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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A STUDY OF SURFACE AND SUBSURFACE GROUND MOTIONS AT CALICO HILLS, NEVADA TEST SITE

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ABSTRACT

A study of earthquake ground motions recorded at depth in a drill hole and at the ground surface has derived the surface to subsurface transfer functions such as might be expected at a potential nuclear waste repository in a similar setting. The site under investigation has small seismic velocity contrasts in the layers of rock between the surface and the subsurface seismometer location. The subsurface seismic motions were similar in spectral characteristics to the surface motions and were lower in amplitude across the recorded band-width by a factor of 1.5.

INTRODUCTION

An important aspect of siting a nuclear waste repository is the prediction and evaluation of earthquake-induced ground motions expected at the facility depths. The limited research on observed, measured or modeled subsurface ground motions reported in the literature indicates that the subsurface motions are similar in frequency to the surface motions, but generally will be two to ten times smaller in amplitude. The basic goals of this study are to derive the subsurface to surface seismic motion transfer functions at an area similar to a potential nuclear waste repository, and to determine the feasibility of using surface motion scaling laws to predict the subsurface motions. The seismic energy sources used in this study are local earthquakes.

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PROCEDURE

The study was conducted at the UE25a-3 hole which is located in the Calico Hills, Nevada area (Fig. 1). The hole is approximately 12 kilometers east of Yucca Mountain where exploration for a nuclear waste repository is being conducted.

Four seismic profiles were made by refraction techniques at or near the hole. One 160-meter-and two 30-meter-length refraction lines were run to detect the specific seismic velocity changes in the upper 50 meters of the rock profile near the UE25a-3 hole (Fig. 2) The A line indicated disturbed site conditions from the drilling activity. Line B and C were offset from the hole 10 meters northwest on undisturbed soil. A tripartite seismometer package was installed at the southern end of the B line in approximately 1 1/2 meters of soil.

The drill hole is within sedimentary rocks of the Mississippian and Devonian Eleana formation. The hole was drilled to a 771 meter total depth with casing set to 58 meters. A tripartite seismometer was emplaced at a depth of 332 meters in the drill hole. The hole was backfilled with medium-grained sand to a depth of 275 meters.

The seismometer packages are Mark Products L-1-3DS downhole seismometers. They are shallow well, three-directional L-1 geophones contained in a waterproof, cylindrical aluminum shell. The L-1 has a transduction constant of 1.97 volts/cm/sec., a natural period of 0.22 second (4.5 Hz) and has a damping ratio of 0.67 to critical damping. The horizontal, east-west

