FEASIBILITY STUDY FOR A SEISMIC DRILL BIT LOCATION AND GUIDANCE SYSTEM

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The feasibility of seismically monitoring a rotary drill bit as a means of continuously tracking the location of the bit as it drills into the earth was investigated. A beam-steering array processing technique was used to locate the drill bit. Recorded data is analyzed in a manner similar to that used to locate earthquakes. Results demonstrate that the drill bit generates a unique coherent signal which can be used to locate the bit in the ground. Comparison of results to a conventional method confirms the deviation angle determined by the new seismic method. This method also supplies azimuthal direction. Benefits to be derived from this study are a reduction in drilling costs for deep wells and a method of providing the driller with information that is needed to reach a target at depth.

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FEASIBILITY STUDY FOR A SEISMIC DRILL BIT LOCATION AND GUIDANCE SYSTEM *

Introduction:

The feasibility of seismically monitoring acoustical emissions, generated from a rotary drill bit, as a means of continuously locating the drill bit in the earth was investigated by Utah Geophysical, Inc. (UGI). North American Royalties, Inc. and Sandefer Oil & Gas provided the Cornelius #1 well located in Matagordo County, Texas for monitoring. Geotechniques, Inc. (GTI) was subcontracted to acquire the field data. In addition, to GTI's DFS III digital acquisition system, UGI acquired back-up data on its FM recording system. The well was monitored intermittently for 7 days.

In mining operations such as in situ leaching, a deep well is drilled into the earth, subsurface formations are then hydrologically or explosively fractured to improve permeability, and leaching solution is injected into the fractures. Secondary wells are then drilled into the fractures to remove the leaching agent. In order to intersect the fractures with the secondary wells directional drilling is performed. Presently, this is performed by periodically interrupting drilling and lowering directional surveying equipment down the borehold. This procedure is time consuming and expensive in that it may reduce drilling time by up to 15 percent. By developing a technique to permit operators

* Patent Pending

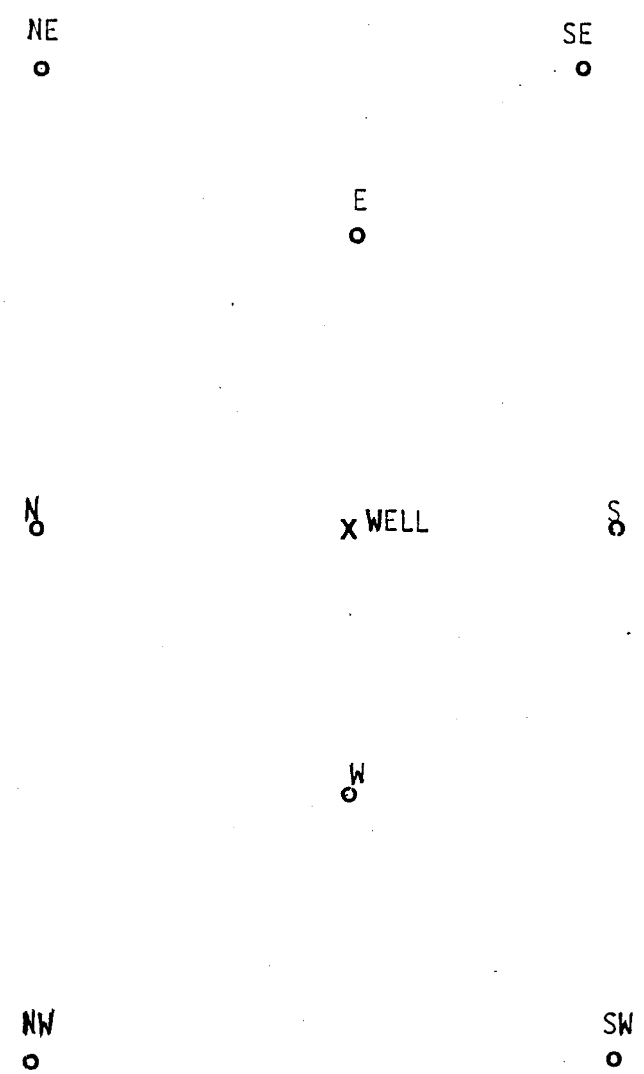
to make directional adjustments while drilling continues, drilling costs would be reduced. The directional driller would also have a means of making more frequent accuracy checks to assure him of intersecting the desired fracture.

The enclosed study encompasses one approach to continuously monitoring the location of the drill bit. In this approach, an array of seismic detectors are placed on the surface of the earth to record acoustic emissions being generated by the drill bit as it rotates against the formation being drilled. The recorded data is then analyzed in a manner similar to that used to locate earthquakes; however, in this case we are interested in locating the drill bit. The above location procedure is also applicable to drilling oil, gas, and geothermal wells.

Data Acquisition:

A seismic array consisting of 8 stations were deployed around the drill rig as is shown in Figure 1. Each station was actually a sub-array made up of a 12 geophone string directed radial to the drill rig. Geophones in the sub-array were spaced at 20 foot intervals. The purpose of the sub-array was to cancel high frequency surface noise coming from the drill rig. A three component geophone was also located at Stations N (North) and S (South).

Data were collected on a DFS III digital acquisition system. The sampling rate was set at 4 msecs and the record length was 15 seconds. In this manner about 16 minutes of continuous data could be recorded on one tape. Field filters were set between



SCALE: 1 inch = 500 ft.

Figure 1. Field configuration. Each station shown consists of 12 geophone string at 20 ft. spacing.

12 and 124 Hz. Because of the slope of the filter at 124 Hz, some Nyquist folding may have occurred at the higher frequencies. However, a tradeoff had to be made between recording a larger amount of data at 4 msecs or increasing the frequency band by recording less data at 2 msecs.

Data Processing and Analysis:

Prior to correlation processing of the data, Power Spectral Density (PSD) plots were generated from data collected during drilling and data collected when drilling ceased (while pipe was being pulled from the hole to change the bit). Figures 2 and 3 show the PSD's, respectively, during drilling and when drilling had stopped for Station N. PSD's for Station S are shown in Figures 4 and 5. A strong signal is noted at about 22 Hz, Figures 2 and 4, when drilling takes place that does not occur when drilling stops, Figures 3 and 5. This signal is believed to be caused by the drill bit. Figures 6 and 7 show the unfiltered field data and 11-44 Hz band pass filtered data, respectively. The filtered data has a 12 db/octive slope. In light of the above findings, data were pre-filtered in the 11-44 Hz band before correlating.

