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UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

An Evaluation of Seismic Reflection Studies in the Yucca Mountain Area, Nevada Test Site

by

Thomas F. McGovern[2]

with an introduction by

L. W. Pankratz[1] and H. D. Ackermann[1]

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1. USGS, Denver, Co.

2. Subsurface, Inc.
Parker, Co.

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Introduction to the Report

by

L. W. Pankratz[1] and H. D. Ackermann[1]

The U.S. Geological Survey (USGS) working under an Interagency agreement, DE-AI08-78 ET 44802, with the Department of Energy is engaged in a broad program to assess and identify potential repositories for high level nuclear waste on the Nevada Test Site (NTS). The USGS program consists of integrated geologic, hydrologic and geophysical studies which range in nature from regional to site specific. This report is an evaluation of seismic reflection studies made at the Yucca Mountain potential repository site in the southwestern part of NTS.

As part of this study the U.S.G.S. contracted with three different organizations in the years 1980, 1981, and 1982 to conduct progressively more complex seismic reflection surveys focusing in the Yucca Mountain area, Southwest quadrant of the Nevada Test Site: 1.) A study was conducted by The Colorado School of Mines in 1980, which resulted in a Master of Engineering Thesis (ER-2429) by Charles Barry (1981). The results presented in this thesis emphasized the negative results of a high resolution seismic survey conducted in the presence of the high background noise environment which exists at Yucca Mountain. 2.) The second survey by Birdwell/SSC was designed with the insight gained by a noise study using elaborate receiver arrays. Extensive computer processing of these reflection data showed, either the possibility of a reflected event or a computer generated false reflection. (Later computer analysis of the noise profiles showed that the recording parameters used for the survey were still insufficient to cancel the predominant noise trains). 3.) On the basis of this possible reflected

[1]U.S. Geological Survey

event, an even more extensive study was undertaken. Following thorough review, a request for bids was issued in January 1982, and a contractor selected in March, 1982. In the meantime at the request of the reviewers the services of a data acquisition processing specialist, Mr. Stanley Brasel, Seismic International Research Corporation, were used to advise the USGS on implementation of the reflection survey. The data acquisition contractor, Seisdata Services, Inc., began operations in March, 1982. Due to the untimely death of Mr. Brasel in February, 1983, SIRC hired a sub-contractor, Subsurface, Inc., to complete the final report which is presented herein.

The seismic reflection technique was predicted to provide information on the geological homogenity of the host rock in the repository. Unfortunately, the nature of the rock structure, over 6000 feet of interbedded highly fractured densely welded and nonwelded volcanic tuffs, coupled with the highly absorptive and ringing nature of the near surface rocks (Pankratz, 1982; Barry, 1980), was not conducive to the reception of reflected events at the surface with sufficient power to be recorded above the noise level. Norman Burkhard (1983) essentially presents this same argument when he concludes that "I believe that the transmissivity of the alluvial and volcanic sections is the single most important factor". The conclusion is reached by the studies presented in the following report, that even with powerful source and receiver arrays the seismic reflection technique cannot discern a signal which can be seen above the noise level received from the tuffs that underlie Yucca Mountain. This problem coupled with the difficult terrain and the prohibitive expense of utilizing the increased power of arrays results in our recommendation that the seismic reflection method should not be employed at Yucca Mountain except as experimental surveys to evaluate new sources or techniques.

The following report by Thomas McGovern of Subsurface, Inc., presents a comprehensive analysis of the seismic reflection work performed at Yucca Mountain.

References of the Introduction

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A Geophysical Evaluation of Seismic Studies in the Yucca Mountain Area, Nevada Test Site

by

Thomas F. McGovern[1]

ABSTRACT

As part of a total geophysical evaluation of Yucca Mountain for use as a Nuclear Waste Repository the seismic reflection technique has been applied. This study has been conducted to analyze the historical and technical efforts which have been used by three geophysical contractors employing a wide variety of techniques ranging from the most simple to very elaborate 3-D surveys. In each case elaborate noise studies were conducted, and based upon their evaluation parameters were chosen for multifold CDP recording. In every case, the signal-to-noise ratio was such that no reflections were discernable. Since the reflections cannot be separated from the noise even using very elaborate noise suppression techniques and up to 384 fold multiplicity it is apparent that in this volcanic terrain reflection surveys can not work.

[1]Subsurface, Inc., Parker, Co.

INTRODUCTION

Yucca mountain (Nevada Test Site) has been the site of some recent important seismic reflection studies (Figures 1 and 1A), conducted by the following geophysical contractors: the Colorado School of Mines (1980), Birdwell/Seismograph Service Corporation (1981), Seismic International Research and Seisdata Services Inc. (1982). Each reflection survey was accompanied by an elaborate noise study. In the most recent study, Seismic International Research Corp. was responsible for the design of the field technique and data processing while Seisdata Services Inc. was responsible for data acquisition. Western Geophysical Inc. was also contracted to process one seismic reflection line as a quality control check on the Seismic International Research data processing. It is the purpose of this investigation by Subsurface Inc. to evaluate the applicability of the seismic reflection technique in the Yucca Mountain (Nevada Test Site) area.

HISTORICAL REVIEW OF SEISMIC REFLECTION SURVEYS DONE AT THE NEVADA TEST SITE

Table 1 displays the field acquisition parameters used in gathering seismic reflection surveys from the years 1972-1982 in the Nevada Test Site. It also shows the survey location areas, geologic setting and estimate of the reflection data quality. Table 1 indicates that most seismic reflection surveys at the Nevada Test Site were acquired as two dimensional profiles employing numerous input sources (Vibroseis[1], Primacord[2], Dynamite) and source array patterns. Many different receiver arrays were also utilized. These arrays were both short and long (up to 440 ft) and employed from 1 to 144 geophones. Our visual examination of the processed data revealed that the profiles from areas usually characterized by complex faulting, volcanics and paleozoic outcroppings (Yucca Mountain, Wahmonie, Calico Hills, and Syncline Ridge) (Christiansen and Lipman, 1965, Lipman and McKay, 1965, Hoover, 1982, Synder and Carr, 1982, and Pankratz, 1982) did not produce any accurate reflection information. However, reflection data acquired in the flat lying alluvial plain (Yucca Flat) which is not quite as complex geologically appeared of much better quality.

In 1982, a three dimensional seismic reflection survey was conducted at Yucca Mountain utilizing a field technique that produced stack fold ranging between 192 and 384. This report will illustrate that this very powerful field technique also did not produce any interpretable reflection events.

[1] Registered trademark, Continental Oil Co.

[2] Registered trademark, Ensign Bickford, Co.

TABLE I

Yr. & Contractor	Instrument	Channels	Amplifier	Geophone Frequency (HZ)	Geophones Trace	Geophone Pattern	Geophone Spacing (ft)	Profile Type	Source	Source Array	Source Spacing (ft)	Stack Fold	Group Interval (ft)	Source Interval (ft)
1972 SSC	TI 10000	24	Fixed-Gain	7.5	36	In Line	12.5 ft. Over 440 ft.	2-D	Vibroseis	4 Vibrators In Line	75 Apart	12	220	220
1978 Western	Litton Coba	48	Floating Point	10	36	In Line Over 440 ft.	12.5	2-D	"	"	75 Total Pattern 440	24	220	220
1978 Western	Litton Coba	48	"	10	24	In Line	19	2-D	"	"	75	24	220	220
1979 Geosource	GUS-HDDR	24	"	10	20	"	2.8	2-D	Dynamite	n/a	n/a	12	55	55
1980 CSM	DFS-5	48	"	18	1	"	55	2-D	Vibroseis	Vibrator In Line	220	24	55	55
1980 Seisdata	DFS III	48	"	10	12	"	10	2-D	Primacord	n/a	n/a	24	55	55
1980 Seisdata	DFS III	48	"	10	12	"	17	2-D	"	n/a	n/a	24	55	55
1981 Birdwell	DFS-5	48	"	10	120	In Line Weighted Array	8.5	2-D	Vibroseis	30 In Line	5	24	50	50
1982 Seisdata	MDS-10	96	"	10	96	Weighted Array	15	3-D	Dynamite	1 Deep Hole	200	192	100	200
1982 Seisdata	MDS-10	96	"	10	96	Weighted Array	15	3-D	Vibroseis	3 Vibrators 18 Sweeps	12.5	384	105-210	105-210
1982 Seisdata	MDS-10	96	"	10	12	In Line	9	3-D	Vector Pulse (Primacord)	7 Elements In Line	16	288	50	50

TABLE I [cont'd.]

Yr. & Contractor	Near Offset (ft)	Far Offset (ft)	Sweep (HZ)	No. of Sweeps	Sweep Duration (sec)	Listening Time (sec)	Sampling Interval (ms)	Field Filter (HZ)	Area	Data Quality	Geological Setting
1972 SSC	880	3300	17 - 56	16	7	10	4	14 - 70	Syncline Ridge	poor	VR over PH
1978 Western	660	5720	14 - 56	16	16	5	4	out-62	Syncline Ridge	poor	"
1978 Western	880	11220	8 - 32	up 32	12	3	4	out-62	Syncline Ridge	very poor - poor	"
1979 Geosource	n/a	n/a	n/a	n/a	n/a	n/a	25	23-180	Yucca Flats	poor-fair	Alluviam over VR
1980 CSM	55	1320	30-120	9	6	3	2	12-180	Wahmonie Yucca Mt. Calico Hills	very poor	AFT over IC & VR
1980 Seisdata	192	1457	n/a	n/a	n/a	n/a	2	18 - 124	Yucca Flats	poor-fair	Alluviam over VR
1980 Seisdata	220	1465	n/a	n/a	n/a	n/a	2	18 - 124	Yucca Flats	poor-fair	"
1981 Birdwell	500	1650	48 - 6	30	16	6	4	out-128	Yucca Mt.	very poor	AFT in MT
1982 Seisdata	800	3100	n/a	n/a	n/a	n/a	2	12-125	Yucca Mt.	very poor	"
1982 Seisdata	840	1940	10-56 22-84 16-62	18	14	4	2	out-125	Yucca Mt.	very poor	"
1982 Seisdata	840	2415	n/a	n/a	n/a	n/a	2	12-125	Yucca Mt.	poor	"

LEGEND

n/a - Not Available
IC - Intrusive Complex
PH - Paleozoic High
VR - Volcanic Rock
AFT - Ash Flow Tuff
MT - Mountainous Terrain

COLORADO SCHOOL OF MINES REFLECTION SURVEY

In 1980, The Colorado School of Mines (CSM) (Barry, 1980) conducted seismic reflection surveys in three areas of the southwest Nevada Test Site. These areas were: Yucca Mountain, Wahmonie, and Calico Hills (Figures 1 and 1A). Their objective was to obtain detailed shallow subsurface geologic information. With this objective in mind, their field technique was directed toward high resolution acquisition utilizing short geophone arrays and high source frequencies. Initially, a detailed noise analysis was conducted in each of the three areas. Each noise profile consisted of a small common depth point reflection line, various geophone arrays and a broad range of input sweep frequencies (8 to 120 hz.). Detailed computer analysis of the noise data indicated that noise patterns, in all three areas, were not effectively cancelled by the suite of receiver arrays tested. Table 2 is a summary of the CSM measured velocities of noise patterns in all the three areas.

In accordance with their high resolution objective, the CSM selected as final production acquisition parameters a receiver array consisting of one buried geophone and a sweep frequency of 30 to 120 hz. Additional acquisition parameters included: 18 hz. geophones, 55 ft. station intervals, 6 second up sweep at nine vibrator positions, 6 ft. vibrator move up, 48 channel recording, 24 fold stack, 2 millisecond sampling interval, and near and far offsets of 55/1320 ft. This survey produced no interpretable subsurface reflection information. It also demonstrated that simple high resolution data acquisition techniques are not applicable in the Yucca Mountain vicinity (Barry, 1980, pp. 36-40).

TABLE 2

NOISE TYPE	VELOCITY ft./sec.
Refraction	11500
Direct Wave	4000-4200
Groundroll	1600-2000
Airwave	1100

BIRDWELL REFLECTION SURVEY

In 1981, Birdwell conducted a seismic reflection survey at Yucca Mountain near Drill Hole Wash from drill holes USW-G1 to USW-H1 (Figure 1A). The objective of this study was to further test the feasibility of the reflection method at Yucca Mountain and establish a tie between the two drill holes. The noise study and a reflection survey were recorded within a few days of each other. The noise study used elaborate receiver arrays (Figure 2) which allowed the testing of various configurations of geophone receiver arrays using different channels in a simultaneous recording. This method utilized the Vibroseis™ source walkaway technique (Sheriff, 1974) where receiver arrays remain stationary as the source moves away in a linear pattern. This profile differed from a standard walkaway procedure in that it utilized closely spaced source points that were received by various array patterns configured on each recording channel. This procedure can provide many types of walkaway profiles by computer plotting of each recording channel for each source point. Analysis of the noise profiles revealed that all receiver arrays tested exhibited similar noise attenuation properties.

Figure 3 is a typical noise profile with automatic gain control. Table 3 is a summary of the measured velocities of the noise patterns as recorded by the Birdwell survey.

TABLE 3

NOISE TYPE	VELOCITY ft/sec.
Refraction	6000, 8000, 10000
Direct Wave	4000-4200
Groundroll	1600-2000
Airwave	1100

Recording parameters for the reflection survey were chosen on the basis of field examination of the noise profiles. They consisted of a rectangular 100 x 200 ft. receiver array containing 10 rows of 12 geophones each separated 8.5 ft. and a 48 to 6 hz. downsweep. Additional parameters included: 24 channels, 24 stack fold, 16 second downsweep, 3 vibrators 50 ft. apart inline with a 5 ft. move up, 50 ft. station intervals, 4 millisecond sampling interval and near and far offsets of 500/2850 ft.

The raw unstacked records were dominated by several types of noise the character of which appears to change with shot-receiver offset distance (fig. 4). For the near receiver offsets, the seismic records are dominated by high frequency random noise, probably produced by instrument electronics, wind and seismic crew related activities. For far offsets the records are dominated by low frequency source generated coherent noise which propagates horizontally through the near surface. No reflections could be observed on the raw reflection records. Processing was done by Seismograph Service Corporation (SSC). The data were initially demultiplexed, summed, cross-correlated, edited and CDP sorted using standard procedures (Anstey, 1977). Various tests were then employed (e.g. autocorrelation, power spectrum analysis , filtering, deconvolution, and scaling) to help determine further processing procedures. The data set was filtered with a 14 to 48 hz. bandpass and constant velocity stacks run to determine normal moveout.

At this point, a source and receiver simulation test was performed to determine if a larger array interval would effectively cancel dominant noise patterns. (This procedure mathematically transforms one recorded source and receiver array configuration to another by means of a running sum mix of adjacent traces). Selective stacking was performed using varying offset distances to determine whether lateral continuity of reflection events could possibly be enhanced by using only the near, or the intermediate, or the far offset traces. These specific stacks led to the conclusion that both the near and medium to far offsets were dominated by noise. Figure 4 displays a typical field recording which exhibits very coherent noise patterns in most areas of the seismic reflection record.

During the normal data processing routine, several CDP stacks were generated for quality control and these, curiously, led to some interesting conclusions. First, a CDP stack was produced that had only a normal moveout correction applied (Figure 5). This type of stack is normally produced as a quality control check before application of automatic residual statics. This CDP stack yielded no interpretable continuous reflection events. Then automatic residual statics were applied to the data (Figure 6) which produced an apparent reflection at 1.2 seconds. In reference to Figure 4, we note that the shallow part of the seismic reflection record above 2.0 sec is dominated by coherent noise which may be the source of this apparent reflection. To test this concept (Taner et al, 1974), a CDP stack was produced without the presence of this coherent noise (Figure 7) using velocity filtering (Sheriff, 1974) and selective muting to eliminate these coherent noise patterns. Automatic statics were also applied and the CDP stack (Saghy and Zelei, 1975) yielded no apparent continuous reflection information, therefore, we conclude that the automatic statics routine aligned noise trains to produce an inferred reflected event. A discussion of this routine necessarily follows. The automatic statics routine used by SSC employed a seven CDP correlation model and a 0.5 - 1.2 second correlation window. Seven common depth points and their respective traces were stacked to produce this model which was then cross-correlated with each trace within the central common depth point. The time shifts observed between the model and the CDP traces are assumed to be residual static errors and these time shifts are then applied to the traces. This cross-correlation technique is amplitude dependent. If high amplitude events existed within the correlation window, they were shifted to align with corresponding high amplitude events contained in the model. If these high amplitude events represented coherent noise, the resulting stack would have aligned coherent noise. Therefore, the reflection at 1.2 seconds observed in figure 6 is no more than alignment produced by the automatic statics routine. Despite this maximum processing effort no interpretable reflections were observed.

SEISMIC INTERNATIONAL RESEARCH CORP. - SEISDATA SERVICES INC. SURVEY

In 1982, Seismic International Research Corp. (SIRC) and Seisdata Services Inc. (SSI) conducted a three dimensional seismic reflection survey in the Yucca Mountain vicinity. (Figure 1A). A historical analysis of previous reflection surveys proved that standard simple acquisition techniques could not be applied in this area. This reflection survey had to maximize all field efforts if reflection information was to be obtained. A three dimensional effort was proposed and accepted because it favored an extremely high stack fold (192 to 384) for common depth points and provided a very effective method of attenuating noise patterns thereby improving the signal to noise ratio.

The Vibroseis™ method was chosen for use as long as the terrain was flat and accessible, however, where the terrain was rugged and inaccessible, surface source explosives (Primacord™) were employed. Previous acquisition efforts utilized simple receiver and source arrays. Serious consideration had to be given to the concept of employing complicated source and receiver arrays which with their combined effort offered a very powerful technique for coherent noise attenuation.

Several conclusions can be reached from the two previous reflection surveys conducted in the Yucca Mountain vicinity. First, the CSM survey was designed with high resolution acquisition in mind. Therefore, they utilized short geophone arrays and high source frequencies. This technique employed a simple 9 element single vibrator source array and a single geophone array. However, this method was much too simple for an area where the dominant recorded energy is noise. Figure 8 is an array response curve for the total combined technique (Halzman, 1963) used in the CSM reflection survey. This technique resulted in a maximum effort of 12 db. attenuation for noise wavelengths of 10 to 70 ft. The Birdwell reflection survey differed from the CSM survey in that it did not employ high resolution acquisition techniques, only a complicated receiver array and a simple source array. The input source frequencies were fairly low (6 to 48 hz.) Figure 9 is an array response pattern for the combined field technique used in the Birdwell reflection survey. The maximum effort is a 29 db. attenuation for noise wavelengths of 12 to 160 ft. Because no reflection information was obtained, this still proved too low of an attenuation factor for this noise dominated area.

SIRC/SSI designed a much stronger method using receiver arrays consisting of 120 geophones, and either 3-4 vibrator trucks or Vector PulseTM[1] for source arrays. Figure 10 is a response curve for a total combined source and receiver array using 3 vibrator trucks (Geyer, 1970), 54 sweeps with 12 foot spacing and a 96 geophone array at 15 foot spacing. This combined technique produced an attenuation power of 68 db. for noise wavelengths of 18 to 122 feet. Figure 11 shows the response curve employing the same receiver array but a Vector Pulse™ source array consisting of 12 equally spaced elements. This combined effort is also very powerful because it provides a 53 db. attenuation for noise wavelengths of 18 to 122 feet.

1.) Vector Pulse is a Registered Trademark, Seisdata Services Inc. It employs elements consisting of 0.5 in steel rods approximately 4 ft long loaded with Primacord™ emplaced in the earth.

Noise studies conducted by SIRC/SSI consisted of both inline (walkway) and circular (tornado) profiles. These noise profiles were recorded in the alluvial valley directly east of Yucca Mountain which afforded accessibility and mild terrain and also allowed the use of both Vibroseis™ and Vector Pulse™ source methods. The objectives of these noise studies at Yucca Mountain were:

a) to measure the range in velocity of all source generated noise,

b) to test for reflected or broadside noise,

c) to determine the dominant noise patterns,

d) to test several input frequency ranges for penetrating and resolving power,

e) to compare Vibroseis™ and Vector Pulse™ energy sources,

f) to generate a physical model of noise distribution, and

g) to seek a window between noise patterns for observing reflection information.

INLINE NOISE PROFILE

The inline noise spread was designed to measure velocity, frequency and wavelength of source generated noise in the line of profile. It consisted of 96 recording stations each with 12 bunched geophones 10 feet apart. Four shotpoints were used, each 950 feet apart as illustrated in Figure 12. Both Vector Pulse™ and Vibroseis™ energy sources were tested. The Vibroseis™ sweep frequencies used were 10 to 56, 16 to 72, 22 to 84, 32 to 96 and 38 to

104 hz. This profile simulated a standard walkway procedure (Sheriff, 1974) with the source moving away at selected increments from a stationary recording cable. Table 4 is a summary of the measured velocities, frequencies and wavelengths of the dominant noise patterns.

TABLE 4

NOISE RELATED PROPERTIES FOR THE INLINE SPREAD

Noise Type	Velocity (ft/sec)	Frequency(hz.)	Wavelength(ft.)
Groundroll	1640-2000	12-20	82-166
Direct	3170	20-35	91-159
Reflected	none observed	N/A	N/A
Refracted	none observed	N/A	N/A

CIRCULAR NOISE PROFILE

In addition to identifying the functions of noise in the line of profile a circular noise spread was used to identify noise patterns originating as reflected-refractions or broadside noise from hills, mountain ranges or man-made objects. It is ideal, therefore, in the Yucca Mountain area. This profile used concentric circular spreads (Brasel, 1979) with 32 stations at 10 foot spacing on the inner circle of 52 ft. radius and 64 stations at 10 foot spacing on the outer circle of 102 ft. radius (fig. 13). Each station consisted of 12 bunched geophones. The radii were chosen to effectively measure the smallest noise wavelength which may exist in this area. Source points (VP-1) began at the center of the circles and progressed outward in a straight line at 200 foot intervals. Several input sources were tested in this study. Shotpoints 1-19 were recorded using Vibroseis™ with 32-96 hz. sweeps. Shotpoints 1, 3, 6, 9, 12, 15, and 18 were recorded with both Vector Pulse™ and Vibroseis™ using sweep frequencies of 10 to 56, 16 to 72, 22 to 84, 38 to 104, 44 to 108 hz.

Table 5 displays the measured velocities, frequencies, and wavelengths of dominant noise patterns interpreted from offset distances of 400 to 2850 feet from the circular noise spreads.

TABLE 5

NOISE RELATED PROPERTIES FOR THE CIRCULAR SPREAD

NOISE Type	Velocity(ft/sec)	Frequency(hz.)	Wavelength(ft.)
Groundroll	1800	15-25	72-144
Direct	2100	20-50	65-156
Reflected	none observed	N/A	N/A
Refracted	none observed	N/A	N/A

ANALYSIS OF NOISE PROFILES

The final acquisition parameters for the three dimensional reflection survey were selected based upon the analysis of the properties observed in the noise profile data. The dominant noise recorded on both inline and circular noise spreads is groundroll and direct. The noise wavelength range observed for groundroll and direct noise is 65 to 166 feet. These wavelengths are well within the attenuation power of the combined source and receiver arrays discussed in a previous section (Figures 10 and 11).