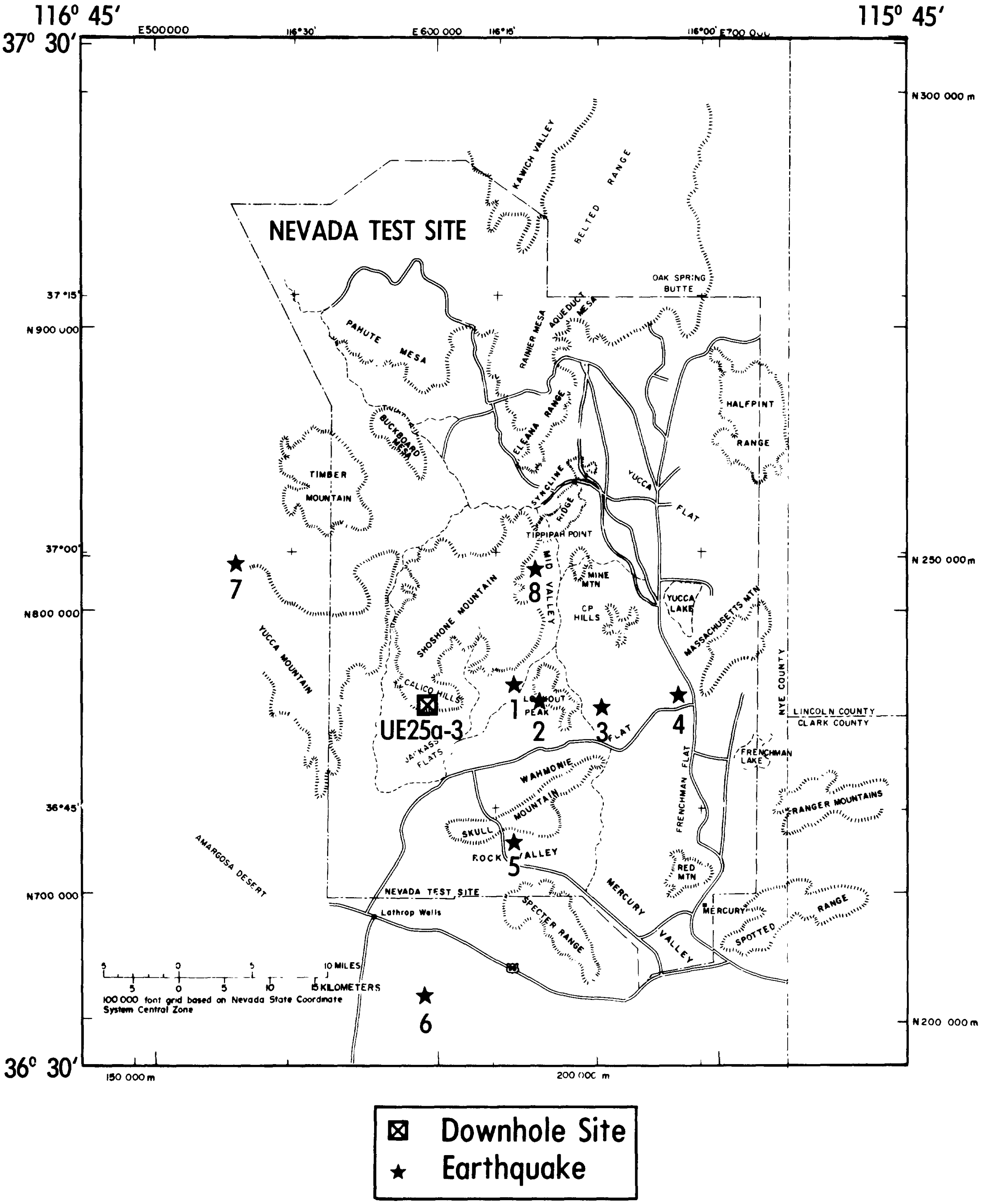

Figure 1.--Map of the Nevada Test Site, Nevada showing locations of the test well and earthquakes.

