# NEW ERUPTION PARAMETERS AND SPECTRAL RELATIONSHIPS BETWEEN SEISMIC AND INFRASONIC SIGNALS FROM EREBUS VOLCANO, ANTARCTICA

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***Abstract:*** Magnitude and energy of the September 1984 eruptions have been calculated from seismic, infrasonic and gravity signal data. For the large initial eruption at 13d 05h 07m UT, the local magnitude obtained from the Scott Base WWSS seismograms was 2.0. Some eruptions were reported as felt at McMurdo Base, 37 km from the crater. If the eruption earthquakes were felt, the magnitude would be at least 3, but probably the air wave was felt.

The largest magnitude from Rayleigh waves recorded on the tidal gravity meter at South Pole Station, 1390 km from Erebus was 2.4 for the eruption at 13d 15h 47m. Assumptions as to the instrumental response are involved here.

For infrasonic signals, the largest eruptions grossly overloaded the University of Alaska short period recorders at Windless Bight, 26.6 km from the crater, but the air wave energy of medium eruptions which were just clipped was $2\times10E7$ J. The eruption at 17d 10h 11m was clipped for 80 s, and had air wave energy of at least $1.6\times10E9$.

The histogram of time intervals between the 110 eruptions during the first 7 days of initial high activity had a peak at 35–40 min. The distribution is asymmetrical, with mean at $87\pm72$ min. Repose period analysis favours a poisson random distribution, with a loading time of 20 min.

Spectrograms of telemetered signals typical of normal activity in previous years are presented, showing that the durations of the earthquake seismograms are clearly correlated with those of the infrasonograms from accompanying eruptions. Such agreement in duration would not be expected if the eruptions were triggered at a distance from the earthquakes by a seismic signal.

## 1. Introduction

Erebus is a 3794m high anorthoclase-phonolite volcano on Ross Island, Antarctica, with an active lava lake and explosive vent which have erupted an average of 3.6 times a day during observations between 1974 and 1982 (Dibble *et al.*, 1984). These eruptions have been recorded by seismometers and infrasonic microphones via radio telemetry on a Sony FM tape recorder since December 1980, and the last part of this paper compares sonograms of the seismic and infrasonic waves, so as to compare the sources of these waves.

On 13 September 1984, the activity level suddenly increased to 8–19 much larger explosive eruptions per day. Unlike most of the previous eruptions, these were clearly recorded on the WWSS station at Scott Base, 37 km away; heard at Scott and

McMurdo bases; recorded on the University of Alaska's infrasonic array at Windless Bight, 26.6 km away; and recorded on the UCLA tidal gravity meters at South Pole (Scott-Amundsen) Station, 1390km away from Erebus crater. Thanks to the dedication of the technicians operating the equipment, and the generosity of the Principal Investigators in each case, summaries of the recorded data were telexed to vitally interested parties, including the National Institute of Polar Research, enabling the following analysis of the energy and magnitude of the eruptions to be carried out while they were still in progress.

## 2. Eruption Earthquake Magnitude

The best estimates of local magnitude are obtained from the short period horizontal components of the WWSS seismograms at Scott Base (37 km from the crater), which have magnification $B_s=50000$ at the wave period of 1 s reported for the earthquakes.

RICHTER (1958) defines local magnitude as:

$$M_L = \log A - \log A_0 ,$$

where $A$ is the trace amplitude (mm) recorded on a standard Wood-Anderson seismograph (magnification $B_{wa}=1350$ at 1 s), and $A_0$ is the peak trace amplitude (mm) of a zero magnitude earthquake recorded in the same conditions. Then

$$M_L = \log A_s - \log B_s + \log B_{wa} - \log A_0,$$

where $A_s$ is the peak amplitude (mm) recorded on a non-standard seismograph of magnification $B_s$. This equation is accurate provided $B$ is taken at the period of peak amplitude which would have been recorded on the standard seismograph, assumed here to have been the same (1 s) as on the Scott Base seismograph. For 37 km distance, RICHTER (1958) gives $A_0 = -2.35$ and the resulting magnitudes are given in Table 1.

