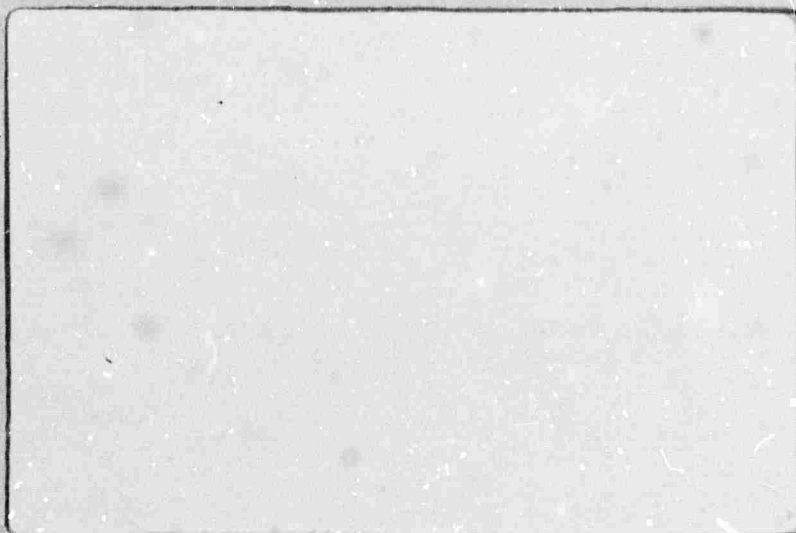


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National Center for Earthquake Research
345 Middlefield Road
Menlo Park, California 94025

TECHNICAL LETTER NCER-9

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P_n SPECTRAL VARIATIONS OF THE
GASBUGGY EXPLOSION AT INTERMEDIATE
DISTANCE RANGES*

by

W. H. K. Lee and R. D. Borchardt

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*Work done under ARPA Order No. 1094

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INTRODUCTION

The Project GASBUGGY nuclear explosive of 26-kilotons design yield was detonated on Sunday, December 10, 1967, 1230:00.136 MST, at latitude $36^{\circ}40'40.4''$ North and longitude $107^{\circ}12'30.3''$ West, about 55 air miles east of Farmington, New Mexico. The U.S. Geological Survey recorded seismic waves generated by the explosion along five lines radiating from the shot site, using truck-mounted seismic-refraction recording systems described by Warrick, et al. (1961), plus other units. The unit impulse response for ground velocity of the recording systems is approximately flat from 2 cps to above 15 cps. A preliminary data report on traveltime and amplitude variations with azimuth and distance was prepared by Warren and Jackson (1968).

The present ^{study} paper is submitted as a data-analysis report whose primary purpose is to study variations of P_n ^{Rayleigh} spectra as a function of distance and azimuth. Seismic records were digitized from 19 stations

in the distance range 300 to 500 kilometers from the shotpoint (Figure 1 and Table 1). Time-series analysis was then applied to the portion of seismic records containing essentially the P_n phase (the first 3 seconds after the first arrival). The results indicated significant variations of P_n spectra from station to station. Following a brief summary of the method of data analysis, the results will be discussed in detail.

DATA ANALYSIS

The first 3 seconds of the seismic records after the first arrival were digitized at a sampling rate of 50 per second, and calibrated such that the data represent absolute ground velocity in μ/sec normalized with zero mean value. The usual method of time-series analysis was then applied as described by Blackman and Tukey (1958). For a time series $X(t_1), X(t_2), \dots, X(t_n)$ with zero mean, the autocovariance function at lag ζ is computed by

$$R(j) = \frac{1}{n-j} \sum_{i=1}^{n-j} X(t_i) X(t_{i+j}) \quad (1)$$

for $j = 0, 1, 2, \dots, m$; and $\zeta = j\Delta t$, where $\Delta t = t_i - t_{i-1}$.

The raw estimate of the spectral density at frequency f_k is obtained by

$$\hat{P}(f_k) = \frac{2\Delta t}{\pi} \sum_{j=0}^m \epsilon(j) R(j) \cos(2\pi f_k j\Delta t) \quad (2)$$

where

$$\epsilon(j) = \begin{cases} 1 & 0 < j < m \\ 1/2 & j = 0, m \end{cases}$$

for $f_k = \frac{k}{2m\Delta t}$, $k = 0, 1, \dots, m$.

