Shallow structure of Mt. Vesuvius volcano, Italy, from seismic array analysis

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Abstract. Data from a portable dense seismic array deployed on Mt. Vesuvius in May 1994, during a 2D seismic tomography experiment, are analyzed in the present paper. The array consisted of two groups of short period geophones, 4.5 hz natural frequency, formed by 16 and 25 vertical components (plus two horizontal components), distributed along an arc like shape along the summit crater. Stacks of later arrivals, interpreted as reflected phases, provide a significant constraint to a boundary layer located in the depth range 1.5 - 2.2 km beneath the summit crater with average velocity V = 1.8 - 2.2 km/s, interpreted as the top of the limestone basement. The correlation methods applied on microtremor records allowed to infer the shallow velocity structure, up to 400 m, beneath the crater rim.

Introduction

The deployment of dense seismic arrays on volcanoes is becoming a diffused technique for studying details of the seismic sources in relation to volcanic activity, other than a method for understanding the velocity structure beneath these regions (see f.i.: Ferrazzini and Aki, 1992; Ferrazzini et al., 1991; Furumoto et al., 1992; Goldstein and Chouet, 1994; Metaxian et al., 1994; Chouet, 1996).

During the 2D seismic tomography experiment performed in the period 4-6 May 1994 (Zollo et al., 1996), two dense arrays of short period seismographs belonging to the University of L'Aquila and Salerno were installed along the crater rim of Mt. Vesuvius. The first array, of the Salerno group, consisted by a set of 15 vertical seismographs, natural frequency 4.5 hz, connected by cables to a 12 bits *A/D* card controlled by a *PC-IASPEI* data acquisition system (Lee and Dodge, 1992). The second array, managed by the group from L'Aquila, was formed 25 vertical seismographs and 2 horizontal ones, with natural frequency 4.5 hz, located next to the previous array (Fig. 1). This array consisted of a light portable unit, with transducers linked by cables to a *PC-IASPEI* data acquisition system having a resolution of 16 bits. In both equipments the same time signal, the code *DCF-77*, provided by two radio receivers, was digitized and recorded on a separate channel. The spacing between the seismometers for both arrays was about 25 m and close to the center of the second array additional 8 seismometers, having an ellipsoidal shape, were installed. The total aperture for both arrays has been about 1 km.

Two main scientific objectives were envisaged: (a) to record the seismic waveforms from artificial explosions with dense sampling in space; (b) to image the velocity structure of Mt. Vesuvius in the upper layers under the central crater with a very high resolution.

These two objectives were interrelated. In fact records with dense space sampling were planned in order to achieve the best correlation length for waveform analysis and their discrimination. On the crater summit of Mt. Vesuvius it is expected a high degree of heterogeneity of seismic velocities due to the presence of a highly fractured material and topographycal irregularities.

Data Processing

The recordings obtained for the three shots reveal a low degree of spatial coherence and many features of the recorded waveforms seem to indicate the presence of complex particle motion and of diffraction effects, as theoretically expected for such frequencies and structure. The recorded waveforms of the shots S2 and S3, fired at close distance from the array, are illustrated in Fig. 2 and Fig. 3. These figures show the appearance and lack of later arrivals which are probably a resonance effect from upper layers modulated by the irregular topography around the crater. Data processing has prioritary given to records from shots S2 and S3, disregarding the data from the first array, for their amplitude saturation due to the relatively lower dynamic range. We considered consequently the array formed by 25 vertical receivers, having a linear extension of about 450 m.

The data have been analyzed through the software *Seismic Unix* (Cohen and Stockwell, 1994), requiring a data conversion from *IASPEI* format to *segY*. The seismic records have been corrected for the offset, by using the origin times of the shots and a time window of 30 sec. Records have been also corrected for the elevation by shifting the travel-time of each station by a quantity $dt = dz/V$, where dz is the difference between the altitude of the stations and those of the shots, and $V = 2.3 \pm 0.25$ km/sec deduced from the work by Zollo et al. (1996). Records have been also filtered in the band 2-15 hz and their amplitudes normalized using the procedure *Automatic Gain Control* (*AGC*) with 2 s time windows for the shot S2 and 3 s for the shot S3.

