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Naturally Fractured Tight Gas Reservoir Detection Optimization

Quarterly Report
July - September 1994

Work Performed Under Contract No.: DE-AC21-94MC31224

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
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1.0 Summary

This report details the field work undertaken by Coleman Energy & Environmental Systems - Blackhawk Geosciences Division (CEES-BGD) and Lynn, Inc. during the summer of 1994 at a gas field in the Wind River Basin in central Wyoming. The field surveys were performed for the Department of Energy, Morgantown Energy Technology Center, under Contract No. DE-AC21-94MC31224, "Naturally Fractured Tight Gas Reservoir Detection Optimization". The site has been previously described in detail in DOE topical reports prepared by CEES-BGD entitled, "Environmental Impact Statement for Vertical Seismic Profile, Fremont County, WY" and "Field Test Plan" for the VSP. The field work described herein consisted of two parts:

- Multicomponent feasibility studies during the 3D P-wave survey on the site, and
- 9C VSP in a well at the site.

The objectives of both surveys were to characterize the nature of anisotropy in the reservoir. With the 9C VSP, established practices were used to achieve this objective in the immediate vicinity of the well. With the multicomponent studies, tests were conducted to establish the feasibility of surface recording of the anisotropic reservoir rocks.

A summary of activities associated with the contract is given in Table 1-1.

Table 1-1. Summary of Activities

Date (1994)	Activity
July 11	Contract negotiations complete. Contract signed.
July 19	Kick-off meeting with CRC, Lynn Inc., and the owner/operator
July 20-23	Site visit to the field.
August 1	NEPA and Test Plan submitted to DOE.
August 6-28	3D P-wave survey and multi-component tests.
September 9	TD in test well.
September 17-18	9C VSP acquired in the test well, together with limited multi-component tests.

2.0 Background and Objectives

The gas field is located in the northeast corner of the Wind River Basin, Wyoming. The field encompasses several townships and two Federal Exploratory Drilling Units.Thermopolis lies to the north, and the nearest airport is at Riverton to the Southwest. The field is a large Laramide-age anticline that extends west to east for approximately 20 miles in length and 10 miles in width. No expression of the anticline is seen at the surface of the site. The topography is gently rolling hills dissected by ephemeral creeks in steep-sided canyons. The terrain has been classified, in part, as badlands type with thin topsoil (Fig. 2-1). Vegetation is limited except along the major creeks, where irrigation supports limited agriculture.

The basin lies within an elevation range of 5,000 ft to 7,000 ft with the Owl Creek Mountains to the north and the Wind River, Bridger, and Granite Mountains to the south. The field activity described in this report is presented in two sections. First, the surveys associated with a 37 sq. mile 3D P-wave acquisition are described, and this is followed by the 9C-VSP.

3.0 Data Acquisition and Processing

3.1 Multicomponent Recording Associated with Owner /Operator 3D P-wave

The 3D P-wave survey was conducted from August 6 to August 20, 1994. The survey was conducted using an I/O-2 system, dynamite shots, and a helicopter crew. The objectives of the 3D P-wave survey were to:

- image that part of the crest of the anticline with most wells, and
- image the South Bounding Fault that controls the southern extent of the reservoir at depth.

Additional objectives pertinent to the DOE study, include:

- obtaining quality 3D seismic data for AVO analysis about fracture densities and gas presence, and
- image a 3D volume around the VSP test well for later comparisons with the shear wave results.

The timing for 3D P-wave acquisition was determined by the necessity to acquire data before significant noise sources were added to the site in the fall. Both of these, together with the growing infrastructure at the site complicate the acquisition of seismic data at the site.

The 3D survey was designed by the field operator and was conducted on approximately 37 sq. miles over the crest of the anticline. North-south receiver lines with 220 ft stations were deployed at 1,320 ft intervals. Shot lines consisting of 20 lb dynamite charges nominally at 100 ft depth were deployed in a checker block east-west pattern at 440 ft shot intervals. Thus, subsurface cells or bins of 110 ft (N-S) by 220 ft (E-W) were obtained. Of note, for future (DOE-sponsored) surface seismics at the field, was the drilling of dynamite holes in environmentally sensitive areas (such as the hay fields) during the winter. This greatly reduced the impact the dynamite had on those areas to the point that for the majority of holes no evidence of a shot location could be seen after shooting. The receiver groups were 12 geophones buried in a 20 ft diameter circle about the station flag. The field acquisition conducted by the operator was permitted through the BLM, State and local private landowners. The data were collected in 28 swaths or N-S strips beginning in the west and shooting to the east (Fig. 3-1 - the site map figure 3-1 will be included at a later date when it is avaliable). For each shot line, four receiver lines on each side of the swath were active.

