John P. Hoffman and Samuel T. Harding

STRONG GROUND MOTION IN THE TULAROSA BASIN, NEW MEXICO

Open file Report 77-143

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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By

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1977

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INTRODUCTION

This report contains strong ground motion measurements associated with two large, ground level explosions on the White Sands Missile Range in south central New Mexico. These explosions, which were detonated on August 12 and September 22, 1975, were part of Project Dice Throw, a weapons research experiment carried out by the U.S. Air Force. Each explosion was equal in energy to 100 tons of TNT.

The Air Force Weapons Lab at Kirtland AFB requested that the USGS assist them in monitoring ground motion close to the shot point. An agreement was reached whereby the Albuquerque Seismological Laboratory would monitor both blasts using seven field seismograph systems spread along an east-west line through the shot point, and submit the data in a digital format to the Air Force for analysis.

Three other organizations were also involved in monitoring these blasts. The Air Force Weapons Lab used strong motion systems to monitor ground vibrations from 1,000 (305 m) to approximately 4,000 (1220 m) feet distant from the shot point. A group from the Environmental Research Institute of Michigan, Ann Arbor, Michigan, monitored ground motion on a north-south line through the shot point, and Southern Methodist University installed two field systems near the eastern end of the USGS line.

The purpose of this paper is to investigate the attenuation of the various ground motion frequencies across that portion of the Tularosa Basin monitored by the USGS seismograph systems. The Air Force was primarily interested in ground motion close to the shot point, and the furthest station was only 18 kilometers distant.

Location

The shot points were located within several hundred meters of each other in the northeastern portion of the Tularosa Basin near the foothills of Capitol Peak on the eastern site of the San Andreas Mountains (Figure 1). This is in the White Sands Missile Range, which is a restricted military area. The relatively high water table in this part of the basin, approximately two meters below the surface at the shot points, was considered an important factor in site selection by the Air Force.

Geology

Structurally the Tularosa Basin is a graben capped by bolson deposits (Sandeen, 1954). The bolson deposits are the heterogeneous, poorly consolidated sediments which cover the underlying Mesozoic and Paleozoic sediments. They consist generally of fanglomerates, conglomerates, soft sandstones, caliche, and gypsum. These deposits thin out to the west towards the foothills of the San Andreas Mountains which consist of a granitic intrusive. East of the shot point, the basin thickens and depth to bedrock towards the middle of the basin is estimated at 500-700 meters. A lava flow, known as the Malpais, cuts through the center of the basin in this area on a north-south line. The Malpais is an extensive lava flow more than 65 kilometers in length, and varies in width from 1.5 to 8 kilometers. Average height above the basin floor varies from 6 to 10 (2 to 3 m) feet. The USGS seismograph field systems were deployed from the foothills of the San Andreas Mountains on the west to the Malpais lava flow on the east, a distance of approximately 16 kilometers.

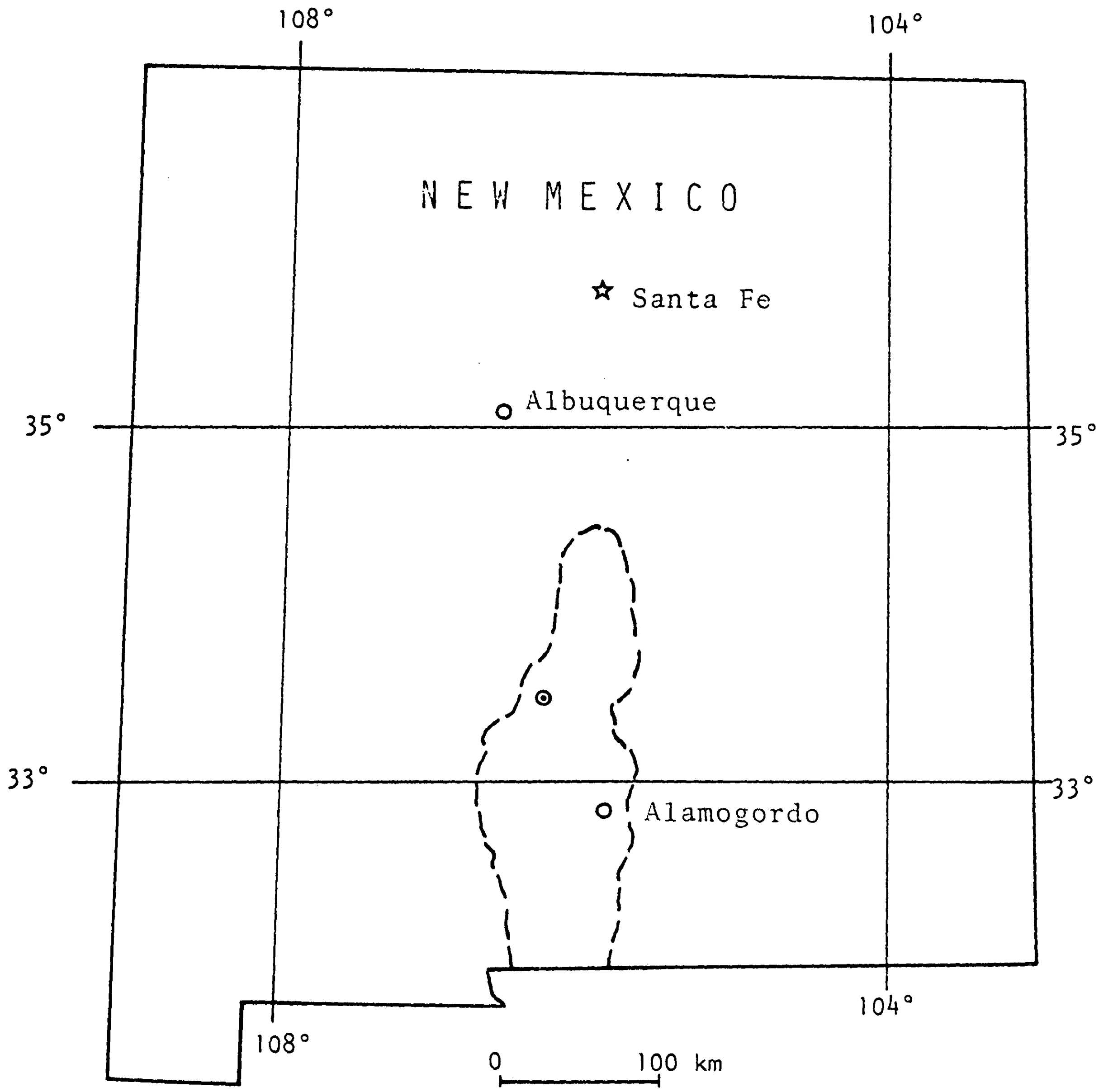

Figure 1. Boundaries of the Tularosa Basin in the State of New Mexico. ⊙ indicates approximate location of shot-point.

Instrumentation

Six of the seven field-instrument systems used on this project were model AS-2[1/] seismograph systems developed at the Albuquerque Seismological Laboratory (ASL) primarily for use in vibration and aftershock studies. These systems used the model S-13 seismometer developed by the Geotechnical Corporation, and the data is recorded in analog form on magnetic tape. These are three component systems complete with a crystal oscillator timing unit, amplifiers, and tape drive, and are packaged in two easily portable containers plus the seismometers (Figure 2). Automotive batteries were used as the power source. The seventh system was an L-7 velocity seismograph on loan from the U.S. Geological Survey in Las Vegas, Nevada (King, 1969). All of the model ASC-2 systems were calibrated at the ASL prior to installation in the field, and the L-7 system was calibrated on location. Response curves for both field systems are shown in Figures 3 and 4.

Field operations

The station alignment for the shot on August 12, 1975, is shown in Figure 5. Station locations and distances from the shot point are listed in Table 1. Small concrete pads were used beneath the seismometers to provide better coupling with the underlying alluvium. To protect the timing systems and tape recorders from the desert heat, ventilated plywood boxes, painted white, were used as protective covers (Figure 6). The horizontal seismometers were aligned transverse and radial to the shot point. The last two stations to the east are quite close to each other to measure the

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[1/] Use of brand names in this report is for descriptive purposes only and in no way constitutes endorsement by the U.S. Geological Survey.

amplification effects of different types of ground. One station was located on the Malpais lava flow and the other on nearby alluvium.

The station locations for the shot on September 22 are shown in Figure 7, and their coordinates and distances from the shot point are given in Table 2. Three stations were located on existing sites used during the first shot, and the remaining four stations were relocated along a paved road for easier access. Heavy thunderstorms in the area preceding the second shot made several of the original sites inaccessible.

Good data were recorded at all sites for both shots. As these were surface shots, which characteristically exhibit poor coupling with the ground, much of the explosive energy went into the air wave (Figure 8). The air waves did not interfere particularly with the recorded data. Analog plots for all stations are included in the appendix. The plots for the ASC-2 data were made on a Versetec digital plotter with a time frame of 180 millimeters per minute. Amplitude is in digital counts. The north-south components were aligned transverse to the shot point, and the east-west components were aligned radial to the shot point. Amplitude for the L-7 plots is velocity in centimeters per second.

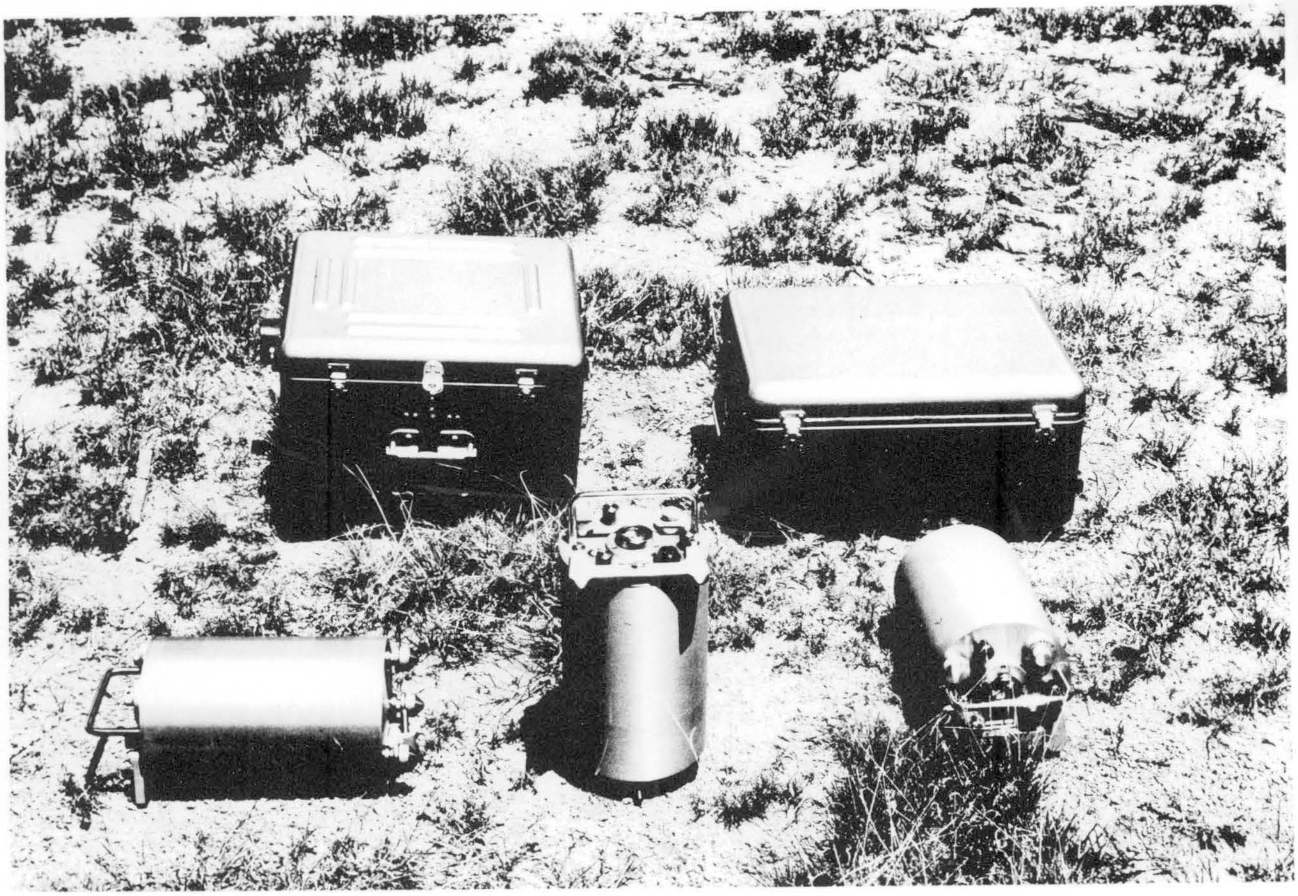
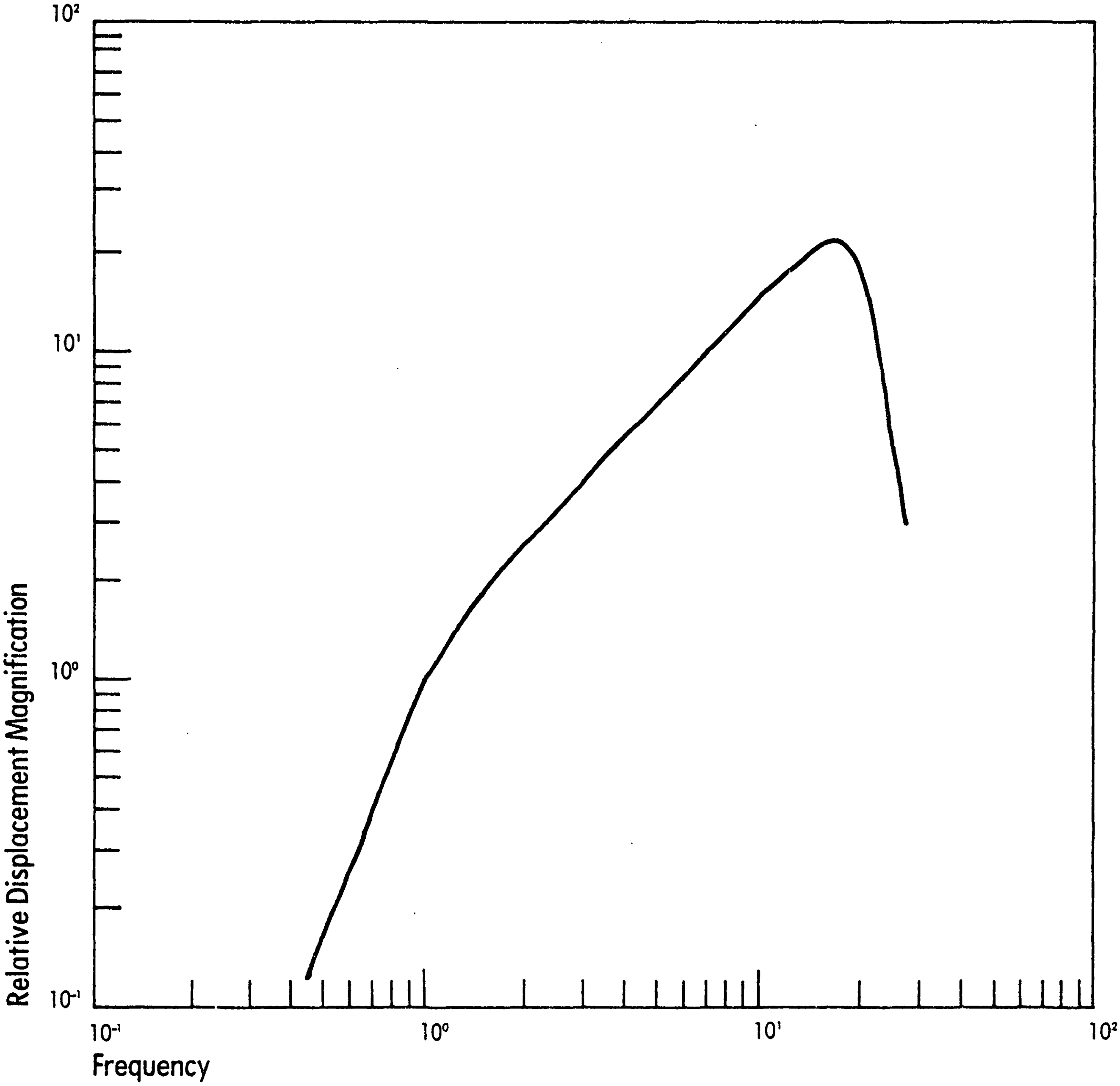
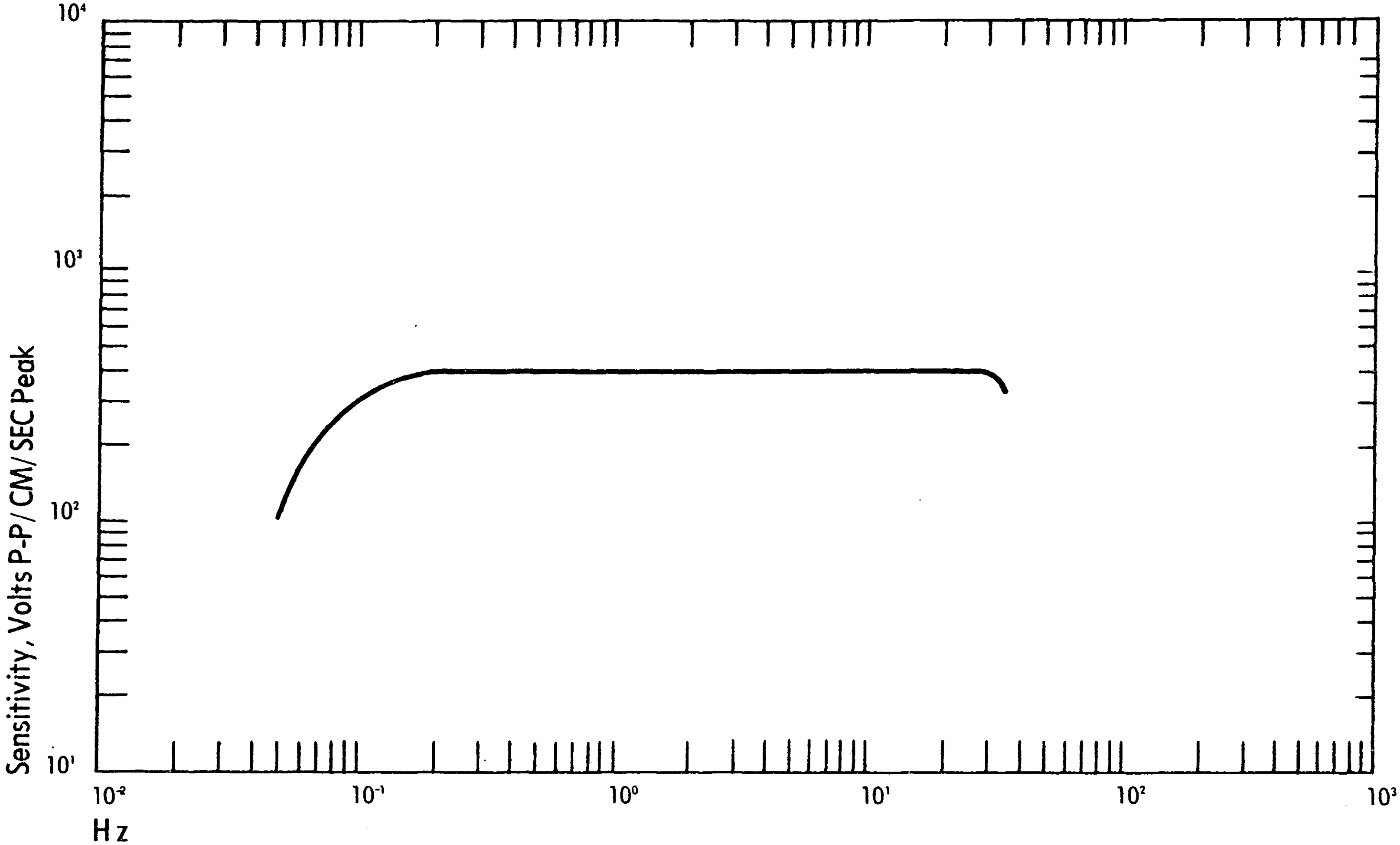


Figure 2. Model ASC-2 Three Component Field System.