Synthetic seismograms have been also generated in orded to test the delay expected with simple models. Computations have been performed by using ray perturbation method in a heterogeneous medium (Farra et al., 1989). For instance by using a schematic model to represent conditions for the S3 shot: offset of the array 2.5 km and relative distance 30 m, flat surface of reflection located at 2.0 km depth and constant P-wave velocity V = 2.3 km/sec, the expected arrival time of the first reflection is 2.0 sec after the origin time. The procedure of *Constant-Velocity* stacking applied to synthetic seismograms allows to obtain the true velocity and the depth of the reflector. Using the same procedure to data from shot S3 (Fig. 4) in a stacking velocity range $1 \leq V_s \leq 8$ km, with 500 m/sec steps in a

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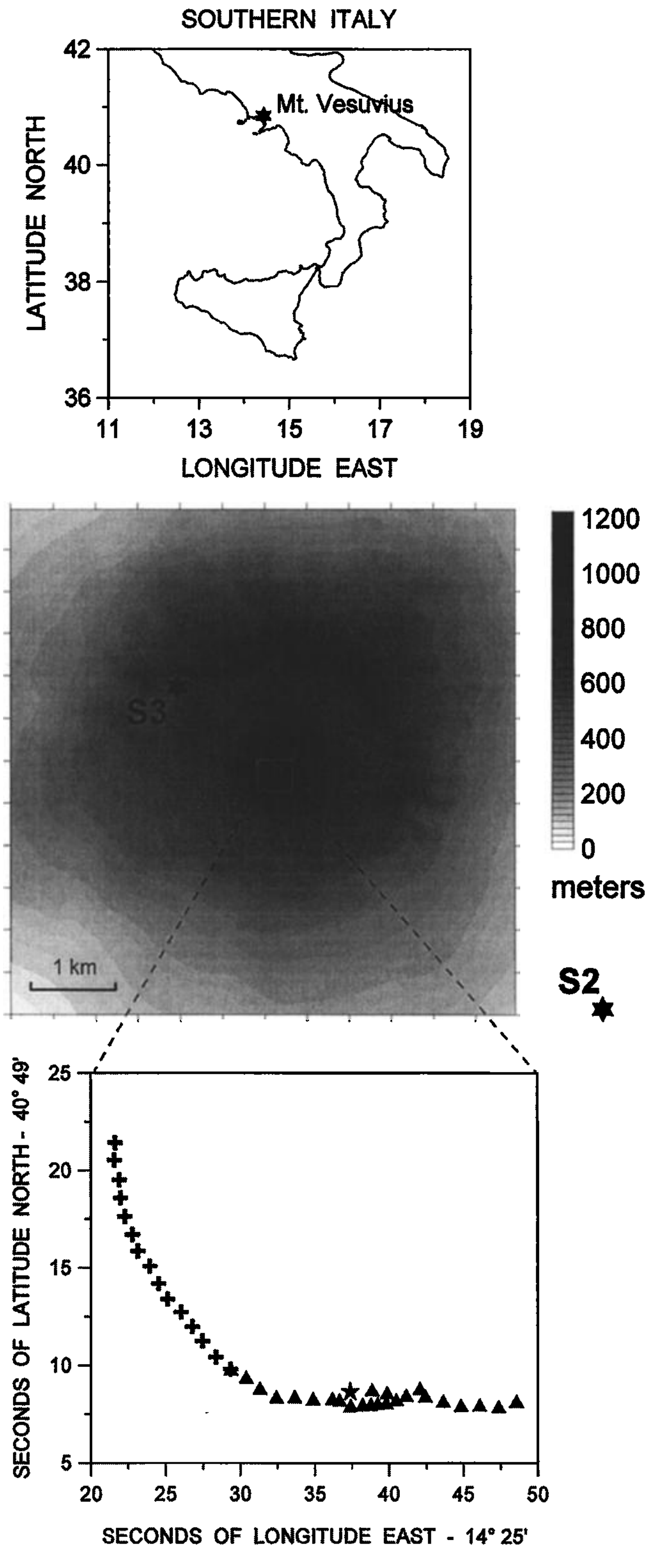

Figure 1. Location of the seismic arrays and shots S2 and S3 fired during the seismic tomography experiment. Crosses indicate the Salerno stations; closed triangles stations from L'Aquila and the star the 3-component station.

