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SUMMARY DATA REPORT

of

DOWNHOLE VELOCITY SURVEYS

in

Neutron Logging Holes

in the immediate vicinity of the

CREST of YUCCA MOUNTAIN

November 2001

Attachment 'B'

to accompany

SCIENTIFIC NOTEBOOK: SN-M&O-SCI-039-V1

Yucca Mountain Project

REDPATH GEOPHYSICS

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Downhole Seismic Velocity Surveys
on the
Crest of Yucca Mountain
Yucca Mountain Project, Nevada

Introduction

This report presents the results of attempts to measure shear- and compression-wave velocities in 8 boreholes in the immediate vicinity of the crest of Yucca Mountain located on the Nevada Test Site. The holes were located within or close to the perimeter of the proposed nuclear-waste repository at the Yucca Mountain Project (YMP). The report also describes the procedures and equipment used to acquire the raw data by means of the standard downhole method. The downhole velocities were intended to corroborate and supplement near-surface velocity information that had been acquired previously from Spectral Analysis of Surface Waves (SASW) surveys. Additional SASW surveys were conducted on the crest at the same time as the downhole surveys described in this report.

The results of SASW surveys previously conducted on the crest indicated that a high shear-wave-velocity gradient may exist in the near-surface rock. Ground motion response calculations suggest that the presence of such a large gradient would result in high values of surface acceleration during an earthquake, and it was considered important to acquire near-surface velocity information from an independent source. It was initially thought that shear-wave refraction surveys on the crest might help to resolve the existence and severity of any velocity gradient. It was also thought that downhole-velocity surveys in steel-cased, neutron-logging holes that had been drilled years ago on and near the crest might be successful.

The first attempt to measure shear-wave velocities with a refraction line [at hole UZ-N27] was not successful, primarily because of a velocity inversion immediately below the surface, and no other refraction surveys were attempted. Despite the seeming unsuitability of the neutron-logging holes for velocity surveys, the initial results were promising and a total of 8 holes were surveyed. The results of the downhole surveys showed that velocity inversions were not unusual in the vicinity of the crest and that further attempts to acquire seismic refraction data were not warranted.

All procedures and relevant calibration information are completely documented in **Scientific Notebook SN-M&O-SCI-039-V1** which was compiled as the field work progressed and as the data were interpreted.

The field work for these investigations was performed from 18 June through 23 June, 2001, with the assistance of Mr. David Merritt of Bechtel/SAIC Company. The scope of work was as follows:

Borehole Number	Ground Elevation - ft	Depth of Survey - ft
UZ-N27	4857	179
UZ-N33	4329	71
UZ-N46	4501	95
UZ-N64	4789	54
UZ-N66	4358	48
UZ-N71	4925	48
UZ-N75	4799	28
UZ-N94	4926	28

A map showing the location of the surveyed boreholes on Yucca Mountain is attached. All of the holes were cased with 5-inch ID steel pipe that had been installed as each hole was drilled, and no grout was used. As a consequence, the contact between the casing and the surrounding material was not well established.

Procedures and Equipment

We used the conventional downhole survey method in which travel times of signals from an impulsive source of energy at the surface are measured to progressively greater depths in the borehole. The corresponding plot of travel time *vs.* depth is then converted to velocity *vs.* depth by computing slopes of the interpreted major straight-line segments of the plotted data.

A vehicle-on-a-beam traction source located several feet from the collar of the hole is normally used to generate shear waves. This source consists of a 7-ft-long 6x6 wood beam with steel end caps, the beam being held in firm contact with the ground by driving the front wheels of a vehicle on to it. Horizontal blows to the ends of the beam with a sledge hammer generate shear-wave pulses. Because of rough terrain and difficult vehicle-access at some of the drill-hole sites, we used a shorter, 3-1/2-ft-long beam weighted down with rocks.

Shear-wave signals with 'positive' and 'negative' polarities are generated by striking each end of the beam in sequence. The 'positive' and 'negative' shear waves are, ideally, mirror images of each other and, viewed as a pair, greatly assist in identifying the shear wave. The sledge hammer has an impact sensor attached to the handle near the head that starts the timing process in the recording instrument upon impact with the beam. At each hole the beam was placed and aligned as local site conditions permitted; there was no attempt to align the beam along any given azimuth as was done at the WHB site last year.

Compression-wave signals were generated by vertical hammer blows to a steel striker plate on the ground, also located close to the collar of the hole.

The downhole sensor for the velocity surveys was a Model BHG-2 geophone manufactured by Geostuff of Saratoga, California. The sensor package contains an orthogonal array of three geophones. We could not use the Geostuff BHG-3 downhole unit that was used for the surveys at the WHB pad because the steel casing rendered its internal fluxgate compass

ineffective. (A servo circuit in the BHG-3 links the compass to the motor-mounted geophone array so that the horizontal geophones maintain a constant, pre-determined azimuth at each measurement point. This allows one of the two horizontal geophone elements to stay aligned with the shear-wave source as the sensor package is raised or lowered in the hole. This capability ensures that the detected shear-wave signal is always the optimum). Both the BHG-2 and the BHG-3 are mechanically locked in the hole casing with a motor-actuated clamping spring operated from the control box at the surface.

In 7 of the 8 holes we were able to align the BHG-2 sensor package so that one of the horizontal geophones was roughly aligned with the shear-wave beam. This was done by attaching a half-inch-square piece of reflective tape to the top of the geophone housing and looking down the borehole with the aid of a bright flashlight. By jiggling the connecting cable we could generally bring the BHG-2 into an acceptable and known alignment simply by observing the position of the reflected spot of light. Because the lock-in spring is extended at the bottom and the transducer is dragged up the hole as the survey progresses, the sensor package tends to maintain its initial azimuthal orientation all the way up the hole. Frequent checks of the orientation were made by looking down the hole and, if necessary, the spring could be released to re-orient the BHG-2. This simple technique was surprisingly effective even to a depth of 100 ft. Hole UZ-N27 was too deep to use this method so, not knowing the orientation of the BHG-2, we recorded the output of both horizontal geophones.

All signals were recorded with a Geometrics R24 'Strataview' digital seismograph. The R24 was configured to record 24 1024-sample channels of data, sampling at a rate of 62 or 125 microseconds, depending on the hole depth.

In a downhole survey the data are collected channel-by-channel until 24 channels have been recorded or until the survey is complete, at which time the signals are transferred to a hard disk drive and printed in the R24's internal printer for field examination. The raw signals on disk can be filtered and processed on playback and prior to printing. The data are ultimately stored in SEG-2 binary format on 3-1/2-inch disks.

Our procedure was to lower the BHG-2 to the bottom of the hole and expand the clamping spring so that it could be pulled up the hole but would still hold its position. Travel times were then measured from the bottom up at 1-meter intervals to the surface. An exception to this procedure was hole N27 in which measurements were made at 2-meter intervals from 55 meters to 9 meters, and then at 1-meter intervals above that. Although a downhole cable with metric depth markers was used, all results are reported in feet and ft/sec.

With the exception of hole N27, careful attention was given to the polarity of the shear-wave signals. As described above, one of the two horizontal geophones inside the BHG-2 was aligned with the shear-wave beam. The survey was conducted so that at each measurement point the first blow to the beam would produce a shear wave for which the initial upward deflection of the seismograph trace was always towards the top of the paper record, and the resulting signal was recorded on an odd-numbered channel. The signal from the blow to the other end of the beam was then recorded on the adjacent even-numbered channel. A compression-wave signal was recorded next (while still at the same depth) and a switch box

directed that signal to a separate block of channels allocated to compression waves. Except for hole N27, each measurement point consisted of two shear-wave signals and one compression-wave signal, so that a total of 8 measurement points comprise a 24-channel record; channels 1 through 16 are shear waves and channels 17 through 24 are compression waves. The ability to keep careful track of the polarity of the shear-wave signals proved to be extraordinarily important in the interpretation of the data acquired in these surveys.

The R24 seismograph has the capability of 'stacking' or linearly adding multiple signals. More than one hammer blow for each signal is sometimes required at the deeper measurement points in order to increase the signal-to-noise ratio or to more clearly develop the shear wave amidst interfering arrivals.

Results and Analysis

Reduced copies of complete sets of the shear- and compression-wave signals are attached to this report. The source offset and the frequency of the low-pass filters used for playback are shown on each set of records. Although shear- and compression-wave signals are recorded on the same seismograph record in the field, they have been played back and presented here as separate paper records. It should be noted that the travel times that were plotted to obtain velocities were read from full-size copies of the recordings.

As stated previously, except for hole N27 the horizontal geophones in the BHG-2 maintained roughly the same azimuth during the course of each survey and, therefore, the polarity of the recorded shear-wave signal was always consistent with the direction of the hammer blow. A blow to the first end of the beam always resulted in an initial upward deflection of the seismograph trace. As noted on the attached copies of the records, a 100-Hz low-pass filter was applied to the shear-wave signals during playback from the hard disk. The signals acquired in the velocity surveys were transferred to the hard drive without any filtering; filtering was used only during playback of the shear-wave signals to the R24's internal printer. The filtering was accomplished by using a digital filter built into the R24's operating system. No filtering was applied to the compression-wave signals

The time of the onset or 'first break' of the shear wave was **not** used as the travel time. The onset of the pulse may sometimes be reasonably clear at shallow depths, but soon becomes vague or completely obscured as the depth increases. The shear-wave signals in these surveys were characterized by an unusually large degree of interference and distortion, probably a consequence of the ungrouted steel casing. For this reason the time of the first peak (and of the first trough of the corresponding reverse-polarity blow) was picked as the travel time of the shear wave. In some boreholes only one polarity of the shear wave resulted in a usable signal, *i.e.*, the blow to the opposite end of the plank did not produce a clean signal. The times picked as travel times are indicated on the attached copies of the shear-wave signals by the small dots. Where possible the average time of a peak and its corresponding trough were used, otherwise only the time of the clearest peak (or trough) was used. The time of the onset of the compression wave was selected as the travel time in all cases.

Because the energy source, whether compression or shear, is offset horizontally from the collar of the hole, it is necessary to correct the travel times at shallow depths for this offset. The correction is intended to convert the actual travel time along the slant path from source to receiver to the equivalent time required to travel vertically from the surface down to the receiver. In the past the correction generally consisted of multiplying the travel time by the cosine of the angle (Θ) between the slant path and vertical, however, this simple cosine correction is only valid if the onset of an unfiltered signal is being used as the travel time. If this simple cosine correction is applied to a later portion of a signal, such as a peak, then the times will be 'overcorrected' and the computed near-surface velocities will be too low. It is also necessary to correct for any time shift of signals caused by filtering before applying the cosine correction. Although the R24 seismograph uses digital filters, they are not 'zero phase' filters and will cause a small time shift. The proper method of correcting for the offset is as follows:

$$t_{vertical} = [(t_{peak} - \Delta t - \Delta t_o) \times \cos\Theta] + \Delta t + \Delta t_o$$

where $t_{vertical}$ is the time that is plotted against the depth to the measurement point, t_{peak} is the time of the selected peak, Δt is the time difference between the onset of the signal and the selected peak (and corresponding trough) for signals recorded at shallow depths, and Δt_o is the time shift of the onset of the signal due to filtering. In practice, the value of $\cos\Theta$ is computed from the source offset, **s**, and the depth to the transducer, **d**, so that the above equation becomes:

$$t_{vertical} = [(t_{peak} - \Delta t - \Delta t_o) \times (d/(d^2 + s^2)^{1/2})] + \Delta t + \Delta t_o$$

The cosine correction is generally required to a depth equal to approximately 10 times the offset distance. Plots of corrected shear- and compression-wave times *vs.* depth are attached to this report; these plots also show the least-squares values of shear-wave velocities, rounded to the nearest 5-ft/sec, and the depths to the interfaces. Compression-wave velocities are problematical, as discussed below.

Very little of the compression-wave data acquired in these surveys is usable. In almost every instance a relatively strong signal propagated down the steel casing (labeled as a 'casing wave' on the attached time *vs.* depth plots) and obscured the compression wave traveling through the rock. A good example of this phenomenon can be seen in the compression-wave records for N27. A casing wave is dominant down to a depth of 15 meters, but below this the true compression wave can be seen. The offset of the compression source from the hole collar was increased in an effort to enhance the actual compression wave, but this was not effective. In general, only data points for the shallowest and for the very deepest measurement points are considered valid. An exception to this is hole N46, for which the compression-wave velocity seems plausible for the entire depth of the hole.

The question as to why the shear-wave data are considered valid and most of the compression signals are considered to be unreliable can only be answered intuitively. The nature of the contact between the steel casing and the surrounding rock is probably spotty and frictional rather than a solid, uniform, cemented bond as would be the case had it been grouted. A

compression wave propagating down through the rock must excite the casing along its axis, *i.e.*, in its stiff direction, in order to be detected by the vertically-sensitive geophone locked inside the casing. I suspect it is difficult for a compression wave with sufficient amplitude to be transmitted across the friction contact between the rock and steel pipe. Conversely, a downward traveling shear wave excites the casing in its radial or flexible direction, and any slippage along the length of the casing at the boundary would not be an issue.

The final values of shear-wave velocities are shown in the attached tables. Compression-wave velocities are not tabulated because of the spotty and questionable results due to interference from the casing wave.

Discussion

All things considered, the overall quality of the raw shear-wave data is unexpectedly good. There is surprisingly little scatter of the data points about their respective trend lines. The scatter is most probably attributable to the absence of grout and the intermittent contact between the steel casing and the rock. The scatter is not due to insufficient signal amplitudes, to noise from extraneous sources such as nearby machinery, nor to some systemic flaw in the recording instrumentation or procedures.

The most questionable data were acquired in hole N71, and two attempts were required to obtain plausible shear signals. The shear waves collected in the first attempt were judged to be non-identifiable, and the source was moved to another location for the second try, which resulted in marginally acceptable signals.

The near-surface velocity inversion at hole N27, noted earlier as an impediment to a refraction survey, is shown on the plot of travel times against depth for that hole. The inversion exists immediately below a thin (≈5 ft), relatively fast (V_s≈2500± ft/sec) layer of rock present right at the surface. In our attempt to collect shear-wave refraction data at N27, usable signals would not propagate beyond about 100 ft, despite many blows to the shear-wave beam, and only the velocity of the thin layer at the surface was evident on the time *vs.* distance plot.

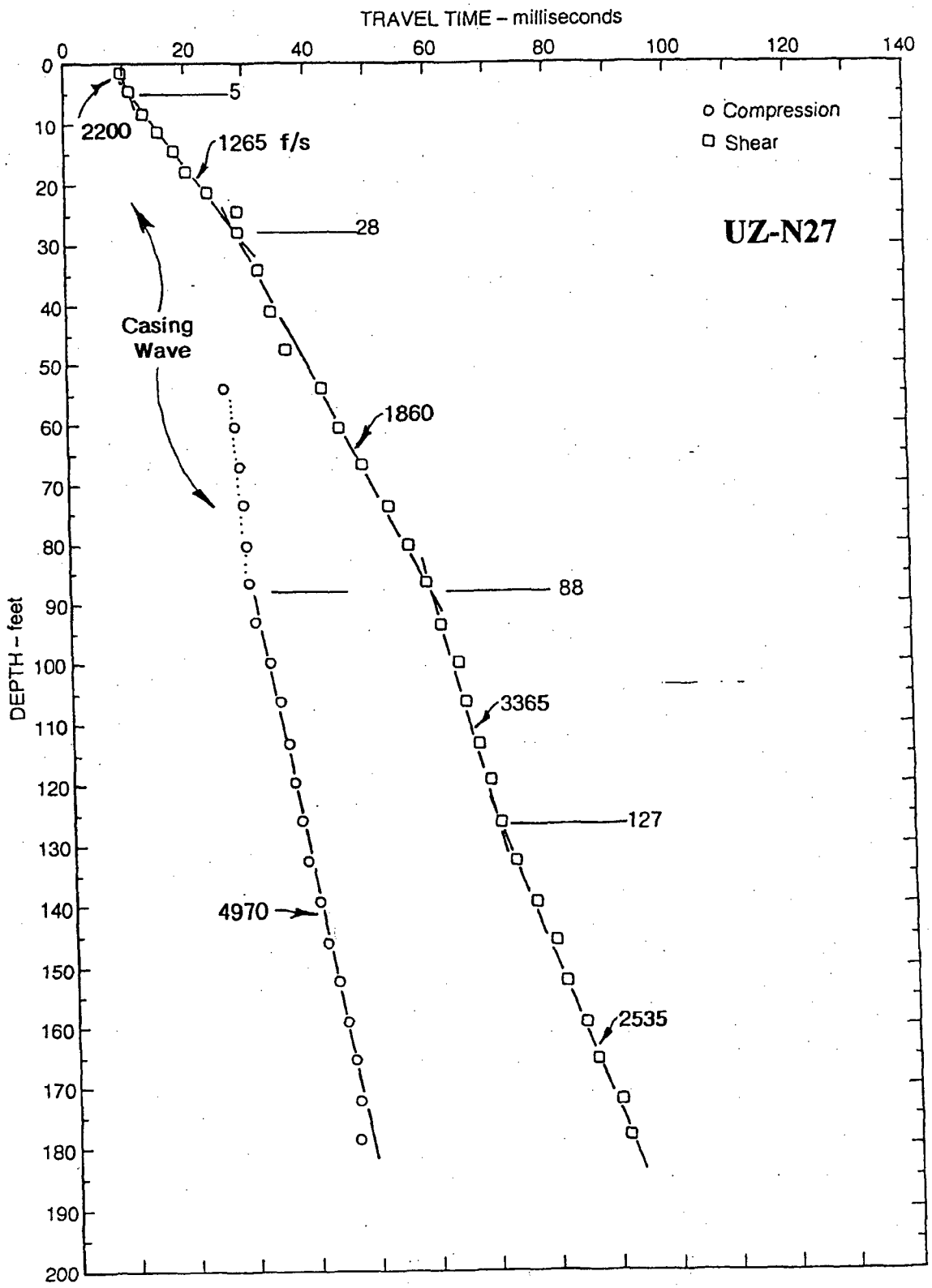
There is always some judgement involved when assigning travel-time data points to a layer. Often the change of slope of the data points is not especially pronounced when crossing the boundary between one velocity zone and the one immediately below, and the exact depth of the boundary becomes somewhat uncertain due to the inherent scatter in the data. Nevertheless, least-squares calculations of slopes were used to determine shear-wave velocities in each hole.