Amplitude Response Model ASC-2

FIGURE 3



Velocity Sensitivity Response Curve of the L-7 Seismograph at 36 db

FIGURE 4

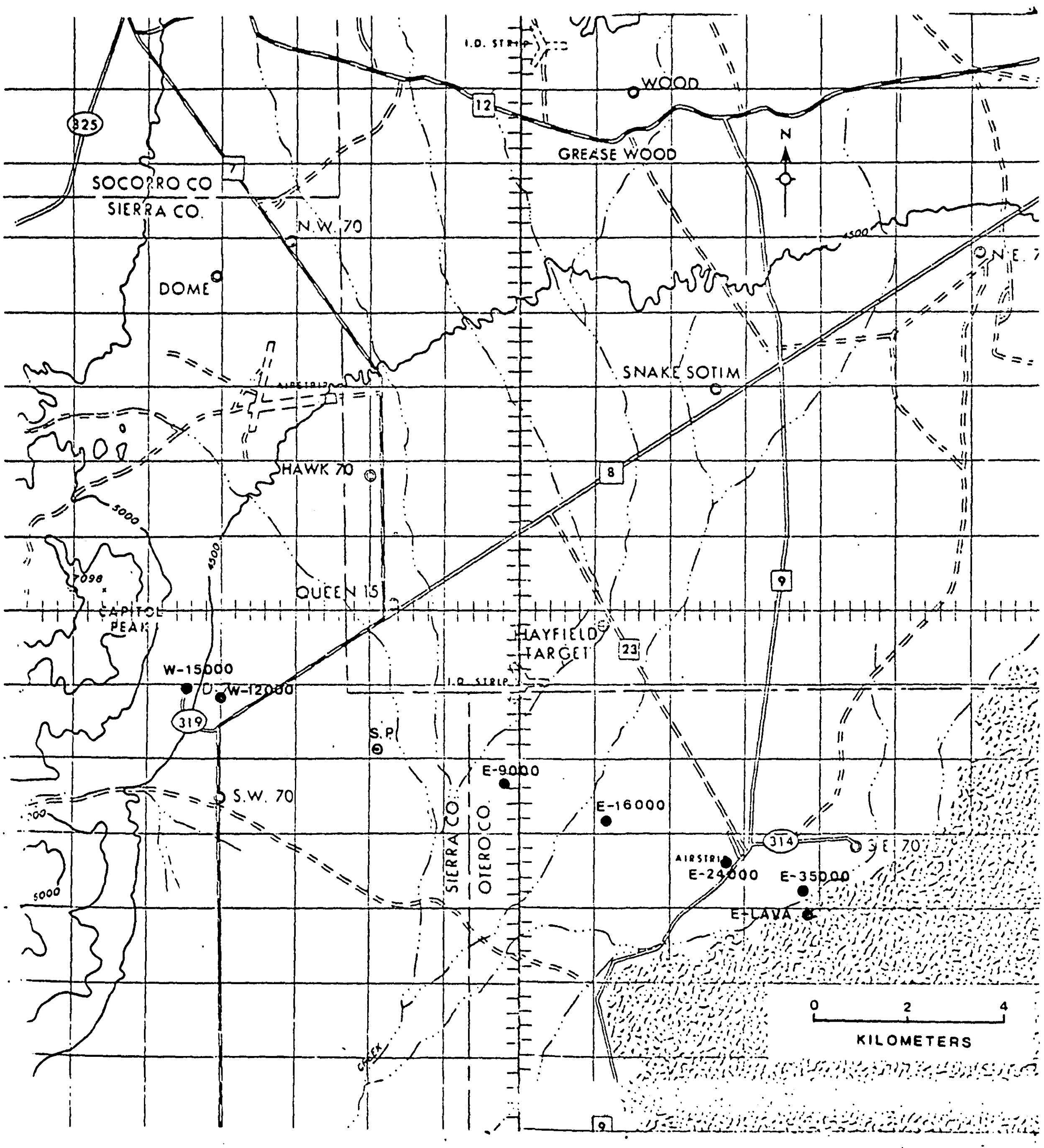


Figure 5. Shot Point and Station Locations for Surface Explosion on August 12, 1975. S.P. is Shot Point. Station Locations given in Table I.

TABLE I

SHOT POINT AND STATION LOCATIONS IN TULAROSA BASIN

FOR AUGUST 12, 1975

Station	Equipment	Distance from Shot Point (Meters)	Latitude	Longitude	Azimuth (Degrees Clock-wise from N.)
Shot Point			$33^{\circ}23'14.42''$	$106^{\circ}22'43.60''$	
E-9000	L-7	2743	$33^{\circ}22'17.25''$	$106^{\circ}20'10.85''$	107.4
E-16000	ASC-2	4875	$33^{\circ}21'56.55''$	$106^{\circ}18'52.46''$	107.4
E-24000*	ASC-2	7361			107.4
E-35000*	ASC-2	9531			107.4
E-Lava*	ASC-2	9753			
W-12000	ASC-2	3659	$33^{\circ}23'19.30''$	$106^{\circ}24'07.27''$	287.4
W-15000	ASC-2	4082	$33^{\circ}23'21.72''$	$106^{\circ}24'23.52''$	286.6

* Not surveyed - Distance from shot point obtained by chaining.

effects of different types of ground. One station was located on the Malpais lava flow and the other on nearby alluvium.

The station locations for the shot on September 22 are shown in Figure 7, and their coordinates and distances from the shot point are given in Table 2. Three stations were located on existing sites used during the first shot, and the remaining four stations were relocated along a paved road for easier access. Heavy thunderstorms in the area preceding the second shot made several of the original sites inaccessible.

Good data were recorded at all sites for both shots. As these were surface shots, which characteristically exhibit poor coupling with the ground, much of the explosive energy went into the air wave (Figure 8). The air waves did not interfere particularly with the recorded data. Analog plots for all stations are included in the appendix. The plots for the ASC-2 data were made on a Versetec digital plotter with a time frame of 180 millimeters per minute. Amplitude is in digital counts. The north-south components were aligned transverse to the shot point, and the east-west components were aligned radial to the shot point. Amplitude for the L-7 plots is velocity in centimeters per second.

TABLE II

SHOT POINT AND STATION LOCATIONS IN TULAROSA BASIN

FOR SEPTEMBER 22, 1975

Station	Equipment	Distance from Shot Point (Meters)	Latitude	Longitude	Azimuth (Degrees Clockwise from N.)
Shot Point			33°22'51.27"	106°21'42.85	
E-16000	L-7	4844	33°21'56.55"	106°18'52.16"	110.4
E-24000*	ASC-2	7328			109.5
W-9000	ASC-2	2764	33°23'10.21"	106°23"32.42"	282.17
W-15000	ASC-2	4131	33°23'21.72"	106°24'23.52"	283.2
OR-1	ASC-2	10088	33°26'38.27"	106°17'06.06"	46.1
OR-2	ASC-2	14325	33°27'54.51	106°14'48.68"	49.3
OR-3*	ASC-2	18593			50.7

* Not surveyed - Distance from shot point obtained by chaining.

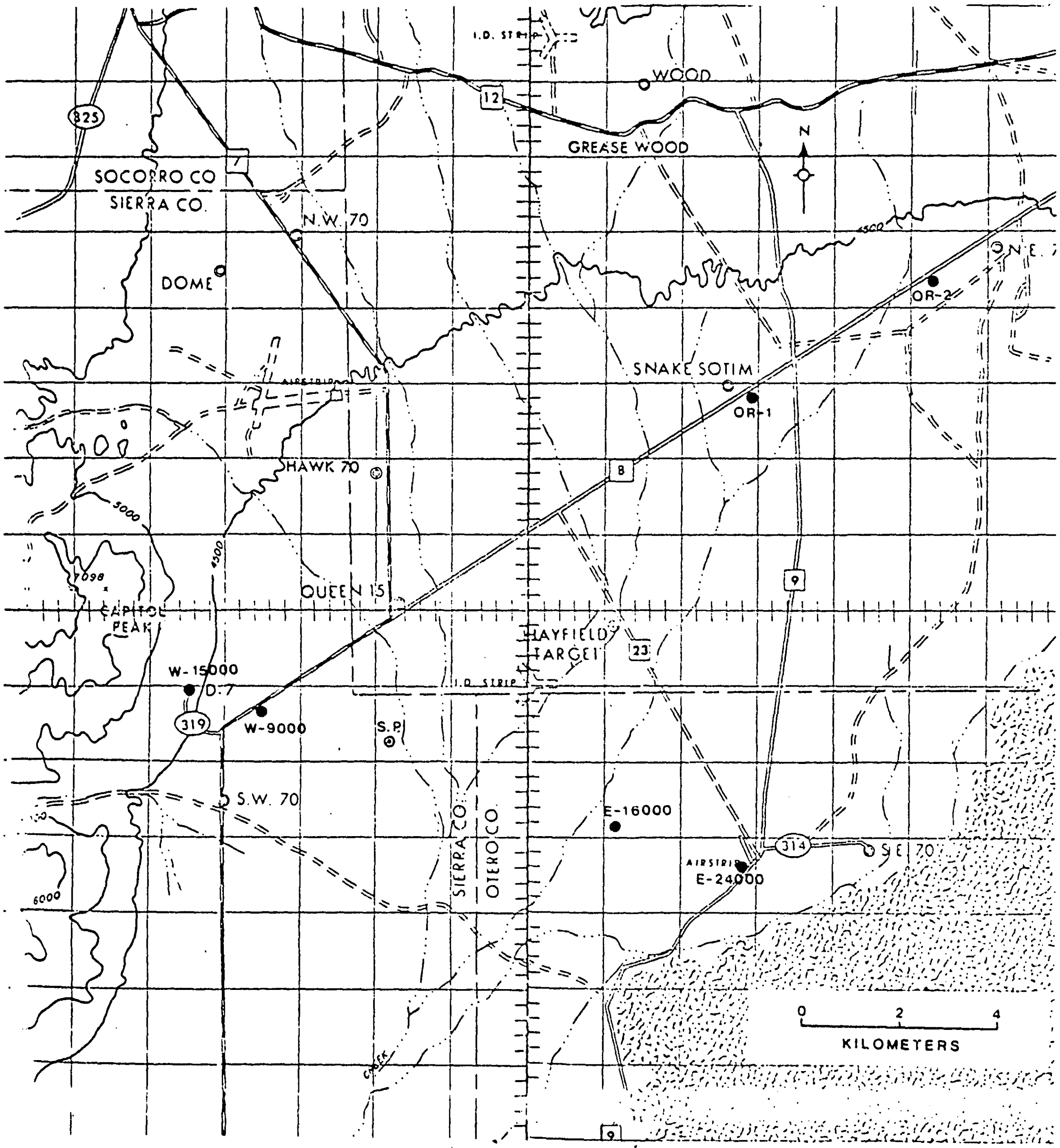


Figure 7. Shot Point and Station Locations for Surface Explosion on September 22, 1975. Station OR-3 is located on Route 8 just off the map. S.P. is Shot Point. Station Locations given in Table II.

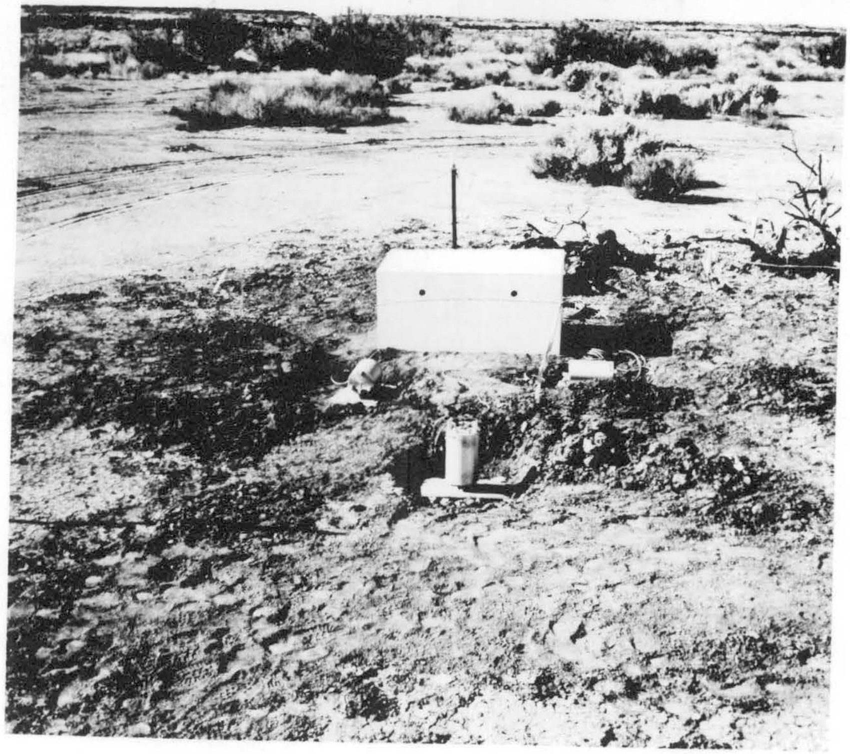


Figure 6. Field installation of Model ASC-2 Seismograph System in Tularosa Basin.

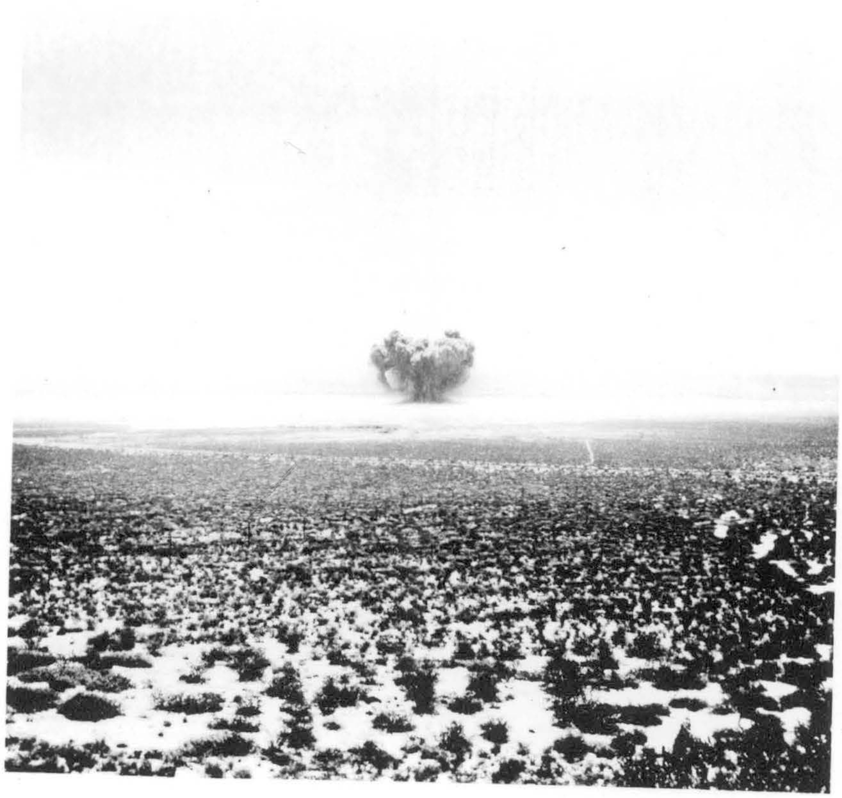


Figure 8. Surface Explosion on August 12, 1975 in Tularosa Basin.

Results

Figures 9 through 18 show the pseudo relative velocity (PSRV) spectra with 5% damping at each station (Jenschke, 1970). The ASC-2 spectra were adjusted to the L-7 spectra using data from station E-16000 as both systems recorded events at this site.