Source frequency tests showed that of the five sweep frequencies tested (Figures 14 to 25), 16 to 72 and 22 to 84 hz. provided the least noise generation and best resolving power. The Vector Pulse™ method generated sufficient resolving power but a large amount of coherent source noise.

In order to understand the relationship between noise distribution and reflection information, a signal and noise schematic was made (Figure 26) which graphically displays all noise distribution common to the Yucca Mountain vicinity. From this graph an offset dependent recording window for observing reflection information can be defined. Analysis of this schematic suggested that a window of 750-2000 feet be utilized if reflection information, for example from the base of the Topopah Spring Tuff, is to be observed. Any defined offset lying outside the perimeters of this window would be overwhelmed by shot generated noise.

THREE DIMENSIONAL PRODUCTION ACQUISITION PHASE

Initial production acquisition parameters were based on results of the noise studies and existing terrain limitations. Three dimensional grids (Figure 27) were designed which employed 96 recording channels and an optimum offset recording window.

Line W-4 (Figure 1) was recorded initially with an 8 x 12 three dimensional receiver array grid consisting of 105 foot station intervals and 800 to 1900 foot receiver offsets. A weighted receiver array of 96 geophones spaced at 15 feet over pattern length of 210 feet, was used. A source array of 3 vibrators sweeping 18 times at a spacing of 12.5 feet and a pattern length of 156 feet was utilized. The initial sweep was 10 to 56 hz. which due to mechanical difficulties caused decoupling effects. The sweep was later changed to 16 to 62 hz. which eliminated these effects. Due to excessive mechanical failures, Vibroseis™ activity was temporarily halted and a Vector Pulse™ source array of 11 elements spaced at 9 feet was employed. Vibroseis™ was once again employed until mechanical failures forced the use of Vector Pulse™ until termination of the project. Because of operational equipment problems and the decision to attempt to record reflections from the beds lying less than 500 feet deep, lines S-2, and S-4 were recorded using different source and receiver arrays. The source array consisted of 7 Vector Pulse™ elements spaced at 16 feet while the receiver array was shifted to a linear pattern of 12 geophones spaced at 9 feet. The three dimensional grid was also changed to a 6 x 16 grid (Figure 27) employing 50 foot station intervals.

Line G-2 which is located along one of the ridges was recorded with a different source and receiver array. The source consisted of 10 pounds of dynamite detonated in 200 foot deep holes and was recorded by receiver arrays of 96 geophones spaced at 15 feet with a total pattern length of 210 feet. The three dimensional grid was changed to a 4 x 24 grid (Figure 27) employing 100 foot station intervals.

THREE DIMENSIONAL DATA PROCESSING METHODS

All of the three-dimensional data were processed by SIRC. Western Geophysical was also contracted to process line S-4 as a quality control check.

SIRC's data processing began with a standard demultiplex and Vibroseis™ cross-correlation. Raw records were plotted for editing and shooting pattern review. Geometry is coded and placed in the trace headers assigning each record trace to it's respective common depth point within the 3-D grid. Several tests were performed on the data at this stage which included: filter tests, autocorrelations, power spectra, deconvolution tests and scaling tests. These test results were analyzed for optimum processing parameters. The data were then filtered with a 10 to 30 hz. operator. Constant velocity stacks were run on the data to provide accurate normal moveout corrections. SIRC elected not to apply automatic residual statics because tests concluded that no apparent reflection information was present for the automatic static picking technique to function properly. The data were stacked in many different configurations (figures 28 to 30) to seek any relevant reflection information. SIRC chose for their final presentation, a stacking configuration that would produce the highest stack fold for each common depth point (figures 31 to 34). The data were filtered with a 10 to 36 hz. operator and scaled with automatic gain control. Western Geophysical, however, elected to apply automatic residual statics and for their final presentation chose to break up line S-4 into 11 CDP lines each consisting of 48 stack fold. Each company produced final CDP stacks that contained no interpretable reflection information. Horizontal time slices were produced by both companies during their data processing efforts, which are discussed in the following section.

SIRC 3-D TIME SLICE DISPLAYS

Seismic reflection surveys are usually displayed as vertical two dimensional profiles that exhibit subsurface strike and dip information. In order to acquire an accurate description of this subsurface information, numerous 2-D reflection profiles must be interpreted. Because 2-D profiles usually offer a coarse sampling of the subsurface, there is a great potential for error. In contrast, a 3-D reflection survey consists of a dense concentration of common depth points distributed over a 3-dimensional grid which provides time planes (Horizontal time slices) common to all depth points (Brown et al, 1982). Subsurface reflection information can be accurately interpreted by observing dip and strike changes with respect to time. Thus, the 3-D grid offers a very fine sampling of the subsurface while a two dimensional grid offers a very coarse sampling of the subsurface. By decomposing the subsurface into small time increments, the interpreter can accurately judge the size and shape of a subsurface geologic structure. However, the poor reflection data in the Yucca Mountain area, produced no interpretable results from the horizontal time slices. Figure 35 represents time slices produced by SIRC. These time slices range from .370 to .480 seconds and are color coded for amplitude strength. In hypothetical terms, a time slice cut through a very strong reflection would be color coded black, and as the reflection strength (amplitude) changes the shade would change. If a reflection event dips from northeast to southwest, corresponding time slices would be color coded black as they intersect the dipping event; therefore, if a black color exists for time slice at .370 seconds at the northeast end of a line, the same color would appear at a time at .480 seconds at the southwest end of a line. This would infer the dip of the strong reflecting event. As figure 35 shows this survey produced no interpretable time slice data.

RECOMMENDATIONS

Subsurface Inc. has reviewed in depth all seismic reflection surveys recorded in the Yucca Mountain region. It is conclusive that useful seismic reflection data cannot be acquired in this area even using the elaborate techniques outlined in this report. The seismic reflection method was developed and has been employed primarily in sedimentary rock environments. Rugged volcanic areas such as Yucca Mountain are not well suited to the seismic reflection technique. Many powerful noise suppression techniques were tested in this survey with none of these techniques producing useful reflection information. Additional seismic reflection studies will undoubtedly produce negative results and Subsurface Inc. discourages any additional seismic reflection surveys in the Yucca Mountain complex.

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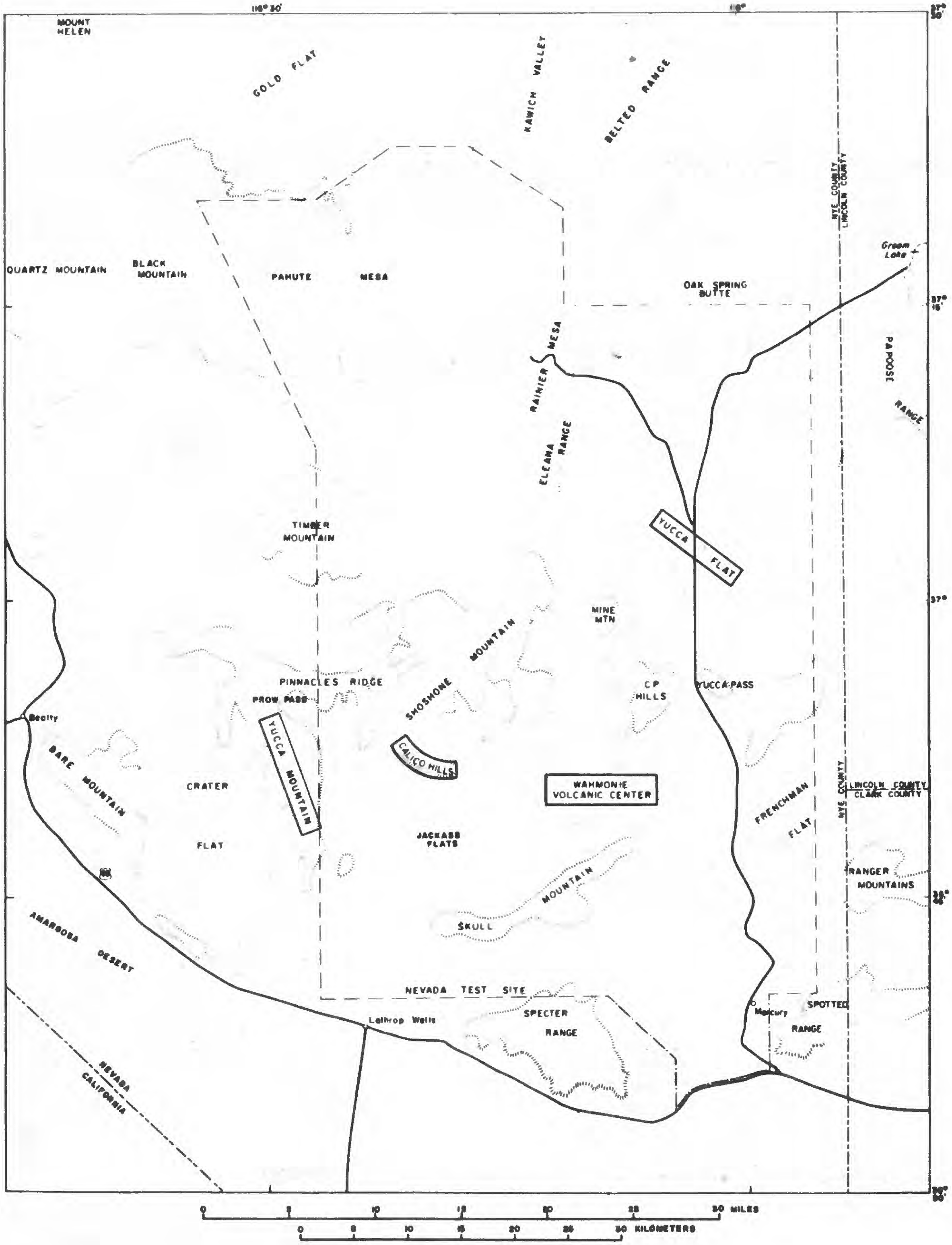
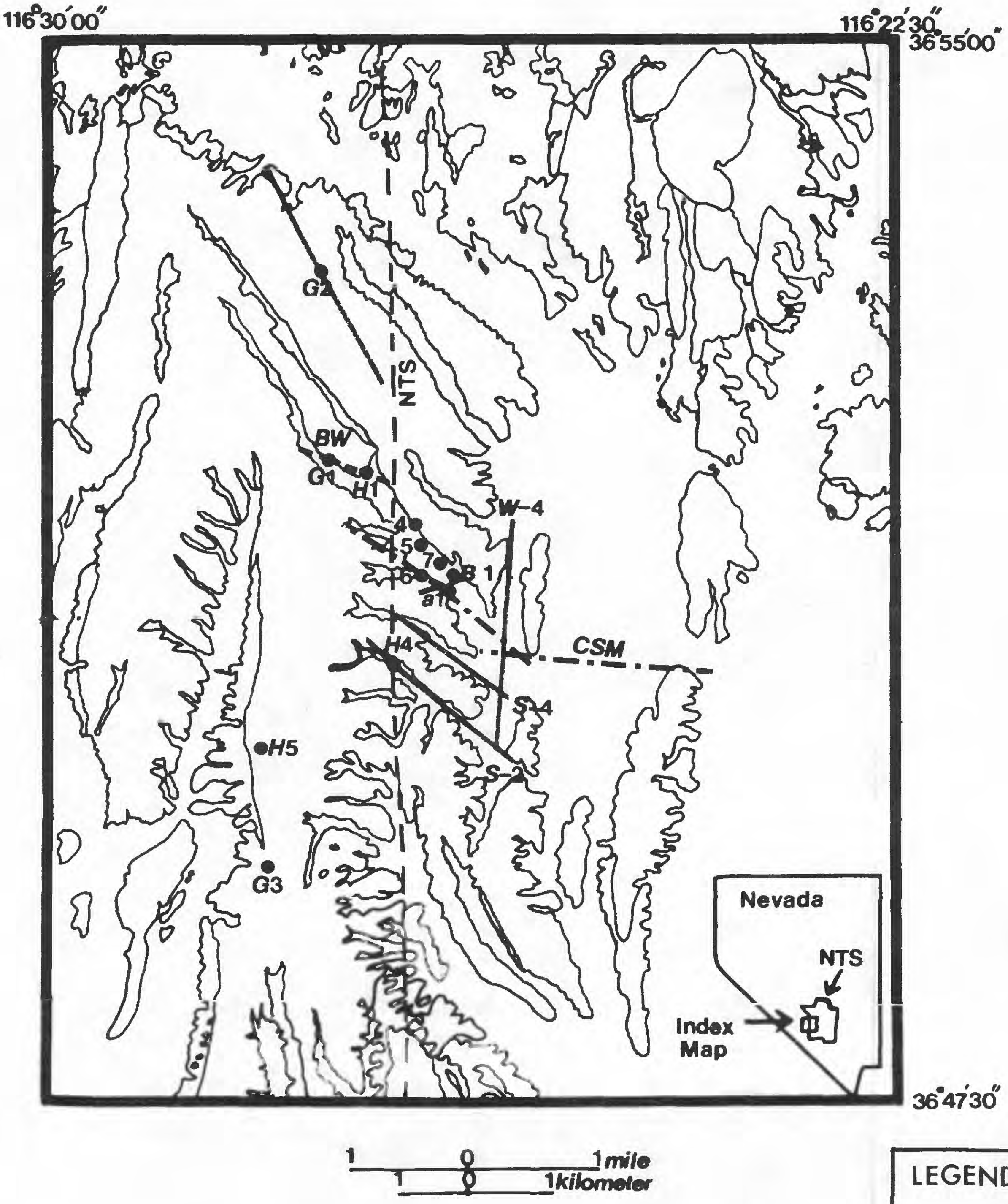
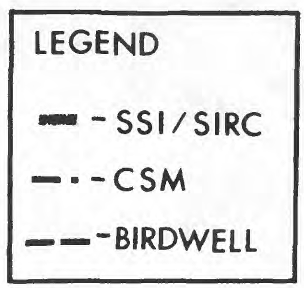


Figure 1.-- Index map of the Nevada Test Site and vicinity showing the areas of investigation

Figure 1A





Yucca Mountain Index Map

BIRDWELL NOISE SPREAD

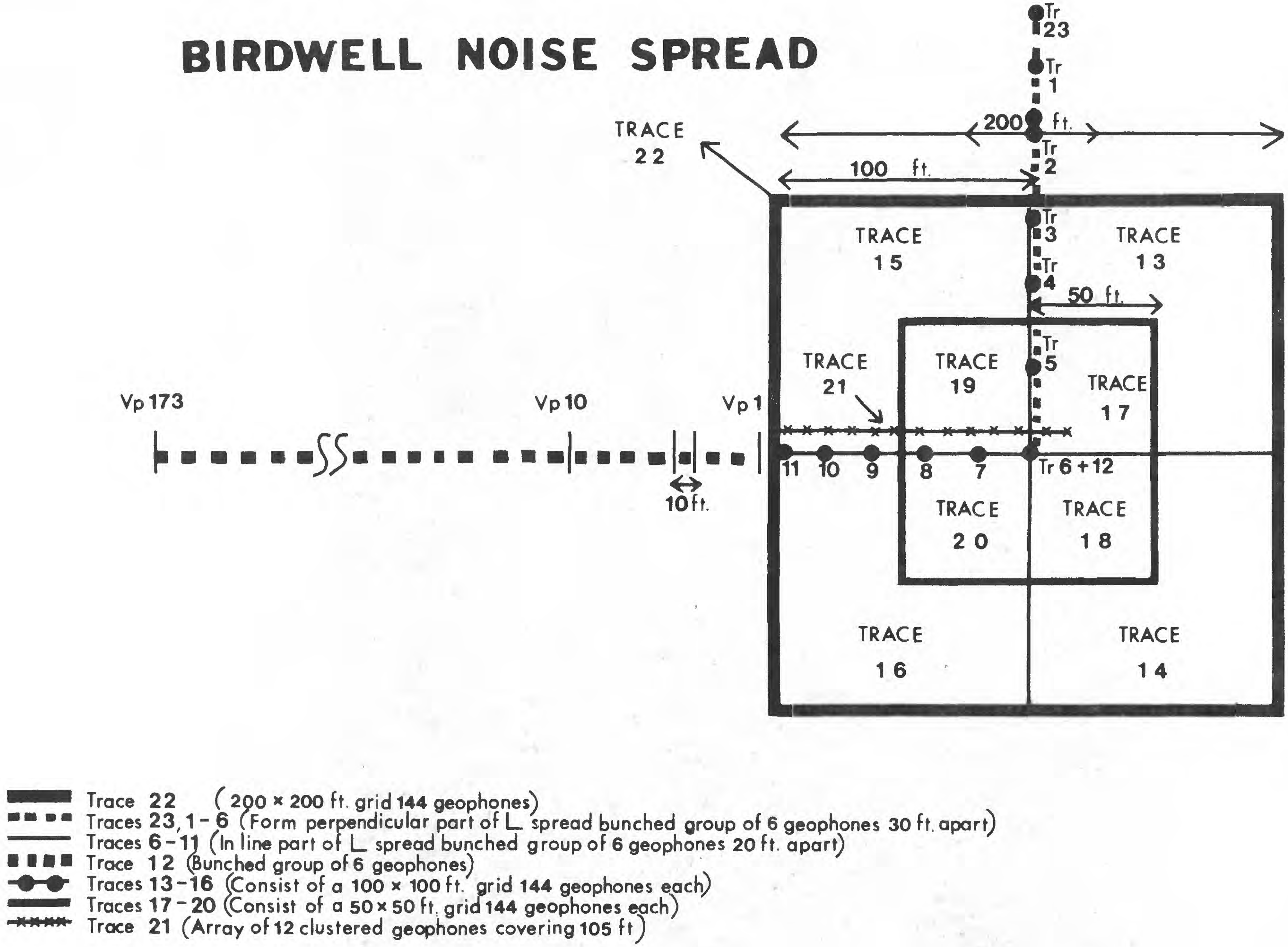
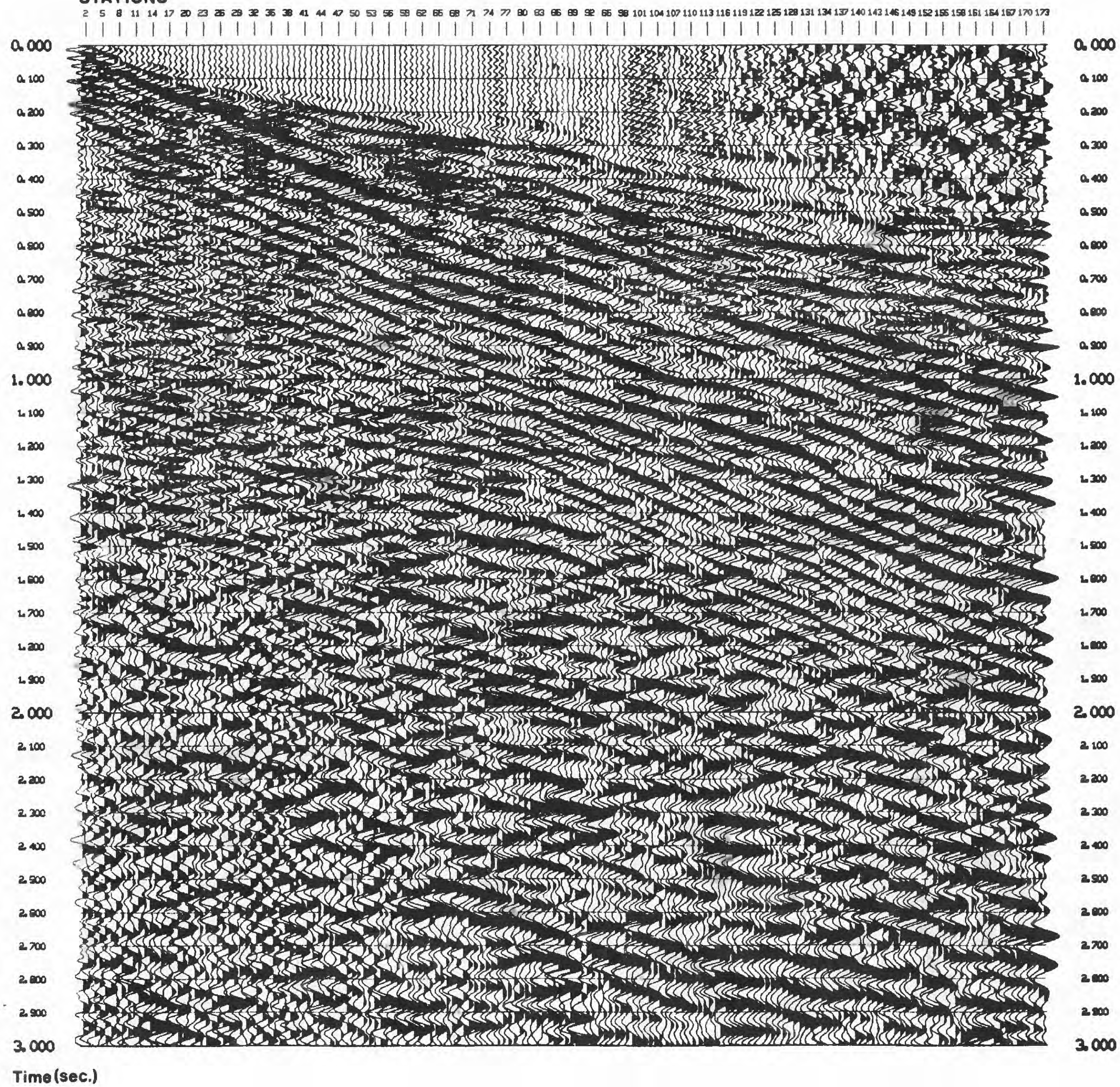


