11. THE 26 MAY 1983 JAPAN EARTHQUAKE RECORDED BY OSS IV[1]

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ABSTRACT

On 26 May 1983, eight and a half months after emplacement of OSS IV, an earthquake of magnitude 7.8 occurred west of Honshu 15.7° from Site 581. *Kana Keoki* was at the site servicing the ocean sub-bottom seismometer (OSS) recorder package at the time and recorded the event in digital format at 100 samples/s with data unclipped and above noise level for over 10 octaves. This is the largest event yet recorded in the deep ocean. Particle velocities are more than 1 mm/s at 16-s periods. The geophone recordings were filtered to present a flat to acceleration record, enabling a direct comparison with the signals recorded on the two tilt meters in the OSS. Whereas noise level at high frequencies is only slightly larger than a picometer, the particle motion amplitude at long periods reaches about 1 mm, a range of about 180 dB. The data suggest that low-frequency, low-noise accelerometers would make excellent seismic detectors in deep ocean boreholes.

INTRODUCTION

On 26 May 1983, eight and a half months after emplacement of OSS IV, an earthquake of magnitude 7.8 occurred west of Honshu 15.7° from Site 581. This major thrust earthquake occurred at 025959.6Z at 40.462°N, 139.102°E, causing a tsunami in the Japan Sea, over 100 deaths, and considerable damage in Japan and Korea. By an astonishing stroke of luck, *Kana Keoki* was at the site servicing the OSS recorder package at the time and recorded the event in digital format at 100 samples/s with data unclipped and above noise level for over 10 octaves. This is the largest event yet recorded in the deep ocean, and the data should supply considerable information concerning the source parameters of this earthquake, the propagation of seismic waves through the earth, and the usefulness of recordings of large events in the ocean.

BACKGROUND

Kana Keoki arrived at Site 581 at 2000Z, 24 May 1983, to change the recorder packages on the ocean sub-bottom seismometer (OSS) and run a real-time experiment in cooperation with the U.S. Navy. The Navy was scheduled to drop SUS explosive charges from a P-3 aircraft to the OSS while *Kana Keoki* was monitoring the data from the wire going to the tool in the hole. The recorder package and cable were brought on board at 1530Z, 25 May, and the tool was tested and found to be in perfect condition in the hole. The cable head was waterlogged, however, and a new cable head was spliced on. Real-time data recording was started at 2348Z, 25 May, and three tapes were running when the P-3 aircraft began dropping SUS charges at 0100Z, 26 May. As the plane was nearing the hole and dropping charges every 40 s, a sound was heard (felt?) at 0303Z that was nothing like the shots that had been heard when we were listening to a sonobuoy over the hole. The sonobuoy recorded nothing unusual, but the OSS geophone signals, set to record on paper at high gain, had suddenly gone wild. The tilt meters were checked to be sure we were not pulling the tool from the hole, but they were stable, leaving the alternative that a large quake was being recorded. Since we could no longer observe the SUS charges, the aircraft was asked to circle until noise level returned to a reasonable value (about 15 min. later). Thirteen-second surface waves were obvious even on the unfiltered records made on the ship. Hours later the news reached us that a large earthquake had occurred in Japan. Statistics on the earthquake from National Earthquake Information Service, Boulder, Colorado (NEIS) are given in Table 1.

This was a major tsunamigenic earthquake, with tsunami heights of 14 m at Minehama, Honshu, 2–6 m along southern Hokkaido and northern Honshu, up to 8 m along the coast of the U.S.S.R., and 4 m along the coast of South Korea (NEIS). In Japan alone, 99 people were killed by the tsunami, 52 homes were washed away, 139 homes were destroyed, 225 fishing boats were sunk, and 414 others were damaged (*Discover*, Aug. 1983, p. 18). An earthquake of this size occurs about once a year in the Pacific and once every five years in the north-

Table 1. Statistics for the 26 May 1983 Japan earthquake and summary of OSS parameters.