The wide range in the values of shear-wave velocity in the neutron-logging holes and the apparent lack of stratigraphic correlation between holes demonstrate the heterogeneous nature of the volcanic deposits that comprise the Yucca Mountain site.

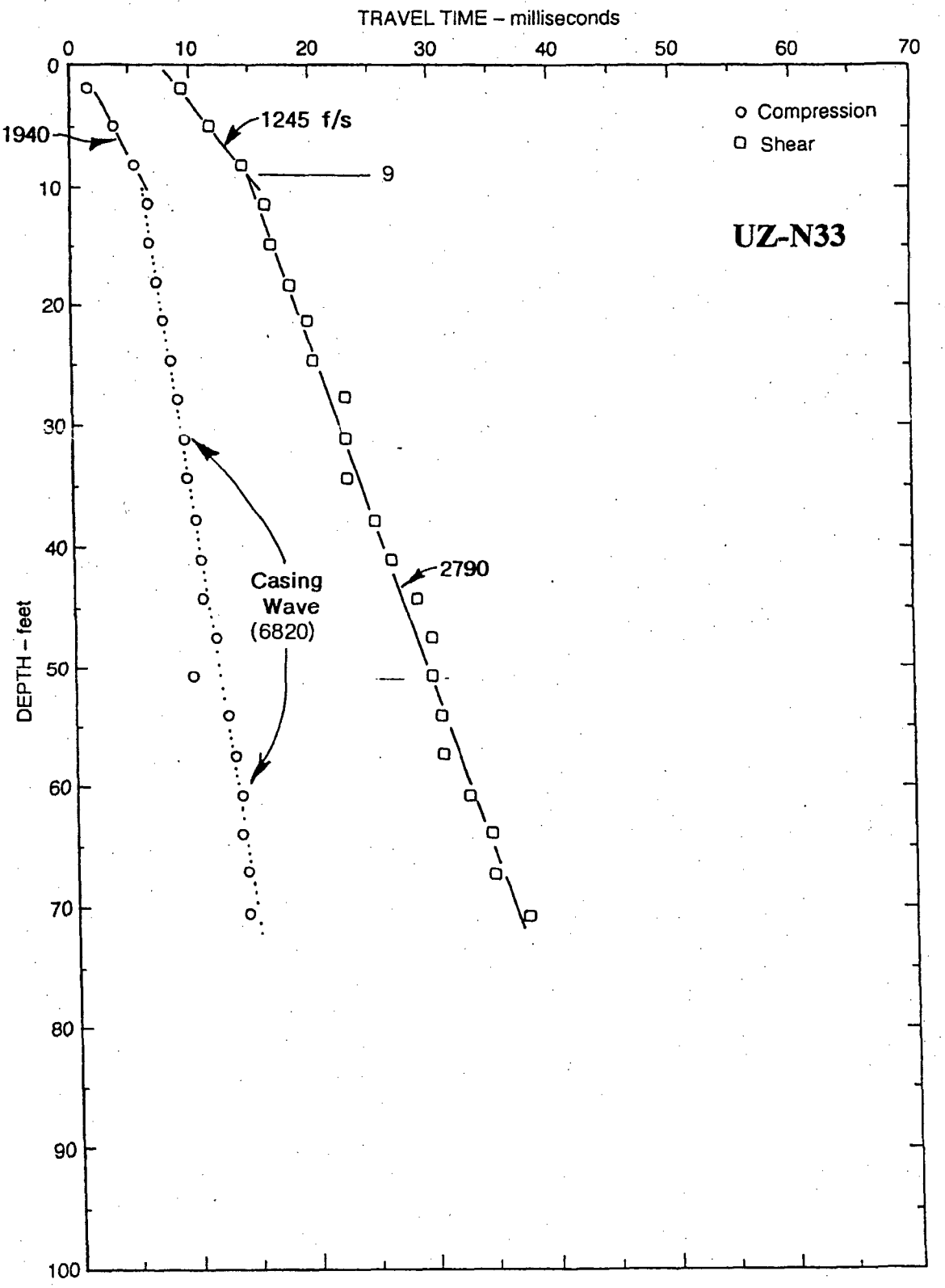
Yucca Mountain Project
DOWNHOLE SHEAR-WAVE VELOCITIES
Crest of Yucca Mountain

Borehole Number	Depth Range - ft	Velocity – ft/sec
UZ-N27	1.5 - 5	2200
	5 – 28	1265
	28 – 88	1860
	88 – 127	3365
	127 – 179	2535
UZ-N33	1.5 – 9	1245
	9 – 71	2790
UZ-N46	2 – 31	1275
	31 – 81	1580
	81 – 95	5500±
UZ-N64	2 – 8	1735
	8 – 31	2140
	31 – 41	3995
	41 – 54	2190
UZ-N66	2 – 5	1525
	5 – 31	2650
	31 – 48	1280
UZ-N71	2 – 22	1735
	22 – 48	5000±
UZ-N75	1.5 – 10	2065
	10 – 28	2680
UZ-N94	1.5 – 25	2835

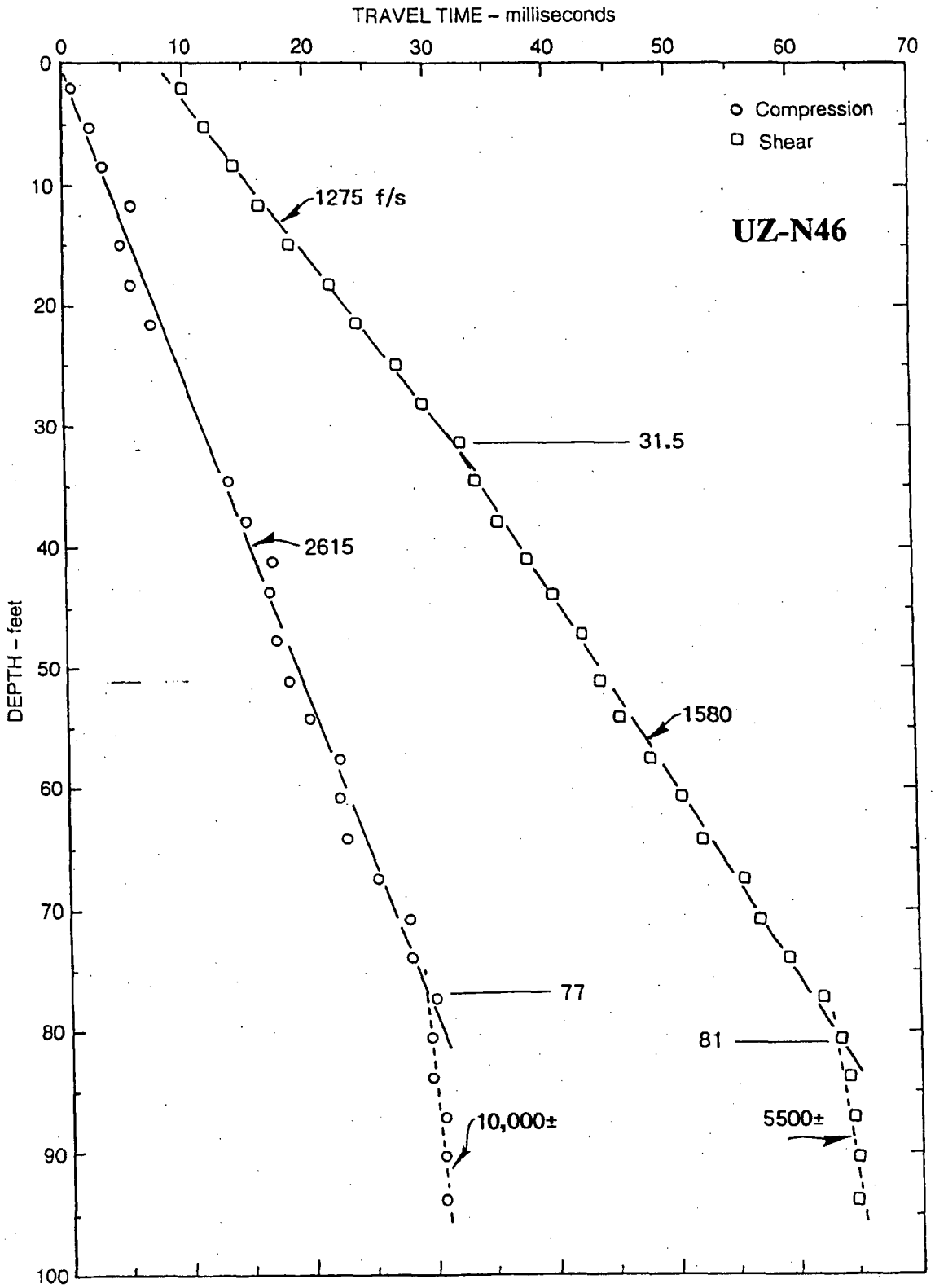
2



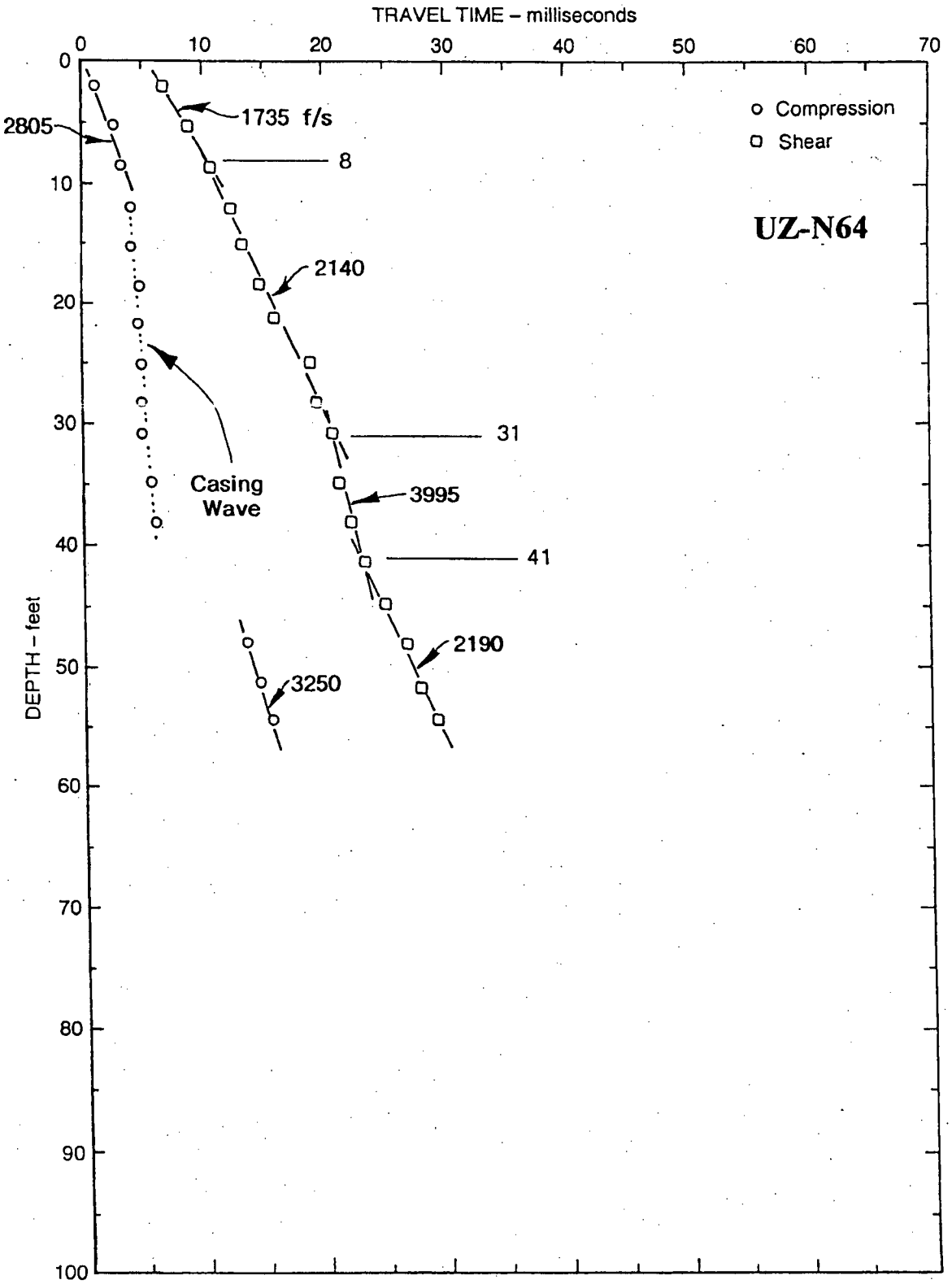
Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N27**, Yucca Crest, YMP Project, June 2001.



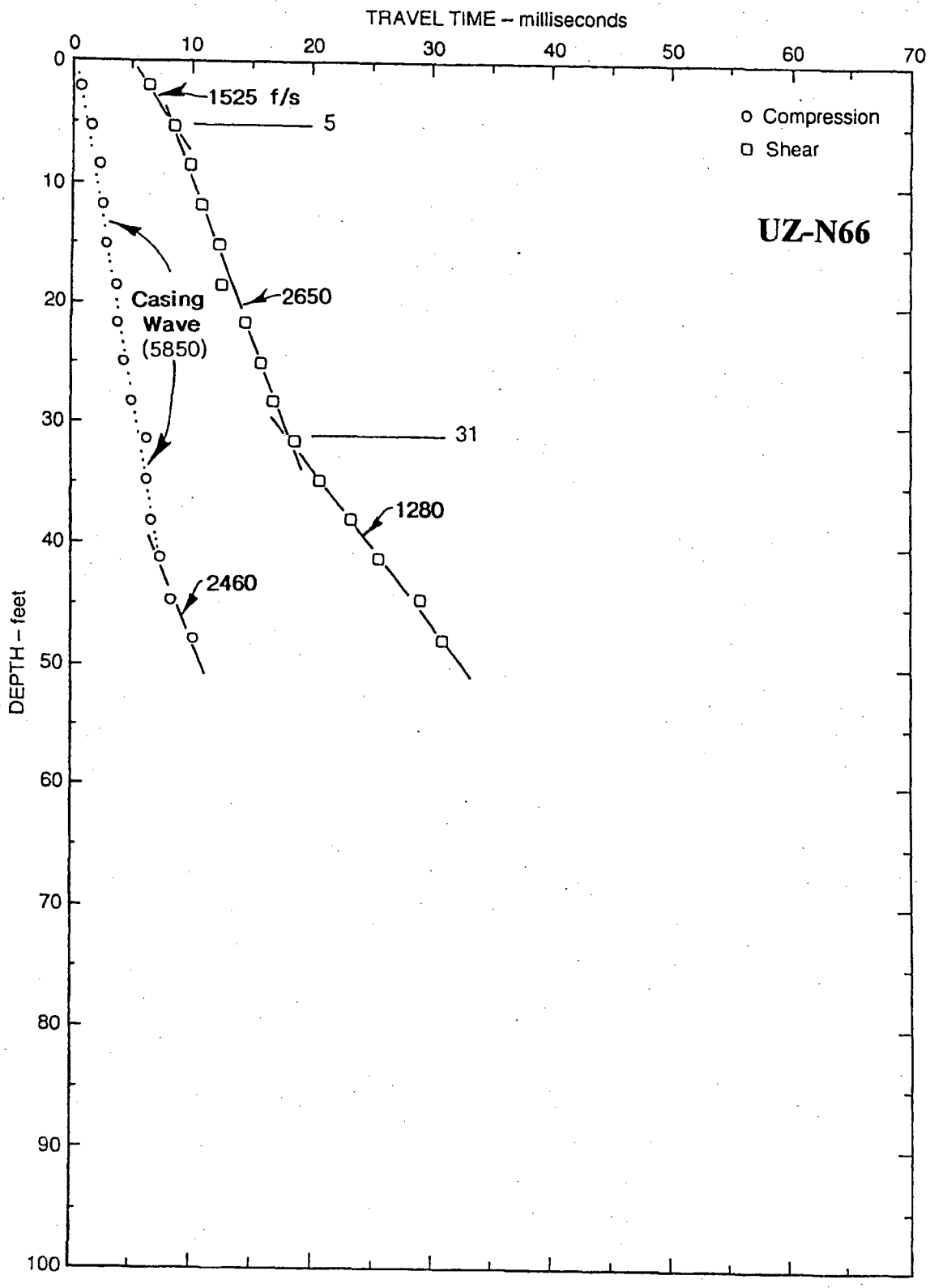
Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N33**, Yucca Crest, YMP Project, June 2001.