figure 2

200 BY 200 ARRAY NOISE SPREAD

TRACE 22, SECT. 5

FIGURE 3



BIRDWELL FIELD RECORD

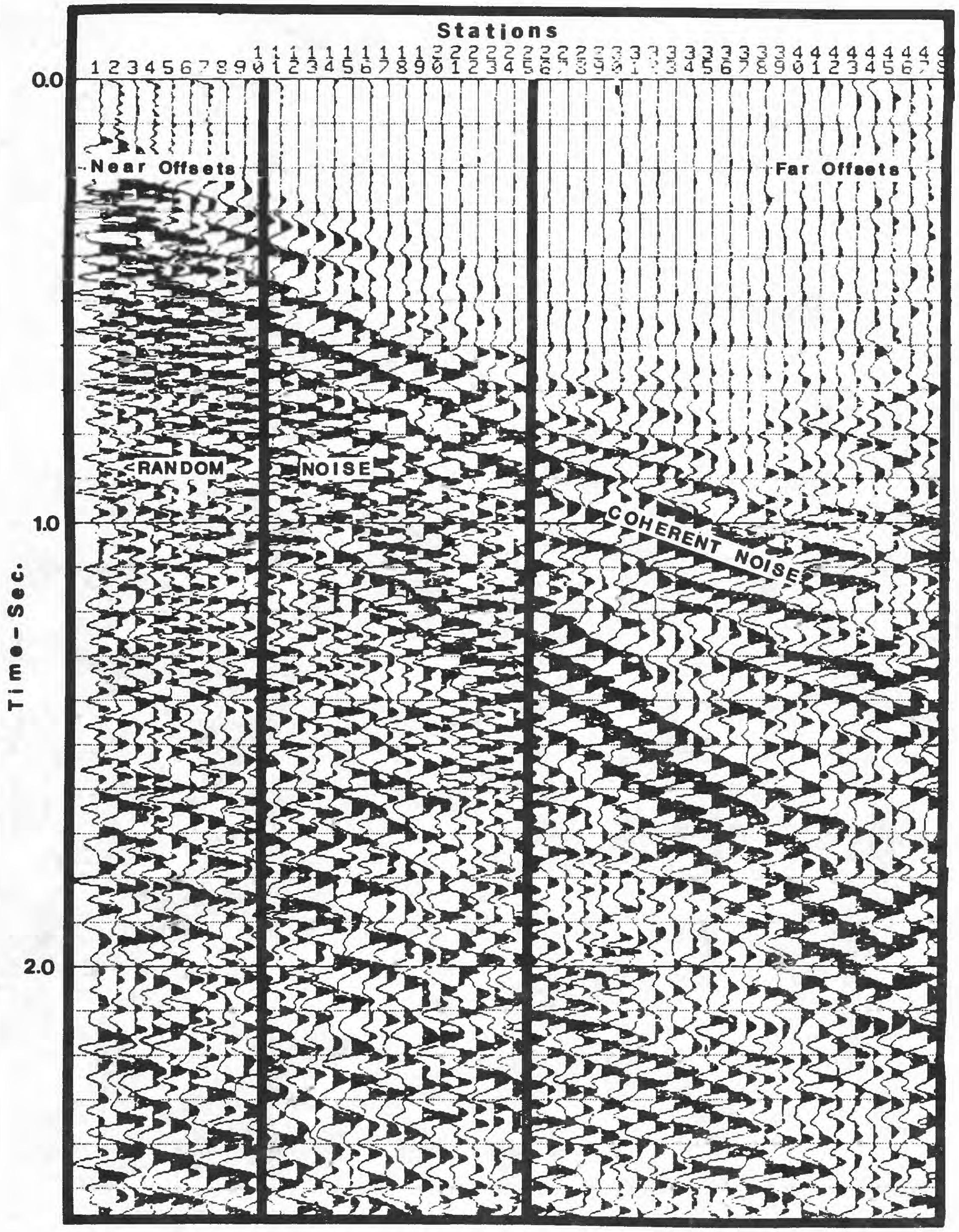


figure 4

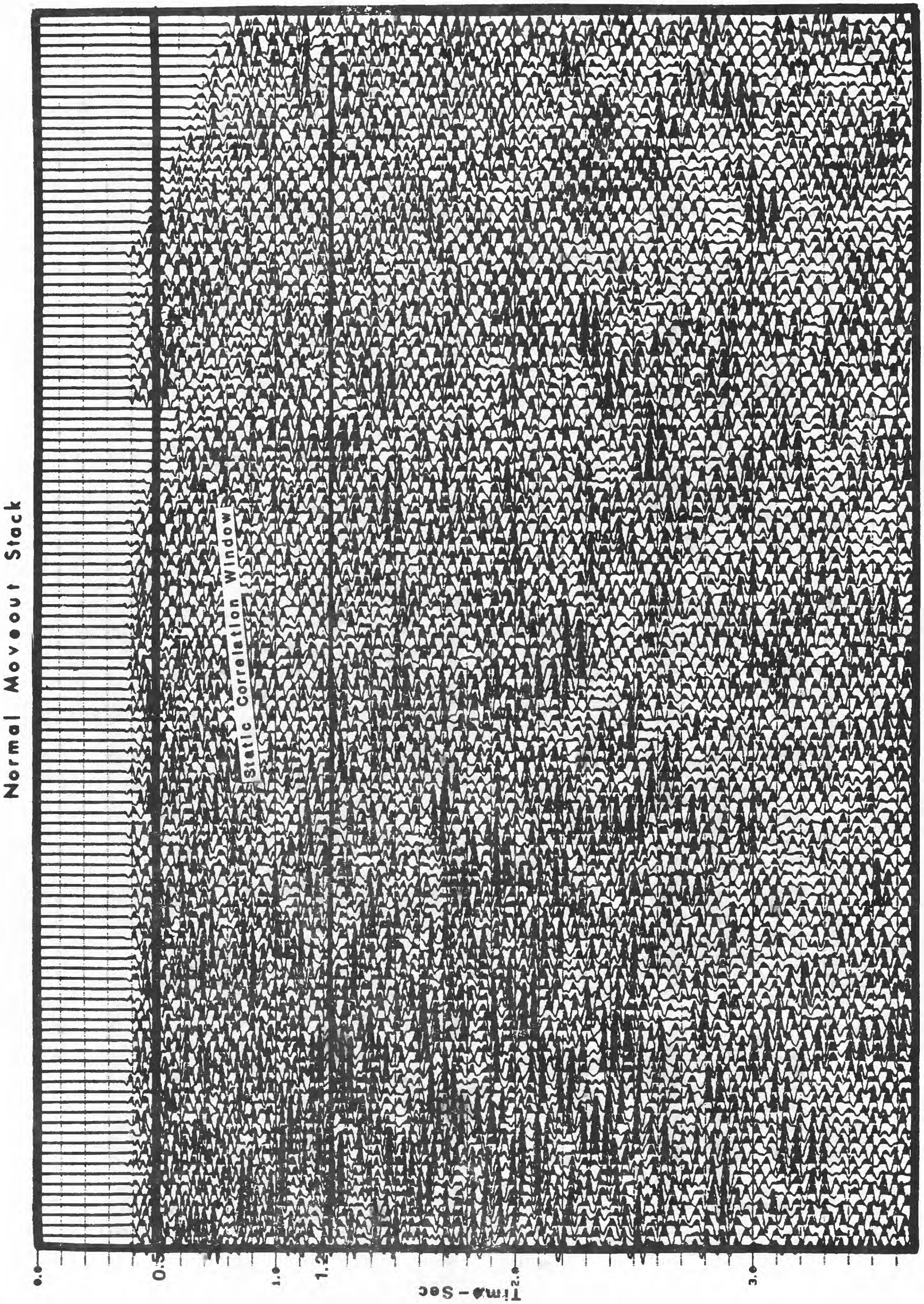

Normal Moveout Stack
Static Correlation Window
0.
0.5
1.0
1.2
2.0
3.0
Time - Sec

figure 5

BIRDWELL SSC

Automatic Statics Stack

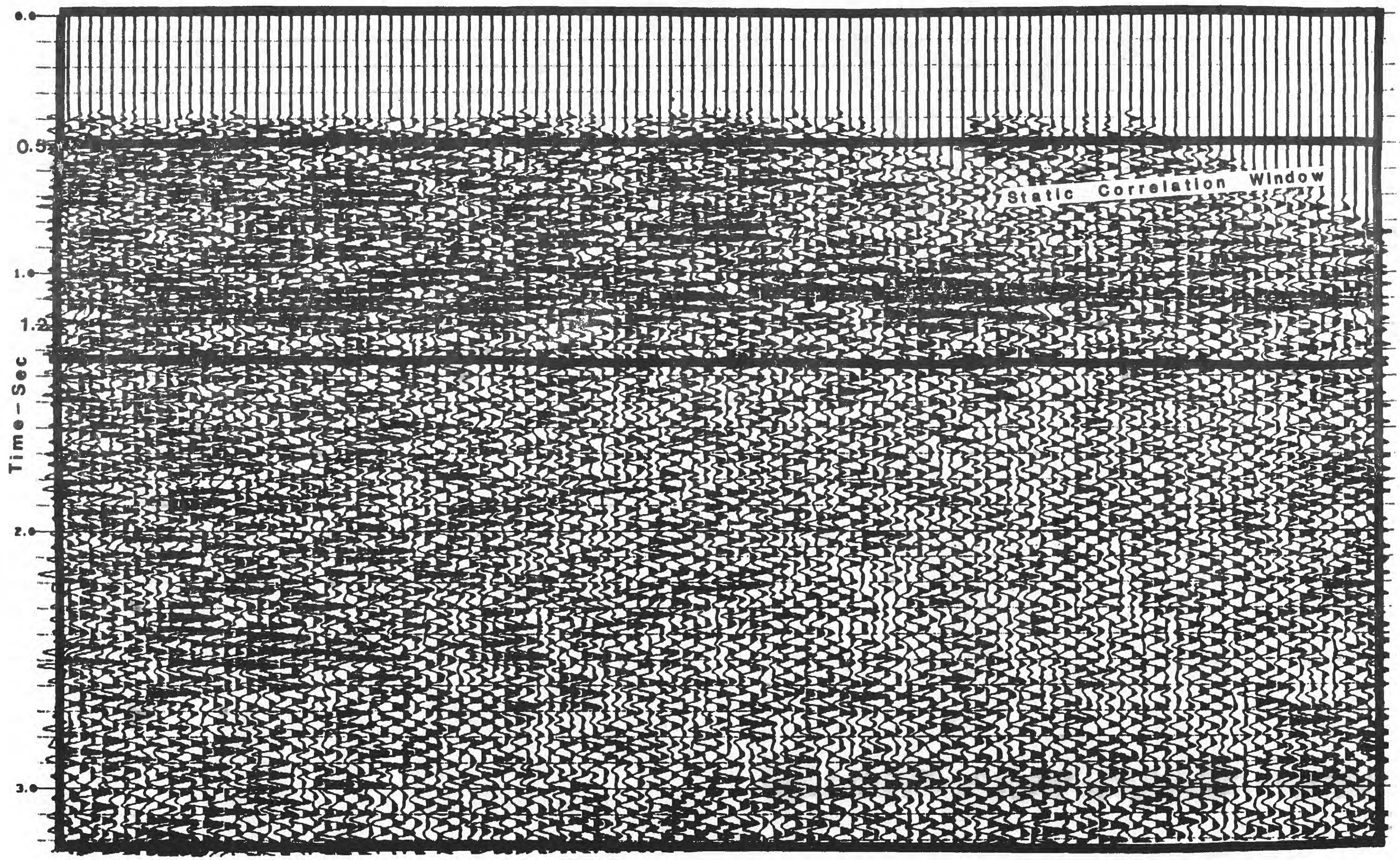


figure 6

BIRDWELL SSC

Velocity Filter Mute Stack

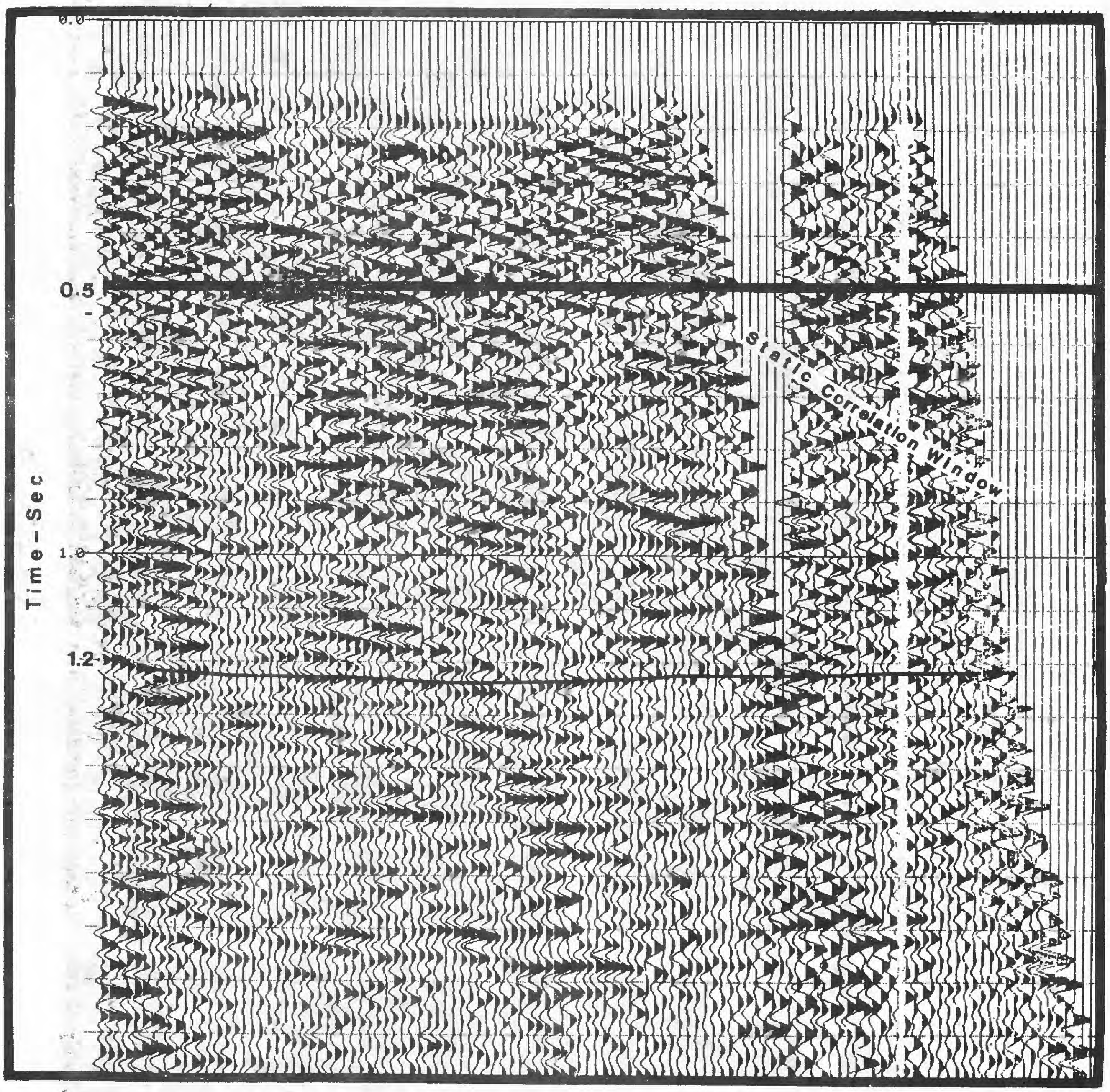


figure 7

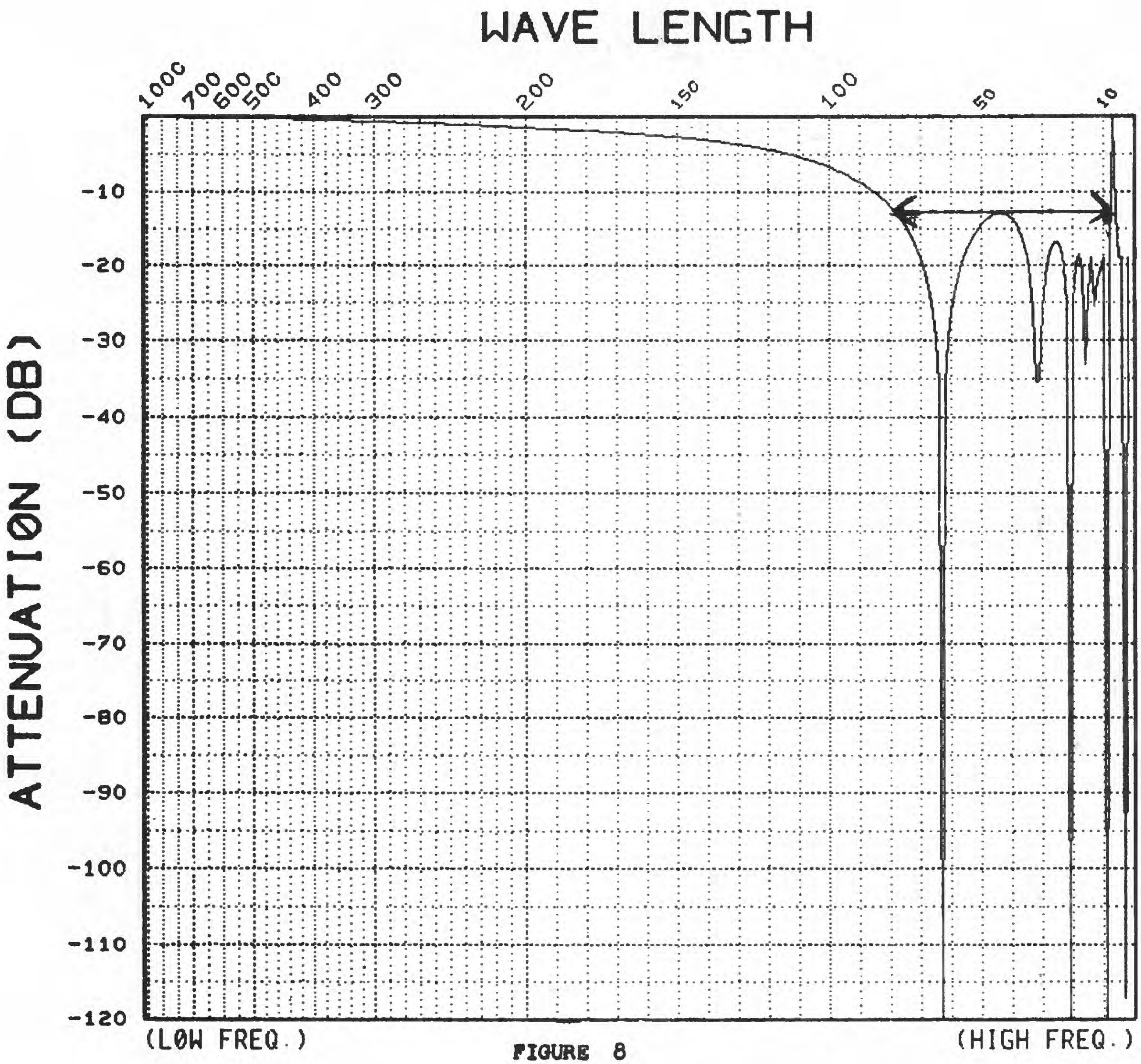


FIGURE 8

SPACING 7
LENGTH 56
WEIGHTS 1 1 1 1 1 1 1 1 1

POINTS 9
ELEMENTS 9

SPACING 55
LENGTH 0
WEIGHTS 1

POINTS 1
ELEMENTS 1

S/N IMPROVEMENT
(AMBIENT NOISE ATTENUATION POWER) 23 03 DB

The COLORADO SCHOOL of MINES COMBINED FIELD TECHNIQUE

TOTAL FIELD EFFORT 12 DB FOR BAND 10 TO 70

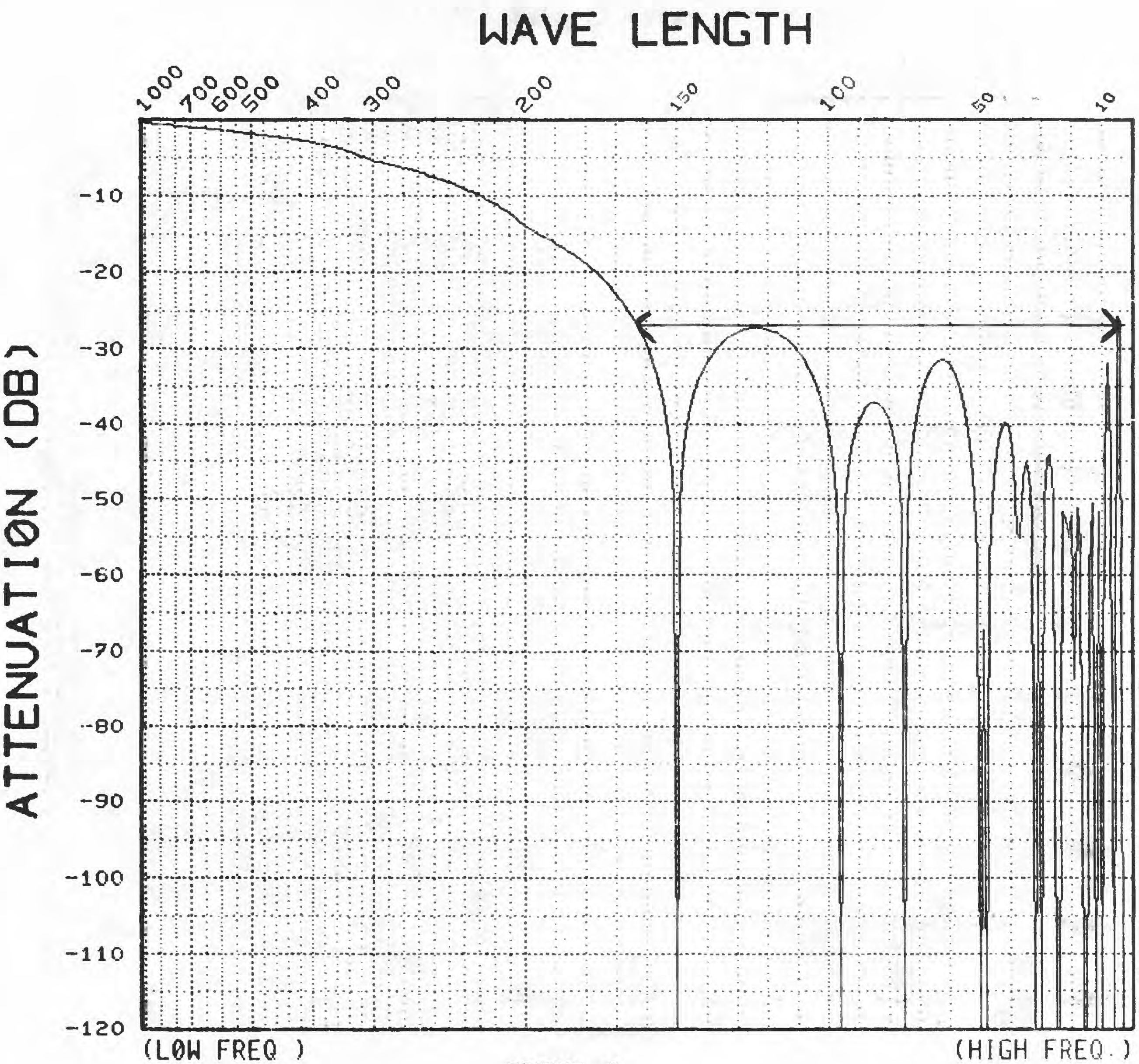


FIGURE 9

SPACING 5 — POINTS 30
LENGTH 145 — ELEMENTS 30
WEIGHTS 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