The spectra along the line show considerable attenuation for the higher frequencies to the east, which would be expected as depth to bedrock increases in that direction. There is a drop in level for all periods at the more distant stations, although the general shape of the PSRV curve remains constant. Spectra around the 1 second period region is dominant at all the eastern stations.

In Figure 19 the PSRV spectra amplitudes are plotted against distance for 0.1 Hz and 1 Hz. This figure shows that more high frequency energy is transmitted west of the shot than east. There may be some contamination from high frequency noise in this portion of the spectrum which could effect this interpretation. The 1 Hz energy shows little or no attenuation which is due to the predominance of one second period in the surface waves and to the so called X wave which is the large surface wave arriving after the main surface wave train and traveling at a slower group velocity than the normal surface wave portion. The nature of this X wave is unknown and subject to a great deal of speculation. The seismograms in the appendix display this phase quite clearly, particularly at station E-24000. Tables 3 and 4 contain arrival times and ground amplitudes for the major phases at each site for each shot.

The E-35000 and E-Lava stations were located about 700 meters apart. E-Lava was placed on the Malpais Lava flow while E-35000 was located on alluvium. The PSRV spectra (Figures 14 and 15) show an increase in energy in the shorter periods on the lava flow. At longer periods beginning near 0.7 seconds, the plots are almost identical.

The Figure 20 shows a comparison of the PSRV spectra between the two shots at station W-15000. The offset in level probably represents small differences between the two explosions and the change in shot point location. Different types of explosives were used together with different methods of detonation. The actual distance between the two shot points was about 1,000 meters. Figure 21 is a velocity profile nearly east-west across the area near the place the stations were situated.

FIGURE 9. PSRV OF STATION W-15000

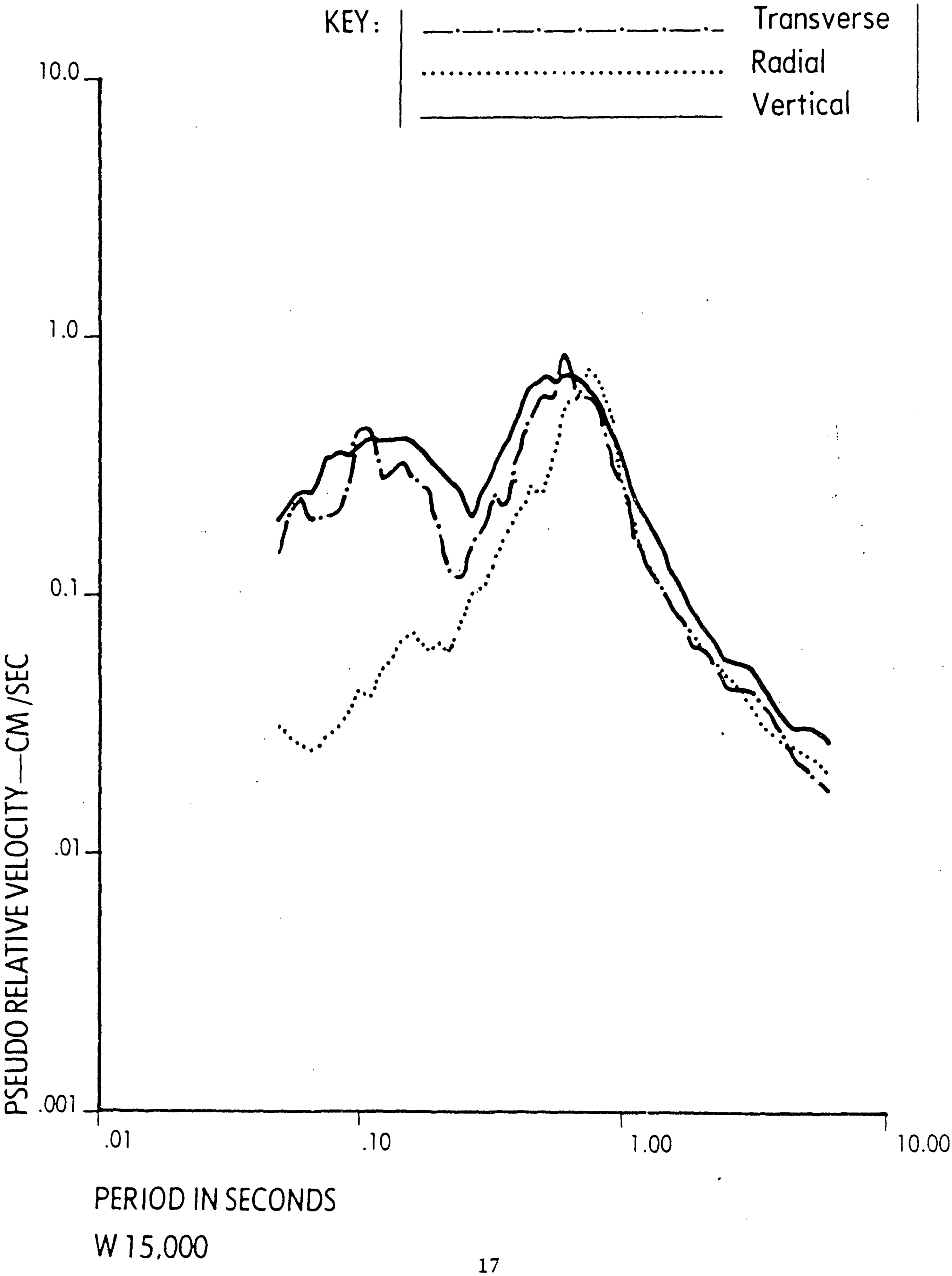


FIGURE 10. PSRV OF STATION W-12000

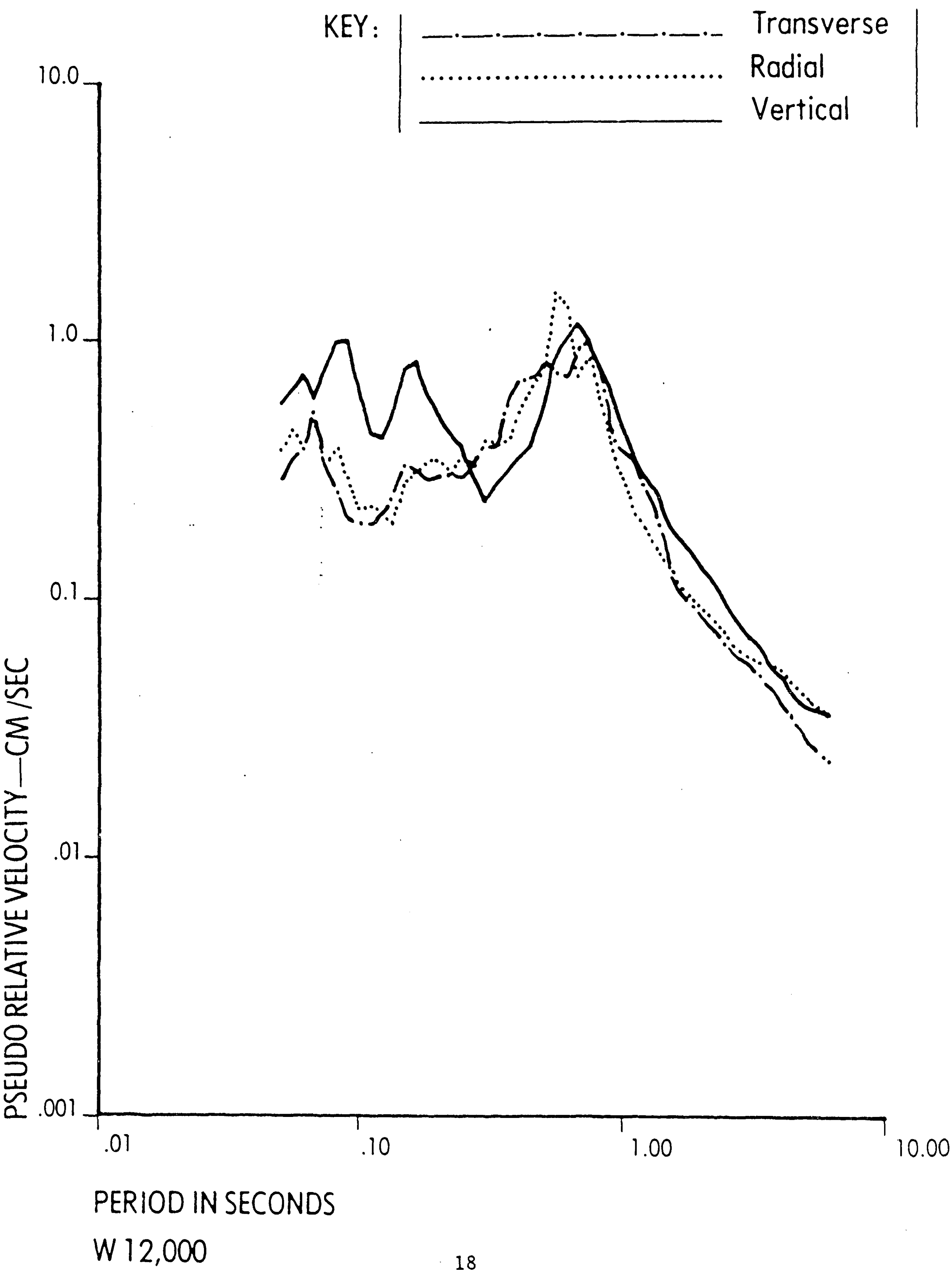


FIGURE 11. PSRV OF STATION W-9000

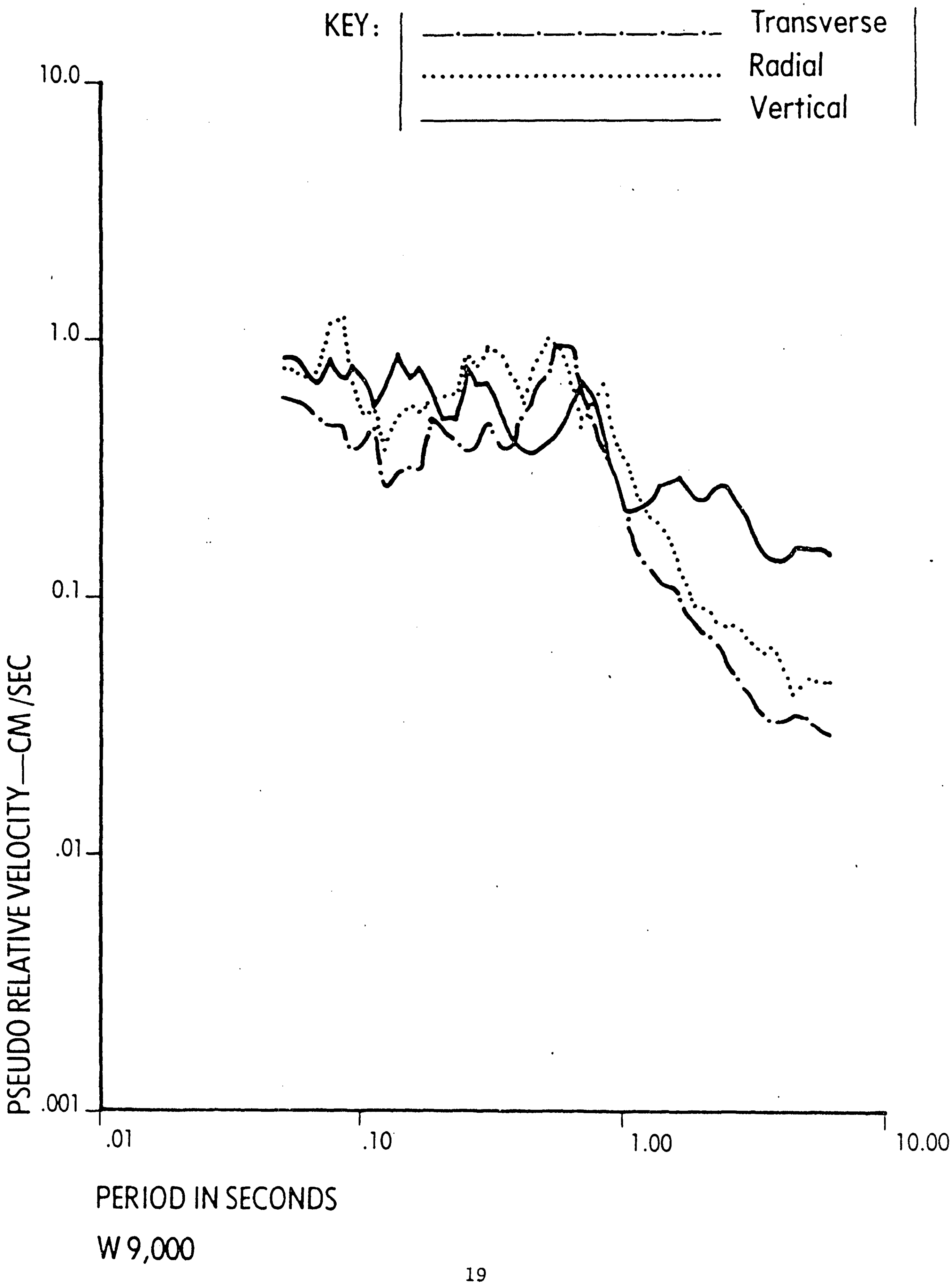


FIGURE 12. PSRV OF STATION E-9000

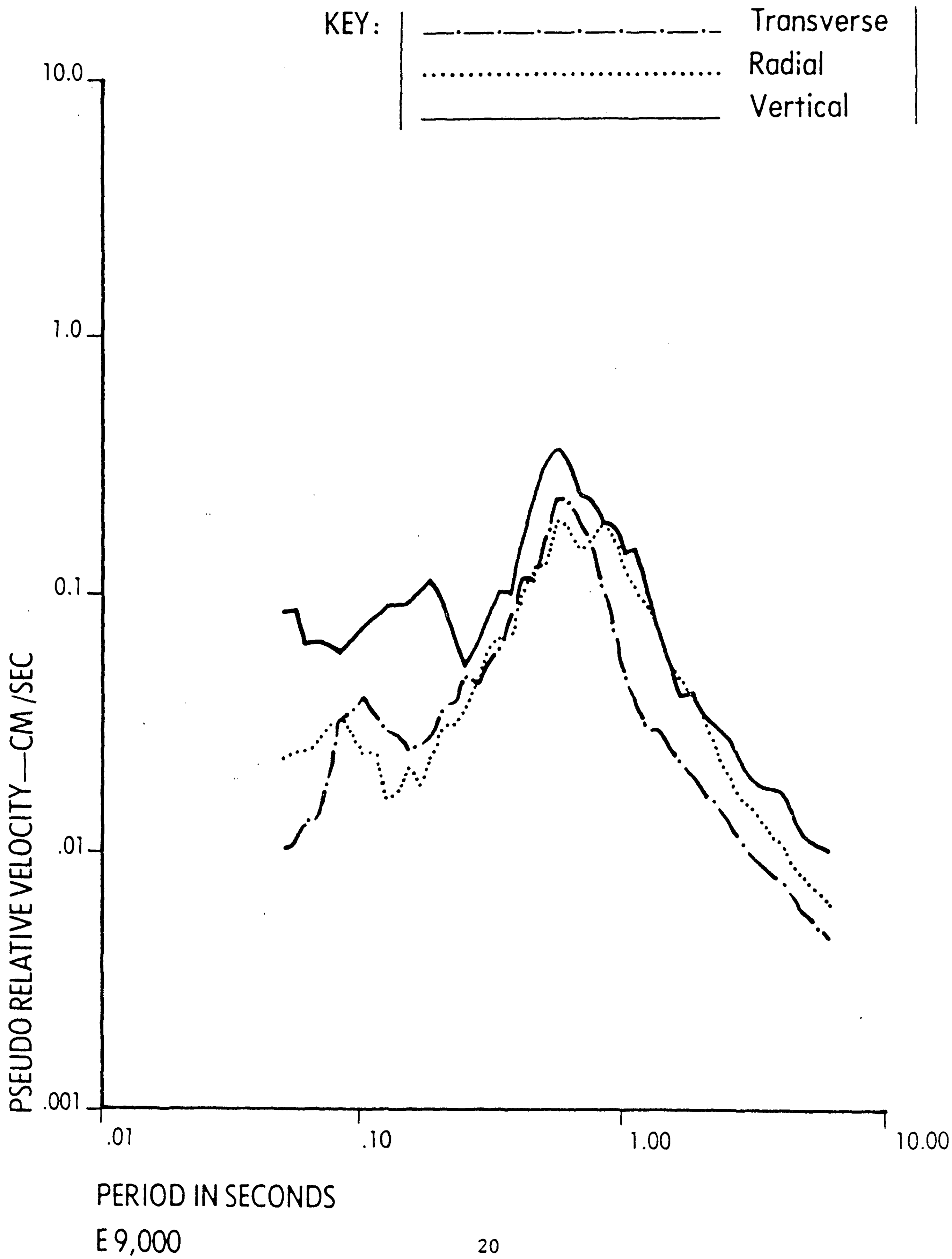
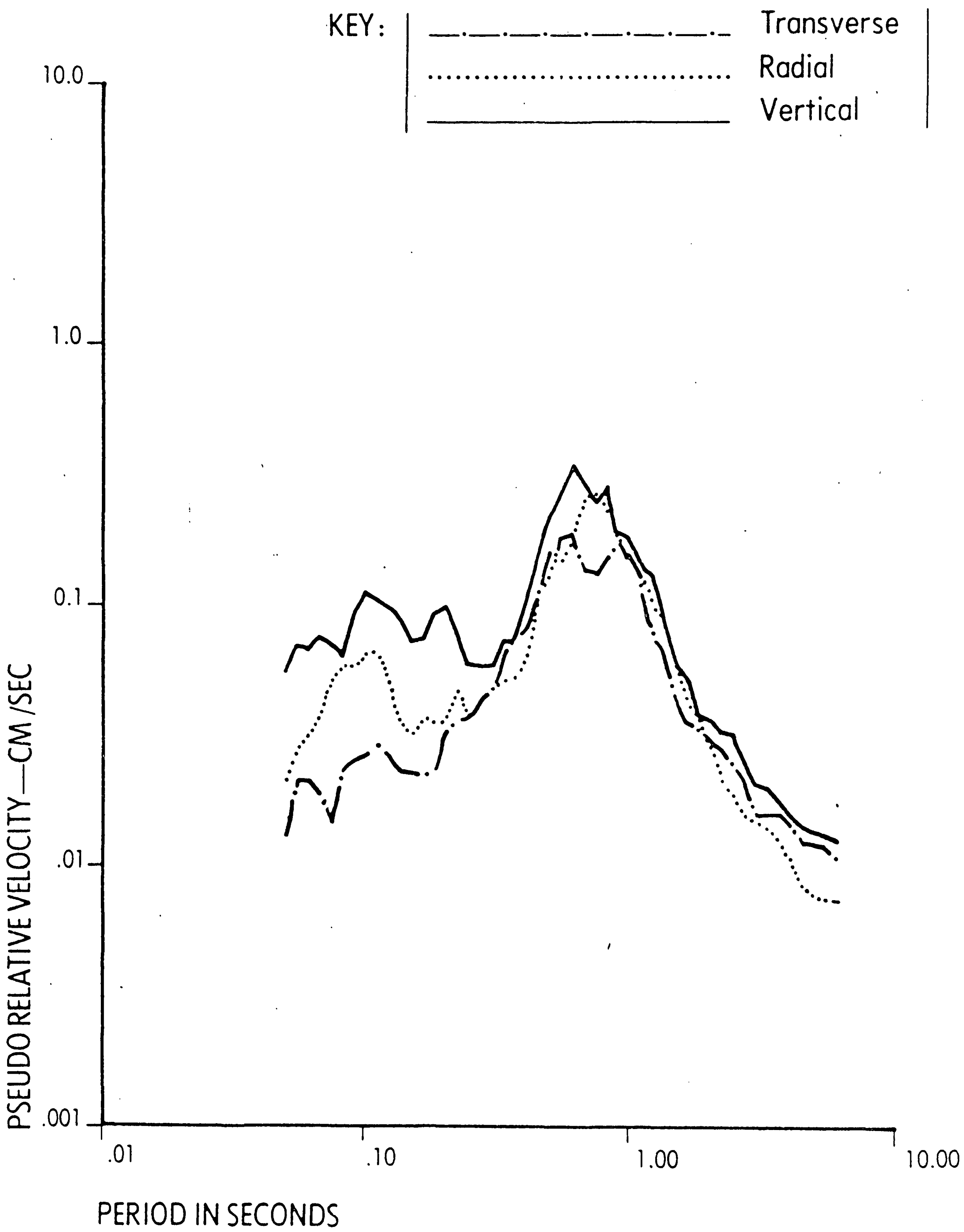