The computations employed in determining the position of the drill bit relies on having a knowledge of the length of drill pipe down the borehole. With this information, the surface detectors can be focused on selected positions within the earth controlled by the length of drill pipe down the borehole. Mathematically, this is achieved as follows:

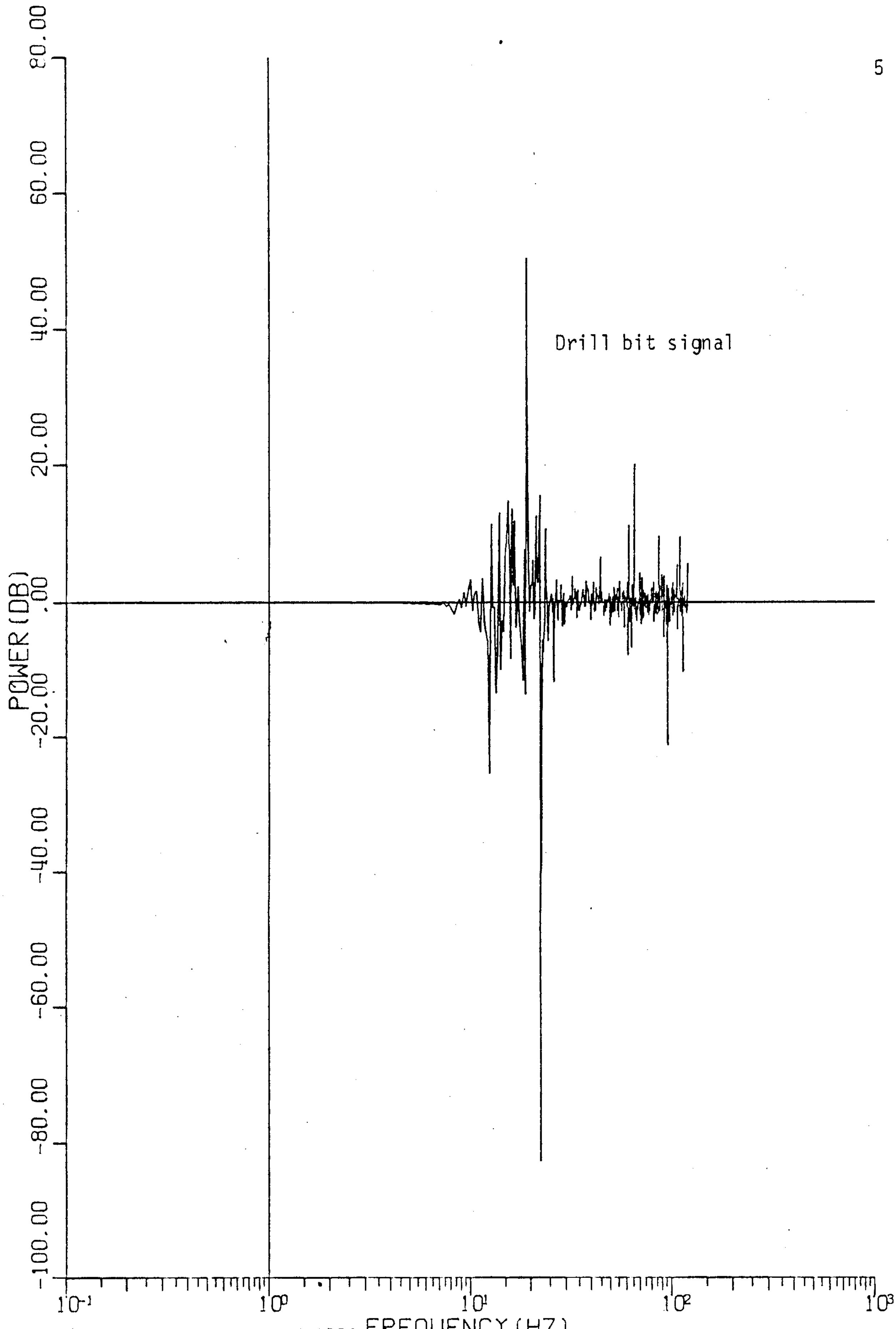


Figure 2. PSD during drilling.

STATION 6-N

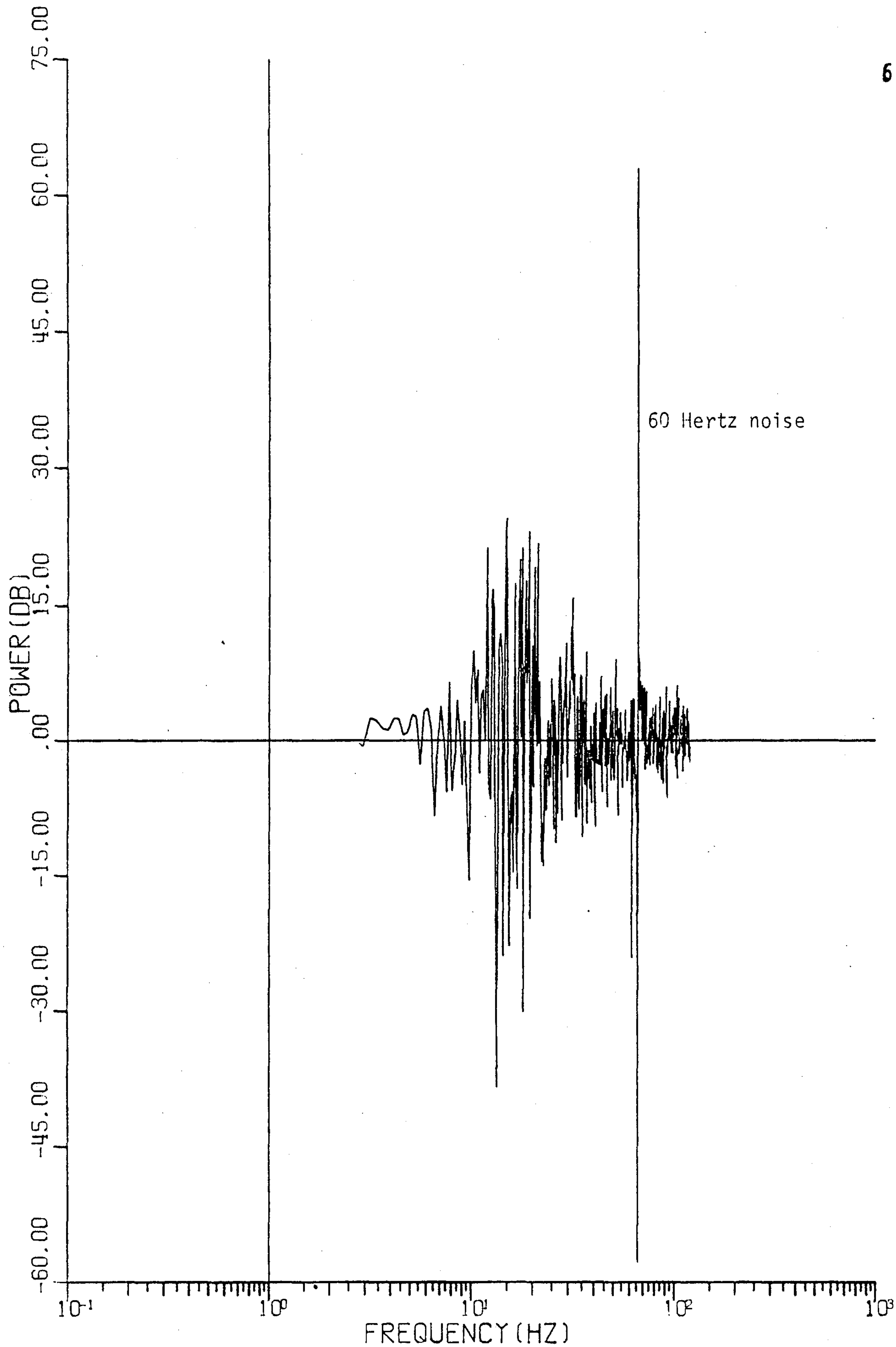


Figure 3. PSD when not drilling.