SPACING 8 — POINTS 12
LENGTH 88 — ELEMENTS 12
WEIGHTS 1 1 1 1 1 1 1 1 1 1 1 1

S/N IMPROVEMENT
(AMBIENT NOISE ATTENUATION POWER) 37 38 DB

BIRDWELL COMBINED FIELD TECHNIQUE

TOTAL FIELD EFFORT **29** DB FOR BAND **12** TO **160.**

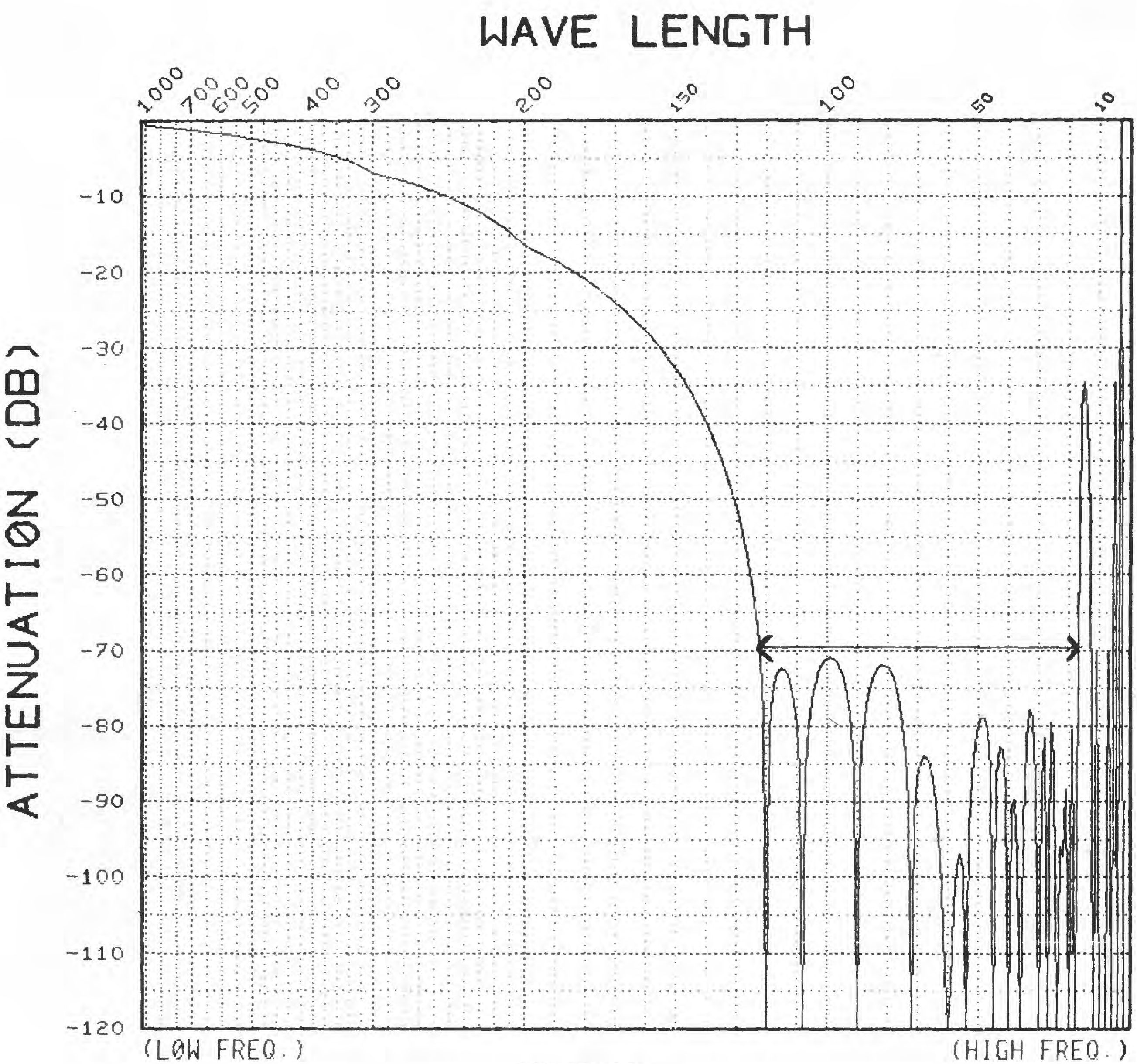


FIGURE 10

SPACING	12	PØINTS	14
LENGTH	156	ELEMENTS	54
WEIGHTS	1 2 3 4 5 6 6 6 6 5 4 3 2 1		

SPACING	15	PØINTS	15
LENGTH	210	ELEMENTS	96
WEIGHTS	1 2 4 6 81011121110 8 6 4 2 1		

S/N IMPRØVEMENT
(AMBIENT NØISE ATTENUATIØN PØWER) 30 35 DB

SEISMIC INTERNATIONAL RESEARCH/SEISDATA SERVICES COMBINED FIELD TECHNIQUE

(VIBRATOR SOURCE)

TØTAL FIELD EFFØRT **68** DB FØR BAND **18** TØ **122**

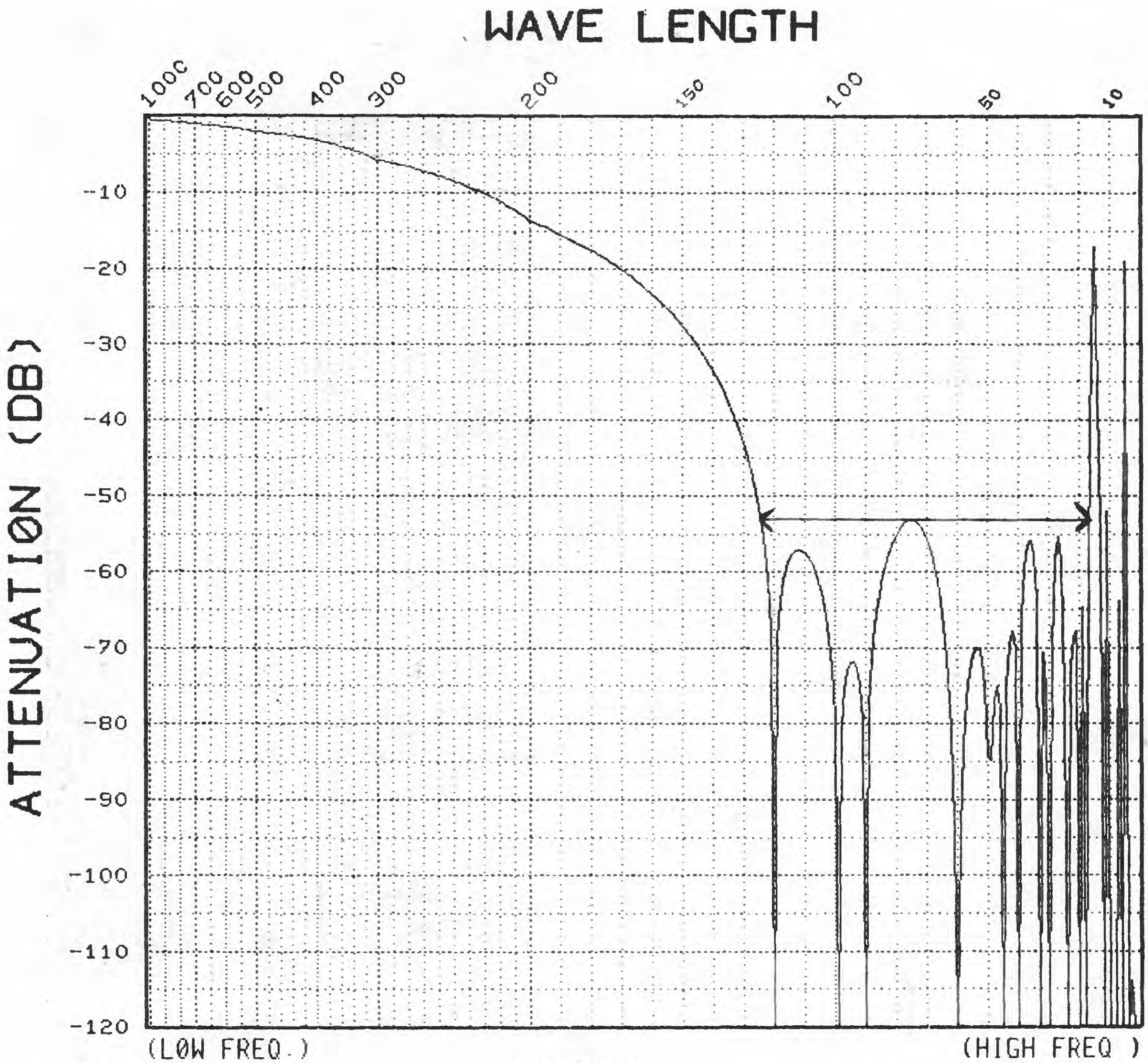


FIGURE 11

SPACING	9.	POINTS	11
LENGTH	88	ELEMENTS	11
WEIGHTS	1 1 1 1 1 1 1 1 1 1 1		

SPACING	15	POINTS	15
LENGTH	210	ELEMENTS	96
WEIGHTS	1 2 4 6 8 10 11 12 11 10 8 6 4 2 1		

S/N IMPROVEMENT
(AMBIENT NOISE ATTENUATION POWER) 25 78 DB

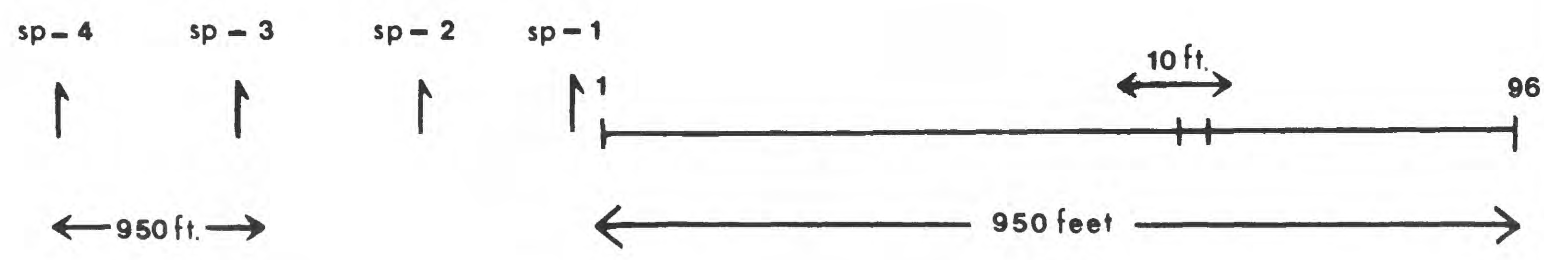
SEISMIC INTERNATIONAL RESEARCH/SEISDATA SERVICES COMBINED FIELD TECHNIQUE

(PRIMACORD SOURCE)

TOTAL FIELD EFFORT 53 DB FOR BAND 18 TO 122

SEISMIC INTERNATIONAL RESEARCH / SEISDATA SERVICES

In Line Noise Spread Configuration



96 Recording stations @ 10 feet

12 Bunched geophones per station

Shot points separated by 950 feet

figure 12

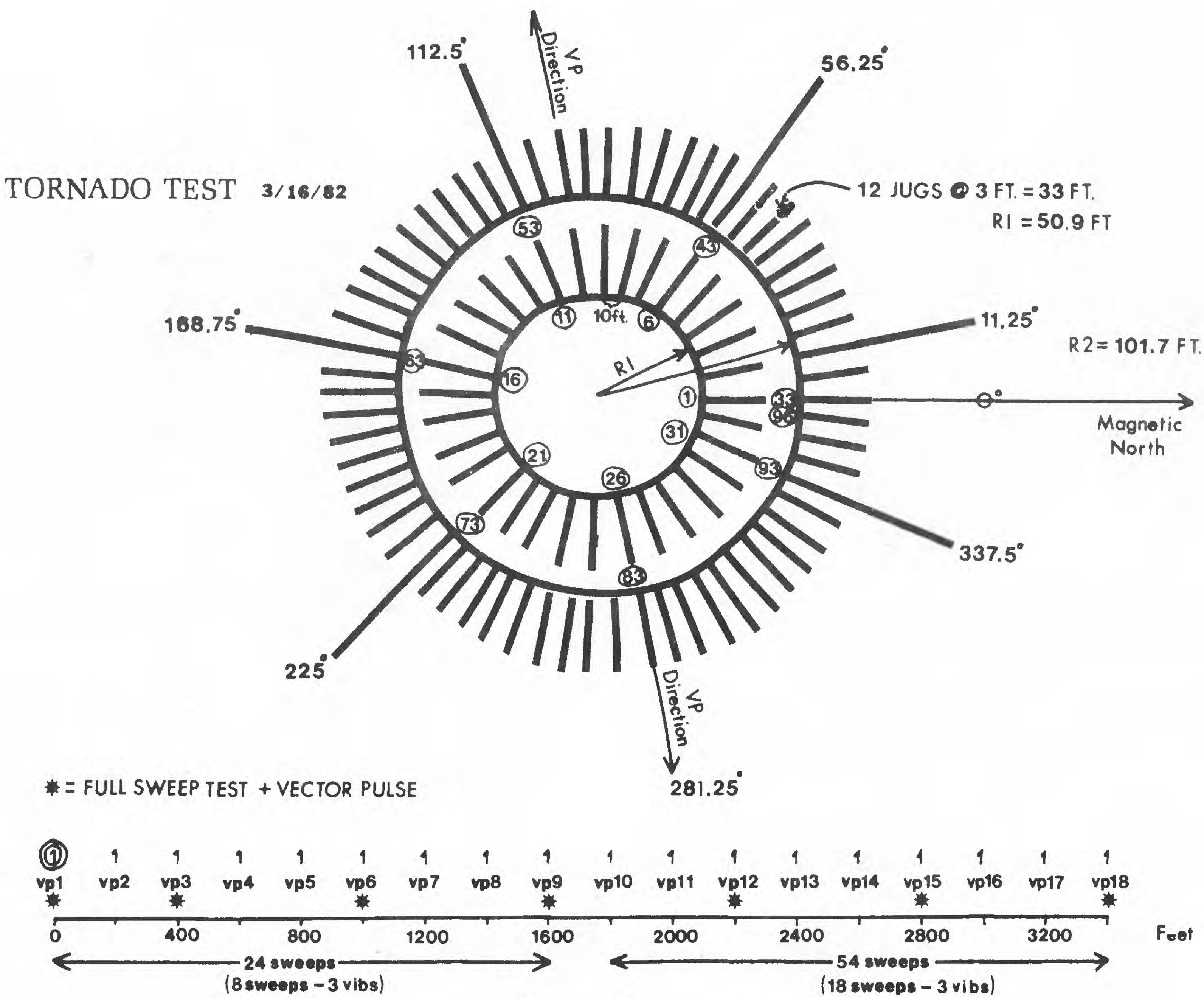

TORNADO TEST 3/16/82
112.5°
VP Direction
56.25°
12 JUGS @ 3 FT. = 33 FT.
RI = 50.9 FT
168.75°
10ft.
RI
11.25°
R2 = 101.7 FT.
0°
Magnetic North
337.5°
225°
VP Direction
281.25°
✱ = FULL SWEEP TEST + VECTOR PULSE
vp1 vp2 vp3 vp4 vp5 vp6 vp7 vp8 vp9 vp10 vp11 vp12 vp13 vp14 vp15 vp16 vp17 vp18
0 400 800 1200 1600 2000 2400 2800 3200
Feet
24 sweeps
(8 sweeps - 3 vibs)
54 sweeps
(18 sweeps - 3 vibs)

Figure 13

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

(IN-LINE SPREAD PRIMACORD)

FIELD ACQUISITION

BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
LOW-CUT FILTER OUT HIGH CUT FILTER 125 HZ
96 STATIONS AT 10FT INTERVAL(IN-LINE NOISE SPREAD)
12 LOS1000 10HZ GEOPHONES (3FT INTERVAL) PER STA

SP-101 SP-102 3FT PRIMACORD AT 4FT DEPTH 6 HOLES
SP-103 SP-104 3FT PRIMACORD AT 4FT DEPTH 11 HOLES

RECORD 1 @ SP-101 10 FEET TO 960 FEET OFFSET
RECORD 2 @ SP-102 970 FEET TO 1920 FEET OFFSET
RECORD 3 @ SP-103 1930 FEET TO 2880 FEET OFFSET
RECORD 4 @ SP-104 2890 FEET TO 3840 FEET OFFSET

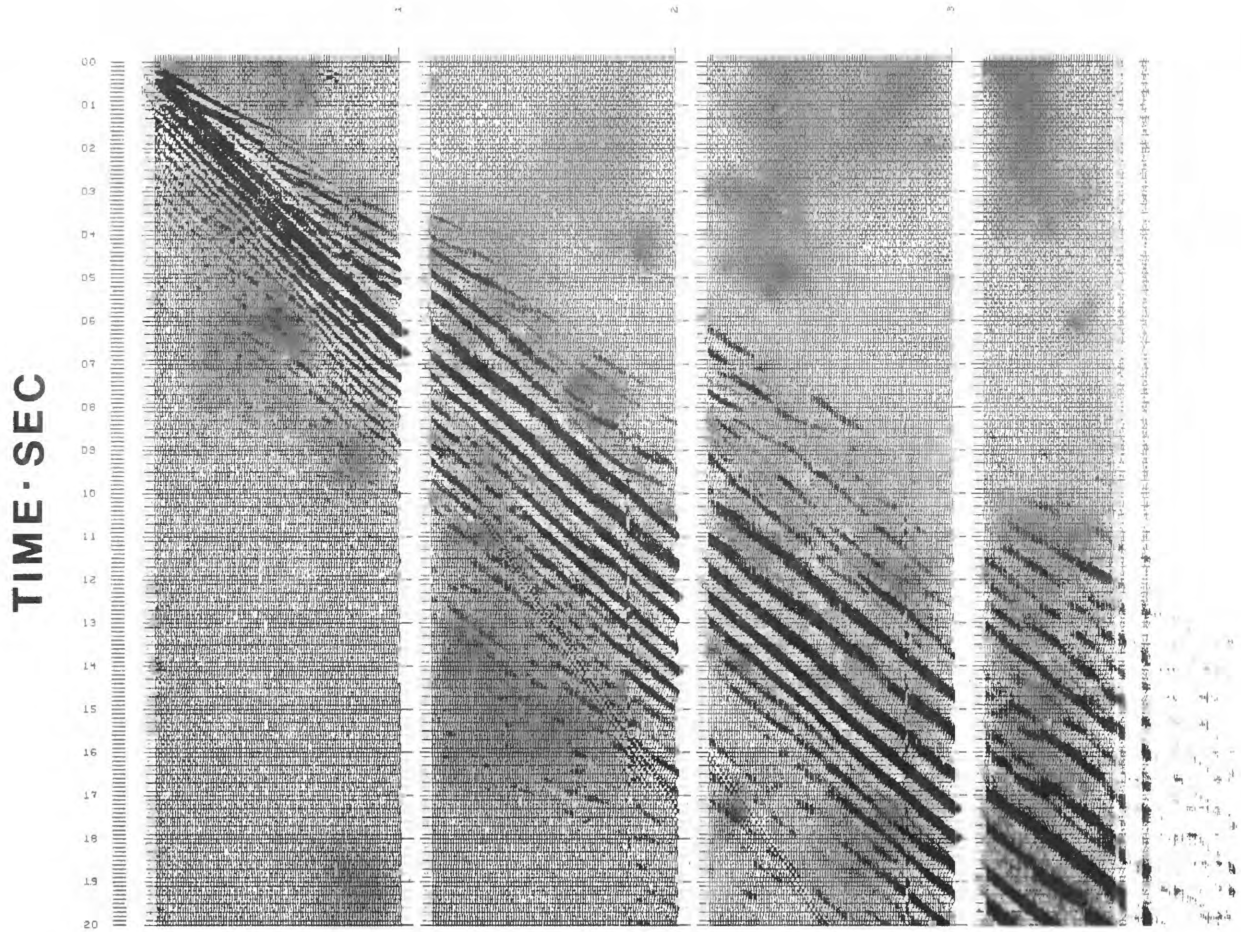


FIGURE 14

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

(IN-LINE SPREAD 10-56 HZ SWEEP)

FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
LOW CUT FILTER OUT HIGH CUT FILTER 125 HZ
96 STATIONS AT 10FT INTERVAL(IN-LINE NOISE SPREAD)
12 LDS1000 10HZ GEOPHONES (3FT INTERVAL) PER STA

VP-101 VP-102 3 VIBRATORS 8 SWEEPS/VIBRATOR
VP-103 VP-104 3 VIBRATORS 18 SWEEPS/VIBRATOR
18 SECOND RECORD 14 SECOND SWEEP 10-56 HZ

RECORD 1 @ VP-101 10 FEET TO 960 FEET OFFSET
RECORD 2 @ VP-102 970 FEET TO 1920 FEET OFFSET
RECORD 3 @ VP-103 1930 FEET TO 2900 FEET OFFSET
RECORD 4 @ VP-104 2890 FEET TO 3840 FEET OFFSET