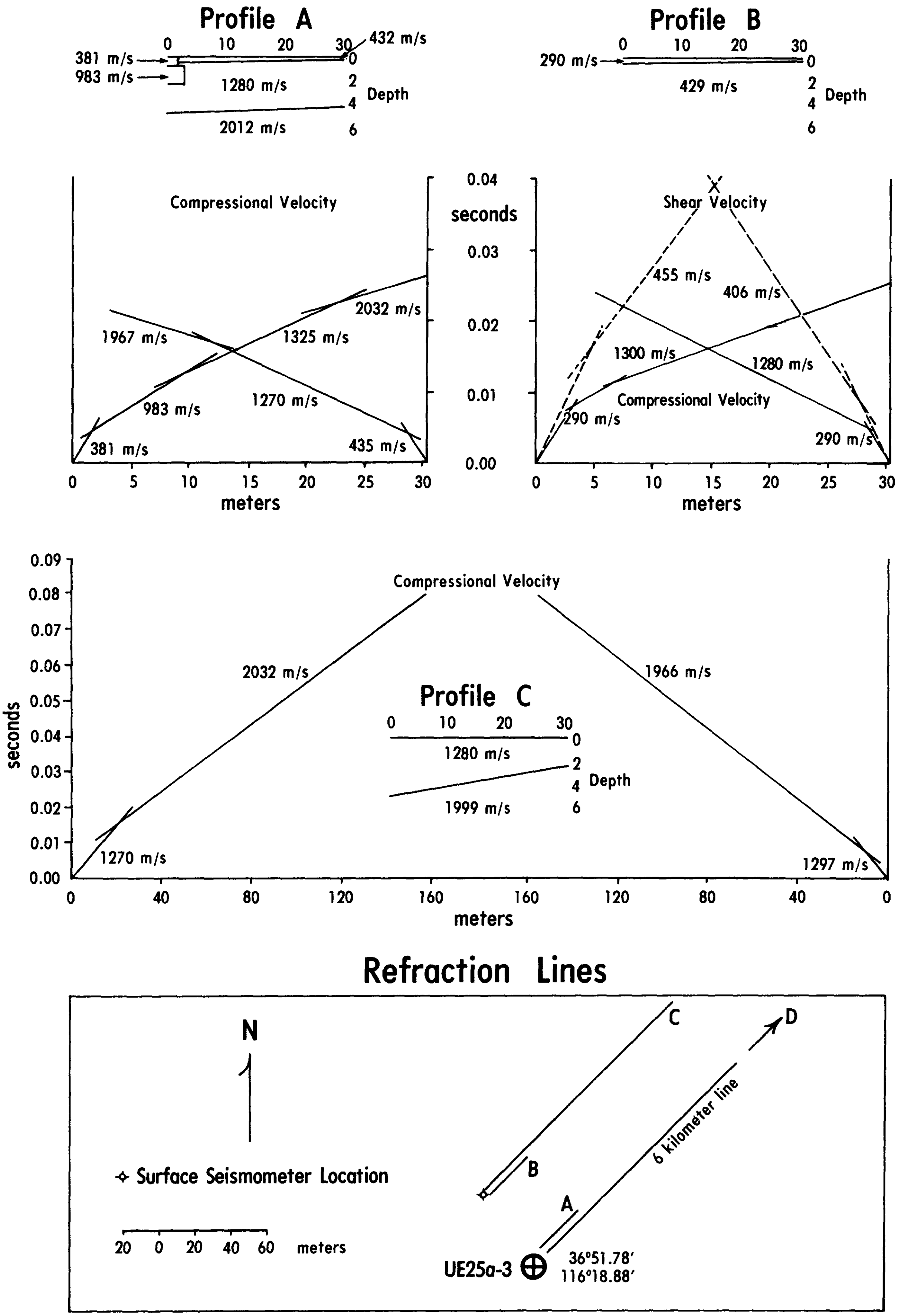

Figure 2.--Seismic refraction profiles at the UE25a-3 test well location.

oriented, L-1 downhole seismometer malfunctioned during the experiment; therefore, all horizontal data analyzed in this study are from the north-south oriented seismometers both downhole and the surface. Approximately 25 days of seismic data were recorded by a portable FM tape recorder.

The recorded event time-history data from the study were intergrated with the Southern Great Basin seismic network data to locate the earthquakes. Time history data which exhibited signal-to-noise ratios lower than two, or were from poorly located earthquakes, were not used for further analysis.

The selected time history data were digitized at 100 samples per second and response spectra were derived using a pseudo-relative velocity algorithm (PSRV). When small damping is used, PSRV is approximately equal to a smoothed Fourier amplitude spectrum (Jenschke, 1970). This study employed a 5 percent damped velocity response spectra. An approximation of the site transfer function for the geologic section between the subsurface site and the surface was computed using the following relationship:

$$SSTF = \frac{PSRV_s}{PSRV_{ss}}$$

where SSTF is the surface to subsurface transfer function, $PSRV_s$ is the response spectrum derived from the surface ground motion time history, and $PSRV_{ss}$ is the response spectrum derived from the subsurface ground motion time history. This technique has been used by several investigators to establish the seismic site response for areas under investigation (Jenschke, 1970; Rogers and Hays, 1978, Borcherdt and others, 1975).

SITE GEOLOGY AND PHYSICAL PROPERTIES

The UE25a-3 hole is located in the Calico Hills in the southwest part of the Nevada Test Site (Fig. 1 & 3). The Calico Hills are believed to be a structural dome produced by an igneous intrusive. The UE25a-3 hole was primarily drilled to verify the existence of the intrusive body (Maldonado and others, 1979). Rock penetrated by the hole is argillite to 416 meters, altered argillite from 416 meters to 720 meters, and marble from 720 meters to the total depth of 771 meters. The geophysical borehole logs indicate a generally uniform rock density of 2.5 g/cm^3 for the argillite, a 2.6 g/cm^3 density for the altered argillite and a wide density variation of 2.3 g/cm^3 to 2.9 g/cm^3 in the marble section (figure 2). The "Vibroseis" downhole survey logged a 2,000 meter/second seismic compressional velocity for the upper 61 meters of rock and a compressional velocity of 2,200 to 3,200 meter/second for the remaining 355 meters of unaltered argillite section. The altered argillite section has an average compressional velocity of 4,100 meters/second and the marble section has a 5,100 meter/second compressional velocity. The geology of the hole is described in detail by Maldonado and others (1979).