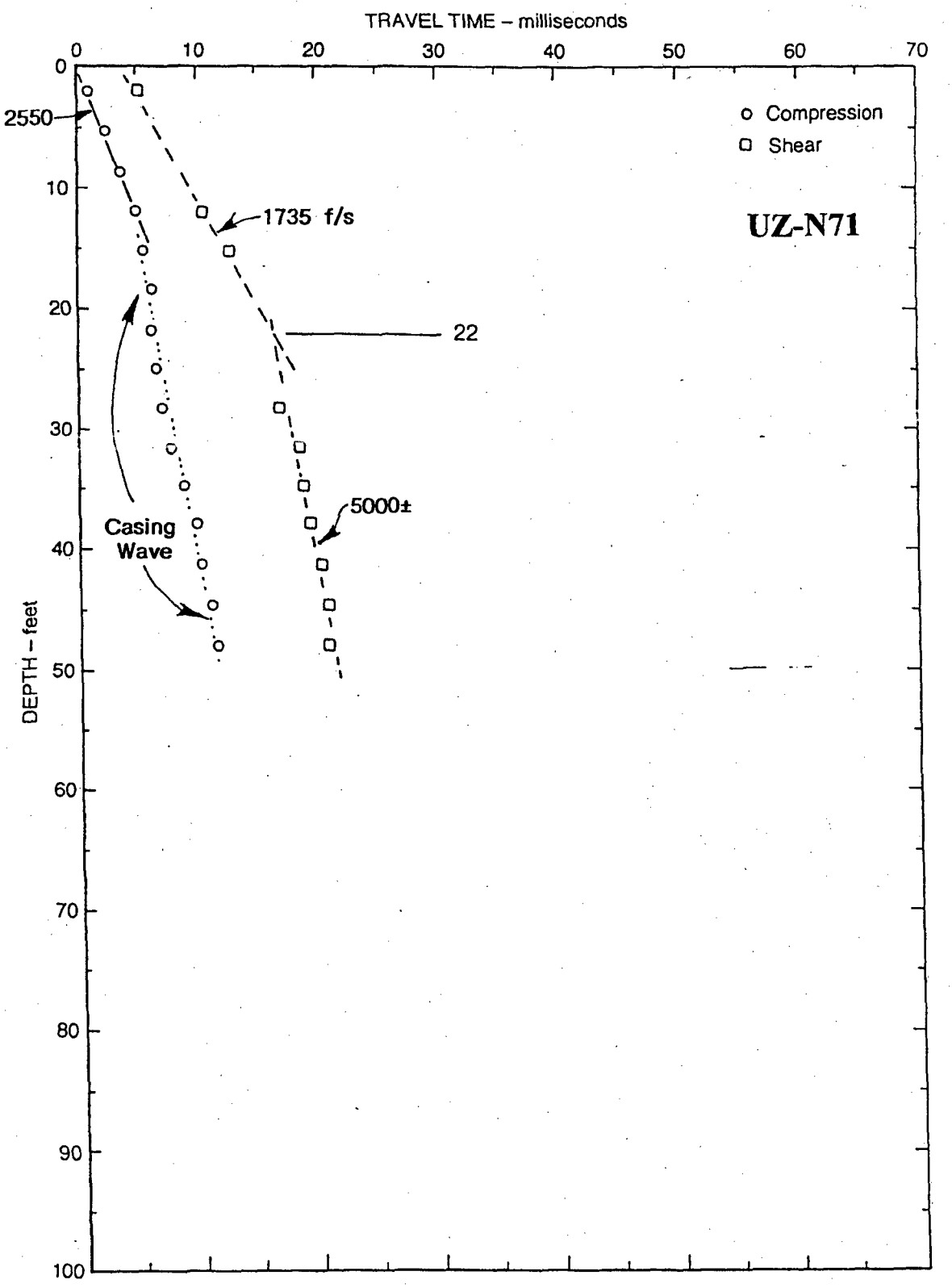
Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N46**, Yucca Crest, YMP Project, June 2001.



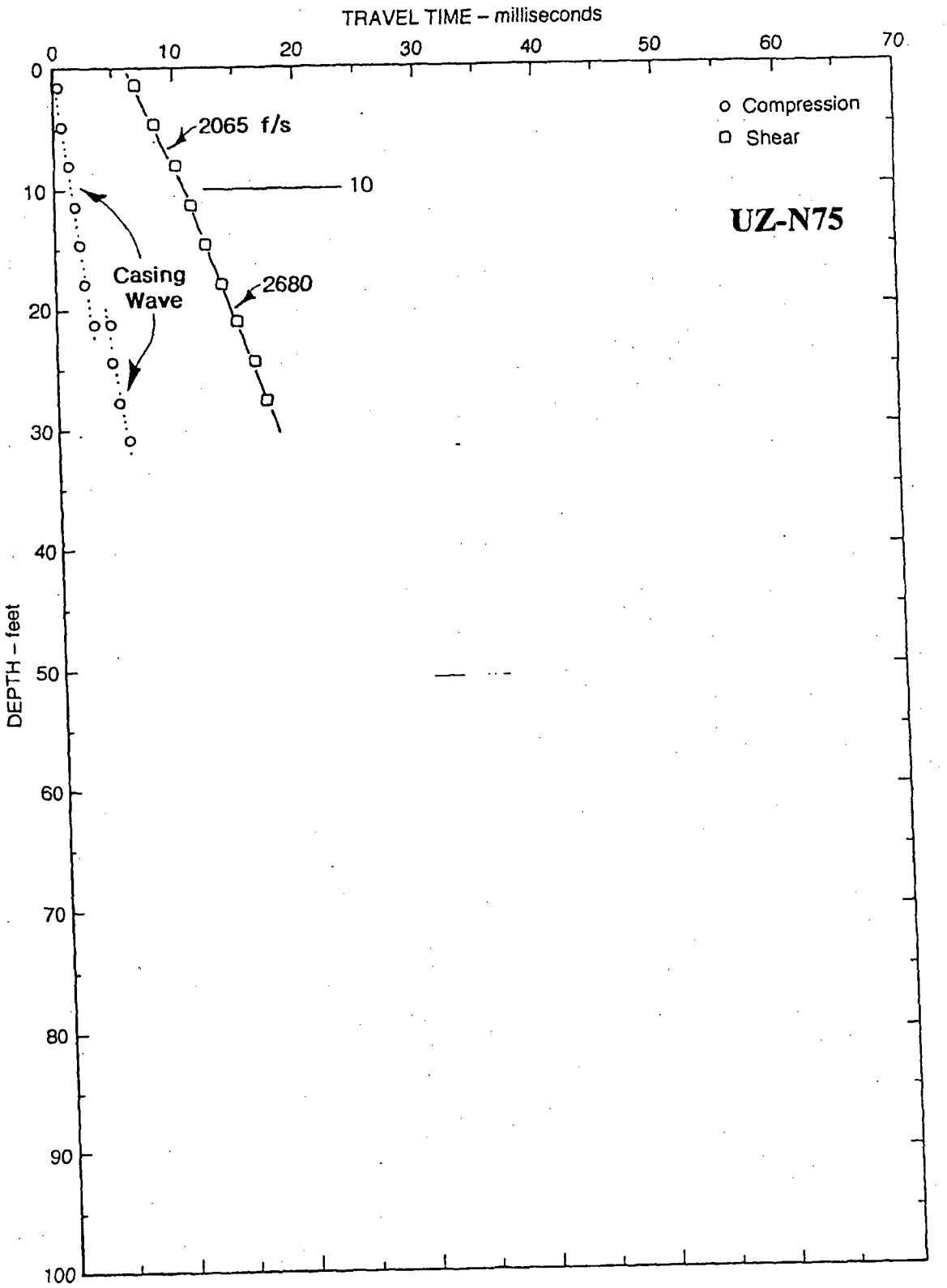
Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N64**, Yucca Crest, YMP Project, June 2001.



Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N66**, Yucca Crest, YMP Project, June 2001.



Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N71**, Yucca Crest, YMP Project, June 2001.



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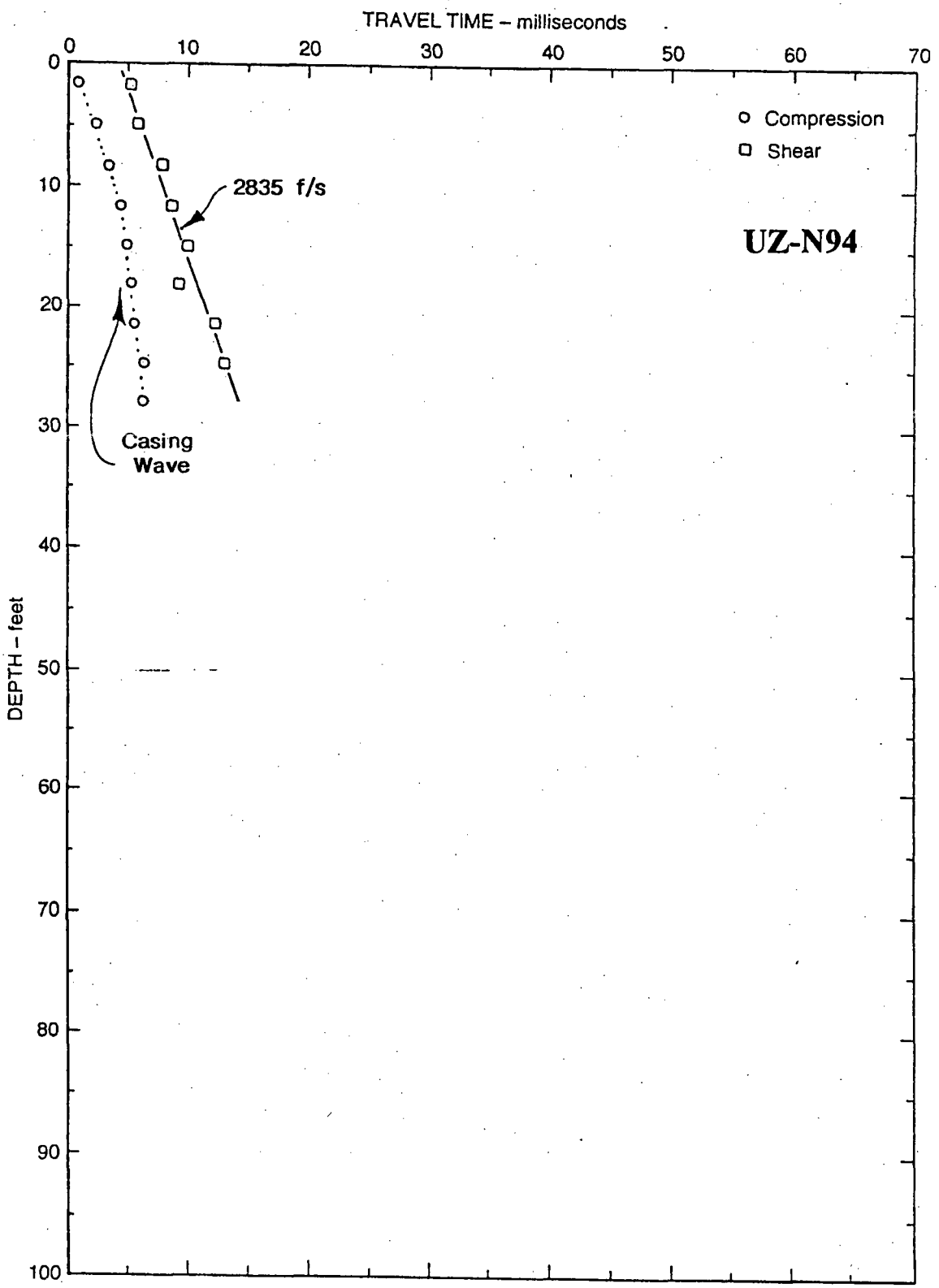
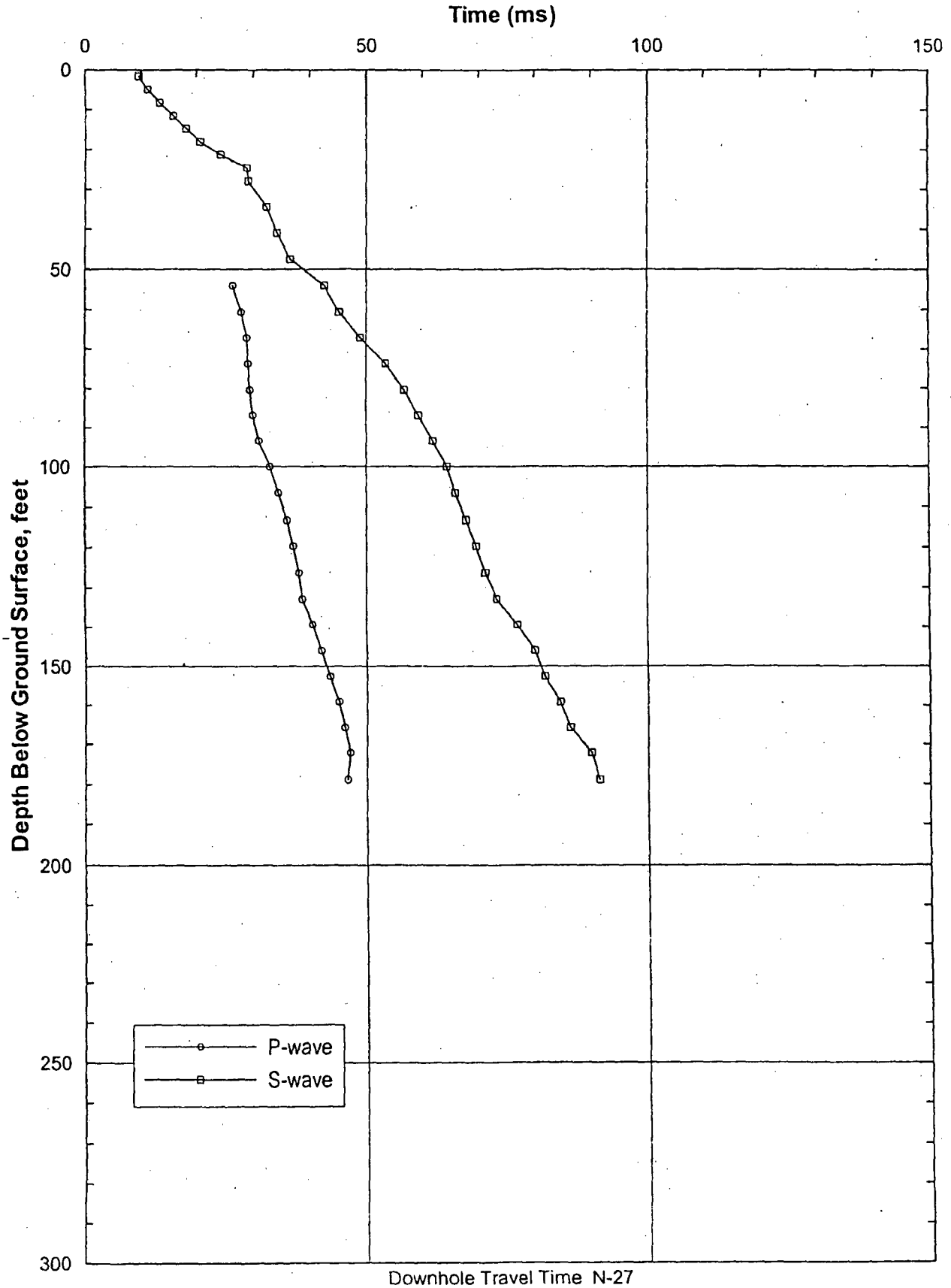


Downhole travel times together with corresponding velocities and depths to interfaces for hole **UZ-N94**, Yucca Crest, YMP Project, June 2001.



