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Giuseppe Imbò and his contribution to volcano seismology

Rolf Schick
Institut für Geophysik, Universität Stuttgart, Germany

Abstract
Together with Fusakichi Omori and Kenzo Sassa, Giuseppe Imbò is one of the founders of volcano seismology. Imbò's novel idea in volcanic tremor analysis was the introduction of what he called «*numeri indici dell'intensità eruttiva*» (numerical indices of the eruptive intensity). It was one of the first attempts to quantify eruptive activity on the basis of seismic data. The indices permitted him to establish correlations at Mt. Vesuvius between seismic observations and eruptive phenomena. He found significant differences in the character of the recorded seismic signals between pre- and post-eruptive phases of effusive and explosive activity of the March 1944 eruption of Vesuvius. According to Imbò, volcanic tremors are the product of a rhythmic hammering caused by the degassing magma normal to the vertically-oriented walls of the feeding conduits.

Key words *Mt. Vesuvius – Imbò – volcanic tremor*

1. Introduction

Volcano seismology did not achieve a prominent rank in the first half of the 20th century. This is surprising, as the beginning of modern instrumental seismology is closely associated with Luigi Palmieri who in the year 1855 established a seismograph station at Mt. Vesuvius. But at the end of the 19th century, the newly opened fields of tectonic earthquake investigation attracted the attention of most seismologists. Seismic events with unclear first motions, phases which could not be assigned to the Earth's structure and long-lasting, irregularily appearing wavetrains on the seismograms recorded at active volcanoes were mostly regarded as «volcanic noise», not appearing to be attractive for closer study.

Mailing address: Dr. Rolf Schick, Institut für Geophysik, Universität Stuttgart, Richard-Wagner-Straße 44, D-70184 Stuttgart, Germany; e-mail: rs@geophys.uni-stuttgart.de

Thus few scientists devoted a great deal of their work to volcano seismology in the hundred years following Palmieri's first seismograph installation. Three names have to be mentioned: Fusakichi Omori, who described «pulsatory oscillations» and earthquakes associated with the eruptive activity of Asama-yama volcano (Japan) in the years 1911-1912 (Omori, 1911); Kenzo Sassa, who made a fundamental «microseismometric study on eruptions of the volcano Aso (Japan)», (Sassa, 1936) and Giuseppe Imbò, who intensively studied seismic signals induced by the activity of Mt. Vesuvius, giving an emphasis to the 1944 eruptions.

2. The physicist

Imbò was born on the Island of Procida, located in the Gulf of Naples, in 1899. After receiving a degree in physics in 1922 he went to the Royal Geophysical Observatory in Catania (Sicily) where after a few years he became director of this institution. But being a real Neapolitan, his heart was apparently more set on Vesuvius than on Etna as even in his time in

Catania he published more papers dealing with Vesuvius than with Etna. After a short interlude at the Casamicciola Observatory in Ischia, he became in 1936 Professor of Earth Physics at the University of Naples and, in a personal joint position, Director of the Vesuvius Observatory. He retired in 1970 and died ten years later in Naples.

Although many of Imbò's investigations were devoted to seismic signals induced by volcanic activity, he regarded himself as a physicist working on a volcano. The spectrum of his investigations of phenomena associated with Vesuvian activities was widespread, including gravity, electricity and magnetism. But his main contribution to volcano physics was his pioneering work (Imbò, 1954) on the great March 1944 eruption of Vesuvius. This work will be reviewed in this article.

3. Imbò's technique of volcanic tremor study

The construction of the seismographs which recorded the 1944 eruption goes back to the first years of the century and in 1944 the instruments

