United States Deparment of the Interior

Geological Survey

Seismic-Refraction Data Taken in Southwest New Mexico and Southeast Arizona

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ABSTRACT

The U.S. Geological Survey is studying some of the features of the earth's crust in the Datil-Mogollon volcanic field, New Mexico. As a part of this study seismic refraction measurements were made in and around the volcanic field using explosions as energy sources. Record sections and travel time tables corrected for elevation differences were derived from the measurements.

INTRODUCTION

In October 1976, the U.S.G.S. recorded seismic waves from the DICE THROW explosion along an 18 station line that traversed the Datil-Mogollon volcanic field in southwestern New Mexico and southeastern Arizona.

In August 1978, an explosion originating in the Phelps-Dodge Corporation's Morenci, Arizona, copper mine was timed by U.S.G.S. personnel and observed at the site of the DICE THROW shot. In November 1979, nine of the DICE THROW stations were re-occupied to record timed explosions from the Cities Service Company's Miami, Arizona, copper mine as well as another Morenci shot. During the fall of 1980 explosions originating at Morenci, Miami, and the Phelps-Dodge Corporation's Tyrone, New Mexico, copper mine were observed at stations along the line as well as at the site of the DICE THROW shot.

This report briefly discusses the explosions used as energy sources and the instrumentation used to record the seismic waves. The travel time tables and record sections for the experiment are then presented.

EXPLOSIONS

The pertinent information on the four timed explosions used as energy sources in this study is given in table 1.

Table 1

Explosions

Explosion	Size (Kilotons)	Latitude (N)	Longitude (W)	Elevation (M)	Date	Time
DICE THROW	.65	33.679	106.521	1442	6 Oct 76	140000.05 UT
Morenci 1	~ .04	33.097	109.369	1385	31 Aug 78	222953.64 UT
Morenci 2	~ .04	33.098	109.366	1387	1 Nov 79	222850.20 UT
Miami	~ .055	33.413	110.963	1204	2 Nov 79	225645.70 UT

The origin time for DICE THROW was provided by the Department of Defense and is correct to less than 10 milliseconds. The other three events were timed by U.S.G.S. personnel. The origin time was obtained by recording the output of a seismometer (figures 1, 2) placed approximately 100 m from the first hole detonated. The times are thought to be correct to about 100 milliseconds.

The origin times for subsequent explosions at Morenci were estimated from: $\Delta t = \frac{\Delta X}{V}$

where Δt (s) = difference in travel time (between a timed shot and a subsequent shot) to a reference station.

ΔX (km) = difference in shot location relative to the reference station.

V (km/s) = the refractor velocity between the shot and the reference station.