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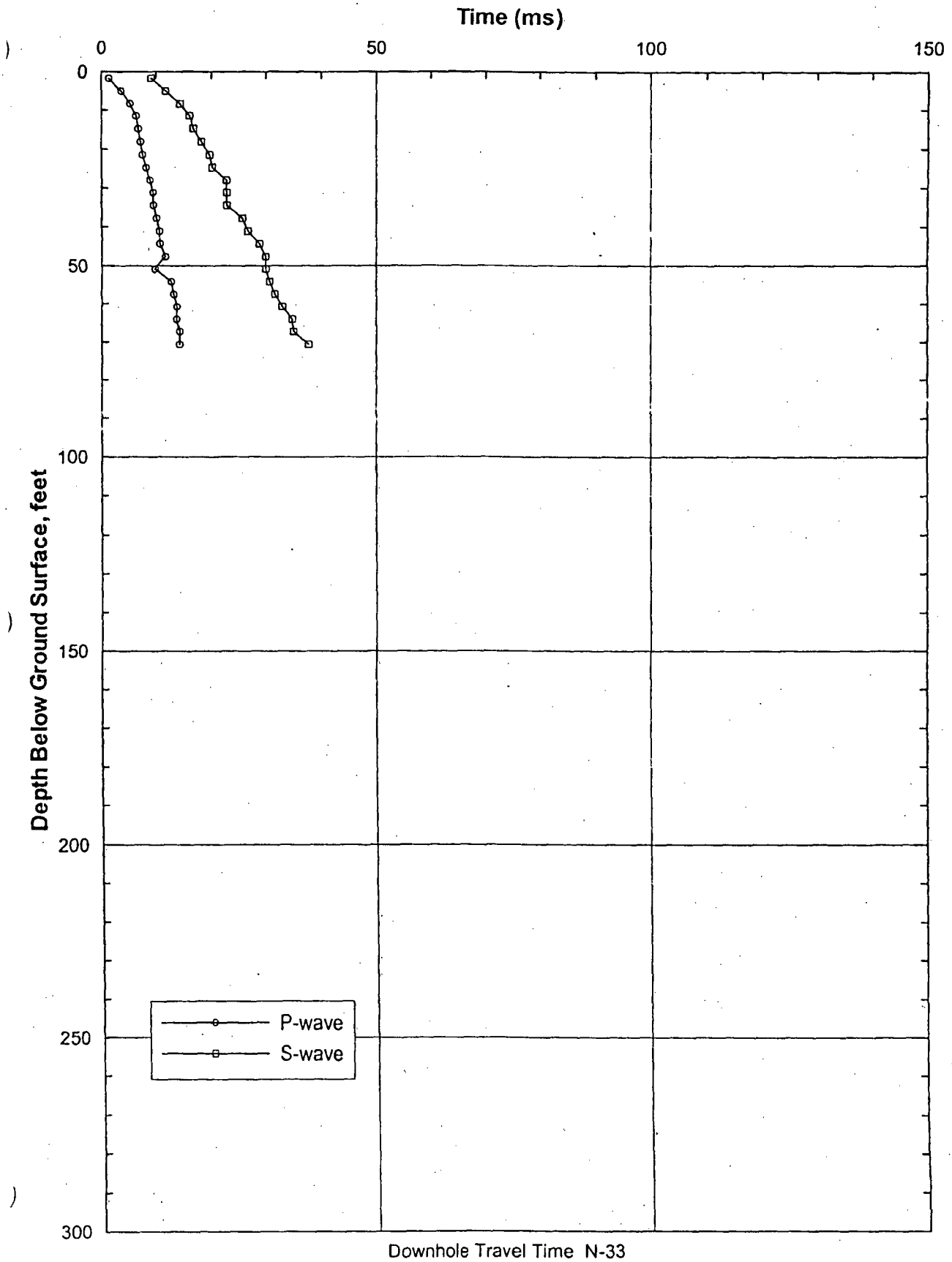

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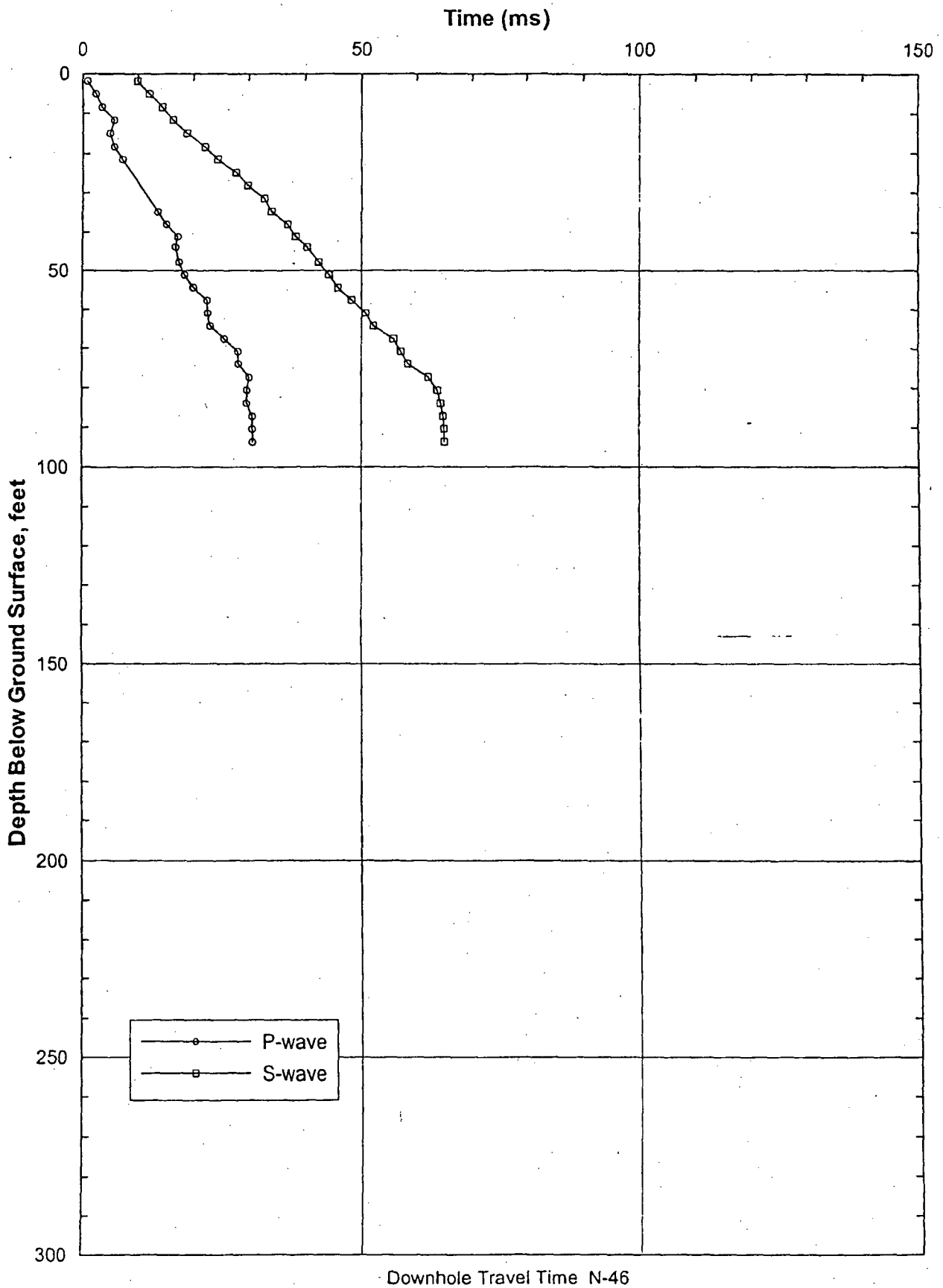

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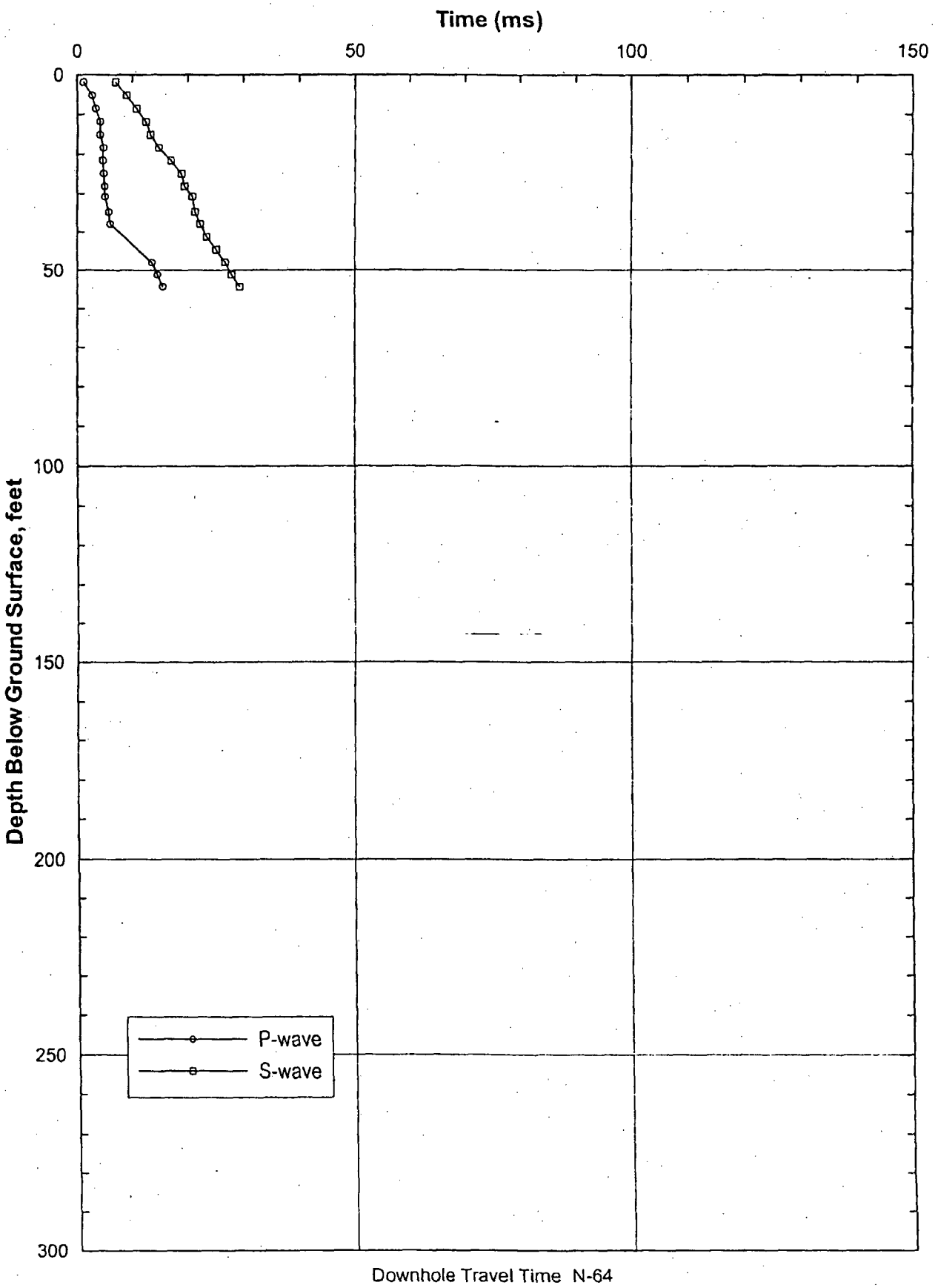

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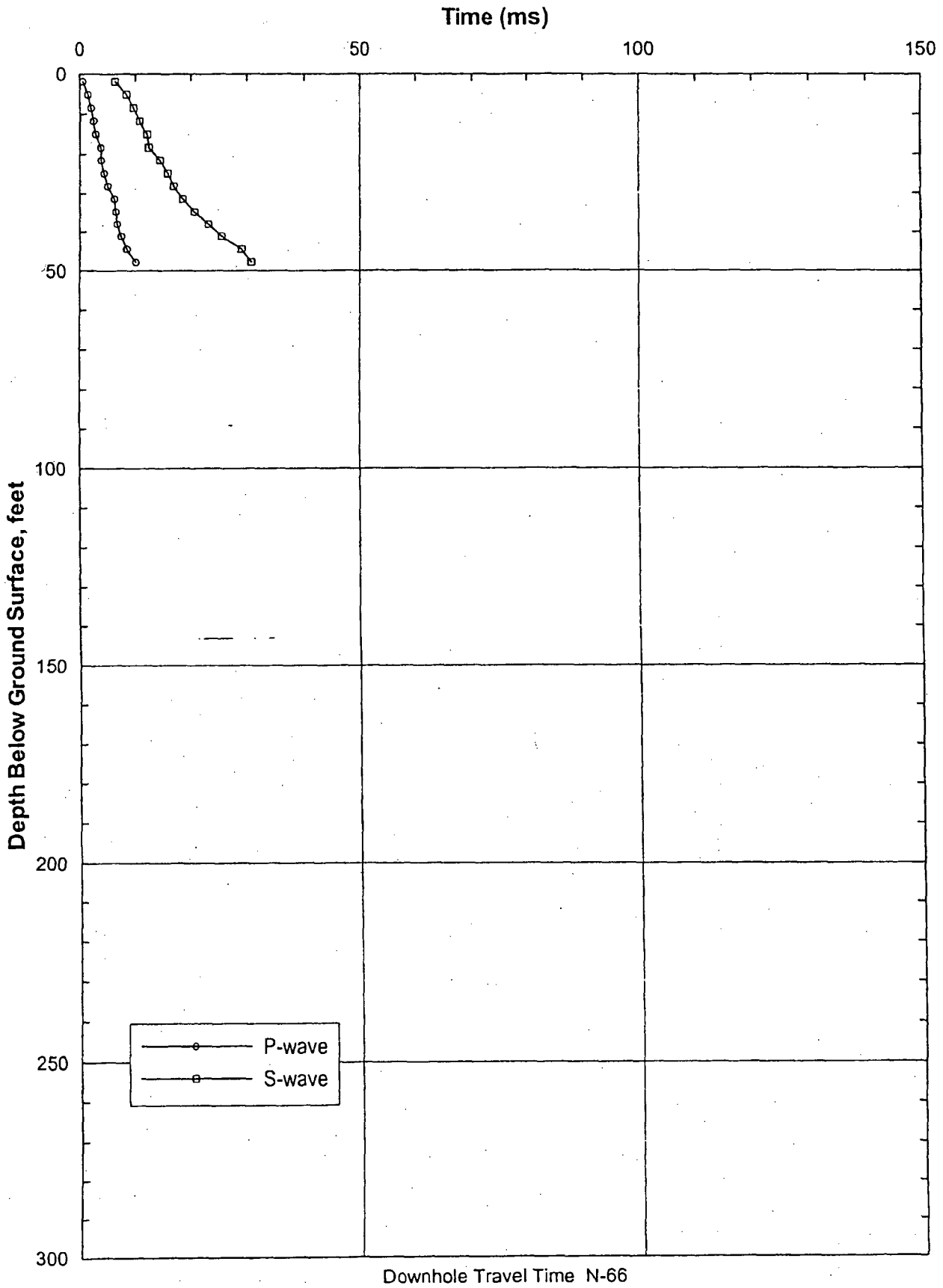

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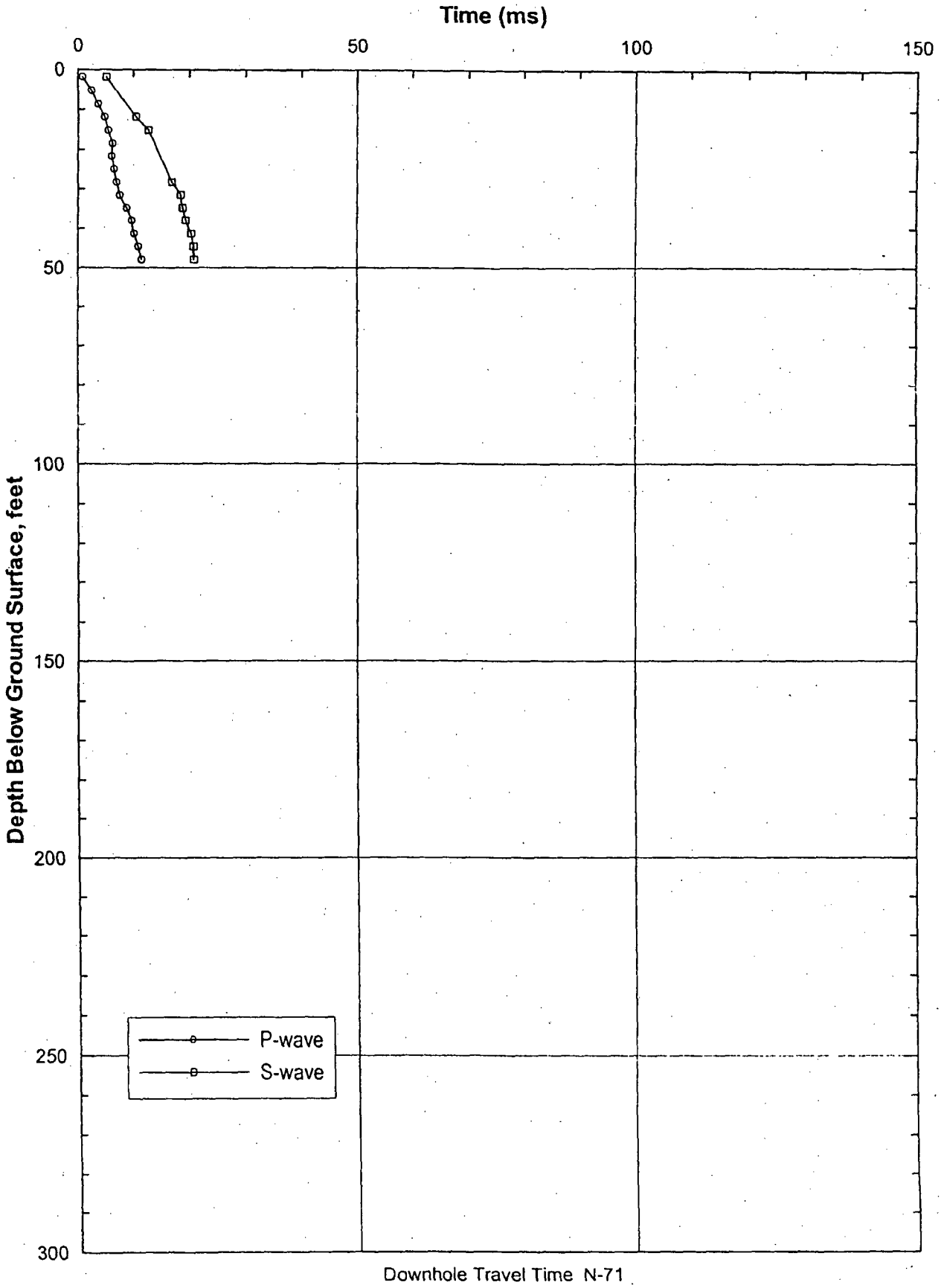