National Earthquake Information Service	
	Origin time: 26 May 025959.6Z
	Location: 40.462°N, 139.102°E
	Depth: 24 km
	Magnitude: M_b = 6.8, M_s = 7.8
Ocean Sub-bottom Seismometer	
	Dist. = 15.69°, azimuth: 70.5°
	Back azimuth: 264.5°
	P traveltime: 220.94 s (JB)
	$dt/d\Delta$ = 12.85 s/°, phase velocity: 8.65 km/s
	Angle from focal sphere: 70°

[1] Duennebier, F. K., Stephen, R., Gettrust, J. F., et al., *Init. Repts. DSDP*, 88: Washington (U.S. Govt. Printing Office).

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west Pacific; thus we were extraordinarily fortunate to be on site at the time of its occurrence.

DATA ANALYSIS

Analysis of this event is far from complete. Presently, we have reduced the data to obtain waveforms and spectra, but to be of real value, the data must become part of the larger data set of recordings from all stations that recorded this event. The recordings presented here are unique in that they (1) are recorded 15.7° from the epicenter in the deep ocean; (2) are recorded on 4.5-Hz geophones; (3) are recorded at 100 samples/s in a digital format; and (4) were obtained over a frequency band of about 11 octaves from a 30-s period to over 20 Hz.

The signal recorded by the geophones (unfiltered) is shown in Figure 1. The sensors have their peak response at about 6 Hz (Byrne et al., this volume). The early part of the record is dominated by frequencies above 1 Hz, and the high-frequency oceanic P and S waves (P_0 and S_0) (Walker, 1984) are obvious. Note that the + east component is nearly radial to the source and the + south is nearly transverse. The P_0 arrival has about the same amplitude on all three components, whereas the S_0 is conspicuously missing on the vertical, implying that most of the S_0 energy is horizontally polarized. The S_0 does not appear to be polarized in the radial or transverse direction within the horizontal plane. The spikes in front of the P_0 are arrivals from the SUS charges fired by the aircraft.

Figure 2 shows the early wave arrivals on an expanded time scale. The higher frequency traces are unfiltered, whereas the smoother trace is low-pass filtered (three poles at 16 s) and amplified. Note that the long-period P-wave arrival begins several seconds after the initial high-frequency P_0 arrives. This early arrival for P_0 is common for earthquakes recorded in the ocean at these distances (Walker et al., 1983; Cessaro and Duennebier, this volume), although the arrivals may be complicated by the geometry of the source–receiver path, passing at an oblique angle through the subducted Pacific Plate. Note that while the long-period P-wave arrival has an impulsive arrival, the P_0 is typically emergent, implying trapped-mode propagation.

Figure 3 shows the geophone recording filtered to present a flat-to-velocity record from 64 s to 4.5 Hz (two-pole, low-pass filter at 64 s). The filtered records emphasize the long-period arrivals. Particle velocities are more than 1 mm/s at 16-s periods. We would have expected the amplitude on the vertical component to be larger than observed with an angle of incidence of about