Magnitudes from gravity meter recordings of Rayleigh waves at South Pole Station, 12.5° from Erebus, are less accurate because RICHTER's (1958) table of $-\log A_0$ for surface waves does not extend below 20° (and has been extrapolated to obtain 3.7 at 12.5°), and also it uses horizontal ground amplitudes. Assuming that horizontal and vertical amplitudes were equal, and that the two La Coste and Romberg earth tide meters were correctly measuring accelerations at wave periods close to their natural

*Table 1. Magnitudes from Scott Base seismograph.*

| Event time 1984, Sept. | Trace amplitude SP, WWSS | | M | Remarks |
|---|---|---|---|---|
| | NS | EW | | |
| 13d 05h 07m | 19 | 18 | 2.0 | First and largest? event |
| 16d 04h 59m | 16 | 18 | 2.0 | "Boom" at ski field |
| 17d 10h 10m | 14 | 19 | 2.0 | Bright glow at crater |
| 17d 10h 17m | 12 | 15 | 1.9 | Glowing bombs 600 m high |

*Table 2. Magnitudes from South Pole gravity meter.*

| Event time 1984, Sept. | Gravity ptp $\mu$gal | T s | Ground Amp $\mu$m | Ms | Remarks |
|---|---|---|---|---|---|
| 13d 09h 57m | 1.0 | 19.6 | .049 | 2.4 | |
| 15h 47m | 1.2 | 20.8 | .066 | 2.5 | |
| 14d 11h 51m | 0.7 | 19.6 | .034 | 2.2 | |
| 15d 02h 34m | 0.7 | 17.2 | .026 | 2.1 | |
| 06h 45m | 0.7 | 17.6 | .027 | 2.1 | |
| 12h 04m | 0.8 | 18.4 | .034 | 2.2 | |
| 18h 15m | 1.3 | 17.4 | .050 | 2.4 | |
| 16d 04h 59m | 1.2 | 18.4 | .051 | 2.4 | "Boom" at ski field |
| 17d 16h 54m | 1.3 | 17.2 | .049 | 2.4 | |
| 20h 23m | 0.7 | 17.2 | .026 | 2.1 | |

periods, results are given in Table 2. Only one event appears in both lists. The magnitudes differ by 0.4 units.

## 3. Eruption Infrasonic Energy

The University of Alaska operates an array of 4 sensors in a square pattern of 700 m spacing at Windless Bight, centred 26.6 km south of Erebus crater (WILSON and NICHPARENKO, 1967). The eruption recordings consists of 1 or 2 cycles of period 3 to 21 s, with an average of 4.6 s. Peak to peak pressure amplitudes are commonly 1.5 Pa (15 $\mu$bar), but 58 events exceeded the dynamic range of the system (unstated, but probably about 1 Pa peak). Typical durations of these 58 events are 5 to 40 s, but the longest event (September 17d 16h 54m) had duration about 80 s.

For an average eruption we adopt:

$P=1$ Pa peak amplitude,
$T=4.6$ s cycle duration,
$t=4.6$ s signal duration,
$L=1470$ m wave length.

For the maximum eruption we estimate conservatively:

$P=2$ Pa,
$T=21.3$ s,
$t=80$ s,
$L=6800$ m.

The wave energy can be calculated from the hydrodynamic theory of sound following SHIMOZURU *et al.* (1975) as follows:

$E=\pi D^2 P^2 t/\rho c$. SI units

Where $D$ is distance (26600 m to Windless Bight),
$\rho$ is air density (1.394 kg/m$^3$ at $-20$°C and 101.3 kPa),
$c$ is sound velocity (319 m/s at $-20$°C),

and for the "average" eruption,

$P$ is pressure amplitude $=1$ Pa,
$t$ is duration $=4.6$ s,
$T$ is wave period $=4.6$ s.

Then $E$ is air wave energy $=23\times 10E6$ J.
For the maximum eruption,
$P=2$ Pa (guesstimate),
$t=80$ s,
$T=21.3$ s.
Then $E=1.6\times 10E9$ J with large uncertainty.