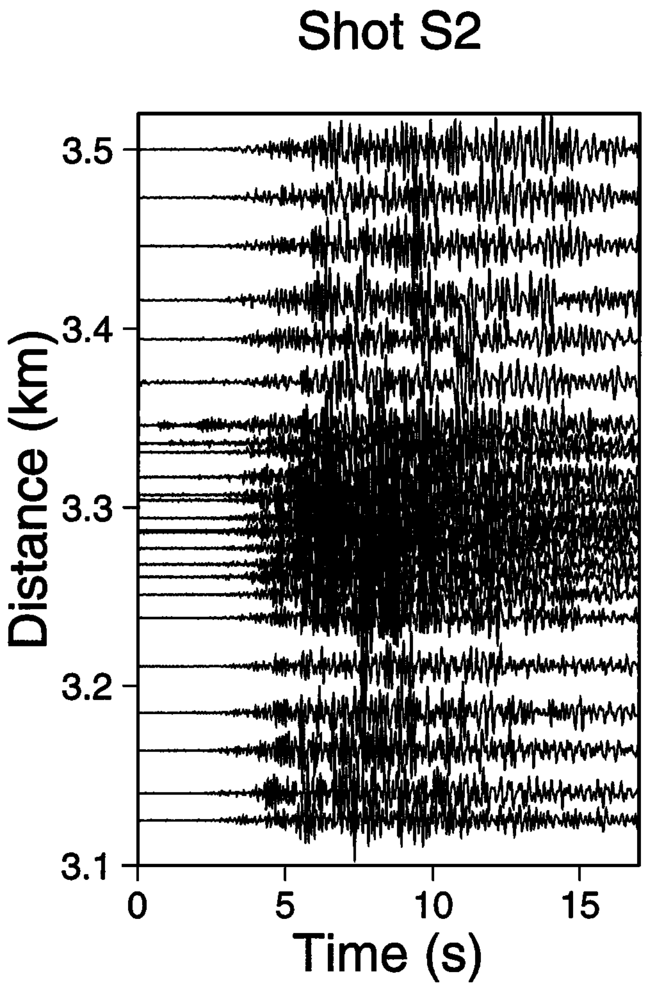

Figure 2. Film section showing records from shot S2 at L'Aquila array.

window 0-3 sec, and lately in the range $1 < V_s < 4$ km/s with steps dv = 200 m/s, it can be observed a flattening in correspondence of the velocity $V = 1.8 \pm 0.2$ km/s and a value of the two-way time $t_0 = 1.7 \pm 0.1$ s, from which it can be deduced, for shot S3, a depth of the reflector $h = 1.5 \pm 0.2$ km. For the shot S2 in the same time window it is obtained $V = 2.2 \pm 0.2$ km/s and $t_0 = 2.0 \pm 0.1$ s and consequently a reflector depth $h = 2.2 \pm 0.2$ km. By considering the model simplifications, basically flat reflection surface and constant velocity averaged through the ray path, the depths resulting in the two time windows can be considered as consistent. The arrival time of the reflected phase for S2 and S3 is consistent with the simulations performed with the best fit model derived from the interpretation of the whole seismic profile discussed by Zollo et al. (1996). The result obtained from these last authors suggests that the horizon K (limestones) is located deeper for shot S2 than for S3. The small aperture array installed along the crater rim confirms this relevant result.

Velocity Structure Beneath the Array

The correlation method has been used to infer the shallow velocity structure beneath the array, by using microtremor records (Ferrazzini et al., 1991). The azimuthal average of spatial correlation coefficients between pairs of signals, computed as a function of frequency and