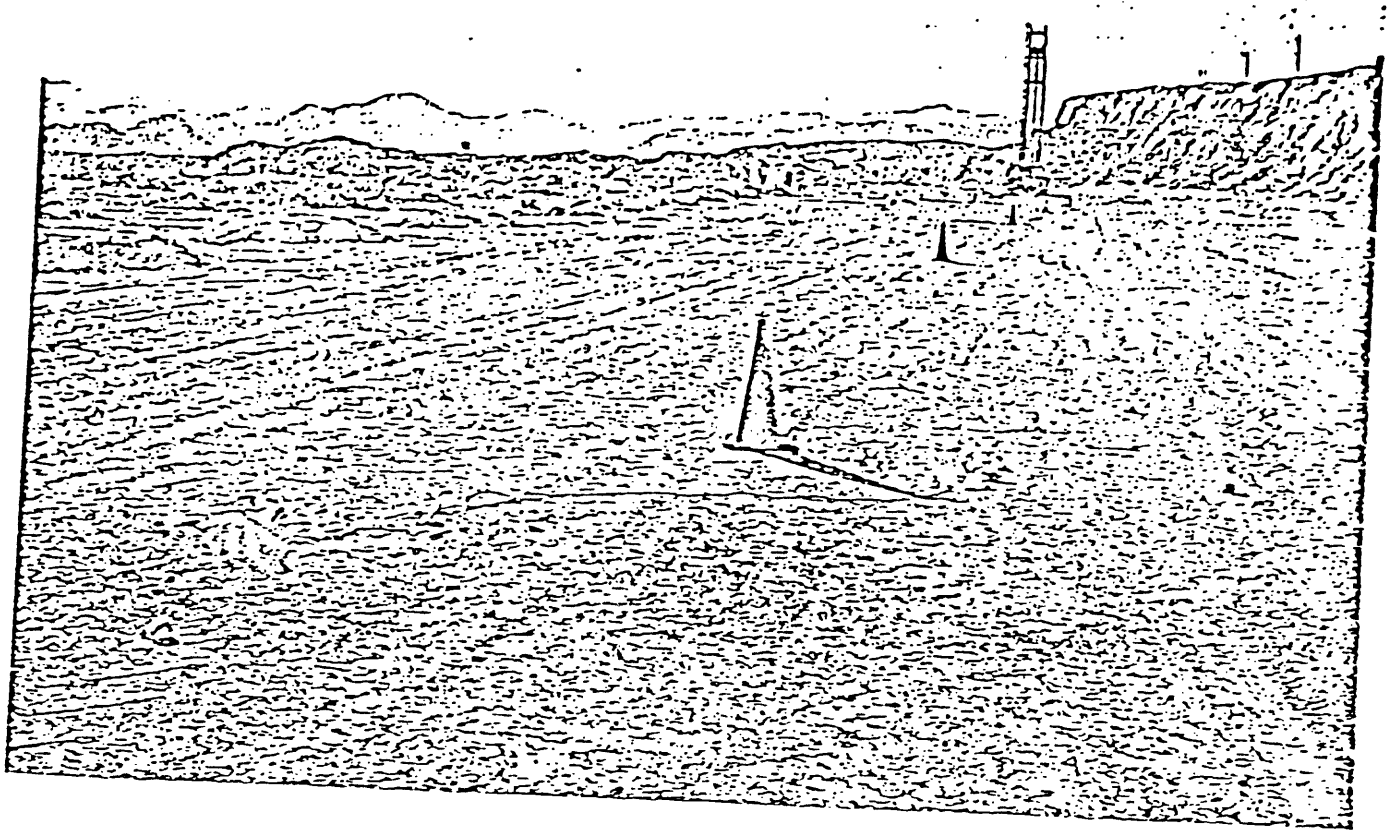

FIGURE 1 - Shotline at Morenci

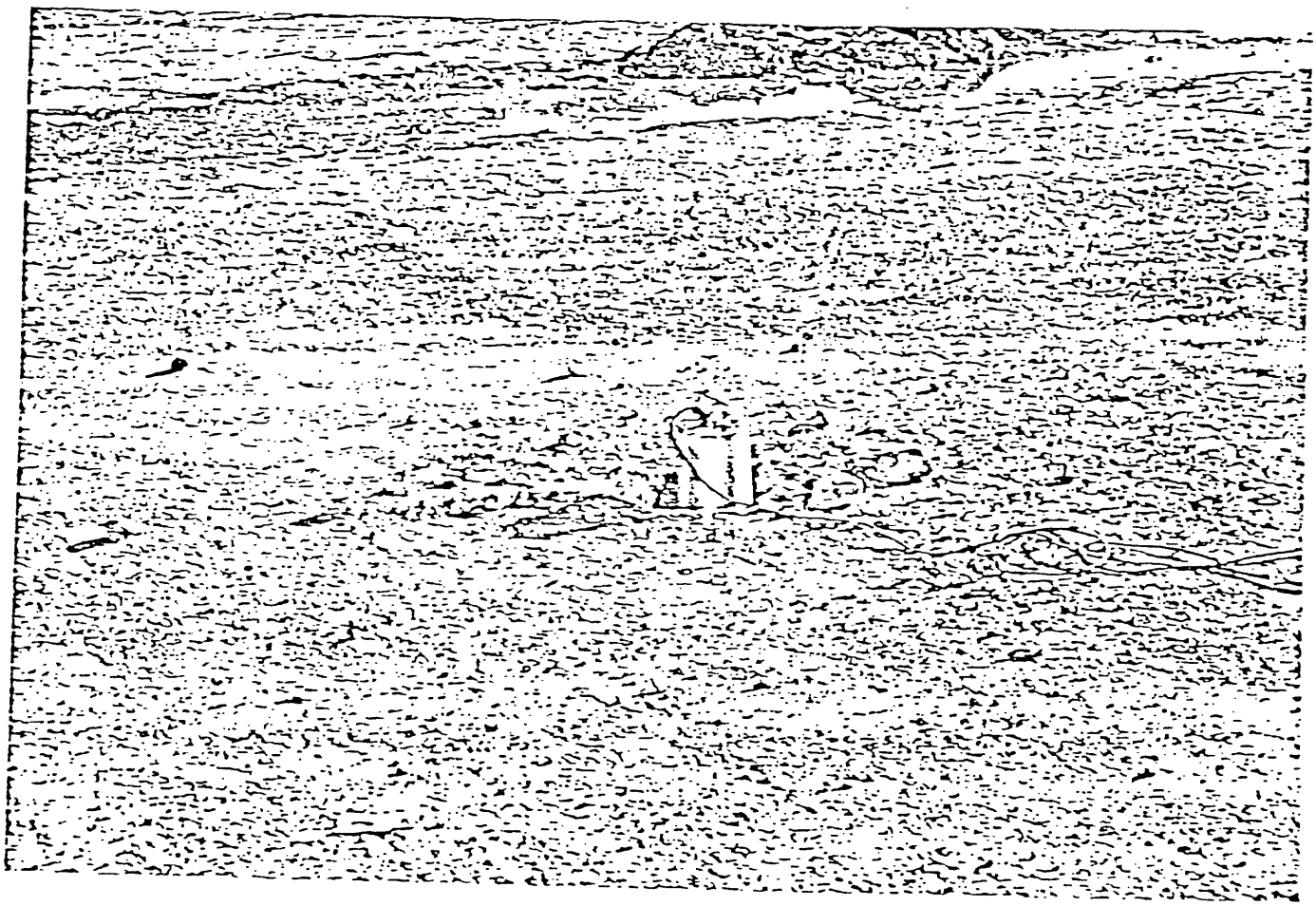

FIGURE 2 - Seismometer emplaced near shot.

The origin times for explosions in the Tyrone mine were estimated from: $\Delta t = -10.8669 + .8598\ X$ (G. R. Keller, personal communication) where:

$\Delta t(s)$ = travel time to the reference station at Silver City, New Mexico (SVM).

X(km) = distance from shot to station SVM.

The record section for the Miami explosions was compiled using relative arrival times. Stations that observed the timed Miami shot were re-occupied along with additional stations at other sites. The travel times to the new sites were estimated relative to the stations that observed both the timed shot and the subsequent shot.

INSTRUMENTATION

A plan view of the experiment is shown in figure 3. A variety of seismic instrumentation was used to gather data for this study. For the DICE THROW shot, the first four stations were the L-4 systems described by King (1969). Stations 5-10 were the ASC-2 systems described by Hoffman and Harding (1977). Stations 11-15 were L-4 systems. Stations 16-18 were portable drum units recording on smoked paper. The ASC-2 and L-4 systems both use FM magnetic tape recorders.