The surface velocity profile from lines B and C indicate a 1 to 3 meter thick layer that has a compressional velocity of 1,280 meters/second, a shear velocity of 429 meters/second and a Poisson's ratio of 0.41 (Fig. 2). The 1,280 meters/second layer thickens to the southwest, and overlies a bed with a compressional velocity of 2,000 meters/second. A 6-kilometer-long refraction line run by the USGS indicated a seismic profile consisting of a surface or weathered velocity of approximately 2,000 meters/second and a first velocity layer of approximately 3,000 meters/second (Leroy Pankratz, oral communication, 1981)

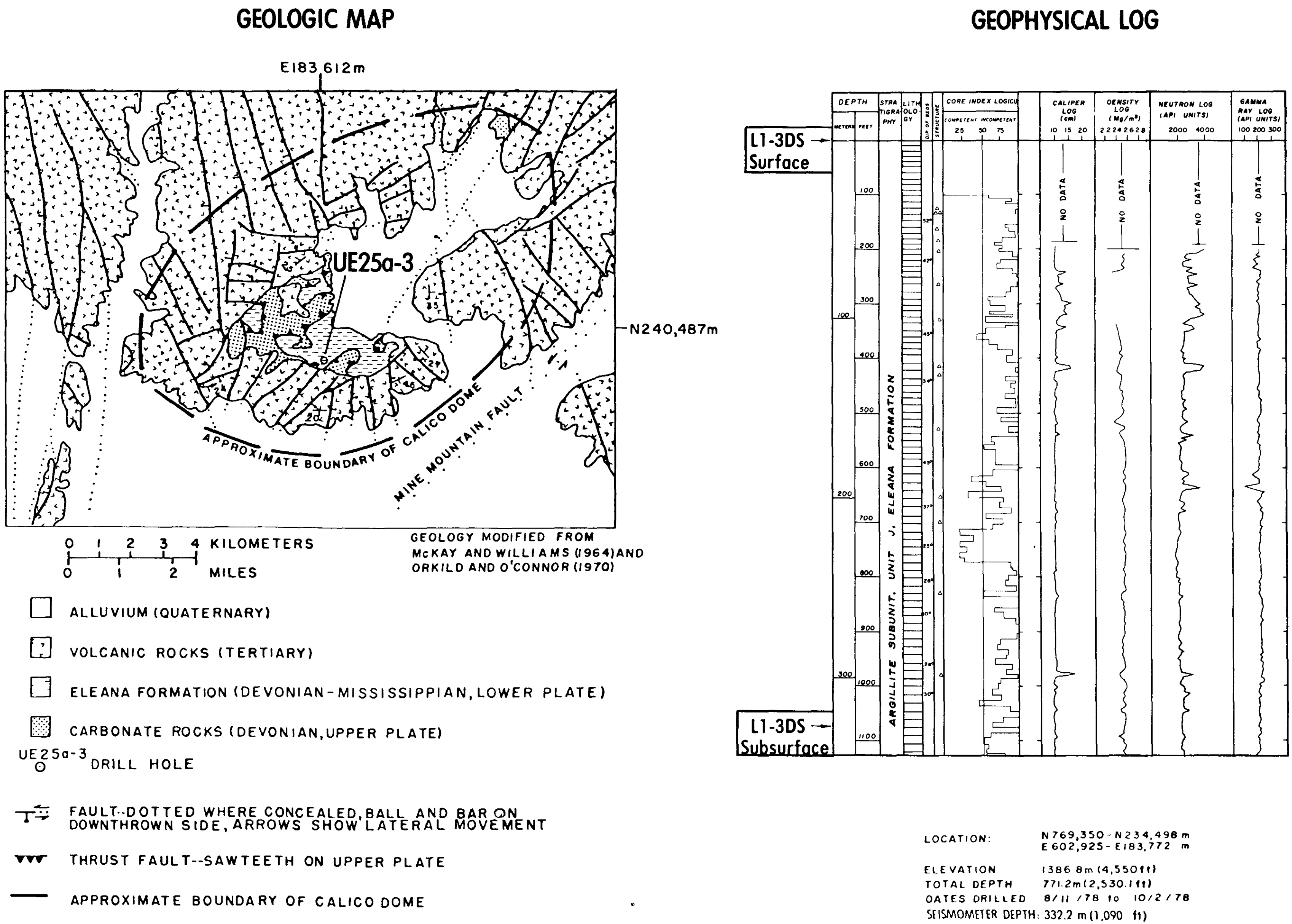

Figure 3.--Geologic map and geophysical well logs of the UE25a-3 test well location.

