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ANALYZING OF SURFACE-MOTION DATA FROM OLD RELIABLE MINE BLAST

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DISCLAIMER

ANALYZING OF SURFACE-MOTION DATA FROM OLD RELIABLE MINE BLAST

ABSTRACT

Seismic data from the Old Reliable Mine blast were studied to evaluate the utility of applying current prediction schemes to predict seismic motions in the Galiuro mountains north of Tucson, Arizona. Air-blast, earth-motion, and structural-response measurements were made at various stations surrounding the blasting point. The major objectives were not realized, but plots were made for Fourier spectra and earth velocity versus range.

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INTRODUCTION

The Old Reliable Mine is located at an elevation of 1140 m (~3740 ft) in the Galiuro mountains 62 km (~39 mi) north of Tucson, Arizona.[1] The area can be reached by driving 15 km (~9 mi) up Copper Creek Road from Mammoth, Arizona (Fig. 1). The mine was discovered in 1890 and worked sporadically for copper from 1890 to 1919 and again in 1953 and 1954. During these times, only limited amounts of copper were taken from the mine.

The geological formations[2] of the area are chiefly limestone, quartzite, conglomerate, shale, and sandstone interbedded with and intruded by andesite, dacite, and rhyolite. The sediments and an andesitic tuff are in turn intruded by a granodiorite. An extensive series of flat-lying basaltic flows overlays the entire complex. The copper is found in a pipe-like structure that appears nearly circular in cross-section, stands nearly vertical, and outcrops as a small but prominent pinnacle. The pipe-filling consists of angular, silicified rock fragments that are cemented chiefly by the quartz, sericite, and copper minerals supplied by the andesitic tuff. Oxidized copper minerals occur just below the leached surface zone and are gradually replaced at depth by copper sulfide. Mineralization is believed to be postbasaltic with the principal copper minerals being chalcocite, chalcopyrite, malachite, chalcanthite, and chrysocolla.

After the early work, the mine proved uneconomic to operate in a conventional manner, even though a large volume of copper remained in low-grade deposits surrounding the old workings. Ranchers Developments Corporation decided the copper could be recovered economically if a different technique were applied. Since mining and hauling the ore away for processing was too costly, this new technique would have to include breaking up the ore in place and removing the copper, with the rock staying in its original formation. Accordingly, with the E.I. DuPont Corporation providing the explosive and technical assistance, they proceeded with a plan to break up the whole ore body with one large blast. In this plan, 4 million lb of prilled ammonium nitrate and fuel oil would be detonated in three tunnel complexes. After the blast, the mountain side would be terraced so that leaching fluids could be injected and percolated through the broken ore body. The copper would be picked up by the downward-percolating fluids, and the loaded liquors would be collected at the base of the ore body. After collection of the liquids, the copper would be recovered by cementation and shipped to a smelter for further processing.

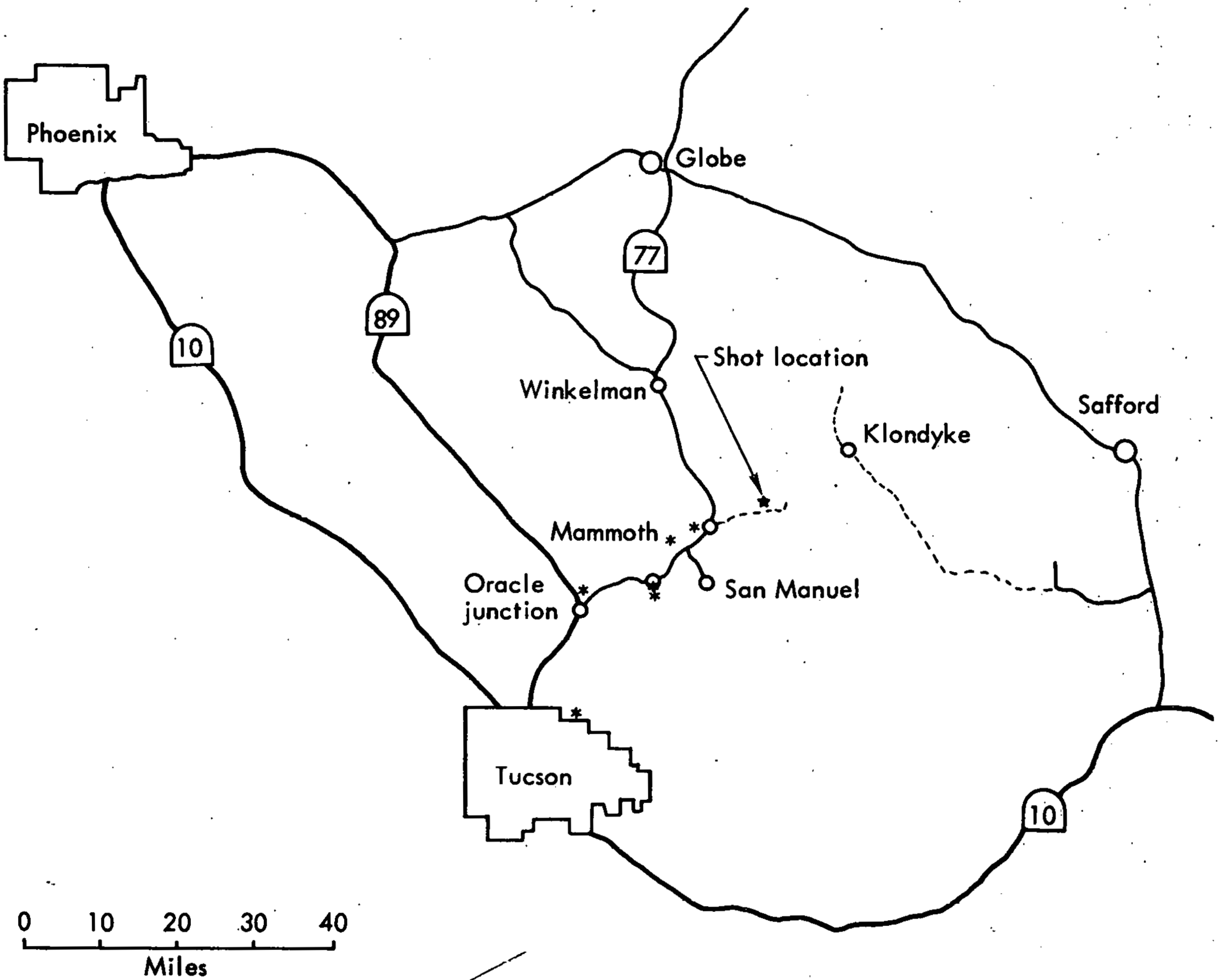

Fig. 1. Map of Old Reliable Mine area. Asterisks show locations of instrument stations for measuring ground motion.