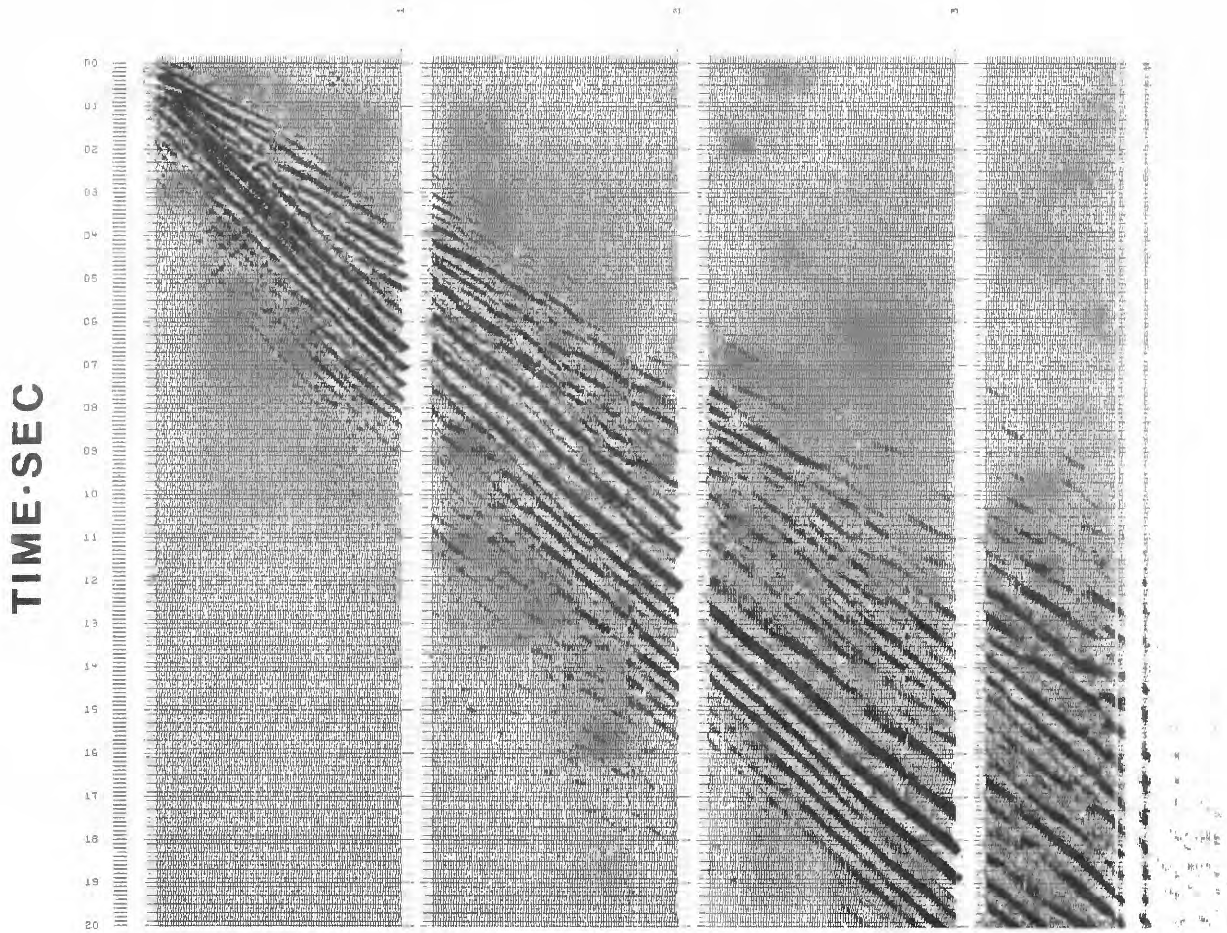


FIGURE 15

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

(IN-LINE SPREAD 16-72 HZ SWEEP)

FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
LOW-CUT FILTER OUT HIGH-CUT FILTER 125 HZ
96 STATIONS AT 10FT INTERVAL (IN-LINE NOISE SPREAD)
12 LDS1000 10HZ GEOPHONES (3FT INTERVAL) PER STA

VP-101 VP-102 3 VIBRATORS 8 SWEEPS/VIBRATOR
VP-103 VP-104 3 VIBRATORS 16 SWEEPS/VIBRATOR
18 SECOND RECORD 14 SECOND SWEEP 16-72 HZ

RECORD 1 @ VP-101 10 FEET TO 960 FEET OFFSET
RECORD 2 @ VP-102 970 FEET TO 1920 FEET OFFSET
RECORD 3 @ VP-103 1930 FEET TO 2880 FEET OFFSET
RECORD 4 @ VP-104 2890 FEET TO 3840 FEET OFFSET

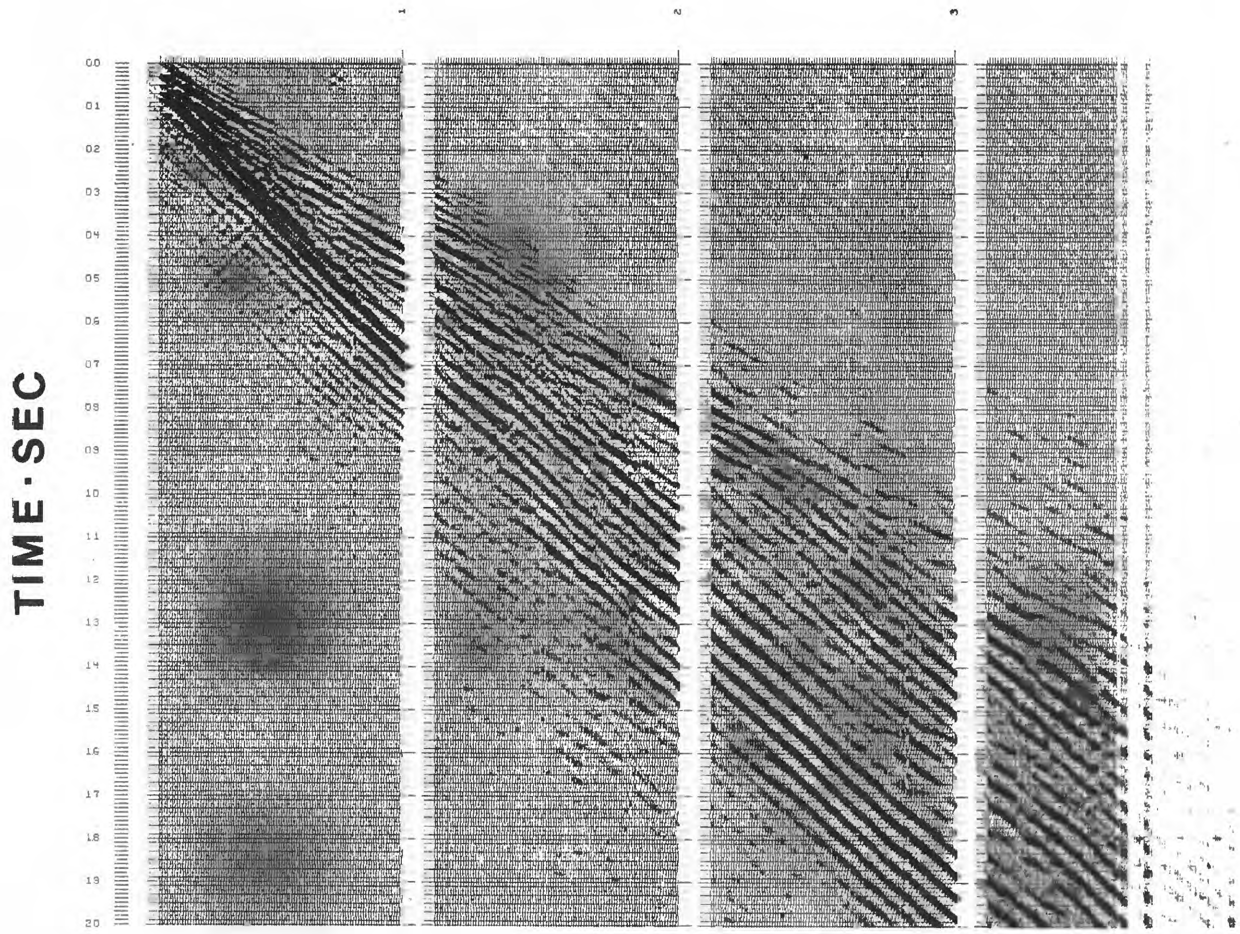
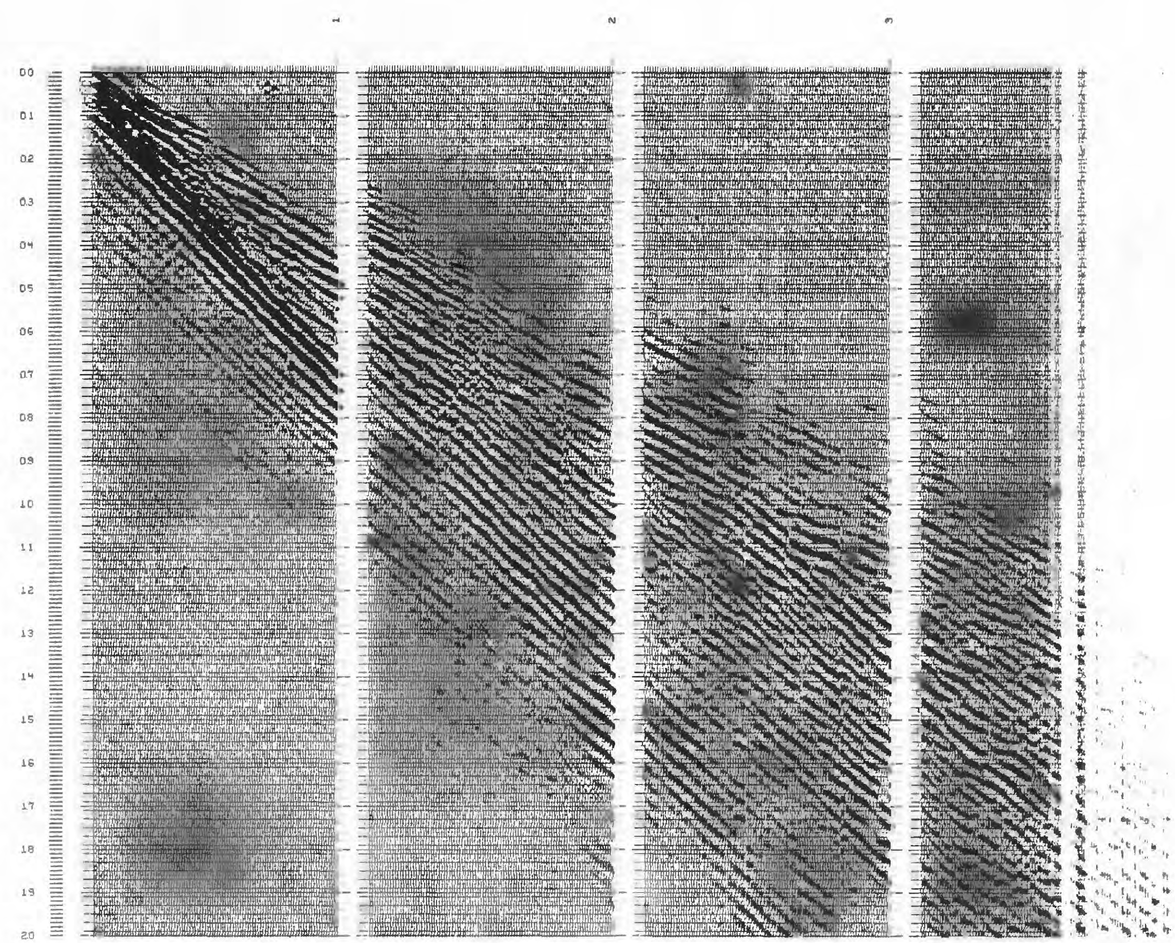


FIGURE 16



DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

[IN-LINE SPREAD 22-84 HZ SWEEP]

FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
LOW-CUT FILTER OUT HIGH CUT FILTER 125 HZ
96 STATIONS AT 10FT INTERVAL(IN-LINE NOISE SPREAD)
12 LOS1000 10HZ GEOPHONES (3FT INTERVAL) PER STA

VP-101 VP-102 3 VIBRATORS 8 SWEEPS/VIBRATOR
VP-103 VP-104 3 VIBRATORS 10 SWEEPS/VIBRATOR
10 SECOND RECORD 14 SECOND SWEEP 22-84 HZ

RECORD 1 @ VP-101 10 FEET TO 960 FEET OFFSET
RECORD 2 @ VP-102 970 FEET TO 1920 FEET OFFSET
RECORD 3 @ VP-103 1930 FEET TO 2880 FEET OFFSET
RECORD 4 @ VP-104 2890 FEET TO 3840 FEET OFFSET

FIGURE 17

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

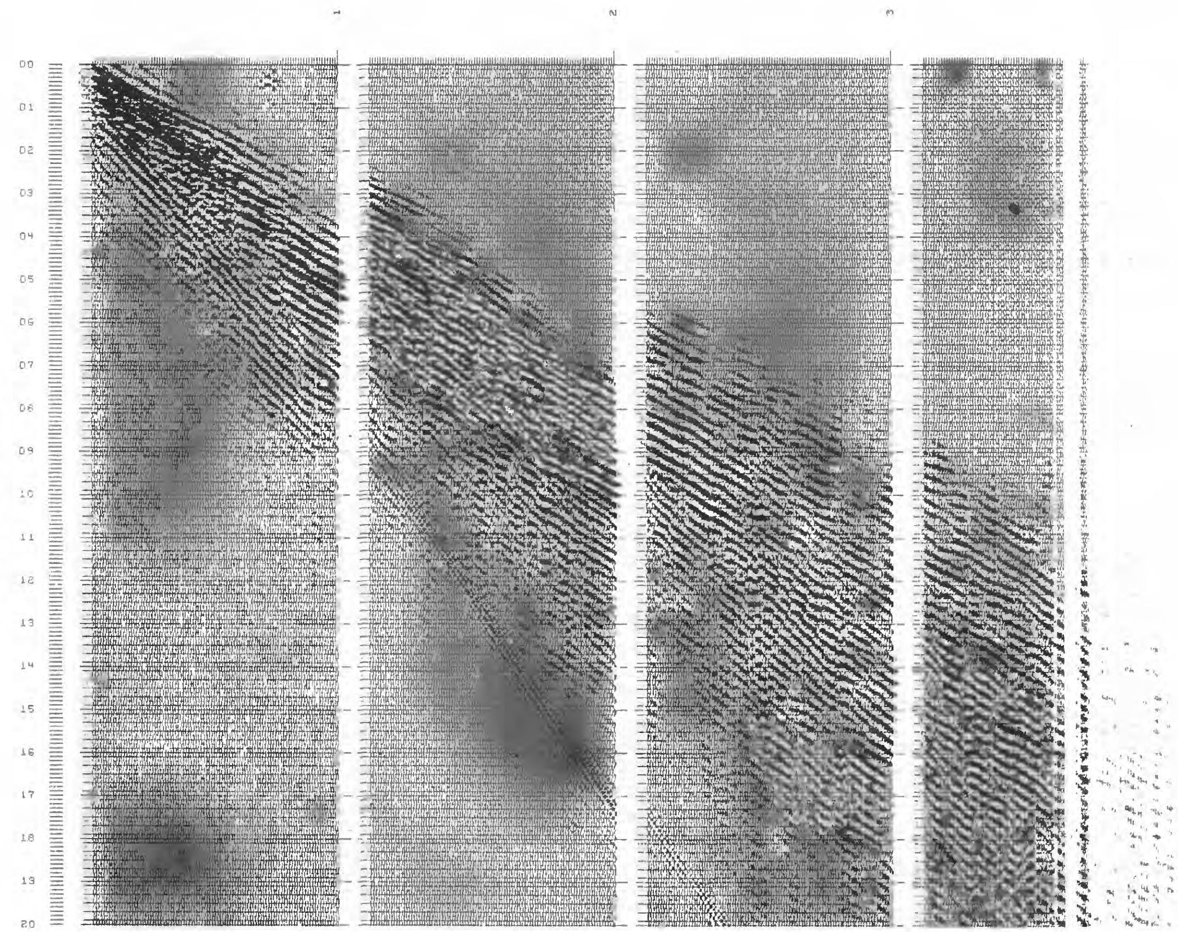
IN-LINE SPREAD 32-96 HZ SWEEP

FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
LOW CUT FILTER OUT HIGH CUT FILTER 125 HZ
96 STATIONS AT 10FT INTERVAL (IN-LINE NOISE SPREAD)
12 LDS1000 10HZ GEOPHONES (3FT INTERVAL) PER STA

VP-101 VP-102 3 VIBRATORS 8 SWEEPS/VIBRATOR
VP-103 VP-104 3 VIBRATORS 8 SWEEPS/VIBRATOR
10 SECOND RECORD 14 SECOND SWEEP 32-96 HZ

RECORD 1 @ VP-101 10 FEET TO 960 FEET OFFSET
RECORD 2 @ VP-102 970 FEET TO 1920 FEET OFFSET
RECORD 3 @ VP-103 1930 FEET TO 2880 FEET OFFSET
RECORD 4 @ VP-104 2890 FEET TO 3840 FEET OFFSET

FIGURE 18



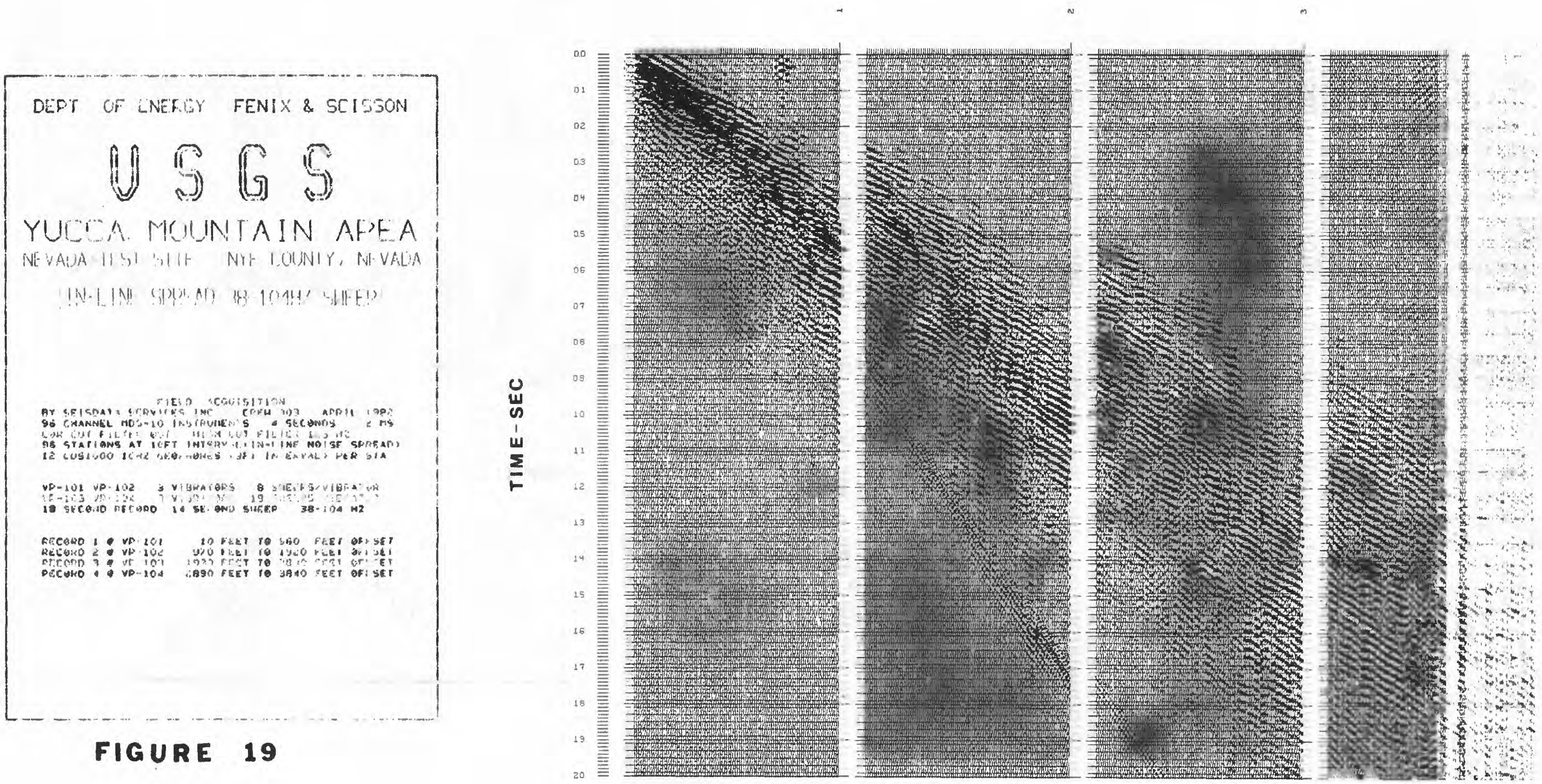

DEPT OF ENERGY FENIX & SCISSON
U S G S
YUCCA MOUNTAIN AREA
IN-LINE SPREAD 38-104HZ SWEEP
FIELD ACQUISITION
96 CHANNEL MDS-10 INSTRUMENTS
96 STATIONS AT 10FT INTERV (IN-LINE NOISE SPREAD)
VP-101 VP-102 3 VIBRATORS
18 SECOND RECORD 14 SECOND SWEEP 38-104 HZ
RECORD 1 @ VP-101 10 FEET TO 960 FEET OFFSET
RECORD 4 @ VP-104 2890 FEET TO 3840 FEET OFFSET
TIME-SEC
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
1
2
3