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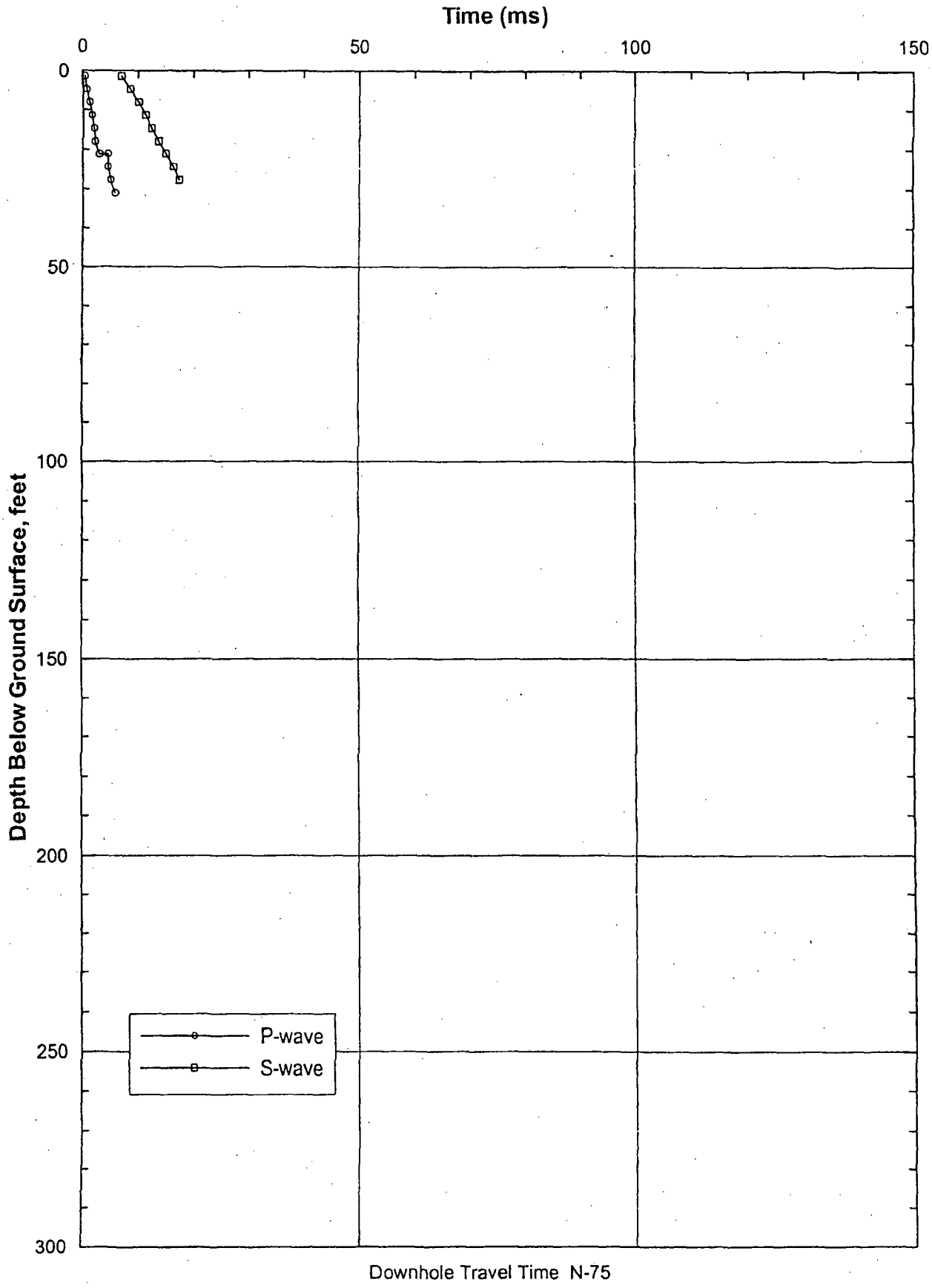

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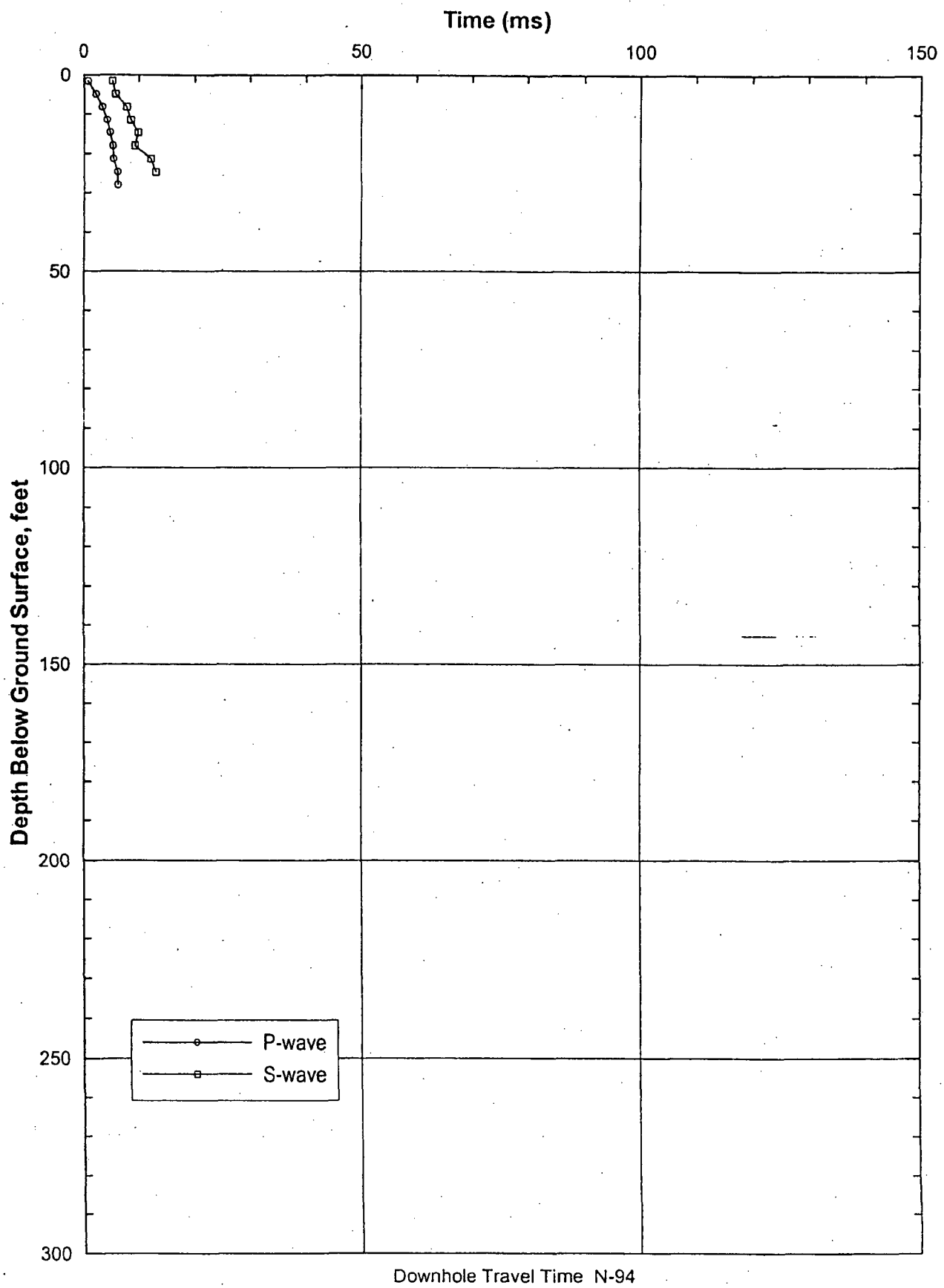