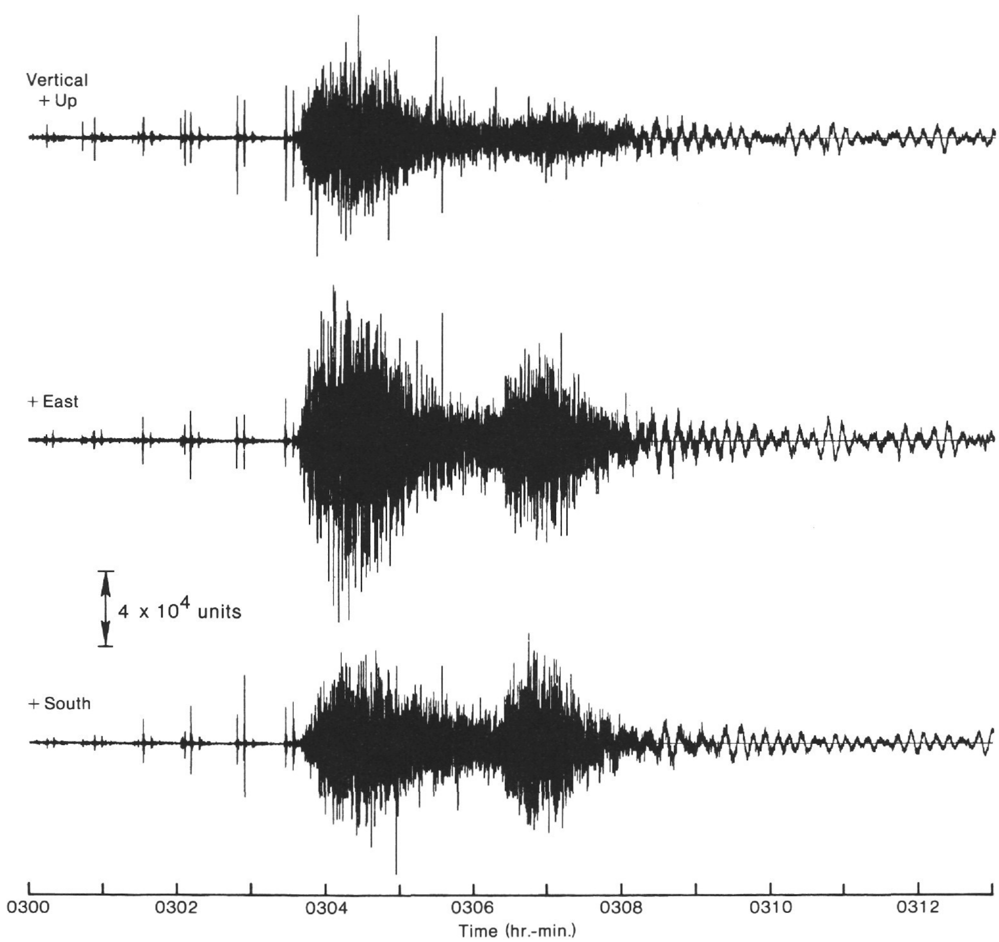

Figure 1. The 26 May 1983 Japan earthquake recorded (unfiltered) by the OSS IV geophones. The spiky arrivals before the earthquake are SUS charge signals.