STATION 6-N

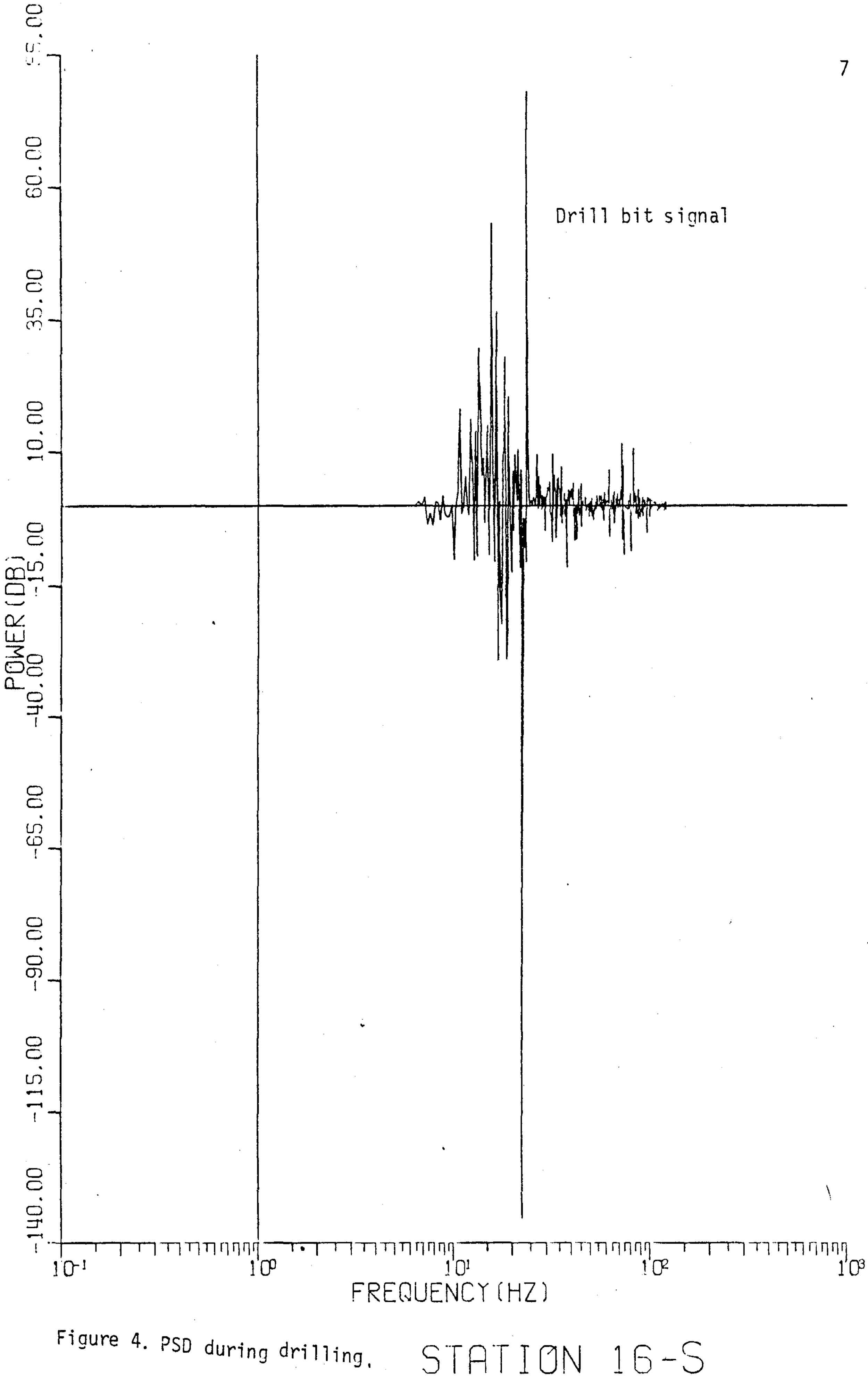


Figure 4. PSD during drilling.