A schematic drawing of the three tunnels is shown in Fig. 2. The two lower tunnels, separated by a vertical distance of 30 m (approx. 100 ft), were dug many years ago during the active mining stages of the ore body. The top tunnel, located a vertical distance of 50 m (approx. 165 ft) above the middle tunnel, was constructed especially for the blast, so that the explosive could be placed for a more efficient breakage of the ore body. The top tunnel was 200 m (approx. 660 ft) long, had 305 m (approx. 1000 ft) of cross drifts, and contained 595,800 lb of explosive. The middle tunnel was 230 m (approx. 760 ft) long, had 945 m (approx. 3100 ft) of cross drifts, and contained 2,103,400 lb of explosive. The bottom tunnel was 255 m (approx. 840 ft) long, had 640 m (approx. 2100 ft) of cross drifts, and contained 1,294,550 lb of explosive. The explosive detonation sequence was initiated in the bunker with an electrical circuit, conveyed by wires to blasting caps near the tunnel entrances, and then distributed via Primacord* to the various high-explosive primers placed among the bags of explosive.

EXPERIMENTAL PLAN

On January 27, 1972, representatives from E. I. DuPont de Nemours and Company, John A. Blume and Associates Research Division, Ranchers Development Corporation, Lawrence Livermore Laboratory, Atomic Energy Commission, U.S. Geodetic Survey, and Sandia Laboratories met to discuss a possible mutual effort in making some measurements of earth motion and related phenomena on this unusually large nonnuclear explosion. Measurements discussed were

- Earth-motion measurements at surface zero;
- Pressure measurements in water wells in the San Pedro River basin;
- Motion measurements on ranch structures very near the detonation point;
- Motion measurements on some of the structures at the Magma Mine facility;
- Earth-motion measurements at several locations along a line between the detonation point and the city of Tucson; and
- Air-blast measurements.

The DuPont-Ranchers people were interested in documenting the earth-motion magnitudes for two purposes: one, the data could be used in a scientific analysis of the performance of the explosive; two, the data would be available for use in possible future litigations if, for any reason, damage claims should be filed after the detonation.

Lawrence Livermore Laboratory's Earth Science Division was concerned with long-range seismic motions. The objectives were

1. To determine if the present prediction scheme for ground motions would apply to the geology of this region;

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

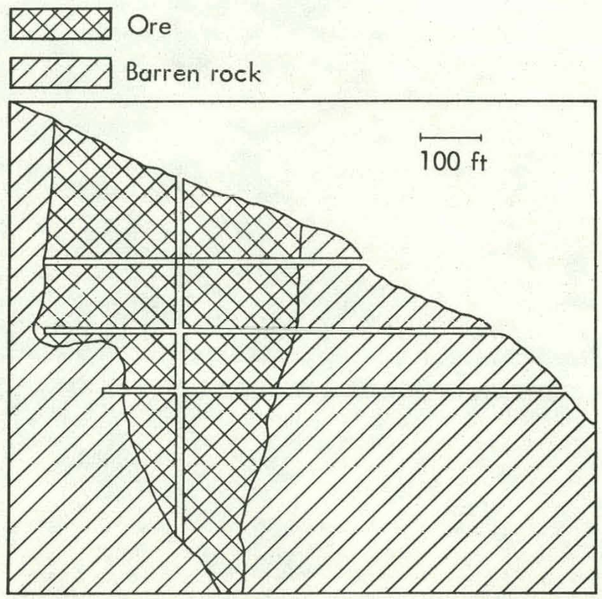

Fig. 2. Tunnels into the ore body in the Old Reliable Mine.

2. If it does not apply, to plan to gather sufficient data to prepare a prediction capability for this geological region; and

3. Given an input motion, to determine how some key structures respond—i.e., smoke stack, mine shaft, tailings pond.

Finally, Sandia's interest was primarily in the domain of air-blast measurements.

Since it appeared impossible to expedite general contracts in such a short time span (execution was planned for the first part of March), it seemed more feasible for each agency to agree to do or to finance some single independent section of the program. After some discussion, an agreement was reached for the following division of effort:

- Sandia Laboratories would finance and do the air-blast measurements.[3]
- The Atomic Energy Commission (AEC) would pay the Earth Science Laboratories (ESL) to do most of the earth-motion field measurements.
- Lawrence Livermore Laboratory (LLL) would supervise the earth-motion measurements and emplace two field stations.
- John A. Blume and Associates would supervise the structure-response measurements in the ranch buildings near surface zero and at the tailings pond near the Magma Mines smelter.
- Explosive Engineering Research Organization (EERO) of the Army Corps of Engineers would field two stations in the town of Mammoth.
- DuPont-Ranchers would pay the Environmental Research Corporation (ERC) a sufficient amount for analysis of the surface motion data to satisfy both DuPont-Ranchers and LLL.

Pertinent data for each of the instrument stations are given in Table 1, and the geographic locations are shown in Fig. 1.

The ESL L-7 seismometer system was used at those stations listed in Table 1 where ESL is indicated to be the fielding agency.[4] The transducer in this system is a highly damped seismometer constrained to operate so that its output is proportional to acceleration. The output from the seismometer is fed to an integration-amplifier complex where a single time integration is performed. After integration, the signal is amplified and then recorded on magnetic tape. A power supply and a timing code network make up the remainder of the system. The overall system specifications are

Bandwidth	0.1 to 34 Hz
Range	10^{-4} to 10^{2} cm/sec
Sensitivity	$\frac{2222 \text{ V rms}}{\text{cm/sec}}$.

Wherever LLL or EERO is indicated in Table 1 as the fielding agency for a station, a Geo Space Corporation's HS-10-1/B transducer was used at that station. The HS-10 is a geophone or electromagnetic velocity transducer with a natural frequency of 1 Hz. It was operated in a nearly critically damped condition in order to obtain the lowest possible frequency response. For the LLL-operated stations, data were recorded on magnetic tape, and the EERO recording system used a paper recorder with a pen-and-ink writing fixture. The HS-10-1/B specifications are

Natural frequency	1 Hz
Bandwidth	1.0 to 1000 Hz
Range	Determined by recording amplifiers
Sensitivity	$\frac{0.72 \text{ V rms}}{\text{cm/sec}}$.

Table 1. Data for the instrument stations.