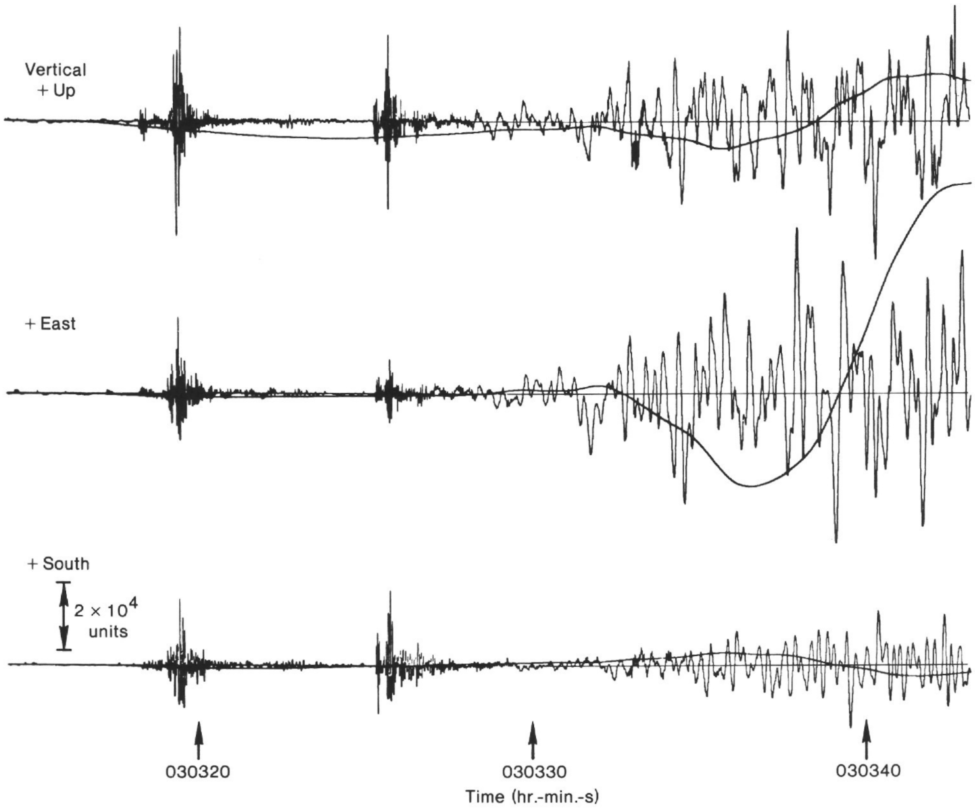

Figure 2. The Japan earthquake early wave arrivals on an expanded time scale. The high-frequency trace is unfiltered; the smooth trace is low-pass filtered (three poles) at 16-s periods. The filtered data are plotted on a vertical scale 50× that of the unfiltered data. The sharp arrivals in front are from an SUS charge. Note the emergent onset of the P_0 wave ahead of the impulsive long-period P-wave.

45°. The small amplitude may be caused by destructive interference with the ocean surface reflection. The direction of first motion on the radial (+east) component suggests first motion to the west (dilatational). This is in agreement with the focal mechanism published by NEIS (monthly listing of epicenters) shown in Figure 4, implying a thrust-fault mechanism.

It is also of interest to filter the data so that the resulting plot (Fig. 5) is flat to acceleration from 64 s to 4.5 Hz (single-pole, low-pass filter at 64 s). The resulting signal is nearly white over a broad band of frequencies. By plotting the data flat to acceleration, a direct comparison with the signals recorded on the two tilt meters in the borehole tool is possible. Since horizontal acceleration is equivalent to a small change in the direction of vertical, horizontal acceleration is indistinguishable from tilt:

$$\ddot{y} = g\phi$$

where $\ddot{y}$ is acceleration measured in the y direction, g is the acceleration of gravity, and ϕ is the equivalent tilt in radians. The tilt meters in the OSS tool (Byrne et al., this volume) were designed to give the angle of the tool from vertical to insure that the horizontal geophones are within their sensitive range at the time of emplacement; they were not meant to be seismic or tectonic tilt sensors. However, with an earthquake of this size, the tilt sensors (sampled at 25 samples/s) yield seismic records of the horizontal acceleration. The tilt records are plotted next to the corresponding horizontal geophone records in Figure 5. The tilt meters are not sensitive to signals at frequencies above about 0.5 Hz. Using the previously mentioned conversion formula and the calibration test data for the sensors, the two tilt signals can be plotted on the same scale as the geophone signals. This is the case for the +east tilt meter and geophone, but there is a discrepancy of about a factor of two between the +south tilt meter output and the +south geophone. The +south tilt meter output is about twice as large as expected and is plotted at half the scale of the +east geophone signal.

This comparison supplies an independent check of the sensitivities of the geophones and implies that the calibration of the +east geophone and tilt meter is correct. The factor-of-two difference in the +south sensors has an unknown source, but it appears that the problem is with the tilt meter, which is noisier than the +east tilt meter and displays signals about twice the size of the +east sensor.