FIGURE 13. PSRV OF STATION E-16000



E 16,000

FIGURE 14. PSRV OF STATION E-35000

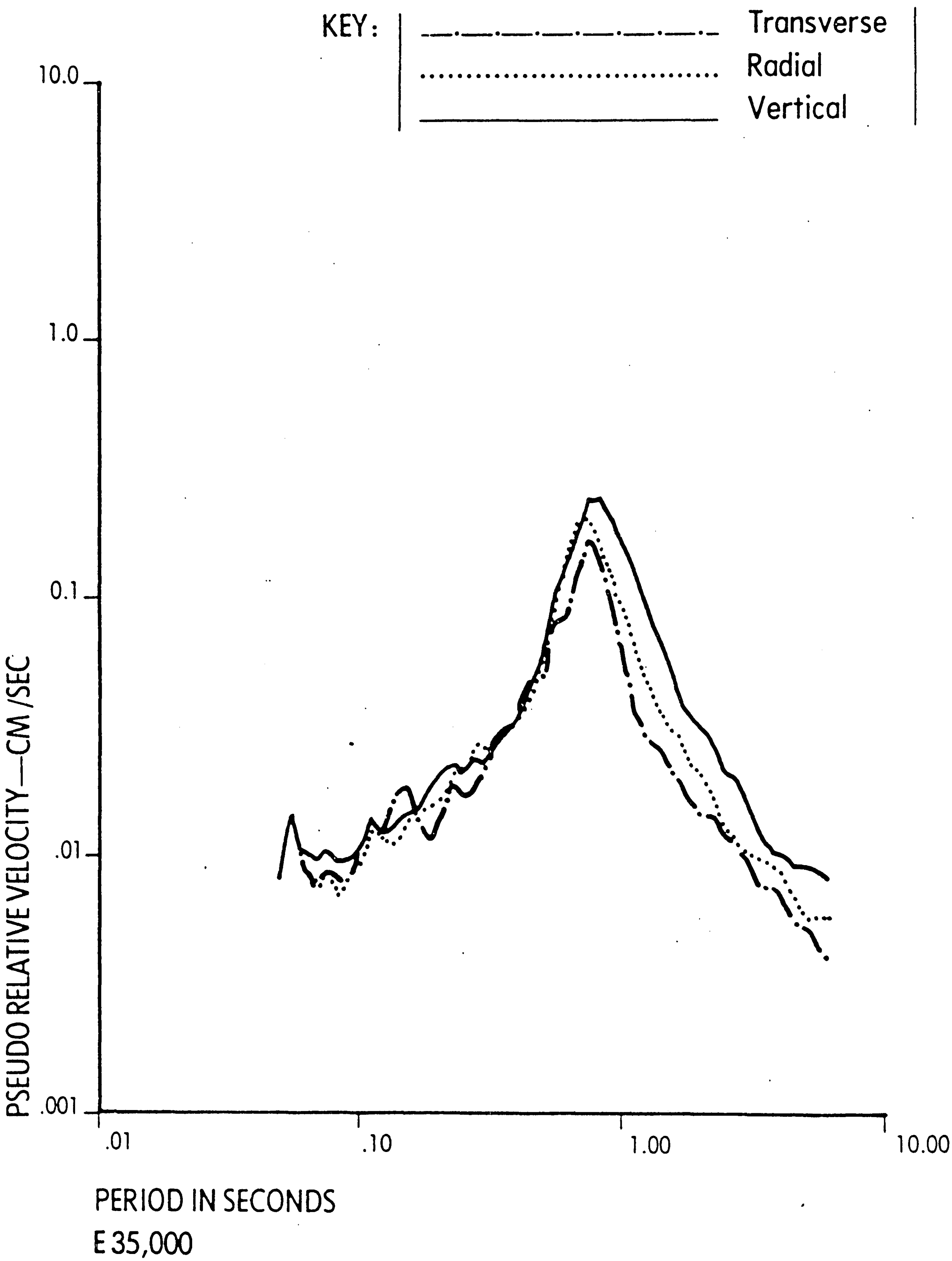


FIGURE 15. PSRV OF STATION E-LAVA

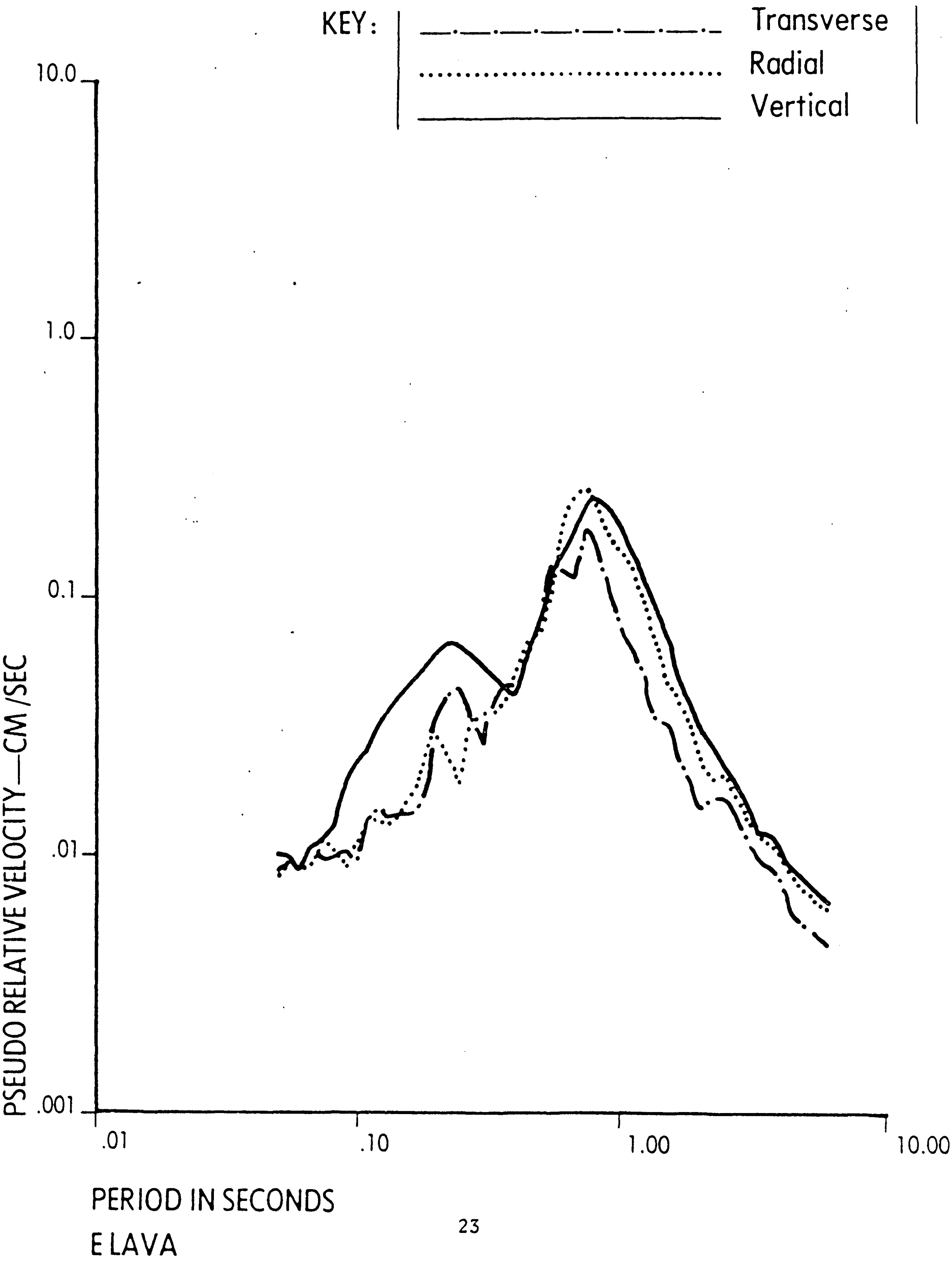


FIGURE 16. PSRV OF STATION OR-1

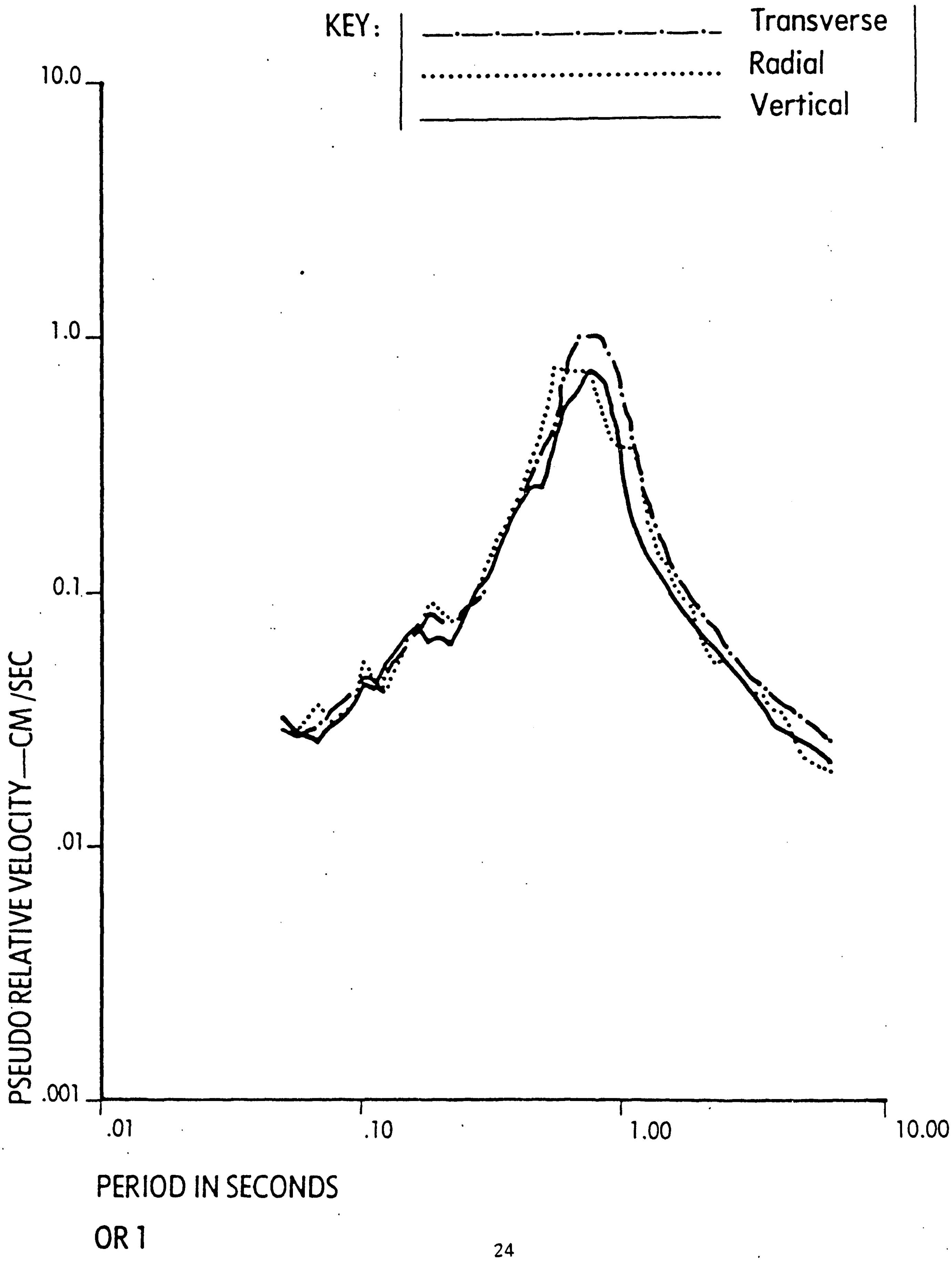


FIGURE 17. PSRV OF STATION OR-2

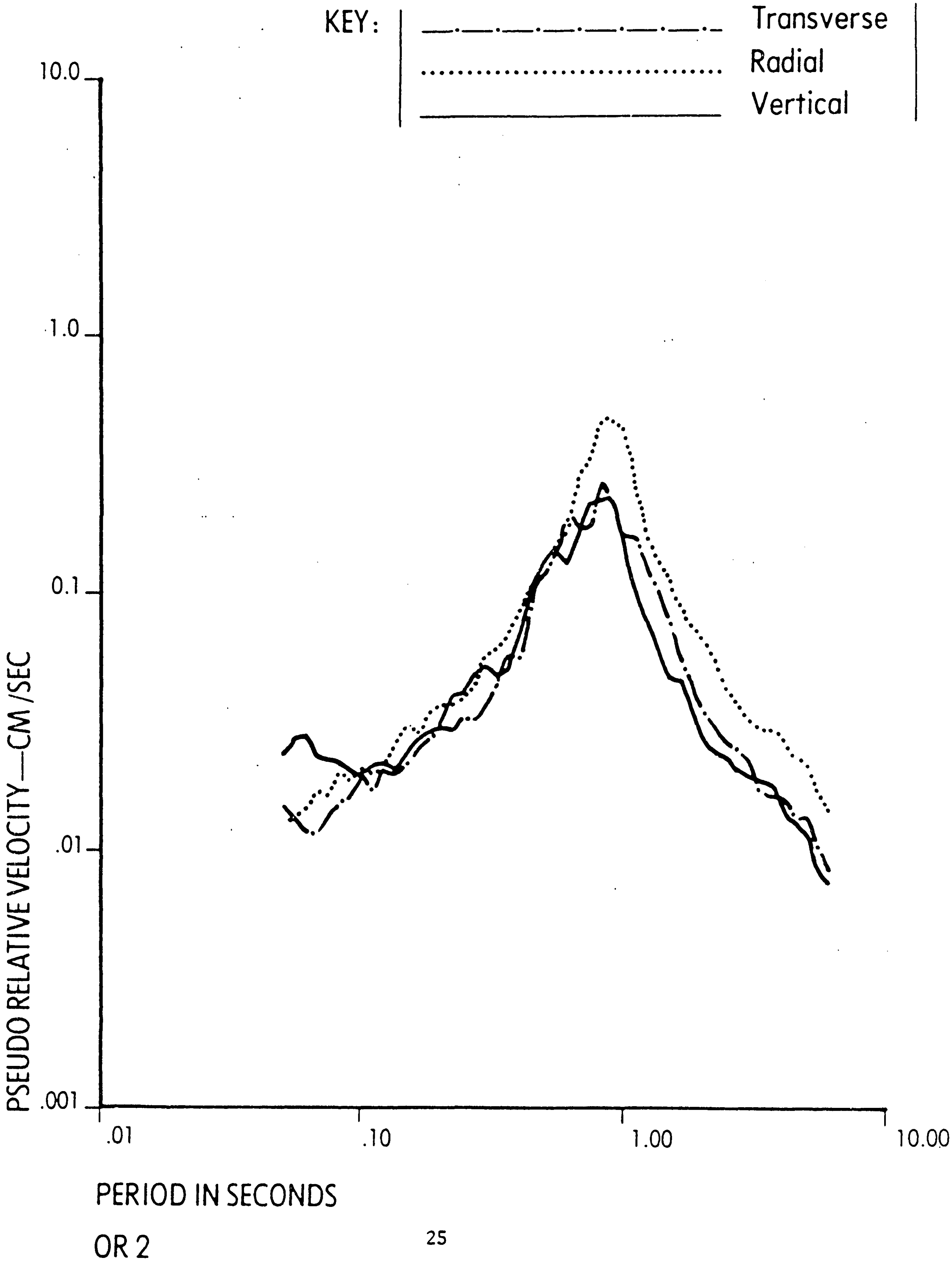
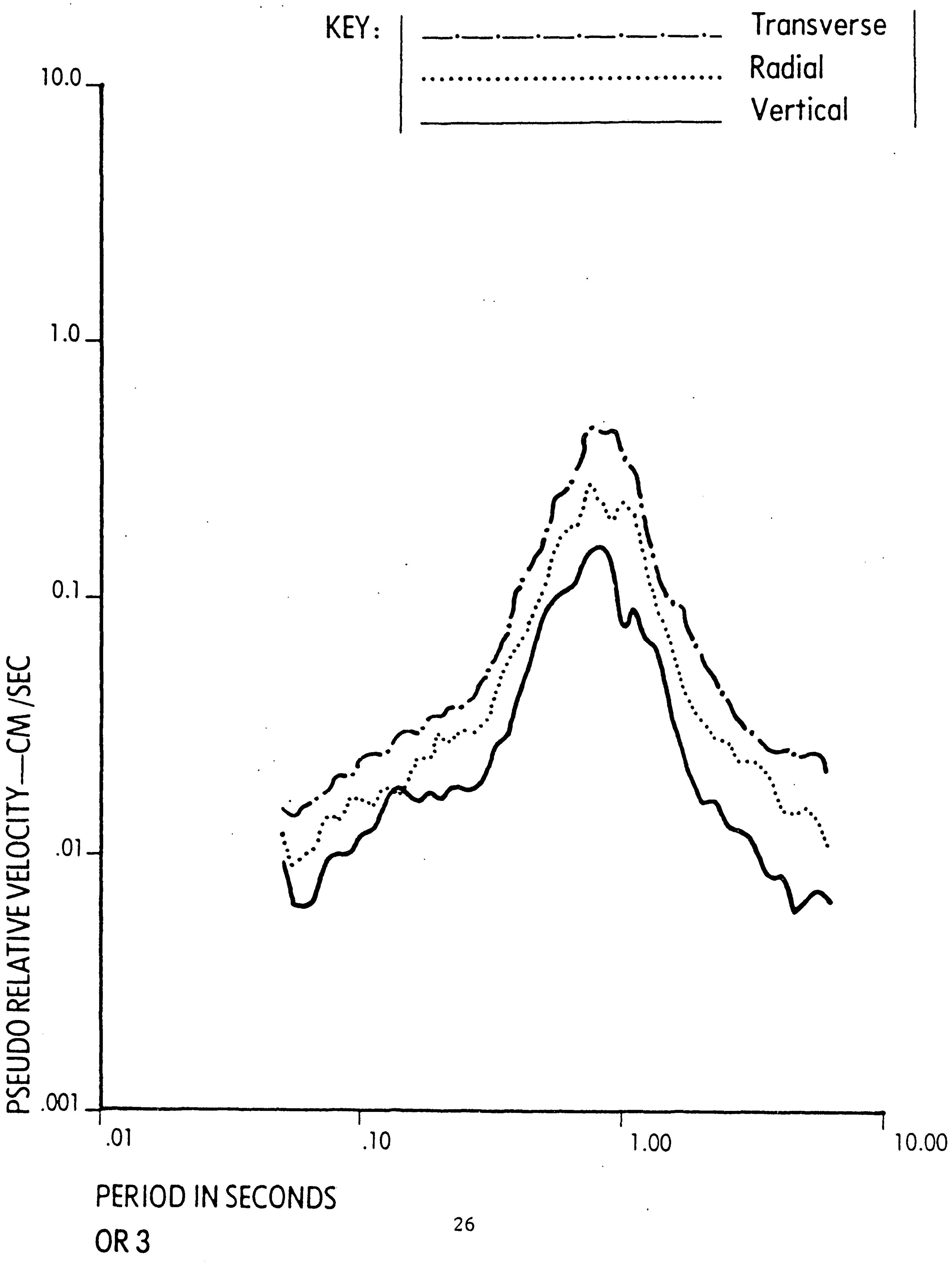


FIGURE 18. PSRV OF STATION OR-3



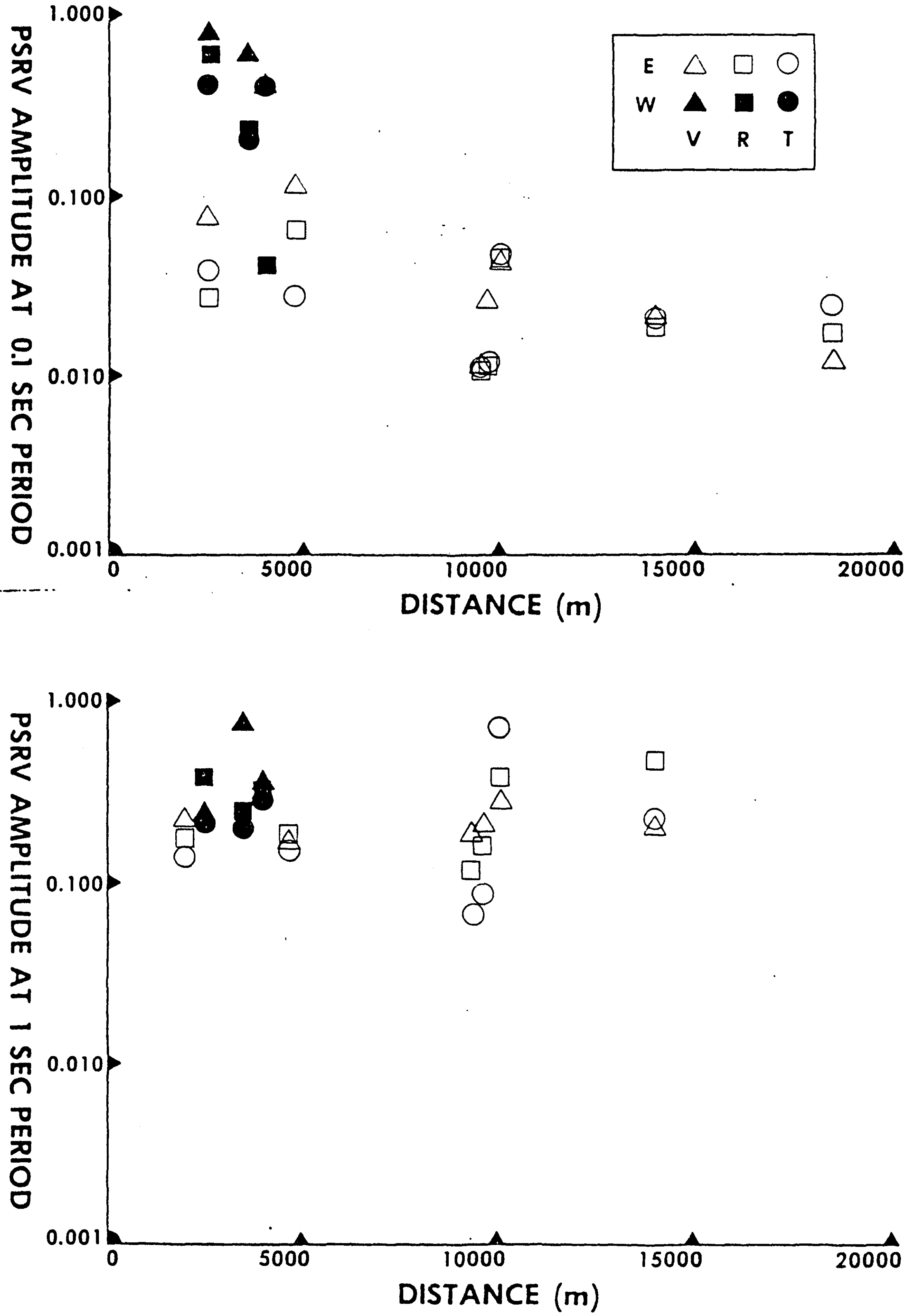


Figure 19. Plots of PSRV amplitude at 0.1 second and 1.0 second versus distance from shot point for vertical, radial and transverse components. Open symbols east of shot point; solid symbols west of shot point.

TABLE 3

ARRIVAL TIMES AND AMPLITUDES FOR AUGUST 12, 1975

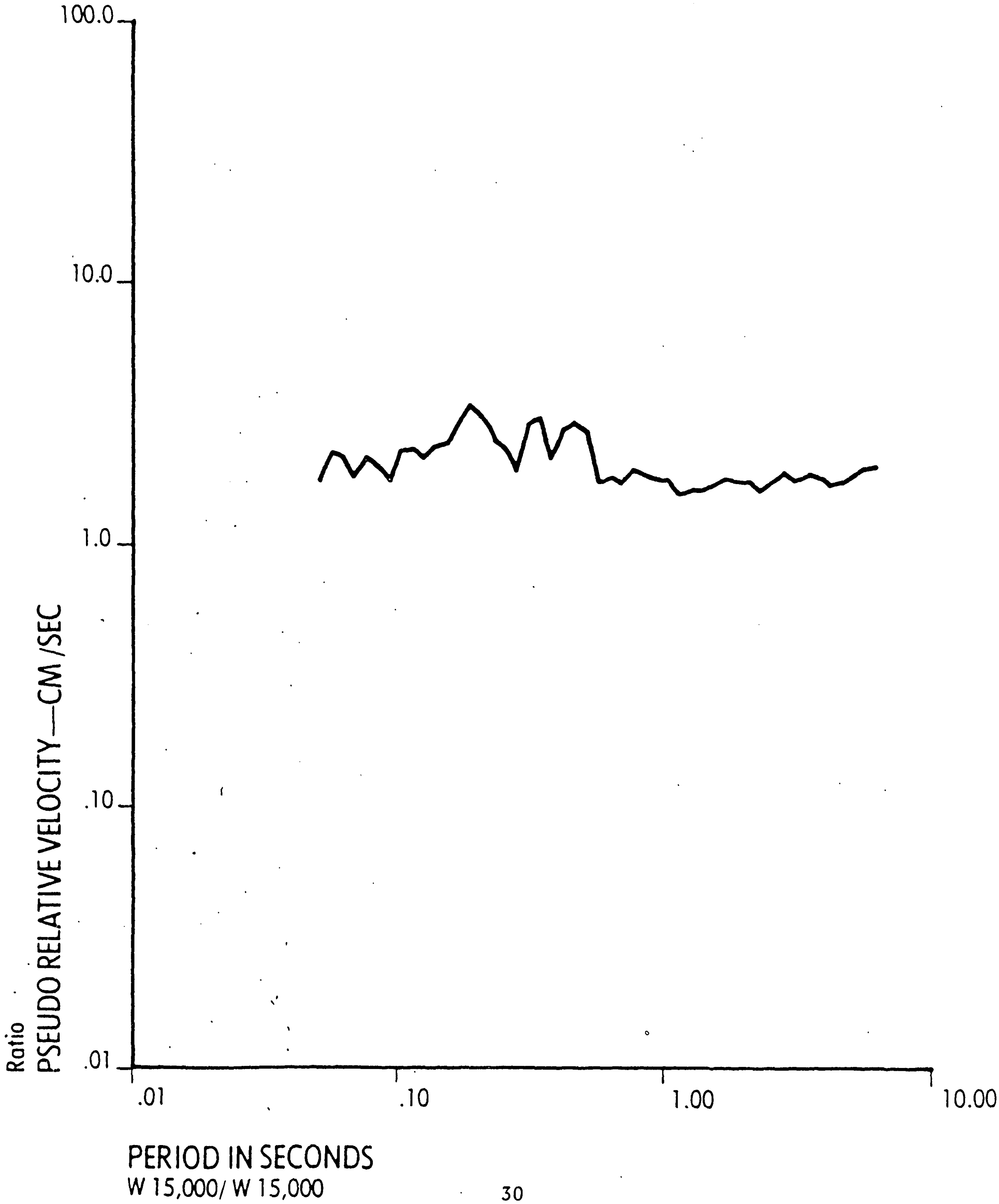
Station	Phase	Arrival Time (GMT)	Frequency (Hz)	Ground Motion (Microns)	Remarks
W-15000	P	17:00:01.20	11.0	2	Initial P phase weak; P_1 considerably stronger. Raleigh wave (R) quite weak on vertical component. All arrivals and amplitudes are picked from vertical component.
	P_1	17:00:01.56	11.0	8.2	
	R	17:00:03.72	1.6	24	
	X	17:00:06.78	1.6	104	
W-12000	P	17:00:01.19	13	22	P phase arrivals very strong; P_1 difficult to pick. R weak on vertical. Arrival times very close to station W-15000.
	P_1	17:00:01.51	13	22	
	R	17:00:03.64	1.6	92	
	X	17:00:06.12	1.6	276	
E-16000	P	17:00:01.12	?	?	Initial P phase very small and emergent, difficult to pick. Ground motion less than 1 micron.
	P_1	17:00:01.68	11	4	
	R	17:00:04.05	1.6	42	
	X	17:00:08.98	1.6	105	