Location	Stations (Components)	Agency[a] (Fielding Grp.)	Range, km	Magnetic Heading[b]	Expected Amplitudes, cm/sec	Recording Range, cm/sec
Sisters Ranch	5 (13)	JABARD (ESL)	2.2	61°		
Copper Creek Rd. (white over red flag)	1 (3)	LLL (ESL)	7.6	79°	0.08	0.015-0.7
Mammoth	2 (6)	LLL (ESL)	14.6	(River N. of town) 82°	0.02	0.004-0.25
	2 (6)	D (EERO)		(School) 77°		
Tailings dike	4 (12)	JABARD (ESL)	17.4	34.5°		
Smoke stack	1 (2) 1 (3)	LLL (ESL) LLL (ESL)	19.7	37.5°	0.02	0.004-0.4 0.004-0.2
San Manuel (N)	1 (3) 1 (3)	LLL (ESL) D (D)	20.9	38.5°	0.015	0.002-0.1
Tiger Mine Subsurface Surface	 1 (3) 1 (3)	 LLL (LLL)	 20.5	 68°	 0.015	 0.001-0.1 0.002-0.1
Oracle	1 (3)	LLL (ESL)	30.1	59°	0.007	0.001-0.05
Oracle Junction	1 (3)	LLL (ESL)	46.3	64°	0.003	0.0004-0.02
North Tucson	1 (3)	LLL (ESL)	61.8	30.5	0.0015	0.0002-0.015
Klondyke	1 (3)	LLL (ESL)	17.5	238°	0.02	0.004-0.2

[a] D - DuPont Company
JABARD - John A. Blume and Associates Research Division
LLL - Lawrence Livermore Laboratory
ESL - Earth Science Laboratories
EERO - Explosive Engineering Research Organization, Army Corps of Engineers

[b] Clockwise from north: 14°.

EXPERIMENTAL RESULTS

The experiment was executed March 9, 1972, without major operational difficulty.

The ground-motion measurements program was not nearly so successful. With the exceptions of the station on the smoke stack and the station at Oracle, all of the ESL stations overranged.[5] The station in Oracle would probably have overranged, except for an anomalous behavior at that location. Either the transducer was not mounted properly or was placed on an atypical geological outcrop, or the general area of the Oracle site has an unusual response to seismic disturbances.

The LLL station and the EERO station did not overrange.

In retrospect, causes leading to the predicament of general overranging of instruments are as follows.

First, the method of calibrating the site for seismic propagation was not adequate to make predictions for the Old Reliable blast. Primarily, the calibration shots were not buried deep enough to give the same energy coupling as that for the later shot. Consequently, the predicted values for earth motion were too low.

Second, ESL's method of setting recording ranges is maximized for data quality, not for maximum range coverage. Therefore, they could not cover the requested recording range with two available tape channels. Due to a breakdown in communication, this range-setting limitation was not detected before detonation. This limited range-coverage, combined with the predicted low values for the earth motions, caused extensive overranging.

With so much of the ESL data overranged and not usable, a large portion of the objectives appeared to be in jeopardy. This loss of data eliminated both the structure-response objective and the tailings pond study. Although the smoke stack records were satisfactory, the base-station data was overranged, which precluded a direct comparison between base and stack response.

Since a large portion of the seismic motion data was lost, success in obtaining a Fourier amplitude analysis did not appear promising. However, there were enough data to warrant an attempt at completing this intermediate objective. The analysis was limited to the four stations described below:

1. The LLL magnetic-tape record from the Magma Mine surface station (Fig. 3).

2. The EERO paper record from the Mammoth station (Fig. 4). The record required a laborious hand digitization.

3. The ESL magnetic record from the Oracle, Arizona, station (Fig. 5). This record would be analyzed, and its validity would be determined after the analysis.

4. The ESL magnetic-tape record from the North Tucson station (Fig. 6). Although there was some spatial separation among the first three stations, it did not cover the magnitude in distance really needed for this analysis. Fortunately, the data from the North Tucson station did not appear to be too badly overranged. Therefore, a reconstruction (Appendix A) should be easy, should not require an enormous amount of time, and should provide a fairly accurate result.

Accordingly, ERC was asked to do the following work in the analysis of these four channels of data:

- Digitize all three components of the four stations, including a hand digitization of the Mammoth record.
- Provide time-history displays of all data.
- Plots of the smoothed Fourier spectra.
- Punch cards containing the smoothed Fourier amplitudes.
- A description of the processing for each station.

The results of the Fourier amplitude analysis are displayed in Figs. 7-10.

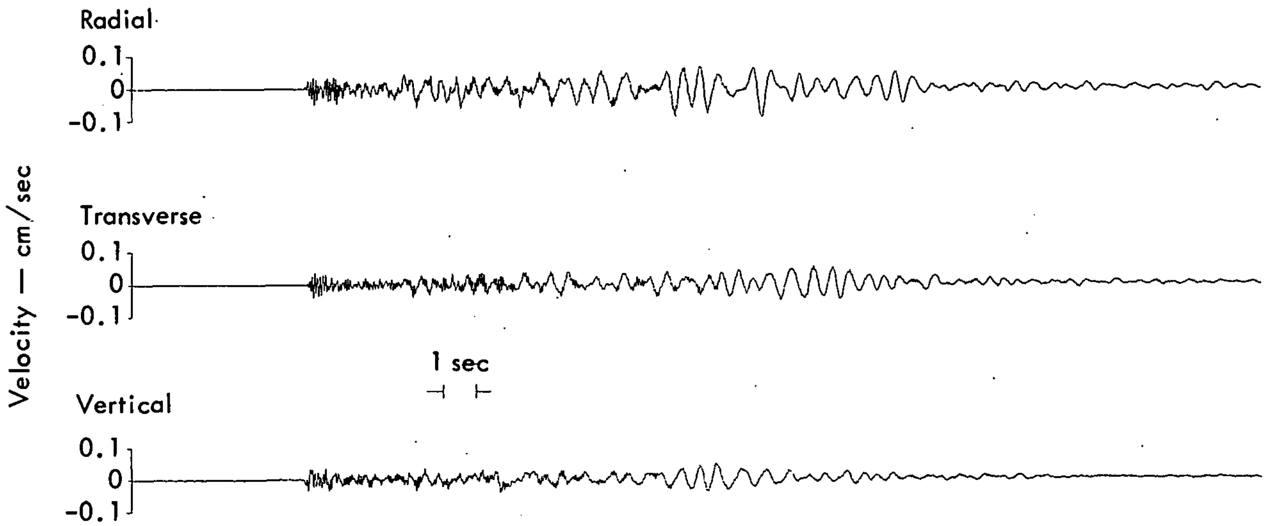

Fig. 3. Surface-motion data from the Old Reliable Mine blast: Magma Mine station.