The Morenci explosion in 1978 was observed on a drum recorder at the site of the DICE THROW shot and at the U.S.G.S. permanent station at Socorro (WTX).

The fieldwork in 1979 was conducted with portable drum units recording with pen and ink (stations 7-10 and 12-15) except for station 16, where an ASC-2 tape recorder was used. The fieldwork

in 1980 was done entirely with the ASC-2 tape recorders. The 1979 and 1980 explosions were also observed at permanent U.S.G.S. stations at Silver City (SVM), Socorro (WTX), and Tucson (TUC). These stations are telemetered to Albuquerque and recorded on 16mm film. All recording units utilize short-period vertical sensors that have a natural frequency of 1.0 hertz. Table 2 is a list of the seismograph stations occupied during the study.

Table 2

Seismograph Stations

Station Number	Station Name	Station I.D.	Latitude (N)	Longitude (W)	Elevation (Meters)	Station Foundations
1.	Harriet Ranch	HAR	33° 39.47'	106° 45.01'	1426	Alluvium
2.	Pope Siding	PSD	33° 35.40'	106° 58.32'	1386	Basalt
3.	Nogal Canyon	NLC	33° 33.66'	107° 13.26'	1611	Gravel
4.	Montoya Butte	MOB	33° 31.68'	107° 32.64'	1761	Gravel
5.	Wild Horse Cnyn.	WHC	33° 30.00'	107° 44.58'	2208	Andesite
6.	Courdoroy Cnyn.	CYC	33° 27.90'	108° 02.22'	2158	Alluvium
7.	Beaverhead	BHD	33° 27.66'	108° 06.84'	2109	Rhyolite
8.	Cooney Tank	COO	33° 26.40'	108° 15.78'	2417	Basalt
9.	Hulse Ranch	HUL	33° 25.38'	108° 21.90'	2304	Alluvium
10.	Snow Lake	SNL	33° 24.78'	108° 27.90'	2429	Basalt
11.	Willow Creek	WIL	33° 24.01'	108° 34.95'	2438	Basalt
12.	Deloche Canyon	DLC	33° 22.80'	108° 45.96'	2170	Rhyolite
13.	Whitewater Mesa	WWM	33° 21.84'	108° 51.96'	1666	Gravel
14.	Rocky Tank	RYT	33° 21.18'	108° 57.24'	1884	Basalt
15.	Smoothing Iron	SMI	33° 19.08'	109° 01.38'	1902	Basalt
16.	Fritz Ranch	FRI	33° 19.26'	109° 11.40'	1358	Conglomerate
17.	Stock Tank #3	STT	33° 18.36'	109° 20.76'	1884	Basalt
18.	Sheep Wash	SHW	33° 17.70'	109° 27.54'	1500	Conglomerate
19.	Silver City	SVM	32° 46.71'	108° 17.79'	1810	Limestone
20.	Socorro	WTX	34° 04.33'	106° 56.75'	1555	Granite
21.	Dice Throw	DTO	33° 40.74'	106° 31.26'	1442	Alluvium
22.	Tucson	TUC	32° 18.58'	110° 46.93'	0986	Granite

TRAVEL TIME TABLES

Travel time tables were derived from the first arrivals after calculating station distances and elevation corrections. The station-to-shot distances were calculated using the computer program HYPO 71 (Lee and Lahr, 1972). This program uses Richter's method for computing small distances (Richter, 1958, p. 701). The distances calculated in this manner are correct to about 0.1 km. The elevation corrections were made by calculating the delay times (Nettleton, 1940) due to different thicknesses of surface rock beneath each station. All of the shots and arrival times were adjusted to the elevation of the DICE THROW explosion by using:

$$(1)\ \text{Correction} = \frac{\text{DICE THROW elevation-station or shot elevation}}{V_0} (\cos i_c)$$

i_c = ARCSIN $\frac{4.0}{6.0}$ for Pg arrivals, $\frac{4.0}{8.0}$ for Pn arrivals.

V_0 = 4.0 km/s.

No geological corrections were made.

The reading accuracy on the different kinds of records varies from less than 25 msec for tape playbacks to almost 100 msec for paper records running at 60 mm/minute. Overall the first arrivals are thought to be accurate to about 50 milliseconds.

Table 3 is the first arrival data from the DICE THROW shot.

Table 3

Dice Throw Data

Station	Distance (KM)	Travel Time (Sec)	Elevation (Meters)	Elevation Correction (Sec)	Δ/6 (Sec)	Corrected Travel Time (Sec)	Reduced Travel Time (Sec)
PSD	43.04	8.60	1386	+ .01	7.17	8.61	1.44
NLC	66.31	12.50	1611	- .03	11.05	12.47	1.42
MOB	96.45	17.77	1761	- .06	16.08	17.71	1.63
WHC	115.18	20.58	2208	- .14	19.20	20.44	1.24
CYC	142.74	25.37	2158	- .13	23.79	25.27	1.48
BHD	149.86	26.45	2109	- .12	24.98	26.33	1.35
COO	163.88	28.15	2417	- .21	27.31	27.94	.63
HUL	173.53	29.34	2304	- .19	28.92	29.15	.23
SNL	183.08	30.55	2429	- .21	30.51	30.34	- .17
DLC	211.28	34.50	2170	- .16	35.21	34.34	- .87
WWM	220.73	35.45	1666	- .05	36.79	35.40	- 1.39
RYT	229.00	36.75	1884	- .10	38.17	36.65	- 1.52
SMI	235.95	37.45	1902	- .11	39.33	37.34	- 1.99
FRI	251.20	38.95	1358	+ .02	41.87	38.97	- 2.90
STT	265.78	41.05	1884	- .10	44.30	40.95	- 3.35
SHW	276.34	41.95	1500	0	46.06	41.95	- 4.11

Figures 4 and 5 are playbacks from stations that recorded DICE THROW on magnetic tape. On these figures the reduced travel time is plotted on the Y axis and the distance of the station from the shot is plotted along the X axis.

