SEISMIC ACTIVITY OF MOUNT EREBUS, ANTARCTICA IN 1983–1984

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Abstract: Mount Erebus is one of the active volcanoes in Antarctica, and seismic observations of it have been made since December 1980 using a radio-telemetered network and several temporary stations. In the 1983–1984 field season, the number of the network stations was increased to eight by adding two new radio-telemetered stations.

Volcanic earthquakes in and around Mount Erebus occurred at a rate of 20–160 events per day, which was almost the same rate as in the previous season. No intense earthquake swarm occurred in the 1983–1984 season. The earthquakes in this season are located wide around Mount Erebus. The clustered earthquakes have a dike-like distribution beneath the northern area of the central cone.

An aseismic zone is recognized beneath the southwest area of the Erebus summit. This aseismic zone may correspond to a magma reservoir.

The earthquakes which were not associated with the eruptions of Mount Erebus can be divided into several types according to their seismograms and spectra of the seismic waves. The seismic waves which may pass through the aseismic zone seem to be strongly attenuated as compared with those which may not pass through the zone.

1. Introduction

Mount Erebus (3794 m), discovered in 1841, is located on Ross Island, Antarctica. Since McMurdo Station and Scott Base were established on the Hut Point of Ross Island in 1957, the volcanic activity of Mount Erebus has been observed continuously. A lava lake of molten anorthoclase phonolite has been present since before December 1972 in the main crater of Mount Erebus which is composed also predominantly of anorthoclase phonolite lava.

The geophysical studies on Mount Erebus are interesting for the following scientific subjects; 1) the tectonics at the tectonic boundary between East and West Antactica, 2) the mechanism of magma supply to a magma reservoir which is considered to be located beneath the persistent convecting lava lake, 3) the structure of Erebus volcano and its vicinity, and 4) the sequence of eruptions which are often accompanied with an explosion earthquake.

To reveal these subjects, a radio-telemetered seismic network was established in December 1980. Continuous seismic observations have been made as a cooperative International Mount Erebus Seismic Study (IMESS) among Japan, New Zealand and the United States (TAKANAMI *et al.*, 1983a; KIENLE *et al.*, 1982).

In the 1980–1981 field season, the radio-telemetered network consisted of four stations (one at the summit, two on the flank and one at Scott Base), and the results of the observation in the season were reported by TAKANAMI *et al.* (1983a, b). Two more stations were installed in the 1981–1982 field season, one on the eastern flank and the other on Mount Terror about 30 km west from the Erebus summit. The results of the observation in the season were summarized by SHIBUYA *et al.* (1983). The observation in the 1982–1983 season was continued by the same stations as those in the previous season and the results were reported by UEKI *et al.* (1984).

According to the seismicity during 1980–1983, volcanic earthquakes in and around Mount Erebus occurred at a rate of 20–160 events per day. The earthquakes are distributed over a wide area around Mount Erebus. Some earthquake swarms occurred in the flank of Mount Erebus. Each swarm lasted for several days, and had over several hundreds earthquakes per day.

In 1983–1984, eight radio-telemetered stations were operated in and around Mount Erebus. Seismic activity observed from September 1983 to January 1984 is summarized and compared with the activity in the previous seasons in this paper.

2. Observation

The seismic network of Mount Erebus is shown in Fig. 1. Solid circles are permanent stations which have been operated since November 1981; ABB at Abbott