The geophysical borehole data and the refraction data are in general agreement and indicate no abrupt or large seismic velocity contrasts in the rock layers between the surface and the subsurface seismometer location. The low velocity surface layer is less than 2 meters thick and was avoided by burying the surface seismometers. In general the surface and subsurface seismometers were in a section of rock with a compressional velocity which increased from approximately 2,000 meter/second near the surface to 3,200 meters/second at the depth of the subsurface seismometer.

DATA ANALYSIS

The seismic data from eight earthquakes were selected for analysis from over 30 earthquakes that were recorded by the surface-downhole seismic system at UE25a-3. These data were selected in order to obtain high signal-to-noise ratio and a wide variety of source-to-recorder azimuths. Event nine was from seismic energy generated by vehicular traffic on the dirt road adjacent to the hole. The specifics of the earthquakes used in the analysis are tabulated in Table 1. The time histories of the analyzed events are shown on figures 4 and 5.

The surface to subsurface seismic spectral ratios are shown on Figure 6. The geometric mean (R) and the geometric mean standard deviations were derived for three groups of data: the events east of the drill hole; the events equi-distant from the drill hole; and all earthquake events used in this study. The equations for the geometric mean and the associated standard deviation calculations are as follows:

$$\text{geometric mean} = \tilde{R}(T) = 10^{\frac{1}{10} \sum_{i=1}^{\tau} \log_{10} R_i(T)}$$

TABLE 1.--Earthquakes, times, coordinates, magnitudes and distance and bearings from UE25a-E analyzed

EVENT	DATE (1980)	LAT.	LONG.	DEPTH (km)	MAG	Q	DISTANCE (km)	BEARING (°)
1	23-8	36.869	116.198	9.4	1.5	b	10	86
2	21-8	36.864	116.183	8.1	1.9	b	12	89
3	23-8	36.846	116.117	2.0	1.3	c	18	96
4	10-8	36.865	116.047	9.4	2.0	b	23	89
5	19-8	36.720	116.229	7.6	1.3	b	18	154
6	4-8	36.555	116.355	5.4	1.6	b	34	186
7	11-8	36.976	116.592	5.0	1.7	c	27	297
8	12-8	36.995	116.221	1.5	1.5	c	17	29
9	7-10	at UE25a-3			surface vehicle on road			
10	7-10	at UE25a-3			surface vehicle on road			