Tables 4 and 5 list the data collected from the timed Morenci explosions.

Table 4

Morenci 1 Shot

Station	Distance (KM)	Travel Time (Sec)	Elevation (Meters)	Elevation Correction (Sec)	Δ/6 (Sec)	Corrected Travel Time (Sec)	Reduced Travel Time (Sec)
WTX	249.74	38.49	1555	- .01	41.62	38.48	- 3.14
DTO	272.62	41.34	1443	0	45.44	41.34	- 4.11

Table 5

Morenci 2 Shot

Station	Distance (KM)	Travel Time (Sec)	Elevation (Meters)	Elevation Correction (Sec)	Δ/6 (Sec)	Corrected Travel Time (Sec)	Reduced Travel Time (Sec)
FRI	29.76	5.75	1358	+ .01	4.95	5.76	.81
WWM	55.19	10.24	1666	- .04	9.20	10.20	1.0
DLC	64.12	11.51	2170	- .14	10.69	11.37	.68
SNL	90.92	16.16	2429	- .18	15.15	15.98	.83
HUL	99.98	17.67	2304	- .16	16.66	17.51	.85
SVM	106.16	18.03	1810	- .06	17.69	17.97	.28
COO	109.53	19.31	2417	- .18	18.26	19.13	.87
BHD	123.38	21.38	2109	- .12	20.56	21.26	.70

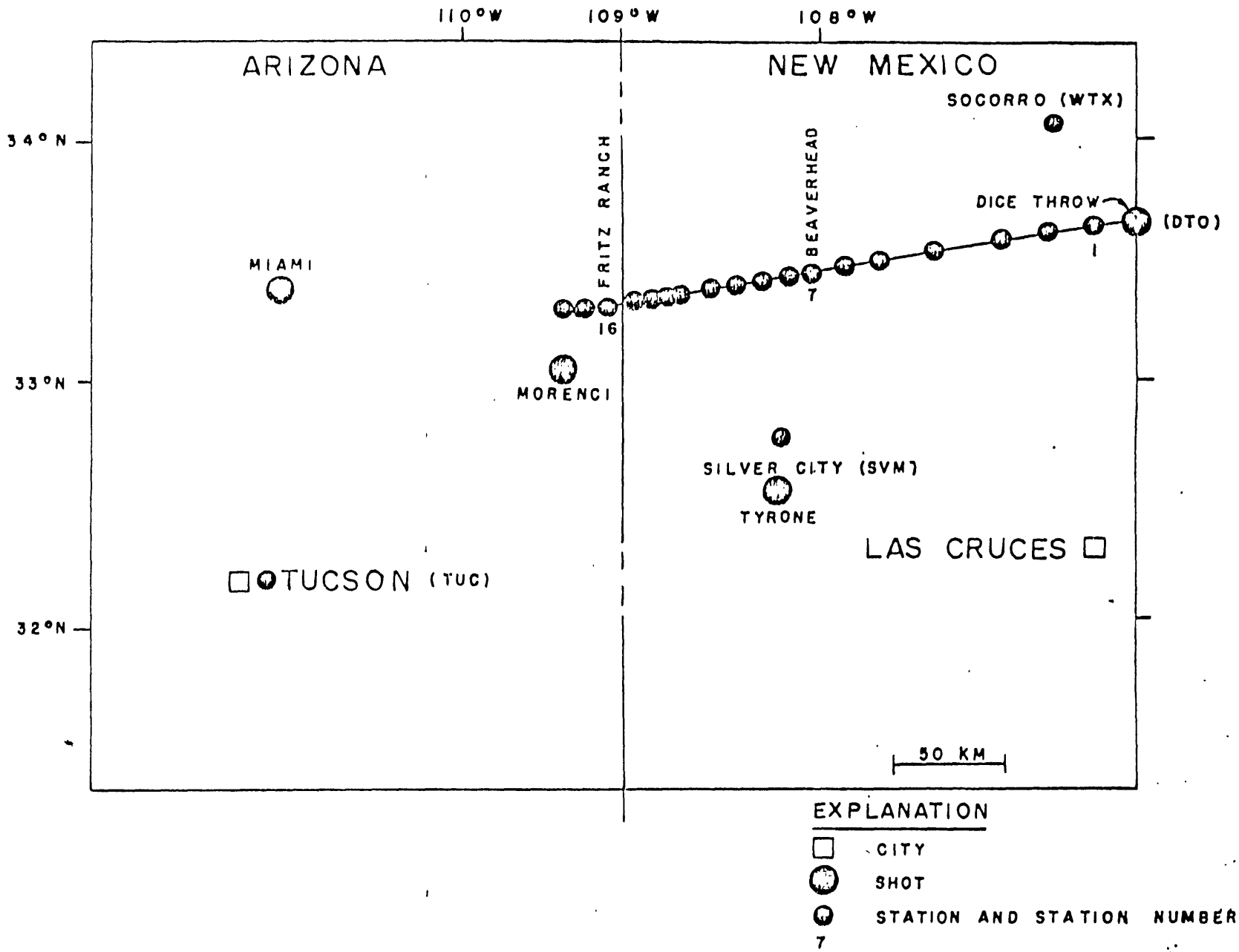
110°W
109°W
108°W
ARIZONA
NEW MEXICO
SOCORRO (WTX)
34°N
FRITZ RANCH
BEAVERHEAD
DICE THROW
(DTO)
MIAMI
16
7
1
33°N
MORENCI
SILVER CITY (SVM)
TYRONE
LAS CRUCES
TUCSON (TUC)
32°N
50 KM
EXPLANATION
CITY
SHOT
STATION AND STATION NUMBER
7