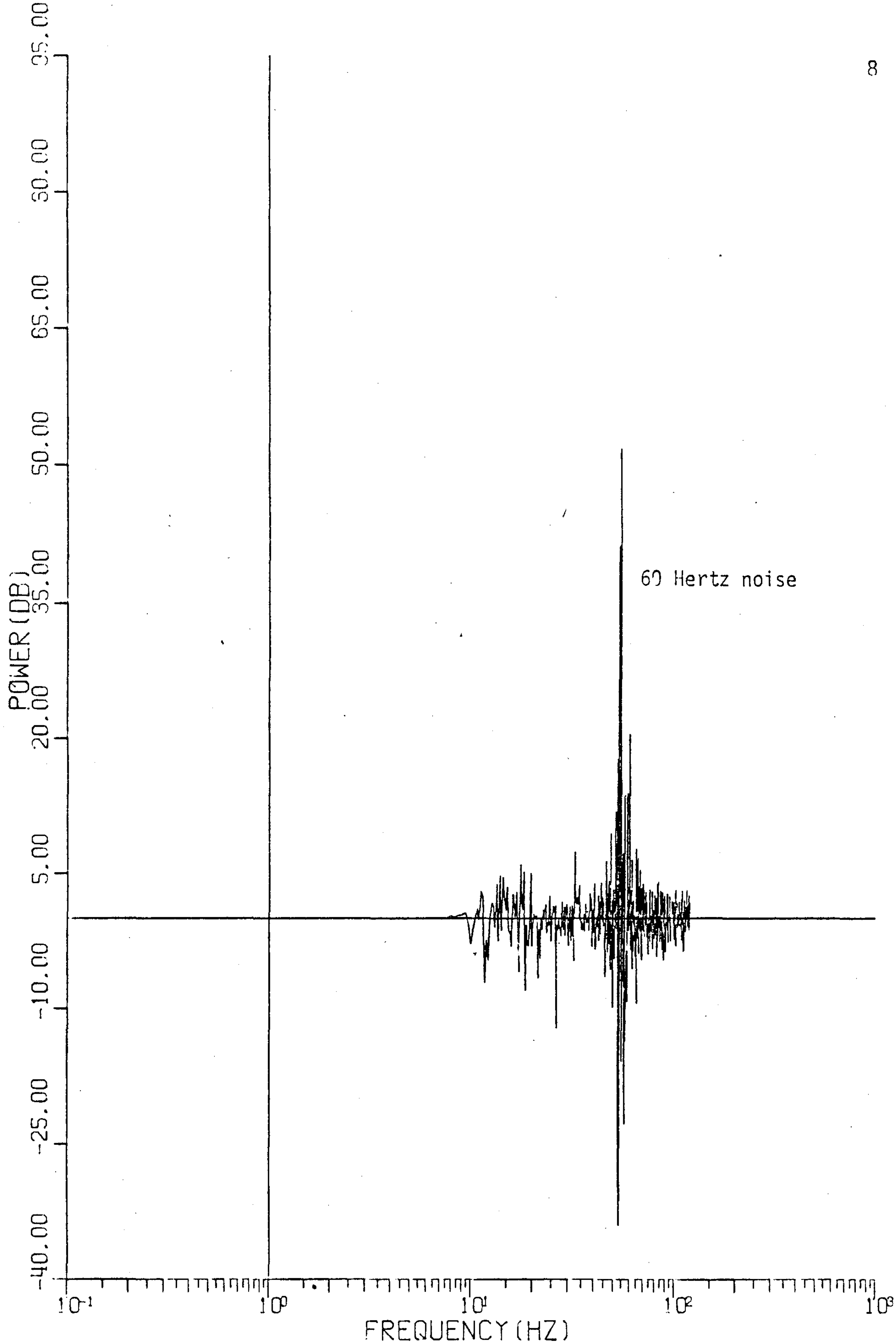


Figure 5. PSD when <u>not</u> drilling.

STATION 16-S

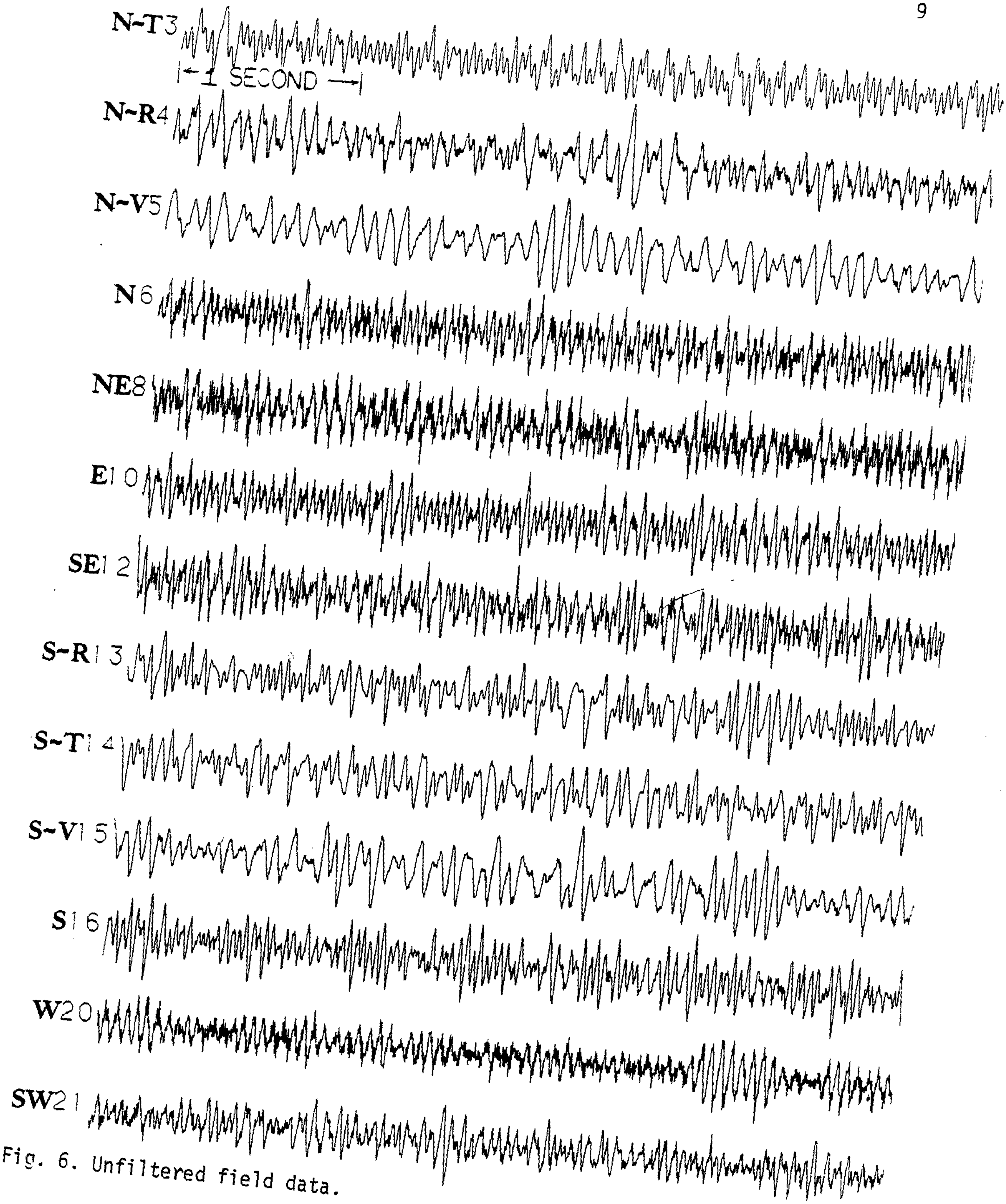


Fig. 6. Unfiltered field data.

