Near Surface Seismicity of Vulcano, Aeolian Islands, Sicily *

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During April 1966 a network of short period seismometers was installed in the Aeolian Islands and on adjacent parts of the Sicilian and Calabrian coasts (see Figure 1) in a joint cooperative programme between Edinburgh University and the Institut International de Recherches Volcanologiques (I.I.R.V.). The instruments recorded onto magnetic tape by radio from a number of outstations to two central recorders on the island of Lipari. Three stations were installed on Vulcano, in the positions shown on Figure 1.

A large number of unusually perfect sinusoidal tremors were recorded at the station marked VL6, in the small parasite crater Forgia Vecchia (1). This station was some 200-300 metres north of the main group of active fumaroles on the northern rim of Gran Cratere, which has been dormant since a violent eruption at the end of the last century.

Figure 2 shows a typical example of one of the larger tremors. The first motion (marked A) is almost always compressional (downwards on the record is an upward ground movement at the seismometer). It is a small movement and is followed at an interval which ranges from 0.19-0.35 sec by a much stronger downward movement of the ground (marked B), which is the beginning of the sinusoidal wave train. This sinusoidal wave train shows practically no dispersion, (the dispersion pattern for two tremors is shown in Figure 3), suggesting that it is not composed of surface waves.

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(1) See Figure 4.