FIGURE 3

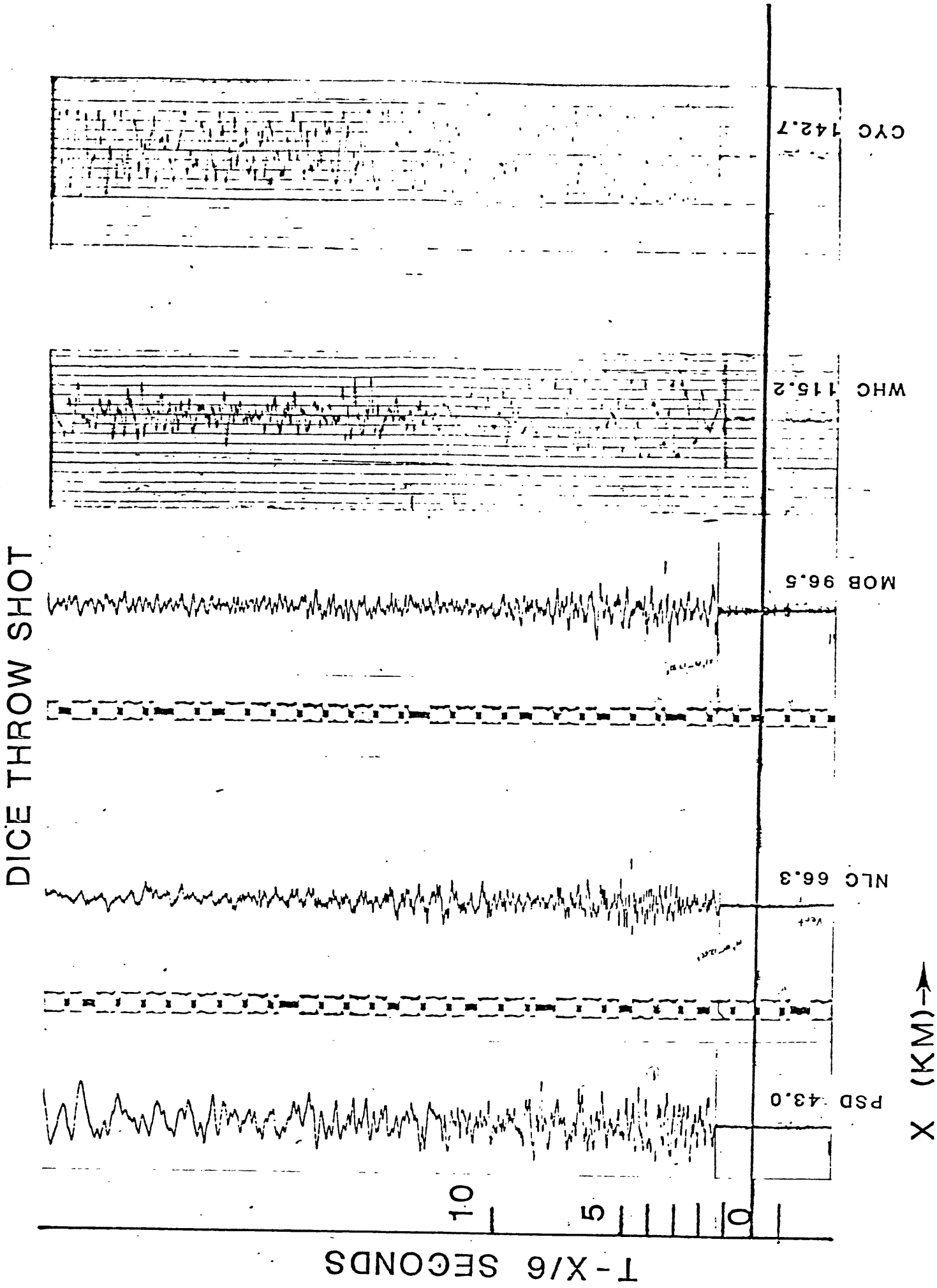
DICE THROW SHOT
CYC 142.7
WHC 115.2
MOB 96.5
NLC 66.3
PSD 43.0
10
5
0
T-X/6 SECONDS
X (KM)→

