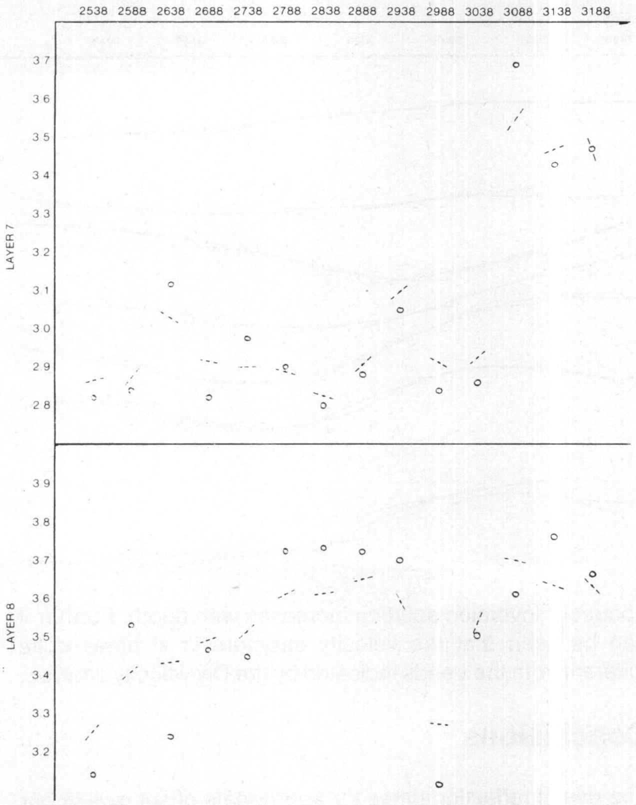

FIGURE 6
Interval velocity profile for layers 7 and 8 obtained from data in Fig. 2.

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An Array Study of Ground Tremors and Its Application to Exploration

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Summary

Micro ground tremors were observed by an array of multiple 3-D geophones of 1 Hz with a short spacing along a traverse in a volcanotectonic zone of northeastern Japan. Instead of line spectral methods by single observation point for earthquake engineering purposes, a continuous spectrum was processed by cross correlation and 2-D filtering in time and then in the frequency domain. In addition to the power spectral profiling, 2-D representation of ground motion vectors assists in understanding a realistic structure. Frequency to depth conversion was made by using the law of a quarter wavelength in assumption of velocity distribution of S- or P-waves. Advanced discussion is proposed on this point considering dispersion of surface waves dominant in the tremors, especially of the longer period. As an example of interpretation of the results, geomagnetic intensity was correlated in detail, and the volcanotectonism was seen as double caldera walls (post Miocene).

Introduction

Micro ground tremors are good measures of dynamic response of the ground to seismic waves originated from an earthquake, volcanic activities, ocean swell, and traffic or machine noises, whether the origin and time of the sources are discriminated or not.

Because the dominant frequency of ground tremors is properly the resonant frequency of ground motion, and its corresponding wavelength is an indication of the thickness of the unconsolidated surface layer considering the law of quarter wavelength, the observation and analysis of the waves is commonly for the purpose of earthquake engineering. The author (1984 and 1986) has carried out such works at a thousand locations over the whole area of Aomori Prefecture in the northeastern part of Japan for estimation of earthquake damage.

Among several line spectra of ground motion, the lower frequency is a realistic indication of basement depth in the Quaternary basin as reported by Sakajiri *et al.* (1974), Ohta *et al.* (1978), and others by observations along a traverse.

The work of observation and analysis is however neither easy nor efficient in the measurement at single stations as in the above case, and the seismic records could not be correlated easily with each other. This results in uneven analysis from point to point in an area, prevents advanced 2-D processing, and most of the signals may be of little use except for estimation of resonant frequency.

Measuring the ground tremors simultaneously at multiple stations in a traverse was therefore designed, and two dimensional analysis was applied to the whole continuous spectra instead of a small number of line spectra. Nevertheless the physical properties of the ground tremors were not distinguished, and the underground elastic structure must be deduced from statistical processing of spectral data (in space and time domains) including miscellaneous noise.

Observation

Observation of micro ground tremors with arrayed seismic stations was examined in a foothill area of Iwaki-san Volcano near Hirosaki.