The passive field monitoring of mode converted data conducted by CRC was subdivided into two parts in order to least impact and slow down the operator's 3D P-wave acquisition. However, each part was aimed at similar objectives. These objectives were to:

- measure the strength of converted shear wave energy from the P-wave charges, and
- estimate the degree of shear wave birefringence.

To accomplish this, multicomponent geophones were deployed in the field at two locations as shown on the site map of Figure 3-1.

Location 1

At the south end of the first seven (7) lines in the west half of the 3D grid, a set of 3-component geophones were buried at the first of the operator's seismic survey flags. The geophones were buried 6" deep within the P-wave geophone circle as shown in Figure 3-2. The two horizontal shear wave elements (H1 and H2) of these phones were connected to two spare takeouts from the main survey. One horizontal element was aligned north-south and one east-west. Data was recorded from these geophones for every charge that the geophysical contractor set off by the I/O-2 system in the vicinity of the receivers. The phones were buried and connected to the cables by CRC and Lynn, Inc.

Location 2

Location 2 was situated between shot stations 225 and 240 along receiver line 155 (Fig. 3-1). At each of the operator's flags, a string of 12- 3C geophones were deployed immediately outside of the 3D P-wave geophone array (Fig. 3-3). The geophones were once again buried to a depth of 6-inches below the surface to reduce the wind noise. All three components in the strings, - namely H1, a horizontal element oriented N-S, H2, a horizontal element oriented E-W, and the vertical element, - were connected to an OYO DAS-1 seismograph. This 24-bit seismograph was used to passively monitor the 3D P-wave shots using the following parameters:

Record length:	12 sec
Sample rate:	2 msec
Lowcut filter:	6 Hz
Tilter slope:	12 db/octave
Number of channels:	
(H_1, H_2, V):	16, 16, 16
Data type:	SEG D 4048 copied to SEG Y
Total number of shots recorded:	165

The OYO DAS-1 was triggered to coincide with the seismic contractor's source effort using a Macha Radio Master/Slave shooting system. Using this arrangement, recordings were made with the DAS-1 for selected shots around the geophone arrays. Timing between the I/O-2 system and the DAS-1 system is discussed later. The cable and phones were deployed by CRC, Lynn, Inc., and seismic contractor and the DAS-1 operated by CRC from August 19-21, 1994.

3.2 Preliminary Results

Location 1

The preliminary results from the 3C phones deployed at Location 1 is awaiting sorting of the 3D data set by the operator. When this data is correctly sorted and the channels of interest for the 3C geophones have been stripped out of the 3D data set, then a request for bid on the processing will be made.

Location 2

Timing System

The first step in the analysis of the results of passive monitoring at Location 2 was to establish the inherent time delay in the DAS-1 and Macha Slave Unit from the shot initiation. To accomplish this, the field monitors from the I/O-2 system and the DAS-1 system were played out for the channels coincident with the 3C geophone spread. An example is given in Figure 3-4. Arrival times to the first break were picked and compared. From this comparison a delay time of 942 msec was determined for the DAS-1 recording system.

3.3 9C VSP and Associated Logging

The 9-component vertical seismic profile (9C-VSP) was acquired by Schlumberger in a recently drilled test well from a depth of 9,300 ft to bottom of double casing at 2,000 ft.

Test Well Completion

The test well was drilled through the month of August and reached TD on August 9, 1994. Difficulties with high mud loss resulting in loss of circulation were encountered at a depth of approximately 9,060 ft during drilling. In excess of 3000 barrels of mud were lost, suggesting significant fracturing at this depth. An additional 2000 barrels of mud were lost from 9,060 ft to TD at 9,400 ft. As a result of this, the hole was immediately cased on completion without any open hole geophysical logs being acquired.

Cement Bond Log

During cementing of the hole, gas cutting of the cement was observed, and from the cement bond log poor coupling was observed for much of the hole above 6,200 ft. An example of a good cement bond log and a poor cement bond log is shown in Figure 3-5. A poor cement bond was also observed from 8,900 ft to the DV tool of 8,060 ft. The overall lack of good cement bond initially caused some concern in the field that the VSP would not show quality data, however, this was not the case during recording because the VSP utilizes a lower frequency wave than the cement bond tool, and is thus less sensitive to the influence of gas cut cement.