FIGURE 4

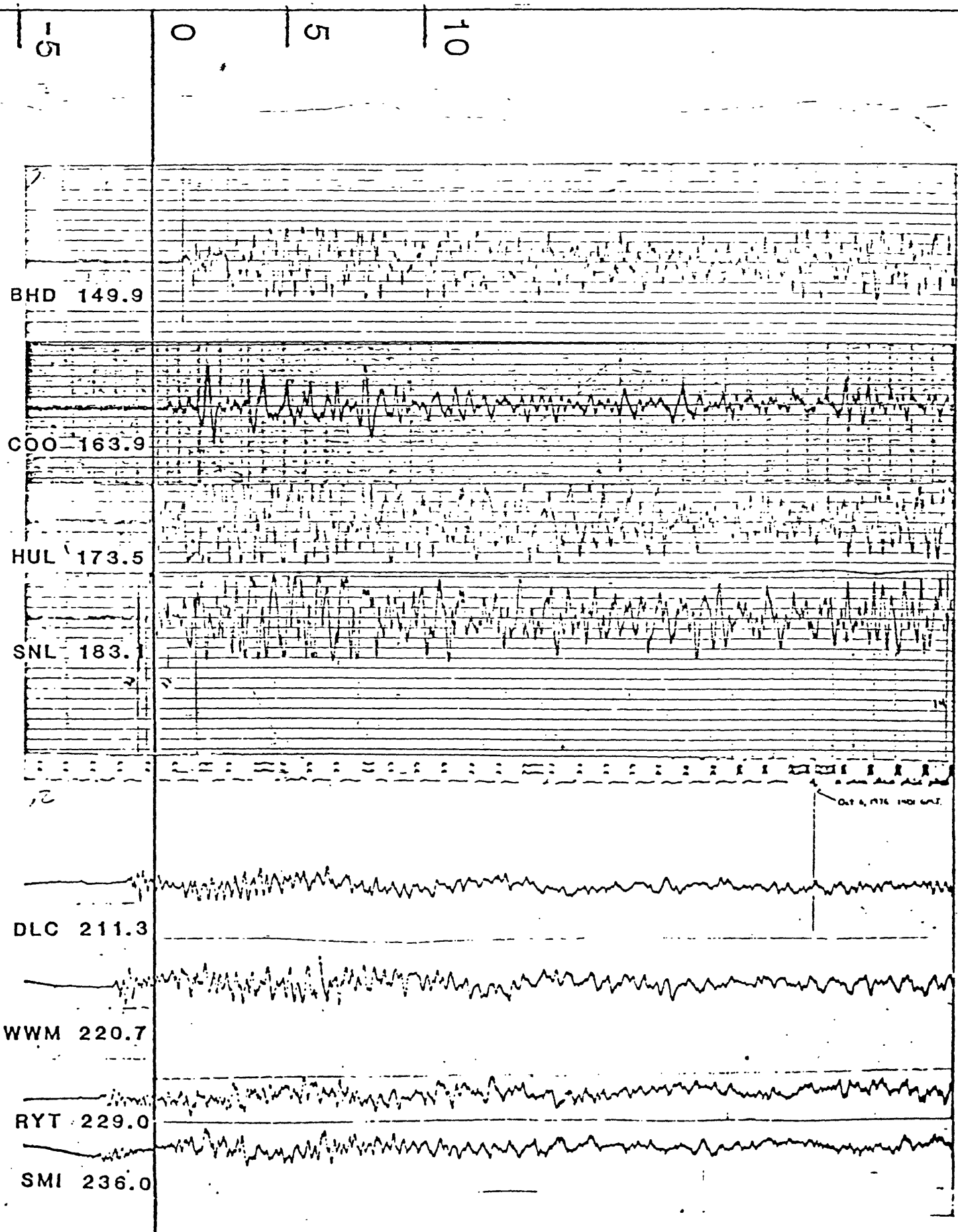
T - X/6 SECONDS
-5
0
5
10
BHD 149.9
COO 163.9
HUL 173.5
SNL 183.1
DLC 211.3
WWM 220.7
RYT 229.0
SMI 236.0
DICE THROW SHOT
X (KM)

FIGURE 5

The record section from the Morenci shot points is shown in figure 6.

Table 6 lists the data for the timed Miami shot and figure 7 is the record section compiled from subsequent shots.

Table 6

Miami Shot

Station	Distance (KM)	Travel Time (Sec)	Elevation (Meters)	Elevation Correction (Sec)	Δ/6 (Sec)	Corrected Travel Time (Sec)	Reduced Travel Time (Sec)
TUC	123.53	21.01	0986	+ .08	20.59	21.09	+ .50
FRI	165.24	27.63	1358	+ .02	27.54	27.65	.11
RYT	187.00	30.43	1884	- .10	31.17	30.33	- .84
SVM	258.65	38.96	1810	- .04	43.11	38.92	- 4.19
WTX	379.54	55.00	1555	- .01	63.26	54.99	- 8.27

The data from the Tyrone shot points is a composite of 3 different explosions, none of which were timed. The records (except for SNL which was recorded at a higher speed) are shown in figure 8.