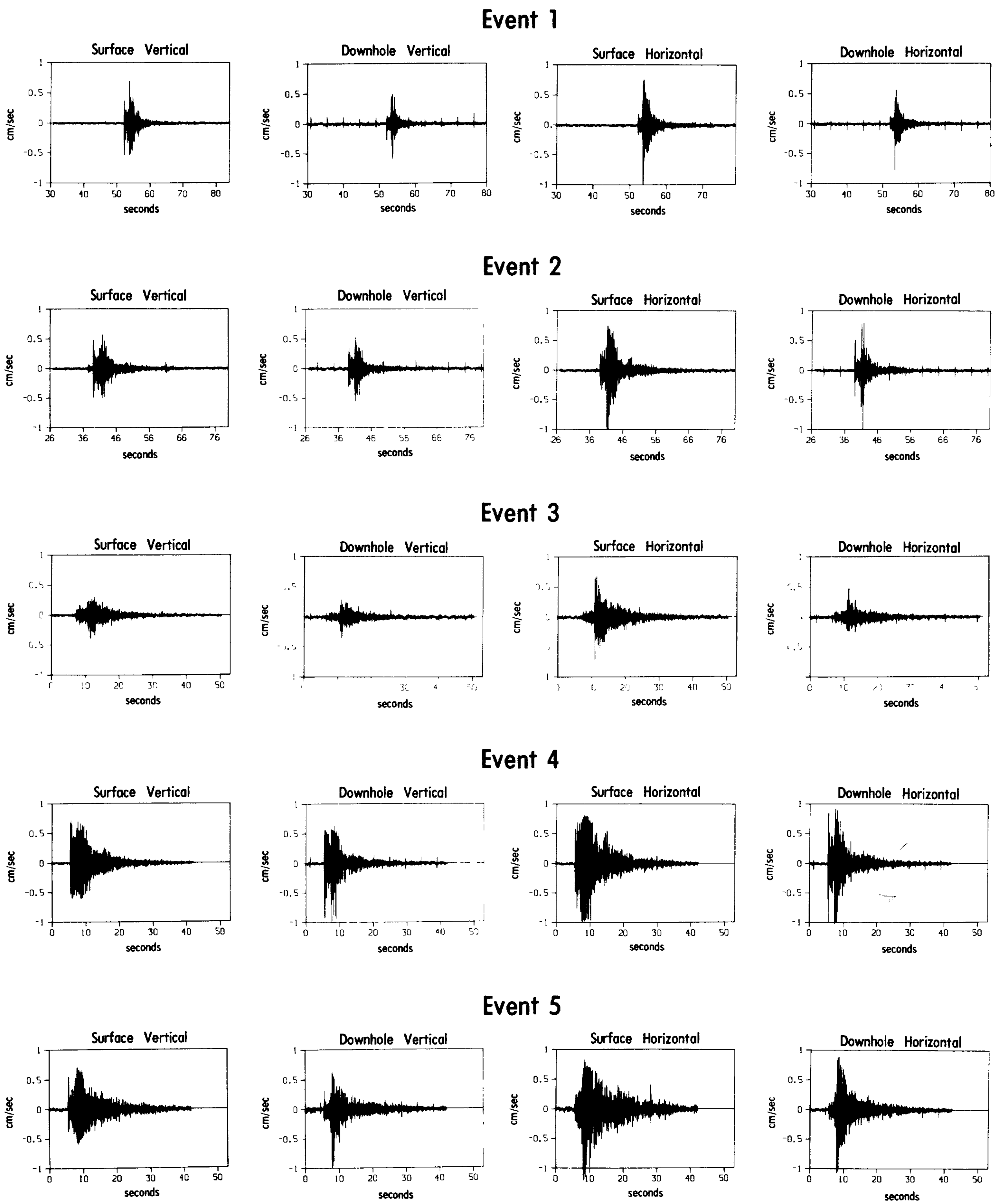

Figure 4.--Analog recordings of earthquakes numbers 1 through 5.