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3

Downhole Velocity Records

SHEAR WAVES

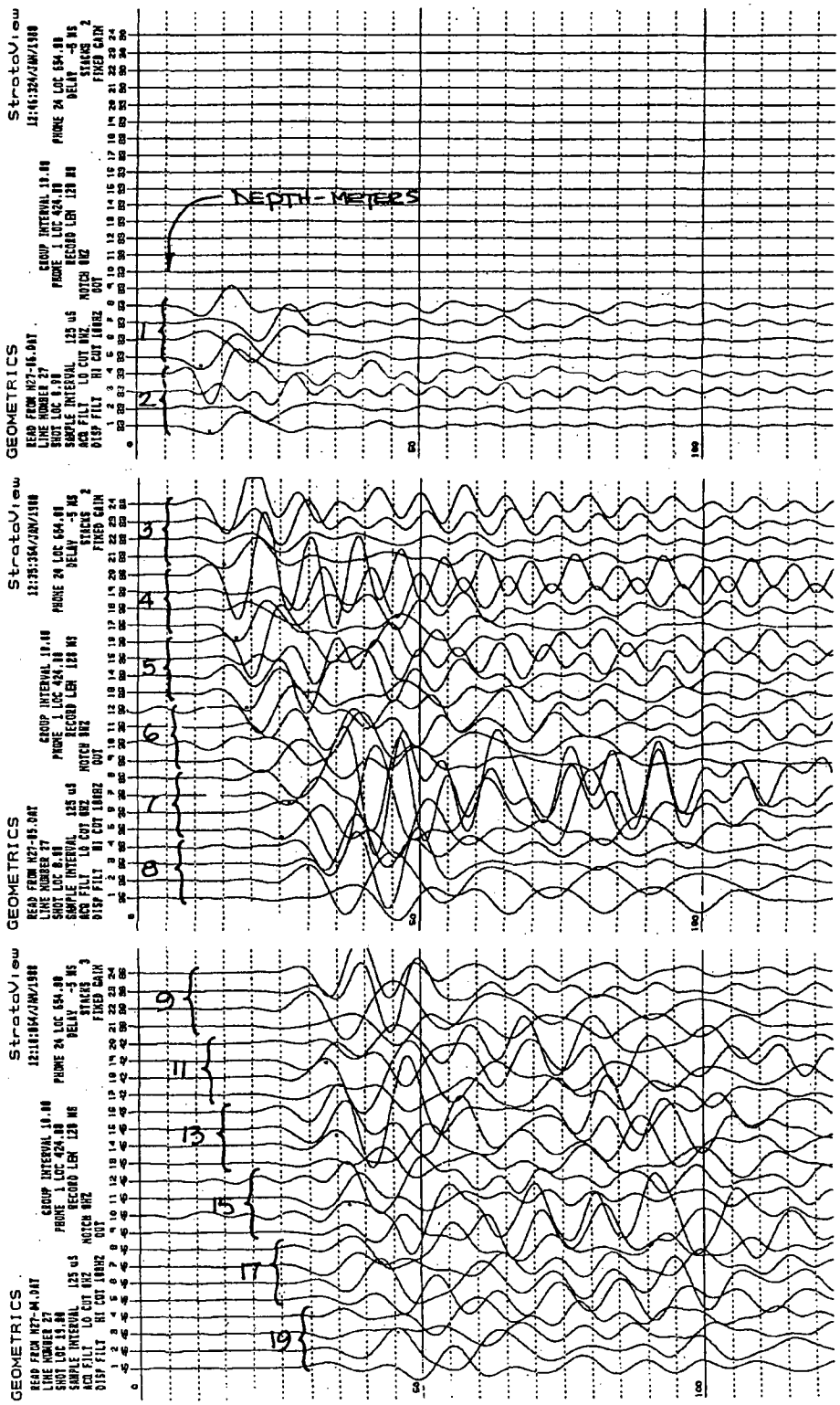
Project YMP CREST

Borehole UZ-N27

Playback Filter 100 Hz Low Pass

Time Scale 5 Milliseconds/Line

Source Offset 8.1 ft



Downhole Velocity Records

SHEAR WAVES

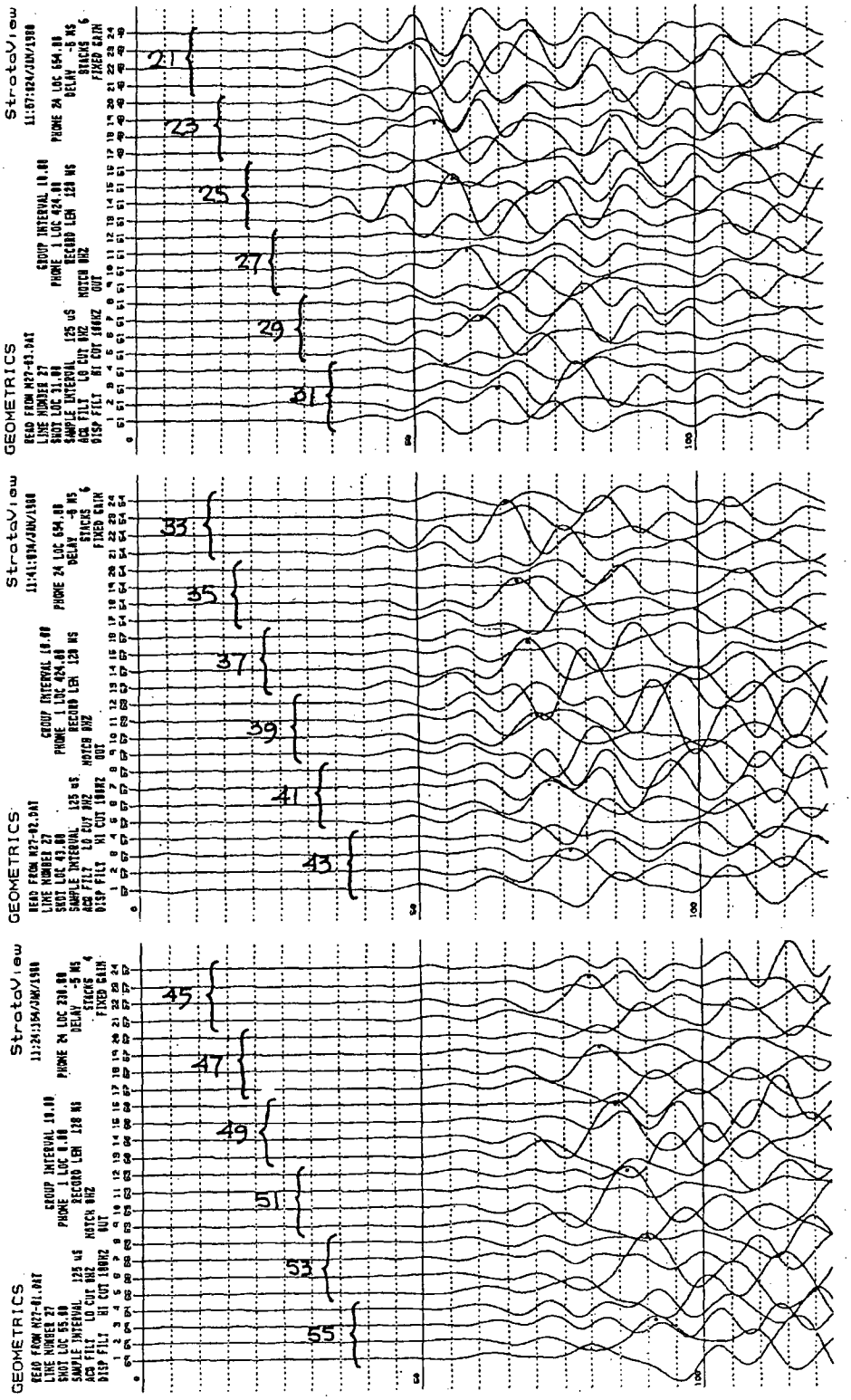
Project YMP CREST

Borehole UZ-N27

Playback Filter 100 Hz Low Pass

Time Scale 5 Milliseconds/Line

Source Offset 8.1 ft



Downhole Velocity Records

SHEAR WAVES

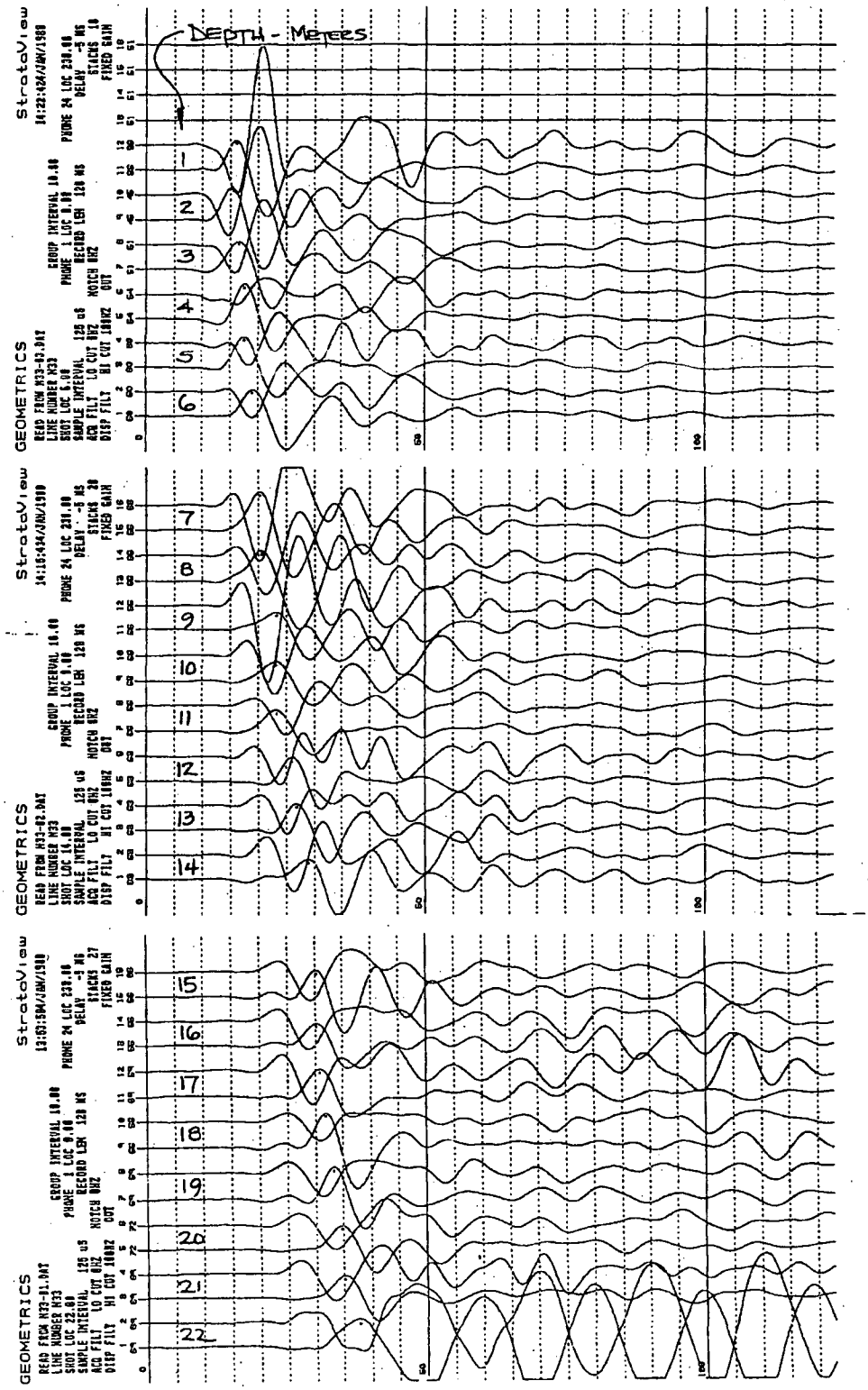
Project YMP CREST

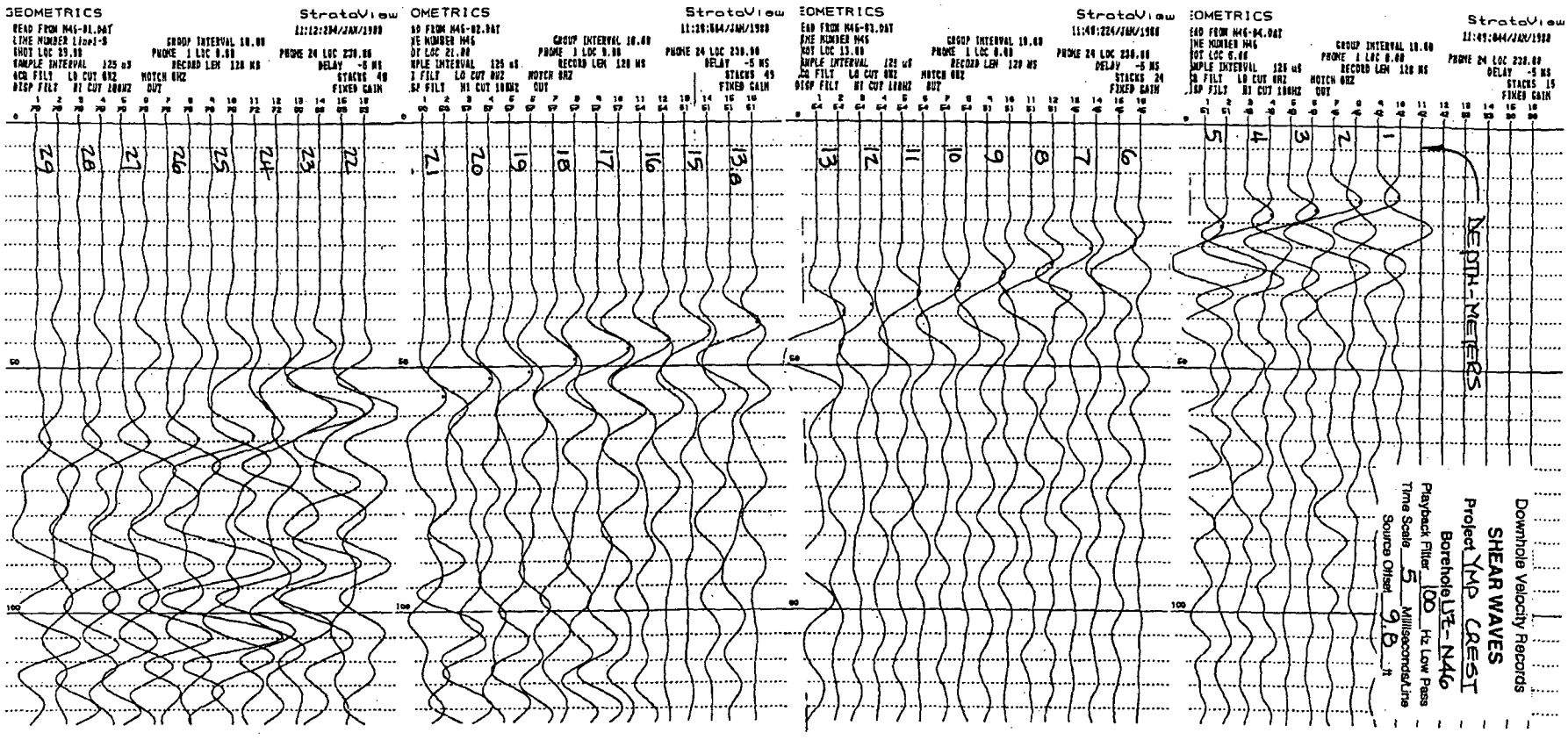
Borehole LZ-N33

Playback Filter 100 Hz Low Pass

Time Scale 5 Milliseconds/Line

Source Offset 6.7 ft





Downhole Velocity Records

SHEAR WAVES

Project YMP CREST

Borehole LTT-N46

Playback Filter 100 Hz Low Pass

Time Scale 5 Milliseconds/Line

Source Offset 9.8 ft

Downhole Velocity Records

SHEAR WAVES

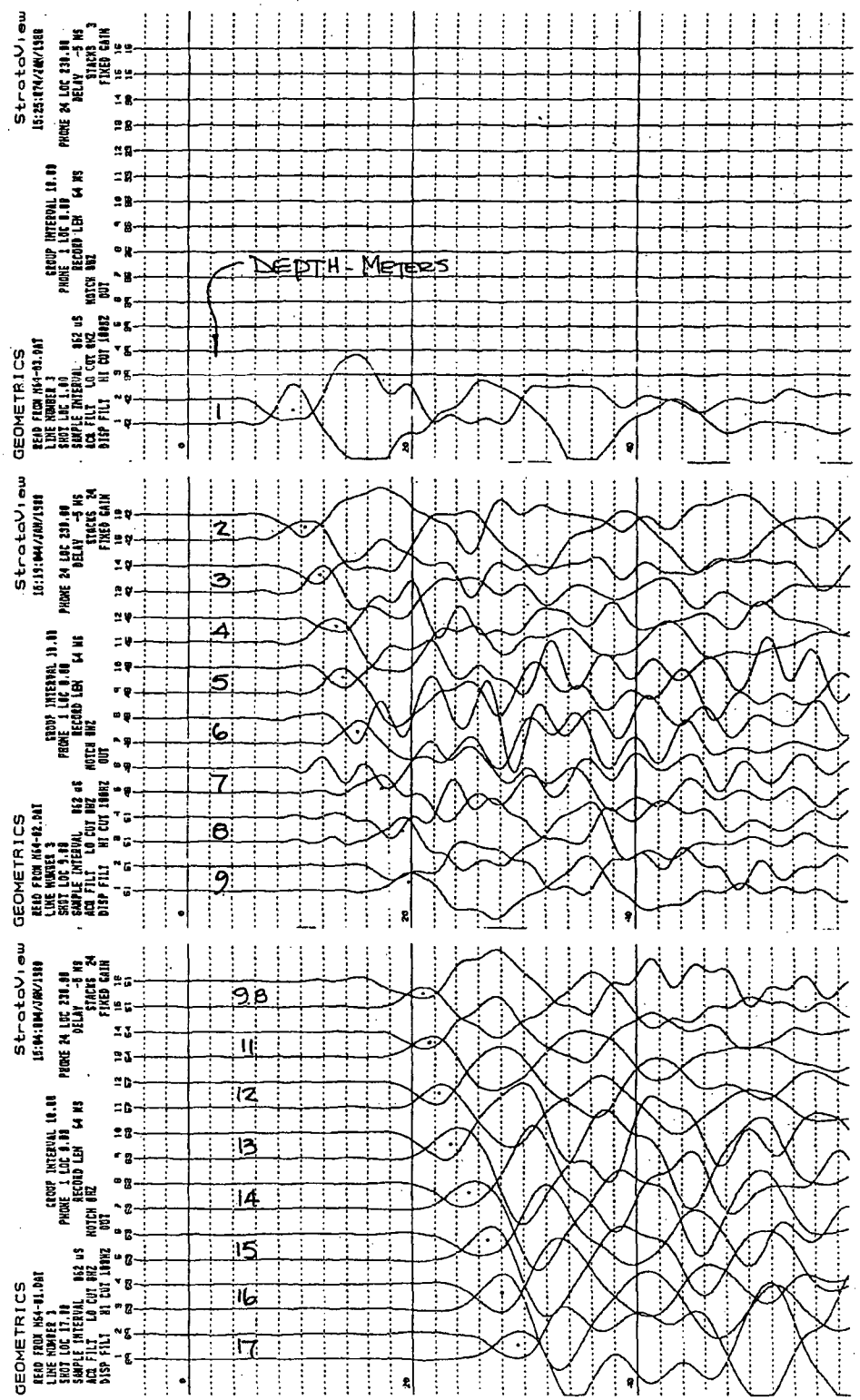
Project YMP CREST

Borehole UZ-N64

Playback Filter 100 Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 5.6 ft



Downhole Velocity Records

SHEAR WAVES

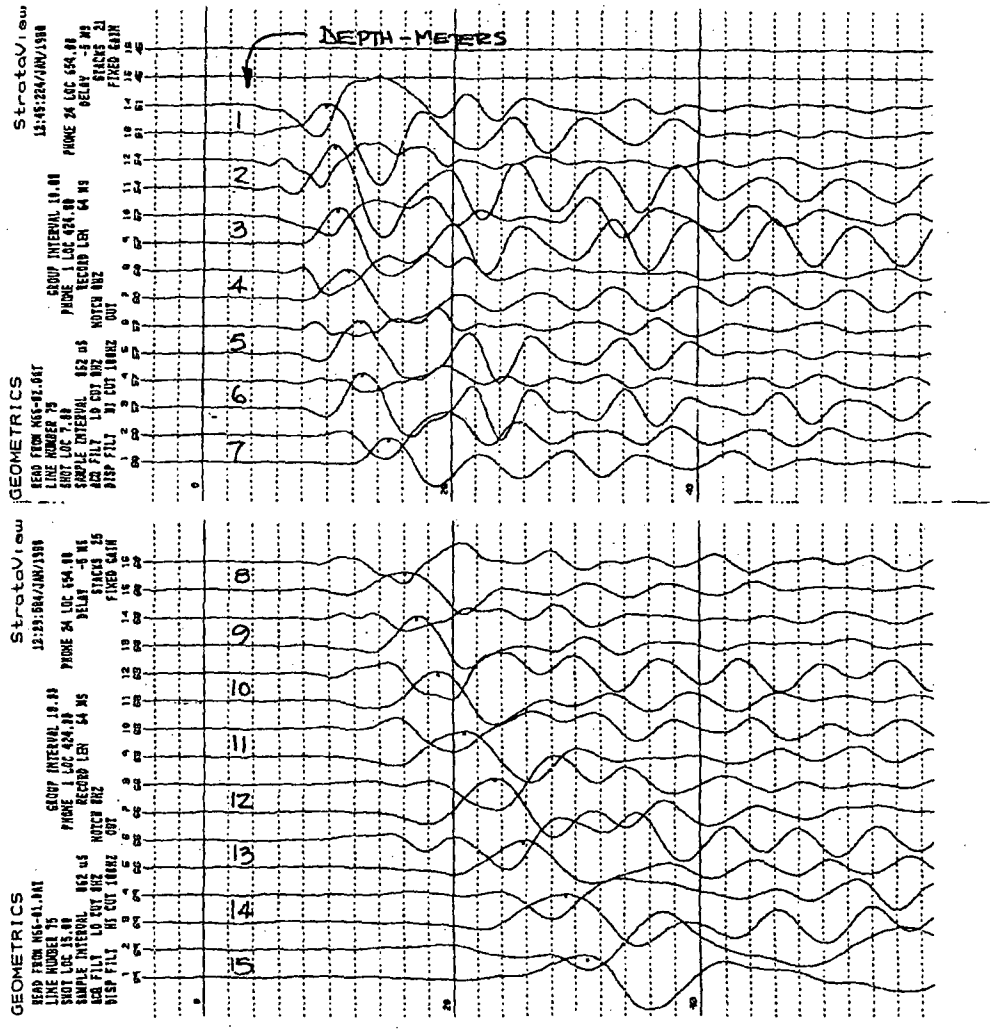
Project YMP CREST

Borehole UZ-N66

Playback Filter 100 Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 6.2 ft



Downhole Velocity Records

SHEAR WAVES

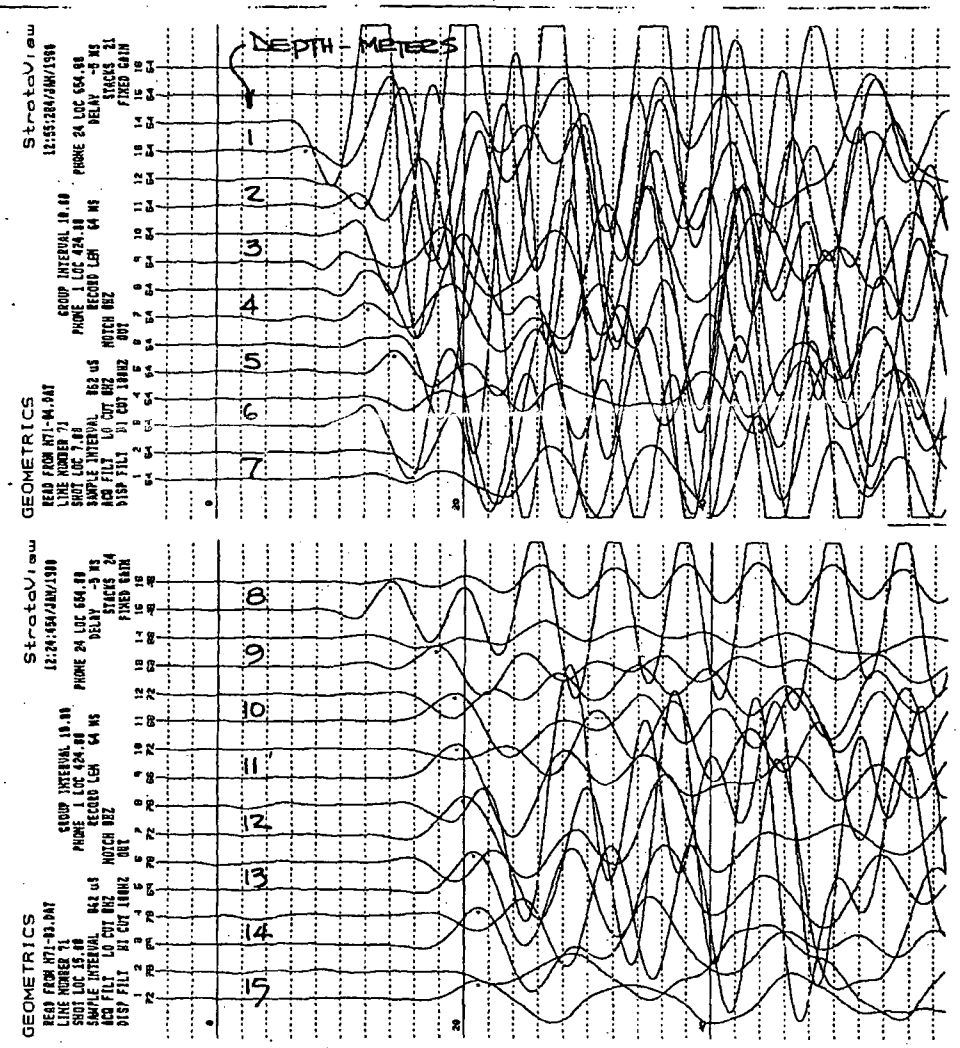
Project YMP CREST

Borehole UZ-N71

Playback Filter 100 Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 10.1 ft