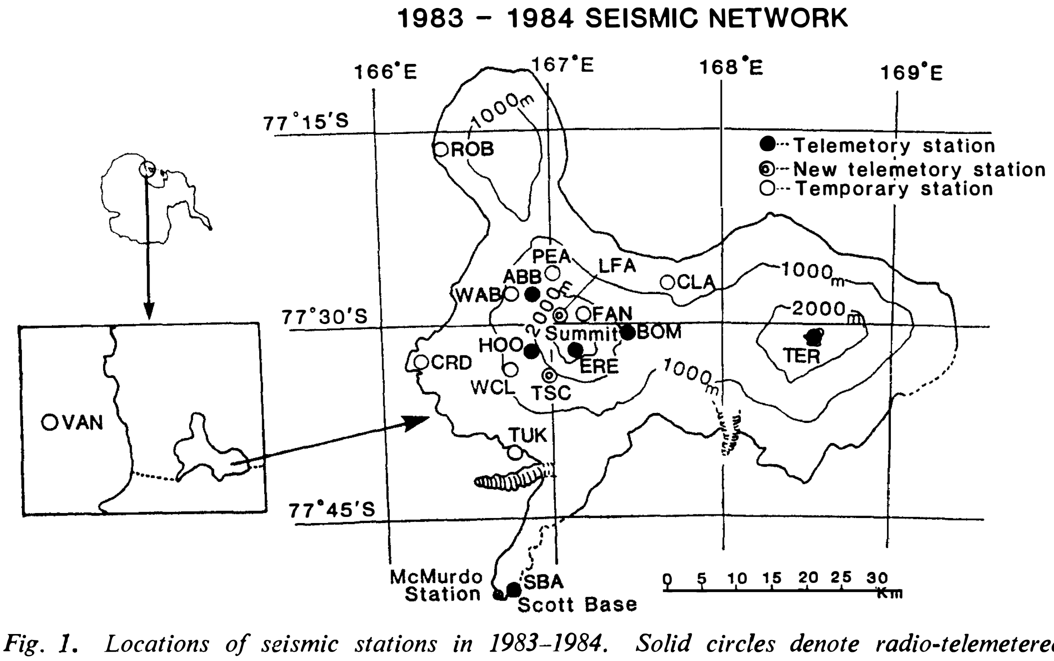


Fig. 1. Locations of seismic stations in 1983–1984. Solid circles denote radio-telemetered stations, double circles denote radio-telemetered stations added in the season, and open circles show temporary stations.

Peak, HOO at Hoopers Shoulder, ERE at the summit of Mount Erebus, BOM at Bomb, TER at the summit of Mount Terror and SBA at Scott Base. Two more stations were installed on the flank as shown by double circles in Fig. 1 in the 1983–1984 field season; LFA at lower Fang and TSC at Three Sisters Cones. All stations have a vertical-component seismometer with 1-Hz natural frequency. An infrasound microphone has also been installed near the summit station (ERE) to detect air pressure changes which may be associated with volcanic eruptions. The signal is frequency-modulated by a VCO, and is transmitted to Scott Base, 38 km south apart from the summit, by a radio-telemetered transmitter. Batteries charged by solar panels supply the power for those equipments. All signals are recorded on magnetic tapes of the 14-channel FM data recorder at Scott Base. The overall frequency responses for ground velocity are nearly flat between 1 and 25 Hz (SHIBUYA *et al.*, 1983).

The radio-telemetered network stopped its signal transmitting in July 1983, when the batteries ran down on account of no power supply from solar panels during the winter. The seismic recording for all stations except Scott Base was interrupted for two months. The batteries restarted to be trickle-charged by solar panels in late August, and the stations gradually came to work in mid-September as daylight increased enough to charge the batteries. The observation at the summit station which had stopped in January 1983 was started again in mid-December, but unfortunately the station stopped to work no longer than a few weeks. Two new stations on the flank were added early in January 1984 (KAMINUMA, 1984).

The open circles in Fig. 1 show the temporary network operating between November 1983 and early January 1984.

3. Seismicity in 1983-1984

3.1. Number of earthquakes

Figures 2a–2d show the plume activity observed at McMurdo Station and the daily number of earthquakes counted at Abbott Peak (ABB), Bomb (BOM) and Hoopers Shoulder (HOO) stations, respectively, for the period from October 1983 to January 1984. The daily number in the figures does not include those of teleseism, local earthquakes far from Ross Island, and icequakes whose wave form is characterized by higher frequency and shorter duration time. No remarkable quasi-periodic change as reported by SHIBUYA *et al.* (1983) and UEKI *et al.* (1984) was observed in this period, as is obvious in Figs. 2b–2d.

The hatched columns in the lower part of Figs. 2b–2d show the daily number of earthquakes with maximum trace amplitude larger than 20 mm on the playback seismogram ($M>$*ca.* 0.5). The seismicity of these larger events is rather constant throughout the season. Only the number of smaller earthquakes seems to change day by day.