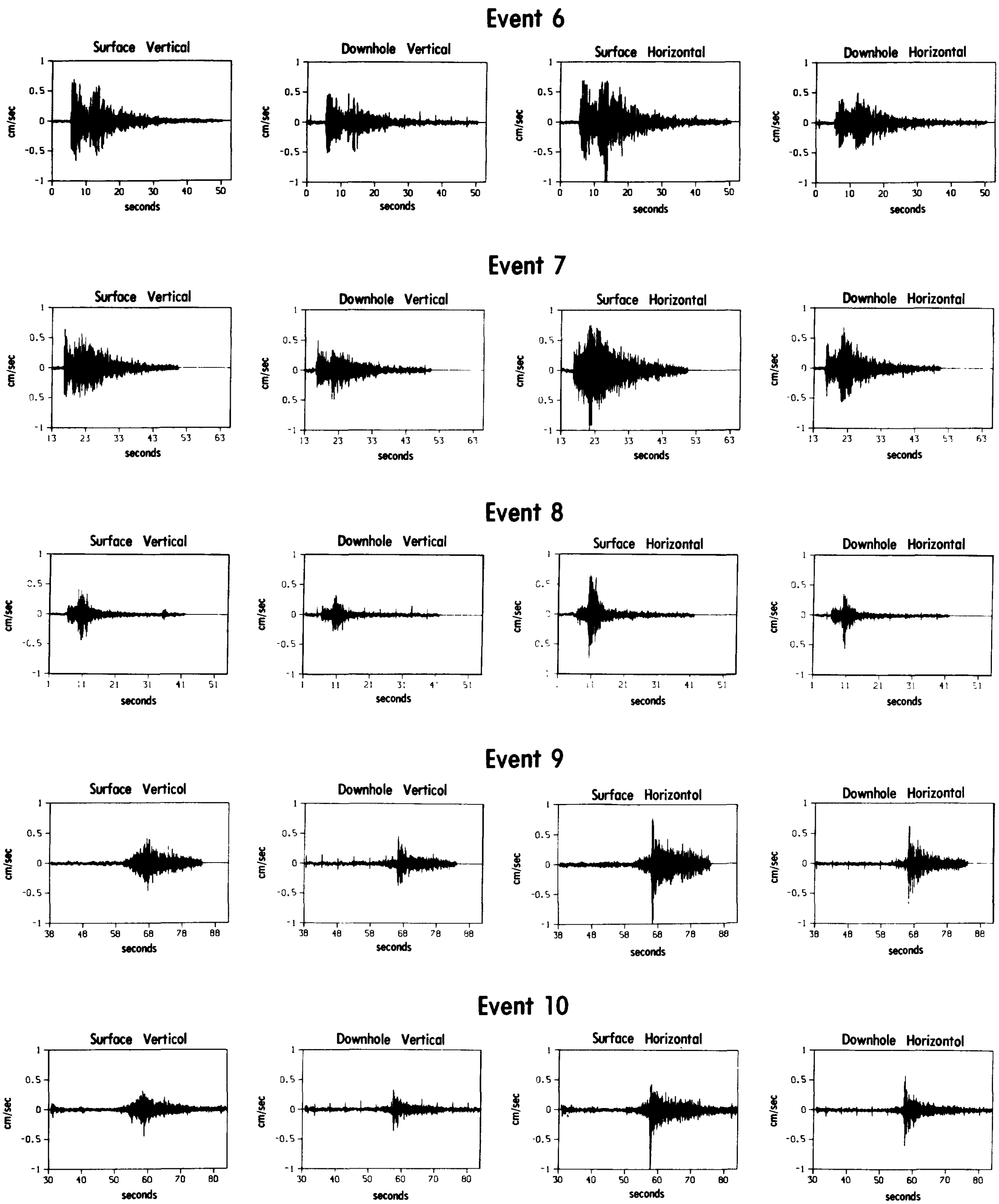

Figure 5.--Analog recordings of earthquakes numbers 6 through 10.