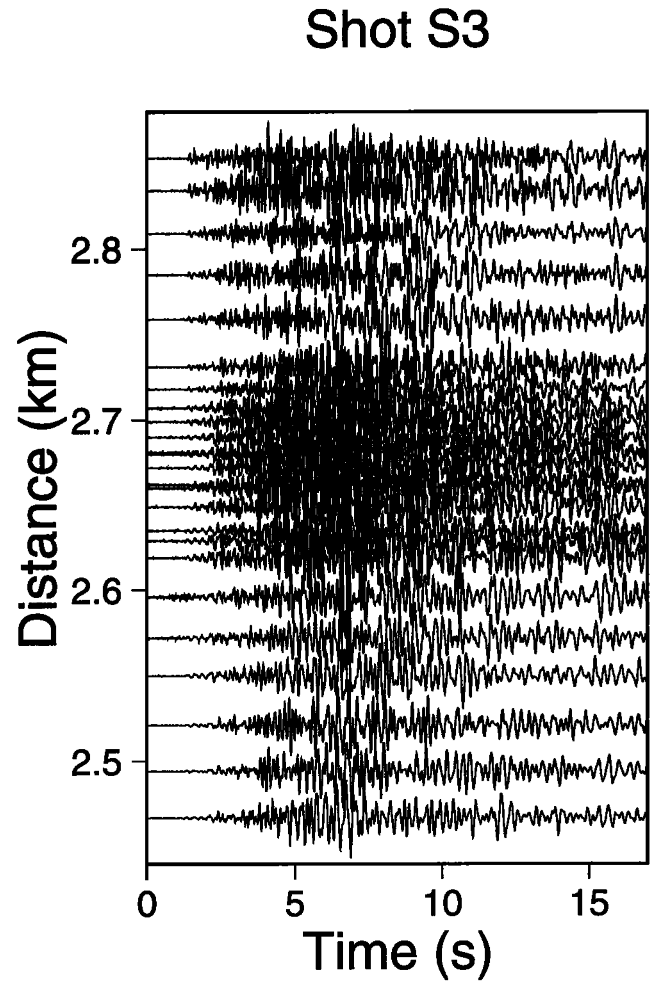

Figure 3. Film section showing records from shot S3 at L'Aquila array.

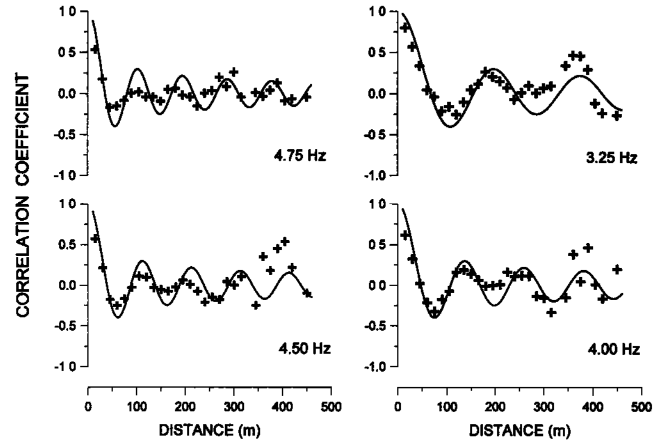

Figure 5. Examples of comparison between theoretical and experimental correlation curves for the vertical component at 3.25 hz, 4.00 hz and 4.75 hz.

distance on narrow bands, has a theoretical behaviour linked to the zero order Bessel function. This is true for vertical component records and wavetrains formed by Rayleigh waves (Aki, 1957). Chouet (1996) extended this method to the horizontal components in order to infer dispersion curves of Rayleigh and Love waves, linked to combination of Bessel functions derived from correlation coefficients of radial and transversal components. The data collected on Mt. Vesuvius are basically from vertical components and contains some minutes of microtremor records, other than the artificial explosions. The signals within a time window 6' 20" have been filtered in 37 very narrow (0.5 hz) bands in the frequency interval 1-10 hz. For each central frequency of these bands cross-correlation coefficients, over 300 distance ranges in the interval 0-500 m have been computed.

The correlation curves for set of 37 frequencies have been then calculated and fitted with Bessel funcions (Fig. 5). Since Bessel functions have terms depending on velocity of surface waves, dispersion curves have been determined (Fig. 6). By using trial and error other than inversion techniques (Aki and Richards 1980; Haskell, 1953; Horike, 1985) a best fit velocity model has been derived (Fig. 7). This result is well consistent, in spite of the low resolution for the deeper layer, with measurements made during the tomography experiments and provides a good constraint for high resolution tomography of the summit crater of Mt. Vesuvius.