Amplitude spectra for the P and S waves for each component of the background noise level are shown in Figure 6. Spectra for all components are shown. Whereas the noise level at high frequencies is only slightly larger than a picometer, the signal particle motion amplitude at long periods reaches about 1 mm, a range of

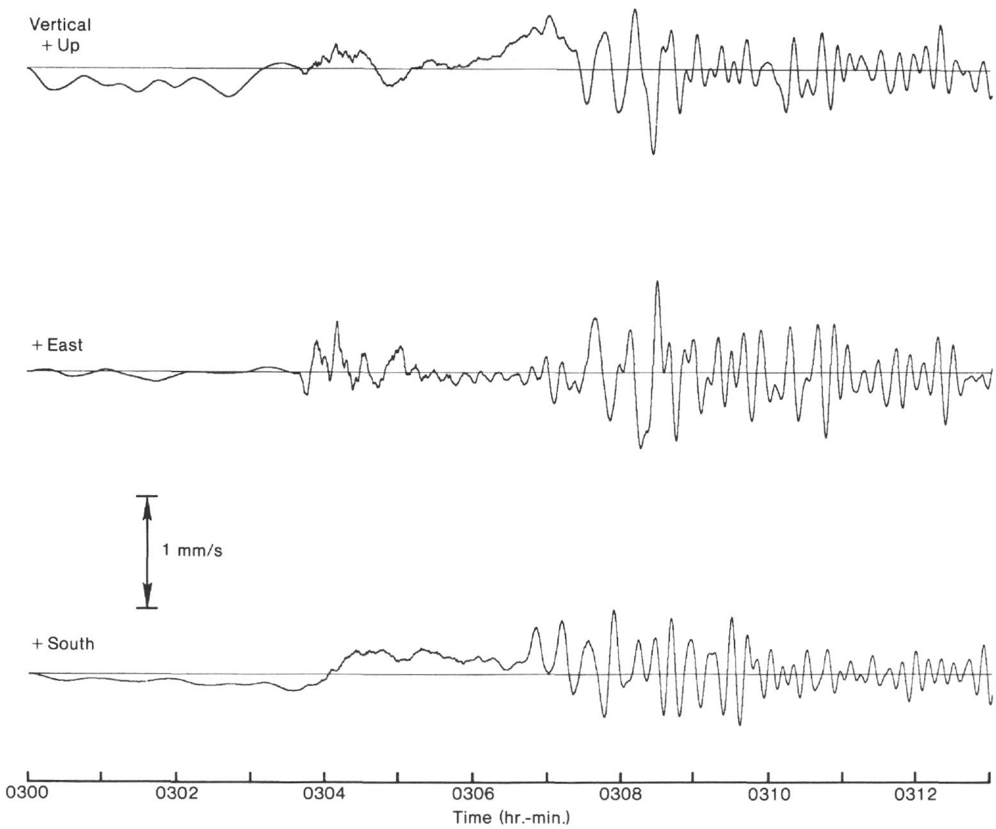

Figure 3. The Japan earthquake recording filtered to be flat to velocity from 64 s to 4.5 Hz. This trace emphasizes the long-period arrivals.

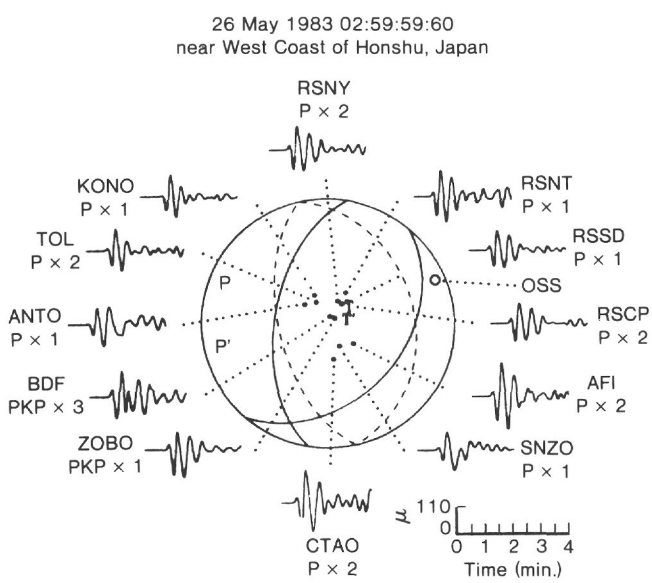

Figure 4. Focal mechanism of the 26 May 1983 Japan earthquake as published in the NEIS monthly listing, together with the OSS IV first motion. Acronyms are seismic station names. The focal mechanism is consistent with thrust faulting.

about 180 dB. Even with this high dynamic range, the signal is not clipped because the response of the geophones has a shape (Byrne et al., this volume) that nearly prewhitens the signal from the earthquake. If this signal is typical of those from large earthquakes, then it is appropriate to use flat-to-acceleration recording systems to prewhiten the signals over a broad frequency band.