Observation by unity spread with eight 3-D geophones of 1 Hz in spacing of 100 m was joined to three spreads down the northern dip. Low frequency motion under 25 Hz was recorded on digital cassette tape for a time interval of 60 minutes by one spread operation.

Stationary microtremors are as a general rule measured in displacement or velocity of a range of 0.05–10 micron (micro-kine) during two minutes or more, in mid night time according to Kanai's (1969) classification of earth's strength. Amplitude of ground motion in daytime increases as much as 12 dB or more, while the frequency spectra are little changed except for occasional disturbances. The author detected tremors in resolution of 1 micro-kine and 0.02 Hz under conditions of quiet daytime as for this experiment.

Data Processing

Unit record lengths of about 1 minute were analyzed in FFT at 4K points, and inspected for stability by Wigner's vector distribution continuously during the observation of 60 minutes in total. Phases with strong disturbances were then omitted from the record and the spectra were stacked up to 56 records maximum. Complex spectra in the frequency domain and orbital motions in the time domain were consequently processed to build up the underground structure model.

After the reduction of time variation of tremor levels, the power spectrum and vector of ground motion were plotted by assuming a seismic wave velocity distribution under the observation point, and arranged in the traverse.

The velocity distribution of seismic waves determines the elastic structure in detail. The law of quarter wavelength was applied to this case on the assumption that velocity increases linearly at 1500+ 0.48.Z (m/s). When the Poisson ratio is assumed as constant, the underground structure determined by using S-waves is proportionally shortened in depth scale.

Several kinds of profiles were derived from the three component motion of ground tremors. One of the profiles is shown in Fig. 1, in which B/W density is the power spectrum in arbitrary intensity scale and vector represents the inclination of ground motion within the N-S plane. Two dimensional profile was generally operated in space with specific filters for particular applications.

Interpretation

In this area, geophysical surveys of gravity, geomagnetic (including airborne), electric (including DES), magnetotelluric, and so on were made since 1972 in order to study the volcanic structure and associated earthquake mechanism. If velocity assumptions were correct, the elastic structures derived from tremors would closely correlate the above geophysical results. As an example of such correlation, total geomagnetic force on the same traverse was plotted in Fig. 2.

From geological considerations in this area, the southern basemental uplift in the Miocene period may be the inner root of a caldera wall in association with basaltic activities, and the northern outer wall in a later period, where 53 or more hills fractured from the main volcanic body are distributed in the vicinity. A ridge structure of gravity and resistivity anomalies is present.

Problems

The following problems remain to be addressed:

1. Relation between higher harmonics of resonant motions and heterogeneity of velocity distribution.
2. The origin and property of individual vector spectrum of ground motion from the viewpoint of dispersive mode of surface waves up to a considerably higher order.
3. Limitation of the first approximation in routine analysis.

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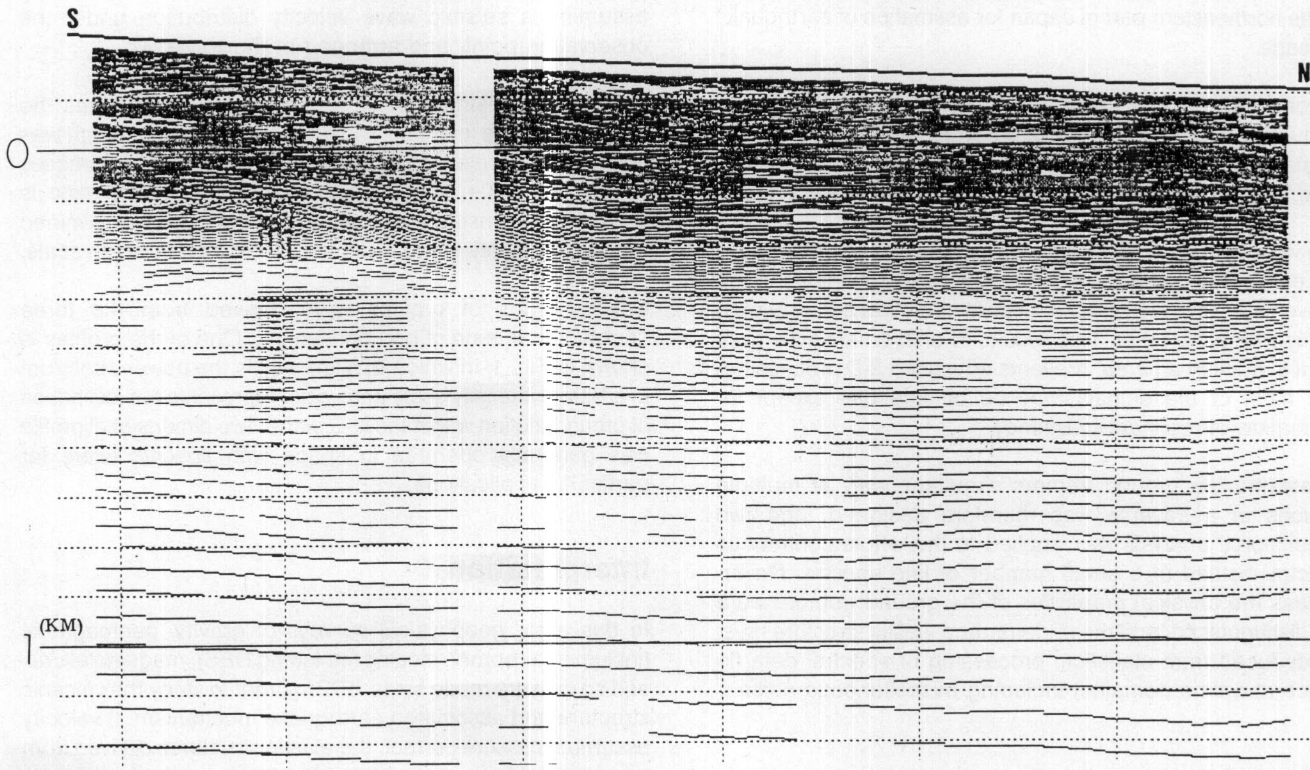