FIGURE 19

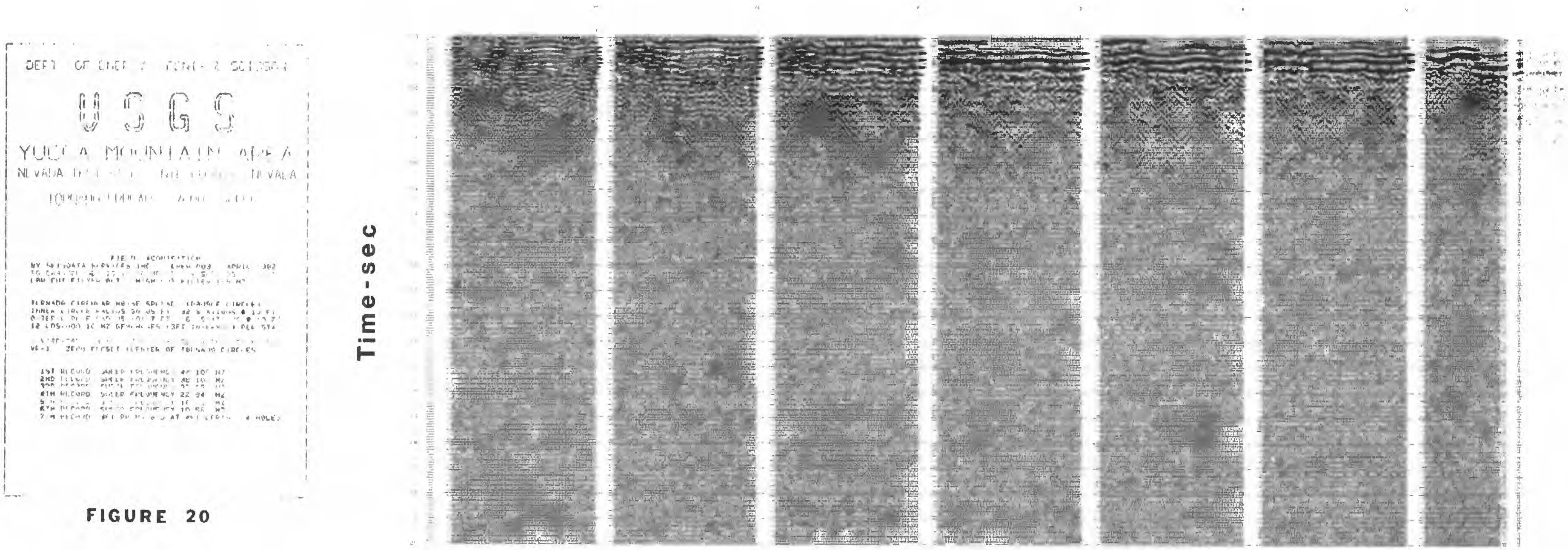

USGS
YUCCA MOUNTAIN AREA
4TH RECORD SWEEP FREQUENCY 22 94 HZ
Time-sec

FIGURE 20

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

TORNADO SPREAD 400' OFFSET

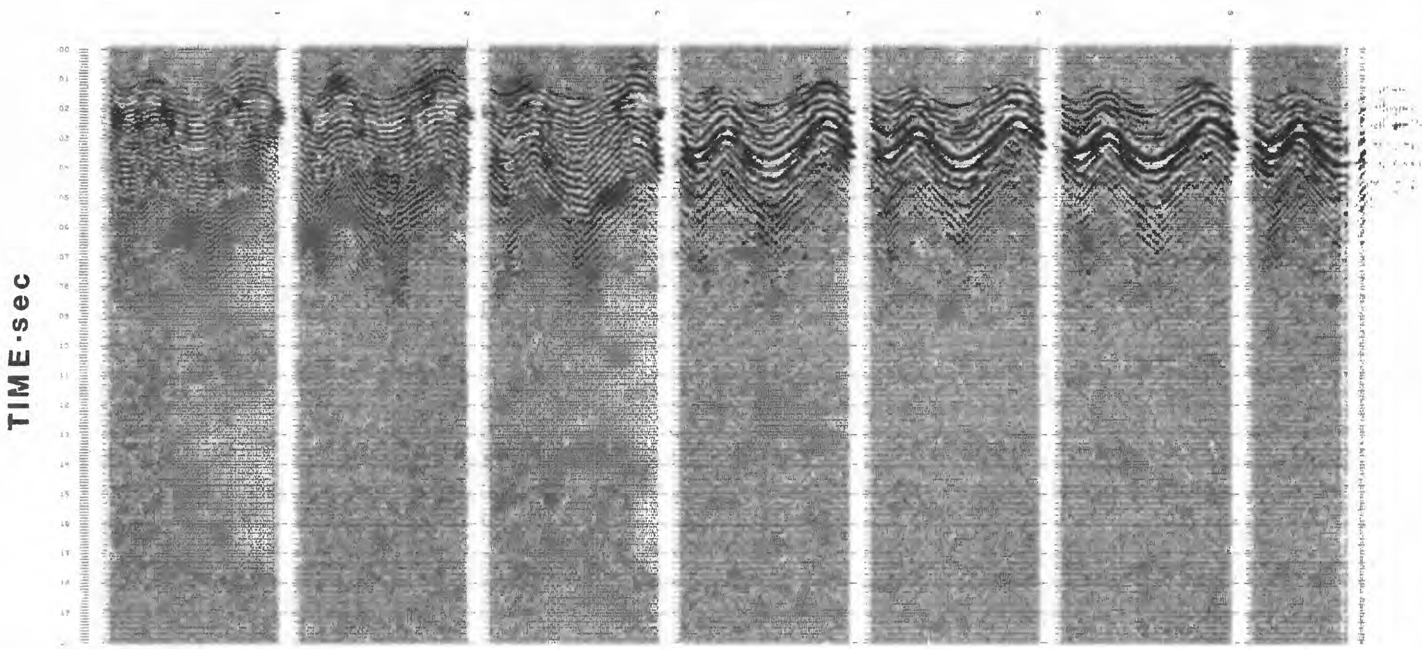
FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS 10 INSTRUMENTS 4 SECONDS 2 MS
LOW-CUT FILTER OUT HIGH CUT FILTER 125 HZ

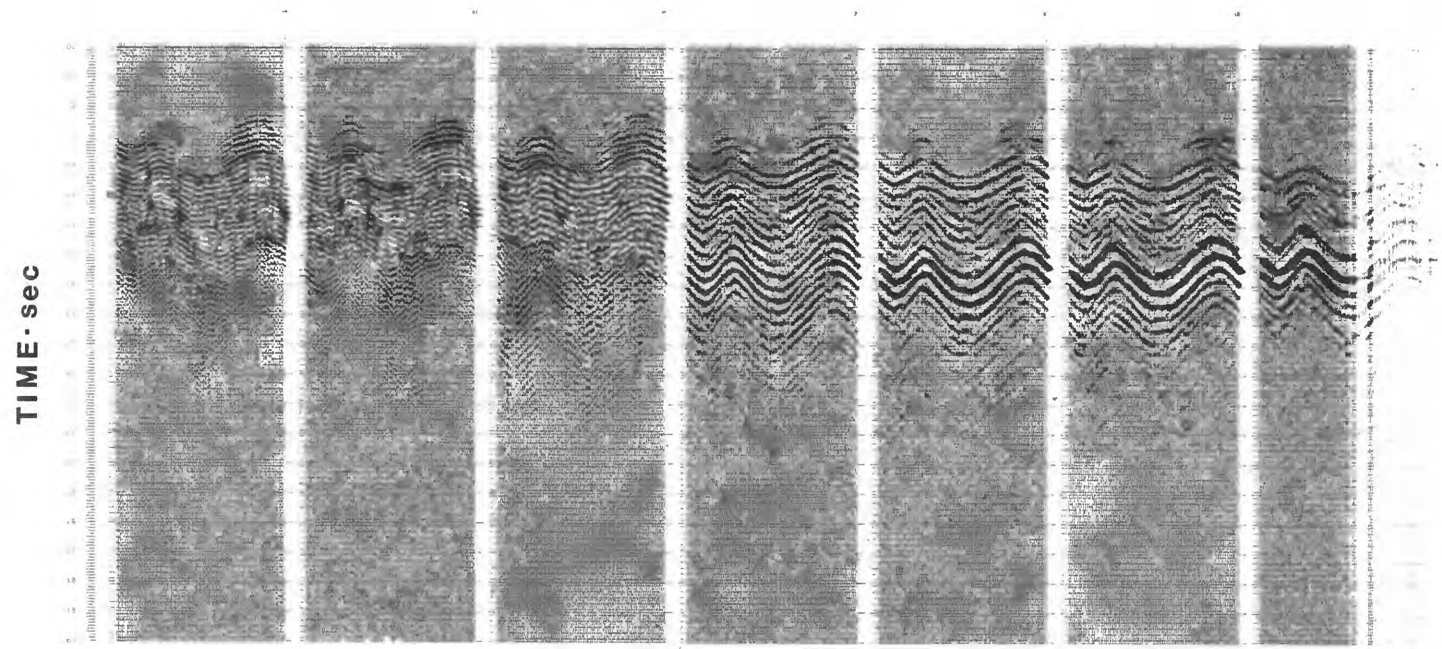
TORNADO CIRCULAR NW-SE SPREAD (DOUBLE CIRCLE)
INNER CIRCLE RADIUS 50.85 FT 32 STATIONS @ 10 FT
OUTER CIRCLE RADIUS 101.7 FT 64 STATIONS @ 10 FT
12 LOS1000 10 HZ GEOPHONES (3FT INTERVAL) PER STA

1 VIBRATOR 18 SEC RECORD 14 SEC SWEEP 24 SWEEPS
VP-3 400 FT OFFSET FROM CENTER OF TORNADO SPREAD

1ST RECORD SWEEP FREQUENCY 44-108 HZ
2ND RECORD SWEEP FREQUENCY 40-[illegible] HZ
3RD RECORD SWEEP FREQUENCY 32-96 HZ
4TH RECORD SWEEP FREQUENCY 22-84 HZ
5TH RECORD SWEEP FREQUENCY 16-72 HZ
6TH RECORD SWEEP FREQUENCY 10-56 HZ
7TH RECORD 3FT PRIMACORD AT 4FT DEPTH 6 HOLES

FIGURE 21





DEPT OF ENERGY [illegible] & [illegible]

USGS

YUCCA MOUNTAIN AREA

NEVADA [illegible]

[illegible]

FIELD ACQUISITION
BY [illegible] SERVICES INC CREW 003 APRIL 1982
[illegible]
[illegible]

TORNADO CIRCULAR [illegible] SPREAD [illegible]
INNER CIRCLE RADIUS [illegible] 32 STATIONS [illegible]
OUTER CIRCLE [illegible] 64 STATIONS [illegible]
[illegible] GEOPHONES [illegible] PER STA

[illegible]
VP-6 [illegible] CENTER OF TORNADO SPREAD

1ST RECORD SWEEP FREQUENCY 34-106 HZ
[illegible]
[illegible]
4TH RECORD SWEEP FREQUENCY 22-94 HZ
[illegible]
[illegible]
7TH RECORD [illegible] 6 HOLES

FIG 22

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY NEVADA

TORNADO SPREAD 1600 OFFSET

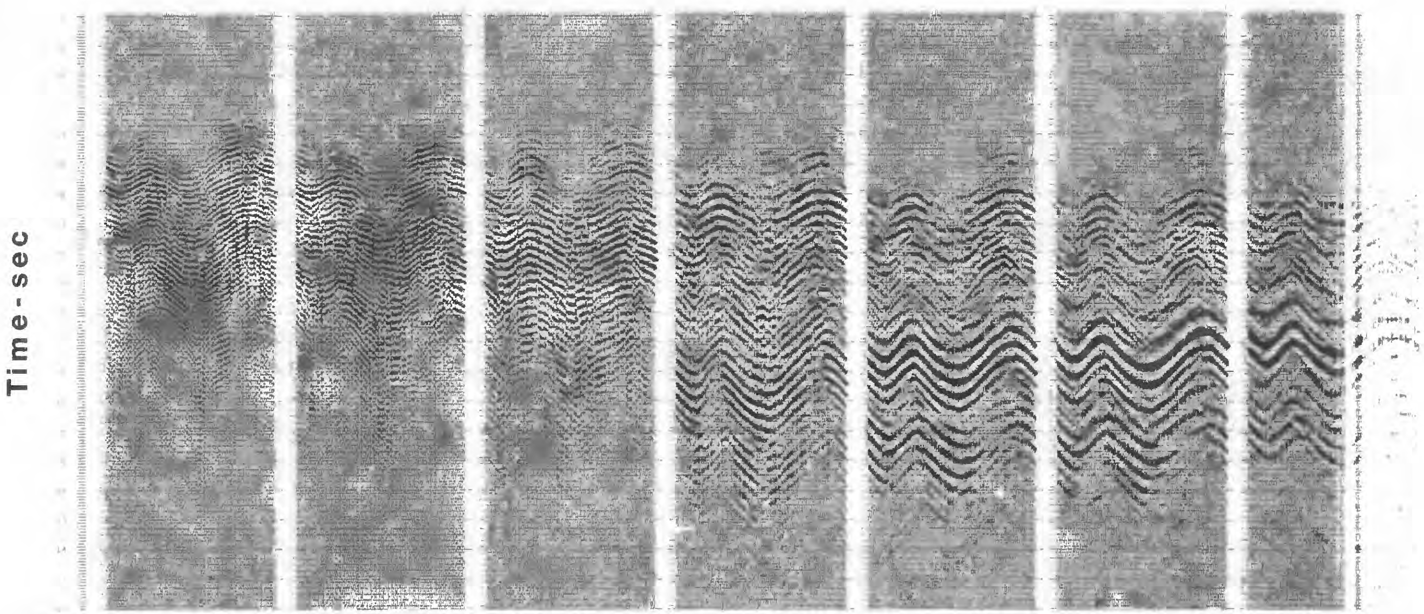
FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL MDS-10 [illegible] 4 SECONDS 2 MS
LOW-CUT FILTER OUT HIGH-CUT FILTER 125 HZ

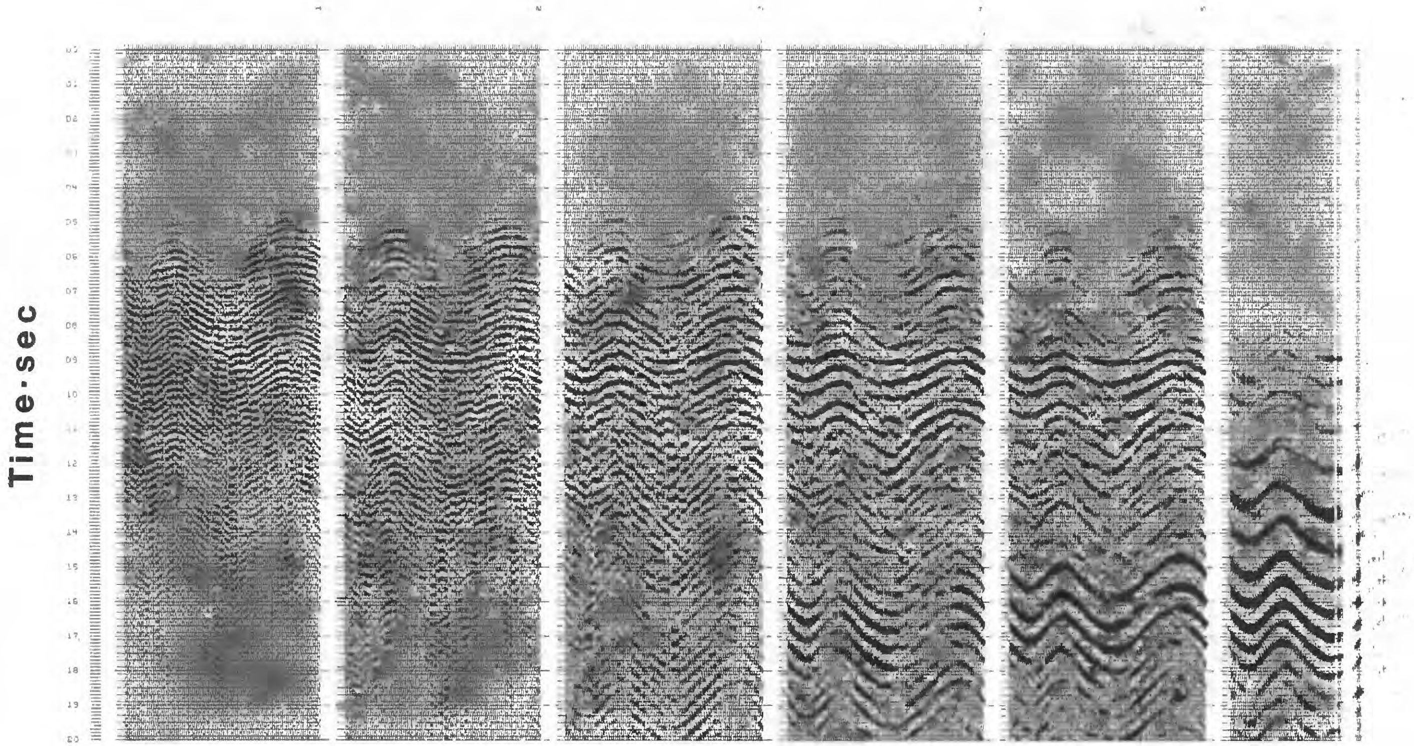
TORNADO CIRCULAR NOISE SPREAD (DOUBLE CIRCLE)
INNER CIRCLE RADIUS 50.85 FT 32 STATIONS @ 10 FT
OUTER CIRCLE RADIUS 101.7 FT 64 STATIONS @ 10 FT
12 LRS1000 10 HZ GEOPHONES (3FT INTERVAL) PER STA

1 VIBRATOR [illegible] SEC RECORD 14 SEC SWEEP 24 SWEEPS
VP-9 1600FT OFFSET FROM CENTER OF TORNADO SPREAD

1ST RECORD SWEEP FREQUENCY 44-108 HZ
2ND RECORD SWEEP FREQUENCY 38-104 HZ
3RD RECORD SWEEP FREQUENCY 32-96 HZ
4TH RECORD SWEEP FREQUENCY 22-84 HZ
5TH RECORD SWEEP FREQUENCY 16-72 HZ
6TH RECORD SWEEP FREQUENCY 10-58 HZ
7TH RECORD 3FT PRIMACORD AT 4FT DEPTH 6 HOLES

FIG 23





DEPT OF ENERGY ... & ...

USGS

YUCCA MOUNTAIN AREA

NEVADA ... COUNTY, NEVADA

TORNADO SPREAD ... OFFSET

FIELD ACQUISITION
BY SEISDATA SERVICES INC ... APRIL 1982
96 CHANNEL ... INSTRUMENTS
LOW-CUT FILTER ... HIGH-CUT FILTER 125 HZ

TORNADO CIRCULAR NOISE SPREAD (DOUBLE CIRCLE)
INNER CIRCLE RADIUS ... 32 STATIONS
OUTER CIRCLE ...
12 LRS1000 10 HZ GEOPHONES (... INTERVAL) PER STA

3 VIBRATORS ... 54 TOTAL ...
18 SECOND RECORD LENGTH 14 SECOND VIBRATOR SWEEP
VP-12 ... OFFSET FROM CENTER OF TORNADO SPREAD

1ST RECORD SWEEP FREQUENCY 38-... HZ
2ND RECORD SWEEP FREQUENCY ...
3RD RECORD SWEEP FREQUENCY 22-84 HZ
4TH RECORD SWEEP FREQUENCY ...
5TH RECORD SWEEP FREQUENCY 10-56 HZ
6TH RECORD ... AT ... 11 HOLES

FIG 24

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

TORNADO SPREAD 2800' OFFSET

FIELD ACQUISITION
BY SEISDATA SERVICES INC CREW 003 APRIL 1982
96 CHANNEL
LOW-CUT FILTER OUT HIGH-CUT FILTER 125 HZ

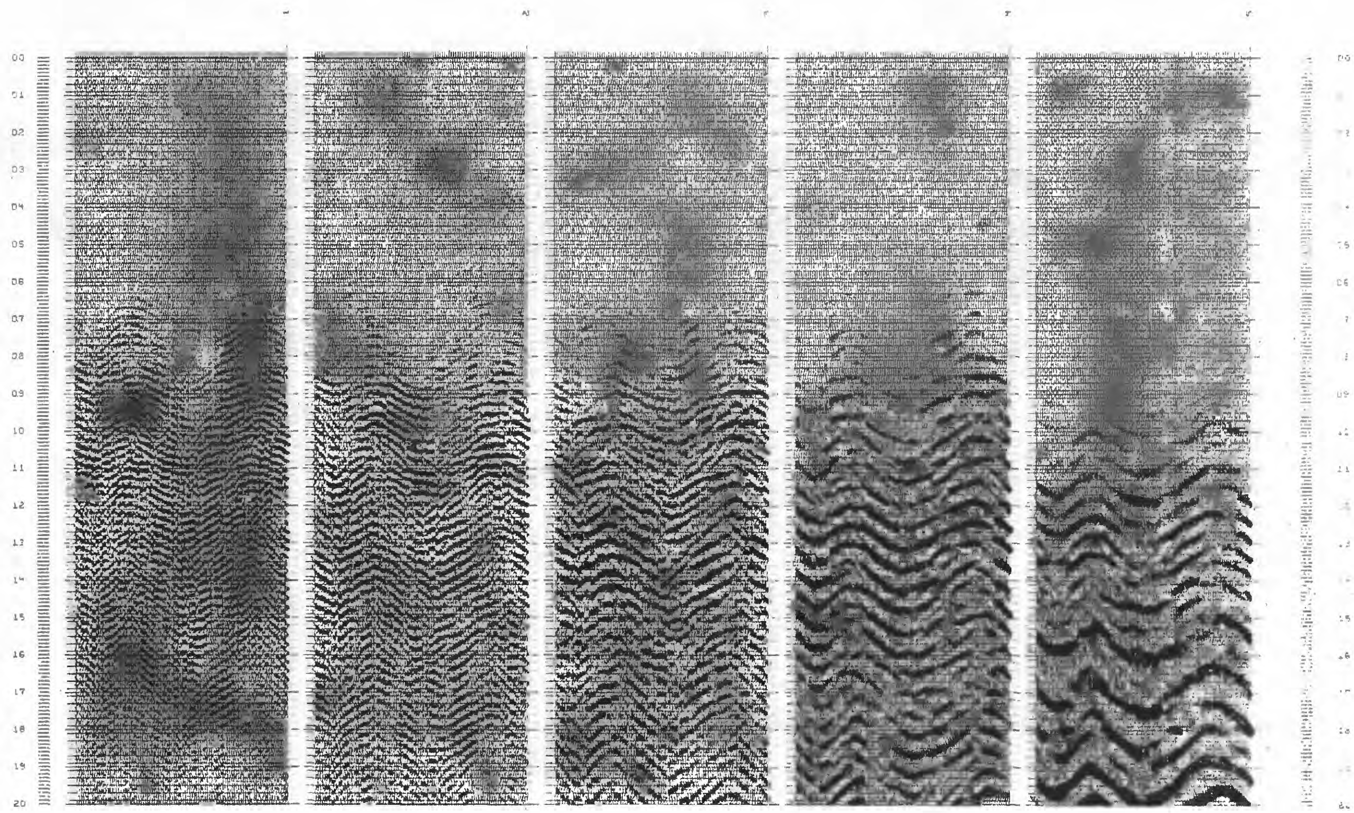
TORNADO CIRCULAR NOISE SPREAD (DOUBLE CIRCLE)
INNER CIRCLE RADIUS 50 85 FT 32 STATIONS @ 10 FT
OUTER CIRCLE RADIUS 101.7 FT 64 STATIONS @ 10 FT
12 LDS1000 10 HZ GEOPHONES (3FT INTERVAL) PER STA

3 VIBRATORS 18 SWEEPS-VIBRATOR 54 TOTAL SWEEPS
18 SECOND RECORD LENGTH 14 SECOND VIBRATOR SWEEP
VP-15 2800FT OFFSET FROM CENTER OF TORNADO SPREAD

1ST RECORD SWEEP FREQUENCY 38-104 HZ
2ND RECORD SWEEP FREQUENCY 32-96 HZ
3RD RECORD SWEEP FREQUENCY 22-84 HZ
4TH RECORD SWEEP FREQUENCY 16-72 HZ
5TH RECORD 3FT PRIMACORD AT 4FT DEPTH 11 HOLES