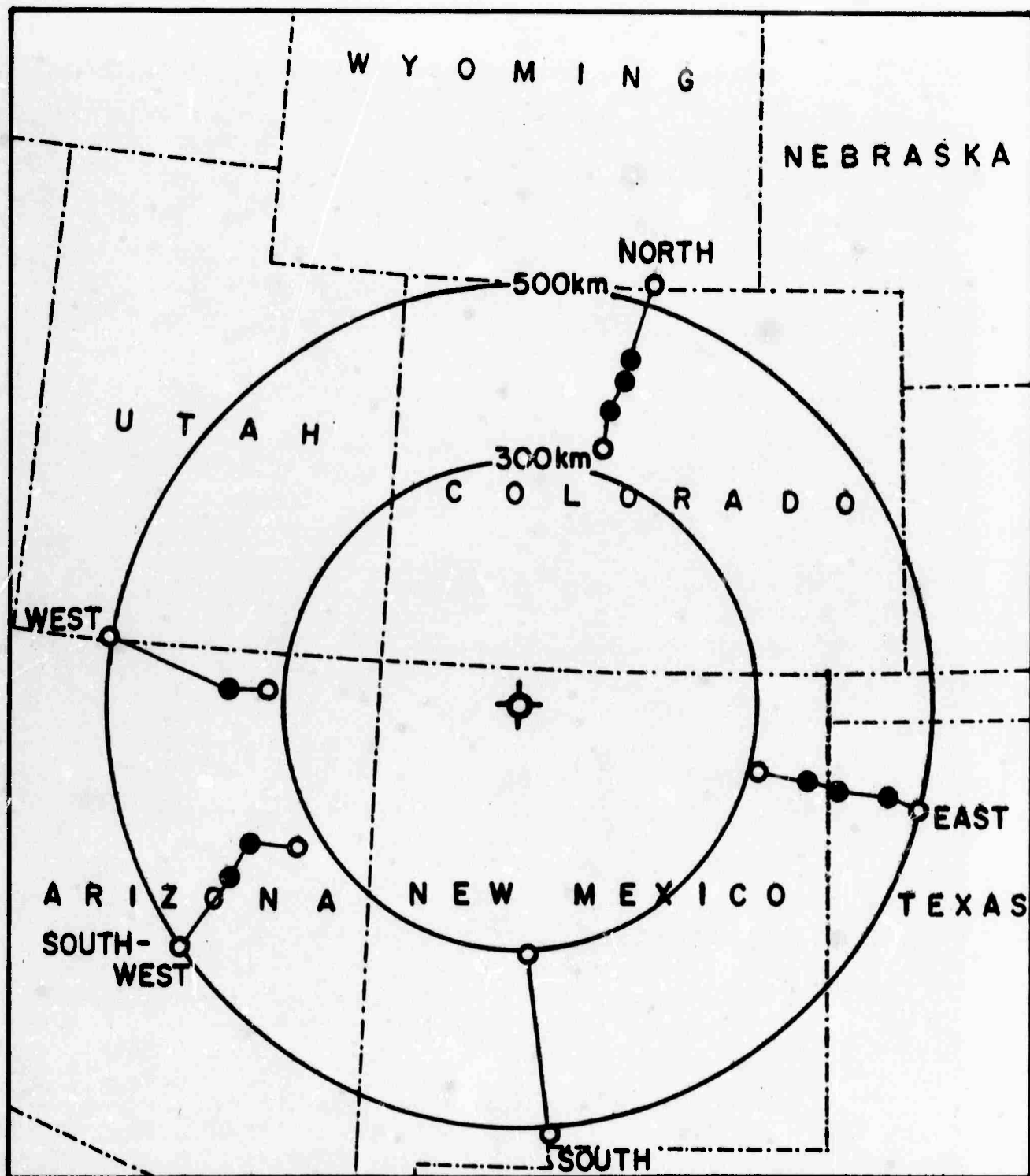


Figure 1. Location map for the GASBUGGY nuclear explosion and recording stations.

Table I
Station Locations and Distances, Spectral Energy
for the P_n Phase, and Q

Direction	Name	Location		Distance, km	Spectral Energy, (μ/sec) ²	Q
		Latitude, N	Longitude, W			
EAST	Roy, N. M.	36°03'	103°56'	302	0.0320	
	Rosebud, N. M.	35°52'	103°21'	358	0.0081	160
	Romero, Tex.	35°43'	102°56'	399	0.0010	110
	Channing, Tex.	35°42'	102°23'	447	0.0023	220
	Amarillo, Tex.	35°31'	101°49'	502	0.0014	250
SOUTH	Socorro, N. M.	33°58'	106°57'	301	0.0280	
	Mesquite, N. M.	32°12'	106°36'	499	0.0012	250
SOUTHWEST	Holbrook, Ariz.	35°06'	110°03'	311	0.8400	
	Winslow, Ariz.	35°04'	110°39'	359	0.1100	90
	Chevelon, Ariz.	34°37'	110°53'	404	0.1100	170
	Sunflower, Ariz.	33°51'	111°26'	496	0.5100	1200
WEST	Shonto, Ariz.	36°36'	110°36'	304	0.3700	
	Kaibito, Ariz.	36°33'	110°07'	351	0.1400	190
	Kanab, Utah	37°01'	112°49'	502	0.0350	350
NORTH	Climax, Colo.	39°20'	106°13'	307	1.3000	
	Dillon, Colo.	39°44'	106°08'	351	0.2600	110
	Granby, Colo.	40°03'	105°56'	391	0.1200	140
	Timber Creek, Colo.	40°23'	105°51'	428	0.0013	70
	Tie Siding, Wyo.	41°02'	105°33'	505	0.0023	120

The raw spectral density estimates are then smoothed by "hamming":

$$P(f_0) = 0.54 \hat{P}(f_0) + 0.46 \hat{P}(f_1)$$

$$P(f_k) = 0.23 \hat{P}(f_{k-1}) + 0.54 \hat{P}(f_k) + 0.23 \hat{P}(f_{k+1}), 0 < k < m$$

$$P(f_m) = 0.54 \hat{P}(f_m) + 0.46 \hat{P}(f_{m-1}). \quad (3)$$

Spectra of ground velocity for the P_n phase recorded along five lines of stations are shown in Figures 2 through 6. In each of these figures, the spectral density of ground velocity for the P_n phase is plotted versus frequency. Stations in the same direction are plotted in the same figure to show the spectral variations as a function of distance. Dominant peaks in the spectra fall mostly between 3 to 5 cps. In general, the maximum spectral density decreases as the distance increases from the shotpoint. A notable exception is station Sunflower at 500 km where the maximum spectral density is almost the same as for station Holbrook at 300 km.

Spectra of ground velocity for the P_n phase recorded at distances of 300 and 500 kilometers from the shotpoint are plotted in Figures 7 and 8 to show the spectral variations as a function of azimuth. At 300 km the maximum spectral density for the north, west, and southwest is larger by a factor of about 30 than that for the east and south. At 500 km the maximum spectral density is highest toward the southwest, decreases by a factor of about 20 toward the west, and decreases by an additional factor of about 10 toward the north, east, and south.

Spectra of all the stations show the spectral energy is concentrated between 2 and 8 cps and becomes insignificant beyond 10 cps.