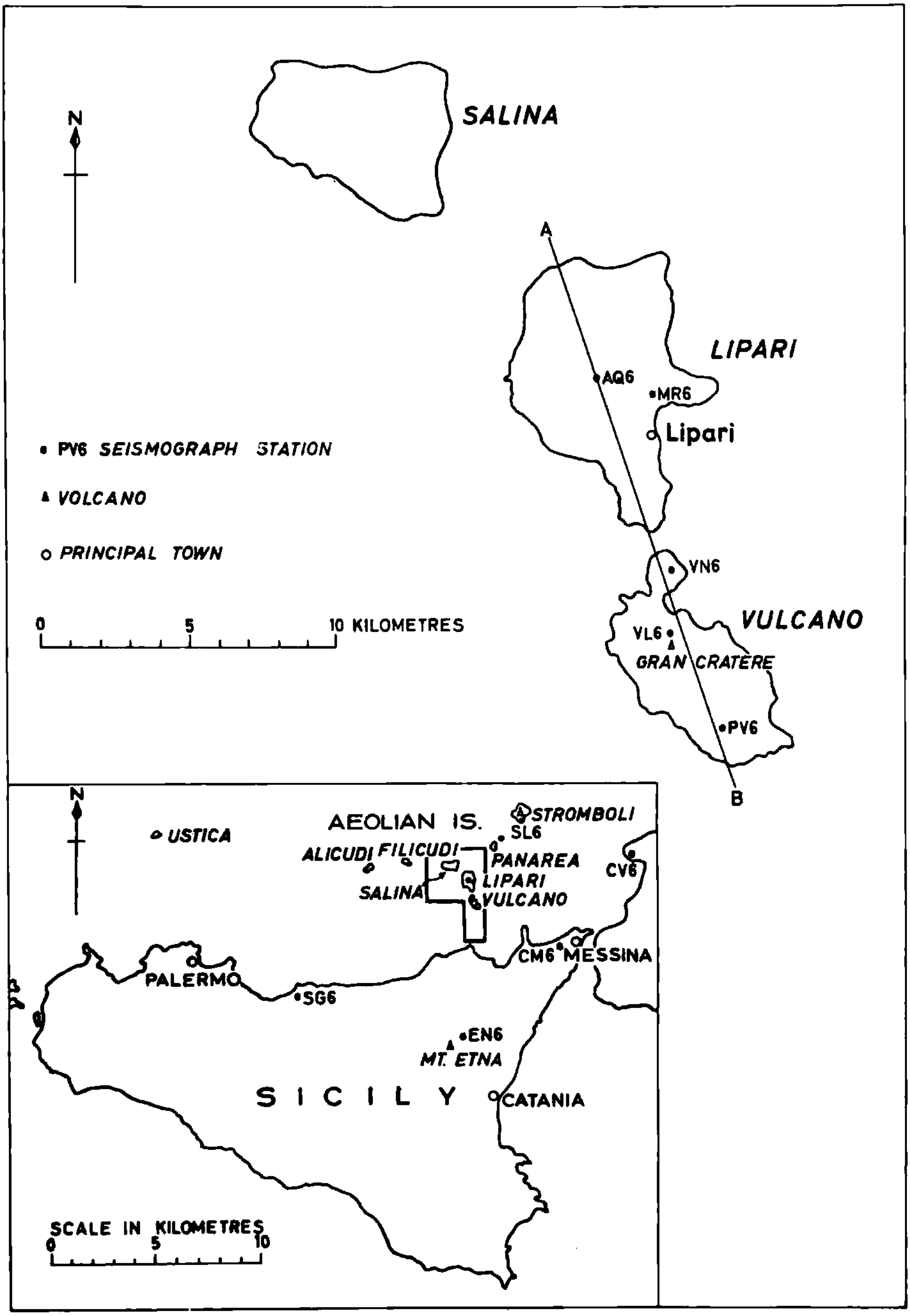

FIG. 1 - Locality map, Lipari-Vulcano, Aeolian Islands, Sicily, showing positions of seismometers of the Edinburgh University - I.I.R.V. Network.

The larger tremors were recorded at the station marked PV6, at a distance of just over 4 km from VL6 on the opposite side of the volcano, with a time interval consistently about 3.85 sec later

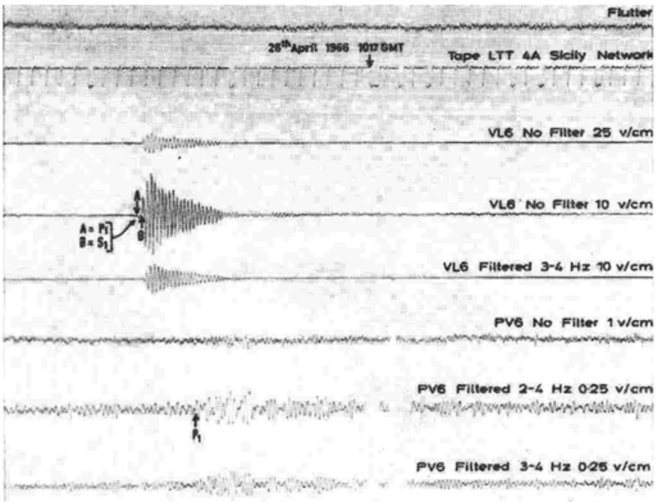

FIG. 2 - Sinusoidal volcanic tremor, Vulcano, recorded at two stations.

than the much stronger VL6 arrival. The maximum apparent velocity (assuming the tremors to have originated at VL6 or to the north of it) which would be compatible with this observation is 1.05 km/sec. Very few, however, were recorded at VN6, less than 1.9 km north of VL6, due presumably to the very high absorption of energy by the unconsolidated tuff and pumice in the area. In a number of cases the most prominent, and sometimes the only arrival at VN6, as a phase with maximum apparent velocity (assuming a source at VL6 or to the south of it) of about 0.3 km/sec. (²).

By interpreting the latter as sound in air from a source slightly to the south of VL6 and by assuming velocities in agreement with those found from arrivals of near earthquakes recorded at the Lipari station (AQ6) as well as at the three Vulcano stations (see Figure 1 and Table 1), the probable source of the disturbances was located in a fumarole field on the northern rim of the crater and on the

(²) See Figure 6.

outer northern slopes of the volcano (see Figure 4). Because of the low wave velocities inferred for superficial rocks in the area, and the presence of the air-wave at VN6, the uncertainties attached to the

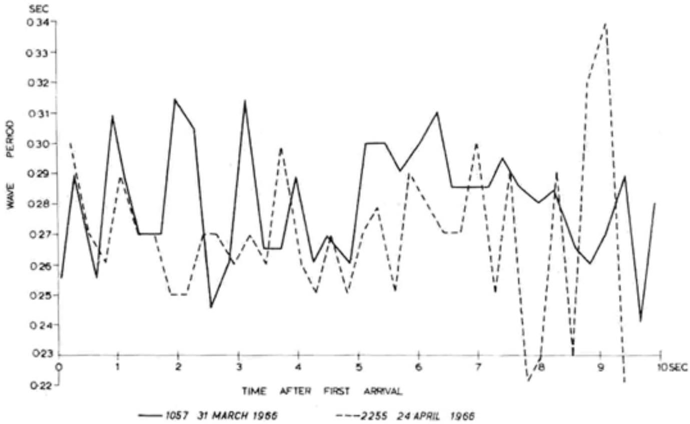

FIG. 3 - Dispersion in two sinusoidal volcanic tremors at Vulcano.