The recording gains at the stations and playing back gains are constant since 1982, and the threshold level of the earthquake counts is the same level as that in UEKI *et al.* (1984). The daily number of earthquakes in 1983–1984 can thus be compared directly with that in 1982–1983. The average number of earthquakes observed at the

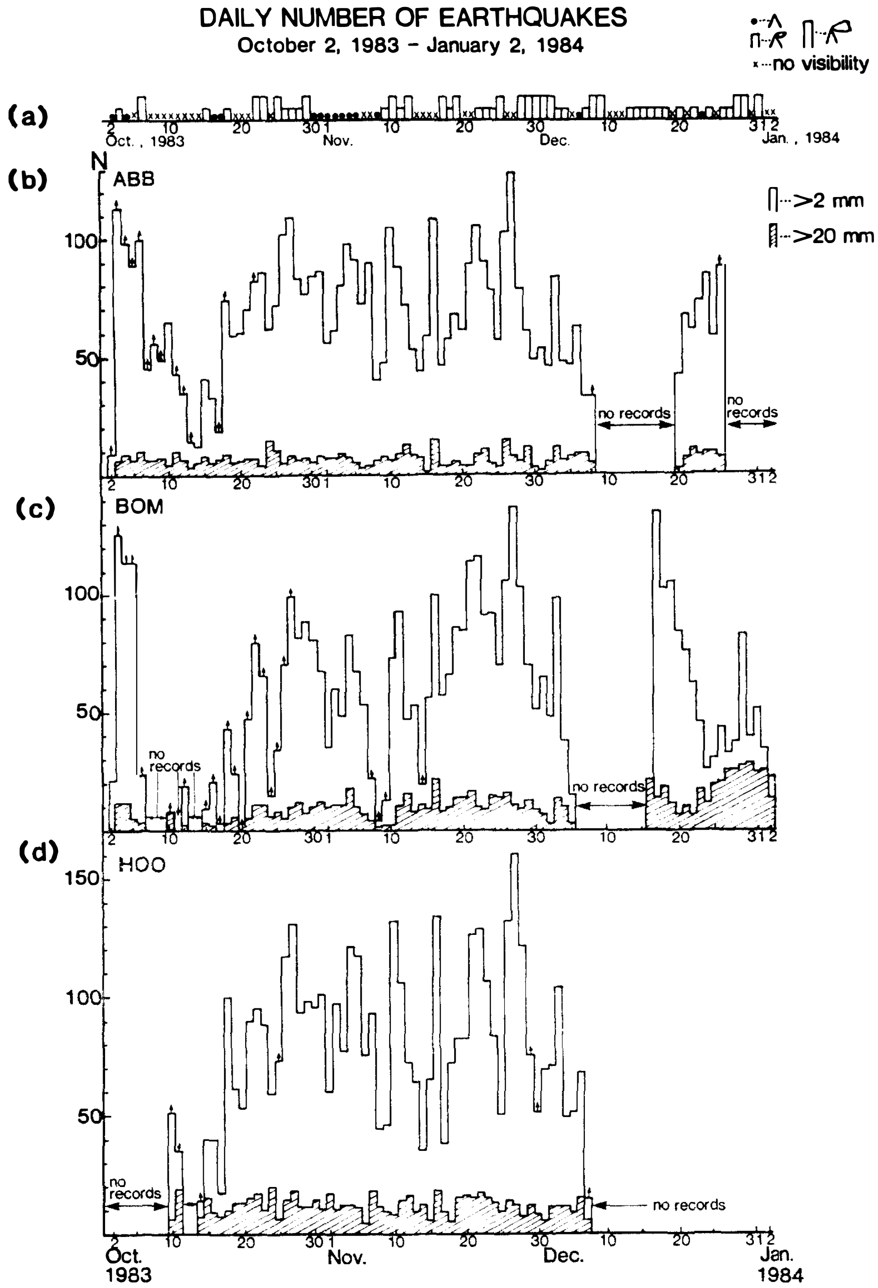


Fig. 2. (a) Quantity of plume observed at McMurdo Station and/or Scott Base. (b) Daily number of earthquakes at Abbott Peak station. (c) Daily number of earthquakes at Bomb station. (d) Daily number of earthquakes at Hoopers Shoulder station. Hatched columns denote the daily number of earthquakes with the maximum amplitude larger than 20 mm on a playback seismogram.

Abbott Peak station in 1983–1984 is 70 events per day, while that in 1982–1983 was 76 per day (UEKI *et al.*, 1984). There is no remarkable change between these numbers.