## 4. Repose Period Analysis

Following the method of WICKMAN (1966a, b), a graph of survival number $\tilde{n}$ *versus* repose period $\tau$ (Fig. 1) was prepared for the first 9 days of the eruption. Explosions were occurring at a fairly constant rate of $15.7\pm 5.7$ events per day. In Fig. 1, the intervals $\tau$ between successive explosions are plotted in decreasing order against the common log of their cumulative number $\tilde{n}$. Events having a poisson distribution in time give a straight line plot, while a gaussian distribution plots as a curve of ever increasing steepness. For poisson distributions, the average repose period can be found from:

$$\bar{\tau}=-1/2.303\,S \text{ time units},$$

where $S$ is the slope of the graph, *i.e.*: log $\tilde{n}$ per unit time. For the first 6 days $\bar{\tau}$

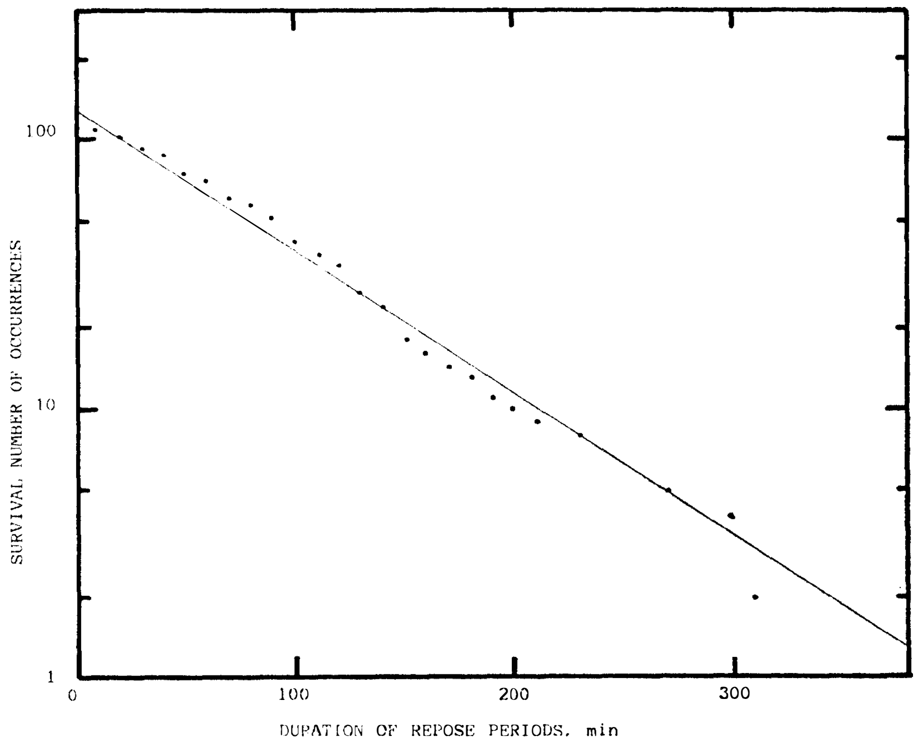


*Fig. 1. Graph of Log survival number versus duration of repose periods between eruptions, during days 13 to 19 September 1984. The eye-fitted line is that for a random poisson process, with an average repose period of 83 min.*

was 83 min. The probability of one or more events occurring in any given period of time $T$ can be found from:

$$p = 100(1 - e^{-T/\bar{\tau}})\% ,$$

and is independent of the past history of events. However as Wickman (1966a) pointed out, an exhaustion or reloading period will cause a decreased slope for shorter repose periods. In Fig. 1 this occurs below 20 min, and results in a peak in the histogram of repose periods at 30–40 min.