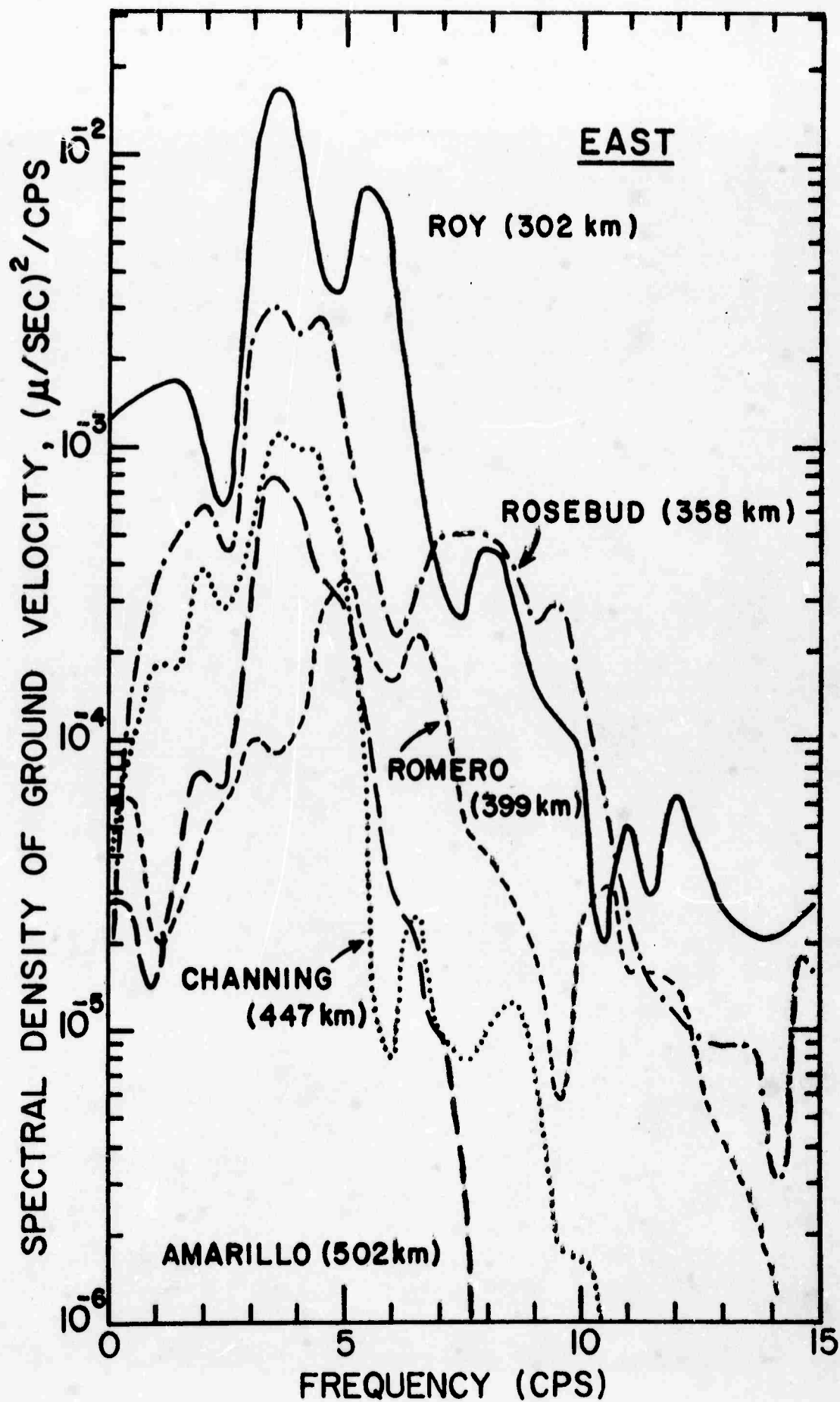


Figure 2. P_n spectral variations along the east line.

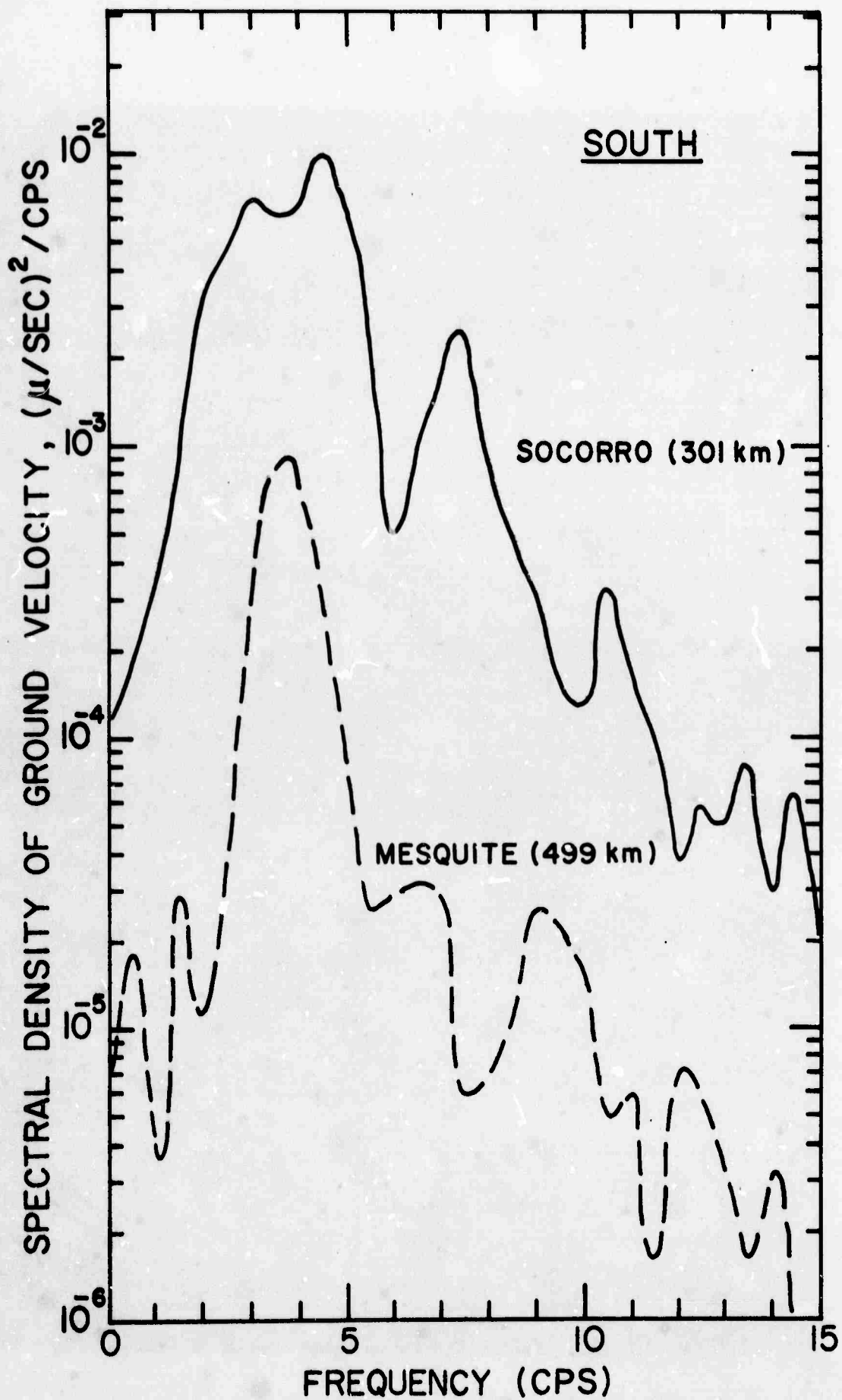


Figure 3. P_n spectral variations along the south line.