E-24000	P	17:00:02.25			Initial P phases very weak.
	P_1	17:00:02.94			
	R	17:00:06.50	1.6	41	
	X	17:00:13.65	1.6	61.5	
E-35000	P	17:00:02.50			Initial P very weak. Start of surface waves (R) very emergent.
	P_1	17:00:03.13	5	4	
	R	17:00:07.86	1.5	35	
	X	17:00:17.06	1.5	29	
E-Lava	P	?			Could not pick initial P.
	P_1	17:00:03.15	5	6	
	R	17:00:08.26	1.5	30	
	X	17:00:17.33	1.5	29	

TABLE 4

ARRIVAL TIMES AND AMPLITUDES FOR SETPEMBER 22, 1975

STATION	PHASE	ARRIVAL TIME	FREQUENCY (HZ)	GROUND MOTION (MICRONS)	REMARKS
OR-1	P	12:00:02.4	5 Hz	2.2	Good record. Starting time for all
	P_1	12:00:03.26	2.7	5	R and X phases are approximate.
	R	12:00:10.1	1.3	62	
	X	12:00:19.2	1.3	28	
OR-2	P	12:00:03.43	---	---	P phase very weak.
	P_1	12:00:04.95	2.7	2	
	R	12:00:12.5	1.2	21	R and X waves appeared continuous, no well defined X arrival.
OR-3	P	12:00:03.77	4.5	0.5	P phases quite small.
	P_1	12:00:05.4	4.5	0.5	
	R	12:00:15.2	1.5	3	R and X phases appear to be
	X		1.5	5	continuous.
E-24000	P	12:00:02.73	6	.8	
	P_1	12:00:03.4	5	5	
	R	12:00:06.6	1.6	56	R and X phases clearly defined.
	X	12:00:13.0	1.6	75	
W-9000	P	12:00:01.62	7	58	P and P_1 phases difficult to separate.
	P_1		---	---	
	R	12:00:03.9	1.6	154	
	X	12:00:05.5	1.6	352	
W-15000	P	12:00:01.8	11 Hz	4	
	P_1	12:00:02.2	11	17	
	R	12:00:04.2	1.9	25	
	X	12:00:07.2	1.9	140	

FIGURE 20. RATIO OF PSRV OF STATION W-15000/W-15000



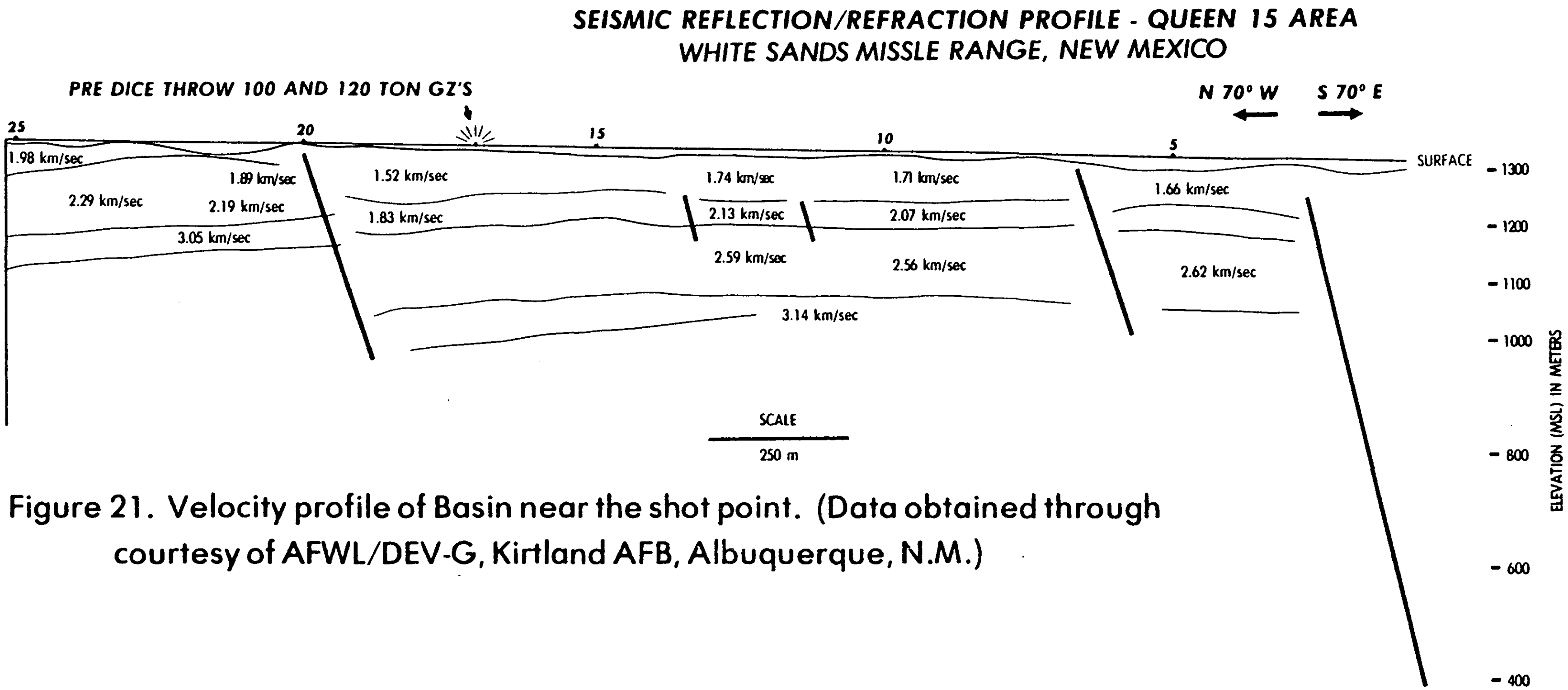


Figure 21. Velocity profile of Basin near the shot point. (Data obtained through courtesy of AFWL/DEV-G, Kirtland AFB, Albuquerque, N.M.)