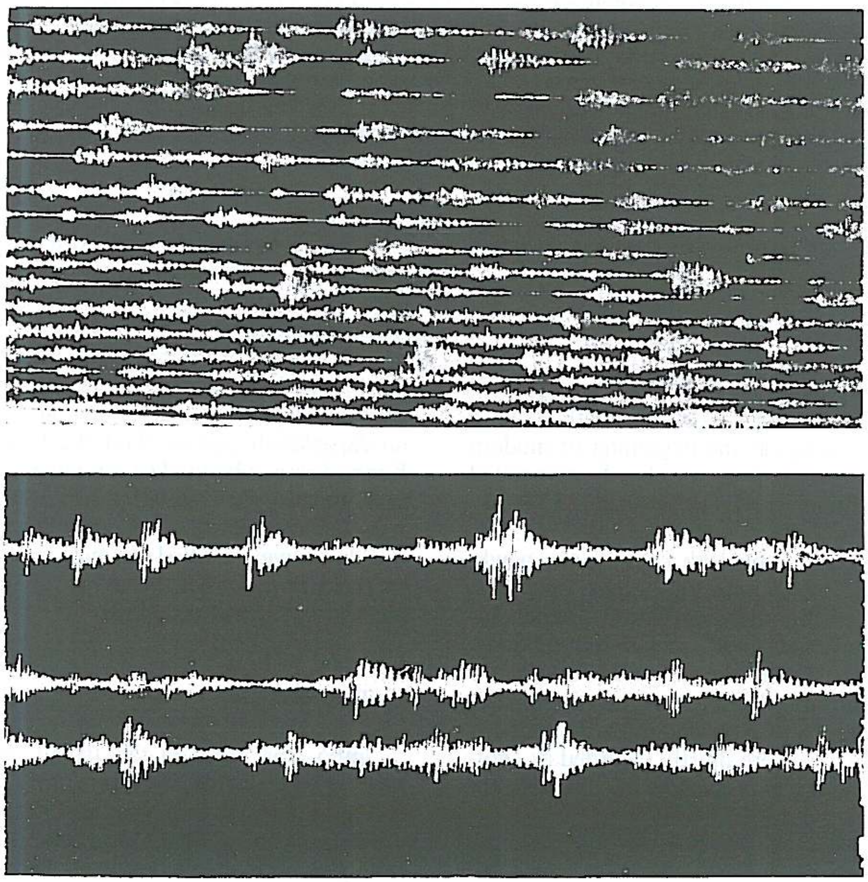

Fig. 1a. Examples of spasmodic tremor, recorded with the OAM seismograph at the Vesuvian observatory in January 1944 (upper seismogram) and March 1944 (lower seismogram). (Imbò, 1954, *tav.* 7).