Dipole Shear Imaging Log (DSI)

Prior to acquisition of the VSP, Schlumberger acquired a dipole shear sonic imager log in the well. The DSI tool utilizes two mutually perpendicular shear sources and eight sets of mutually perpendicular receivers to record the split shear wave and compressional wave through the formations surrounding the borehole. Subsequent to acquisition, the split shear waves are rotated using the Alford Rotation to maximize and minimize the energy on cross components. The amplitude response and time difference is then used to calculate the shear wave percent anisotropy in the formation. An example of the DSI log is shown in Figure 3-6 for a depth around 9,100 ft - 9,300 ft. This zone shows two depth intervals of high anisotropy. The 17% anisotropy indicated at 9,100 ft coincides closely with the large mud loss zone experienced during drilling. This is interpreted to indicate high fracture density. The high anisotropy interval above 9,300 ft was the first interval perforated after logging and was found to flow high water rates, presumably once again from a highly fractured section. The second perforation interval was at 9,200 ft and is now a good, clean gas producer. Unfortunately, no azimuth indicator could be run with the DSI tool because the hole was cased.

Vertical Seismic Profile (VSP)

The principal objective of the 9C-VSP was to record the complexity of wave arrivals from multiple sources through the fractured reservoir rocks surrounding the well and interpret this data using the framework of a cracked medium.

Four source locations were used to acquire the data with both P-wave and shear wave vibrators, as shown in Figures 3-7 and 3-8. The P-wave vibrators were supplied by Northern Geophysical and shear vibrators by HeavyQuip (see Fig. 3-8). Acquisition was accomplished during a continuous 40-hour period on September 17 through 18, 1994. During the VSP acquisition, 14 stations of 3-component surface geophones were also deployed by CRC and Lynn, Inc. to record the near surface characteristics around the well site. These were connected to a DAS-1 seismograph in a similar manner to the previously described surface seismic recording. This system was triggered directly by the Schlumberger recording truck.

For initial source tests, the Schlumberger recording sonde (the ASI magnetically clamped 5-level triaxial tool) was lowered to a depth of 8,000 ft and locked in place. This was a depth where the cement bond log showed a good connection between casing and formation. The source tests consisted of:

1. P-wave vibrator sweep tests for near offset and far offset (number of vibrators, sweep length, sweep frequencies, stack amount).
2. Shear wave orientation for SH and SV. That is, whether to vibrate in a north-south and east-west orientation or NW-SE and NE-SW orientation.

The resulting parameters for the production survey consisted of:

1. Near P-vibrator at 1,091 ft to the south of the well site with 10-60 Hz 15 second sweeps.

2. One shear vibrator oriented with headlights pointing NW at 1,091 ft south of the well and one shear vibrator oriented with headlights pointing NE at 1,091 ft south of the well. The NW and NE pointing vibrator orientation appeared to show higher signal-to-noise than the N and E orientations. This increased signal/noise could be due to individual ground conditions, - that is, the orientation of vibrators with respect to the fractures in the ground, or the fact that ground roll is not directly pointing to the well head when the sources are positioned in the off angles. This may have implications for future surface work at this and other locations. Both S-vibrators swept at 6-36 Hz 15 seconds. The shear vibrators were Mertz Universal vibrators with non-rotating base plates so that shear motion is always perpendicular to the truck axis.
3. Two far P-vibrators at 2,438 ft south of the well with 10-60 Hz, 15 second sweeps. Later in the survey these vibrators were moved to a location 1,651 ft west of the well for additional orientation tests.

From the source tests, it was also determined that sufficient vibrator energy was available through the use of only one vibrator per shear component at the near source offset. This had the benefit that only one run with the ASI tool was required in the borehole, thus guaranteeing that the same recording conditions were experienced for each source type.

3.3.1 Production Surveying

Once testing had been completed, the ASI tool was lowered to just above TD and the following source sequence initiated:

- sweep for far P-vibrators,
- sweep near P-vibrator,
- sweep near "SH" vibrator, and
- sweep near "SV" vibrator.

On completion of this sequence, the ASI tool was unclamped, raised by 250 ft, and the sequence repeated.