FIG 25

TIME-SEC



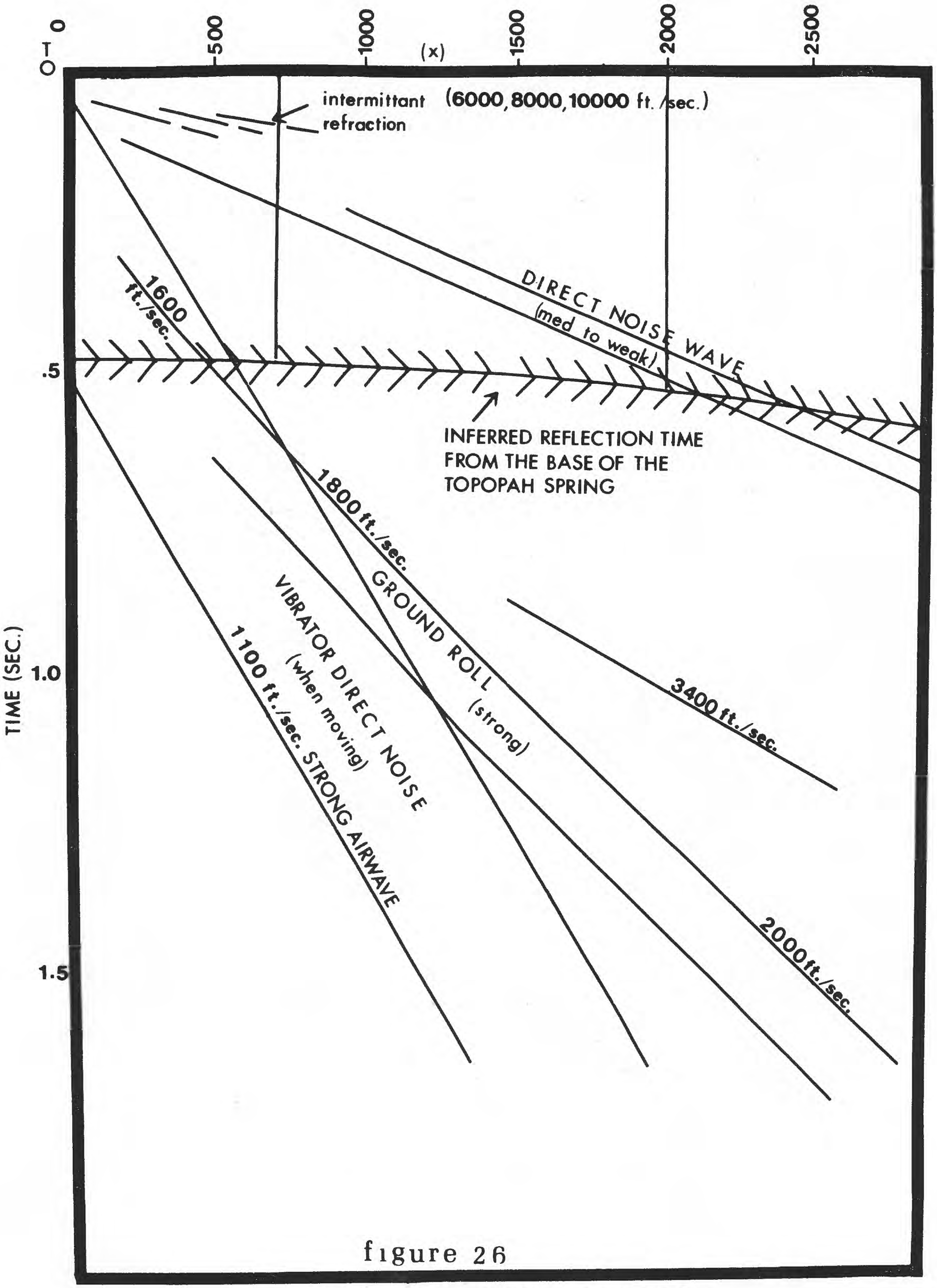


figure 26

SCHEMATIC — SIGNAL AND NOISE

THREE DIMENSIONAL TRAVERSES

```
SOURCE              RECEIVER

  x . . . . . . . o o o o o o o o o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o o o o o o o o o
4 X 1                  4 X 24
```

TOTAL CDP FOLD 192

```
  x . . . . . . . o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o o o o o
6 X 1                  6 X 16
```

TOTAL CDP FOLD 288

```
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
  x . . . . . . . o o o o o o o o o o o o
8 X 1                  8 X 12
```

TOTAL CDP FOLD 384

1). 4 x 24 at 100 ft. = 800-2800 ft.
2). 6 x 16 at 100 ft. = 800-2300 ft.
3). 8 x 12 at 100 ft. = 800-1900 ft.
4). 4 x 24 at 50 ft. = 400-1550 ft.
5). 6 x 16 at 50 ft. = 400-1200 ft.
6). 8 x 12 at 50 ft. = 400-1000 ft.

FIGURE 27

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

LINE W-4 STACK EASTERN HALF

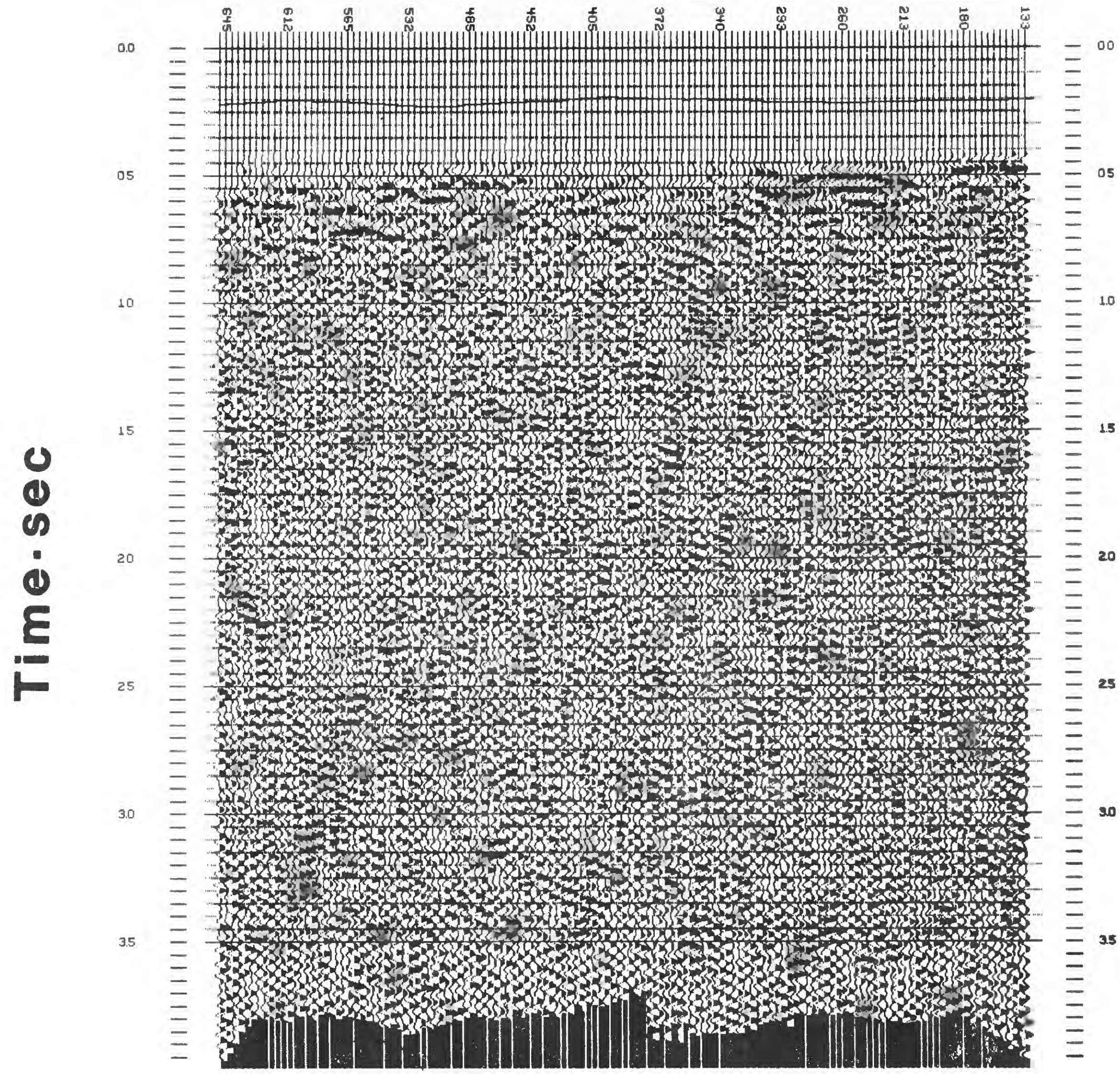
FIELD ACQUISITION

BY SEISDATA SERVICES INC. CREW 003 APR-JUN 1982
96 CHANNEL MDS-10 4 SEC 2 MS FILT OUT-TO-125HZ
3D AREA 8 STATIONS BY 74 ROWS (STA INT 100 FT E/W)
ROW INTERVAL (N/S) 105FT TO STA 364, THEN 210 FEET
RECIEVER STATION MATRIX 8-BY-12 SOURCE 8-BY-1
SOURCE MATRIX OFFEND 840FT TO NEAR RECIEVER ROW
96 LRS1000 10 HZ GEOPHONES/STATION (SET UP N-TO-S)
ARRAY 1 2 4 6 8 10 11 12 11 10 8 6 4 2 1 INT 15FT
TWO SEISMIC SOURCES PRIMACORD CHARGES AND VIBS
3FT PC AT 4FT 11 & 22 HOLE ARRAY 5FT & 10FT INT
3 VIBS @37.5FT (8 POS @12.5FT) 18 SWEEPS/VIB = 54
ARRAY 1 2 3 4 5 6 6 6 6 4 3 2 1 NORTH/SOUTH
LENGTH 162.5FT (DOUBLED FOR 210FT ROWS) 16-62 HZ
16SEC RECORD 12SEC SWEEP TOTAL TECHNIQUE = 6000
STATION 101 TO 692 PROGRESSSESS NORTH TO SOUTH

PROCESSING INFORMATION
SEPTEMBER 10, 1982

REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
CDPS GATHERED NORTH-SOUTH IN 52.5FT INTERVALS THRU
MIDPOINT OF ROWS 365-372/380-373, THEN 105 FT INT
GATHER EASTERN EIGHT COLUMNS OF CDPS (1 TO 8)
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 30 HZ
DIGITAL AUTOMATIC GAIN CONTROL(AGC) 500MS OPERATOR
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
100-6000 480-8000 600-9000 1200-10800 2000-13000
CDP STACKING (FOLD 210)
BANDPASS FILTER 10-36 HZ DIGITAL AGC 1000 MS LEN

FIGURE 28



DEPT OF ENERGY   FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE   NYE COUNTY, NEVADA

LINE W-4 STACK CENTER CDPS

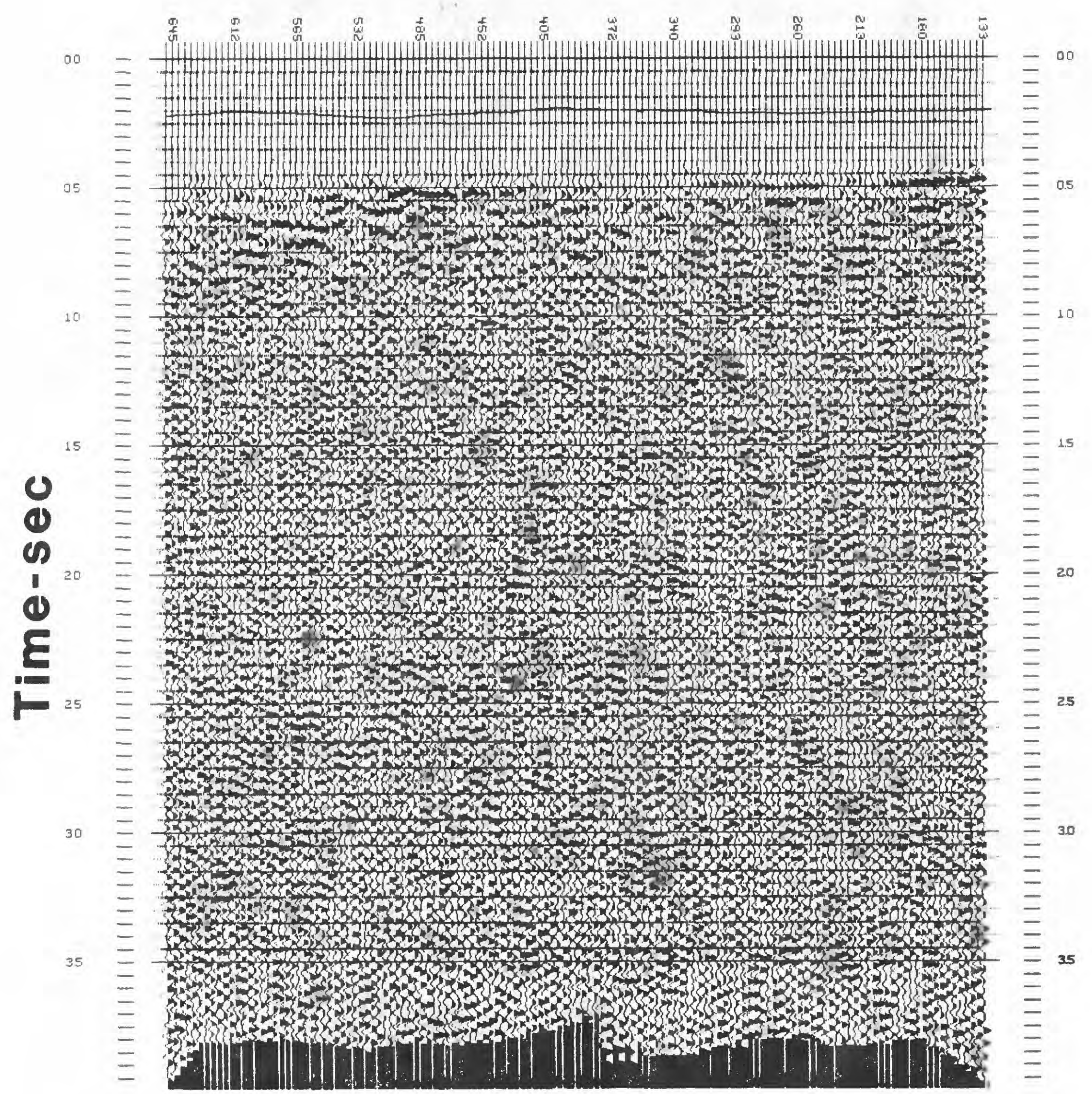
FIELD ACQUISITION

BY SEISDATA SERVICES INC.   CREW 003   APR-JUN 1982
96 CHANNEL MDS-10 4 SEC 2 MS   FILT OUT-TO-125HZ
3D AREA 8 STATIONS BY 74 ROWS (STA INT 100 FT E/W)
ROW INTERVAL (N/S) 105FT TO STA 364, THEN 210 FEET
RECIEVER STATION MATRIX 8-BY-12   SOURCE 8-BY-1
SOURCE MATRIX OFFEND 840FT TO NEAR RECIEVER ROW
96 LRS1000 10 HZ GEOPHONES/STATION (SET UP N-TO-S)
ARRAY 1 2 4 6 8 10 11 12 11 10 8 6 4 2 1 INT 15FT
TWO SEISMIC SOURCES PRIMACORD CHARGES AND VIBS
3FT PC AT 4FT   11 & 22 HOLE ARRAY   9FT & 10FT INT
3 VIBS @37.5FT (8 POS @12.5FT) 18 SWEEPS/VIB = 54
ARRAY 1 2 3 4 5 6 6 6 6 4 3 2 1 NORTH/SOUTH
LENGTH 162.5FT (DOUBLED FOR 210FT ROWS)   16-62 HZ
16SEC RECORD 12SEC SWEEP   TOTAL TECHNIQUE = 6808
STATION 101 TO 692 PROGRESSESS NORTH TO SOUTH

PROCESSING INFORMATION
SEPTEMBER 10, 1982

REFERENCE DATUM +5000 FT   VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
CDPS GATHERED NORTH-SOUTH IN 52.5FT INTERVALS THRU
MIDPOINT OF ROWS 365-372/380-373, THEN 105 FT INT
GATHER CENTER FIVE COLUMNS OF CDPS (6 TO 10)
RESAMPLE TO 4 MS   BANDPASS FILTER 10 TO 30 HZ
DIGITAL AUTOMATIC GAIN CONTROL(AGC) 500MS OPERATOR
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
100-6000 400-8000 600-9000 1200-10000 2000-13000
CDP STACKING (FOLD 180)
BANDPASS FILTER 10-36 HZ   DIGITAL AGC 1000 MS LEN

FIGURE 29



DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

LINE W-4 STACK WESTERN CDP 14

FIELD ACQUISITION
BY SEISDATA SERVICES INC. CREW 003 APR-JUN 1982
96 CHANNEL MDS-10 4 SEC 2 MS FILT OUT-TO-125HZ
3D AREA 8 STATIONS BY 74 ROWS (STA INT 100 FT E/W)
ROW INTERVAL (N/S) 105FT TO STA 364, THEN 210 FEET
RECIEVER STATION MATRIX 8-BY-12 SOURCE 8-BY-1
SOURCE MATRIX OFFEND 840FT TO NEAR RECIEVER ROW
96 LRS1000 10 HZ GEOPHONES/STATION (SET UP N-TO-S)
ARRAY 1 2 4 6 8 10 11 12 11 10 8 6 4 2 1 INT 15FT
TWO SEISMIC SOURCES PRIMACORD CHARGES AND VIBS
3FT PC AT 4FT 11 & 22 HOLE ARRAY 3FT & 18FT INT
3 VIBS @37.5FT (8 POS @12.5FT) 18 SWEEPS/VIB = 54
ARRAY 1 2 3 4 5 6 6 6 6 4 3 2 1 NORTH/SOUTH
LENGTH 162.5FT (DOUBLED FOR 210FT ROWS) 16-62 HZ
16SEC RECORD 12SEC SWEEP TOTAL TECHNIQUE = 6808
STATION 101 TO 692 PROGRESSESS NORTH TO SOUTH

PROCESSING INFORMATION
SEPTEMBER 10, 1982
REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
CDPS GATHERED NORTH-SOUTH IN 105 FT INTERVALS
GATHER ONE WESTERN CDP COLUMN (14)
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 30 HZ
DIGITAL AUTOMATIC GAIN CONTROL(AGC) 500MS OPERATOR
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
100-6000 480-8000 600-9000 1200-10800 2000-13000
CDP STACKING (FOLD 28)
BANDPASS FILTER 10-36 HZ DIGITAL AGC 1000 MS LEN

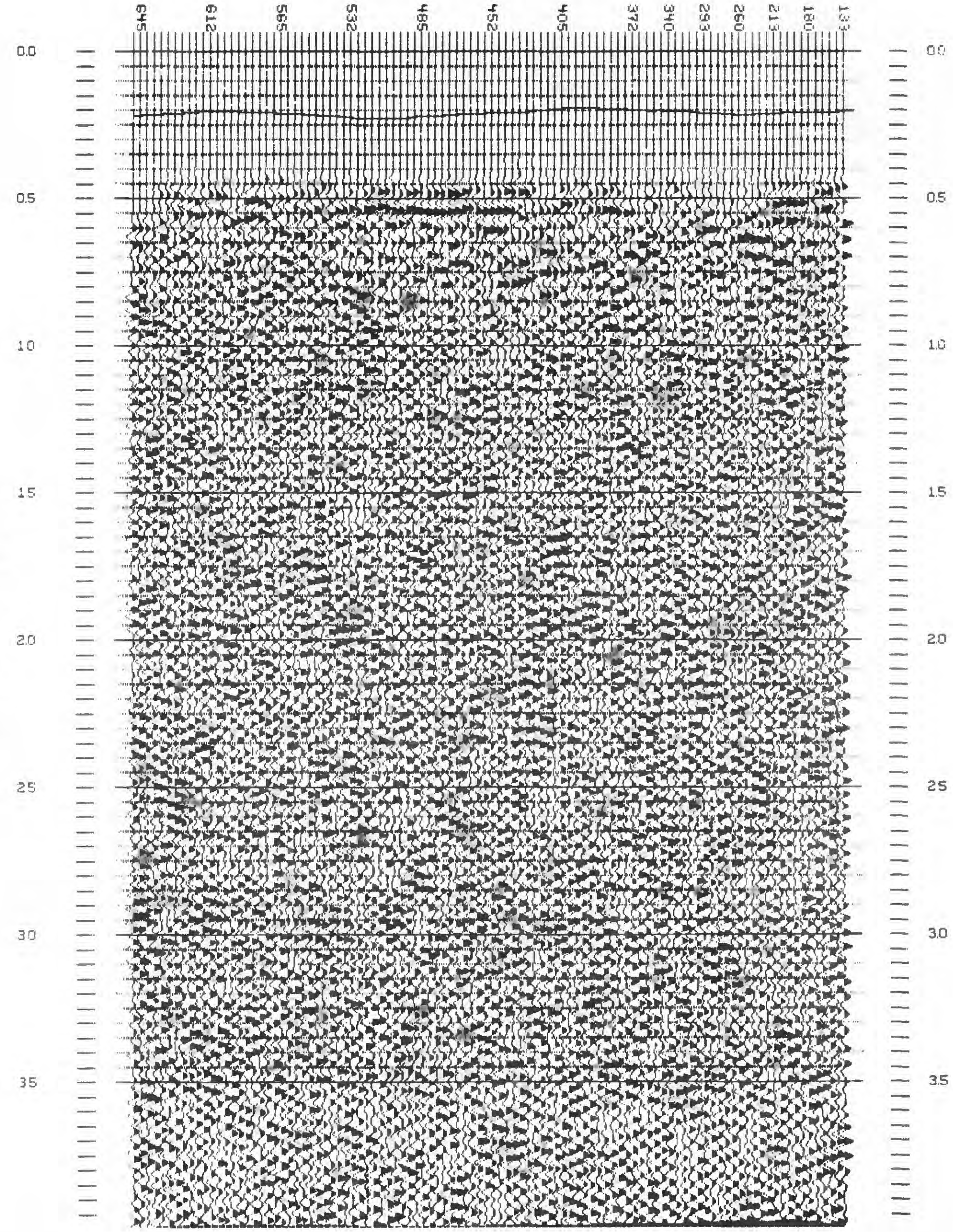


FIGURE 30

DEPT OF ENERGY FENIX & SCISSON

U S G S

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

W-4 ØPTIMUM PRØFILE (105'CDP)

FIELD ACQUISITION
BY SEISDATA SERVICES INC. CREW 003 APR-JUN 1982
96 CHANNEL MDS-10 4 SEC 2 MS FILT OUT-TO-125HZ
3D AREA 8 STATIONS BY 74 ROWS (STA INT 100 FT E/W)
ROW INTERVAL (N/S) 105FT TO STA 364, THEN 210 FEET
RECIEVER STATION MATRIX 8-BY-12 SOURCE 8-BY-1
SOURCE MATRIX OFFEND 840FT TO NEAR RECIEVER ROW
96 LRS1000 10 HZ GEOPHONES/STATION (SET UP N-TO-S)
ARRAY 1 2 4 6 8 10 11 12 11 10 8 6 4 2 1 INT 15FT
TWO SEISMIC SOURCES PRIMACORD CHARGES AND VIBS
3FT PC AT 4FT 11 & 22 HOLE ARRAY 9FT & 18FT INT
3 VIBS 037.5FT (8 POS 012.5FT) 18 SWEEPS/VIB = 54
ARRAY 1 2 3 4 5 6 6 6 6 4 3 2 1 NORTH/SOUTH
LENGTH 162.5FT (DOUBLED FOR 210FT ROWS) 16-62 HZ
16SEC RECORD 12SEC SWEEP TOTAL TECHNIQUE = 68DB
STATION 101 TO 692 PROGRESSESS NORTH TO SOUTH