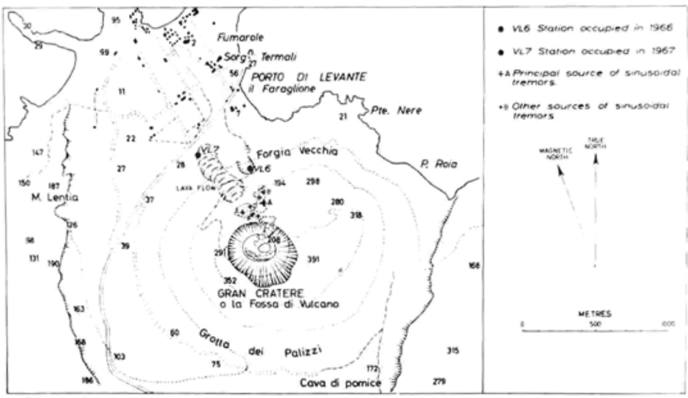

FIG. 4 - Locality map, Vulcano Gran Cratere, showing sources of sinusoidal volcanic tremors and positions of seismometers: area of fumaroles shown shaded: spot heights in metres.

locations, assuming surface foci are of comparatively small dimensions. This and the fact that the positions of all sinusoidal tremors that could be located coincided closely with visible fumaroles seems to indicate that the solution may confidently be accepted. Figure 5 gives an approximate idea of the structure along the line AB (see Figure1), as derived from a study of wave velocities in local tremors in the area.

No changes in visible activity have been detected at the fumaroles which can be correlated with times of occurrence of sinusoidal tremors. A continuously recording temperature gauge was operated for a short period and indicated variations in temperature between 90° and 111°C, but no meaningful correlations could be detected in the short time before destruction of the probe took place. It would be useful to attempt an experiment of long duration in which both the

TABLE 1 - Velocities inferred from observation of near earthquakes.

Phase	*P velocity*	*Lipari - Vulcano area S velocity*	*Tentative identification of rock-type*
P_1	0.98-1.02 km/sec	(S_1 = 0.58-0.59 km/sec)	uncompacted Pumice and dry Tuff
P_2	1.41 km/sec	(S_2 = 0.79 km/sec)	semi-compacted Tuff bands
P_3	2.84 km/sec (mean velocity)	(S_3 = 1.70 km/sec)	Trachyte, Trachyandesite and Andesite
P_4	3.05 km/sec (mean velocity)	(S_4 = 1.80 km/sec)	Liparite
P_5	3.50 km/sec (mean velocity)	(S_5 = 2.13 km/sec)	Basalt
P_g	about 5.5 km/sec	(S_g = about 3.3 km/sec)	Gneissic Basement

Note

Lower P_3 and P_4 velocities than those given above are observed in some cases; this is thought to be due to variable amounts of tuff and pumice interbedded with the lava flows.

temperature and the composition of the gas could be measured. It is highly probable that some correlations would emerge.

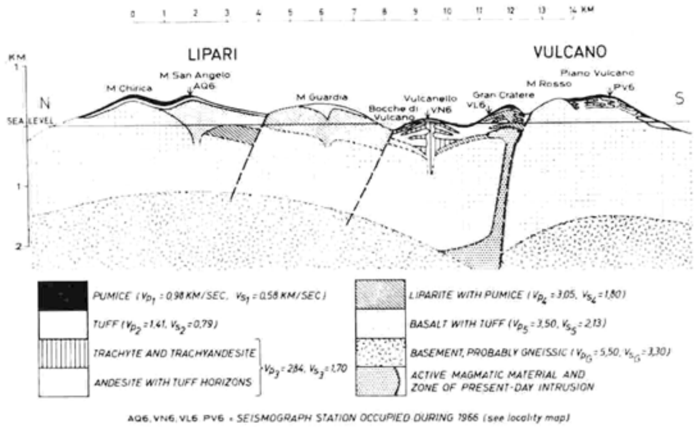

FIG. 5 - Idealised geological section, Lipari-Vulcano.