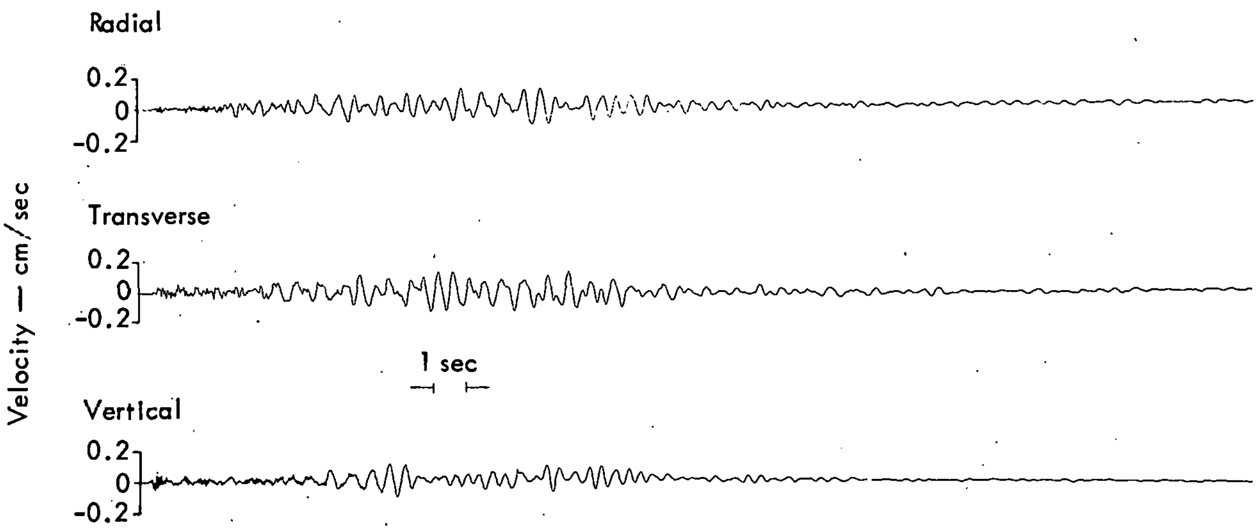

Fig. 4. Surface-motion data from the Old Reliable Mine blast: Mammoth station.

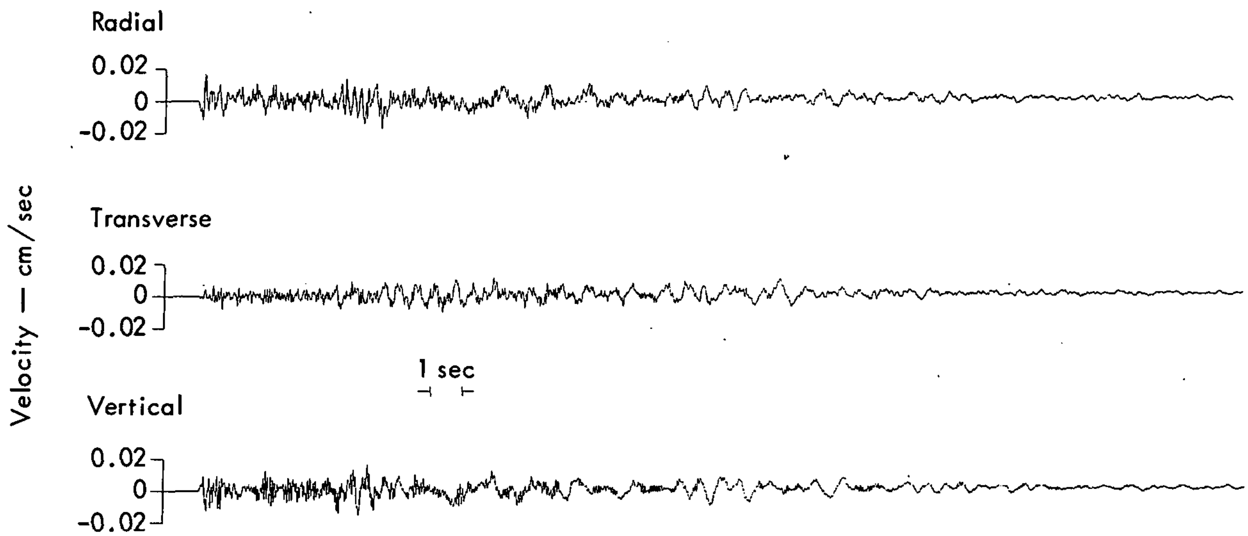

Fig. 5. Surface-motion data from the Old Reliable Mine blast: Oracle station.

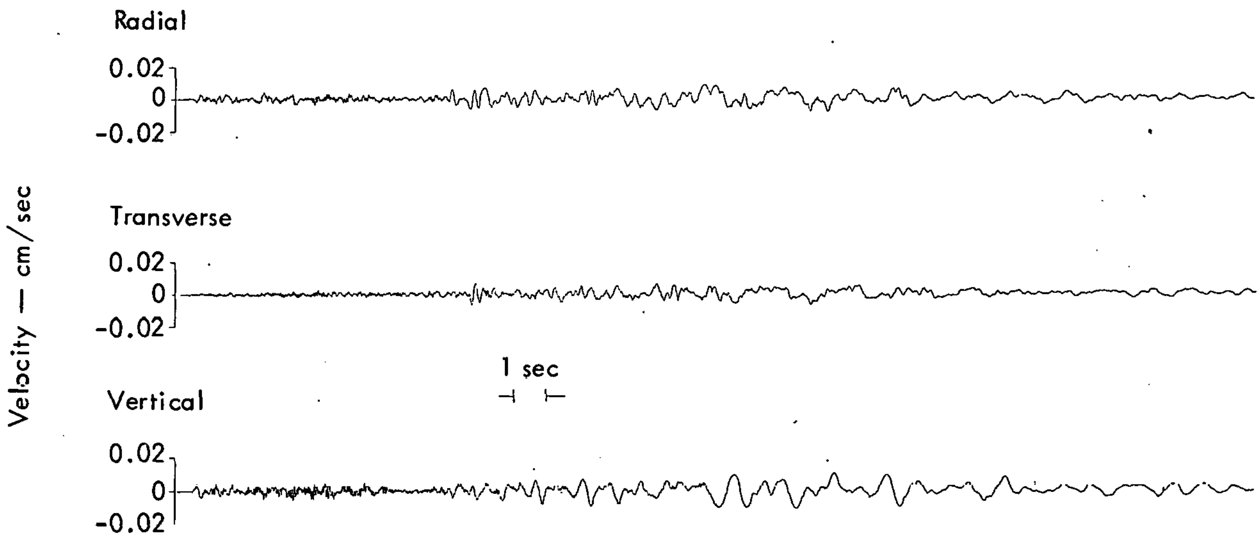

Fig. 6. Surface-motion data from the Old Reliable Mine blast: Tucson station.

