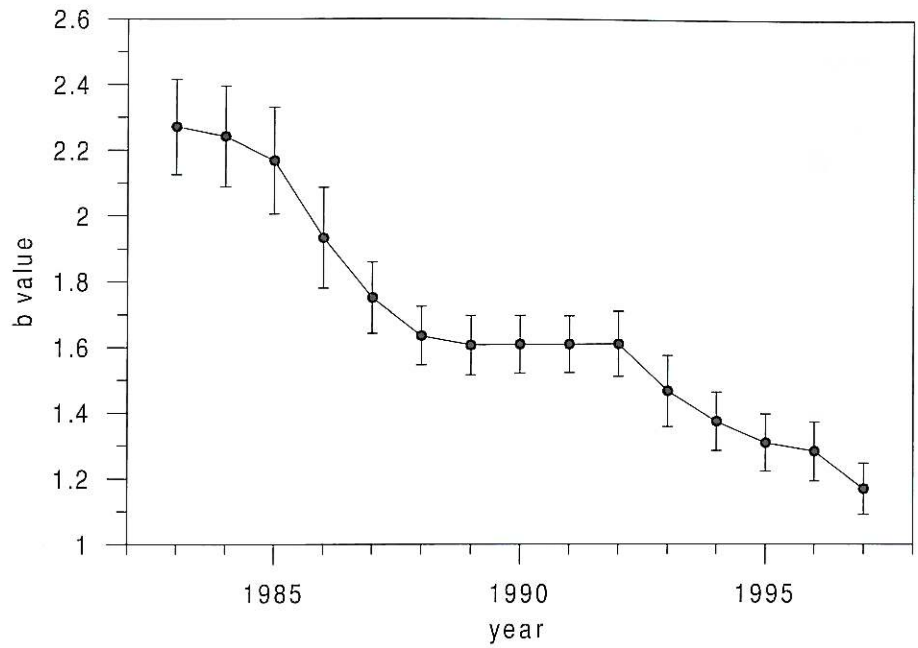

Fig. 13. *b* value *versus* time for the seismicity of Vesuvius. The value of *b* (solid circle) is determined for earthquakes occurred in a time window of 5 years centered on each year, since 1981 until 1999. The error bars represent the 99% significance level.

The obtained distributions are reported in figs. 11 and 12. Figure 11 shows that the average rate of seismicity is some tens of earthquakes per year (mean value 54 ± 15), a significant departure from this mean value occurred only in 1989 and 1990 when more than one hundred earthquakes with $M_D \geq 1.9$ occurred at Vesuvius. The number of earthquakes (44) recorded at OVO station during the year 2000 is similar to the previous years. Similar results can be obtained for the energy distribution shown in fig. 12, where the energy peak of the year 1999 is related to a seismic sequence with a maximum magnitude $M_D = 3.6$.

We also studied the frequency of occurrence of earthquakes during the year 2000 evaluating the *b* parameter of the Gutenberg-Richter relation

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

where N is the cumulative number of events greater than magnitude M. Events smaller than magnitude 1.9 were excluded and for earthquakes above this magnitude a *b* value of 1.20 ± 0.13 was obtained. Zollo *et al.* (2001), analysing the catalogue of the earthquakes recorded at OVO station, estimated the trend of the *b* value as a function of time calculating the *b* parameter in overlapping time windows of 5 years. Figure 13 reports the time dependence of the *b* value as determined by Zollo *et al.* (2001). The *b* value for the year 2000 compared to the estimates obtained by Zollo *et al.* (2001) shows that the magnitude distribution of earthquakes has remained similar in recent years.

4.4. *Focal mechanisms*

Focal mechanisms were computed for seven earthquakes in the year 2000. We used only clear *P*-wave first motions obtained from the