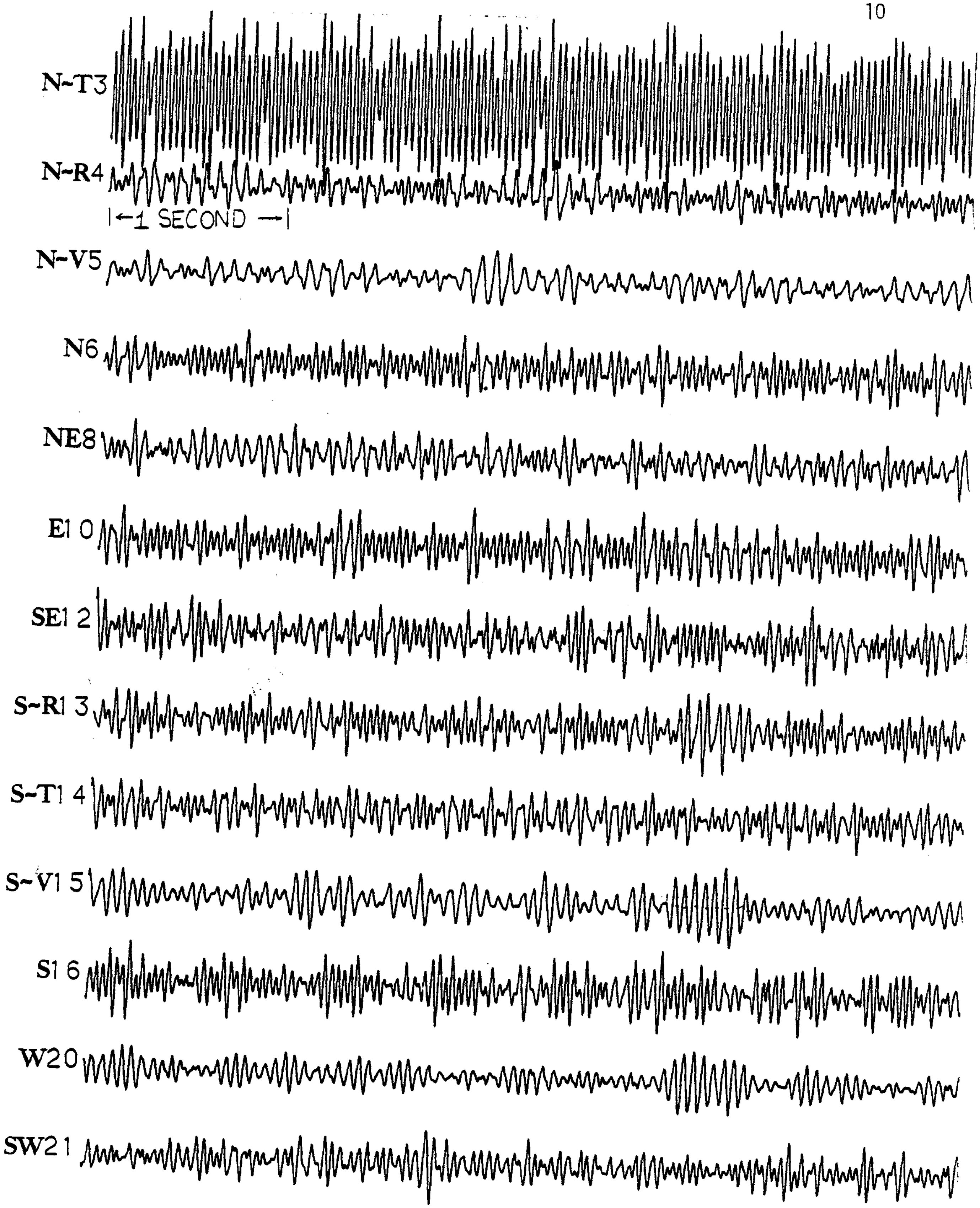


Fig. 7. Filtered(11-44 Hz) data.

First, it is necessary to determine several assumed positions of the drill bit within the earth. Referring to Fig. 8, the position of the drill bit 12 is limited to those positions within the spherical coordinate system defined by the angles θ, ϕ, and by the approximate length of drill pipe L. Thus, by holding one angle constant and incrementing the other angle in sequence, a set of possible drill bit locations is determined. These can be transcribed into Cartisian coordinates by the relationships:

$$X = L\sin\theta\sin\phi$$
$$Y = L\sin\theta\cos\phi$$
$$Z = L\cos\theta$$

Next, the travel times T_0, T_1,...T_n along the seismic paths P_0, P_1,...P_n from point X, Y, Z, at the drill bit to the various surface detector positions G_0, G_1,...G_n whose coordinates are defined as (X_0, Y_0, Z_0), (X_1, Y_1, Z_1),...(X_n, Y_n, Z_n), respectively, are determined. This is accomplished by a ray tracing technique. That is, the velocity structure as shown in Table 1 which was obtained from well logs in the area was used to determine the arrival times from each possible drill bit location in the earth to each seismic receiver at the earth's surface.

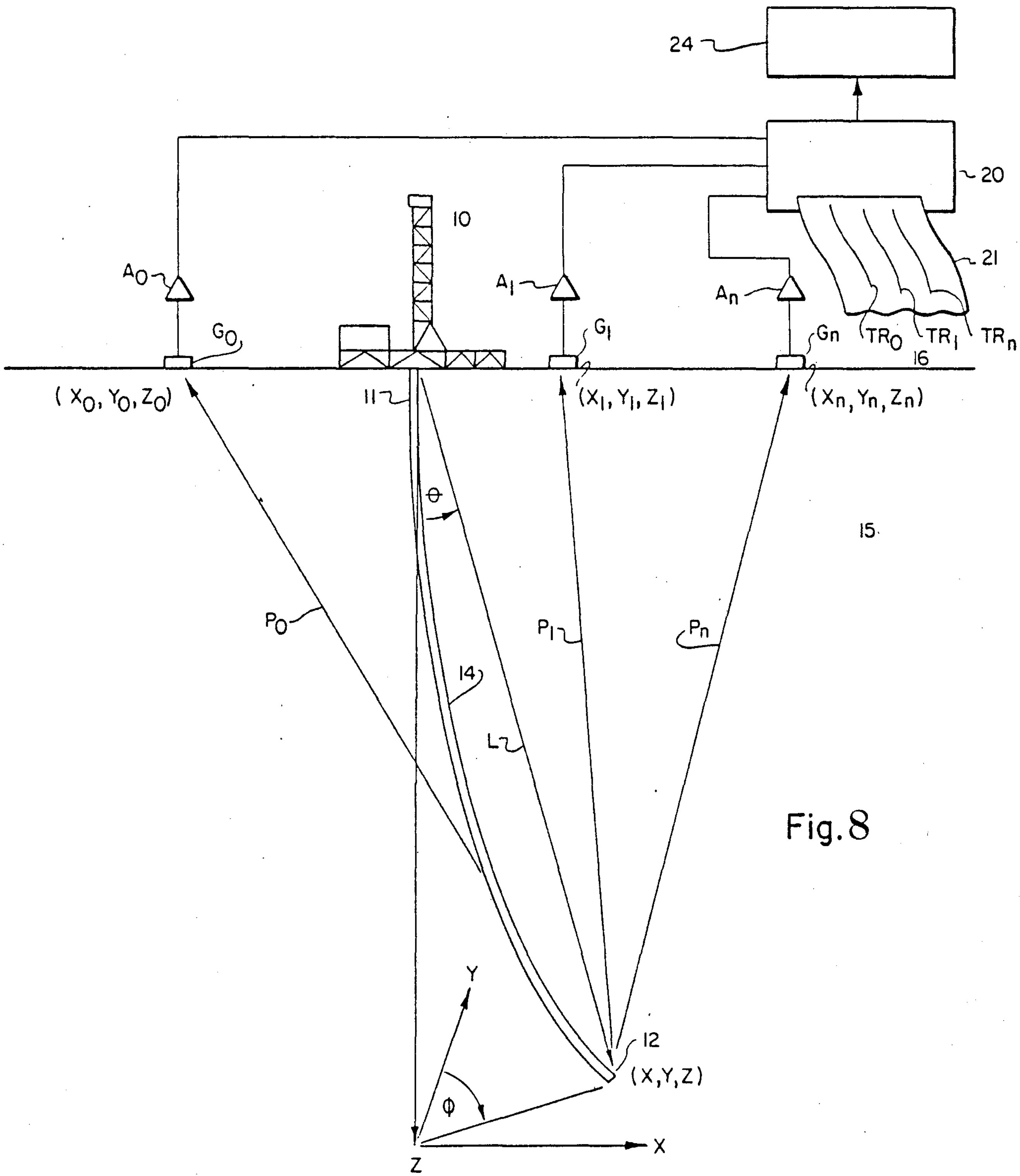


Figure 8. Drilling configuration.

Table 1.