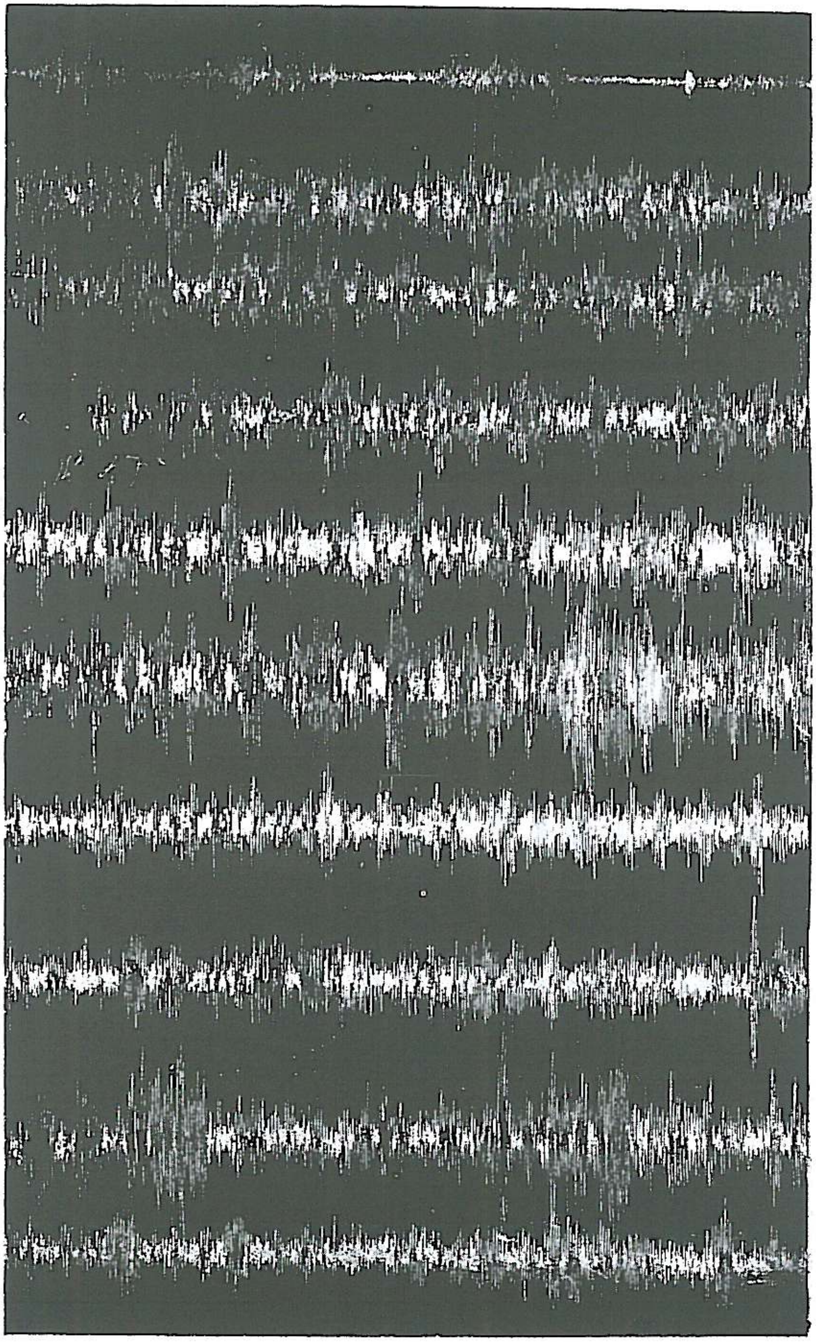

Fig. 1b. Example of harmonic tremor, recorded with the OAM seismograph at the Vesuvian observatory in March 1944. (Imbò, 1954, *tav.* XX).

were already more or less out-of-date. There were two mechanical three-component seismographs in use at the Vesuvius observatory: one of the type Omori-Alfano, later modified by Malladra and called Omori-Alfano-Malladra (OAM). The other seismograph was a construction after Vicentini. The stronger signals from Vesuvius could additionally be recorded with Wiechert seismographs at the Institute of Earth Physics in Naples. Examples of records obtained with the OAM instrument are illustrated in figs. 1a-b.

It is clear that these seismograms could not be analyzed with the then known tools of tectonic earthquake seismology. The novel idea of Imbò and the key to his success was the introduction of, what he named, «*numeri indici dell'intensità eruttiva*» (numerical indices of eruptive intensity).

He determined the indices as follows

$$\sum_{\text{Time}} A_m \text{ * (time of occurrence)}$$

A_m being a mean tremor amplitude. Normally the summation was performed over one hour.

With these indices, Imbò obtained a useful reduction of the seismic data with which he could work. It permitted a quantification of the eruptive activity on the basis of seismograms, making a temporal correlation between seismic recordings and visible eruptive activities possible. Imbò's indices may be regarded as a forerunner to the nowadays used RSAM-numbers. The shortcomings of Imbò's mechanical seismographs with smoke-paper recording are obvious, resulting in a limited dynamic range and frequency resolution. Nevertheless, there exist-