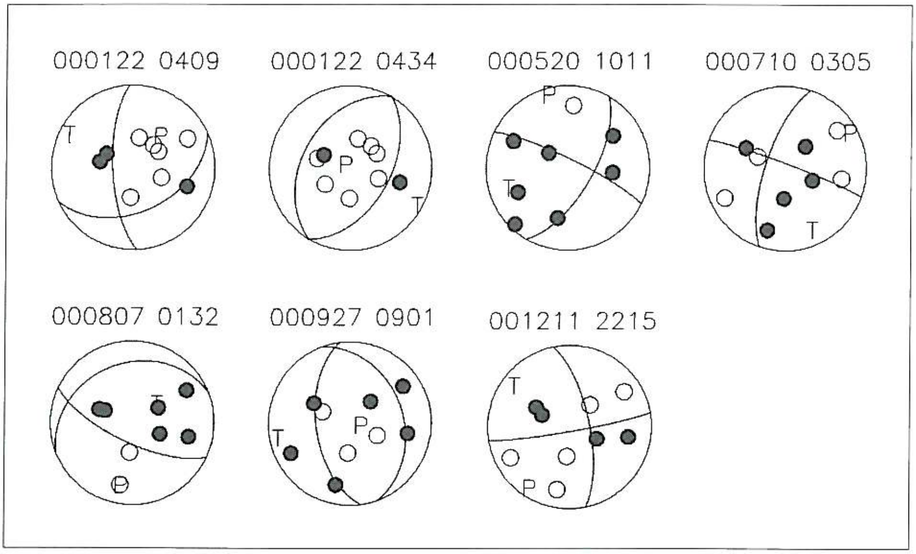

Fig. 14. First motion focal mechanism solution (equal-area, lower hemisphere projection) for seven earthquakes of Vesuvius.

records of the seismic surveillance network. A check on the correct polarity of the seismic stations was performed by visual inspection of the record of several teleseisms and deep focus Thyrrenian earthquakes occurring during 2000. The fault plane solutions were computed by the FPFIT computer program (Reasenberg and Oppenheimer, 1985) using the hypocenters and ray take-off angles obtained for the Lomax *et al.* (2001) 1D velocity model.

Figure 14 reports the computed nodal planes. This figure shows a variety in the type of focal mechanisms, moreover the polarity distributions on the focal sphere indicate a variability of the geometry of the fault planes. Some common features can be deduced from the fault plane solutions:

- A nearly horizontal *T* axis.
- A predominant normal faulting component.

Indeed, two solutions show pure normal faulting mechanism and four solutions evidence a normal faulting mechanism with strike-slip component. An earthquake also shows a predominant inverse faulting mechanism.

Generally, a variability of the fault plane solutions can also be produced by the layered velocity model used for the determination of the take-off angles, which presents velocity contrasts. In fact, the ray path in a layered model can produce large discontinuous jumps in the take-off angles when the focuses lay on the layer boundaries. Consequently, a small error in the hypocenter depth can also produce an erroneous first pattern and an unsatisfactory nodal plane solution simply due to model shortcomings. Anyway, this variety in the type of focal mechanisms was also observed for the earthquakes analysed in the past (Vilardo *et al.*, 1996; Bianco *et al.*, 1998, 1999b).

5. Characteristics of the seismicity at the Campi Flegrei volcanic area

The Campi Flegrei volcanic area is characterized by a continuous slow ground movement (bradyseism). Generally, the ground uplift movements are followed by seismic activity whereas during ground subsidence no seismic activity is detected. The last strong episode of ascending bradyseism occurred in 1982-1984 producing a maximum uplift of about 179 cm. In the same period, several thousands of earthquakes occurred in the area, most of them located in the central part of the Campi Flegrei caldera where the maximum vertical displacement was observed. The 1982-1984 seismic activity was characterized by low energy events, more than 95% of the earthquakes had a magnitude lower than 2 and the strongest shock occurred in December 1984 with $M_D = 4.2$. The whole seismicity was located at very shallow depth in the upper five kilometers (Aster *et al.*, 1992; Orsi *et al.*, 1999). With the ending of the ascending bradyseismic phase, the seismic activity vanished.

In the following years the Campi Flegrei area evidenced a continuous subsidence at a mean rate of some millimetres for month, interrupted by two major episodes of uplift ground movement in 1989 and in the summer 2000 (Del Gaudio *et al.*, 2000).

Both the uplift episodes were accompanied by low energy seismic activity. In particular, during the year 2000, two swarms of micro-earthquakes occurred at Campi Flegrei in the period July 2-7 and August 22. The swarm of July consisted of about ten earthquakes, those of August counted several tens of earthquakes, the maximum magnitude being $M_D = 2.2$.

