UCRL-52048

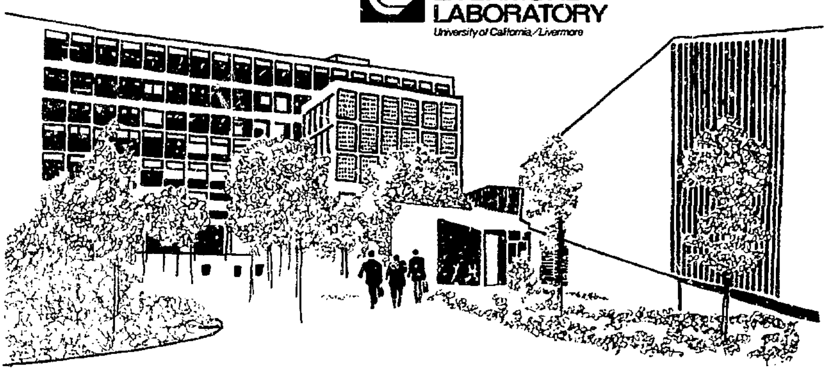
SEISMIC SPECTRA OF EVENTS AT REGIONAL DISTANCES

D. L. Springer and M. D. Denny

April 5, 1976

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore



MASTER

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $; Microfiche $2.25

Page Range	Domestic Price	Page Range	Domestic Price
001–025	$ 3.50	326–350	10.00
026–050	4.00	351–375	10.50
051–075	4.50	376–400	10.75
076–100	5.00	401–425	11.00
101–125	5.25	426–450	11.75
126–150	5.50	451–475	12.00
151–175	6.00	476–500	12.50
176–200	7.50	501–525	12.75
201–225	7.75	526–550	13.00
226–250	8.00	551–575	13.50
251–275	9.00	576–600	13.75
276–300	9.25	601–up	*
301–325	9.75		

*Add $2.50 for each additional 100 page increment from 601 to 1,000 pages: add $4.50 for each additional 100 page increment over 1,000 pages.

Distribution Category

UC-11

LAWRENCE LIVERMORE LABORATORY

University of California Livermore, California 94550

UCRL-52048

SEISMIC SPECTRA OF EVENTS AT REGIONAL DISTANCES

D. L. Springer

M. D. Denny

MS. date: April 5, 1976

Contents

SEISMIC SPECTRA OF EVENTS AT REGIONAL DISTANCES

Abstract

About 40 underground nuclear explosions detonated at NTS were chosen for analysis of their spectra and any relationships they might have to source parameters such as yield, depth of burial, etc. The sample covered a large yield range (<20 kt to >1 Mt). Broadband (0.05–20 Hz) data recorded by the four-station seismic network operated by Lawrence Livermore Laboratory were analyzed in a search for unusual explosion signatures in their spectra. Long time windows (total wave train) as well as shorter windows (for instance, P_n) were used as input to calculate the spectra. Much variation in the spectra of the long windows is typical although some gross features are similar, such as a dominant peak in the microseismic window. The variation is such that selection of "corner frequencies" is impractical and yield scaling could not be determined. Spectra for one NTS earthquake showed more energy in the short periods (<1 sec) as well as in the long periods (>8 sec) compared to those for NTS explosions.

Introduction

In recent years, the Lawrence Livermore Laboratory has operated a 4-station seismic network (at Mina, Landers, Kanab, and Elko) surrounding the Nevada Test Site (NTS) at a distance of 200 to 400 km. It is a broadband vertical-component system whose velocity response is approximately flat between 0.05 Hz and 20 Hz. The system has been operated primarily to record NTS shots.

From these stations, we have accumulated a large library of explosion recordings, of which a substantial fraction has been digitized. Of these, we selected a population of about 40 explosions for study (Table 1). We are reporting on the analysis of velocity spectra of selected NTS explosions and one NTS earthquake using the duration of essentially the whole wave train as

Table 1. Pertinent information for the explosions in this study.

Name	No. of stations[a]	Date	Yield[b] (kt)	Depth (m)	Medium	NTS area
Boxcar	(1)	4-26-68	1200	1158	Rhyolite	Pahute Mesa
Rickey	(1)	6-15-68	L-I	683	Tuff	Pahute Mesa
Chateaugay	(1)	6-28-68	L-I	607	Tuff	Pahute Mesa
Tanya	(1)	7-30-68	L	381	Alluvium	Yucca Valley
Sled	(2)	8-29-68	L-I	729	Tuff[c]	Pahute Mesa
Noggin	(2)	9-06-68	L-I	582	Tuff[c]	Yucca Valley
Knife A	(2)	9-12-68	L	332	Tuff	Yucca Valley
Stoddard	(2)	9-17-69	L-I	468	Tuff	Yucca Valley
Crew	(2)	11-04-68	L-I	604	Tuff[c]	Yucca Valley
Knife B	(3)	11-15-68	L	363	Alluvium	Yucca Valley
Tinderbox	(3)	11-22-68	L	440	Tuff	Yucca Valley
Schooner	(1)	12-08-68	35	107	Tuff	Pahute Mesa
Benham	(3)	12-19-68	1100	1402	Tuff[c]	Pahute Mesa
Vise	(3)	1-30-68	L-I	454	Alluvium	Yucca Valley
Coffer	(3)	3-21-69	< 100	464	Alluvium	Yucca Valley
Blenton	(3)	4-30-69	L-I	557	Tuff	Yucca Valley
Thistle	(3)	4-30-69	L-I	560	Tuff	Yucca Valley
Purse	(3)	5-07-69	L-I	599	Tuff[c]	Pahute Mesa
Torrido	(3)	5-27-69	L-I	514	Tuff	Yucca Valley
Ildrim	(2)	7-16-69	L-I	410	Tuff	Yucca Valley
Hutch	(2)	7-16-69	L-I	549	Alluvium	Yucca Valley
Jorum	(3)	9-16-69	LM	1158	Tuff[c]	Pahute Mesa
Pipkin	(3)	10-08-69	I	617	Tuff/rhyolite	Pahute Mesa
Pod	(4)	10-29-69	L-I	312	Tuff	Yucca Valley
Calabash	(4)	10-29-69	110	624	Tuff[c]	Yucca Valley
Piccalilli	(2)	11-21-69	L-I	394	Tuff	Yucca Valley
Grape A	(4)	12-17-69	L-I	551	Tuff	Yucca Valley
Lovage	(4)	12-17-69	L	378	Alluvium	Yucca Valley
Terrine	(4)	12-18-69	L-I	457	Tuff	Yucca Valley
Labis	(3)	2-05-70	L-I	442	Tuff	Yucca Valley
Cumarin	(4)	2-25-70	L-I	408	Tuff	Yucca Valley
Yannigan	(4)	2-26-70	L-I	392	Alluvium	Yucca Valley

Table 1. (Continued)