Characteristic velocities observed in the sinusoidal and semi-sinusoidal tremors, given the solution adopted, are the following:

TABLE 2

To station VL6	Compressional P, 1.02 km/sec, (P_1)
	downward S, 0.58 km/sec, (S_1)
	(at VL6 S_1 marks the onset of the sinusoidal part of the wave train)
To station VN6	(directions of first motion variable)
	P 2.46 km/sec, (P_3)
	P 1.02 km/sec, (P_1)
	and air-wave 0.33 km/sec in some cases
To station PV6	(directions of first motion variable)
	P about 5.5 km/sec, (P_g)
	P about 3.5 km/sec, (P_5)
	P about 2.5 km/sec, (P_3)
	P about 1.0 km/sec, (P_1)

The tremors showed a clear gradation from the most perfectly sinusoidal (as shown in Figure 2) to examples with strong similarities to small tectonic shocks (see Figure 6), but which nevertheless had a strong frequency content identical to that of the more perfect examples. These in turn graded into typical volcanic shocks of ragged appearance. It was generally the less perfectly sinusoidal that gave

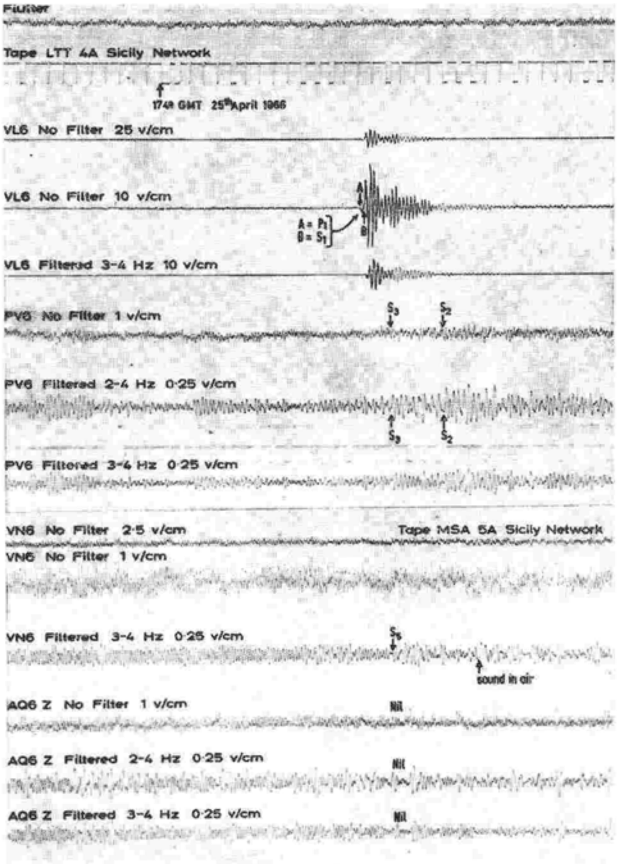

FIG. 6 - Sinusoidal volcanic tremor, Vulcano, recorded at three stations, gradational to normal volcanic shock.

rise to the air-wave which was occasionally recorded at VN6. This is interpreted as evidence of gradation in depth from near-surface foci perhaps 50-100 metres below the mouth of fumaroles to deeper sources in the subterranean conduits of the volcano, the most perfectly sinusoidal originating near the surface but too deep to give rise to an air-wave: it is tentatively suggested that some of the more ragged volcanic shocks originated from depths of 300-400 metres below the floor of the Gran Cratere (*i.e.*, at 400-500 metres below the surface; 100-200 metres below sea level).

A separate category includes small swarm shocks which show multiple phase arrivals: these have a fairly wide frequency range but have maxima near 4.4 Hz (see Figure 7). They are interpreted, because of their multiple phases, a feature characteristic of resonance

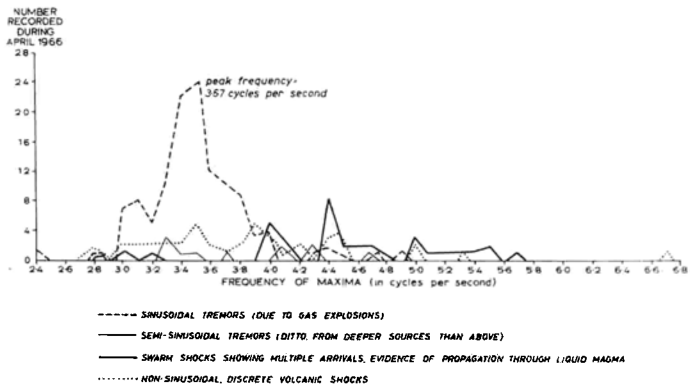

FIG. 7 - Frequency distribution in volcanic shocks from Vulcano.