Downhole Velocity Records

SHEAR WAVES

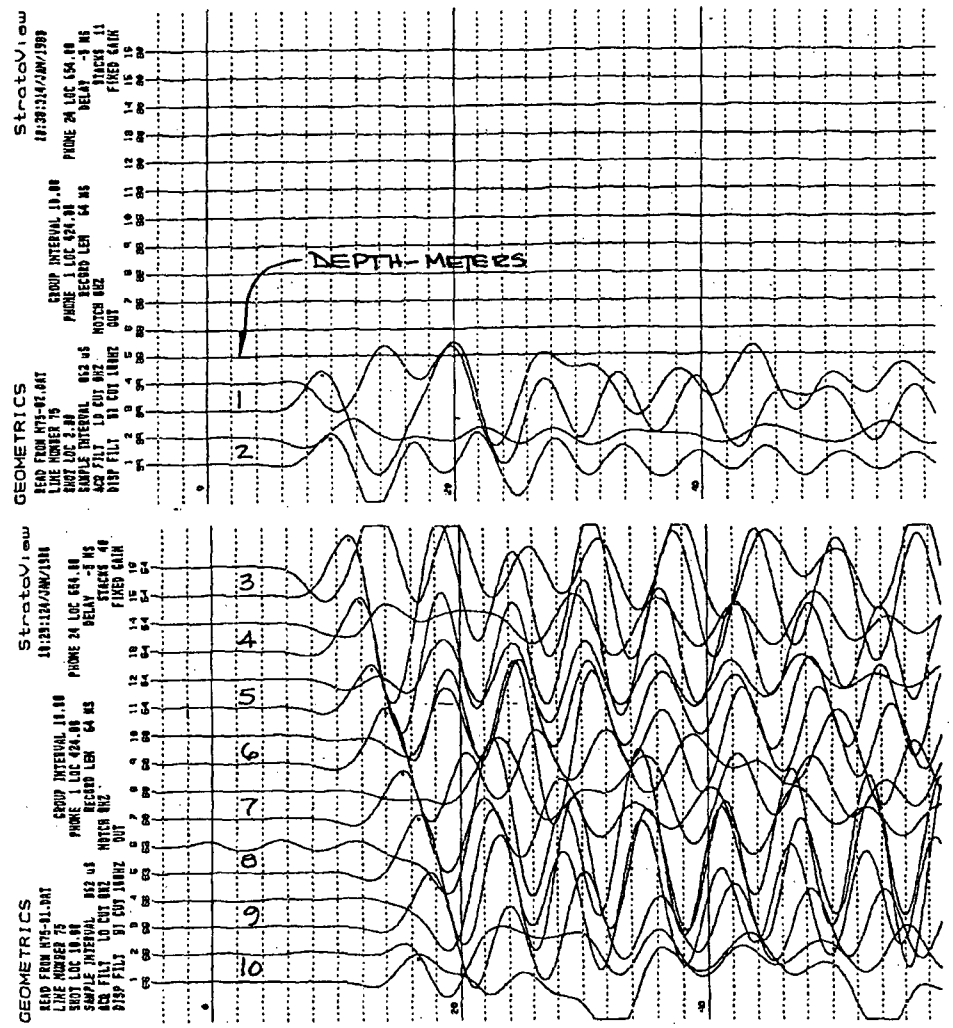
Project YMP CREST

Borehole UZ-N75

Playback Filter 100 Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 5.9 ft



Downhole Velocity Records

SHEAR WAVES

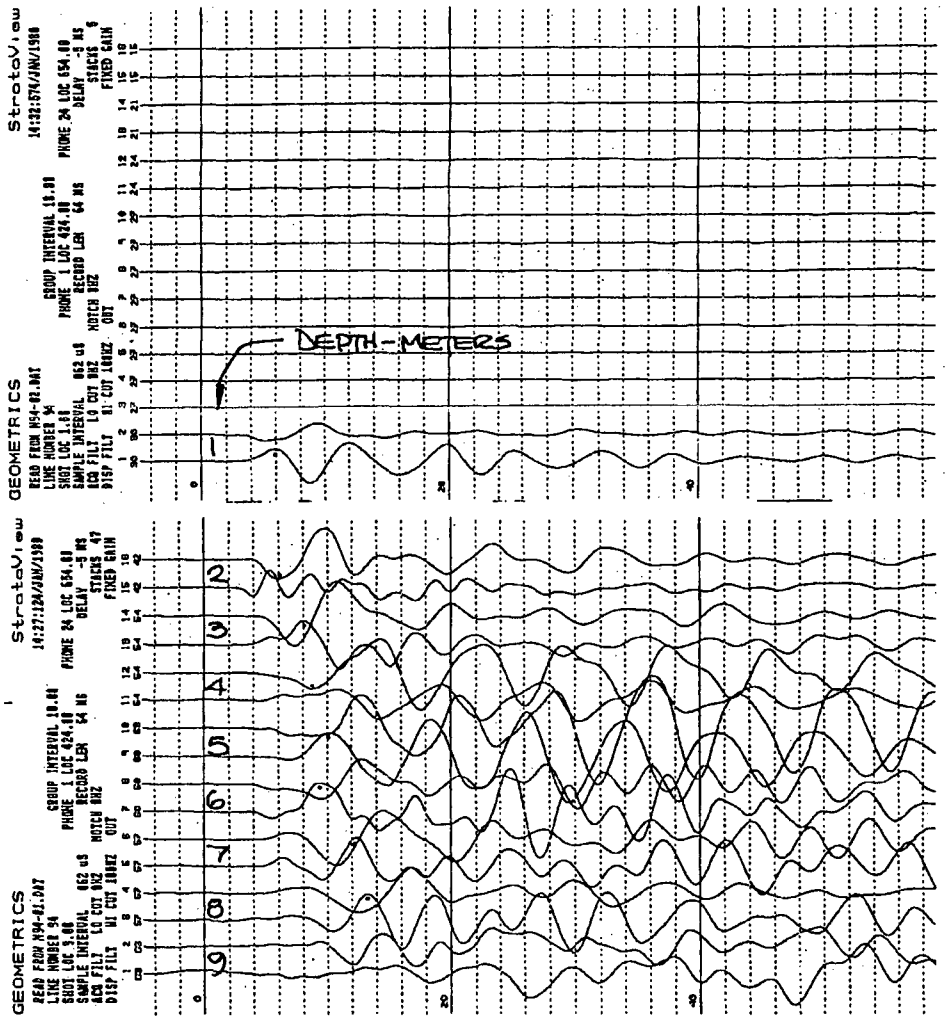
Project YMP CREST

Borehole UZ-N94

Playback Filter 100 Hz Low Pass

Time Scale _____ Milliseconds/Line

Source Offset 4.8 ft



4

Downhole Velocity Records

COMPRESSION WAVES

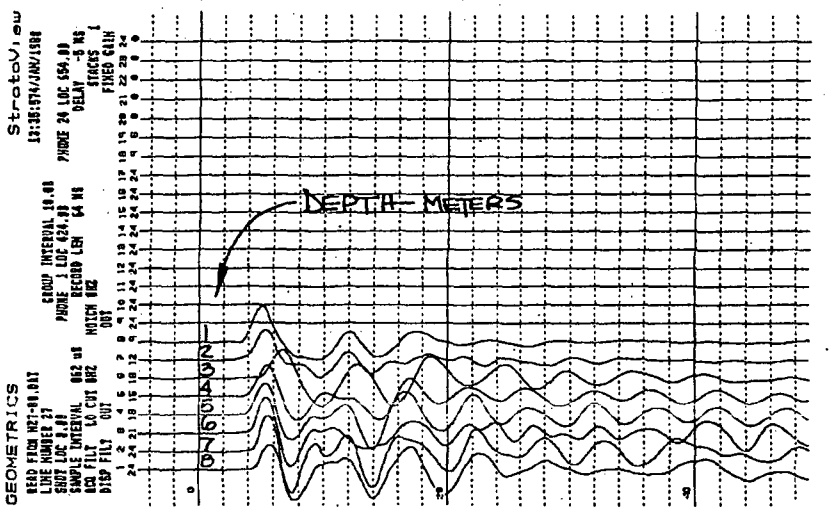
Project YMP CREST

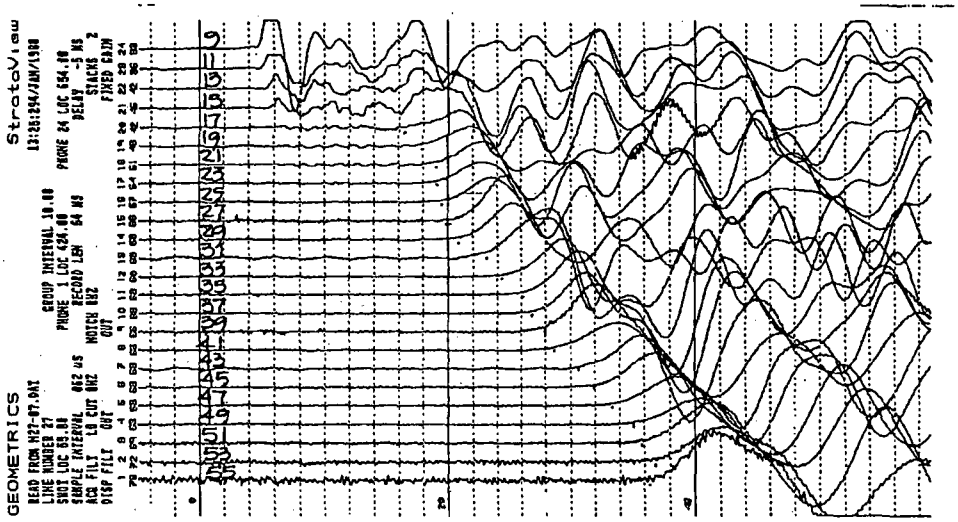
Borehole UZ-N27

Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 51 ft





Downhole Velocity Records

COMPRESSION WAVES

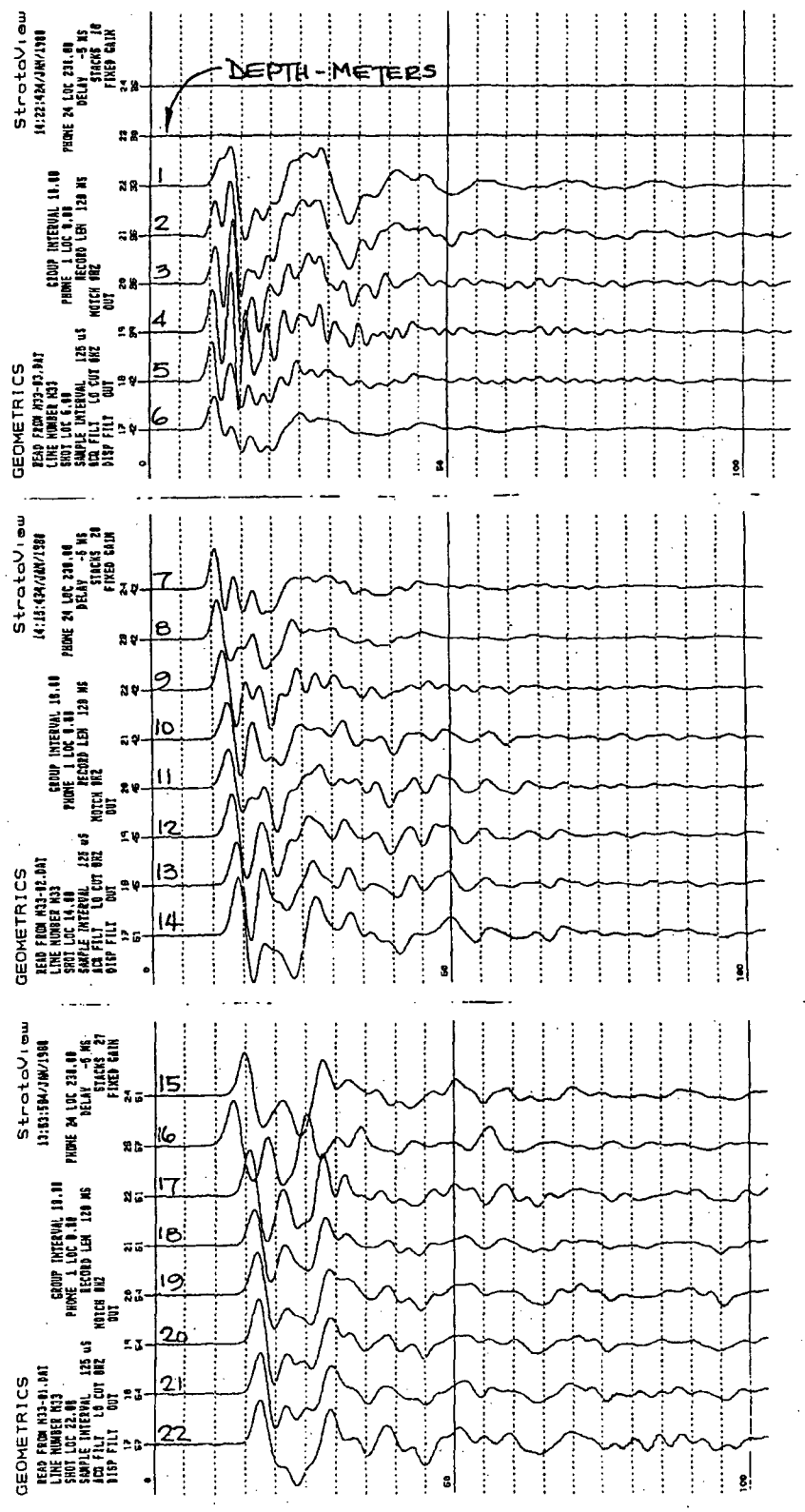
Project YMP CREST

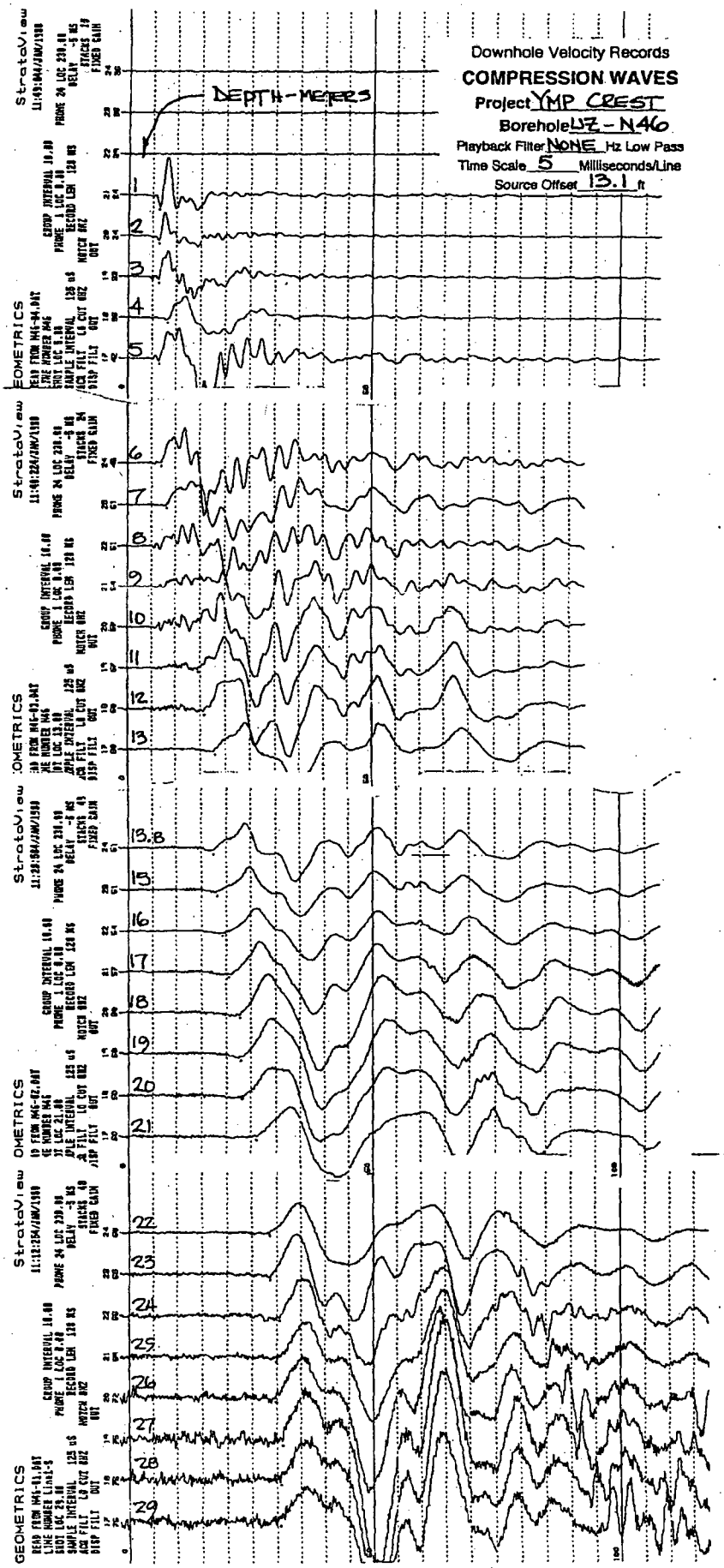
Borehole UZ-N33

Playback Filter NONE Hz Low Pass

Time Scale 5 Milliseconds/Line

Source Offset 11.3 ft




Downhole Velocity Records
COMPRESSION WAVES
Project YMP CREST
Borehole UZ-N46
Playback Filter NONE Hz Low Pass
Time Scale 5 Milliseconds/Line
Source Offset 13.1 ft
DEPTH-METERS
StrataView
GEOMETRICS
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Downhole Velocity Records