Name	No. of stations[a]	Date	Yield[b] (kt)	Depth (m)	Medium	NTS area
Shaper	(4)	3-23-70	L-I	561	Tuff[c]	Yucca Valley
Handley	(4)	3-26-70	> 1 Mt	1206	Tuff[c]	Pahute Mesa
Snubber	(4)	4-21-70	L	343	Tuff	Yucca Valley
Can	(4)	4-21-70	L-I	399	Tuff	Yucca Valley
Beebalm	(4)	5-01-70	L	390	Tuff	Yucca Valley
Cornice	(4)	5-15-70	L-I	443	Tuff	Yucca Valley
Morrones	(4)	5-21-70	L-I	482	Tuff	Yucca Valley
Flask	(4)	5-26-70	105	531	Tuff	Yucca Valley
Arnica	(4)	6-26-70	L-I	309	Alluvium	Yucca Valley
Tijeras	(4)	10-14-70	L-I	561	Tuff[c]	Yucca Valley
Abeytas	(4)	11-05-70	L-I	394	Tuff	Yucca Valley
Artesia	(4)	12-16-70	L-I	485	Tuff	Yucca Valley
Carpetbag	(4)	12-17-70	220	662	Tuff	Yucca Valley
Baneberry	(3)	12-18-70	L	277	Tuff	Yucca Valley

[a] N = Number of LLL stations for which broadband records existed.

[b] L = Low yield: 0 to 20 kt
L-I = Low-intermediate yield: 20 to 200 kt
I = Intermediate yield: 200 to 1 Mt
LM = Low-megaton yield: about 1 Mt

[c] 100% water-saturated because below the water table.

the time window. The spectra have been corrected for instrument response but not for attenuation of the earth.

One of our objectives was to see if we could quantify the characteristics of explosion spectra in terms of source-related parameters. Another objective was to see if any of our population of explosions showed extra surface wave enhancement. If such enhancement existed, we hoped to identify peculiarities such as explosion geometry, location, or medium which might explain it.

Method

The seismic spectra were calculated using the Fast Fourier Transform technique[1] from records 163.84 sec long digitized at 50 points per sec. This gave 8192 total points per record. Each signal record began approximately 10 sec before the onset of the first arrival (P_n) wave. For comparison, background noise records were calculated also and consisted of the time window just preceding the signal record of the same length (163.84 sec).

Both a signal record and a noise record from each of the four stations were transformed for each event studied. However, before transforms were taken, the mean value (bias) was removed from each record and a 1% cosine taper applied to the beginning and end. Next, the spectra were smoothed using a filtering technique which treats the amplitude spectrum as if it were a signal with high frequency noise which can be removed by low-pass filtering. The filter used was equivalent to a 50-point smoothing operator. Finally, the smoothed amplitude spectra were divided by the amplitude response of the instrument in order to correct the high and low frequency parts of the spectra.

Power spectra were calculated as well as amplitude spectra. Additionally, since the seismic records were records of ground velocity, they were converted to ground displacement spectra. Both smoothed and unsmoothed versions of the displacement and velocity spectra were calculated, although this report is limited to discussion of the smoothed velocity spectra.

Analysis and Interpretation

Spectral calculations as outlined above were made for the explosion population of Table 1. The descriptive information in the table is from the nuclear explosion summary of Springer and Kinnaman.[2] A set of the calculated ground velocity spectra is given in the Appendix. Because of the format of these presentations, no vertical scale is given; however, the spectra are plotted on a common amplitude scale with a decade of amplitude having the same dimension on the graph as a decade of frequency.

Figures A-1 through A-4 in the Appendix show the calculated spectra of the wave trains recorded at the four LLL stations for Yucca Valley underground nuclear explosions; Figs. A-5 through A-8 show the same spectra for Pahute Mesa explosions. As Table 1 indicates, these populations cover a wide range of yields, depths, and coupling media. The spectra are arranged in order of increasing average spectral density energy (from bottom to top of each figure). This ordering reflects the relative coupling efficiencies of the shot media, the yields of the explosions, and to some extent the effect that near-source geology has on the propagating waves (absorption, scattering, etc.).

Some brief comments on some of the spectra are appropriate. For instance, for the spectra of many of the smaller events (Beebalm, Snubber, Stoddard, Abeytas, Lovage, Knife-A, Knife-B, and Schooner) the broad peak in the spectra in the 0.1-Hz to 0.2-Hz range is due to microseismic noise contamination. There is a similar but smaller effect for Baneberry, Tanya, and Coffer.

One of the stated objectives of this work was to attempt to quantify the explosion spectra for characteristics associated with the source. This was not possible because of significant variations in the spectra which appeared to be related to slight differences in location (presumably giving differences in propagation path). These variations deserve more study, but for the moment we will mention the gross similarities in the spectra and comment on some of the "exceptions," those spectra which appear to be substantially different from spectra with similar source parameters.

For instance, one exception is the spectrum of the Tanya explosion in Fig. A-1a which appears to be shifted to higher frequencies with respect to the others. Tanya was a low-yield test detonated in dry alluvium at a shallow depth. Whether the apparent spectral shift is a result of source-related or propagation-path-related parameters cannot be determined because only the Mina station data are available.

The Baneberry spectra in Fig. A-1a, A-2a, A-3a, and A-4 are different in at least one respect: the spectral amplitude at about 2 Hz is markedly reduced compared to other shot spectra at Mina, Kanab, Landers, and perhaps also at Elko. Since this characteristic prevails at most of the stations, it seems to be source-related rather than propagation-path related. Baneberry vented significant radioactivity through hot gases finding their way to the surface, and that is the only obvious "difference" in the source compared to other tests. Such a connection is speculative at best—the seismic data alone are not definitive enough to give specific answers.

The Vise and Morrones spectra at Kanab (Fig. A-2a) are somewhat similar to each other, but they lack the prominent spectral peak at about 0.7 Hz that is characteristic of the Kanab spectra for most Yucca explosions.

As a general rule, the spectra at a given station show the greatest similarity with each other at the long-period end. Figures A-5 through A-8, which give spectra at the four stations for Pahute Mesa detonations, illustrate this. Although there are exceptions such as Schooner (which may be explained, at least in this case, by its being an excavation experiment), most of the spectra are very similar in the 0.08- to 0.4-Hz region which is dominated by Rayleigh-wave energy. The spectra at Landers (Fig. A-7) are the most similar-looking group over the entire spectral range compared to those at other stations.

An examination of these results indicates considerable variation in the shapes of the spectra even though some gross features are characteristic of all. For instance the peak of each of the spectra occurs in the frequency range 0.3 to 0.7 Hz (about 1.5- to 3-sec periods). The slope of the high-frequency side of the spectra varies from about -2 to -3. The variation does not appear to be related to yield or to any obvious geophysical parameter such as depth of burial but is probably a result of near-source propagation due to the complicated crustal structure in the NTS vicinity and to distance of propagation (attenuation). Even these smoothed spectra exhibit considerable "notching" that is probably due to reverberations (echoes) in the crust at the source and at the receiver.