Saccorotti *et al.* (2001) analysed the seismic sequences evidencing a striking difference between the spectral content of the two swarms. The events of July show a low frequency content with spectra characterized by a narrow frequency band in the range 1-5 Hz. The earthquakes of August swarm had a spectral shape typical of high frequency micro-earthquakes and similar to those occurring during the bradyseismic crises of 1982-1984 (fig. 15a,b). Saccorotti *et al.* (2001), performed the earthquake locations using a non-linear search technique with travel-times computed for a 3D structure of Campi Flegrei. The hypocenter depth of the earthquakes of the two swarms are distributed in the upper five kilometres in an area of few square kilometres around the Solfatara crater. The analyses performed by Saccorotti *et al.* (2001) suggest a direct involvement of magmatic/hydrothermal fluids in the source process of the July swarm. A mechanism of brittle shear failure was proposed for the August 2000 swarm, similar to those of the earthquakes during the 1982-1984 crises.

In the other months of year 2000 no local earthquakes were recorded by the seismic stations operating in the Campi Flegrei area.

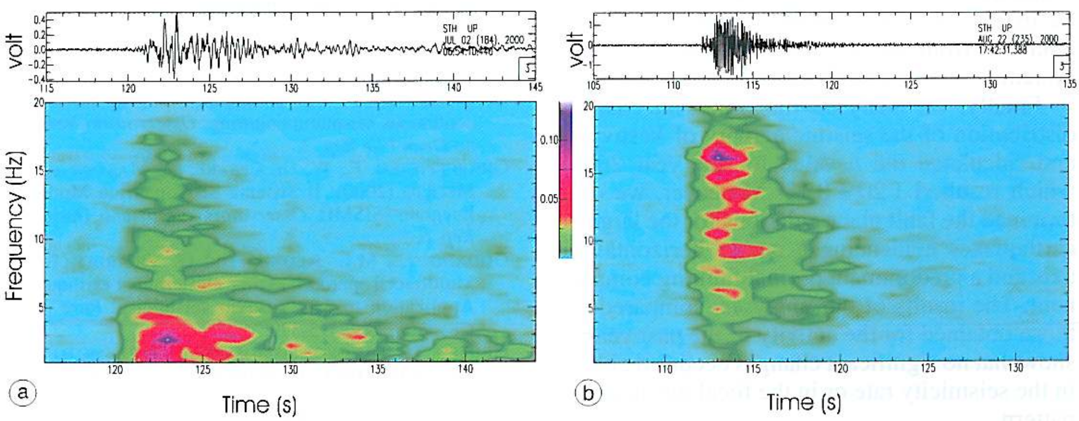

Fig. 15a,b. Example of earthquakes recorded during the uplift episode of Campi Flegrei in the year 2000. The figure shows the vertical component seismogram and spectrogram for the earthquake recorded at STH station on July 2 (a) and August 22 (b). The spectrogram is calculated for 2-s-long time windows, with 1-s of overlap. The figure evidences a lower frequency content of the first earthquake, compared to the August event.

6. Conclusions

In this paper, we described the characteristics of the seismic activity in the Neapolitan volcanic areas during the year 2000 and we presented the procedures of seismic data analysis.

About 68% of the seismic data consist of natural events, mainly earthquakes in the Vesuvius area (as shown by the geographical distribution). The remainder of the recorded signals have been classified as blasts due to mining or fishing activity.

We located the Vesuvius earthquakes using a new velocity model obtained by the analysis of active seismic experiments performed in the area (Lomax *et al.*, 2001) and we compared the locations with those obtained using the old 5-layer velocity model. Since we obtained lower errors and rms values, we introduced the new model for routine earthquake location. Moreover, the stronger clustering of the hypocenters produced by the new model can be well correlated with the observed constant values of T_s-T_p.

As a consequence of the introduction of the new seismic acquisition system, we re-calibrated the magnitude-duration scale for the earthquakes occurring in the Vesuvius area, obtaining a new relation. The re-calibration of the scale was necessary because of slight differences in the earthquake time durations estimated using the digital seismograms recorded by the new acquisition system and those obtained from the previously used recording system.

Finally, we analysed the time and energy distribution of the seismic activity of Vesuvius and calculated the *b* value for the year 2000 which resulted 1.20 ± 0.13. Moreover, we determined the fault plane solutions for the largest earthquakes evidencing a nearly horizontal *T* axis and a predominant normal faulting component. The results of our analyses, compared to those obtained for the activity of the past years, show that no significant changes occurred either in the seismicity rate or in the focal mechanism pattern.

In the last part of our paper, we briefly described the seismic activity recorded in the Campi Flegrei, where two seismic swarms occurred in the summer of 2000.

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