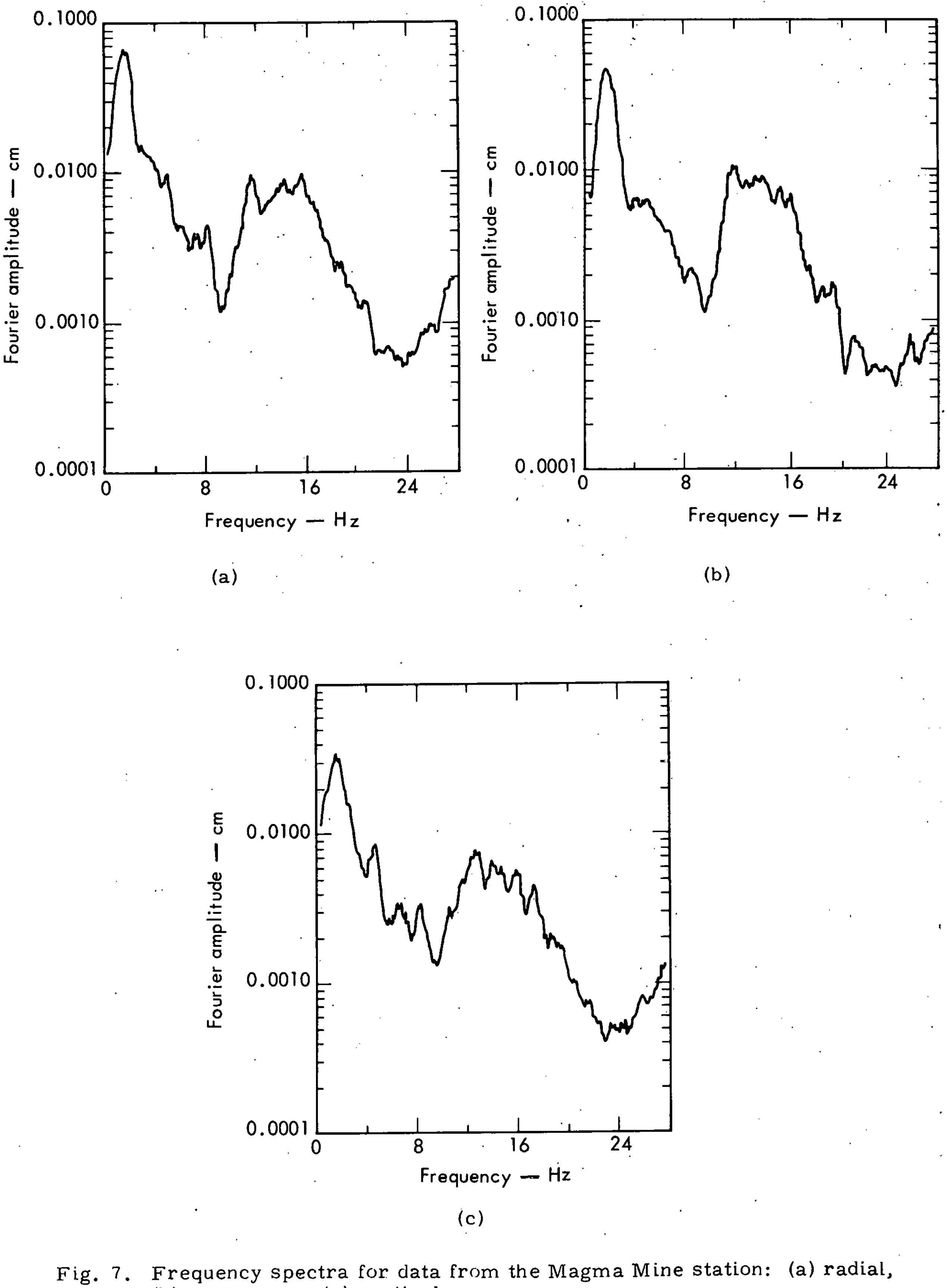

Fig. 7. Frequency spectra for data from the Magma Mine station: (a) radial, (b) transverse, (c) vertical.

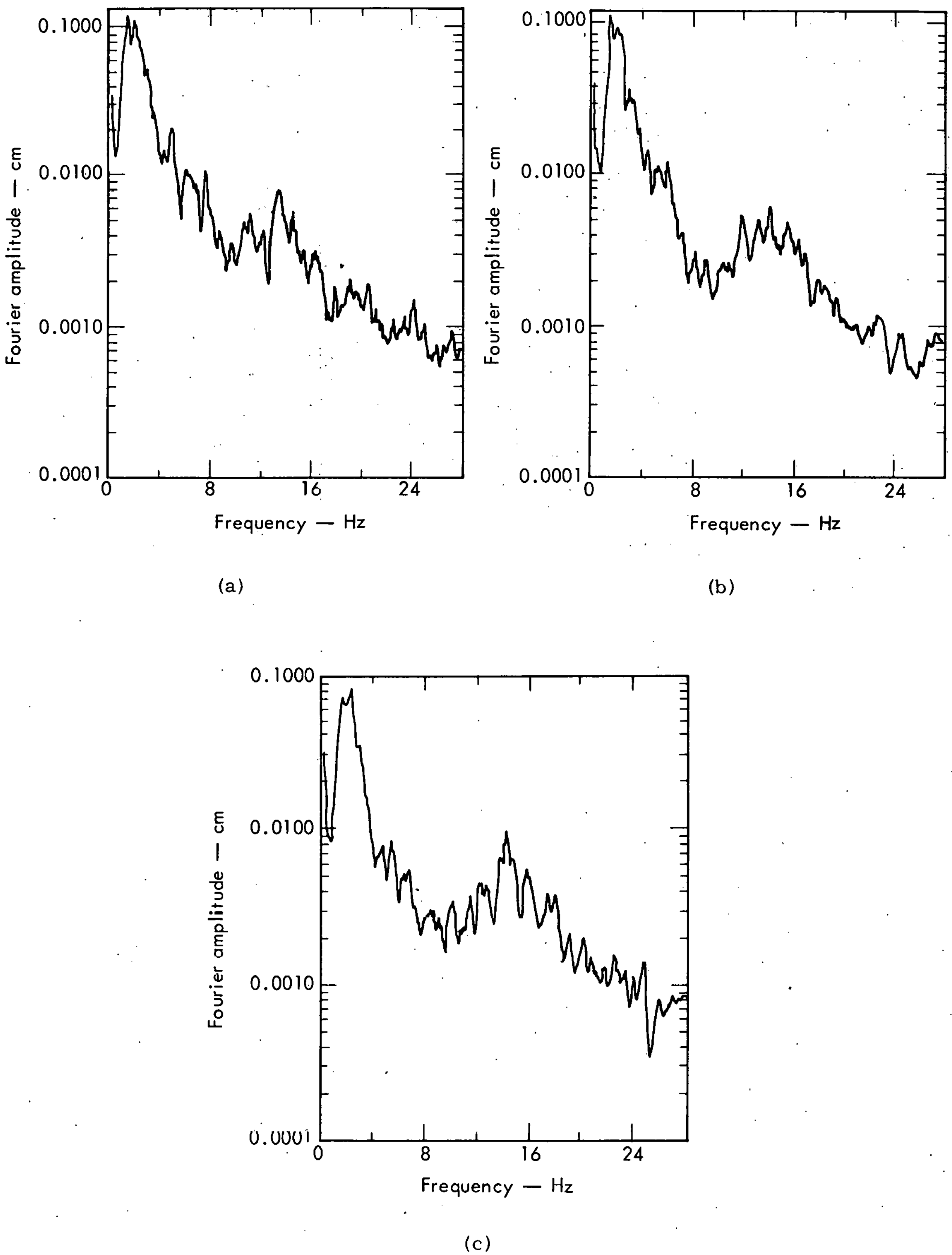

Fig. 8. Frequency spectra for data from the Mammoth station: (a) radial, (b) transverse, (c) vertical.