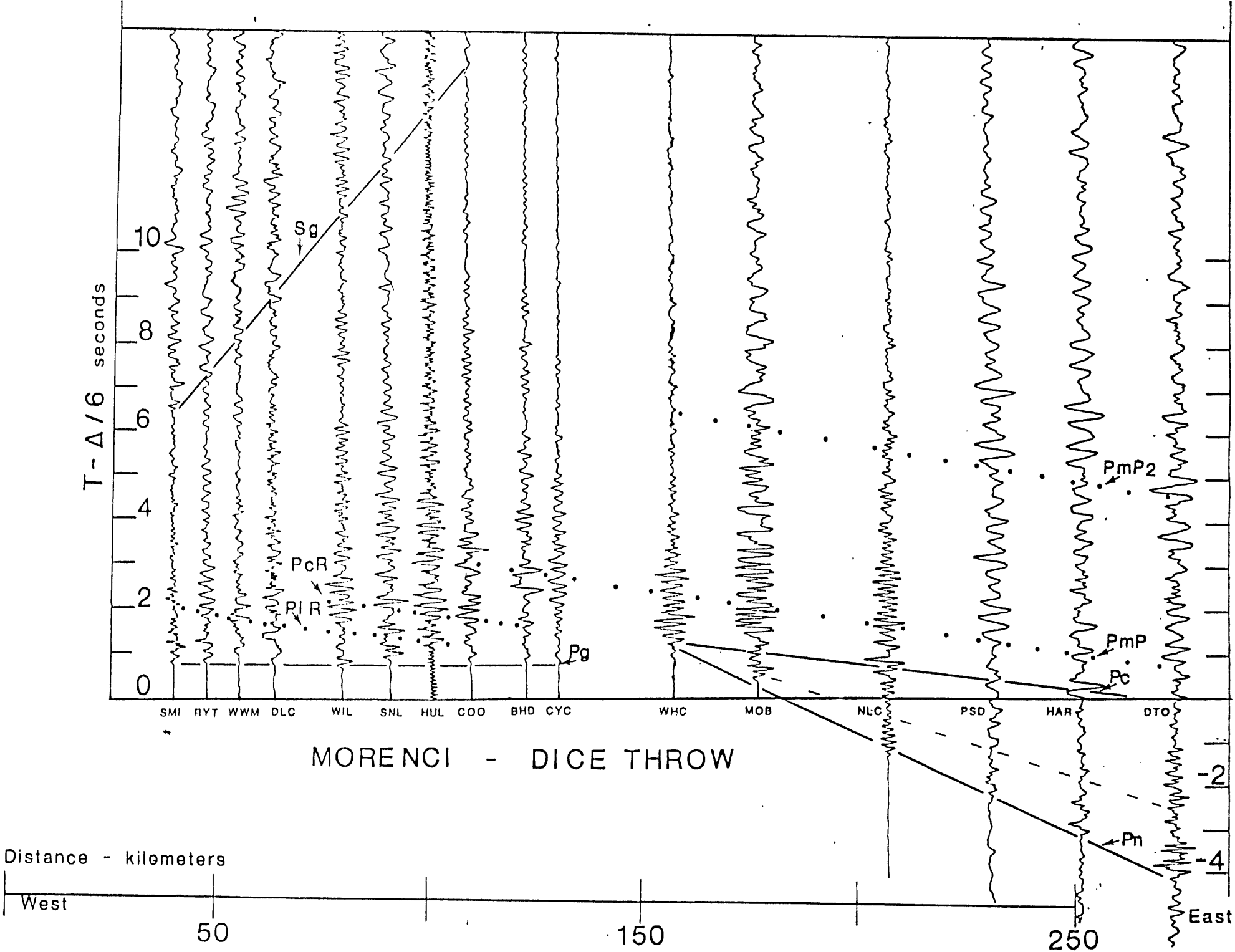
T - Δ / 6 seconds
10
8
6
4
2
0
Sg
PcR
PlR
Pg
PmP2
PmP
Pc
Pn
SMI RYT WWM DLC WIL SNL HUL COO BHD CYC WHC MOB NLC PSD HAR DTO
MORENCI - DICE THROW
-2
-4
Distance - kilometers
West
East
50
150
250

FIGURE 6

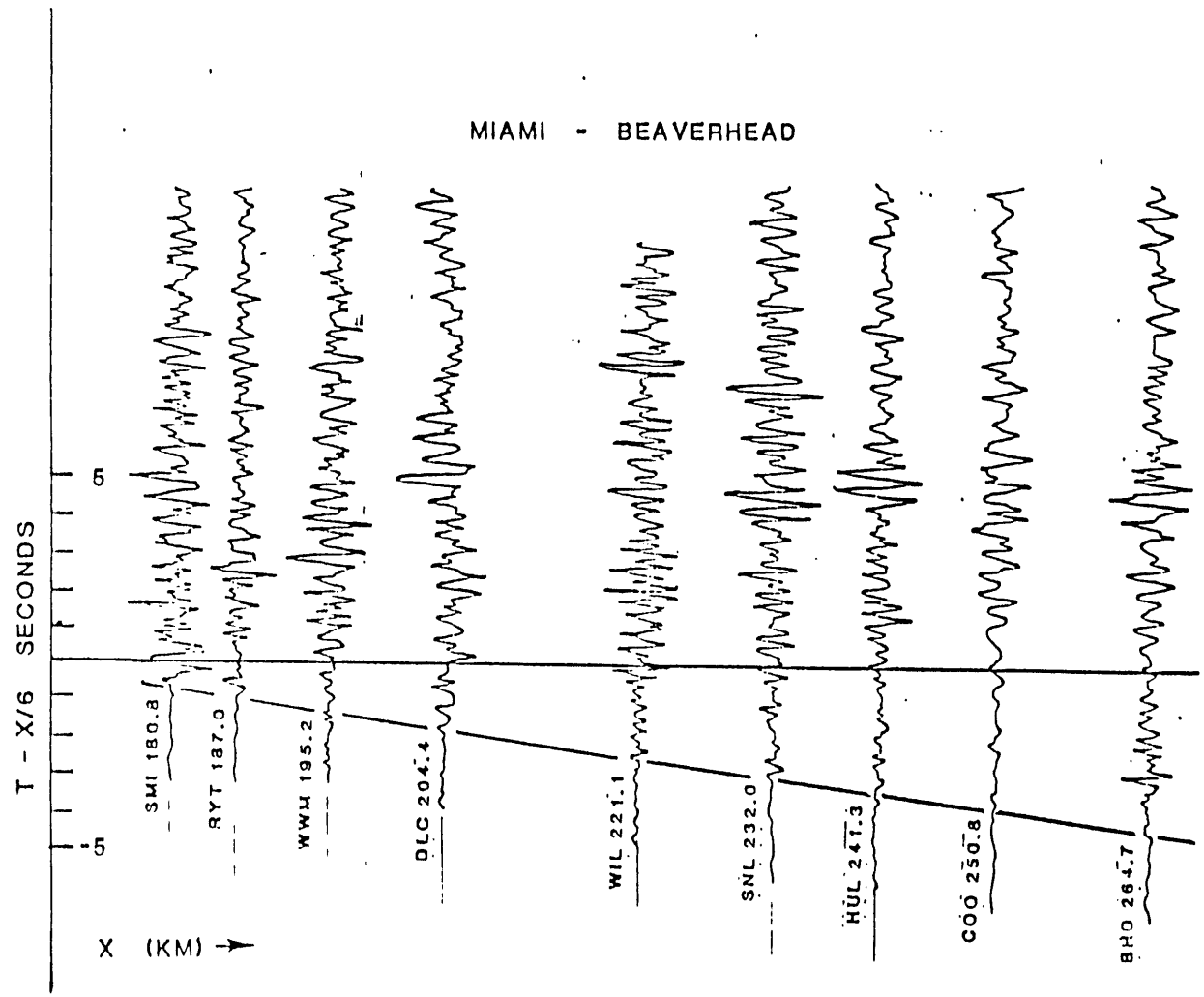
MIAMI - BEAVERHEAD
T - X/6 SECONDS
5
-5
X (KM)
SMI 180.8
RYT 187.0
WWH 195.2
DLC 204.4
WIL 221.1
SNL 232.0
HUL 241.3
COO 250.8
BHO 264.7