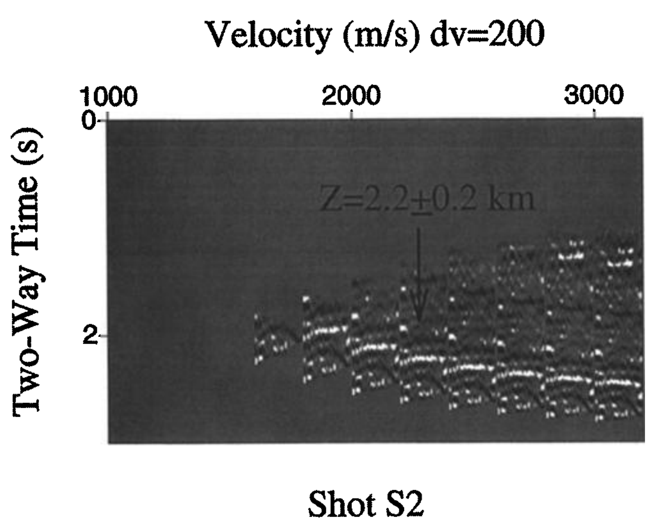

Figure 4. Constant Velocity Stacking of shots S2 and S3 within a 3 s time window.

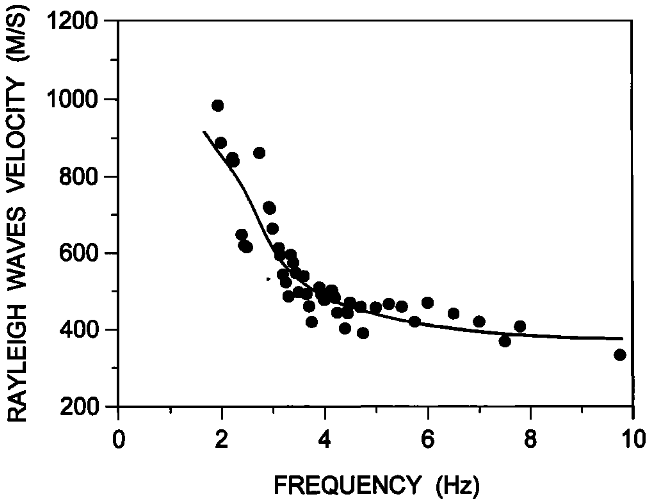

Figure 6. Comparison between dispersion curves observed and modeled for Rayleigh waves.

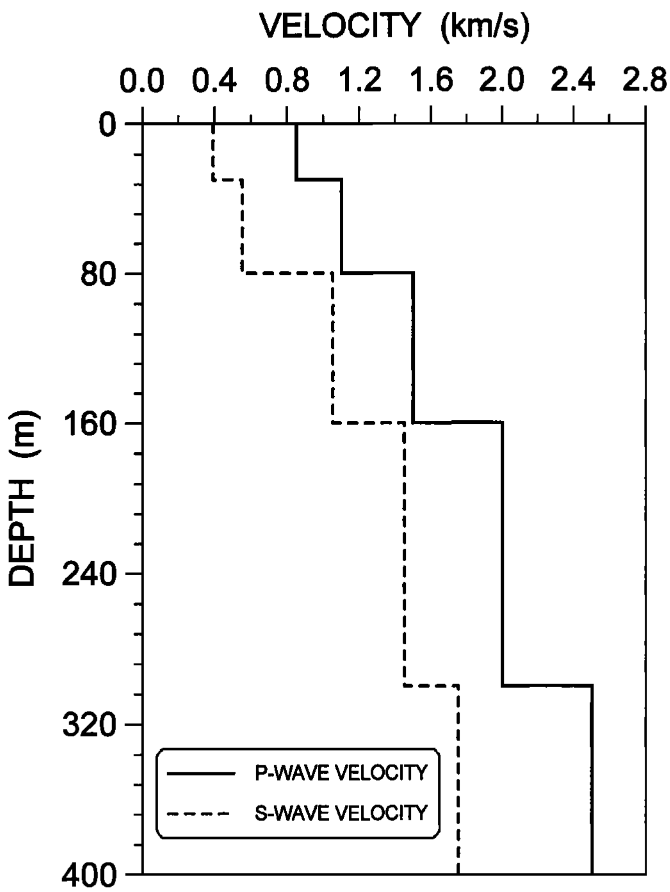

Figure 7. Velocity model derived beneath crater rim of Mt. Vesuvius.

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