COMPRESSION WAVES

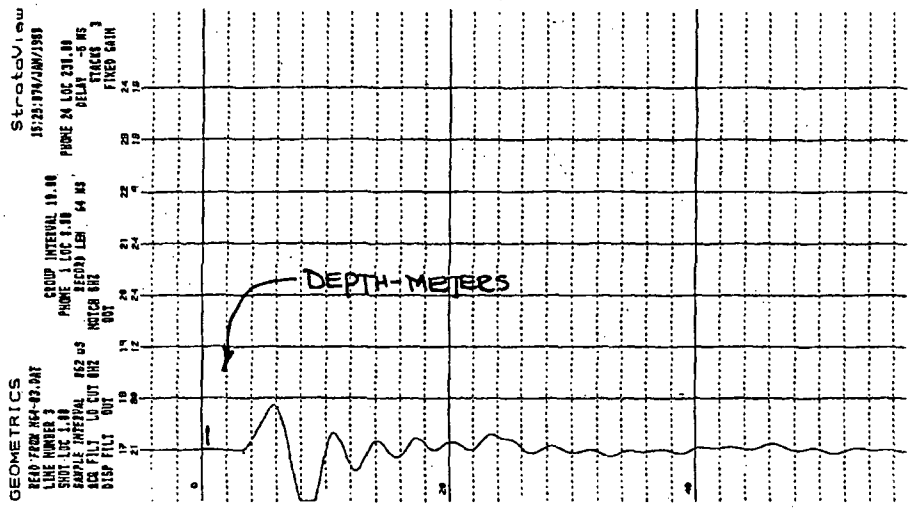
Project YMP CREST

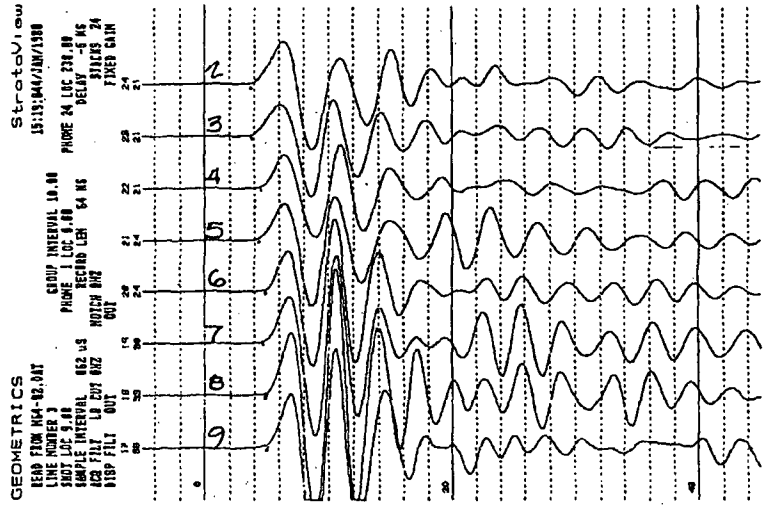
Borehole UZ-N64

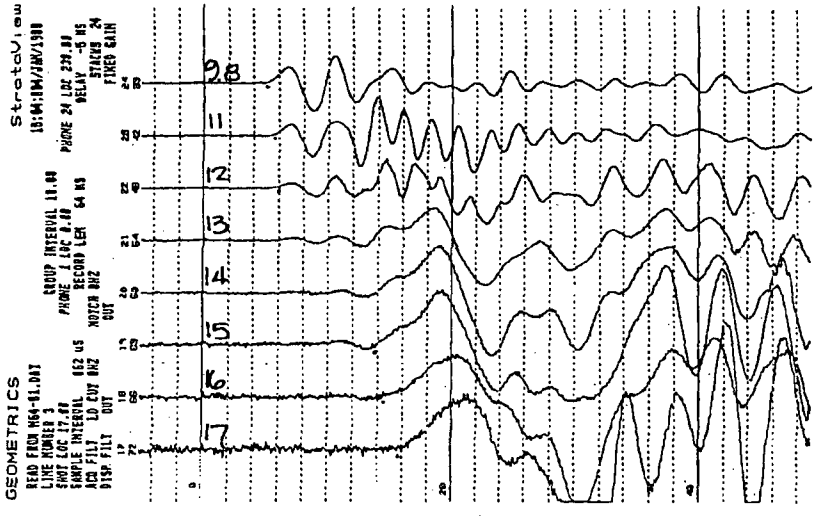
Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 53 ft







Downhole Velocity Records

COMPRESSION WAVES

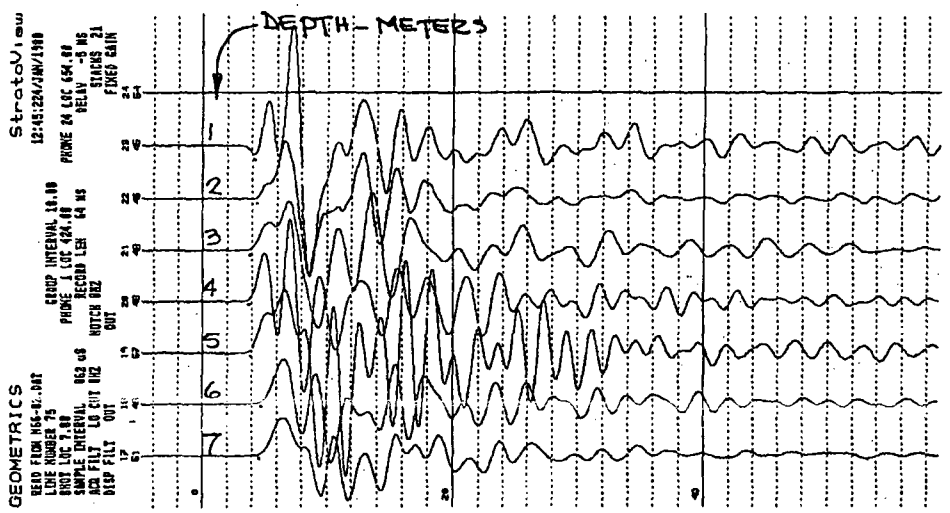
Project YMP CREST

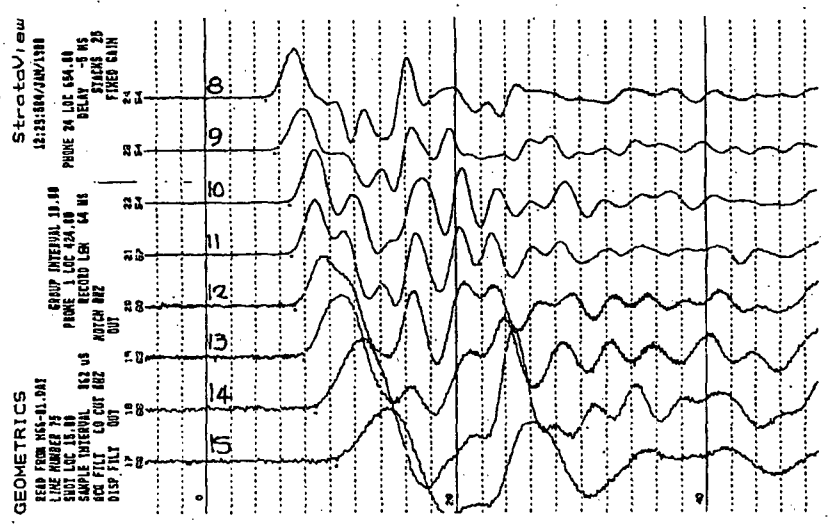
Borehole DZ-N66

Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 13.3 ft





Downhole Velocity Records

COMPRESSION WAVES

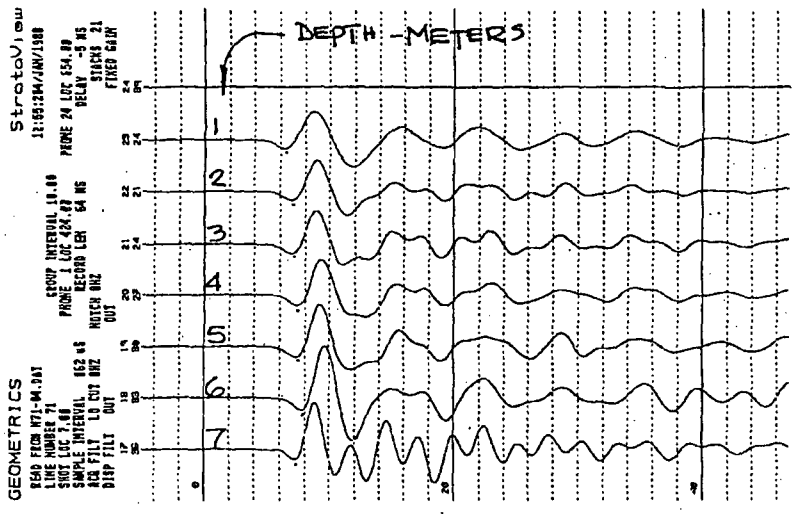
Project YMP CREST

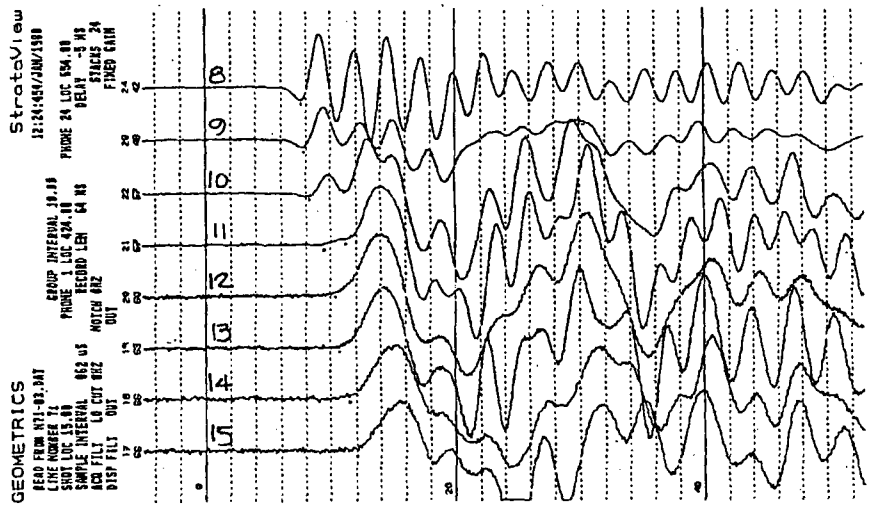
Borehole UZ-N71

Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 14.0 ft





Downhole Velocity Records

COMPRESSION WAVES

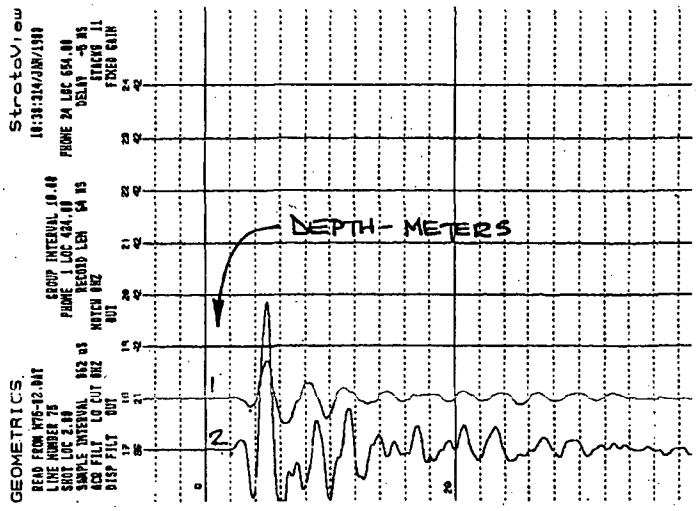
Project YMP CREST

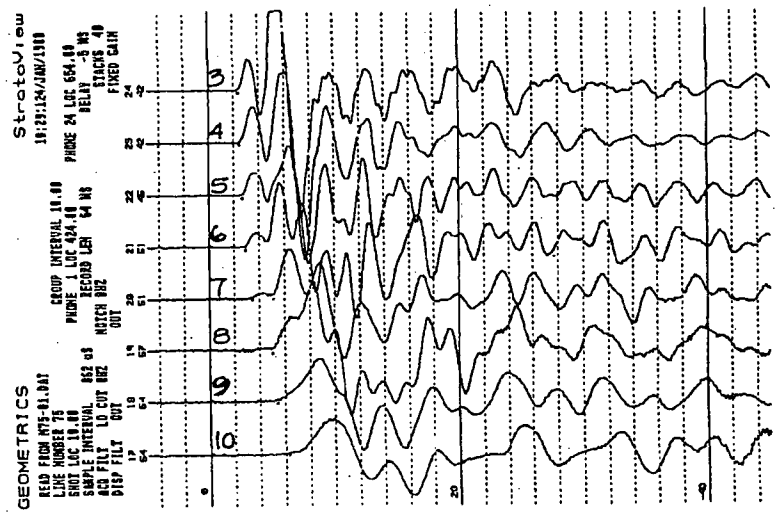
Borehole UZ-N75

Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 11.8 ft





Downhole Velocity Records

COMPRESSION WAVES

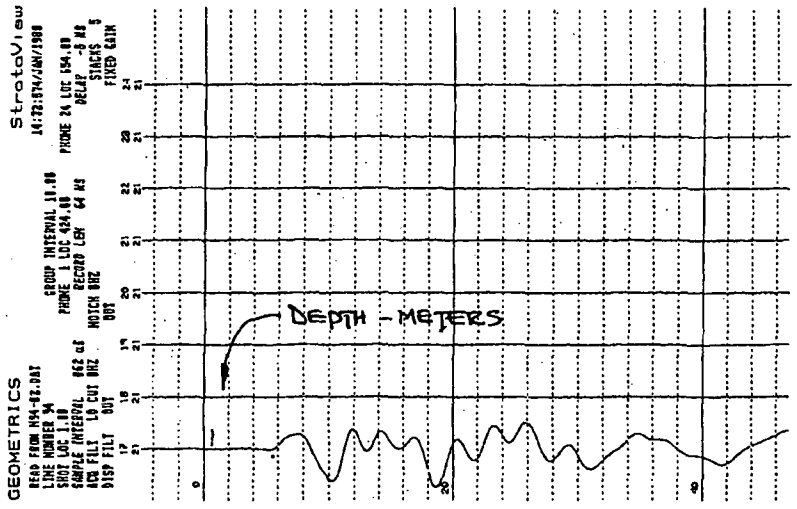
Project YMP CREST

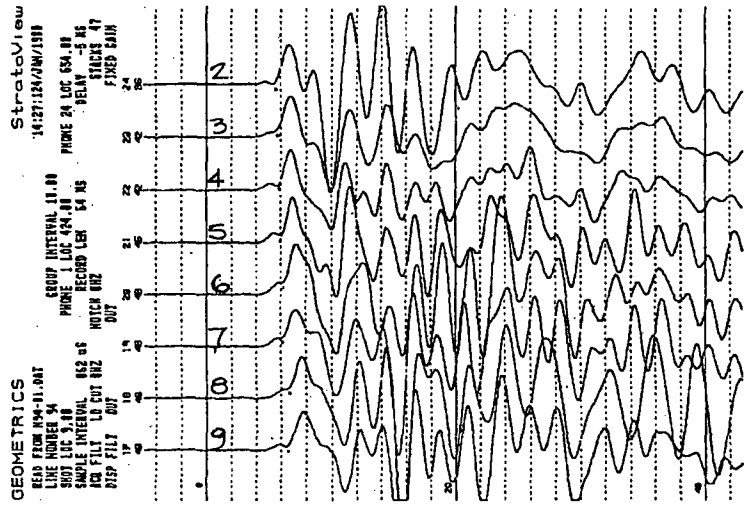
Borehole UZ-N94

Playback Filter NONE Hz Low Pass

Time Scale 2 Milliseconds/Line

Source Offset 11.6 ft





OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

file list 4-25-02 mk

1. QA: QA

Page: 1 of: 1

Complete Only Applicable Items

This is a placeholder page for records that cannot be scanned.

2. Record Date 11/01/2001	3. Accession Number Att. to MOI.20020429.0152
4. Author Name(s) BRUCE REDPATH	5. Author Organization REDPATH GEOPHYSICS

6. Title/Description
ONE 3 1/2" DISK FOR YUCCA MOUNTAIN CREST DOWNHOLE VELOCITY DATA WITH EXCEL FILES OF TRAVEL TIME VS. DEPTH FOR HOLES UZ-N27, N33, N46, N64, N66, N71, N75 AND N94 FOR SUMMARY DATA REPORT OF DOWNHOLE VELOCITY SURVEYS IN NETRON LOGGING HOLES, ATTACHMENT B TO SCIENTIFIC NOTEBOOK: SN-M&O-SCI-039-V1, DOWNHOLE SEISMIC LOGGING AT YUCCA MOUNTAIN CREST

7. Document Number(s) N/A	8. Version Designator N/A
9. Document Type Data	10. Medium Disk

11. Access Control Code
Pub

12. Traceability Designator
SN-M&O-SCI-039-V1, ATTACHMENT B

13. Comments
The following files are on the disk:

EXCEL file: Downhole_Redpath.xls
WINZIP file: Downhole_Redpath.zip

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