Mount Terror station (TER) frequently recorded more than one hundred earthquakes per day in this field season. However, the station worked only intermittently in late 1983, and we could not give details of the daily number of earthquakes. The seismic activity in the 1983–1984 season has no unusual events such as the remarkable earthquake swarm on October 8–9, 1982 which was reported by UEKI *et al.* (1984) and KAMINUMA *et al.* (1985a).

The plume activity from the Erebus summit was observed at McMurdo Station for the period from October 2, 1983 to January 2, 1984 as shown in Fig. 2a. The plume quantity in the figure is indicated by the following symbols; solid circles indicate that no plume was seen through the day, short columns indicate a small amount of plume, long columns indicate an extended plume streaming away from the summit, and crosses indicate no visibility of Mount Erebus as illustrated in the right upper part of Fig. 2a. The number of days for the long column is 20 days out of 60, 26 days for the short column and 14 days for the solid circles.

Figures 3a and 3b show the daily number of earthquakes recorded at new stations on the flank of Mount Erebus, lower Fang (LFA) and Three Sisters Cones (TSC) during 12 days between 9 and 20 January 1984. Figures 3c–3e also show the

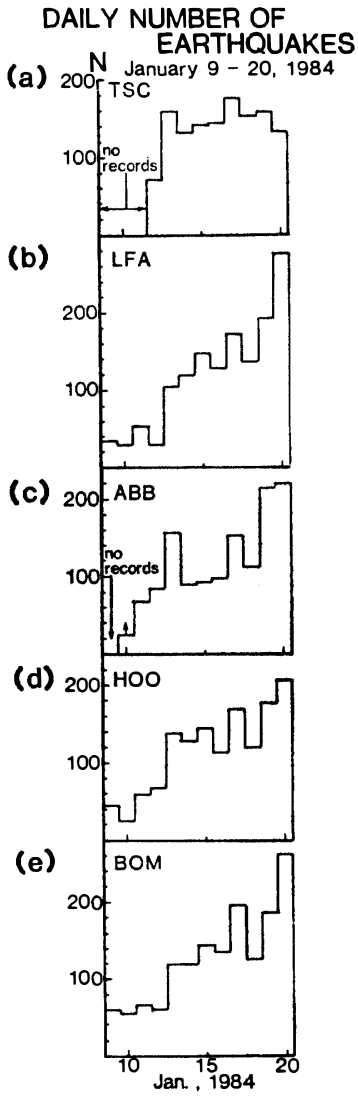


Fig. 3. Daily number of earthquakes at Three Sisters Cones station (a), at lower Fang station (b), at Abbott Peak station (c), at Hoopers Shoulder station (d) and at Bomb station (e).

daily number of earthquakes recorded at Abbott Peak (ABB), Hoopers Shoulder (HOO) and Bomb (BOM), respectively. The earthquakes recorded at each station are counted from about thirty to more than 200 events per day. Though the period of observation is very short, no difference among the stations seems to be found in the daily number patterns as shown in the figures.

3.2. *Hypocenter distribution*

More than 200 events were determined for the hypocenter calculation in the period between September 28, 1983 and February 11, 1984. At least five arrival times of *P*- and/or *S*-wave were used for the calculation. One second is 25 mm on the playback seismogram and the time code signals are formated 10 Hz clock signals, and the accuracy of phase readings is better than 0.05 s.

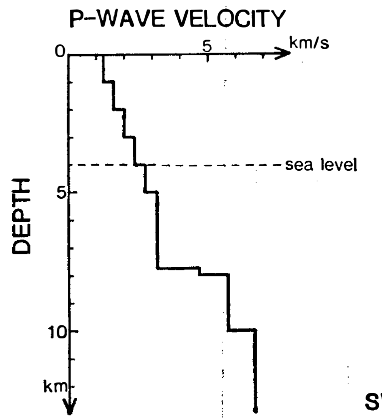


Fig. 4. P-wave velocity model for the determination of hypocenters.