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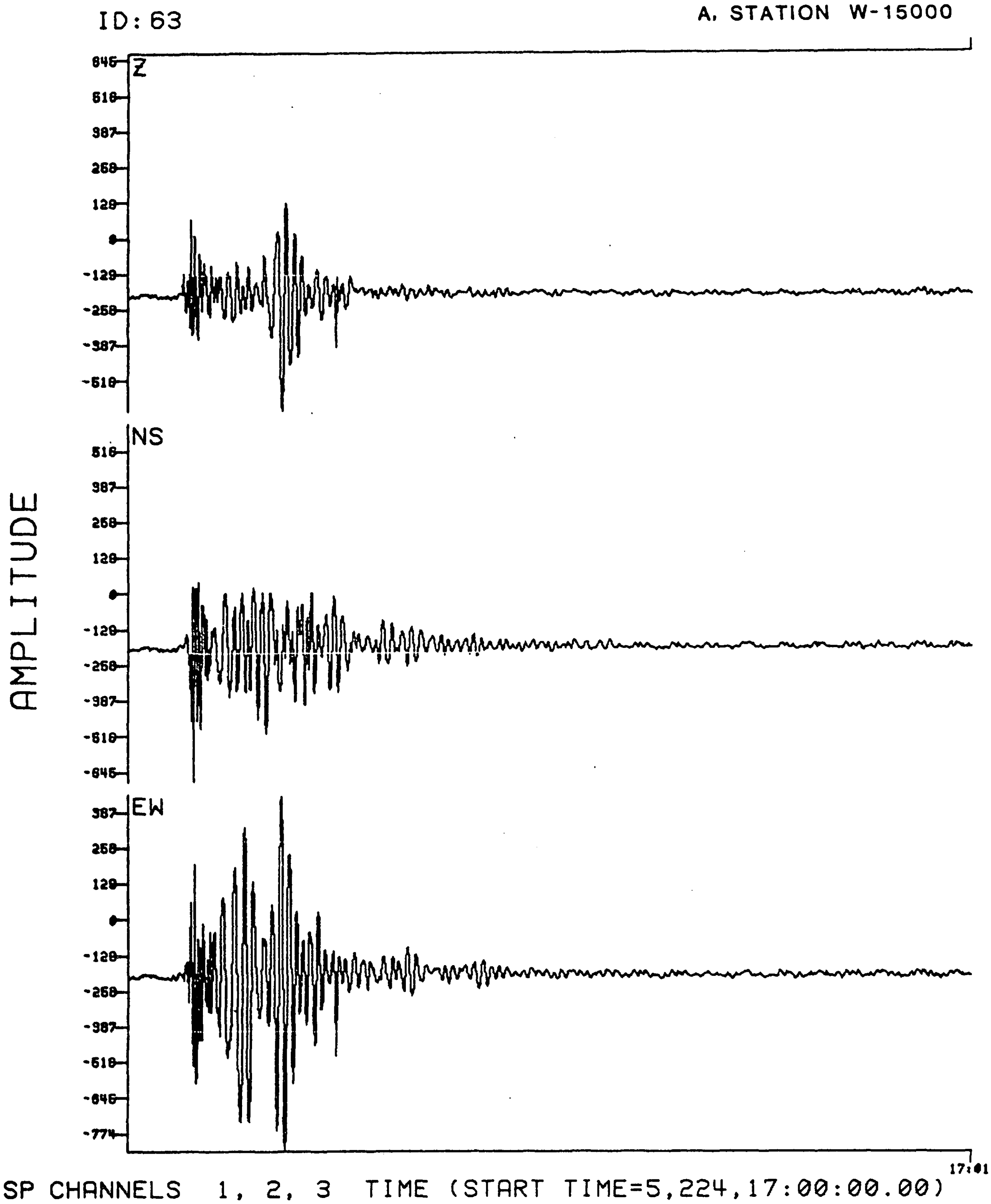
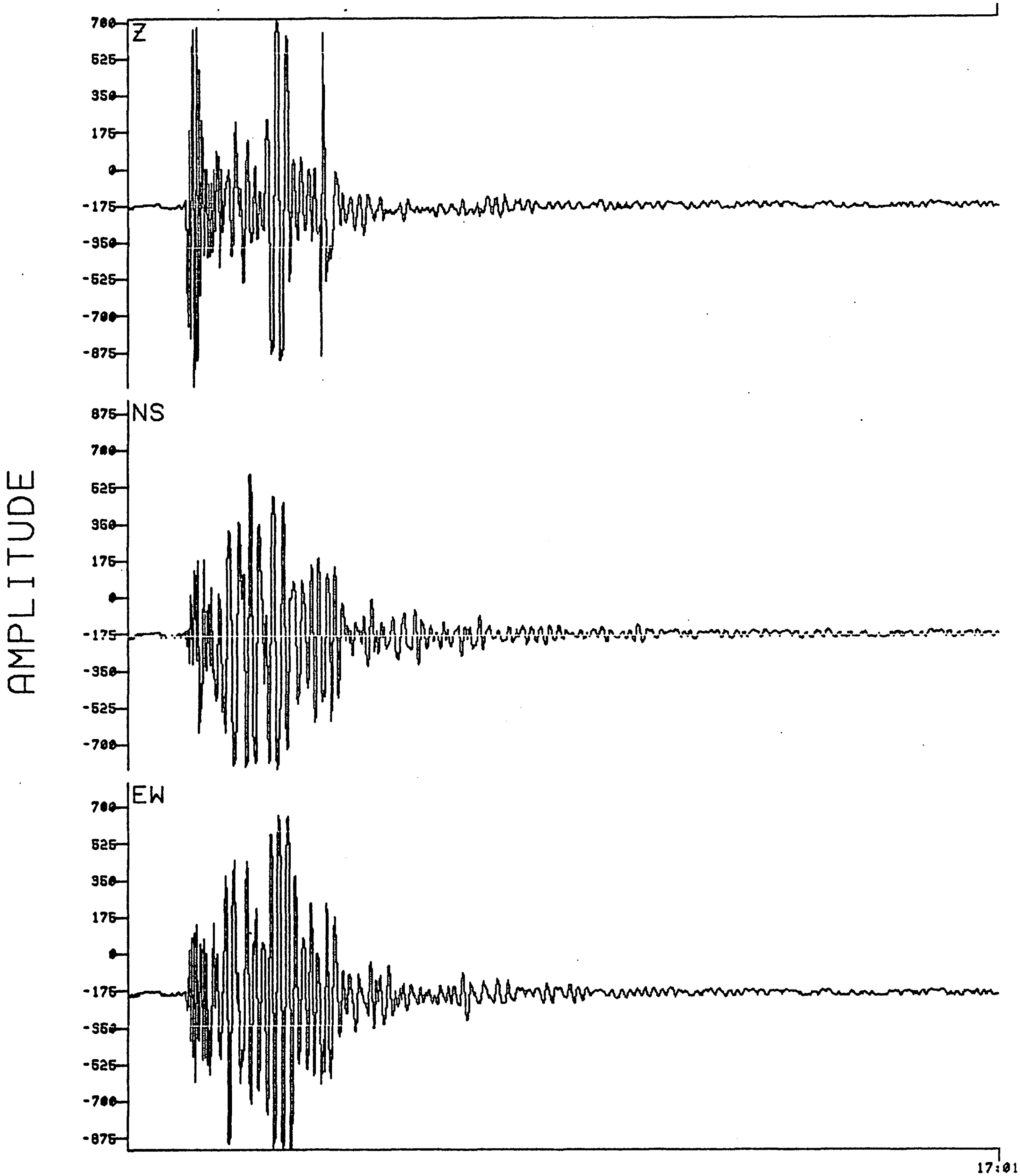
APPENDIX

Seismograms from all Field Stations

for August 12, and September 22, 1976



ID: 61 B. STATION W-12000



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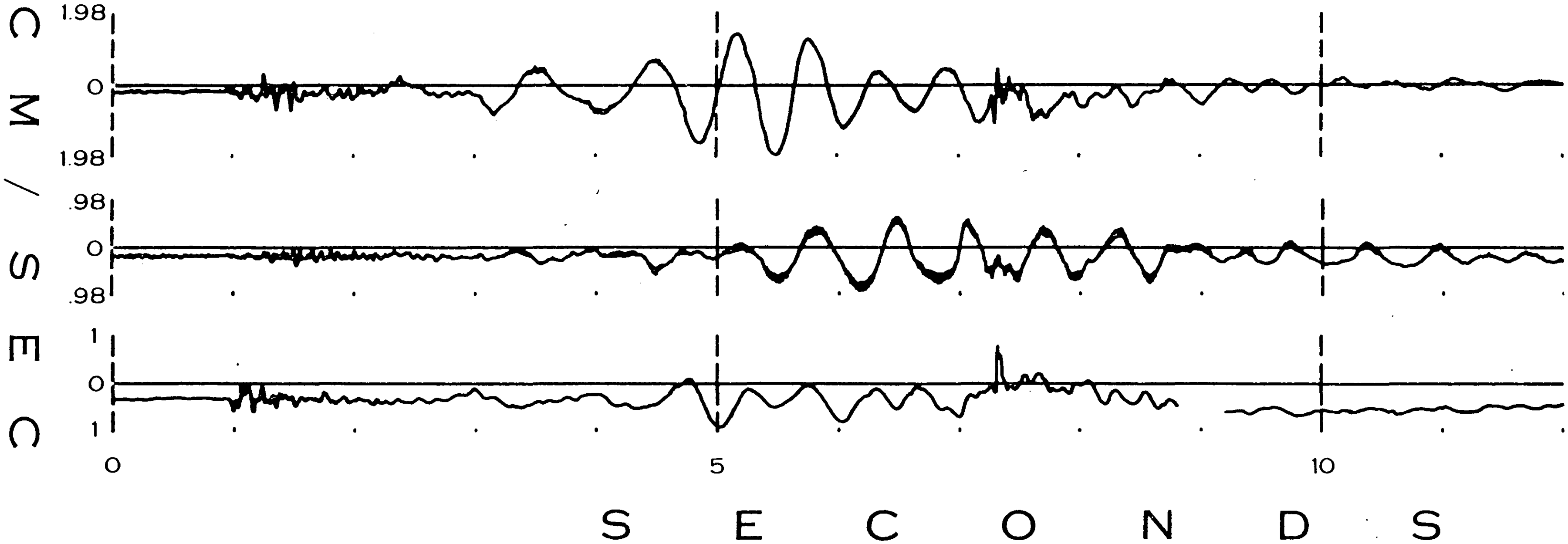

C. STATION E-9000

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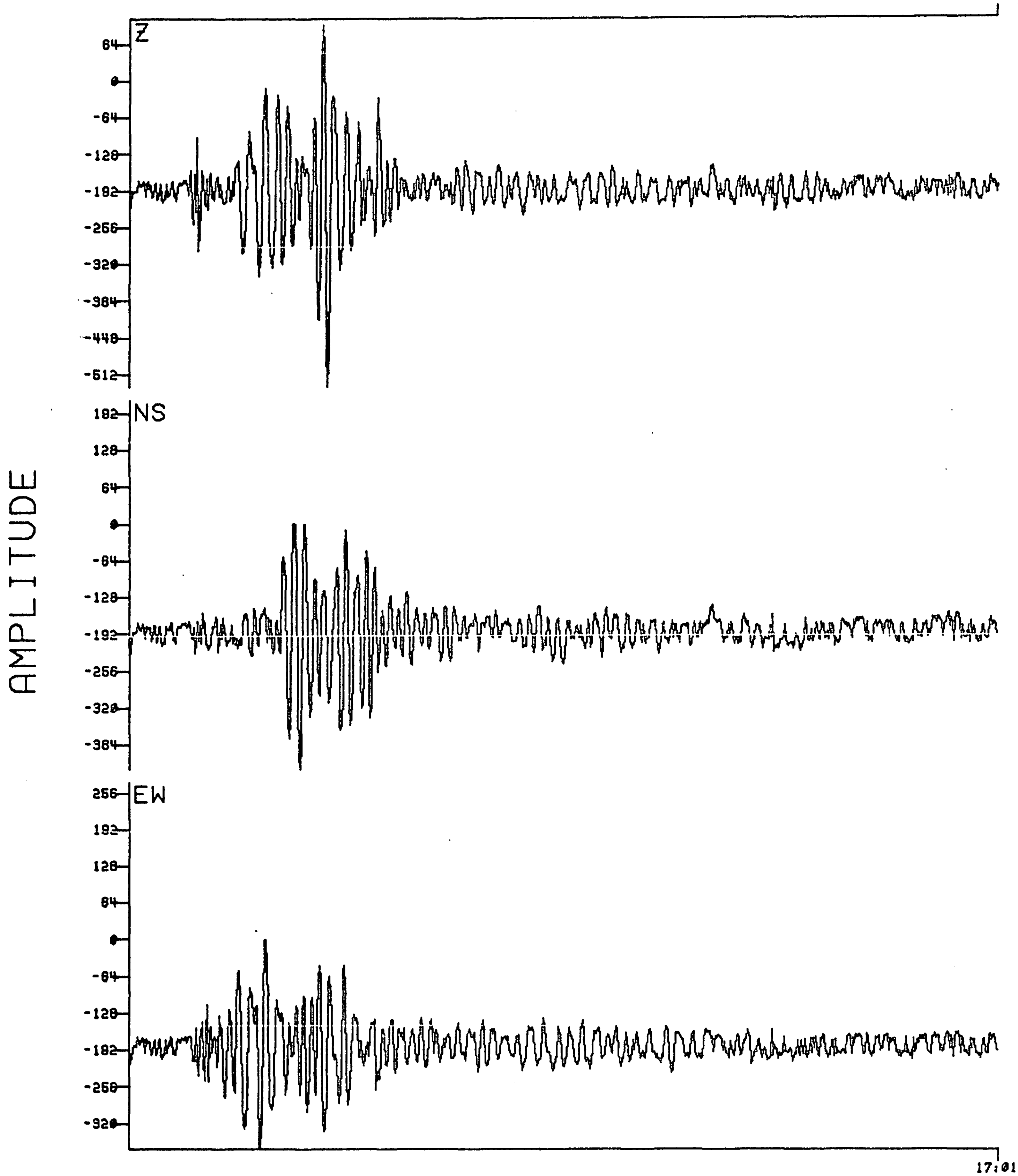
D. STATION E-16000