The slope of the low-frequency side is also quite variable among these spectra, ranging from about 1 to 2 or so. This variation can be attributed to interaction of microseismic noise, Rayleigh-wave signal, and instrumental noise introduced when instrument corrections were made to the spectra. More of these matters will be discussed later. At this point it is sufficient to state that the variations in the spectra of the whole wave trains precluded a quantitative analysis in terms of source-related parameters. Such an analysis may be possible if the wave train can be separated into distinct phase contributions, and we will pursue those possibilities in the future.

The preceding discussion dealt with general similarities and dissimilarities in the entire set of calculated spectra as presented in the Appendix. The following discussion points out more specific examples and comparisons.

Figure 1a shows the sections of the broadband wave train which contribute to the various parts of the computed spectrum. The surface-wave energy is concentrated in the time segment after 35 sec from initial onset. The peak of the Mina velocity spectrum for Pahute Mesa explosions detonated near or below the water table is formed primarily by P-wave energy arriving within 6 sec of initial onset. However, the peak for intermediate and low-intermediate yield explosions located below the static water table in Yucca Valley seems to be formed by a mixture of these early P waves and some very late-arriving energy. We will show an example of this later. The slope of the spectrum on the high-frequency side is about -3, but as mentioned earlier there is quite a variation from shot to shot even at the same station. Also, since several phases may be mixed even within the short 6-sec segment and since earth attenuation has not been corrected for, interpreting this slope in terms of source function should be done cautiously, if at all.

The spectral peak at about 1 Hz is dominated by P energy rather than SV energy as Fig. 1b shows. Since we are looking at vertical component data only, we are not observing SH energy at all.

Figure 2 gives examples of the variation of spectra as a function of source parameters and of path. In Fig. 2a are spectra at Mina of two Yucca Valley shots of about the same yield and depth separated by about 4.5 km in the direction nearly perpendicular to the azimuth toward the station. Depth of burial for Cornice was 444 m and for Terrine was 457 m. The lower two spectra in the figure are of a noise segment of the same duration immediately preceding the shots. Notice the difference in the microseismic noise levels: Cornice was detonated in May 1970 and Terrine in December 1969, and the difference in the noise spectra illustrates the seasonal variation in microseismic noise levels typical at our stations—about a factor of 5 in the 5- to 8-sec range.

Figure 2b shows spectra at Mina of four explosions detonated at widely separated locations in Yucca Valley. Coffer and Crew were located several kilometers north and slightly west of the Lovage and Abeytas locations (see Fig. 3). Coffer was buried at 465 m, Crew at 604 m, Lovage at 378 m, and Abeytas at 394 m. Crew was the only shot fired below the static water table level. The yields of these shots span a factor of four. The

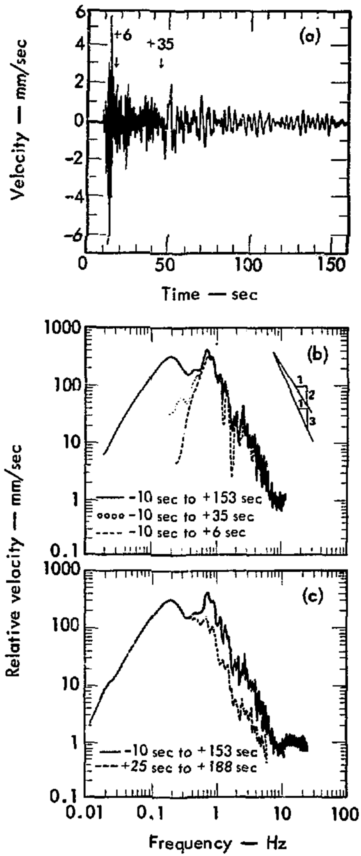


Fig. 1. Handley explosion recorded at Mina. (a) Seismic wave train; (b) relative ground velocity spectra for the time segments indicated; (c) relative ground velocity spectra for the time segments indicated.

similarity of the spectra, despite the differences in source parameters, tends to suggest that propagation path differences are producing the major portion of the differences in spectra from one shot to another at a given station.

Figure 2c shows the variation of the velocity spectra for Handley at our four stations. Mina is 190 km from the Handley location, Kanab 331 km, Landers 323 km, and Elko 398 km. Our four stations essentially cover the four quadrants and give good azimuthal coverage but not good distance coverage (over a similar azimuth). However, one can see the tendency of the earth to attenuate more and more of the high frequency seismic energy as distance increases. The large amplitude at about 0.8 Hz in the Mina and Kanab spectra is substantially attenuated relative to the rest of the spectrum at the Landers and Elko distances. However, this is only a general trend and applies more to the high-frequency portions of the spectra and not to the low-frequency portions. Portions of the spectra formed by 5- to 10-sec Rayleigh waves seem to be more dependent on particular travel paths than on distance. This suggests that there are significant differences in Rayleigh wave propagation at the regional level in the Western U.S., thus suggesting significant structural differences in the earth's crust.

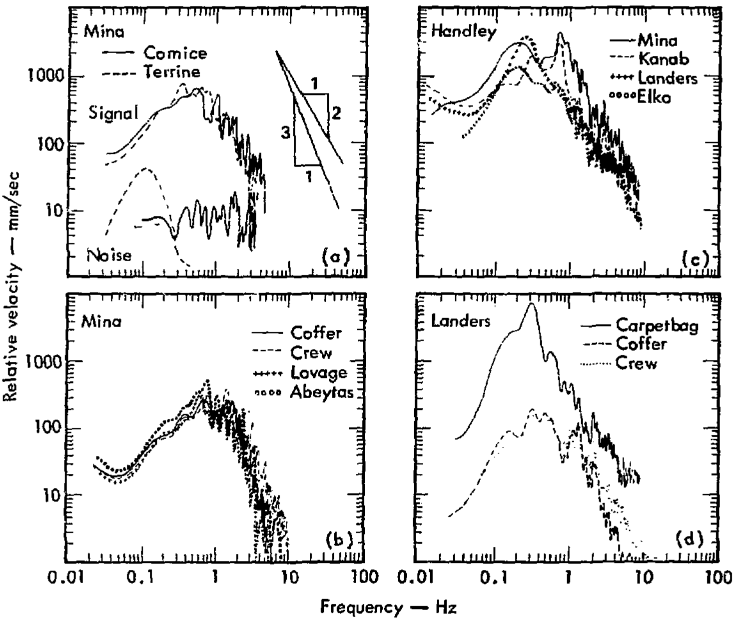


Fig. 2. Several comparisons of calculated spectra. (a) Two Yucca Valley explosions recorded at Mina (~230 km); (b) four Yucca Valley explosions recorded at Mina (~240 km); (c) Handley recorded at the four LLL stations; (d) three Yucca Valley explosions recorded at Landers (~305 km).