FIGURE 1
2-D vector profile of tremors converted from frequency to depth.

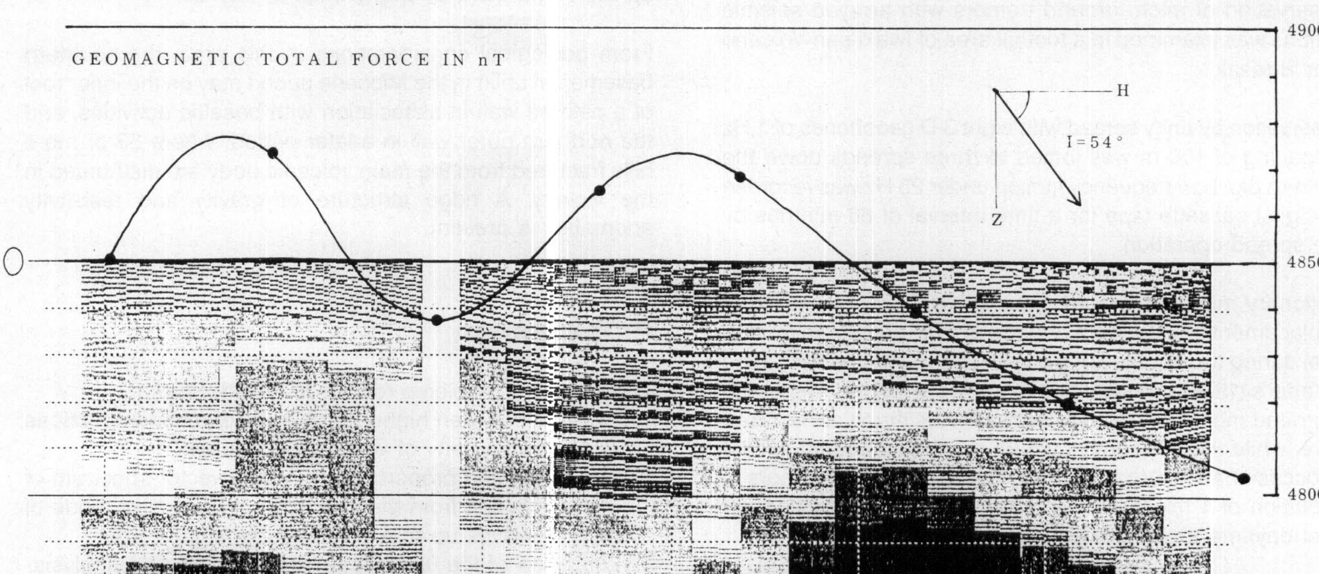

FIGURE 2
Correlation of tremor structure and geomagnetic force.