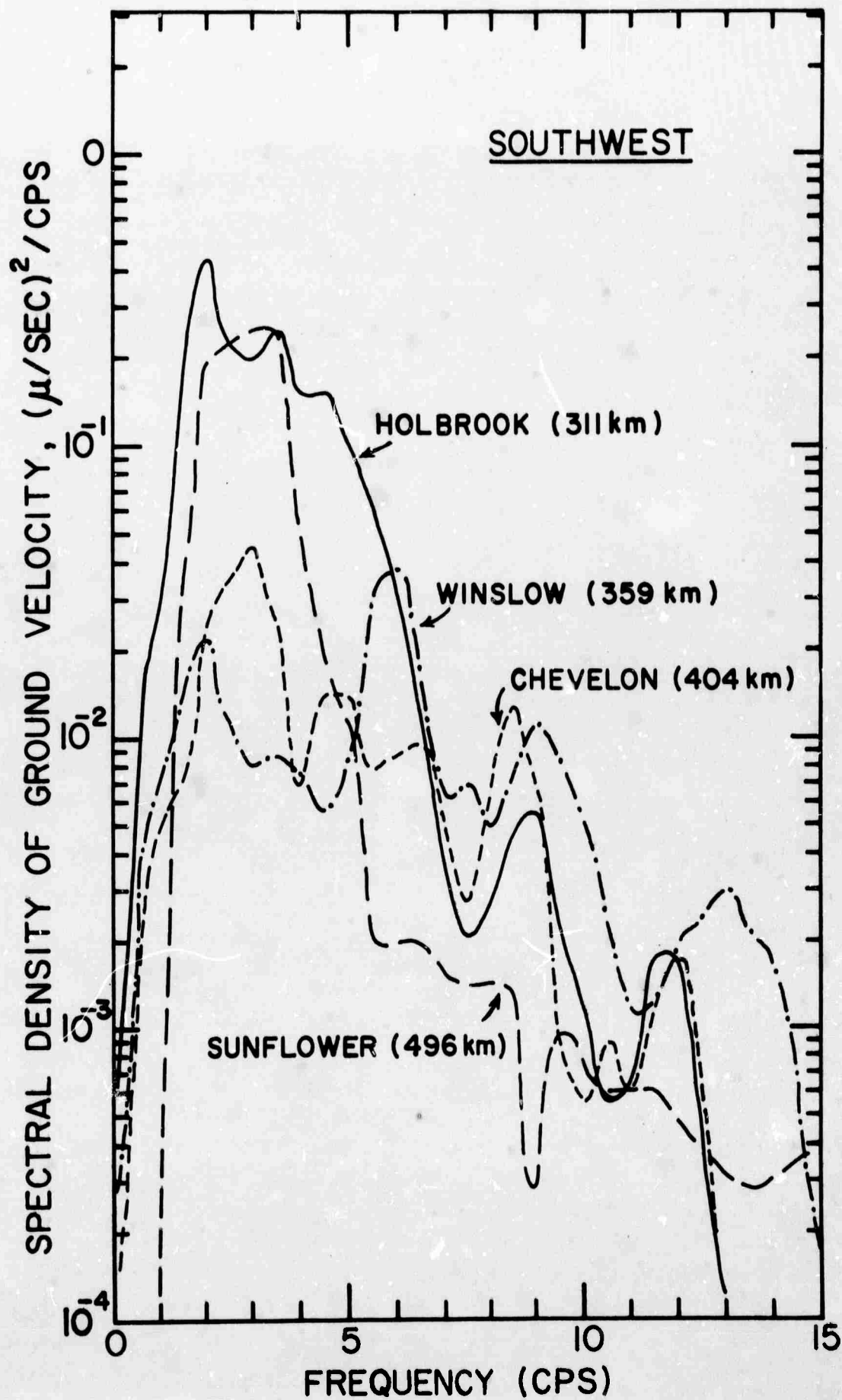


Figure 4. P_n spectral variations along the southwest line.