Velocity Model

Cornelius #1 Well

Depth (feet)	Velocity (FPS)
0 - 4000 ft.	7,300 fps
4,000 - 9,500	8,695
9,500 - 15,000	10,328

The next step is to time shift the waveforms recorded at each surface detector by the appropriate travel times T_i for that detector position and test the coherency between waveforms. The above procedure is repeated for various assumed positions of the drill bit. By introducing the proper phase shifts to each of the waveforms recorded for all possible locations of the drill bit one can expect high coherency or power values whenever the waveforms are aligned for the proper location of the drill bit and lesser coherency values as one moves away from the position of the drill bit. In this manner, an array of acoustical detectors located at the surface of the earth can be focused on precise positions within the earth.

In the present study θ was chosen as 0.5 degrees and ϕ equal to 30 degrees. Analysis was performed when the length of drill pipe down the hole equalled 7715 feet. Results of the correlation procedure are shown in Plates 1 through 4. Plate 1, shows the location and correlation values using Stations N, E, W and a sampling rate of 4 msecs. The 4 msec sampling rate restricts the correlation shifts to intervals of 4 msecs. In order to improve spatial resolution one half the difference between successive samples were taken to yield an effective sample rate of 2 msecs. Correlation shifts could now be incremented in 2 msec intervals. Results for Stations N, E, W at 2 msec are shown in Plate 2. Plate 3 shows results for the inner N, S, E, W array of stations and Plate 4 for the outer NE, SE, SW array of stations. Tables 2 through 5 summarize these results.

Data Interpretation:

Results from a conventional deviation survey of the Cornelius well are summarized in Table 6. Assuming a 1 degree average deviation to 7715 feet, according to this log, the drill bit would be located at about 135 feet from center (7715 Sin 1^{o}). The above referenced deviation survey does not supply azimuthal direction. However, Mr. Gilbert Eppich of Sandeler Oil & Gas (oral communication) has informed us that from his experience the drill bit tends to migrate updip which would be in a southern direction in the Cornelius well. The scale on Plates 1 through 4 are 1 inch equal to 100 feet. Plate 3, for stations N, E, W and S locates the bit at 135 feet from center in a southernly direction. Therefore, the seismic continuous bit location approach investigated in this survey has located the bit with perhaps greater accuracy than the conventional logging method that was used.

Due to legibility problems, pages 15-18, Tables 2-5, have been omitted.*

*These are available upon written request from:

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Using a 4 msec sampling rate for the correlation processing, produces an error region of ±100 feet (Plate 1). At 2 msecs spatial resolution is improved to ± 35 feet (Plate 2). Increasing the aperture of the array (using larger spacing) further improves spacial resolution to ± 20 feet (Plate 4). However, the correlation values decrease with increased travel distance from source to receiver. This probably results from signal attenuation with increased distance from the source. As a rule of thumb, seismic signals are known to attenuate at the rate of $1/R^2$, where R is distance traveled. Therefore, the signal to noise ratio at more distant stations is reduced causing lower correlation values. However, the relative position of these values remains unchanged.

A small discrepancy can be seen in the drill bit position as shown in Plate 4 for the outer array and that of Plate 3 for the inner array. This probably results from an error in the location of Station SE which may have been mislocated.

Conclusions:

The feasibility and success of this experiment can be summarized as follows:

1. The seismic bit location method under investigation in this study resulted in locating the drill bit in a position having the same deviation angle as that found by a conventional survey. The seismic technique also provided the azimuth (southernly) direction of the drill bit.

2. A large signal, 70-100 db above the background noise level, was found to be generated at about 22 Hz when drilling occurred. This signal was no longer present when drilling stopped (Figures 2 through 5).

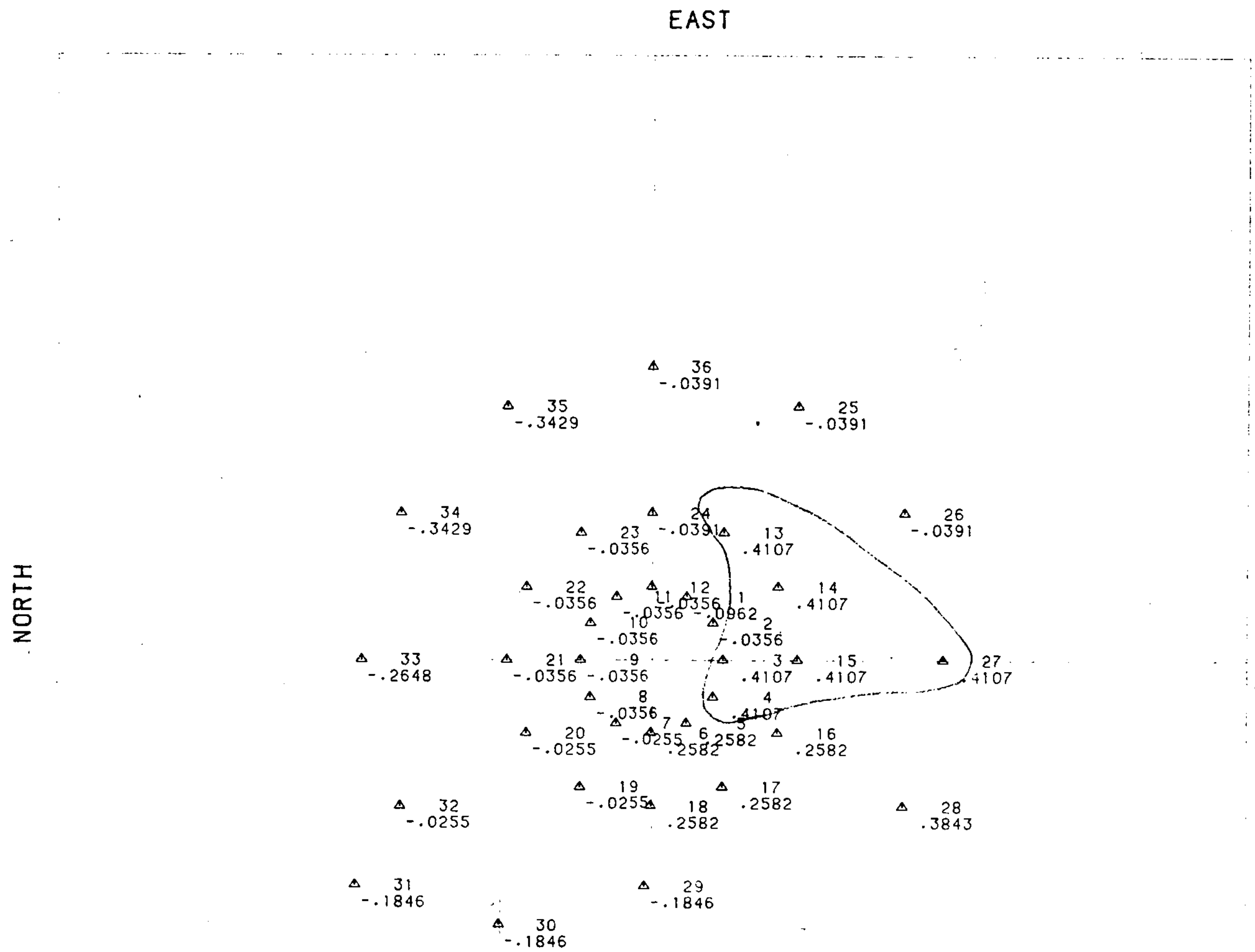
3. A correlation value of 0.41 was found at the inner array of stations. This value is about 40 times background level indicating that a coherent signal is being recorded. A value in this range for a seismic noise signal is extremely high.