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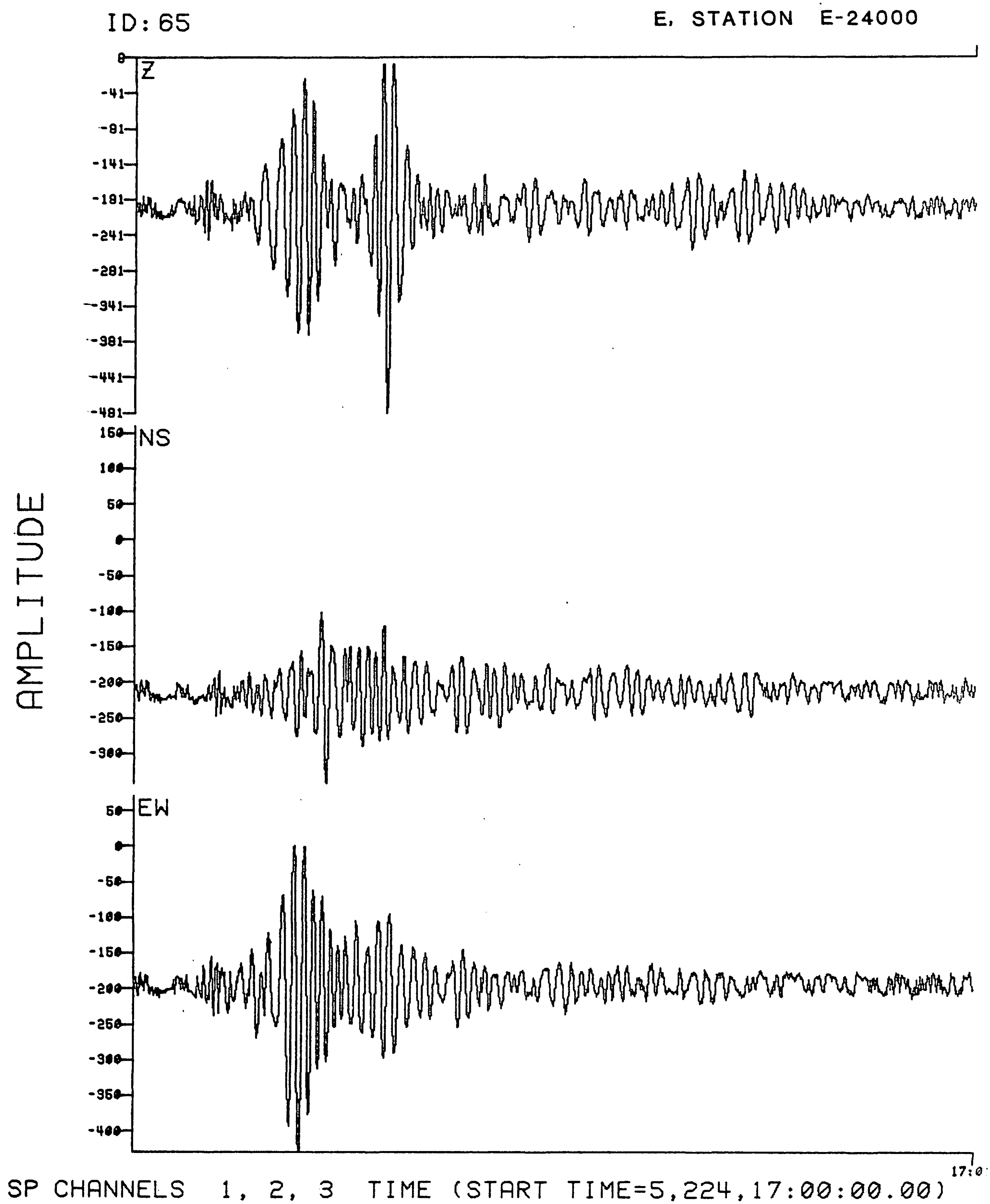
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Z
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EW
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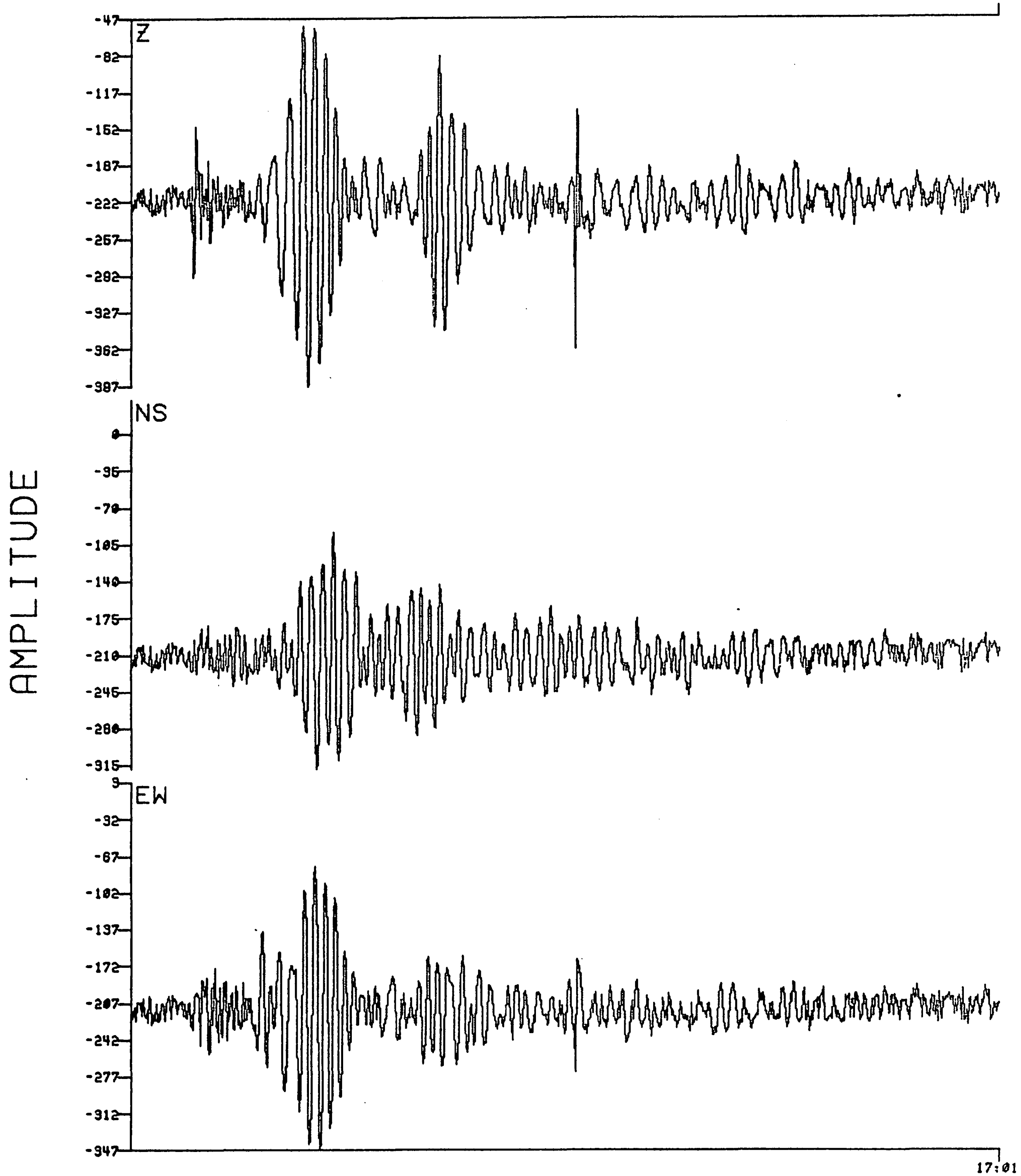
ID:66

F, STATION E-35000



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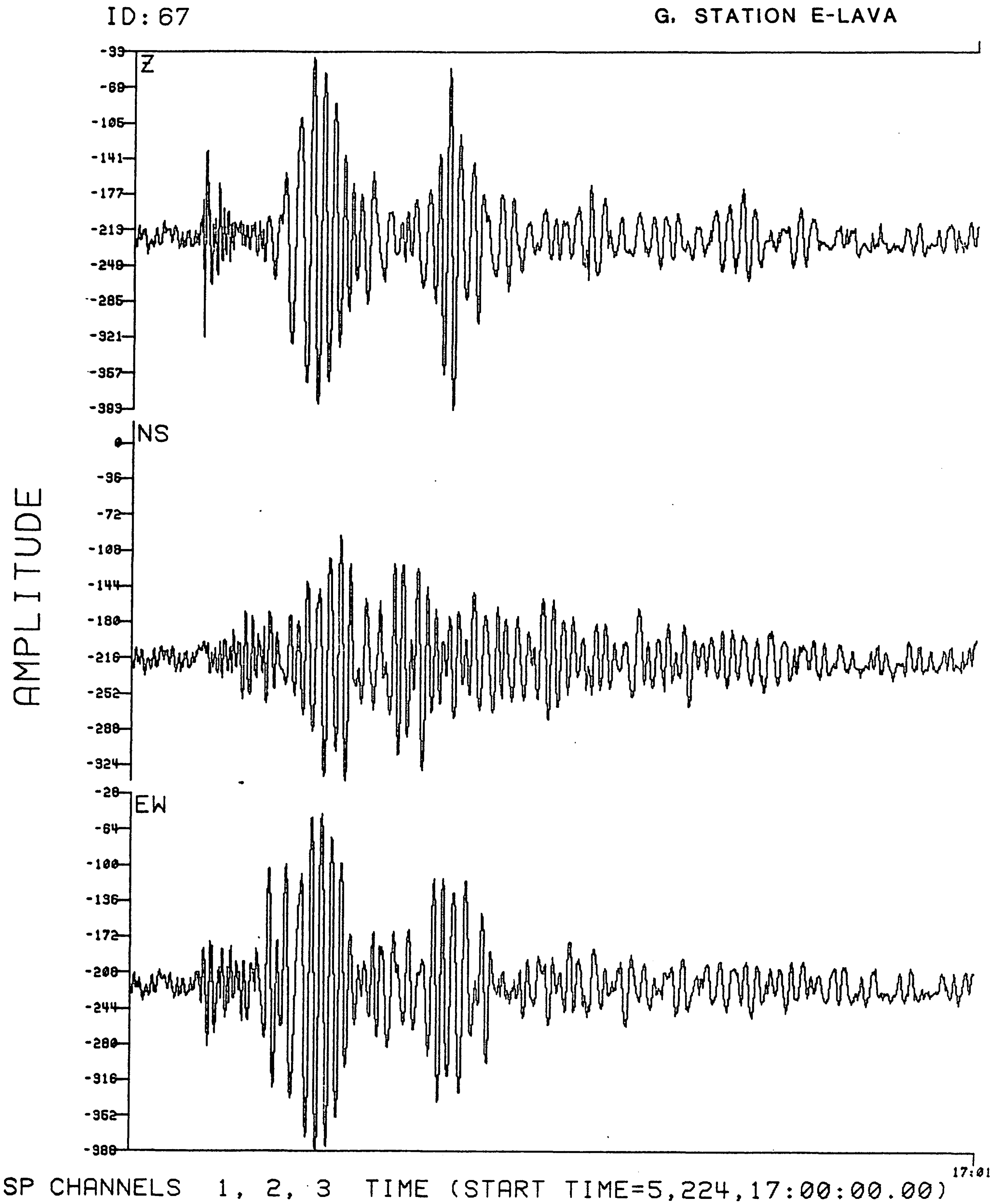

ID: 67
G. STATION E-LAVA
Z
NS
EW
AMPLITUDE
-33
-69
-105
-141
-177
-213
-249
-285
-321
-357
-393
0
-36
-72
-108
-144
-180
-216
-252
-288
-324
-28
-64
-100
-136
-172
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-244
-280
-316
-352
-388
17:01
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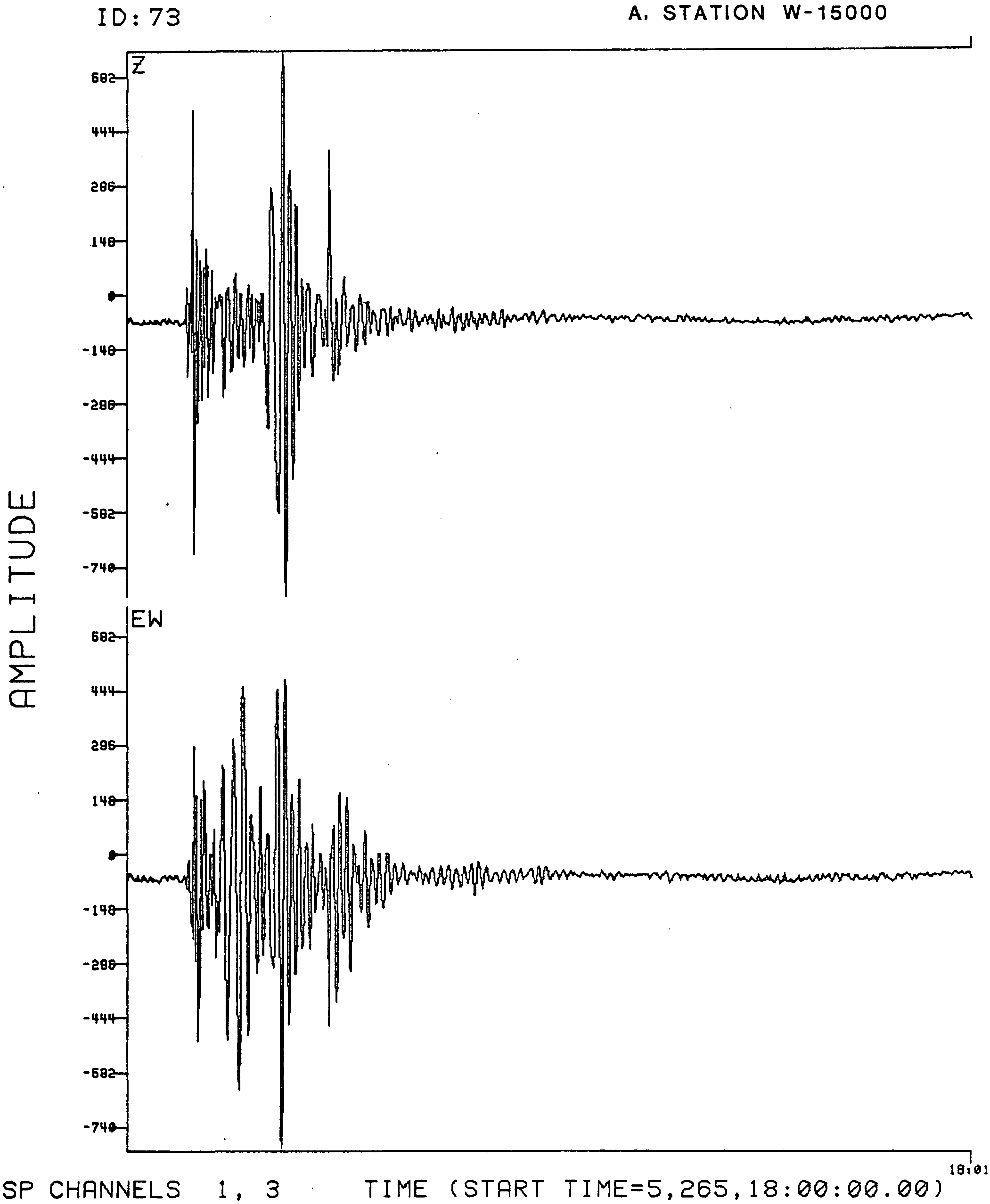
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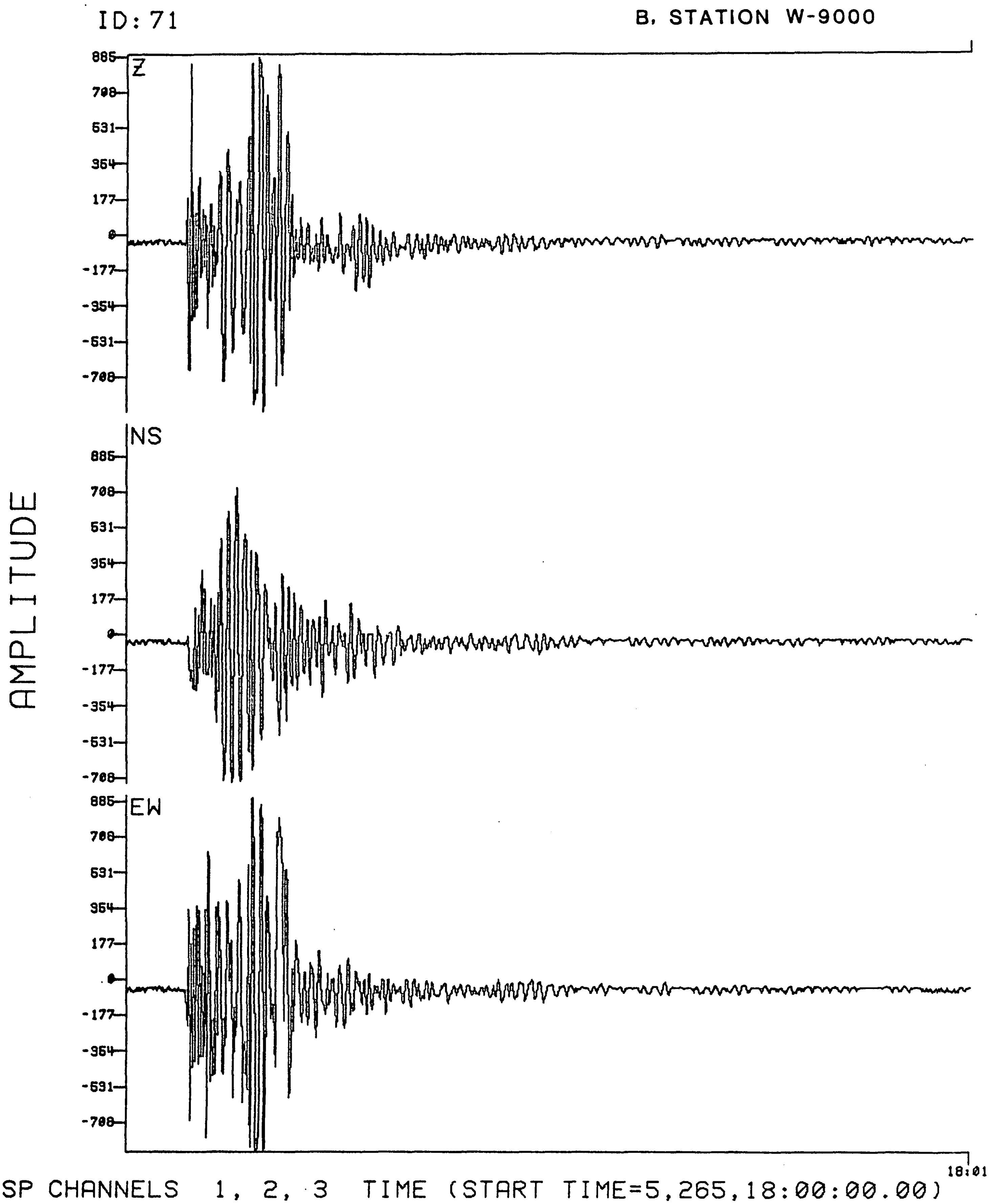
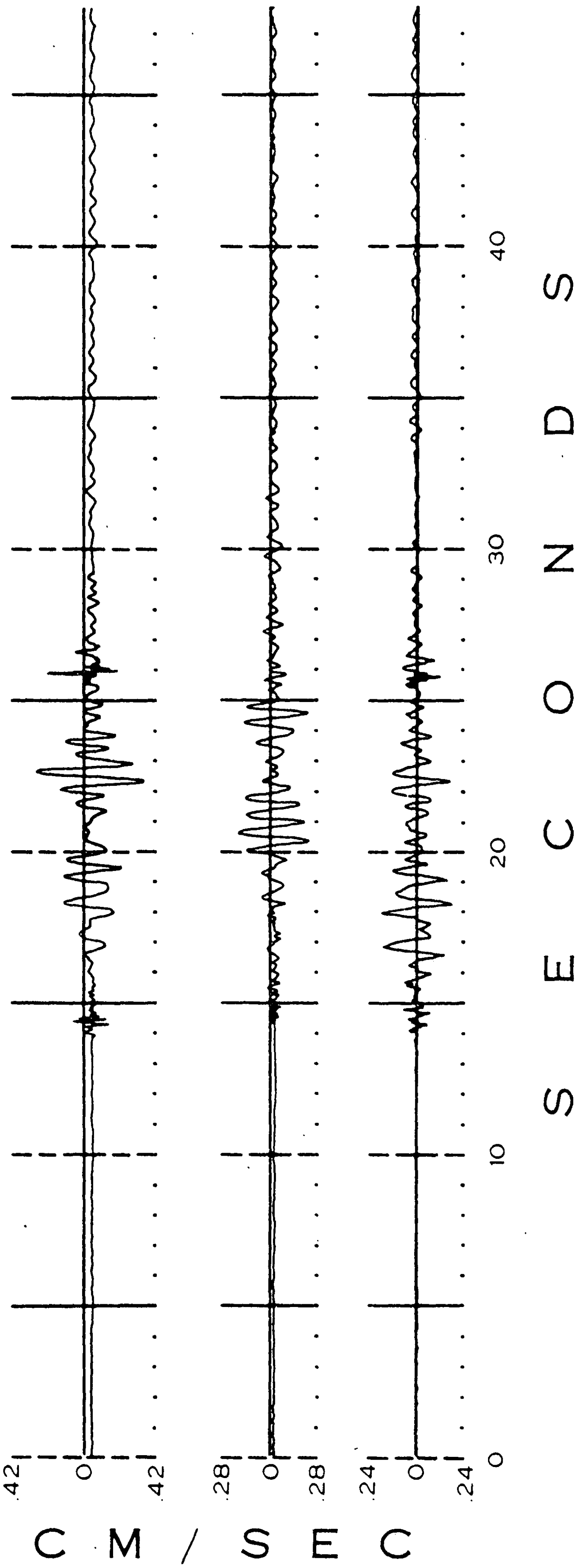
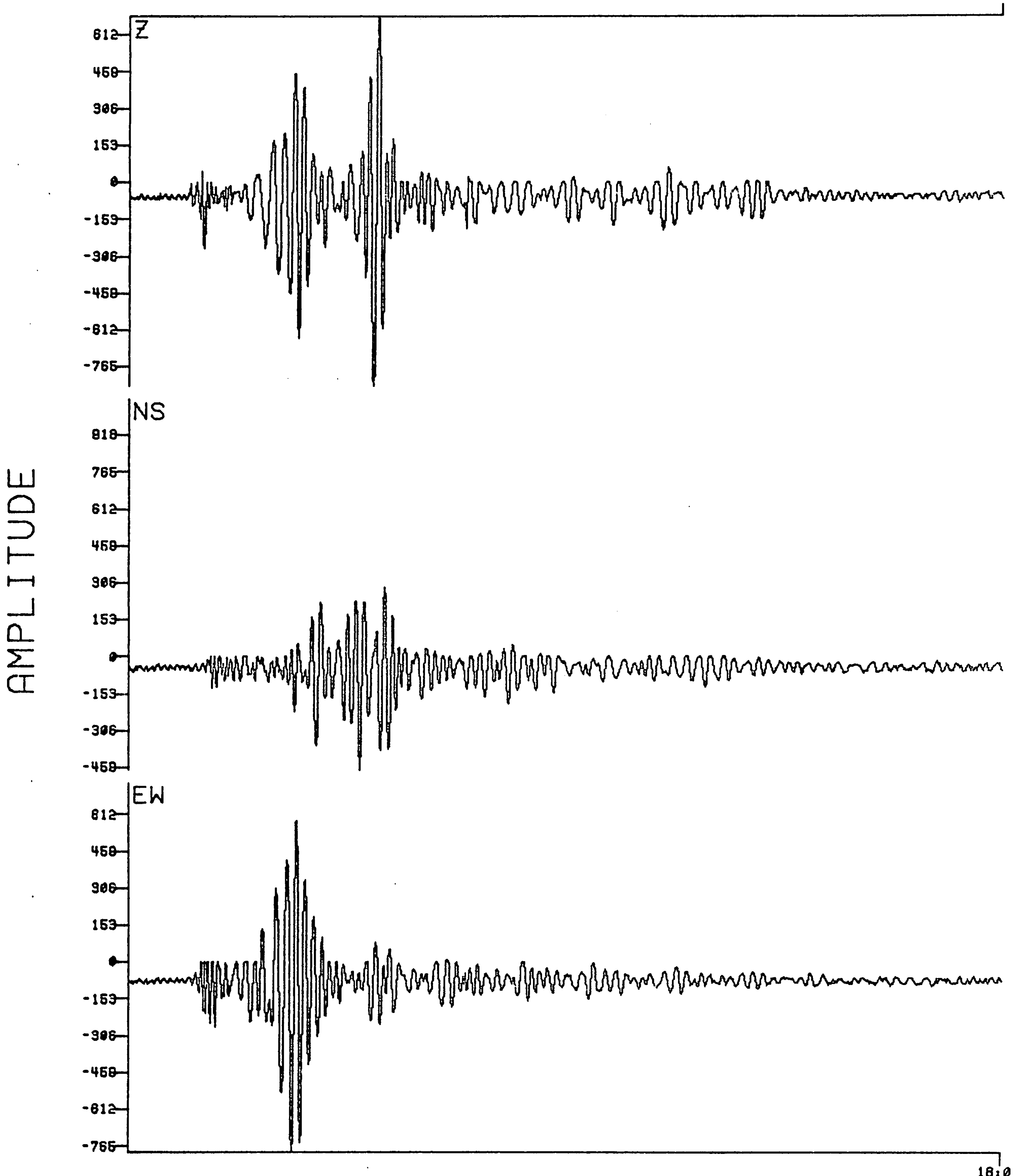
A, STATION W-15000
Z
582
444
286
148
0
-148
-286
-444
-582
-740
EW
AMPLITUDE
18:01
SP CHANNELS 1, 3
TIME (START TIME=5,265,18:00:00.00)