At 7,890 ft, one shear vibrator had settled into the ground too far for a good coupling between the source plate and ground. The vibrator was therefore moved forward by 8 ft and the level repeated.

Acquisition continued to 4,890 ft at which depth the arrivals had deteriorated due to the poor cement bonding. The ASI tool was raised to 3,490 ft and acquisition continued in the better cement bond section up to the double casing at 2,000 ft. When the tool was at 3,240 ft the far P-wave vibrators were moved to a location 1,651 ft to the west to provide a further check on the ASI tool polarity and orientation. Once in the double well casing, the wave arrivals further deteriorated and the VSP production was terminated. The VSP is of good quality for the majority of the well as indicated above. Subsequent to acquisition, Schlumberger transmitted the VSP data by Satellite to their processing center in Calgary.

3.3.2 Multicomponent Surface Seismic

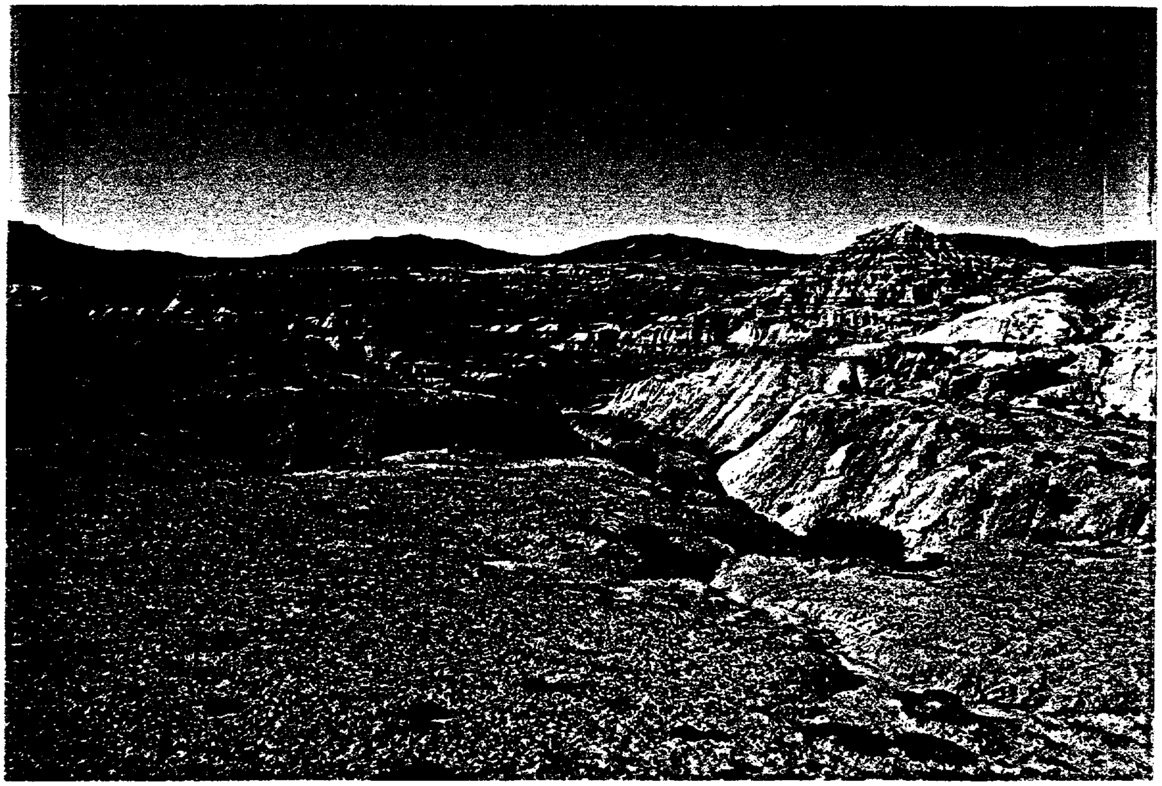
During VSP acquisition, 14 stations of 3-component geophones were deployed in a line from the near vibrator location through the well site. The purpose of these surface geophones was to record the vibrator signals for P-wave, and split shear wave. A comparison of the data could then be made to the dynamite sources recorded previously to better determine the optimum source type for future surface shear wave acquisition.