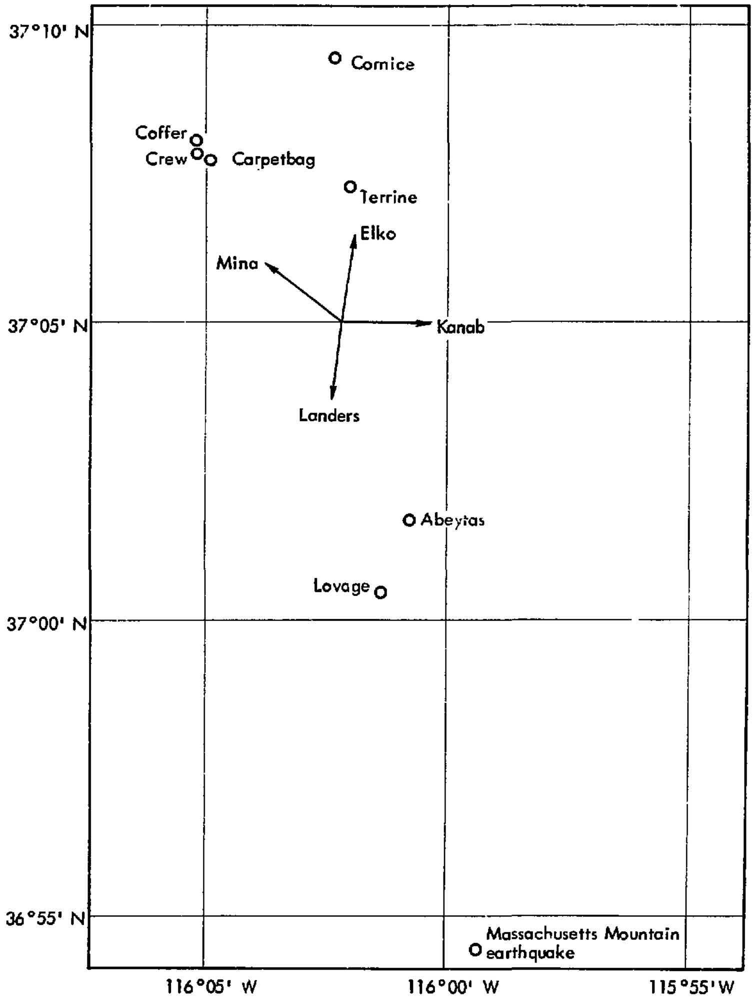


Fig. 3. Map of Yucca Valley area with locations of certain explosions and an earthquake.

Figure 2d shows the effect of yield on the spectrum as seen at our Landers station. We believe the effect is of yield, not of depth or medium, because Carpetbag and Crew have more similar depths than do Coffer and Crew, yet the former pair's spectra show a relatively large difference. These results would indicate a larger surface wave magnitude (M_s) relative to compressional body-wave magnitude (m_b) for Carpetbag than for Coffer or Crew with about the same M_s relative to m_b for Coffer and Crew. These three explosions were within a kilometer laterally of each other; thus their propagation paths might be considered identical for all but the higher-frequency waves. Earlier work showed that long-period wave amplitudes scale with yield with a higher exponent than do P-wave amplitudes.[3] These spectra show the same trend in that as yield increases, the differences in amplitudes at longer periods tend to be greater than those at shorter periods.

This brings up another question about scaling: do the frequencies of spectral peaks scale with the cube root of the yield as might be expected for P waves from simple spherical explosion source models? Notice that the peak in the spectra of these explosions occurs at about the same frequency. But, since we are looking at spectra of the entire wave train which may be dominated by the Rayleigh wave and its higher modes, we should not be too surprised at this result. Generation of Rayleigh waves by explosions is not completely understood, so no definitive answer can be given here. Also, the spectral peak may be masked by the effect of attenuation, i.e., lower yields which generate characteristic high frequency energy compared to higher yields will suffer more attenuation. Their spectra will appear to have lower peak frequencies.

Figure 4 illustrates the complexity of the problem and the danger of using spectra of stations at regional distances (and in particular at one station) to make source-related conclusions about the ideal spherical sources that explosions are often assumed to be. As noted earlier, these three explosions were at essentially the same location and now, while the Coffer and Crew spectra are nearly identical except at higher frequencies, the Carpetbag spectrum not only is larger in amplitude but has suffered a substantial shift in frequency of the peak. The time traces of Carpetbag and Coffer are shown to illustrate the point further as well as to show the source of the spectral difference. The large late

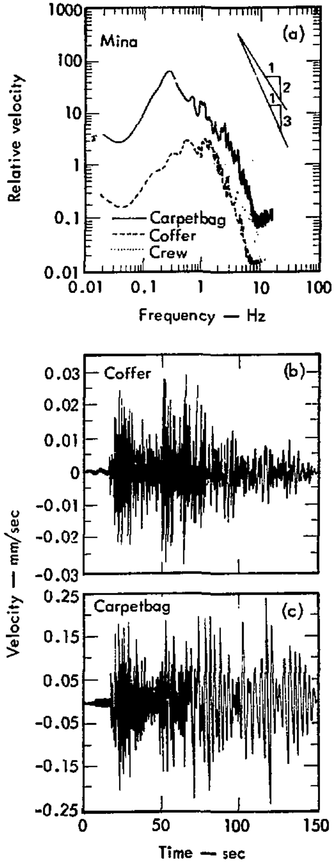


Fig. 4. Three explosions recorded at Mina. (a) Spectra for Carpetbag, Coffer, and Crew explosions; (b) seismic wave train for Coffer; (c) seismic wave train of Carpetbag. The Crew wave train is similar to the Coffer wave train.

phases in the Carpetbag signal are essentially non-existent for Coffer and Crew. This would suggest a basic difference in the source function of Carpetbag as compared to Coffer and Crew from the standpoint of the energy partitioning at or very near the explosion.

Figure 4 is one of the more extreme examples of non-reproducibility, and it shows the problem we have in characterizing NTS underground explosions by their spectral shapes. In attempting to determine if peak frequency scales as the cube root of yield, we grossly oversimplified the spectra. We simply picked the frequency at which the spectral peak occurred and plotted it versus yield at each station. We regret not being able to show these plots because of the classification of yields. However, the dependence of this parameter on yield was weak, especially over the lower half of the yield range where almost no dependence appeared to exist (approximately the sixth root, or less, of yield). The yield range was roughly 2 orders of magnitude.

Furthermore, we considered the spectra of only the first several seconds of P phases for Chateaugay and for Handley (two shots at Pahute Mesa). The frequencies of the spectral peaks did not scale as the cube root of yield. As a matter of fact, the peaks appeared to be at the same frequency. Thus, we conclude that oversimplified spherical source models do not apply across the board to NTS explosions. Earlier work suggested a similar conclusion.[3] If this weak dependence of peak frequency on explosion yield really exists, it explains why some investigators observe the M_s/m_b relation as a straight line.