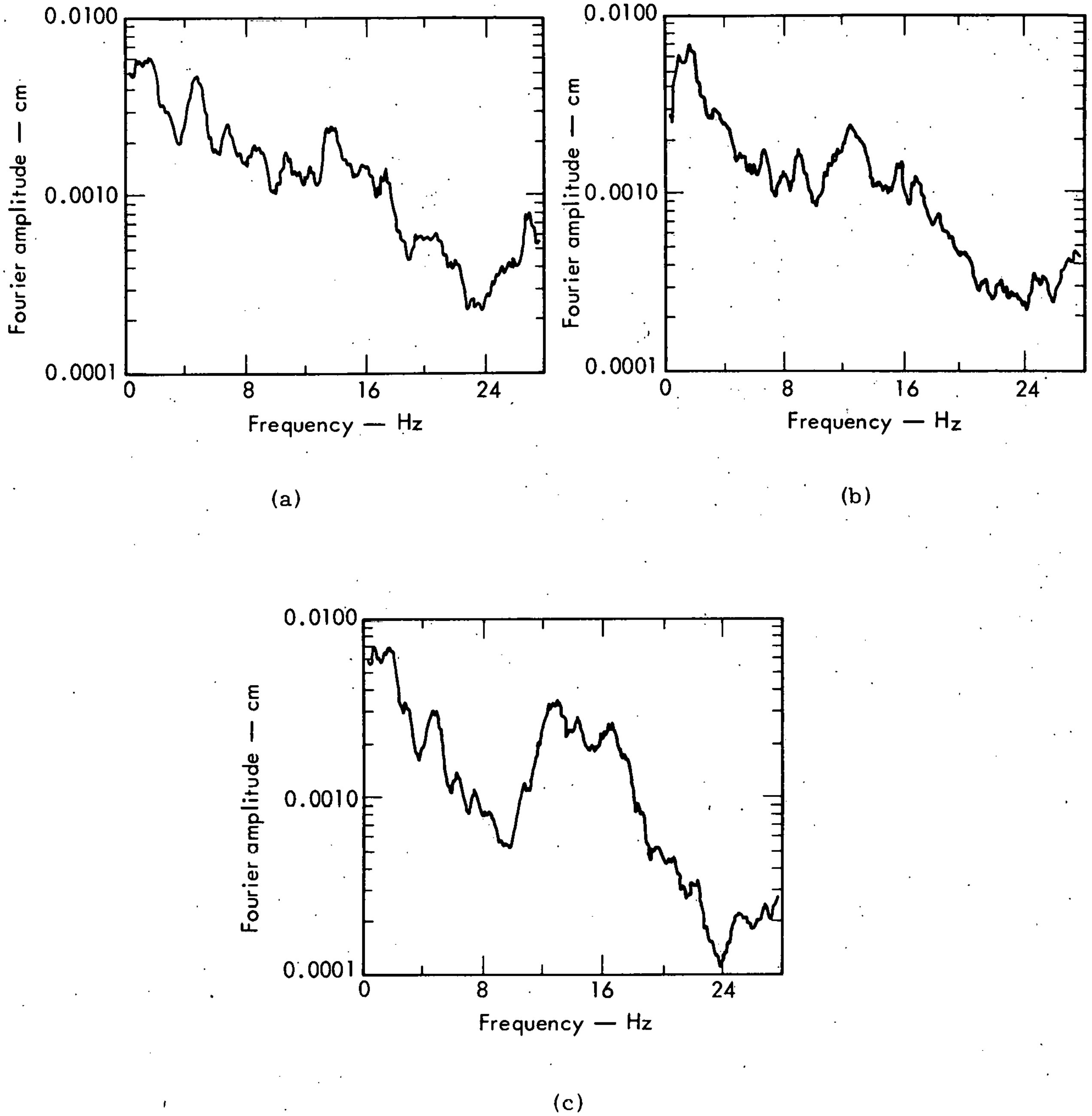

Fig. 9. Frequency spectra for data from the Oracle station: (a) radial, (b) transverse, (c) vertical.