## 5. Comparison of Seismic and Infrasonic Spectrograms of Certain Eruptions

As a means of testing the hypothesis of Shibuya *et al.* (1983) that the alpha type "explosion" earthquakes and the explosions themselves are separate in time and space, and that the earthquake triggers the explosion via a seismic signal, the sonograph

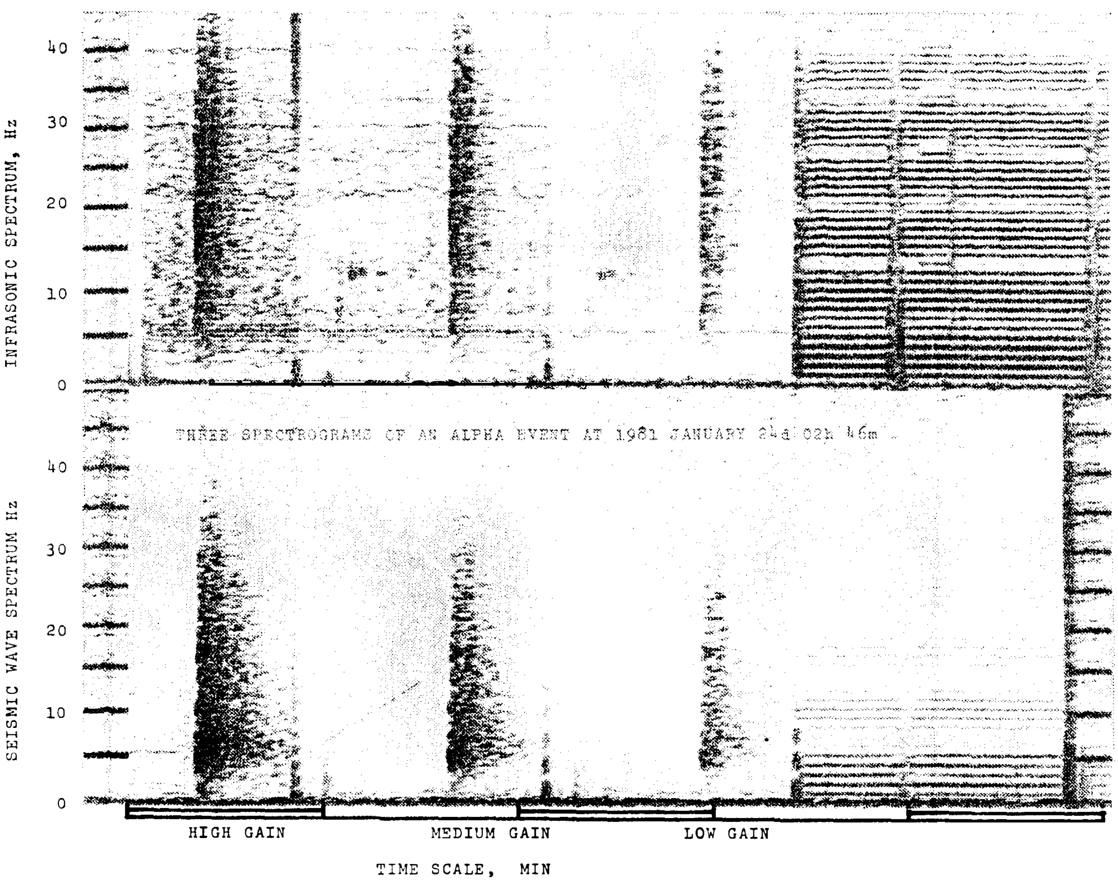


*Fig. 2. Sonograph spectrograms of a short duration alpha type eruption of Erebus at 1981 January 24 d 02 h 46 m, showing the infrasonic spectrum versus time (upper) compared with the seismic spectrum (lower). Both sensors were on the SW rim of the main crater and were recorded without distortion. Three different sonograph gains were used, decreasing left to right in 10 dB steps, to show more clearly the agreement between the durations and structure of the 2 signals.*