in liquid, as small shocks that have occurred in or near a high level magma chamber. The failure to propagate to stations other than VL6 restricts their probable depth of origin to a few hundred metres, but existing data are insufficient to locate them more accurately. Irregular low amplitude disturbances of long duration also occur. They are very like some examples from Ruapehu volcano shown to me by Mr G. R. T. CLACY, and are tentatively attributed to magma movements at depths of less than 1 km.

All types of disturbance can be readily identified in the process of playing out the tapes, during which the speed of recording (0.133 in/sec) is increased by a factor of 56, thus bringing seismic frequencies into the audio range (see PARKS, 1966). Both the perfectly sinusoidal and the gradational type produce a uniquely distinctive sound on playback, which enables them to be detected even when the wave-train is completely obscured by high noise levels. Other sinusoidal disturbances of a different kind, long duration « envelopes » containing a much wider range of frequencies, have been identified as due to movement of ships and hydrofoils in the area ([3]).

The unusual sinusoidal appearance of the tremors suggests a process of resonance in the interior of the volcano. Assuming a gas-filled cavity in which waves move with approximately the speed of sound in air, and given an average frequency for the sinusoidal wave-tran of 3.5 Hz, see Figure 7, the size of a cylindrical gas-filled cavity would be 190-200 metres in longest axis. There are many different possible shapes for the cavity; if it were in the shape of a bottle with a narrow neck, its dimensions would be much smaller. On the other hand, because of the nature of the gas filling the cavity and the elevated temperature, the dimensions might be correspondingly greater.

A more complete analysis is required, using records subsequently made at other sites on Vulcano. On the basis of the evidence at present available, it seems that the tremors are due to gas explosions in cavities above the magma chamber beneath Vulcano. Their magnitudes range from a maximum of about M_L -0.7 to a minimum several orders of magnitude lower. The individual energy release of a single tremor reaches a maximum of only about 5×10^6 ergs. With an average of perhaps 25 tremors per day, daily energy release is only about 10^8 ergs ([4]). Ground amplitudes at VL6 range from 140 millimicrons down to a mere 5 millimicrons (below which they are unobservable). There was no marked variation in the rate of occurrence of the tremors during the sample period of a month which was studied.

The process of energy release is clearly a gentle one, and it is suggested that the tremors are due to gaseous stoping in the roof of the magma chamber beneath Vulcano Gran Cratere or in fissures above the chamber. This is occurring especially beneath the northern slope of the volcano, the most active fumarolic area on the cone.

An alternative suggestion, which was put to the Author by Mr G. R. T. CLACY, who has observed similar though less perfectly sinusoidal tremors at Ruapehu volcano in New Zealand, is that the

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([3]) See LATTER (1965) for description of similar interference effects recorded at Rabaul, New Guinea.

([4]) These figures are considerably lower than earlier estimates, now believed to be incorrect, which were given in a preliminary paper (LATTER, 1967). Corresponding daily energy release in volcanic shocks at Stromboli and Etna amounts to about 10^{12} and 10^{14} ergs respectively.

effect may be due to oscillation of water at temperatures above 600°C (the « Leidenfrost » effect, see HOLTER and GLASSCOCK, 1952). This represents a possible mechanism since the gas-phase present at the top of the magma chamber is likely to be predominantly composed of water-vapour.

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References

HOLTER, N. J. and GLASSCOCK, W. R., 1952, *Vibrations of Evaporating Liquid Drops.* Journal of the Acoustical Society of America, Vol. 24, No. 6, p. 682-686.

LATTER, J. H., 1965, *Sinusoidal disturbances due to shipping, on Seismograms at Rabaul, New Britain.* Nature, Vol. 207, No. 4999, p. 845-847.

————, 1967, *The relationship between seismicity and volcanism in the Sicilian volcanoes.* Proceedings of the Geological Society of London, No. 1637, p. 58-59.

PARKS, R., 1966, *Seismic data acquisition and processing equipment for Edinburgh Royal Observatory.* Journal of the Institution of Electronic and Radio Engineers, Vol. 31, No. 3, p. 171-180.

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