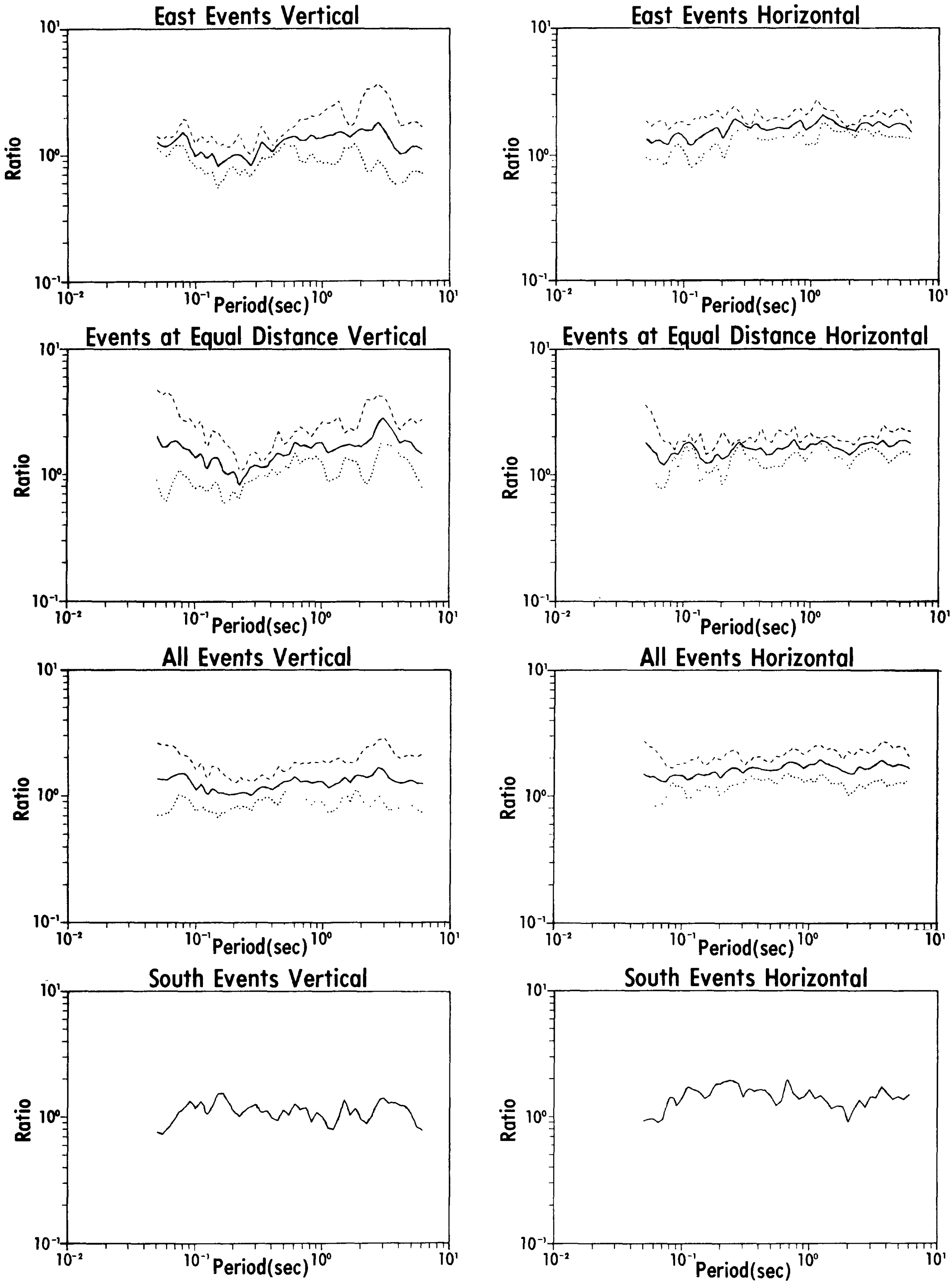

Figure 6.--The geometric mean and geometric standard deviation of the earthquake ground motion spectral ratios-surface to subsurface.

$$\text{geometric mean standard deviation} = GM_{sd}(T) = 10^{\left[\frac{1}{N-1}\sum_{i=1}^{\tau}\left(\log_{10} R_i(T) - \log_{10}\tilde{R}(T)\right)^2\right]^{1/2}}$$

where $\tilde{R}(T)$ = the value at period T

The comparison of transfer functions shown in figure 6 indicates no significant variation in the mean between groups. The nominal range in the geometric means is from 1.0 to 1.5. Although a weak but persistent peak appears in the vertical component transfer function at a period of approximately 3 seconds, for all practical purposes the site transfer functions are independent of the period. The induced surface seismic noise from a vehicle on the road adjacent to the hole has a vertical transfer function which indicates no significant difference across the recorded bandwidth. The horizontal component transfer function from the induced surface noise is very similar to those from the earthquake induced motions.

CONCLUSIONS

Analysis of the seismic data from the UE25a-3 study indicates that the subsurface motions have frequency characteristics similar to the surface motions. The analysis also shows the subsurface motions to have a velocity spectral amplitude that is less than the surface velocity spectral amplitude by a factor of 1.5.

The similarity of the frequency characteristics between surface and subsurface locations in this study agrees well with reports on subsurface surface motions in literature (Kanai and Tanako, 1951; Allingham and Zutz, 1961; Okamoto, 1973). The surface to subsurface ground motion factor of 1.5 is slightly lower than the factors of 2 to 10 reported in subsurface motion studies in literature (Kanai and Tanaka, 1951; Iwasaki and others, 1977). The difference in factors could be due to the fact that the velocity contrasts of the intervening rocks at UE25a-3 were lower than those reported in the subsurface motion studies in the literature. The existing 1.5 factor at the study site is probably due to a combination of free surface effect, attenuation of body waves and the average mode shapes for the surface waves.

The results at this site suggest that standard ground motion prediction techniques used to estimate ground motions on rock (Murphy and O'Brien, 1977; Schnabel, and Seed, 1973) could be modified to predict the subsurface motion by introducing a reducing factor of approximately 1.5. The study indicates that the reported procedure can establish a surface to subsurface amplitude factor which is repeatable for a variety of earthquakes at different ranges and azimuthal distributions. It is recommended that similar seismic data be obtained at any future repository site to establish an accurate estimate of the subsurface ground motion factor.

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