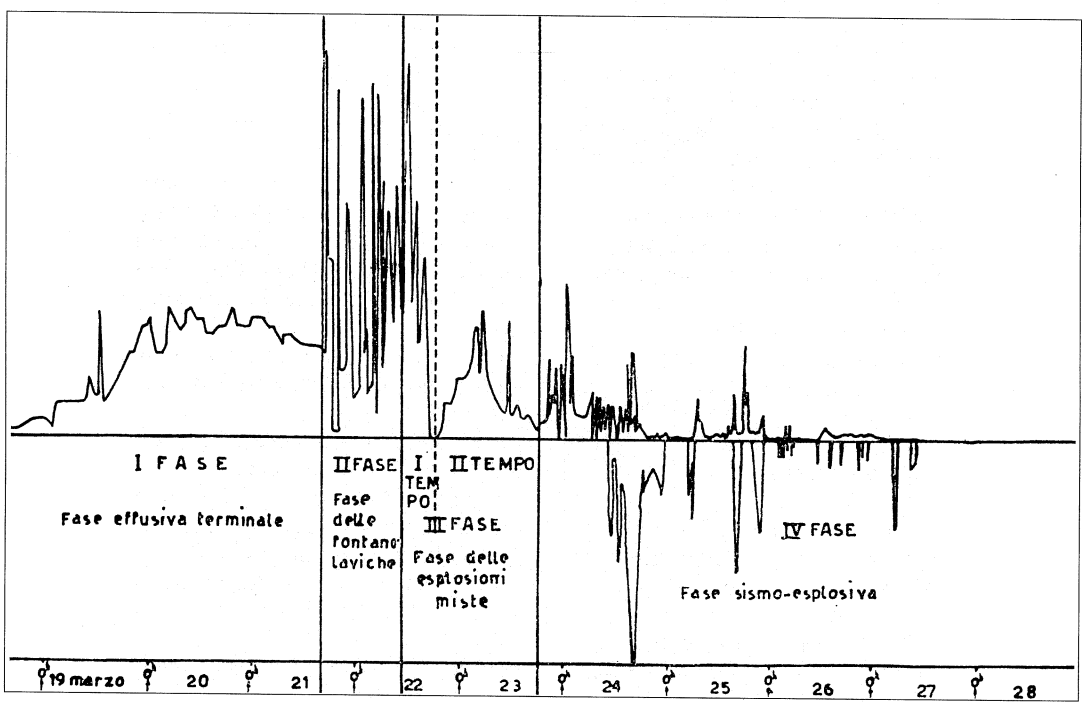

Fig. 2. Variation of the numerical indices from 18-28 March 1944, in connection to eruptive phenomena (Imbò, 1954, p. 197).

ed also something positive. He did not have to bother with complicated electronic systems, sensitive to all kind of failures and it permitted him to get long, undisturbed time series with no gaps. The installation of the seismographs with an immediately visible recording in range of sight of the eruptive apparatus of the volcano was of further great benefit. It made a quasi real-time correlation between the types of eruptive activity and the character of the seismograms possible.

4. The numerical indices in correlation to eruptive activities

A plot of Imbò's indices *versus* time and type of eruptive activity is shown in fig. 2. In this diagram Imbò distinguishes four types of activity: an effusive, terminal phase (I), a phase with lava fountaining (II), a phase with explosions (III) and a seismic-explosive phase (IV). In phase IV the seismic events were not associated with crater explosions.

Phase I shows a feature of special interest (fig. 3). A gradually increasing seismic intensity is overlapped by oscillations with periods close to 3 h. Quite similar observations were made in recent times using modern data acquisition and data analysis (Kirbani, 1983). The correlation which Imbò made in respect of the influence of earth tides on volcanic action must remain doubtful, however.

Figure 4 documents the detailed and careful connection which Imbò reports between seismic observations and volcanic phenomena.

5. Explanations and source models

Imbò's long-term observations allowed him to draw generally valid conclusions on possible relationships between seismology and volcanology as well as the source mechanisms associated with different kind of seismic recordings.

He supposed that spasmodic tremor, *i.e.* tremor with a strongly varying signal envelope, indicated a preparation or persistence of explosive phenomena. Harmonic tremor should be excited by free and buoyancy caused degassing of

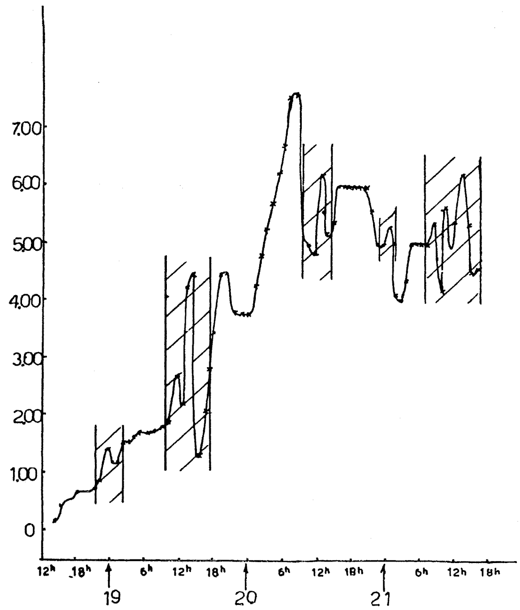

Fig. 3. Variation of the numerical indices in the starting phase of the March 1944 eruption (Imbò, 1954, p. 45).

the magma in the conduit. This tremor is found in the period range 0.59 s to 0.78 s (1.3-1.7 Hz). Imbò noted that these periods are independent of the stations where they were observed and therefore should be associated with the source process. Longer and beating periods of 16-25 s he attributes to rhythmic up and down movement of the magma level in the feeding conduit.