ID: 71
B. STATION W-9000
Z
NS
EW
AMPLITUDE
885
708
531
354
177
0
-177
-354
-531
-708
18:01
SP CHANNELS 1, 2, 3 TIME (START TIME=5,265,18:00:00.00)



C, STATION E-16000

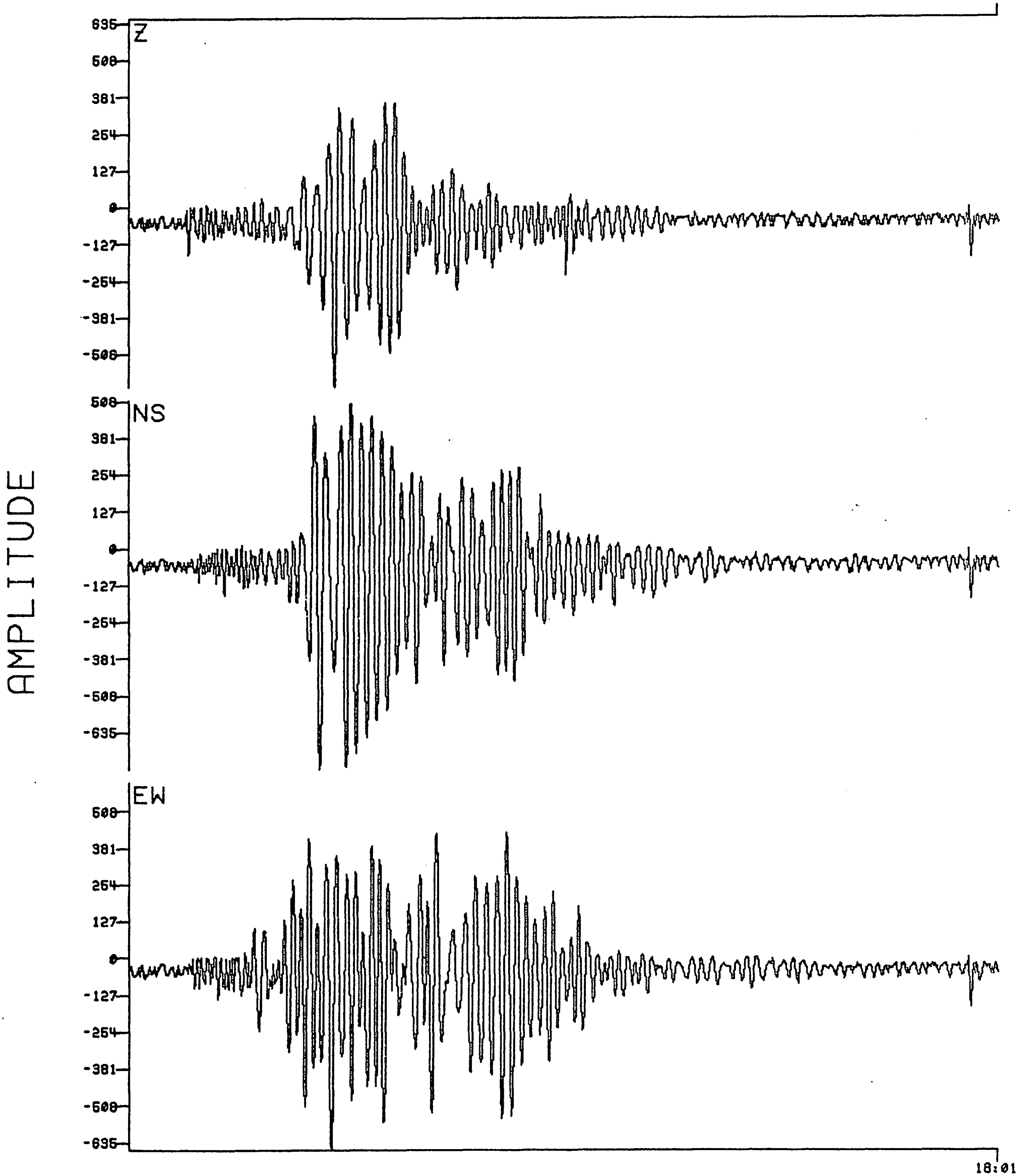
ID: 78 D. STATION E-24000



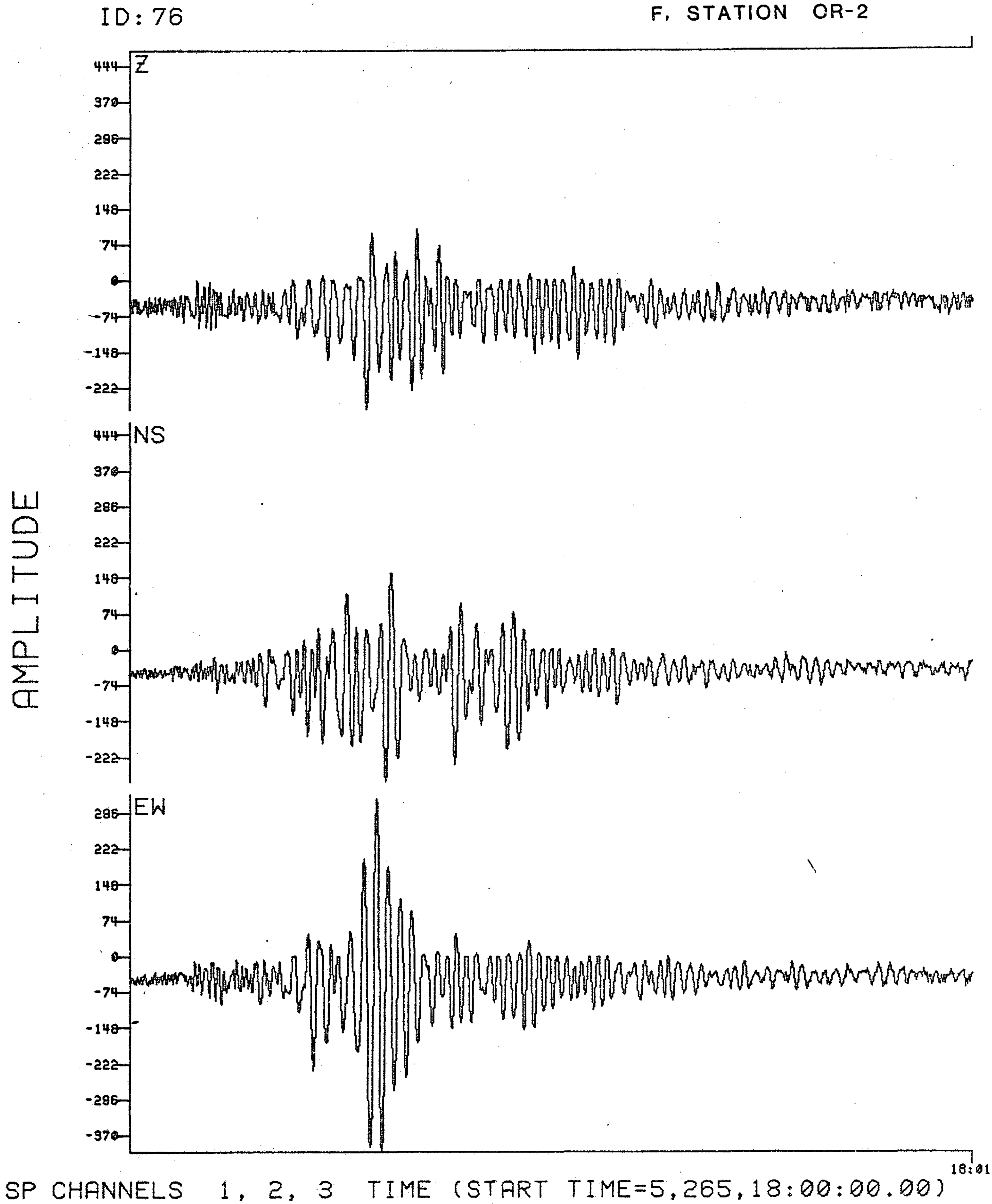
SP CHANNELS 1, 2, 3 TIME (START TIME=5,265,18:00:00.00)

ID: 74

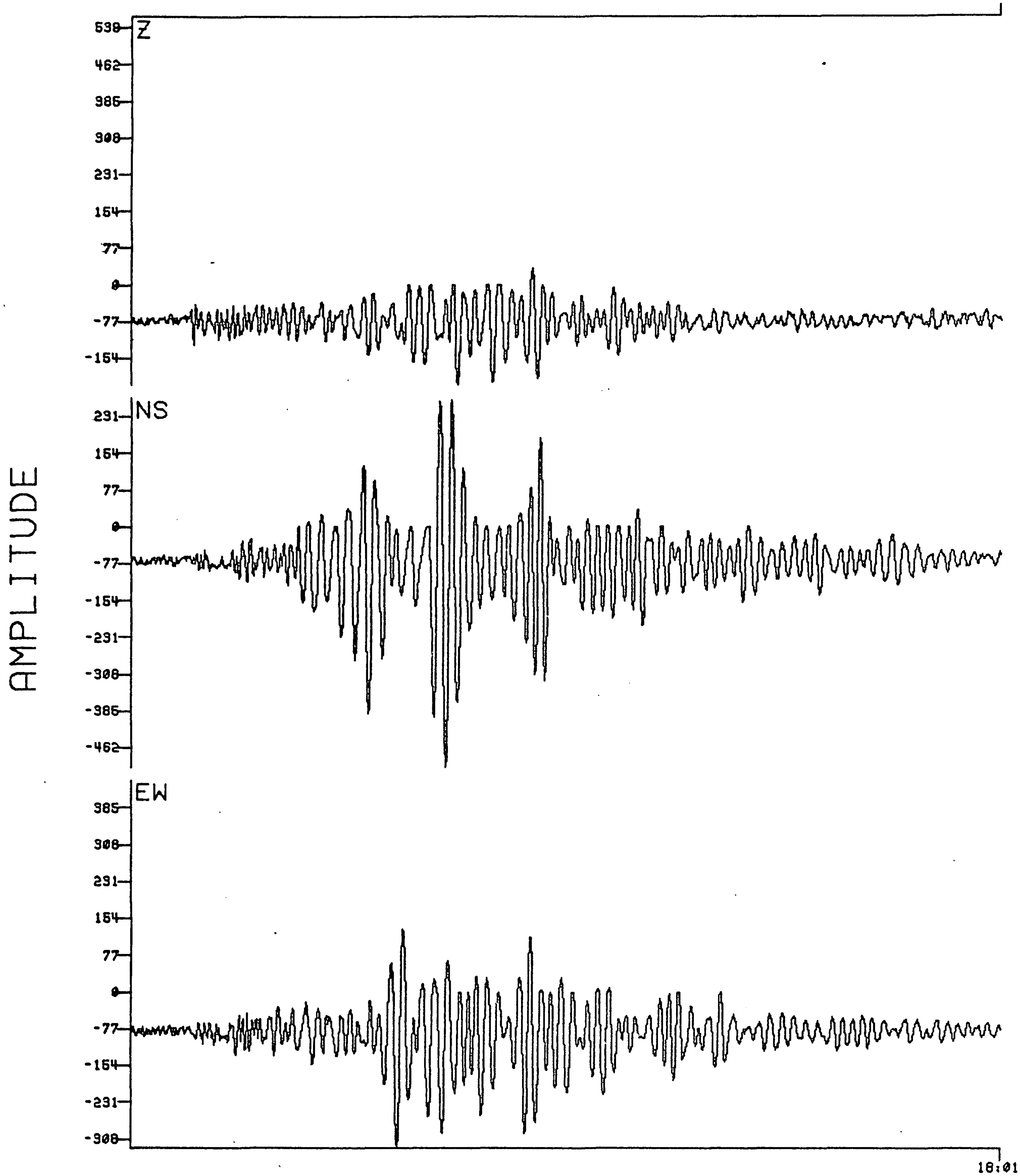
E. STATION OR-1



SP CHANNELS 1, 2, 3 TIME (START TIME=5,265,18:00:00.00)


ID: 76
F, STATION OR-2
Z
NS
EW
444
370
296
222
148
74
0
-74
-148
-222
-296
-370
AMPLITUDE
18:01
SP CHANNELS 1, 2, 3 TIME (START TIME=5,265,18:00:00.00)

ID: 77 G. STATION OR-3



SP CHANNELS 1, 2, 3 TIME (START TIME=5,265,18:00:00.00)