Fourteen stations were deployed at 110 ft separation from the near vibrators. The geophones were oriented with horizontal components in north-south and east-west orientations. The geophones were connected to a DAS-1 seismograph which was triggered by the Schlumberger recorder. The seismograph was operated by CRC and the data will also be processed by CRC. After completion of the 9C VSP acquisition effort, a short line of 16, 3C geophones were laid out at 10 ft separation adjacent to the well site. This spread was then used as a surface walkaway with the P-vibrator and shear vibrators used at source locations to the south. The results of this, together with an impact study into the 10 ft geophone spread, will be processed by CRC. The objectives of these studies are:

- to determine the near surface velocity for P, shear percent anisotropy, and anisotropy orientation, and
- to determine the polarity of the shear wave vibrator sources.

The results for the surface seismic feasibility studies will be presented in full when processing is complete. The implication of results to date indicates that further study of the feasibility of using the shear vibrators for acquisition of multicomponent data at the field is needed before a full field program is undertaken.

A)



A) VIEW LOOKING NORTH OVER CANYON TYPE TOPOGRAPHY AT THE FIELD.

B)

B) VIEW LOOKING SOUTH OVER BADLANDS TYPE TOPOGRAPHY AT THE FIELD.

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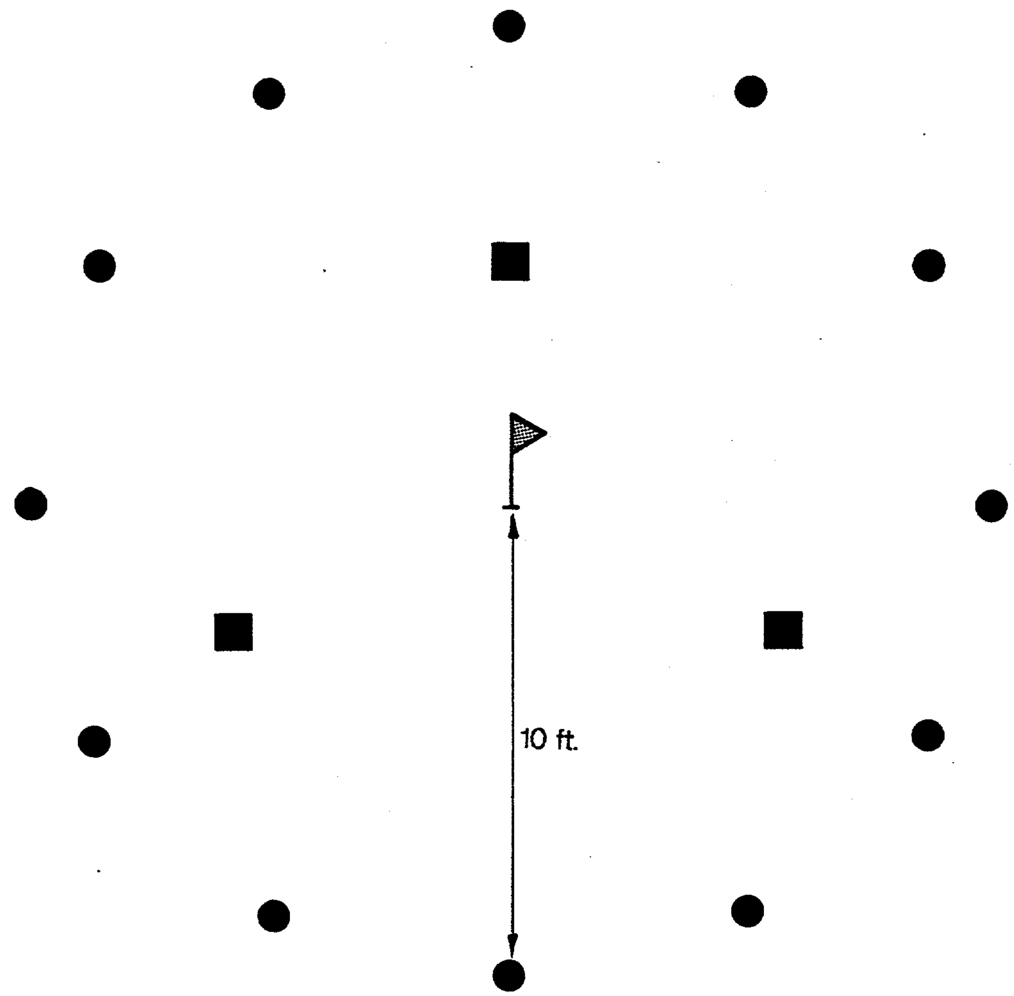
PROJECT NO. 6805-001
FIGURE 2-1