PROCESSING INFORMATION
SEPTEMBER 10, 1982
REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
CDPS GATHERED NORTH-SOUTH IN 105 FT INTERVALS
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 30 HZ
DIGITAL AUTOMATIC GAIN CONTROL(AGC) 500MS OPERATOR
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
100-6000 480-8000 600-9000 1200-10800 2000-13000
CDP STACKING (OPTIMUM PROFILE FOLD 384)
BANDPASS FILTER 10-36 HZ DIGITAL AGC 1000 MS LEN

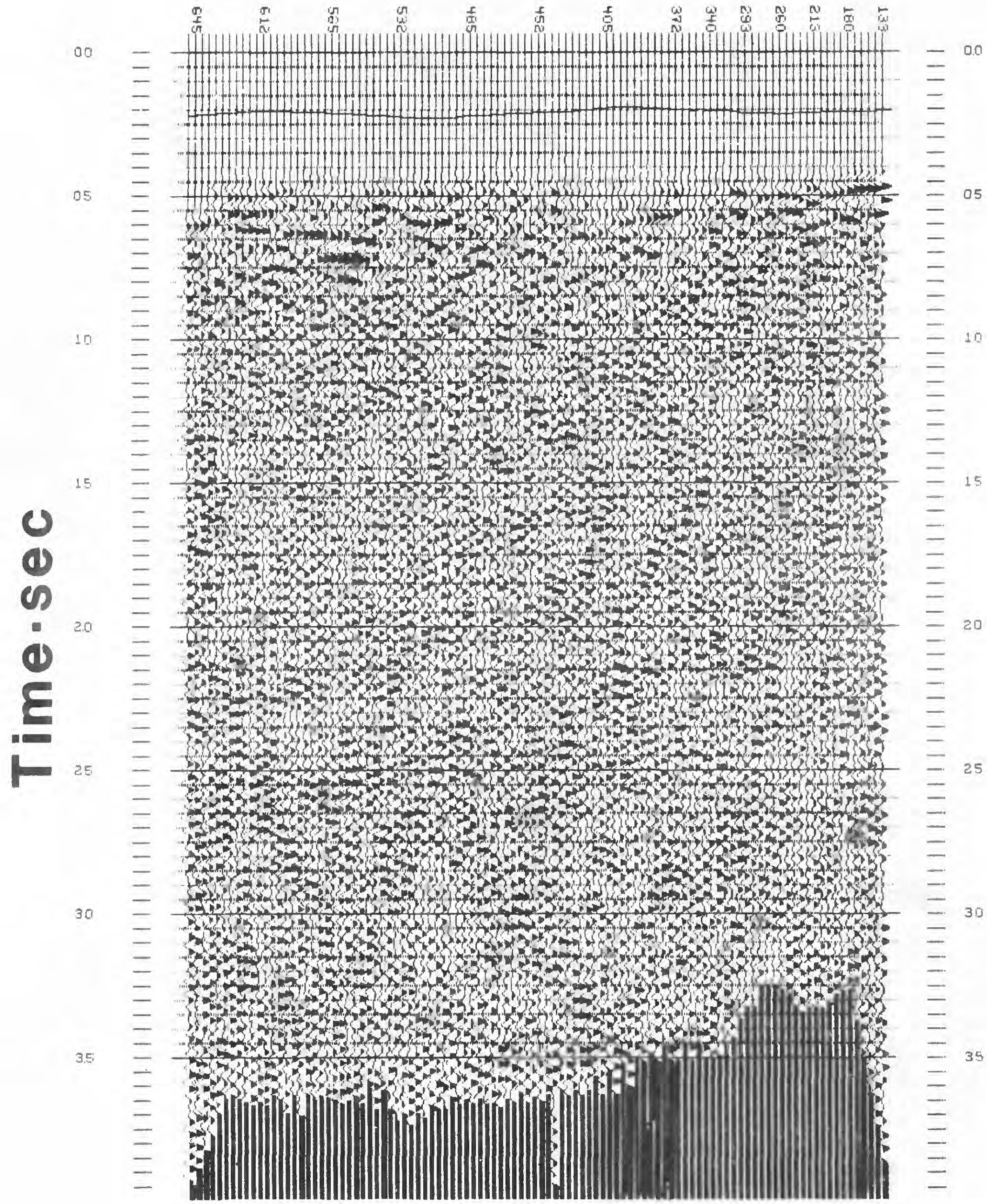


FIGURE 31

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

THREE-D LINE G-2 STACK

FIELD ACQUISITION

BY SEISDATA SERVICES INC. CREW 003 JUNE 1982
96 CHANNEL MDS-10 INSTRUMENTS 4 SECONDS 2 MS
FIELD FILTER 12 TO 125 HZ REC MODE HAS 0P IFP
96 LRS1000 10HZ GEOPHONES PER GROUND STATION
RECEIVER MATRIX 4-BY-24 100 FT STATION INTERVAL
SINGLE HOLE DYNAMITE SHOT 10-25LB 195/200FT DEPTH
SOURCE OFFSET 400FT TO NEAR RECEIVER, 2700FT FAR
STATION 101-240 SE/NW SHOTPOINTS 1-19 SE/NW

PROCESSING INFORMATION
SEPTEMBER 10, 1982

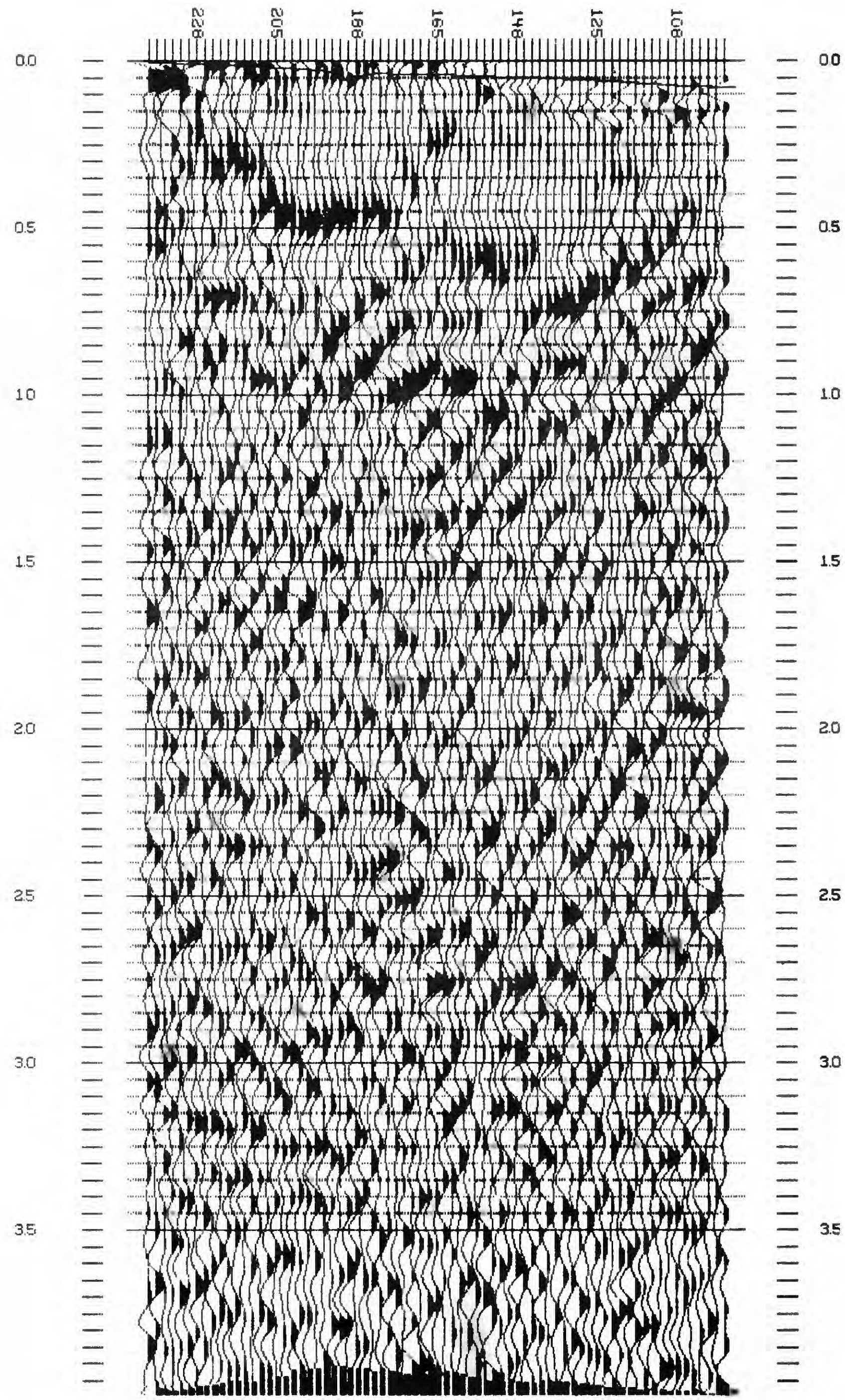
REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
ARRANGE TRACES TO THREE-D COMMON DEPTH POINTS(CDP)
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 30 HZ
DIGITAL AUTOMATIC GAIN CONTROL(AGC) 500MS OPERATOR
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
100-6000 480-8000 600-9000 1200-10800 2000-13000

CDP STACKING (MAXIMUM FOLD 92)

1ST DISPLAY FILTER 10-36HZ DIGITAL AGC 1000MS
2ND DISPLAY TIME SERIES INTEGRATION

FIGURE 32

Time·sec



DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

THREE-D LINE S-2 STACK

FIELD ACQUISITION

BY SEISDATA SERVICES INC CREW 003 JUN-JUL 1982
96 CHANNEL MDS-10 4SEC 2MS FILT 12 TO 62 OR 125HZ
3D AREA 6 STA(NE/SW) BY 179 ROWS(NW/SE) 50FT GRID
RECIEVER STATION MATRIX 6-BY-16 (96 TOTAL STA)
12 LRS1000 10HZ GEOPHONES/STATION 9FT INTERVAL
VECTOR PULSE SOURCE MATRIX 6-BY-1 (OFFEND 450 FT)
56IN PC BURIED @16IN 7 HOLE ARRAY 16FT SPACING
STATION 101 TO 1174 NORTHWEST-TO-SOUTHEAST

PROCESSING INFORMATION
SEPTEMBER 10, 1982

REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
ARRANGE TRACES TO THREE-D COMMON DEPTH POINTS(CDP)
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 50 HZ
DIGITAL AUTOMATIC GAIN CONTROL (AGC) 50MS OPERATOR
EARLY MUTING AND AIRWAVE SUPPRESSION MUTING
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
120-5000 320-8125 1320-9530 4000-15000
POST-MOVEOUT MUTE (500MS/1000MS) DATUM STATICS

CDP STACKING (MAXIMUM FOLD 297)

BANDPASS FILTER 10-36 HZ DIGITAL AGC 1000 MS LEN

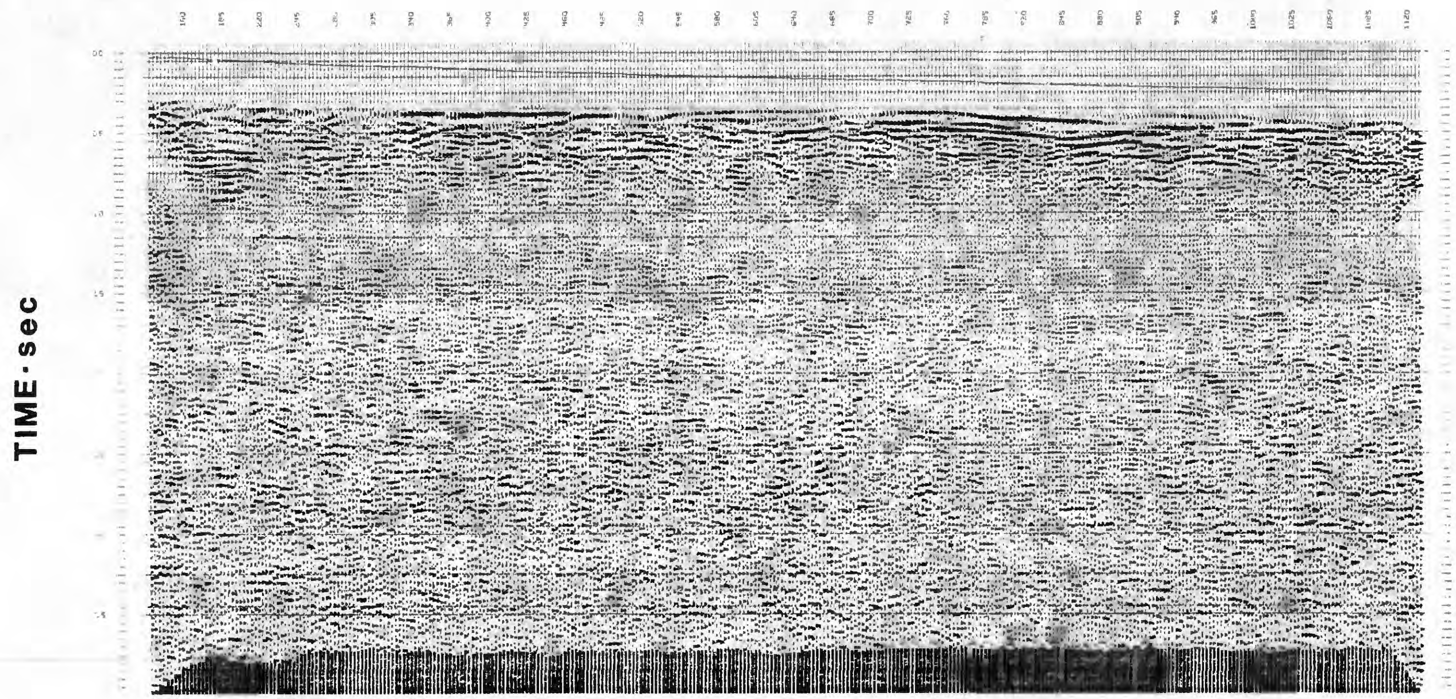


FIGURE 33

DEPT OF ENERGY FENIX & SCISSON

USGS

YUCCA MOUNTAIN AREA

NEVADA TEST SITE NYE COUNTY, NEVADA

THREE-D LINE S-4 STACK

FIELD ACQUISITION

BY SEISDATA SERVICES INC CREW 003 JULY 1982
96 CHANNEL MDS-10 4 SEC 2 MS FILTER 12 - 62 HZ
3D AREA 6 STATIONS BY 126 ROWS 50 FT STATION INT
12 LRS1000 10 HZ GEOPHONES/STATION 9 FT INTERVAL
RECEIVER STATION MATRIX 6-BY-16 (96 TOTAL STA)
VECTOR PULSE SOURCE MATRIX 6-BY-1 (OFFEND 450 FT)
56IN PC BURIED @18IN 7 HOLE ARRAY 16FT SPACING
STATION 101 TO 856 NORTHWEST-TO-SOUTHEAST

PROCESSING INFORMATION
SEPTEMBER 10, 1982

REFERENCE DATUM +5000 FT VCORR 8000 FT/SEC
DEMULTIPLEX SEG-B TO SEG-Y RECORD & TRACE EDITING
ARRANGE TRACES TO THREE-D COMMON DEPTH POINTS(CDP)
RESAMPLE TO 4 MS BANDPASS FILTER 10 TO 50 HZ
DIGITAL AUTOMATIC GAIN CONTROL (AGC) 50MS OPERATOR
EARLY MUTING AND AIRWAVE SUPPRESSION MUTING
NORMAL MOVEOUT (2-WAY TIME IN MS - RMS VELOCITY)
120-5000 320-8125 1320-9530 4000-15000
POST-MOVEOUT MUTE (500MS/1000MS) DATUM STATICS

CDP STACKING (MAXIMUM FOLD 288)

BANDPASS FILTER 10-36 HZ DIGITAL AGC 1000 MS LEN

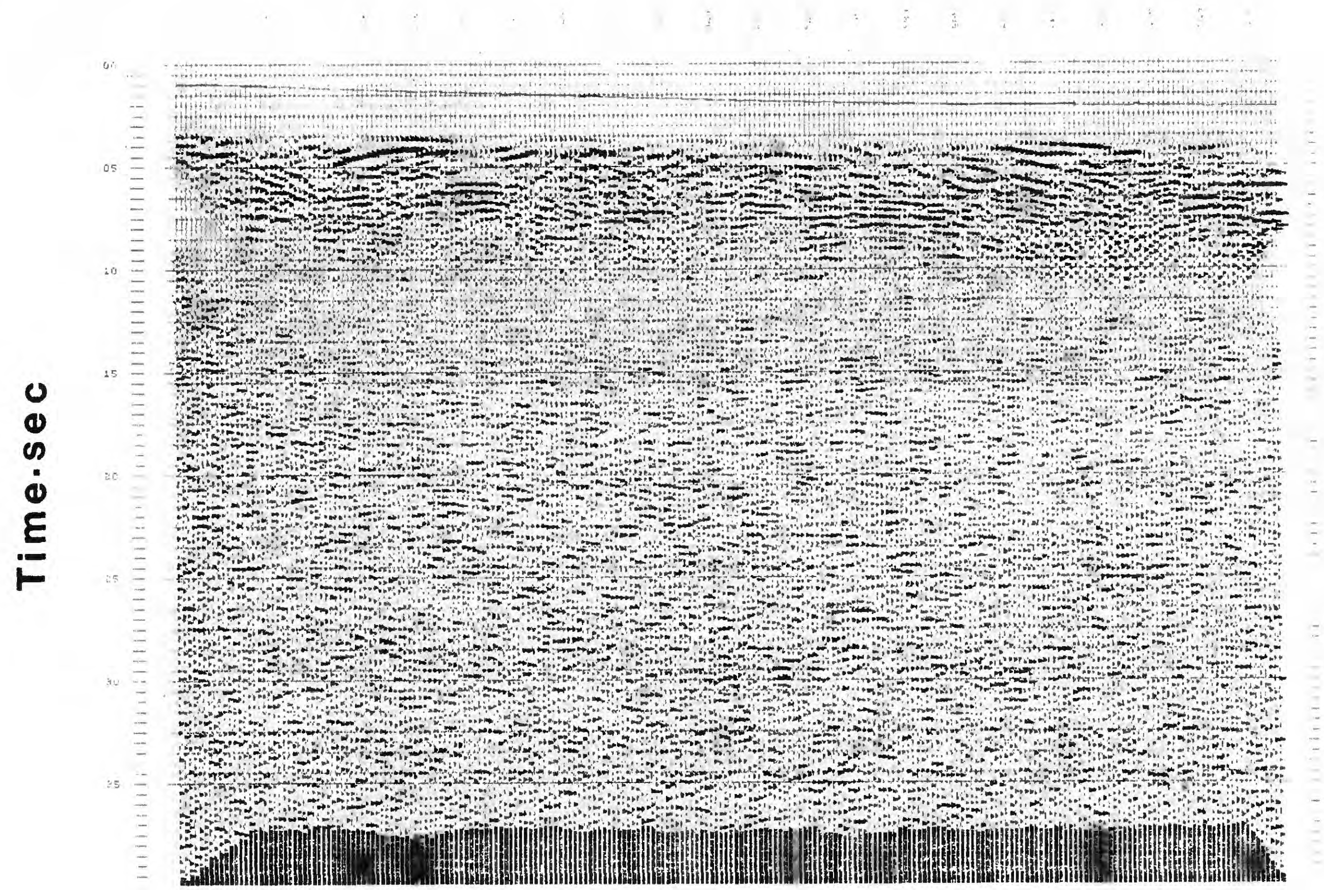
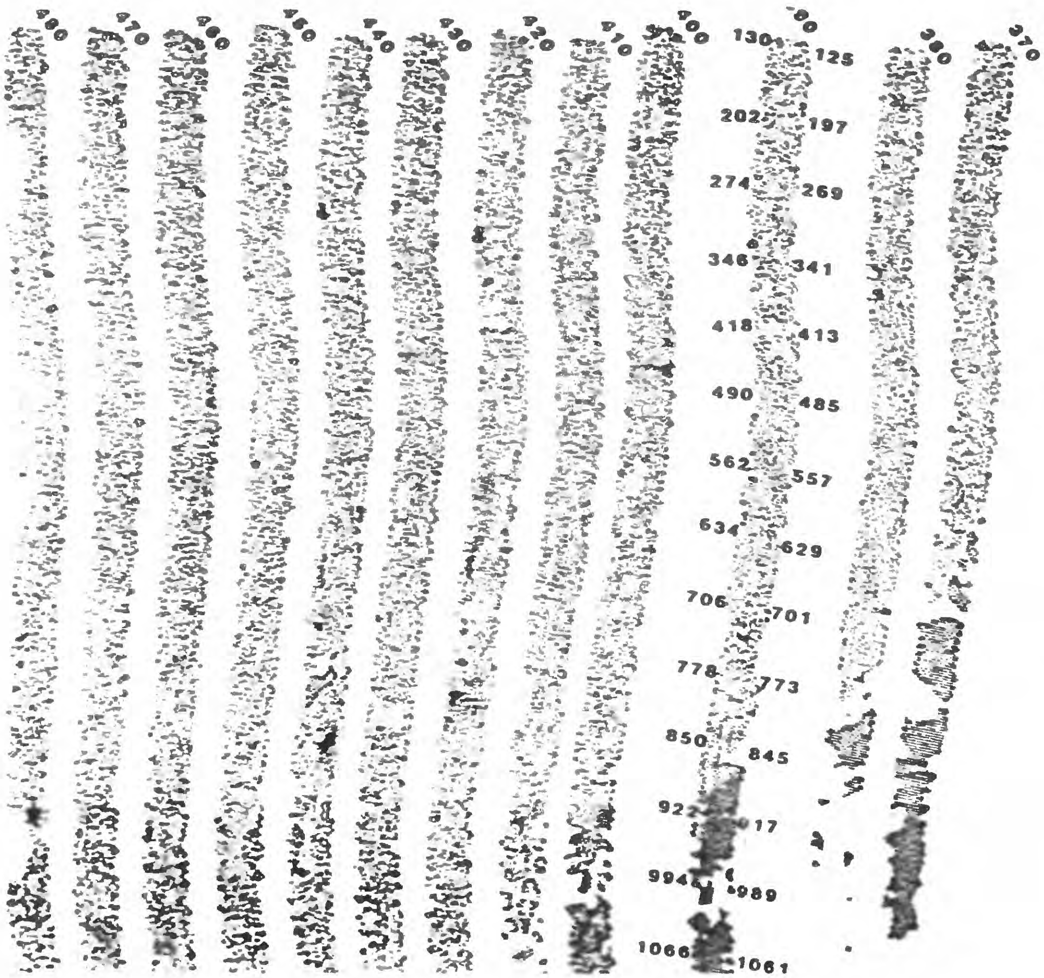


FIGURE 34



TIME

YUCCA MOUNTAIN 3-D TIME SLICES LINE S-2

NORTH

FIG 35

SCALE 1" = 1000'