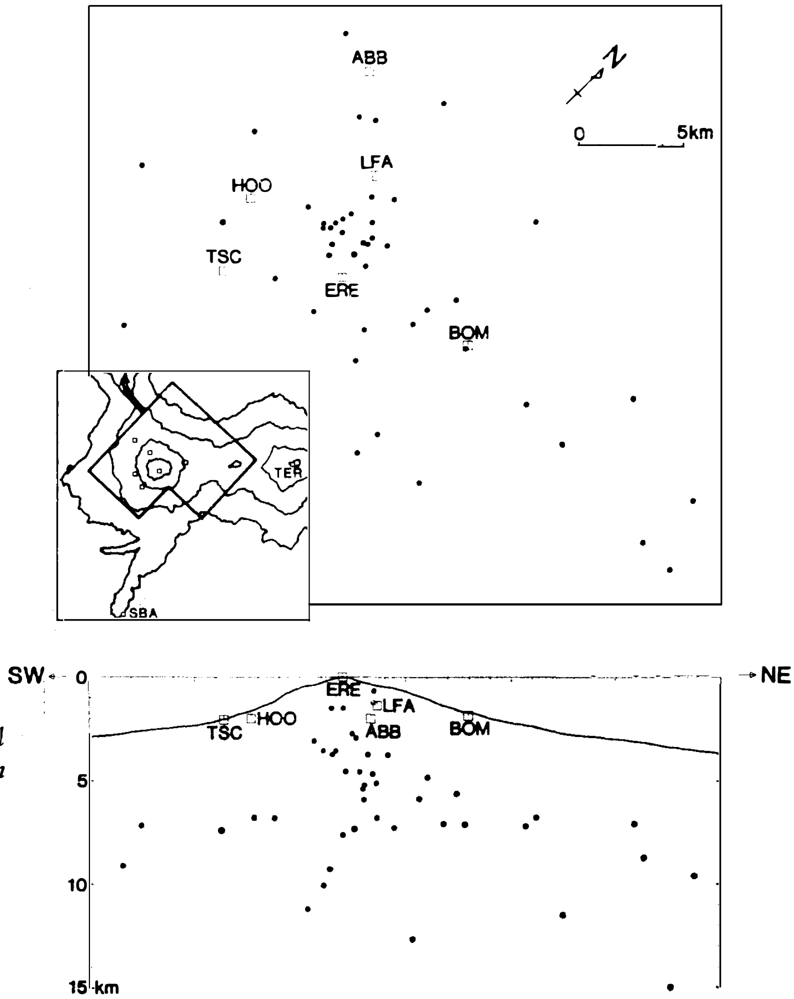


Fig. 5. Hypocentral distributions of earthquakes in the period from September 28, 1983 to February 11, 1984. Top: epicenter locations. Bottom: focal depth distributions projected onto a vertical cross section oriented SW-NE. Soild circles denote earthquake hypocenters and open squares denote radio-telemetered stations.

Figure 4 shows the *P*-wave velocity structure of the Mount Erebus region used for the hypocenter calculation. The structure is assumed to be horizontally multi-layered. The *P*-wave velocities of the upper five layers 1 km thick each are assumed as shown in Fig. 4, and those deeper than 1 km below sea level are the same velocity model proposed by WILLSON *et al.* (1981).

Figure 5 shows the epicentral distributions of earthquakes (upper part) and the focal depth distributions (lower part) projected onto a vertical NE-SW section across Ross Island. About 40 earthquakes out of 200 with clear *P*- and/or *S*-wave arrival time readings are used for the hypocenter calculation. These hypocenters have horizontal and vertical location errors within 3 km. Though the hypocenters scatter wide around Mount Erebus, the slight concentration in the north area of the central