Figure 5 shows a comparison at our four stations of the spectra of two events of about the same body-wave magnitude--one is the Massachusetts Mountain earthquake, the other is the underground nuclear explosion Lovage. Approximate distances to the stations are: Mina 250 km, Kanab 285 km, Elko 425 km, and Landers 285 km. The two events are about 10 km apart. The

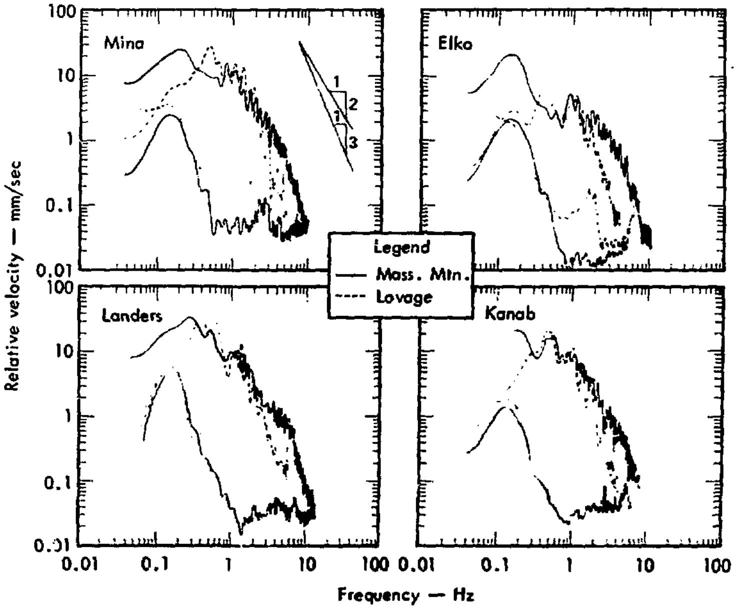


Fig. 5. Comparisons of signal spectra and noise spectra for the Lovage explosions and an NTS earthquake from seismograms produced at the four LLL stations.

earthquake occurred just before a planned nuclear test, so we have excellent data for it. The lower pair of curves in each plot are the spectra of a segment of noise immediately preceding the event's signals. Body-wave magnitude (m_b) for the earthquake was about 4 and depth about 4-1/2 km.[4] On the basis of spectral amplitudes at about 1 Hz, the m_b's of the two events are presumed equivalent.

Figure 5 illustrates several significant points. First, the long-period, Rayleigh-wave amplitudes for the earthquake are about an order of magnitude larger than those for the shot, when short-period amplitudes are about equal. Thus, the M_s-m_b method would discriminate between this earthquake and the representative explosion. Second, the peak of the Rayleigh-wave signal spectrum occurs in the microseismic window for both the earthquake and the explosion. Thus, as at teleseismic distances, the microseismic noise levels would be the limiting factor in the practical application at regional distances of the M_s/m_b discriminant, presuming one always must measure an M_s. At first, one might be tempted to set up a detection system in the regional distance ranges with instrument response peaks coinciding with the s[illegible]l peaks in order to obtain maximum S/N. However, a more thorough analysis should be performed before such systems are designed, because it may be that actual S/N could be optimized at a frequency other than that at which amplitudes of the microseisms and these signals are greatest. A steeper slope appears to exist for the low-frequency side of the noise spectra than for that of the earthquake signal. That suggests S/N is larger at lower frequencies than at the peak frequencies.

Third, notice the high-frequency side of these spectra. Recall that the Lovage spectra are typical of many shot spectra. The earthquake has an apparently lower slope than does Lovage which would suggest that the equivalent source function of the earthquake is more impulsive at time t_0 than is that of the Lovage explosion. We assumed the earth's attenuation is about the same for the two because of the shallow depth of the earthquake focus. To check this, we calculated the relative amount of spectral amplitude loss for the explosion compared to the earthquake using the expression for amplitude attenuation

$$e^{\frac{-\omega R}{2cQ}}$$

where ω is circular frequency ($2\pi f$), R is the difference in P-wave, travel-path distance for the two events, c is P-wave velocity over this part of the travel path, and 1/Q is the specific attenuation factor.[5] For this case, R is about 5 km and c is about 5 km/sec; R/c is taken to be essentially unity. It is clear that the more critical parameters in the above expression are ω(or f) and Q. Large values of f and/or low values of Q will give large attenuations. Using a conservative value for Q of 25, the expression above yields a predicted amplitude reduction of about 50% at 5 Hz for the explosion compared to the earthquake. This is much less than is seen in Fig. 5 where there is typically an order-of-magnitude difference at about 5 Hz between the spectral amplitude of the explosion and that of the earthquake. It would require an extremely low Q for the crust to account for such a large difference. Thus, we presume that most of the difference is related to real differences in the source functions of the earthquake and explosion.

Furthermore, notice that the spectra of the two events are very similar at a given station at frequencies around 1 Hz. This implies that propagation paths are similar for 1-Hz waves and that the large differences observed at higher and lower frequencies are related to source-mechanism differences, not to propagation-path differences. If this is true, compared to the explosion this earthquake is characterized by one or more of the following:

- A more discontinuous displacement history at t = 0 (high stress drop?).
- A shorter rise time in the source function (a slower displacement or a smaller volume over which displacement took place).
- A more slowly decaying, or a non-decaying, source function (i.e., greater permanent displacement).

Summary and Conclusions

In this study we attempted to identify underground nuclear explosions whose regional spectra were grossly different from typical explosion spectra. In particular we were interested in finding any explosions that showed enhancement of the long-period portions of the spectra. However, only a few spectra could be categorized as "grossly different," and in general these tended to be inconsistently different, suggesting propagation path as the reason, i.e., spectra at four different stations for the same explosion were not all grossly different from those for a typical explosion. We did find spectra which showed some apparent enhancement of long-period energy, but again this feature did not show up consistently at all stations for a given explosion.

One of the most significant results of this study came from comparing the spectra of an NTS earthquake with those of an explosion of about the same body-wave magnitude. As might be expected, the earthquake spectra showed relatively greater energy in long-period surface waves than did the explosion spectra. The interesting result was that the earthquake spectra showed relatively greater energy in high-frequency (>2 Hz) P waves than did the explosion spectra. In addition, it appears that either the slope of the high-frequency part (P-wave) of the spectrum for the earthquake is less than that for the explosion or the "corner" frequency of the earthquake spectrum is greater than that for the explosion.