From the dominance of the amplitudes on the horizontal components, Imbò concludes that volcanic tremor is essentially caused by rhythmic pulsations of the magma column, causing a hammering of the magma normal to the vertically oriented walls of the feeding conduits. He further postulates that the energy density shall be constant and that the tremor amplitude is related to the area of the wall where the tremor are excited. Following this model, he suggests that a higher tremor amplitude means a higher magma level in the magma feeding conduit(s) of the volcano.

	»	18	—	Ripresa agitazione armonica da quasi percettibile a debole. L'agitazione pseudospasmodica prosegue ad andamento inalterato.	Assenza di fenomeni esplosivi.
	»	»	14^{h}	Decisa graduale intensificazione dell'agitazione armonica.	Prosegue cessazione attività per ostruzione del condotto.
	»	»	$16^{h}.4$	Agitazione armonica, con intermittenti spasimi, ad ampiezza tendenzialmente crescente. L'andamento reale presenta scostamenti dal medio, rivelante esistenza di continue oscillazioni a piccola ampiezza ed a periodo semidiurno lunare, intermittentemente interrotte da oscillazioni a periodo di 3^{hc}. ($22^{h}.5$ - $1^{h}.5$).	Brusca riapertura del condotto con inizio contemporaneo di poderoso efflusso lavico e di vivace attività esplosiva.
	»	19	—	L'agitazione diventa prevalentemente armonico-impulsiva con ampiezza media ancora in aumento. L'andamento rivela più ampie oscillazioni a periodo semidiurno lunare ed un gruppo di due successive oscillazioni a periodo di 3^{hc}. ($10^{h}.5$-$17^{h}.5$).	Portata lavica in crescente aumento. Attività esplosiva intensa a carattere di fontane in corrispondenza dei due massimi relativi alle due oscillazioni a periodo di 3^{h}.
Fase effusiva	»	20	—	L'ampiezza media dell'agitazione armonico-impulsiva raggiunge un massimo nella mattinata. Successivamente si mantiene quasi costante. Notevolmente ampie le oscillazioni a periodo semidiurno lunare. Si hanno anche oscillazioni a periodo di 3^{hc}. ($12^{h}.5$ - $14^{h}.5$ = $23^{h}.5$ - $2^{h}.5$).	Quasi costanza nella portata degli efflussi e nell' intensità dell'attività esplosiva.
	»	21	—	L'ampiezza media della predetta agitazione, solo lievemente inferiore a quella del giorno precedente, si mantiene presso a poco costante con le solite oscillazioni a periodo semidiurno lunare.	L'attività esplosivo-effusiva non ha presentato alcun mutamento sensibile nel comportamento.
	»	»	6^{h}	Nell'andamento spicca brusco inizio di tre successive oscillazioni a periodo di 3^{h} ($7^{h}.5$ - $16^{h}.5$). In corrispondenza del prolungamento del minimo, con massima accentuazione tra $17^{h}.2$ e $17^{h}.3$ l'agitazione è armonica, interrotta da relativamente deboli spasimi.	Prosegue inalterata attività.
	»	»	$17^{h}.3$	Brusco rinforzo nell' agitazione che da armonica passa ad armonico-impulsiva e ad impulsiva a gruppi per poi tornare armonica con rinforzi e successivamente armonico-spasmodica. Il fenomeno si ripete, presentando caratteristiche delle oscillazioni a	Può ritenersi praticamente cessata alimentazione efflussi. Ripetizioni di violente crisi esplosive a carattere di fontane, separate da depressioni, nel corso delle quali l'attività è limitata ad

Fig. 4. Example of Imbò's meticulous correlations between seismic observations and eruptive phenomena during the March-April 1944 eruption (Imbò, 1954, *quadro* XXVIII). Columns from left to right: types of volcanic phases, days and hours, characteristics of seismic signals, volcanic phenomena.

6. Conclusions

The work of Imbò shows that modern data acquisition and signal processing is no substitute for long-term and continuous seismic measurements with parallel meticulously collected observations of the volcanic activity.

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