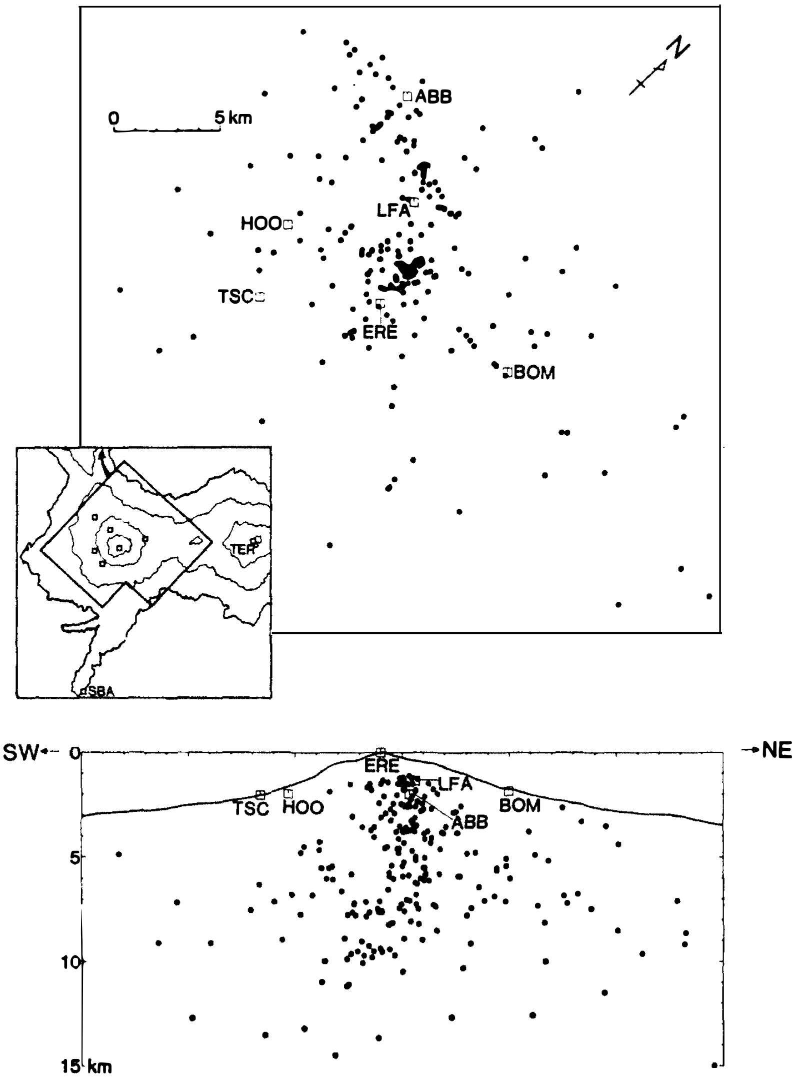


Fig. 6. Hypocentral distributions of earthquakes in the period from February 16, 1982 to February 11, 1984. Top: epicenter locations. Bottom: focal depth distributions projected onto a vertical cross section oriented SW-NE. Solid circles denote earthquake hypocenters and open squares denote radio-telemetered stations.

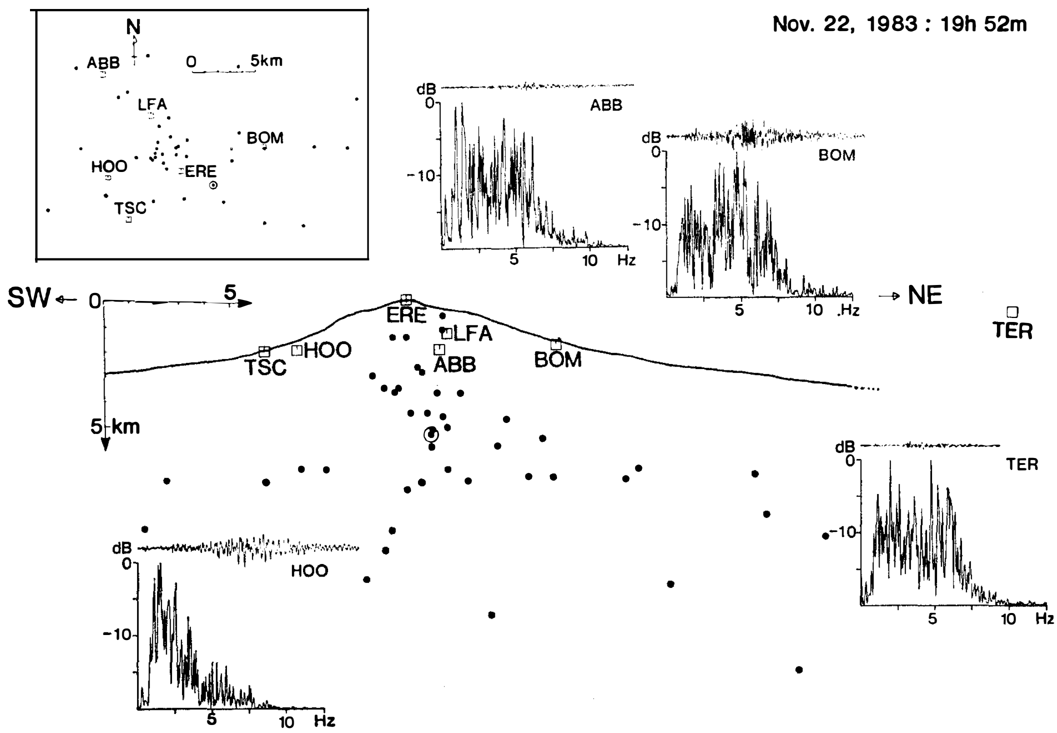
cone of Mount Erebus is found. The focal depth distribution ranges about 0–5 km beneath the summit northward. These earthquakes seem to be explosion earthquakes as mentioned by SHIBUYA *et al.* (1983) and UEKI *et al.* (1984).