CONCLUSIONS

The 26 May 1983 Japan earthquake was recorded with high fidelity over a broad frequency band by the OSS IV geophones and also by the tilt meters. The signal shows maximum particle displacements of more than 1 mm (peak to peak) and particle velocities of almost 1 mm/s. The amplitude spectrum shows signals above noise over about 11 octaves and a range of particle motion amplitudes of about 180 dB. The data suggest that low-frequency, low-noise accelerometers would make excellent seismic detectors in deep ocean boreholes.

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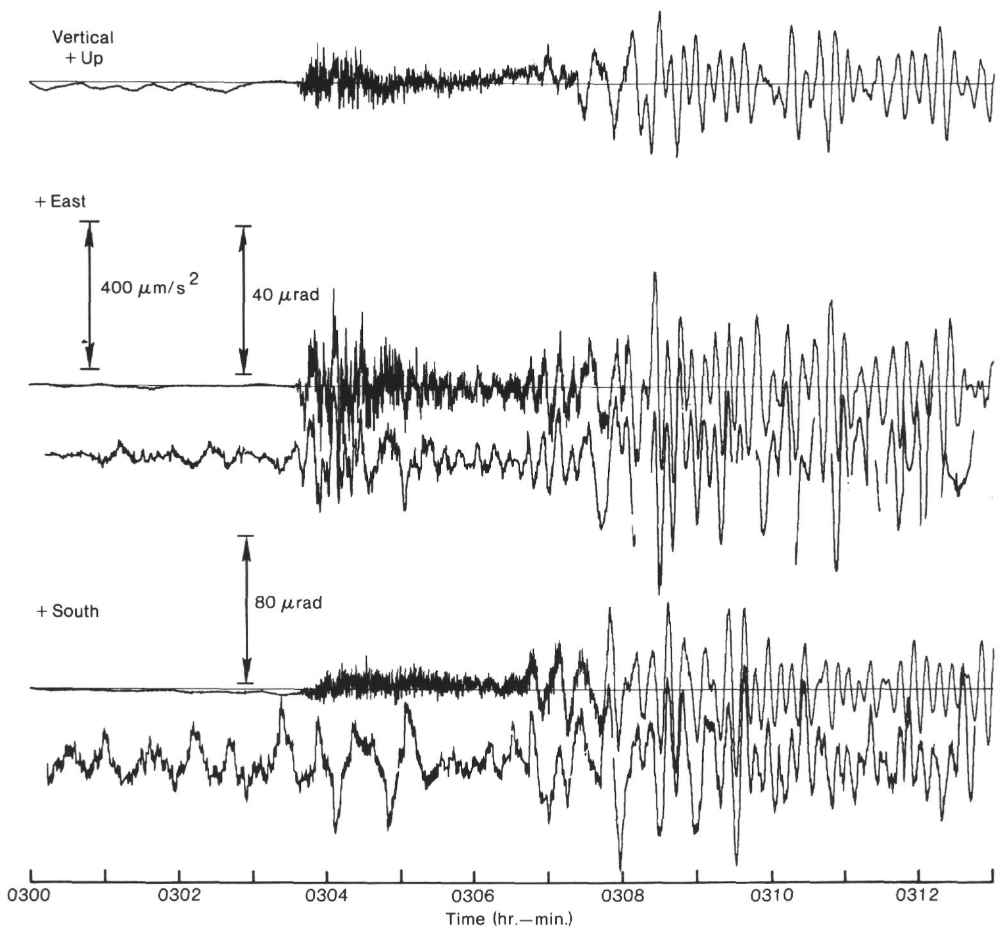

Figure 5. A comparison of the OSS IV tilt meter and geophone traces for the Japan earthquake of 26 May 1983. The geophone traces are filtered to be flat to acceleration from 64 s to 4.5 Hz. The OSS IV tilt meter records are shown below the two horizontal geophone traces. Note that the +south tilt meter is plotted at half the vertical scale of the other sensors.