References

1. J. W. Cooley and J. W. Tukey, Math. Comp. 19, 297 (1965).

2. D. L. Springer and R. L. Kinnaman, Bull. Seism. Soc. Am. 61, 1073 (1971).

3. D. W. Springer and W. J. Hannon, Bull. Seism. Soc. Am. 63, 477 (1973).

4. F. G. Fischer, P. J. Papanek, and R. M. Hamilton, The Massachusetts Mountain Earthquake of 5 August 1971 and Its Aftershocks, Nevada Test Site, U.S. Geological Survey, Menlo Park, Calif., Rept. USGS-474-149 (1972).

5. L. Knopoff, Rev. Geophys. 2, 625 (1964).

Appendix. Calculated Velocity Spectra.

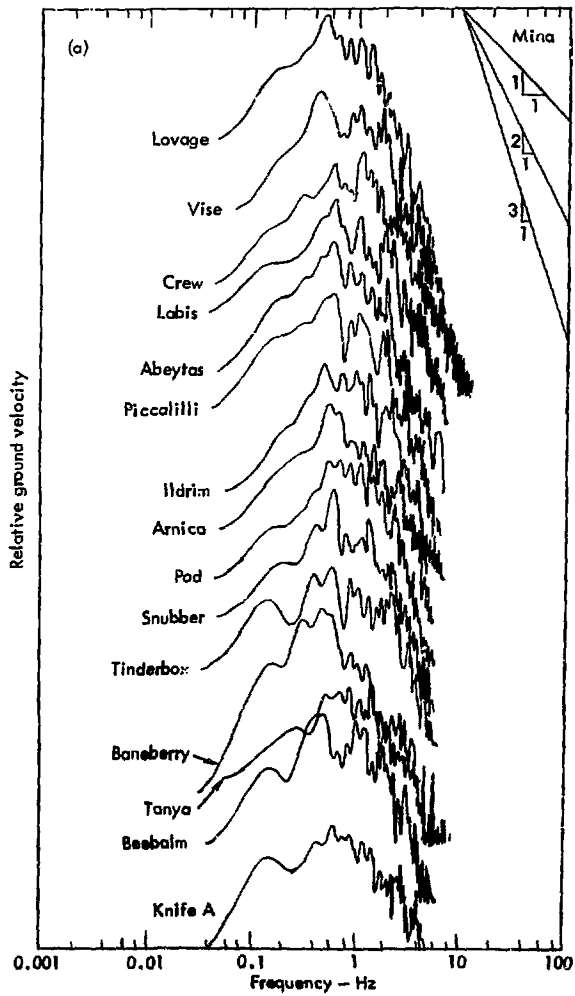


Fig. A-1. (a) and (b) show relative ground velocity spectra calculated for some Yucca Valley underground explosions from broadband seismograms produced at the Mina station.

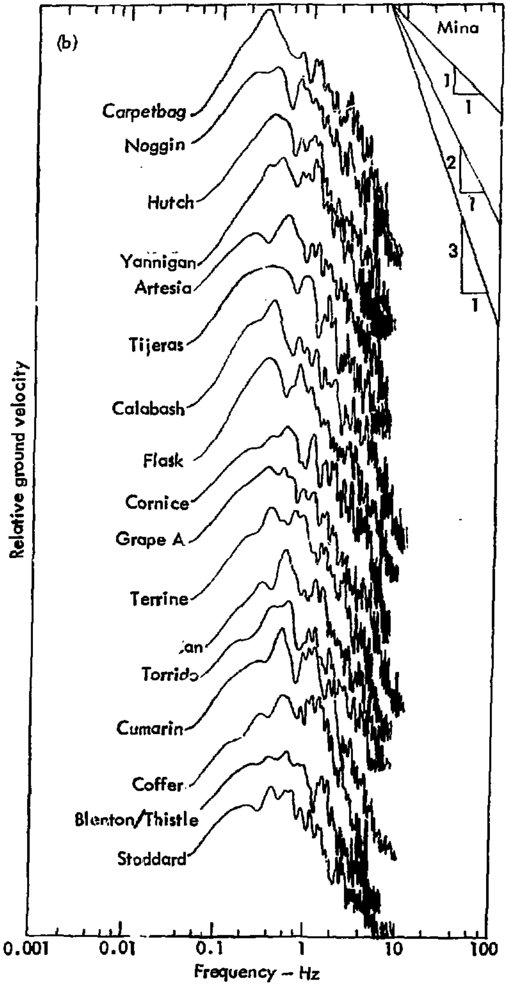


Fig. A-1. (continued)

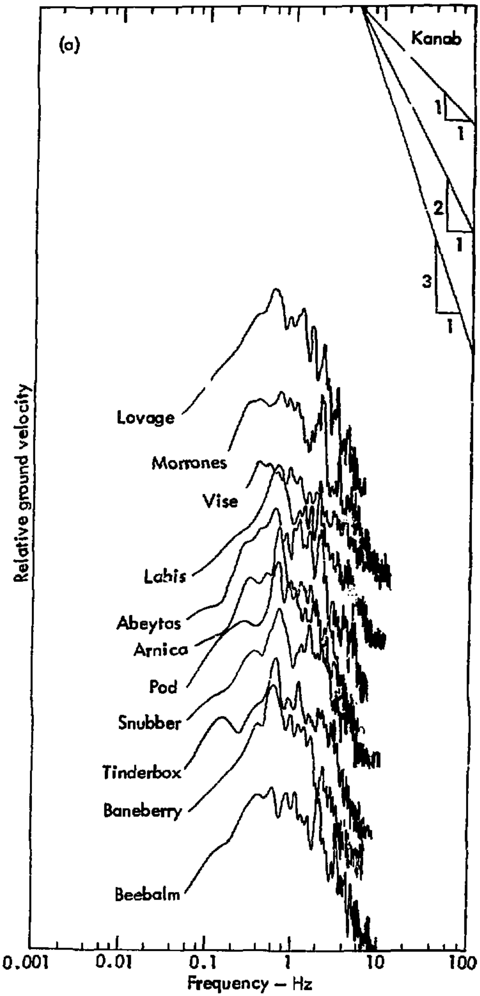


Fig. A-2. (a) and (b) show relative ground velocity spectra calculated for some Yucca Valley underground explosions from broadband seismograms produced at the Kanab station.