Thus, it has been shown that (1) a drill bit generates a coherent seismic signal and (2) a seismic method can be employed to continuously locate a drill bit in the earth while drilling takes place.

Table 6.

Hole Deviation Survey
Cornelius #1 Well

Depth (feet)	Deviation (degrees)
527 ft.	1/2 °
1,036	1/4
1,514	1
4,445	1
4,951	3/4
5,476	1 3/4
6,022	1
6,570	1
7,140	1
7,622	1 1/2
11,231	1 1/4



LEGEND

△ 1 -.0962 CORRELATION VALUE XXX

SCALE 1" = 100'

PLATE 1

UTAH GEOPHYSICAL, INC

SALT LAKE CITY, UTAH

DRILL BIT LOCATION PLOT
STAT.N,E,W-4MSECS.
CORNELUIS #1 WELL

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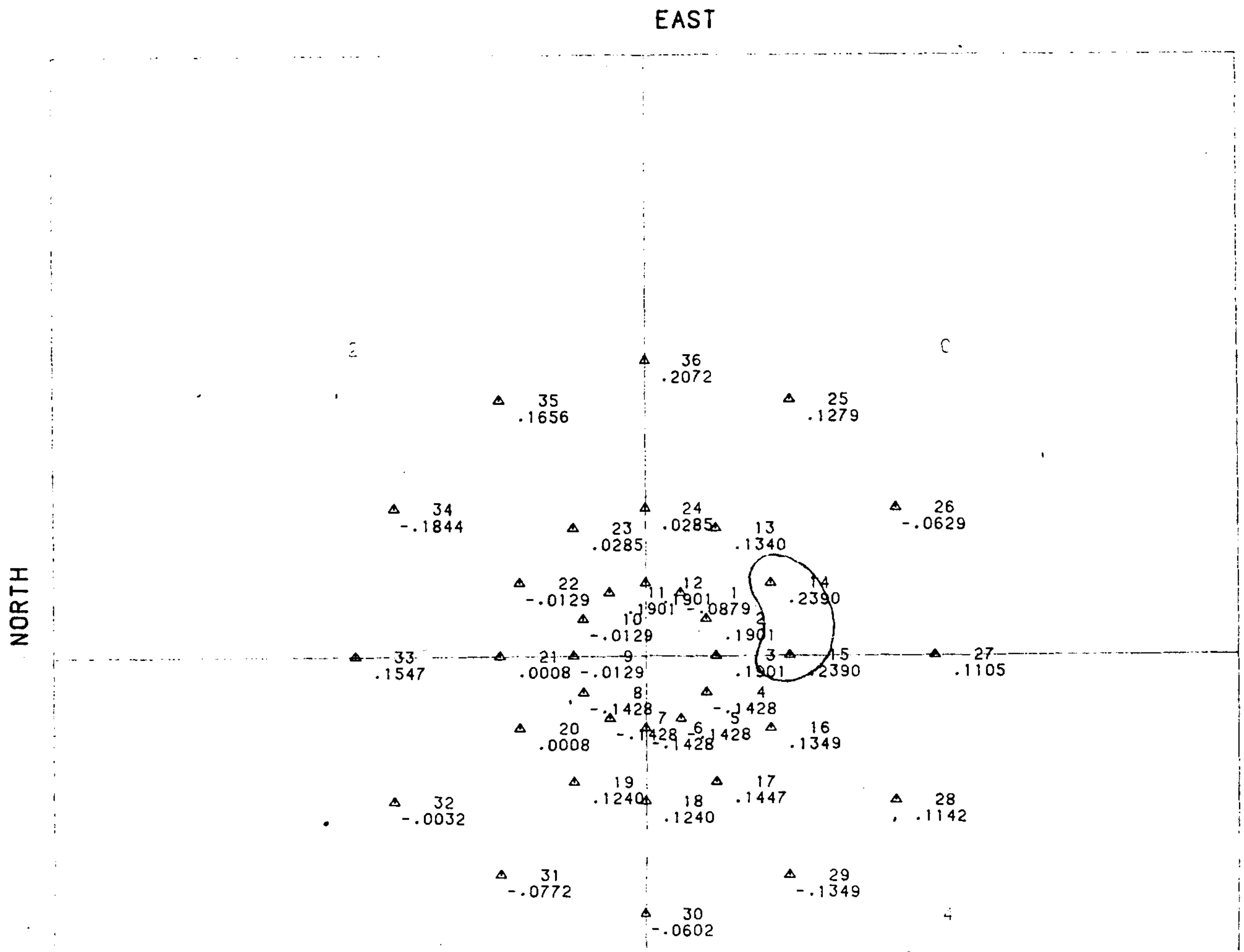
30 11:46 51 875901 $PLOT1 (9) (15 BY 18)



LEGEND

△ 1
-.0879 CORRELATION VALUE
XXXX

SCALE 1" = 100'