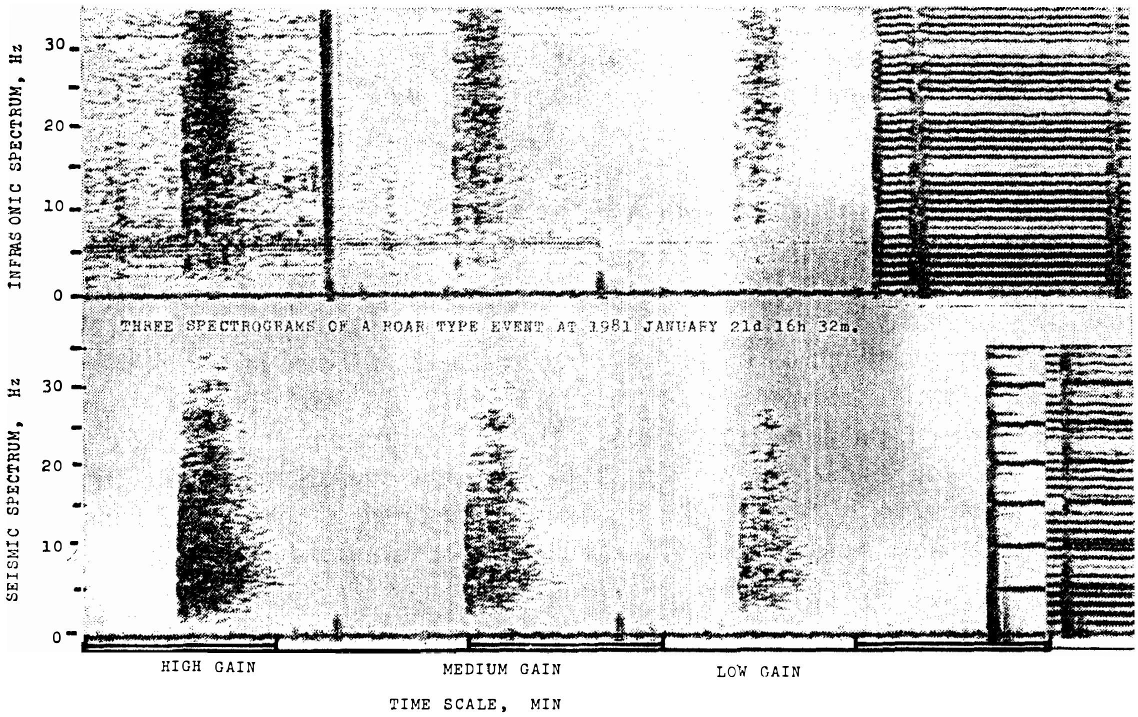


*Fig. 3. Sonograph spectrograms of a long duration alpha type eruption at Erebus at 1981 January 21 d 16 h 32 m, made under the same conditions as Fig. 2. The longer durations are again the same for both infrasonic and seismic signals.*