An aseismic zone with few earthquakes is located in the southwest area of the summit as shown in Fig. 5. Such aseismic zone is also reported in the previous seasons by SHIBUYA *et al.* (1983), UEKI *et al.* (1984) and KAMINUMA *et al.* (1985b). Figure 6 shows the epicentral distributions (upper part) and the focal depth distributions (lower part) projected onto a vertical NE-SW section across Ross Island in the period between February 1982 and February 1984. About 230 earthquakes are located in Fig. 6 and their horizontal and vertical location errors are within 3 km. The existence of the aseismic zone became clear through the observation of 5 years. The aseismic zone might be a magma reservoir which supplies continuously fresh magma to the lava lake at the Erebus summit.

3.3. Wave form

The volcanic earthquakes which occurred in and around Mount Erebus can be divided into several types according to their seismic wave form. As the seismic wave form of explosion earthquakes is discussed by KAMINUMA *et al.* (1985b), the wave form of other types of the earthquakes is mentioned below.

(a)

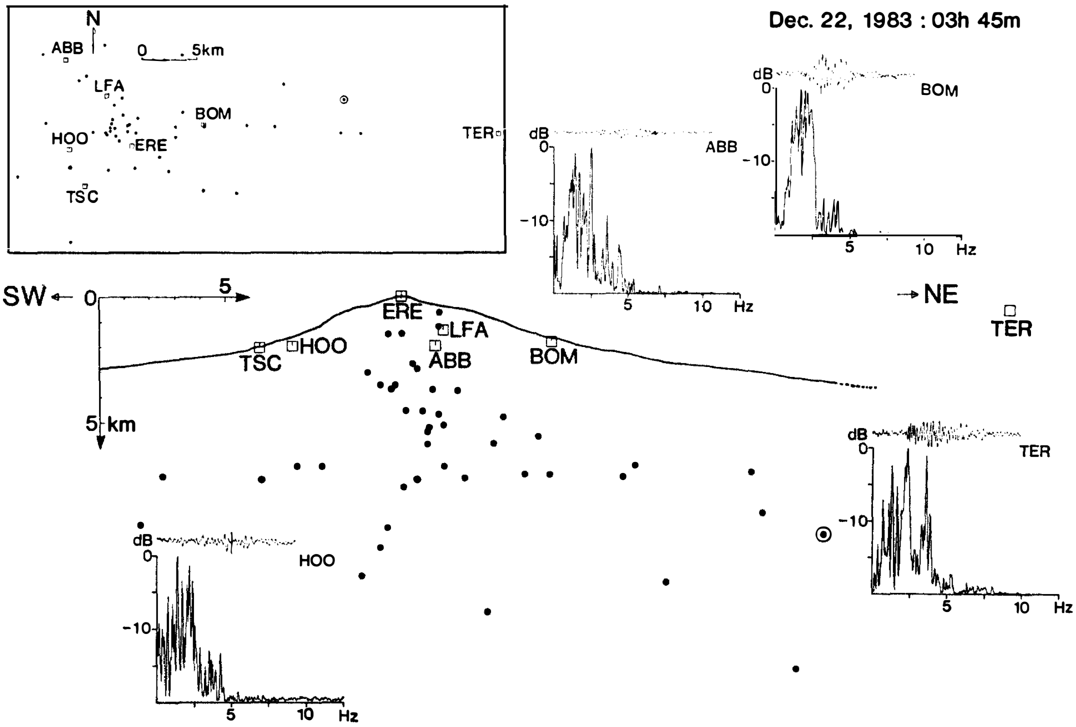


Figs. 7a–c. Spectra of seismograms for several types of earthquakes which are not accompanied with eruption at the summit. Locations of the earthquakes are given by double circles. Soild circles in the box (top left) of each figure indicate epicenter locations in 1983–1984. Vertical cross sections (center) show focal depth distributions in 1983–1984.