PLATE 2

UTAH GEOPHYSICAL, INC
SALT LAKE CITY, UTAH

DRILL BIT LOCATION PLOT
STAT.N.E.W-2 MSECS.
CORNELIUS #1 WELL

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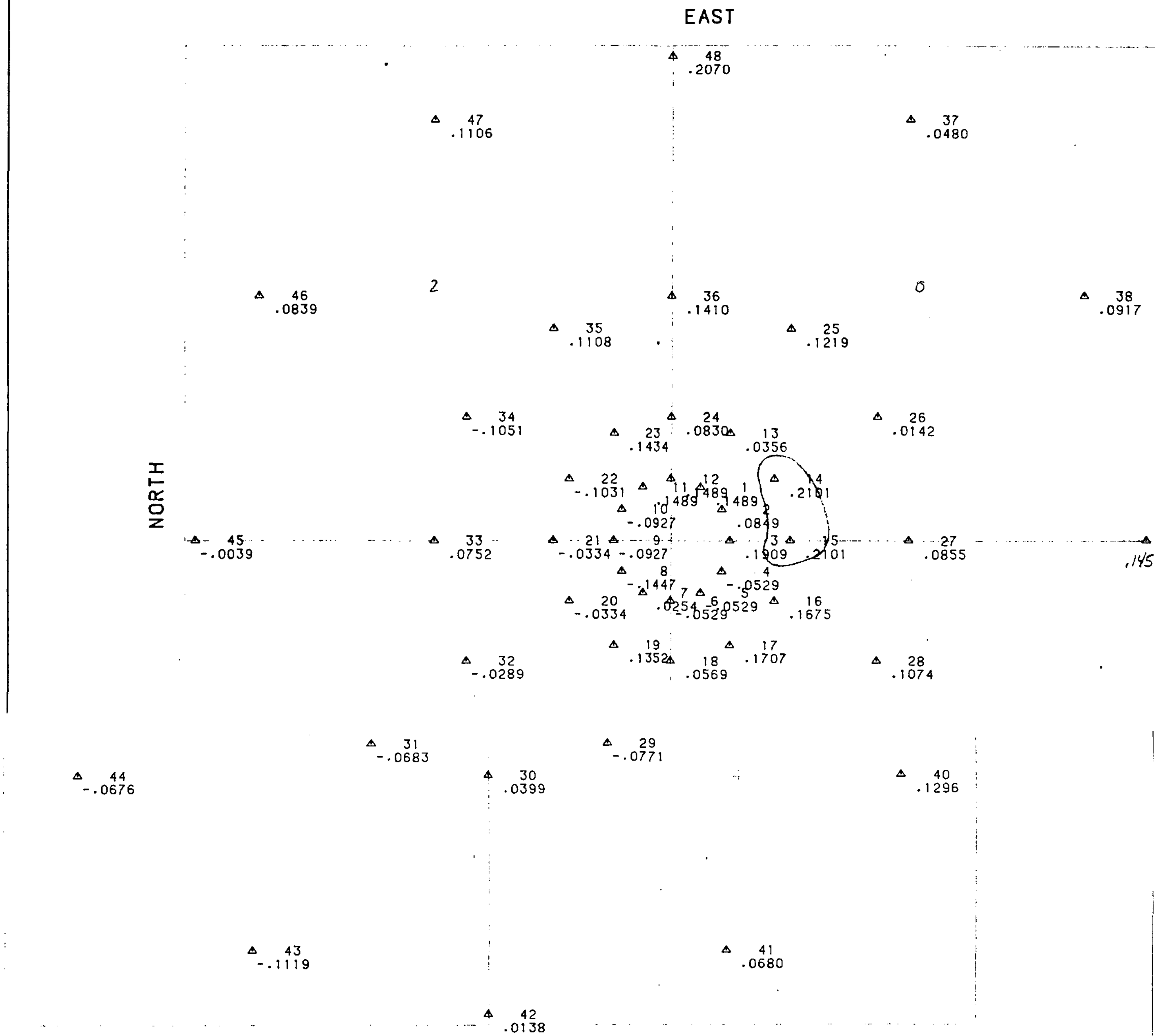
03/28/80 11.46.30 275901•$PLOTS(8) (15)BY 18



LEGEND

△ 1 .1489 CORRELATION VALUE
XXX

SCALE 1" = 100'

PLATE 3

UTAH GEOPHYSICAL, INC
SALT LAKE CITY, UTAH

DRILL BIT LOCATION PLOT
STAT.N,E,W,S-2 MSECS.
CORNELUIS #1 WELL

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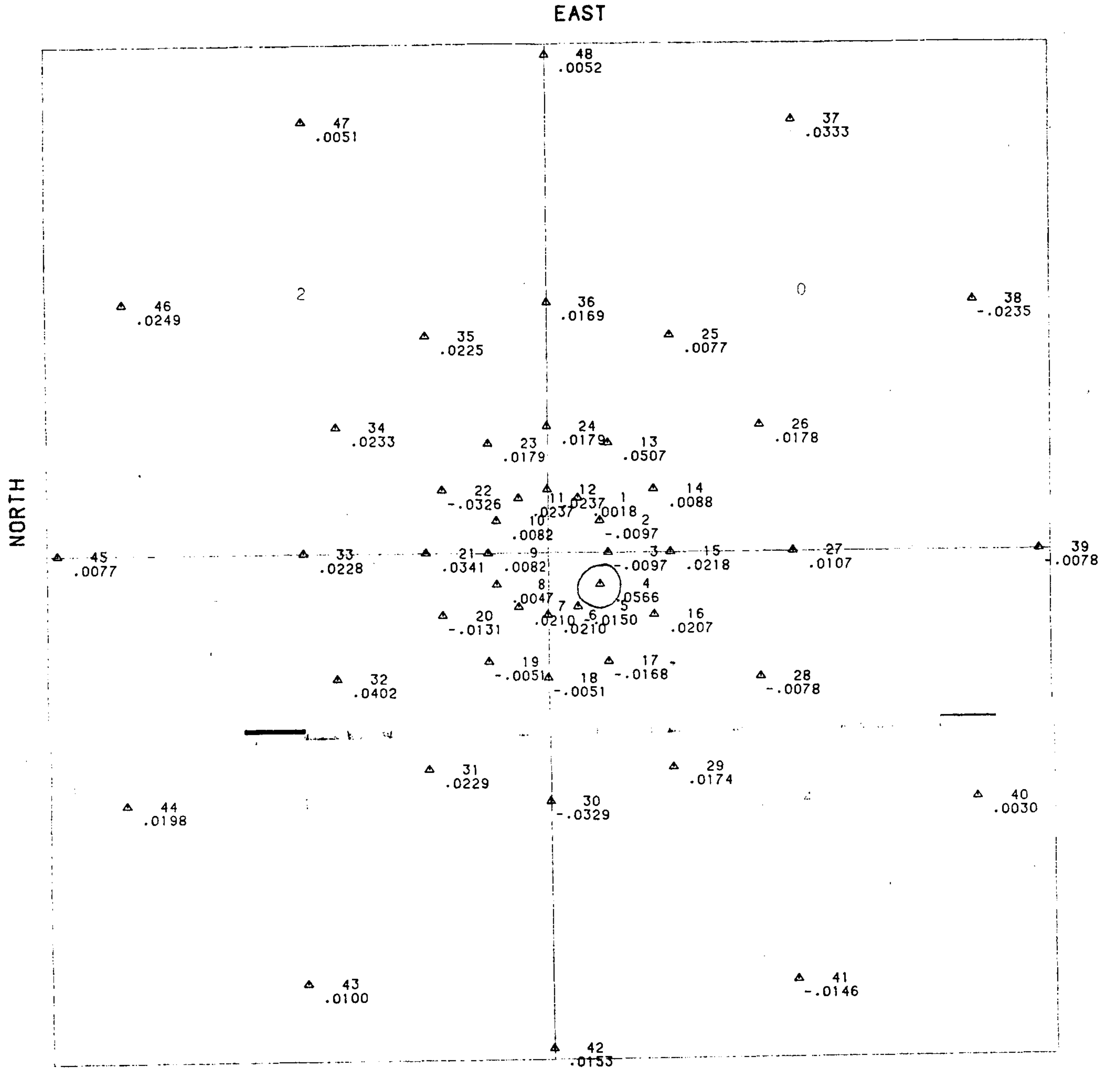
23



LEGEND

1
.0018 CORRELATION VALUE
XXXX

SCALE 1" = 100'

PLATE 4

UTAH GEOPHYSICAL, INC

SALT LAKE CITY, UTAH

DRILL BIT LOCATION PLOT
STAT.NE,SE,SW-2MSECS.
CORNELUIS#1 WELL

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