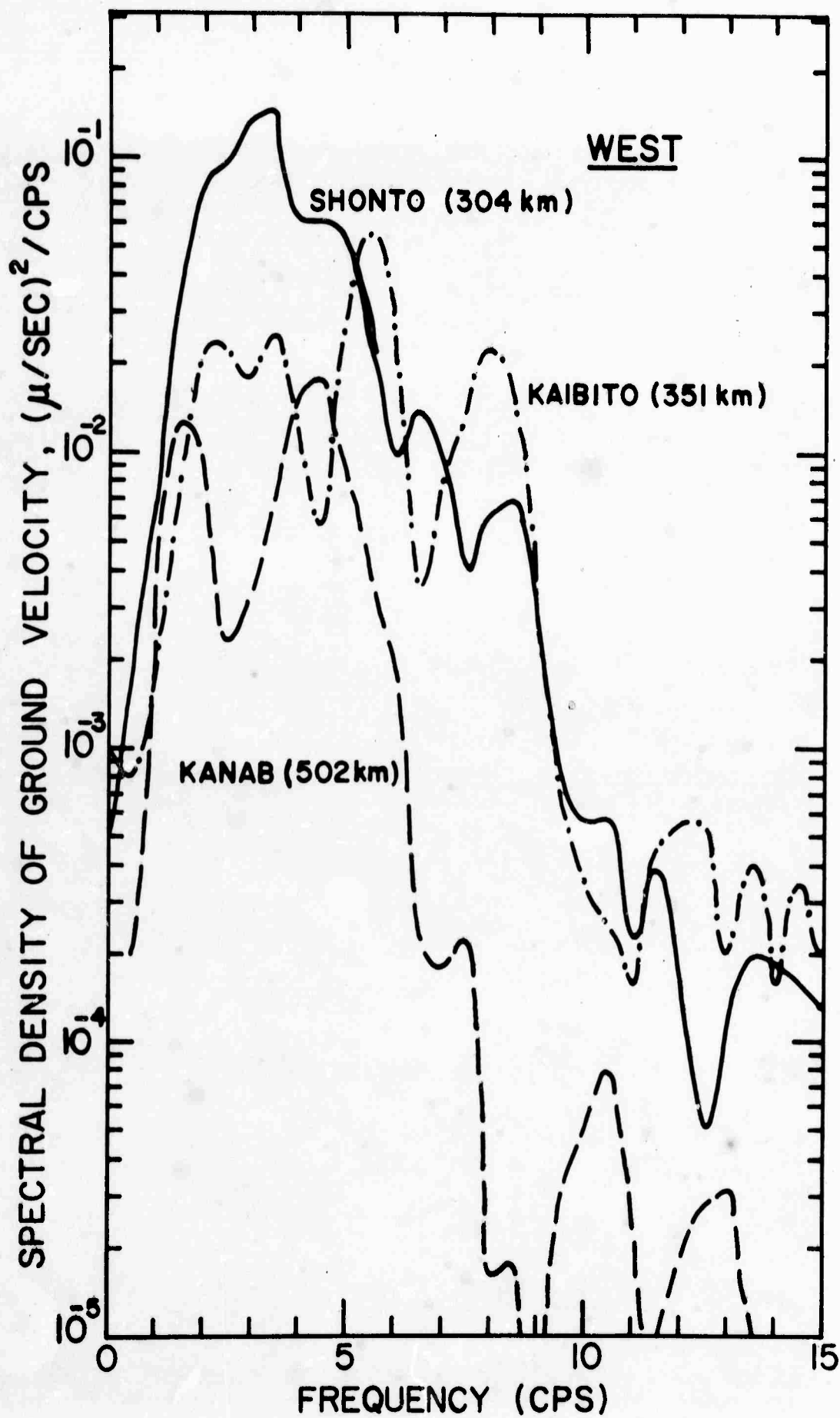


Figure 5. P_n spectral variations along the west line.

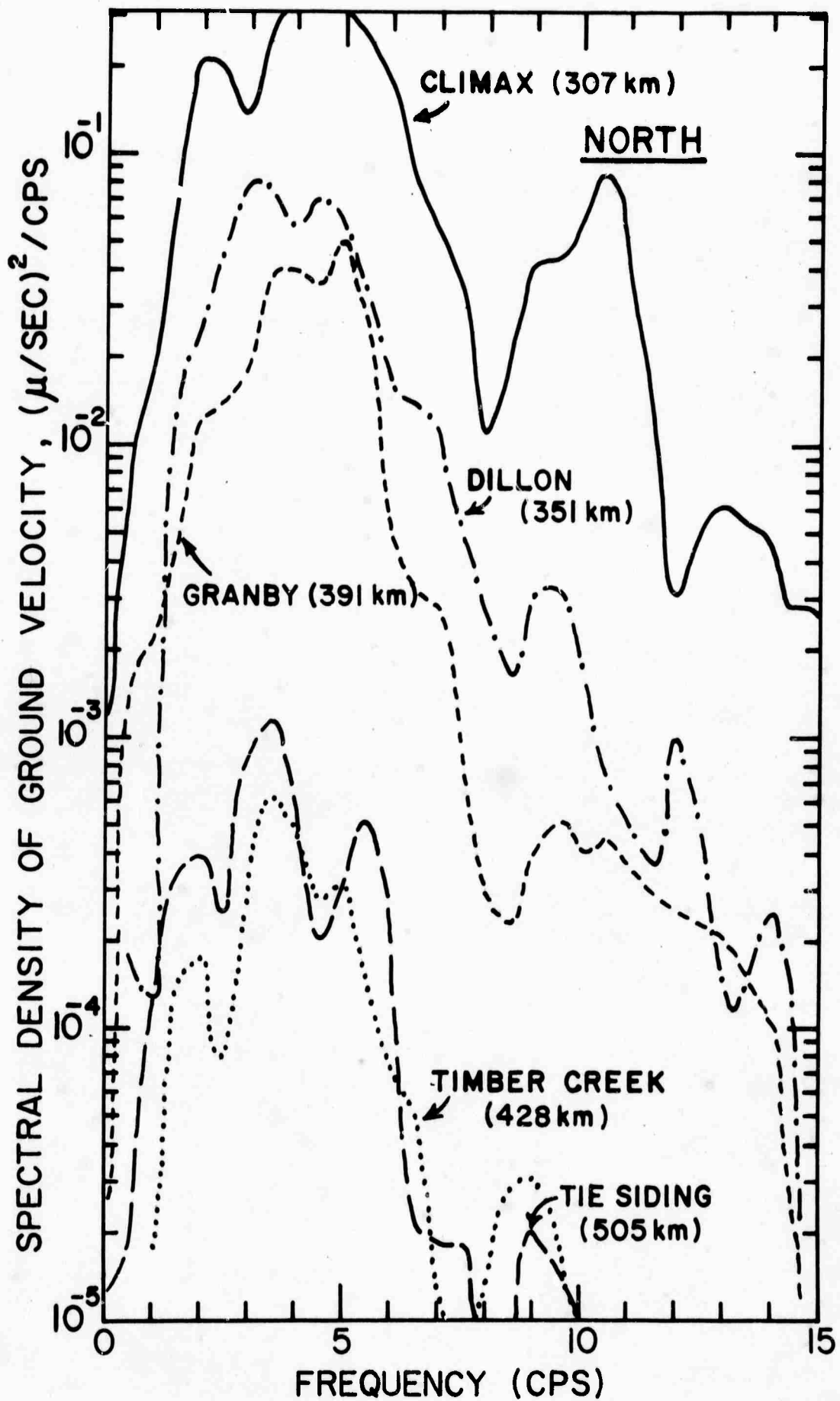


Figure 6. P_n spectral variations along the north line.