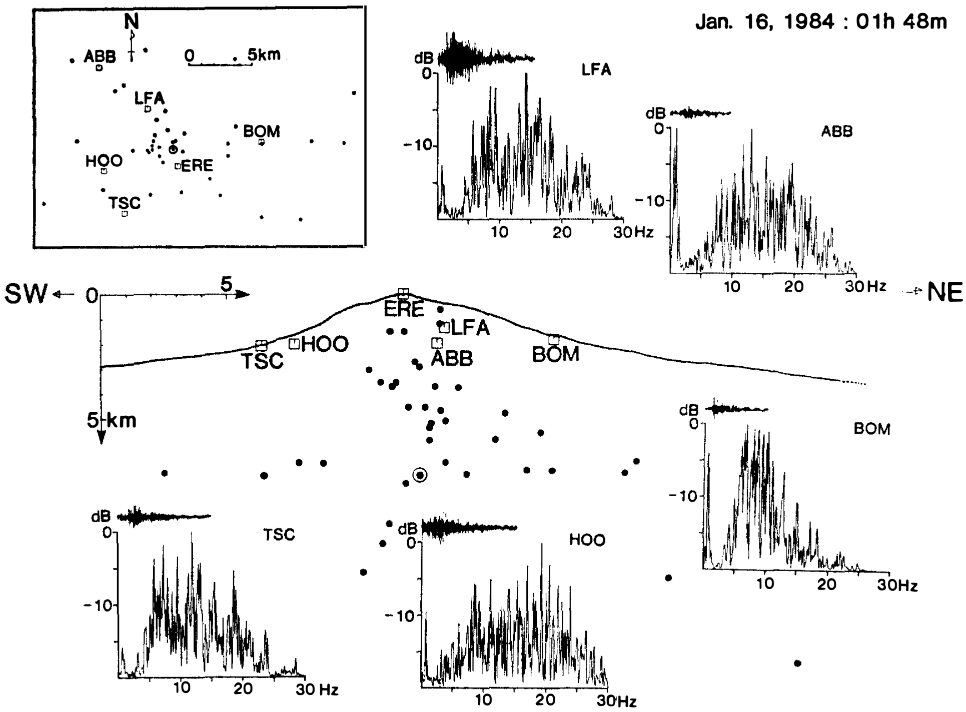
Figures 7a–7c show the seismograms and their spectra for the earthquakes which are not accompanied with the eruptions of Mount Erebus, and the locations of these events are given by double circles in Fig. 7.

The earthquake shown in Fig. 7a is located near the aseismic zone and the seismic ray path toward the Hoopers Shoulder station may pass through the magma

(b)



(c)



reservoir which is discussed in the previous section. The spectra of the seismic waves observed at the three stations on the flank of Mount Erebus and at the Mount Terror station are given in Fig. 7a for comparison with each other. The spectra of the seismic waves at the Abbott Peak station, the Bomb station and Mount Terror station have peaks in the range of 1–7 Hz as shown in the figure. On the contrary, the spectra at the Hoopers Shoulder station have peaks in the lower range of 1–3 Hz as compared with the above-mentioned stations.

The seismic waves of the earthquake shown in Fig. 7b are characterized by narrow spectra whose peaks are in the range of 1–3 Hz. As shown in Fig. 7c, the spectra have peaks in the range of about 5–25 Hz, and their frequency range is higher than that for other two types.

4. Conclusion

The seismic activity observed in and around Mount Erebus is summarized for the 1983–1984 field season with the following results:

1) Earthquakes occurred in and around Mount Erebus at a rate of 20–160 times per day. No remarkable earthquake swarm occurred in the season.

2) The earthquakes are distributed in a wide area around Mount Erebus. There is a dike-like distribution beneath the summit.

3) The earthquakes can be divided into several types according to the spectra of their seismic waves.

4) There seems to be an aseismic zone beneath the southwestern flank of Mount Erebus. The seismic waves passing through the zone seem to be strongly attenuated for higher frequency which suggests that the zone is a magma reservoir.

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