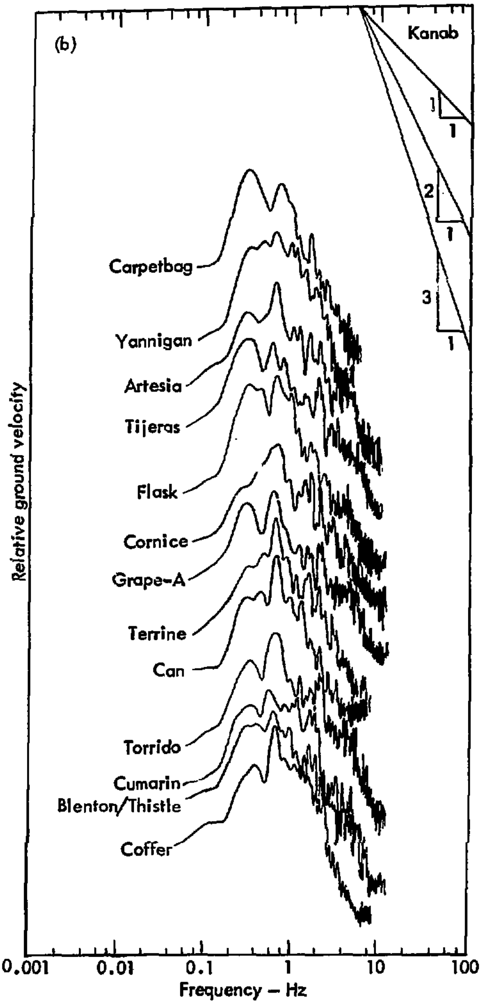


Fig. A-2. (continued)

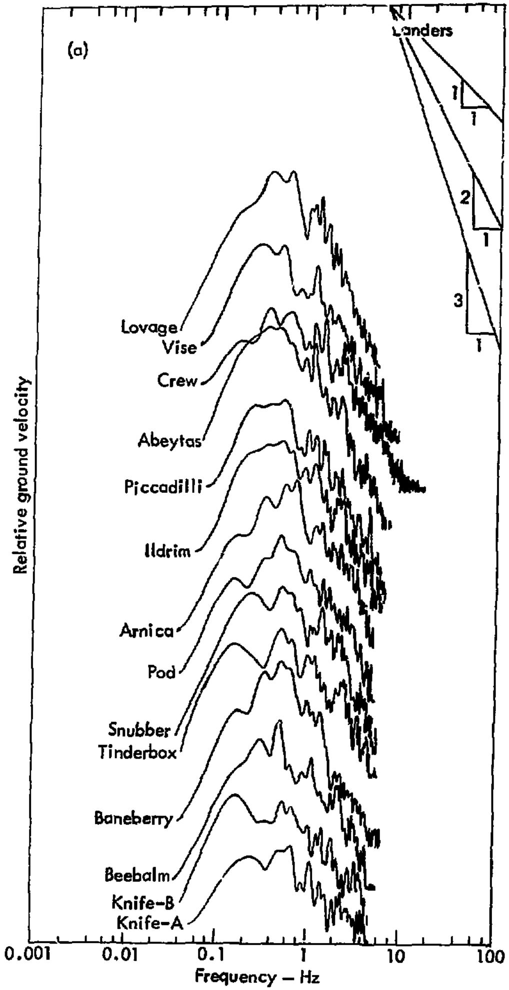


Fig. A-3. (a) and (b) show relative ground velocity spectra calculated for some Yucca Valley underground explosions from broadband seismograms produced at the Landers station.

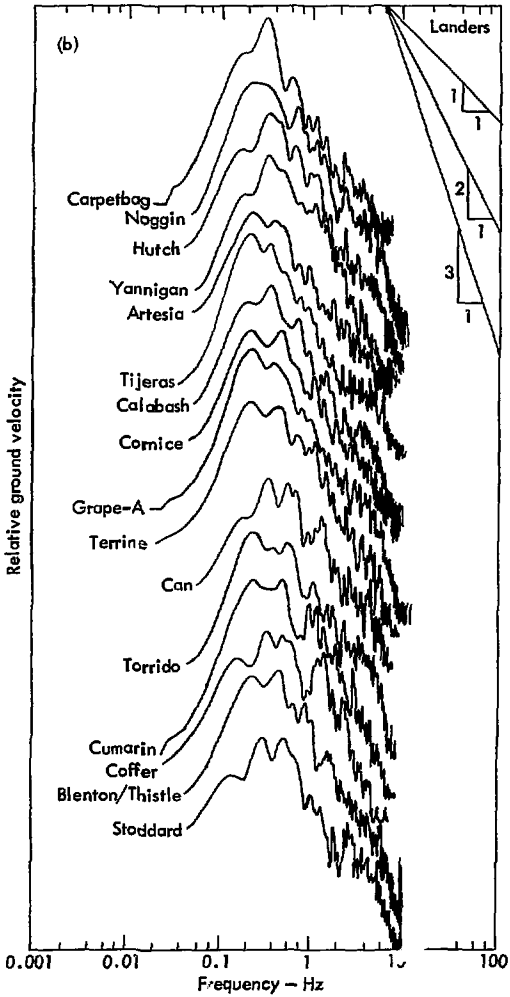


Fig. A-3. (continued)

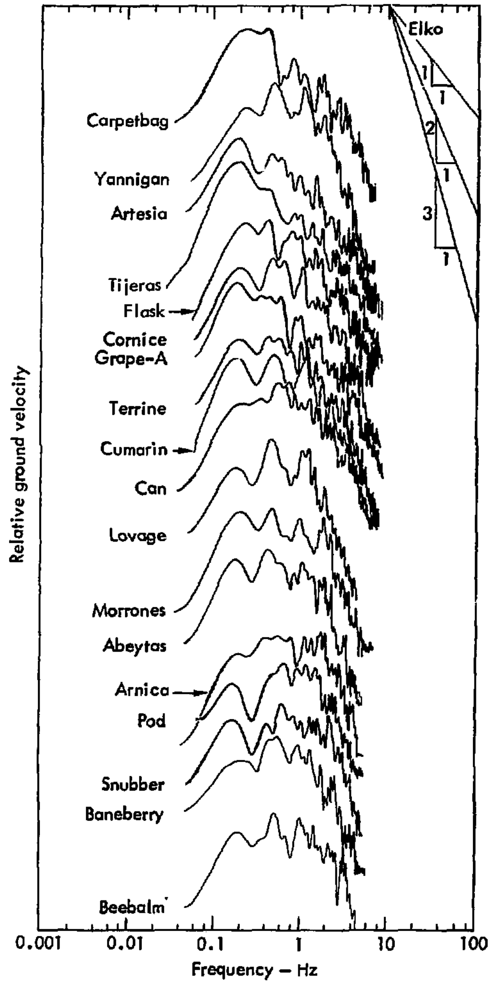


Fig. A-4. Relative ground velocity spectra calculated for some Yucca Valley underground explosions from broadband seismograms produced at the Elko station.