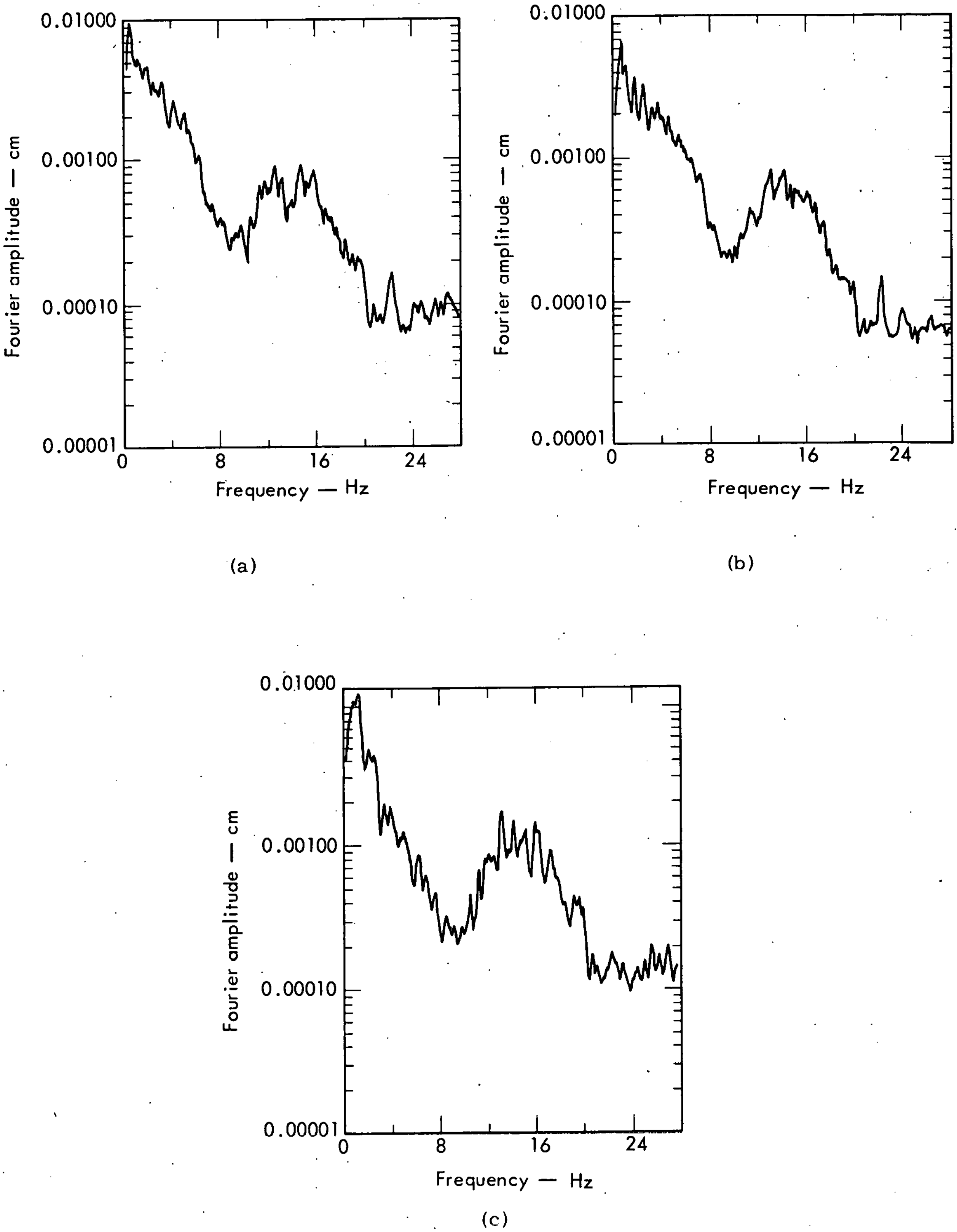

Fig. 10. Frequency spectra for data from the Tucson station: (a) radial, (b) transverse, (c) vertical.

CONCLUSION

The primary objective of developing a capability to predict ground motion could not be realized with the limited amount of data collected. A possible minor objective is to use these data to predict ground motions for other explosions of about the same magnitude and spatial distribution as the Old Reliable blast (Fig. 11).

To develop a prediction capability for any area, the source- and depth-dependent components of the data must be removed and the earth's transfer function derived for this region. Except for the source-function description, the procedure is fairly straightforward if good data exist for a fairly large spatial range. Since data from the Oracle station are anomalous, only two discrete spatial locations, Magma Mine-Mammoth and Tucson, are available for a transfer-function derivation. Therefore, it does not appear possible, with this limited spatial distribution of data, to derive a transfer function for the area surrounding the Old Reliable Mine blast. Even if the data were adequate, the problem of developing a source-function description would still present a huge obstacle to reaching the primary objective. Developing a source-function description for a distributed source like that used in the Old Reliable Mine blast is extremely time-consuming and difficult, if not impossible. Therefore, when the limited-data predicament and the expected difficulty with a source-function description were considered, work was stopped when the Fourier amplitude analysis was finished for the four stations described in the text.

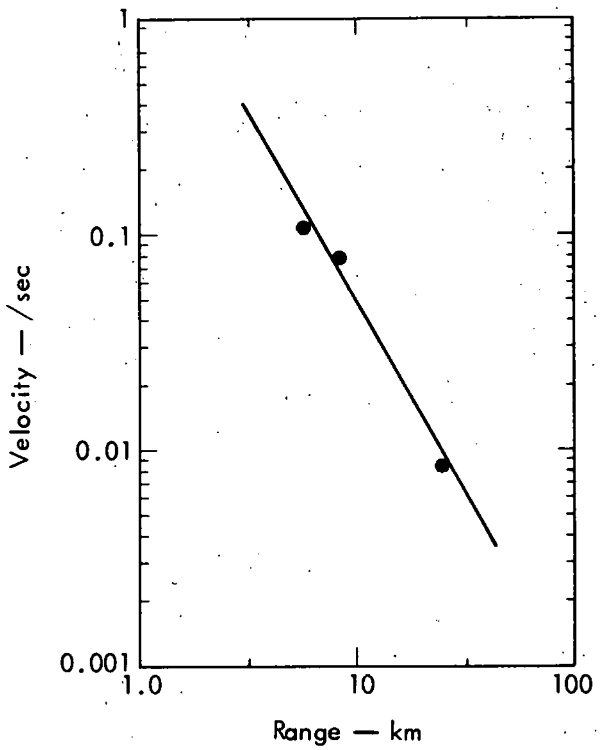

Fig. 11. Peak radial surface velocity versus range.

REFERENCES

1. Old Reliable Mine, Pinal County, Arizona, War Minerals report 275, (U.S. Department of the Interior, Bureau of Mines, 1944).
2. M. H. Ward, "Engineering for In Situ Leaching," Mining Congr. J. 59, 21 (1973).
3. L. J. Vortman, Airblast from Sequenced Explosions of Charges Horizontally Dispersed in Three Vertical Layers, Sandia Laboratories, Albuquerque, New Mexico, Rept. SC-RR-72 0517 (1972).
4. R. Navarro, Preliminary Calibration of the Scatt-1 System, U.S. Coast and Geodetic Survey, Rept. CGS-C-119 (1968).
5. R. Navarro, Old Reliable Mine Project, Seismic Measurements, NOAA Technical Memorandum ERL-ESL-19 (1972).

APPENDIX A. RECONSTRUCTION OF CLIPPED SEISMIC SIGNALS

Leo J. O'brian

The problem is to reconstruct a time-varying signal from a record wherein the recording system was not properly ranged and therefore all ground motions exceeding a certain amplitude level were saturated or clipped.

A representative pulse of the time history where clipping occurred would be similar to that shown in Fig. A-1. The objective, then, is to develop a method that will provide a reasonable representation of the lost portion of the signal. Although no method can exactly produce the lost section of time history, the proposed method should provide both a reasonable estimate of the amplitude and a consistent estimate of the frequency content of the signal.

For any method, certain assumptions must be made about the character of the missing signal. These assumptions must be physically realizable and they must be consistent with normal seismic measurements. Three basic assumptions were made for this reconstruction scheme:

1. The clipped portion of the signal can be accurately represented by a half cycle of a sine wave of a certain frequency.

2. For a short time-duration, the signal prior to clipping and the signal after clipping can be accurately approximated by straight line segments having nearly equal slopes (absolute value); an average of the two slopes is used in the computations.

3. For a short time-duration, the clipped signal can be approximated by a linear continuation of the straight line segments derived above.

These assumptions no doubt lead to some errors in the reconstruction of the signal, but they seem to be justified on the basis of previous experience with seismic-signal data processing.