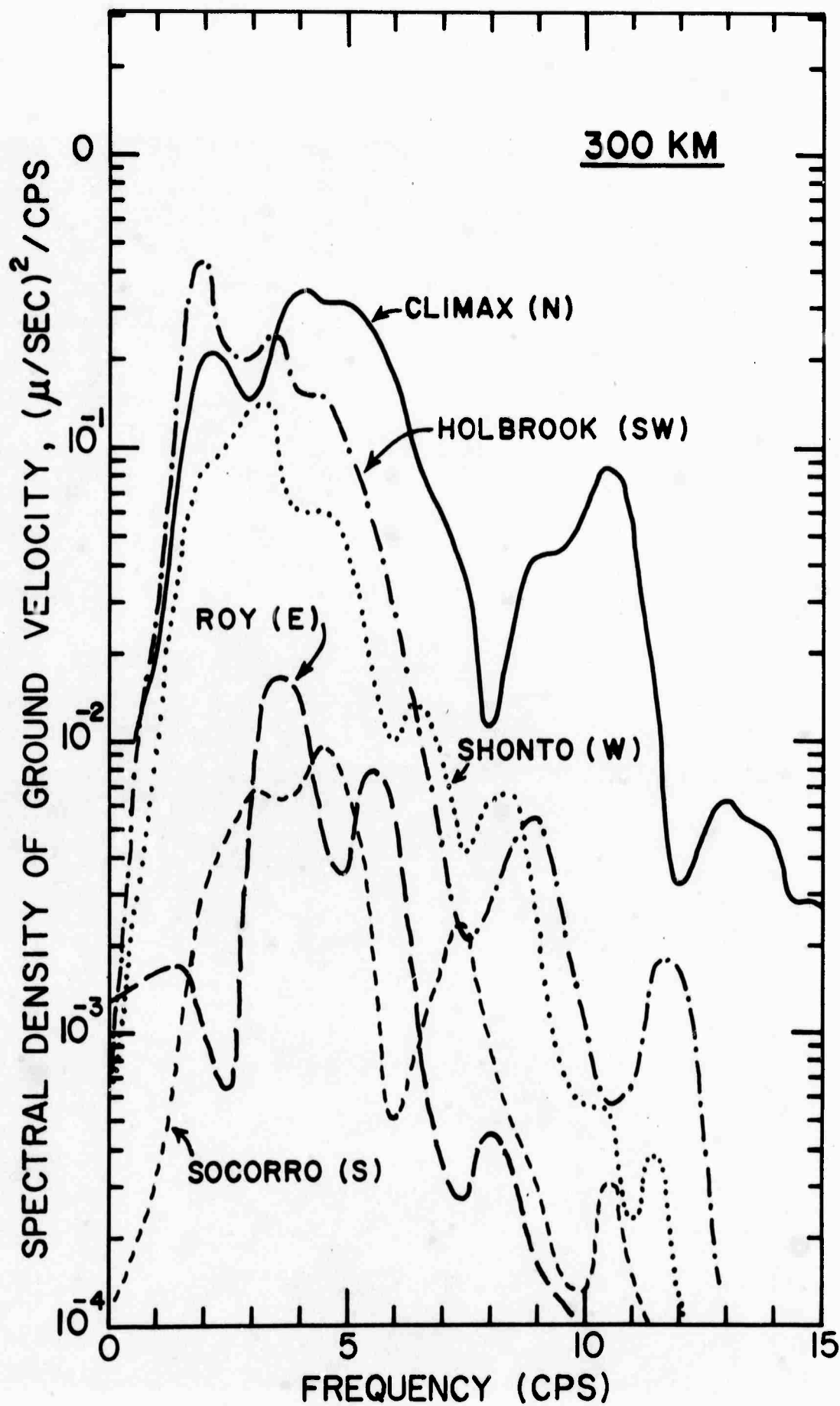


Figure 7. P_n spectral variations at 300 km from the shotpoint.