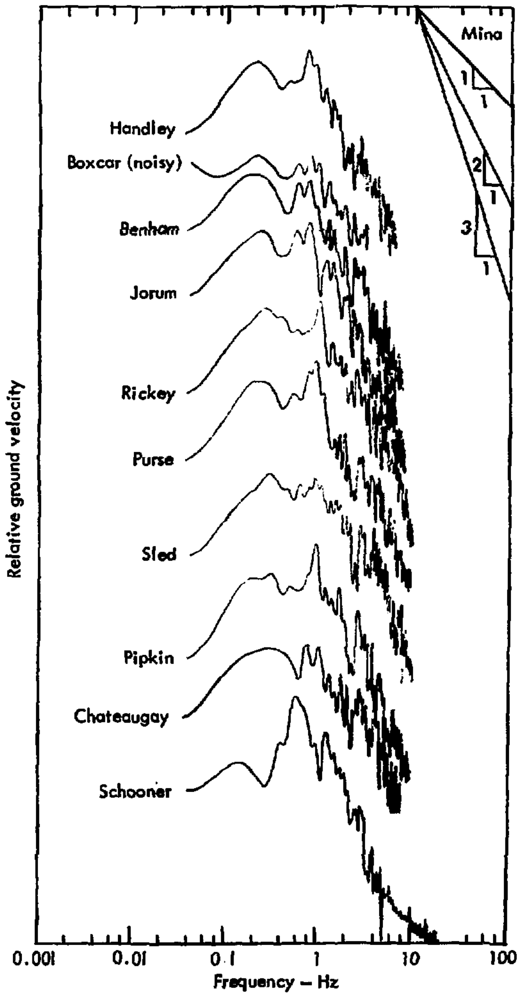


Fig. A-5. Relative ground velocity spectra calculated for some Pahute Mesa underground explosions from broadband seismograms produced at the Mina station.

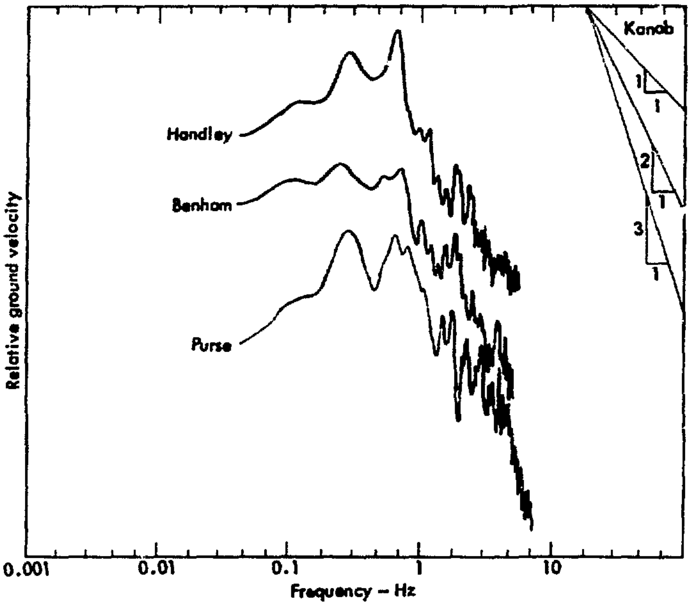


Fig. A-6. Relative ground velocity spectra calculated for some Pahute Mesa underground explosions from broadband seismograms produced at the Kanab station.

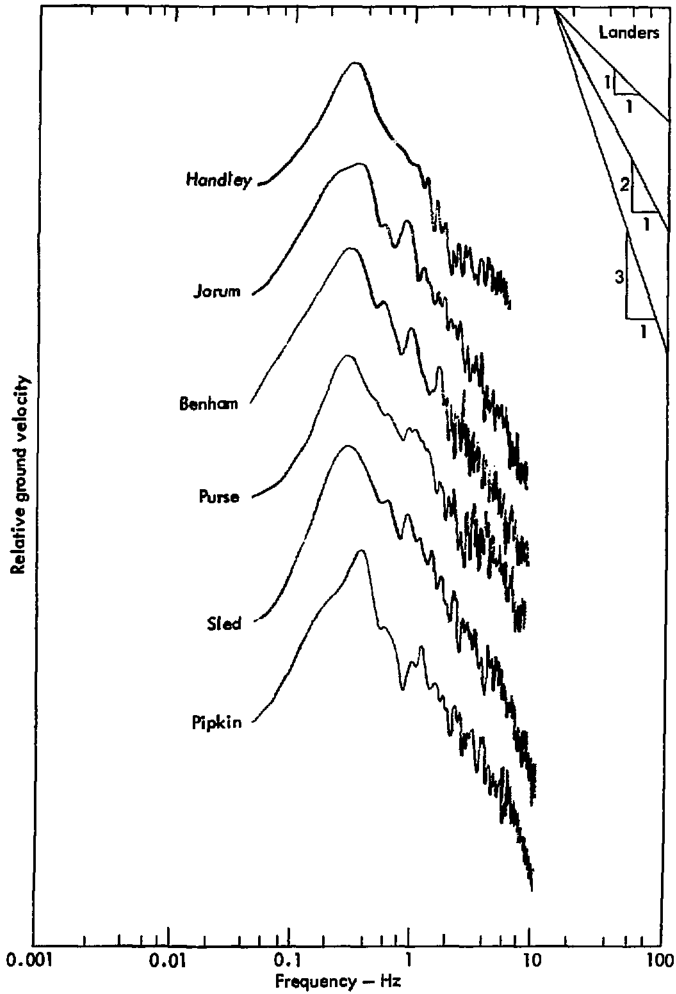


Fig. A-7. Relative ground velocity spectra calculated for some Pahute Mesa underground explosions from broadband seismograms produced at the Landers station.

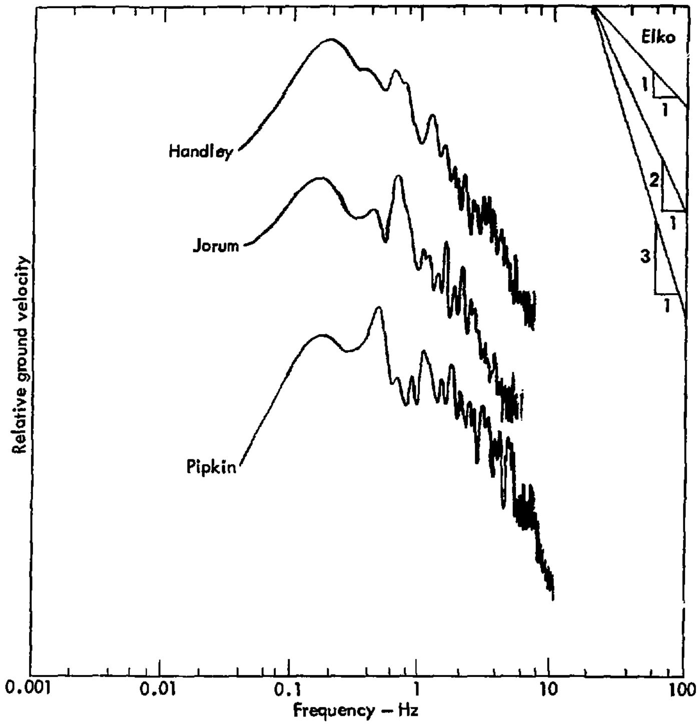


Fig. A-8. Relative ground velocity spectra calculated for some Pahute Mesa underground explosions from broadband seismograms produced at the Elko station.

JS/gw/vt