FIGURE 7

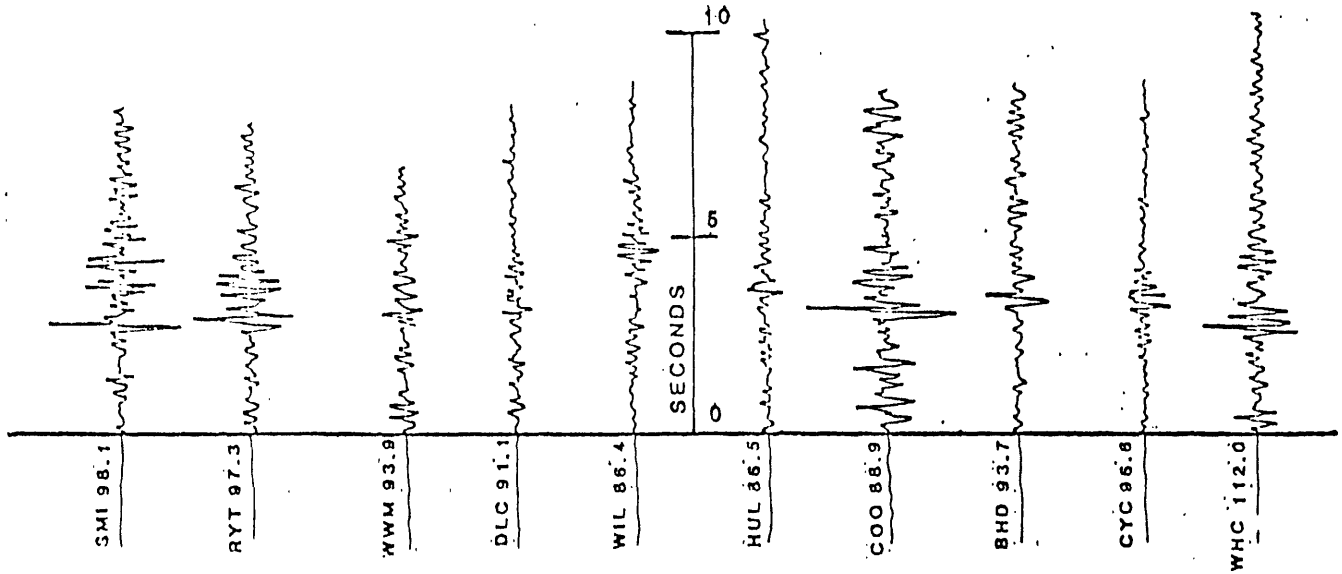
TYRONE TO LINE
SMI 98.1
RYT 97.3
WWM 93.9
DLC 91.1
WIL 86.4
SECONDS
0
5
10
HUL 86.5
COO 88.9
BHD 93.7
CYC 96.8
WHC 112.0

FIGURE 8

SUMMARY

A seismic refraction field program was conducted by the U.S.G.S. in the Datil-Mogollon volcanic field during 1976, 1978, 1979, and 1980. Travel time tables corrected for differences in elevation were derived from the field measurements. Record sections from 4 shot points have been compiled.

ACKNOWLEDGEMENTS

We are pleased to acknowledge the splendid cooperation of Mr. John Bolles, Phelps-Dodge Corporation, Morenci, Arizona, Mr. G. E. Napp, Cities Service Company, Miami, Arizona, and Mr. A. E. Himebaugh, Phelps-Dodge Corporation, Tyrone, New Mexico. Without the help of these individuals and members of their respective organizations this study could not have been completed.

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FIGURE CAPTIONS

Figure 1. Shotline at Morenci

Figure 2. Seismometer emplaced near shot.

Figure 3. Planview of the seismic refraction experiment in southwestern New Mexico and southeastern Arizona.

Figure 4. Seismograms from stations 2-6 for the DICE THROW explosion. Stations are identified by I.D. in Table 2. The shot-station distance is given after the I.D.

Figure 5. Seismograms from stations 7-10 and 12-15 for the DICE THROW explosion. Stations are identified by I.D. in Table 2. The shot-station distance is given after the I.D.

Figure 6. Record section of the Morenci DICE THROW profile.

Figure 7. Part of section of the Miami to DICE THROW profile. Stations are identified by I.D. in Table 2. The shot-station distance is given after the station I.D.

Figure 8. Tracings of seismograms recorded on the refraction line from the Tyrone, New Mexico shot point. Stations are identified by I.D. in Table 2. The shot-station distance is given after the station I.D.