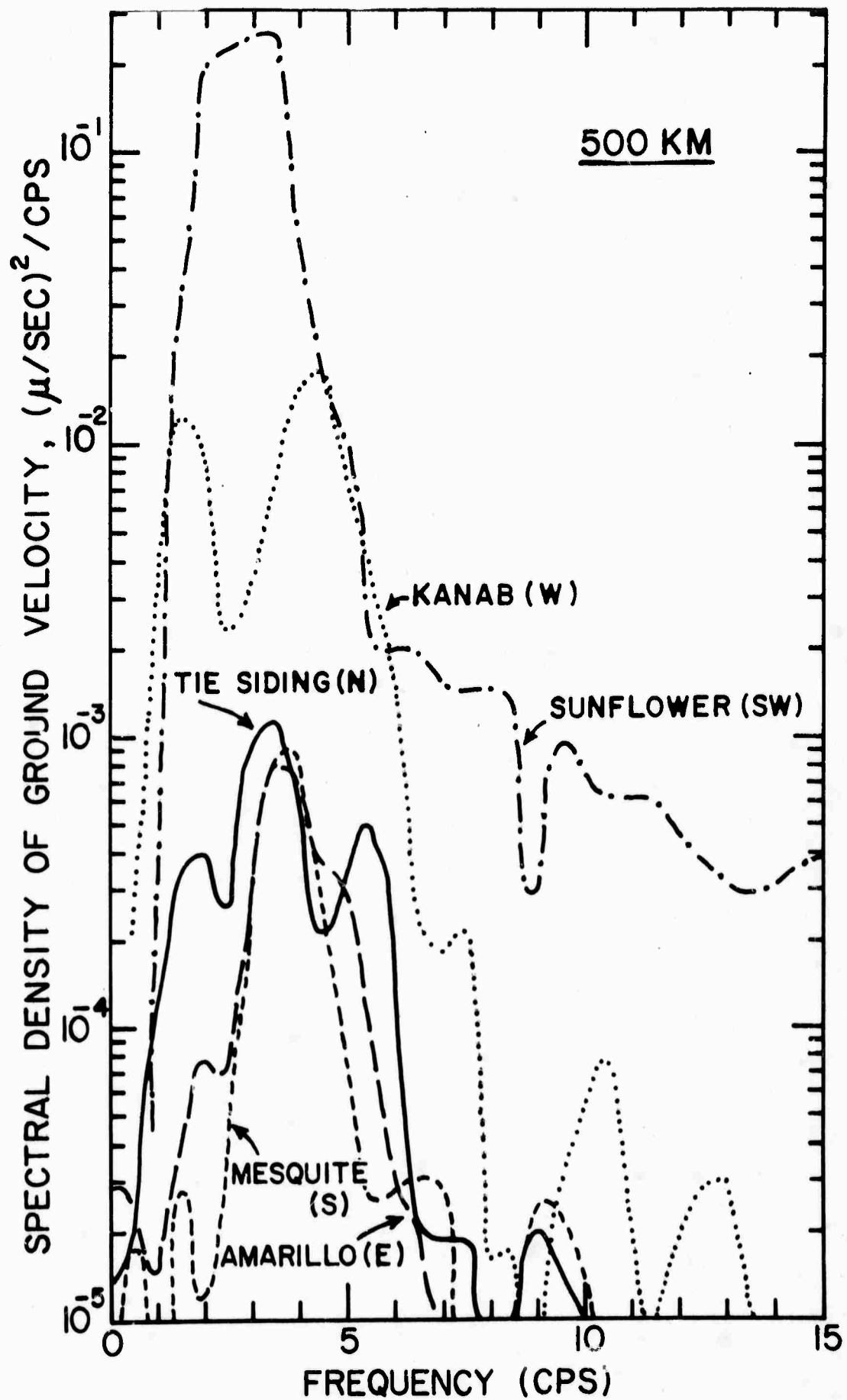


Figure 8. P_n spectral variations at 500 km from the shotpoint.

The spectral energy of ground velocity can therefore be obtained by integrating the spectral density from 2 to 10 cps:

$$E = \int_2^{10} P(f) df \quad (4)$$

The results are tabulated in Table I. Spectral energy is plotted against distance in Figure 9, and a contour map of iso-spectral energy is shown in Figure 10. These figures show that the spectral energy is about 2 orders of magnitude higher for the southwest and west than for the east and south. The spectral energy along the north line is similar to the southwest and west lines for the distance interval 300 to 400 km, but is similar to the east and south lines from 400 to 500 km.

Attenuation of the P_n phase can be studied by calculating the Q values between pairs of stations. The dimensionless quantity, Q , is the reciprocal of the specific attenuation factor (Knopoff, 1964) and is defined by Gutenberg (1958) as:

$$Q = \frac{\pi}{kTV}, \quad (5)$$

where

k = the coefficient of absorption

T = period of the seismic wave

V = seismic velocity.

The absorption coefficient k is defined by

$$\frac{A_1}{A_2} = e^{-k(D_1 - D_2)}, \quad (6)$$

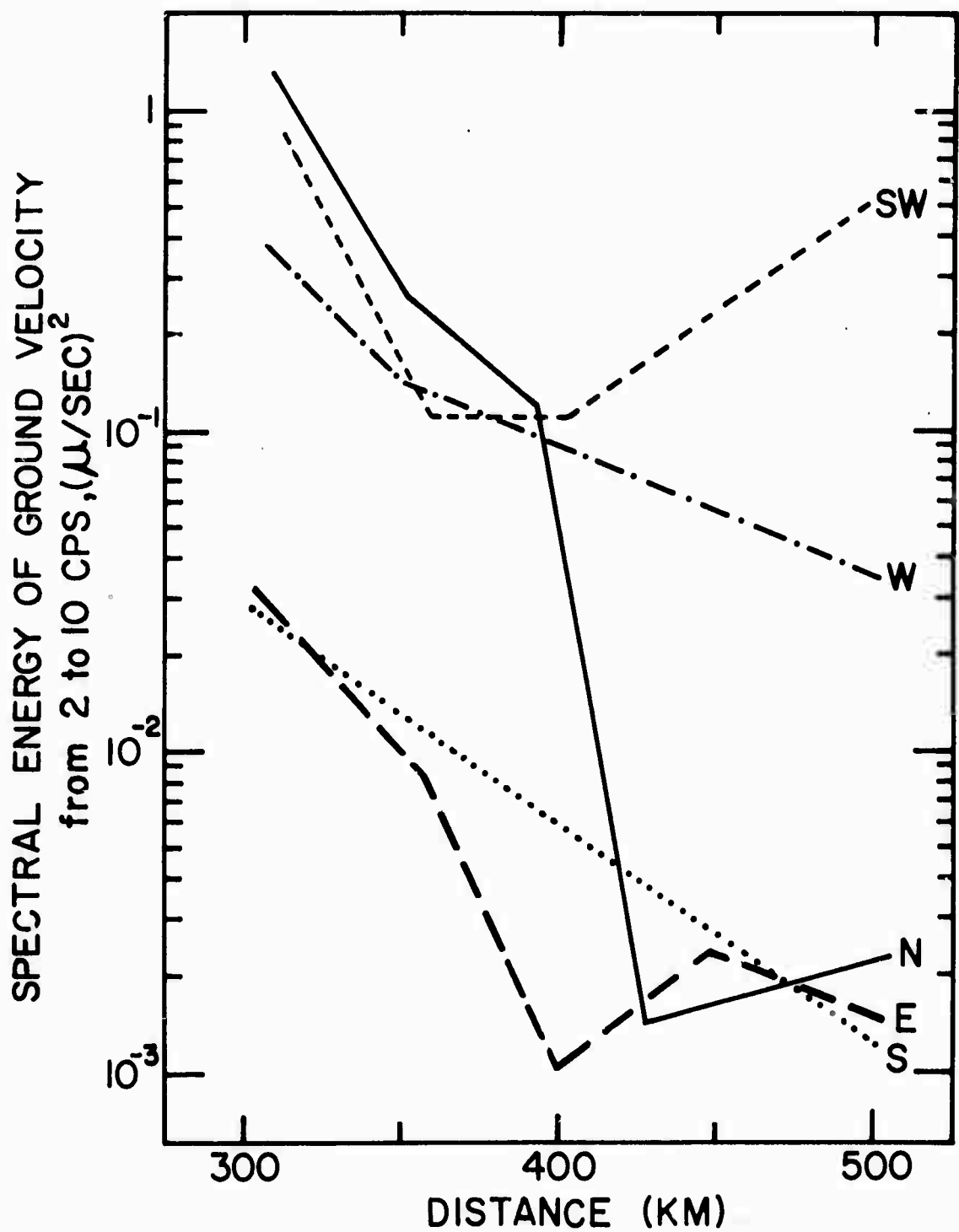


Figure 9. Spectral energy of ground velocity from 2 to 10 cps for the P_n phase as a function of distance along the five lines of recording.