Figure A-2 gives an exaggerated picture of the method used in the reconstruction process. In this figure, Δt is the sample rate, T is the length of time the signal is clipped, and the pairs (t_k, x_k) represent the digitized time and amplitude coordinates of the time history. In accordance with the assumptions, a half cycle of a sine wave with a frequency of (π/T) is fitted to the clipped region of the signal. The points (t_i, x_i) and (t_{i+1}, x_{i+1}) represent the true signal before clipping, and the points (t_j, x_j) and (t_{j+1}, x_{j+1}) represent the signal after the clipping has ceased. The points (t_{i+2}, x_{i+2}) and (t_{j-1}, x_{j-1}) are the points of the reconstructed signal. Computations are begun by determining the average slope of the two line segments:

$$\beta = \frac{(x_{i+1} + x_i^j) - (x_i + x_{i+1}^j)}{2\Delta t} . \qquad \text{(A-1)}$$

Based on the assumption of linearity between points, the amplitude value of x_{i+2} point can be computed by using the following formula:

$$x_{i+2} = \beta\, \Delta t + x_{i+1} . \qquad \text{(A-2)}$$

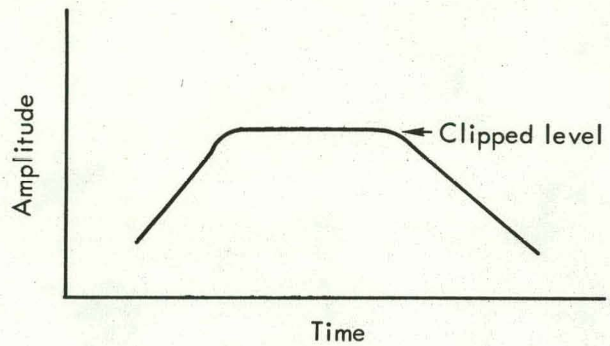

Fig. A-1. Representative pulse of time history, showing where clipping occurred.

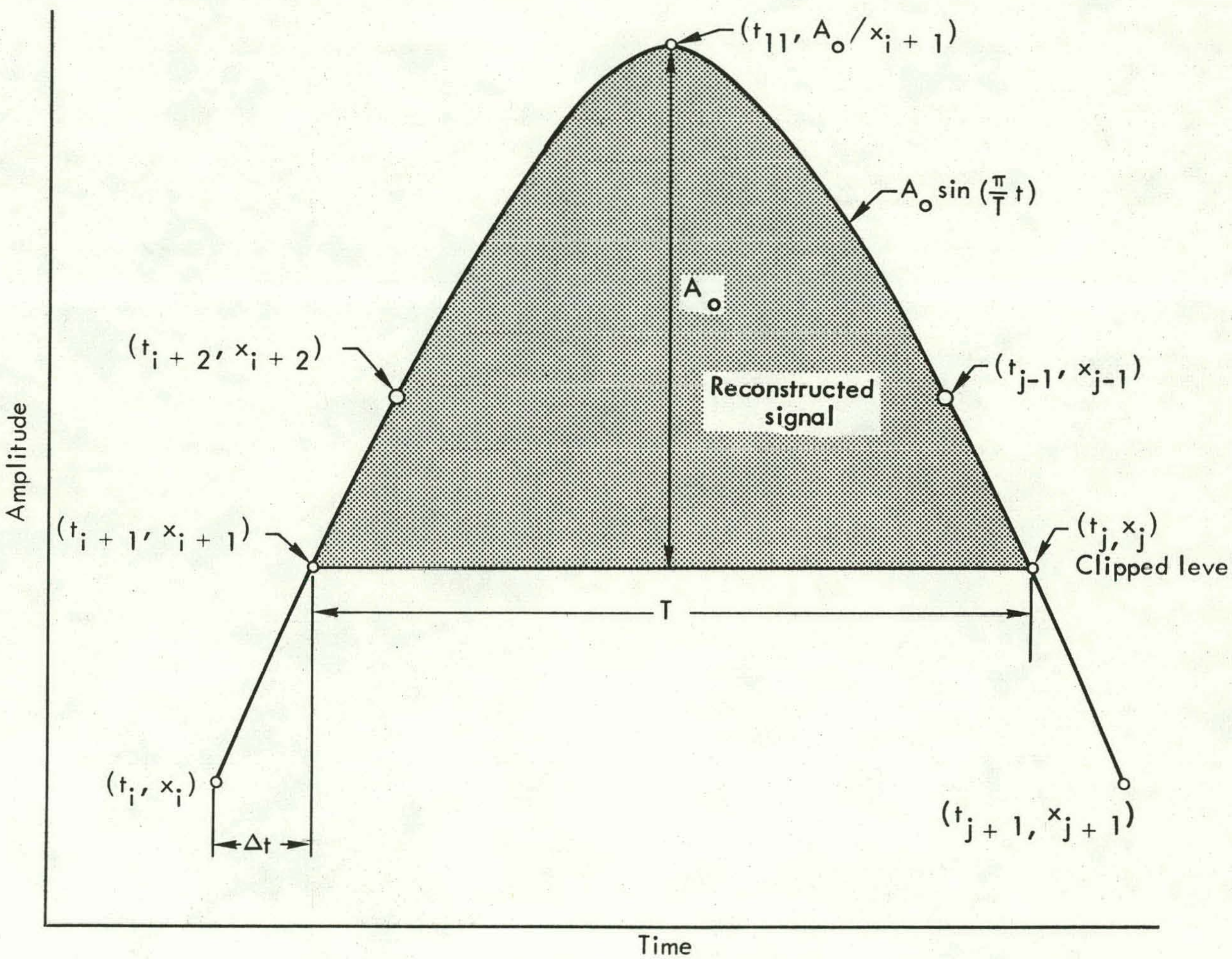

Fig. A-2. Graphical representation of the reconstruction method.

Now, if the point (t_{i+1}, x_{i+1}) is treated as the initial point of its half-cycle sine wave $(\omega_o = \pi/T)$ and the computed value of x_{i+2} is treated as the second point of the sine wave, each point of the sine wave through the clipped region can be calculated as follows. First, set

$$x_{i+2} = A_o \sin \omega_o t_{i+2} , \qquad \text{(A-3)}$$

where t_{i+2} in this special case is equal to Δt. Now, using the assumption of linearity again, the slope of this line segment can be written as

$$\beta = \frac{A_o \sin \omega_o \Delta t}{\Delta t} . \qquad \text{(A-4)}$$

Solving Eq. (A-4), the amplitude of this half-cycle sine wave is

$$A_o = \frac{\beta \Delta t}{\sin \omega_o \Delta t} . \qquad \text{(A-5)}$$

Replacing β with its value from Eq. (A-1), Eq. (A-5) becomes

$$A_o = \frac{(x_{i+1} + x_i) - (x_i + x_{i+1})}{2 \sin \omega_o \Delta t} . \qquad \text{(A-6)}$$

With Eq. (A-6), amplitude values of the sine wave $A_o \sin \omega_o t$ can be computed for equally spaced points along the half-cycle sine wave shown in Fig. A-2. The process of reconstruction is complete when the initial amplitude value x_{i+1} is added to each of the computed points.

Attempts were made to devise additional schemes to reconstruct the lost signal, but none provided reasonable estimates and the calculations were quite involved. Therefore, considering its simplicity of formulation and the validity of its basic assumptions, the method described in this paper appears to provide the best estimate of the lost portion of the signal.

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