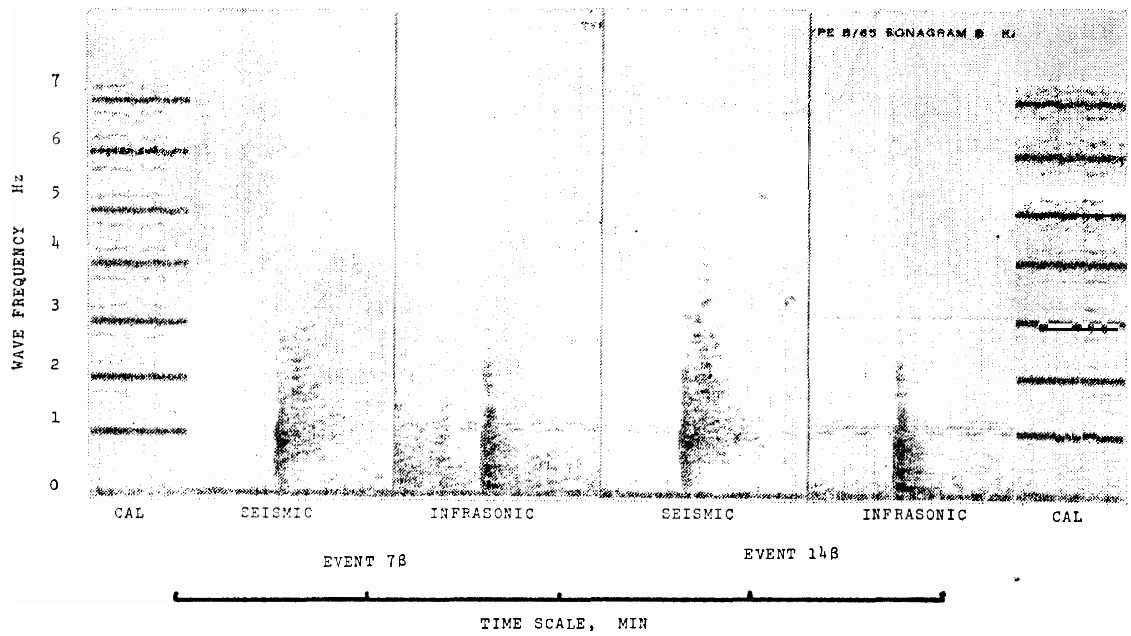


*Fig. 4. Sonograph spectrograms of 2 beta type events (eruptions), numbers 7β (left pair) and 14β (right pair) in the 1982 NIPR edited tape file. The infrasonic sensor was now on the main crater floor and often suffered overload distortion. Also the seismic spectrogram is on the left in each pair, and a single gain setting is displayed. The signals are of much lower frequency than for alpha type eruptions, and the durations and structure of the infrasonic and seismic signals are different.*

spectrograms of short (Fig. 2) and long (Fig. 3) duration eruptions were compared. In each figure, the spectrogram is repeated 3 times at different gains, to compensate for the limited dynamic range of the sonogram display. For both short and long events the seismic and infrasonic spectrograms have very similar time variations. This would not be expected if the "explosion" earthquake merely triggered the start of the explosion. A more continuous connection is required. The simplest example is when they occupy the same time and space.

For beta type events, for which eruption observations are very sparse, there is much less similarity between the seismic and infrasonic spectrograms in both the time and frequency coordinates. In the 2 well recorded events shown in Fig. 4, the seismic signal begins with a narrow spectral peak at 0.9 Hz, followed about 6 s later by a broadband signal extending to at least 5 Hz. The infrasonic signals have narrow peaks at 0.2 and 0.4 Hz, and no later high frequency arrivals. Also, the infrasonic wave sometimes clearly precedes the seismic wave recorded at the same distance from the vents. Further work is needed to investigate the variations in beta type events.

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## References

DIBBLE, R. R., KIENLE, J., KYLE, P. R. and SHIBUYA, K. (1984): Geophysical studies of Erebus volcano, Antarctica, from 1974 December to 1982 January. N. Z. J. Geol. Geophys., **27**, 425–455.

RICHTER, C. F. (1958): Elementary Seismology. San Francisco, Freeman, 768 p.

SHIBUYA, K., BABA, M., KIENLE, J., DIBBLE, R. R. and KYLE, P. R. (1983): A study of the seismic and volcanic activity of Mount Erebus, Antarctica, 1981–1982. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 54–66.

SHIMOZURU, D., UTIBORI, S., GYODA, N., KOYAMA, E., MIYAZAKI, T., MATSUMOTO, T., OSADA, N. and TERAO, H. (1975): The explosive activity of Asama volcano; General description of volcanic and seismic events. Tokyo Daigaku Jishin Kenkyujo Ihô (Bull. Earthquake Res. Inst.), **50** (1), 115–151.

WICKMAN, F. E. (1966a): Repose period patterns of volcanoes. 1. Volcanic eruptions regarded as random phenomena. Ark. Mineral. Geol., **4** (7), 291–301.

WICKMAN, F. E. (1966b): Repose period patterns of volcanoes. V. General discussion and a tentative stochastic model. Ark. Mineral. Geol., **4** (11), 351–367.

WILSON, C. and NICHPARENKO, S. (1967): Infrasonic pressure waves in the auroral zone. Geophys. Inst. Publ., Univ. of Alaska, College, Alaska,

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