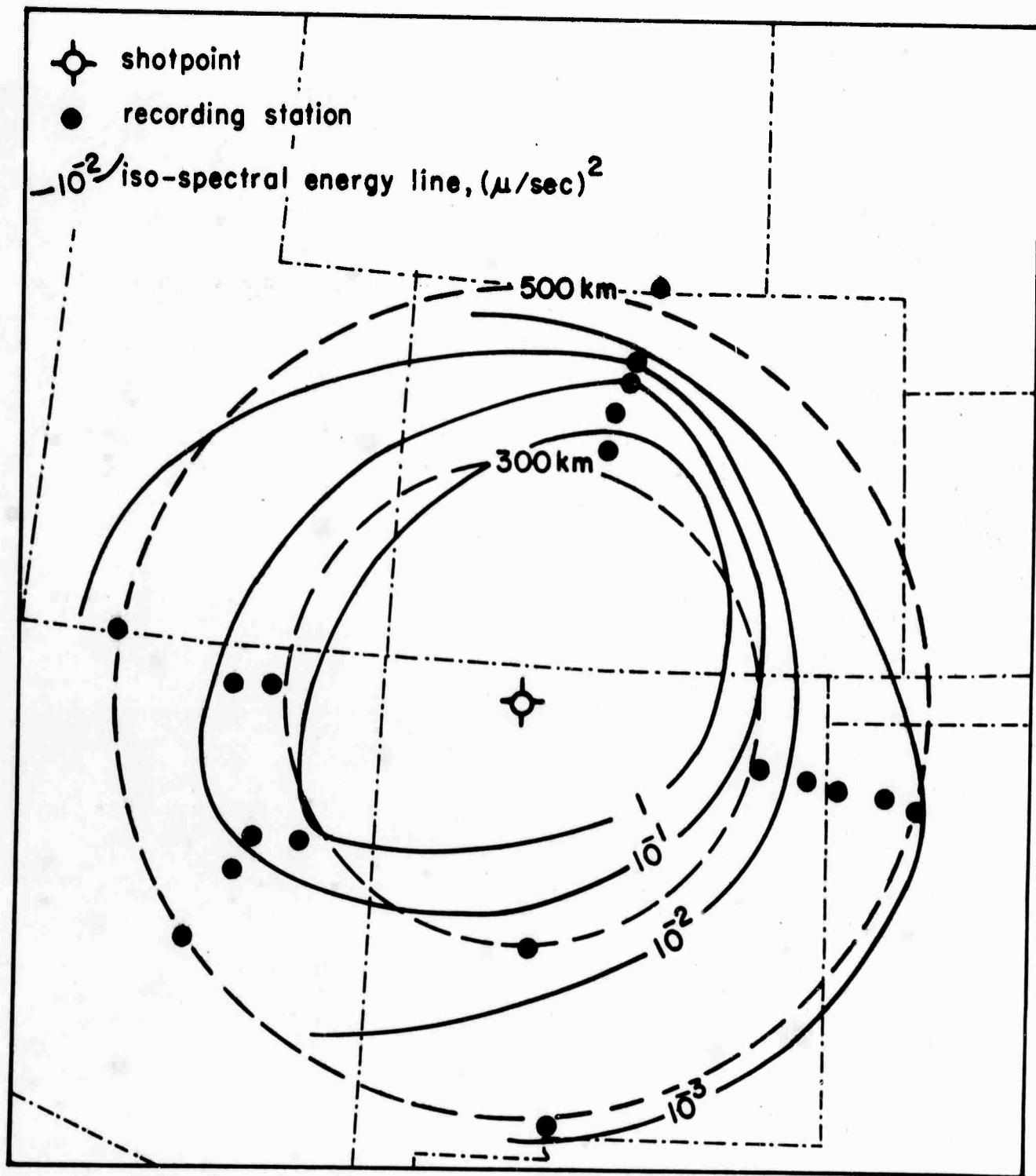


Figure 10. Contour map of spectral energy of ground velocity from 2 to 10 cps for the P_n phase.

where

A_1/A_2 = ratio of amplitude of seismic wave at location 1 to
location 2

$D_1 = D_2$ = distance between location 1 and location 2.

For rough estimates of Q , we use the spectral energy of ground velocity for the P_n phase from 2 to 10 cps so that:

$$\frac{A_1}{A_2} = \sqrt{\frac{E_1}{E_2}},$$

$$T \approx \frac{1}{5 \text{ cps}} = 0.2 \text{ sec},$$

and

$$V \approx 8 \text{ km/sec} \quad (7)$$

The results are tabulated in Table 1. Values of Q range from about 70 to 350 and agree with the general estimate of 60 to 450 made by Anderson (1966) for the lower crust and upper mantle. The only exception is the Q value (1200) between Holbrook and Sunflower. This may be due to local conditions at Sunflower.

CONCLUSIONS

Studies on the P_n phase recorded at 19 stations for the GASBUGGY nuclear explosion show the following:

(1) Spectra of ground velocity differs from station to station. The gross characteristics are similar, but the maximum spectral density may differ by 3 orders of magnitude. Dominant peaks in the spectra are mostly between 3 and 5 cps.

(2) There is a general decrease in the spectral energy as distance increases from the shotpoint. Spectral energy is strongly dependent on the azimuth, being two orders of magnitude higher toward the southwest and north than toward the east and south.

(3) A contour map of iso-spectral energy indicates that attenuations of seismic waves is higher in the east and south than in the west and southwest. This result is consistent with the heat-flow measurements showing higher heat flow toward the southeast than toward the northwest (John Sass, personal communication).

(4) The reciprocal of specific attenuation factor, Q , was estimated from the spectral energy ratios between pairs of stations. Values of Q (70 to 350) are consistent with the general range estimated for the lower crust and upper mantle.

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