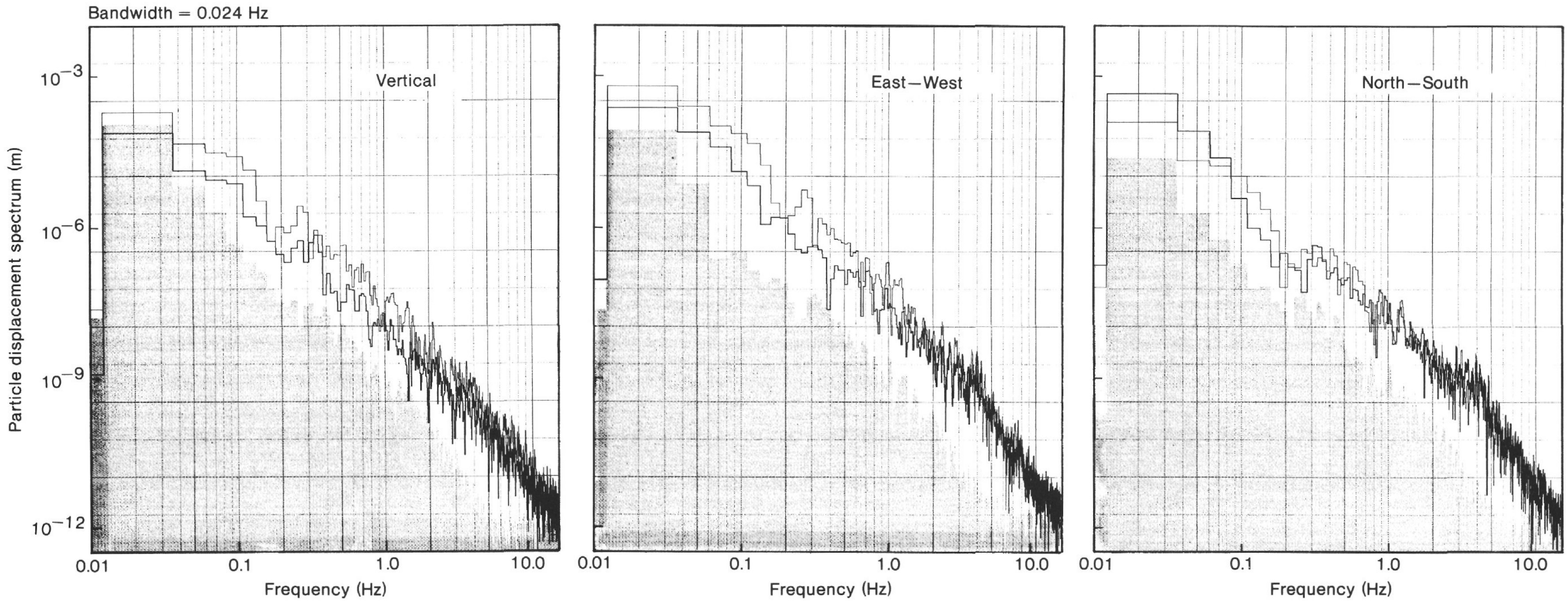

Figure 6. Amplitude spectra for the P and S waves recorded by the OSS IV geophones during the 26 May 1983 Japan earthquake. Background spectra (shaded) were measured before the earthquake. The + east horizontal geophone is nearly radial to the source; the + south horizontal is nearly transverse. The signal spectrum is about 20 dB above the noise over a large frequency band. The P wave is larger on the east-west component as expected. The S waves are marked with a heavy line, P waves with a fine line.