EXPLANATION

RECEIVER STATION FLAG

P-WAVE GEOPHONE

3-C GEOPHONE

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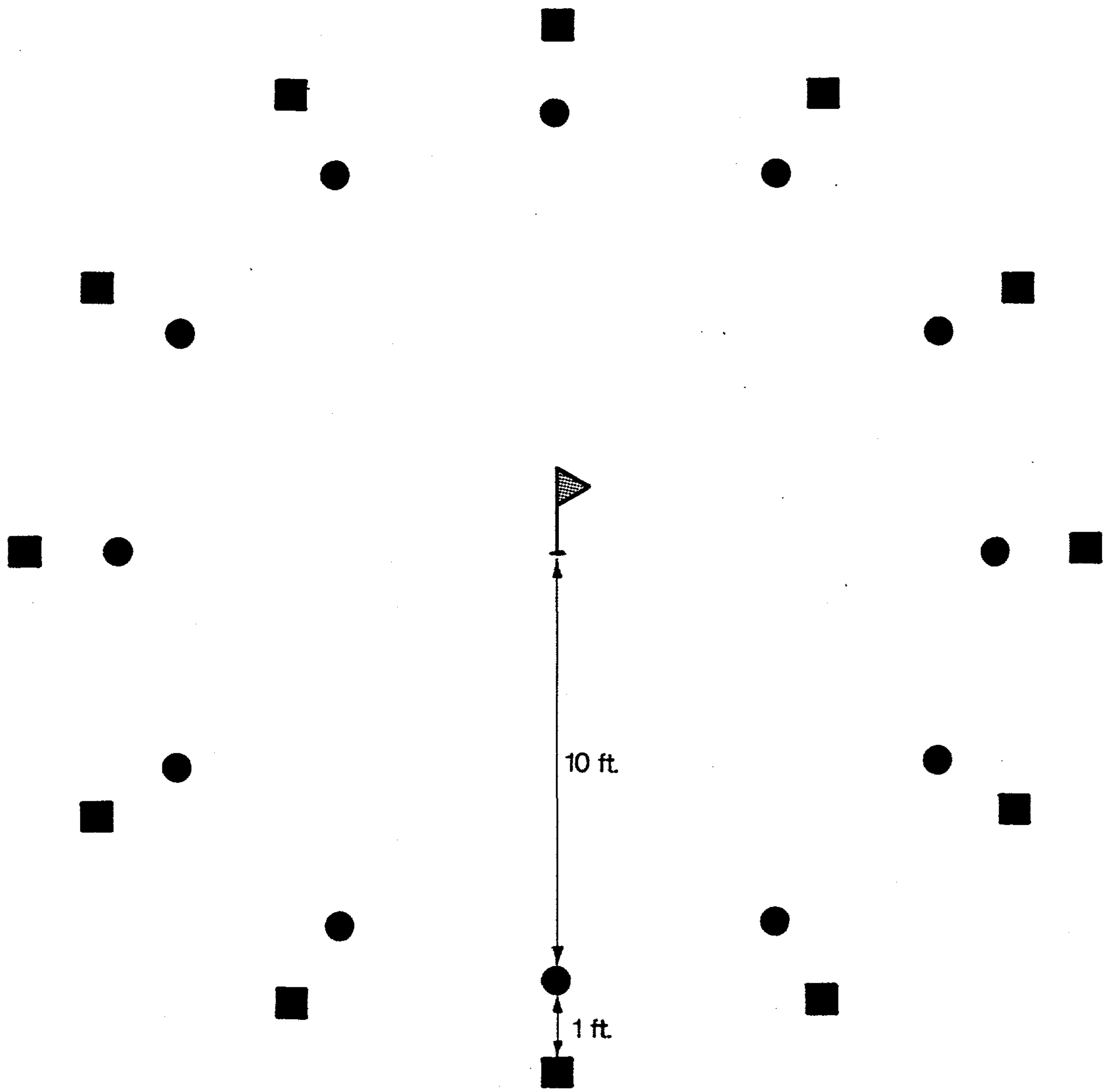
LOCATION 1 GEOPHONE ARRAY

PROJECT NO. 6805-001 FIGURE 3-2



EXPLANATION

RECEIVER STATION FLAG

● P-WAVE GEOPHONE

■ 3-C GEOPHONE

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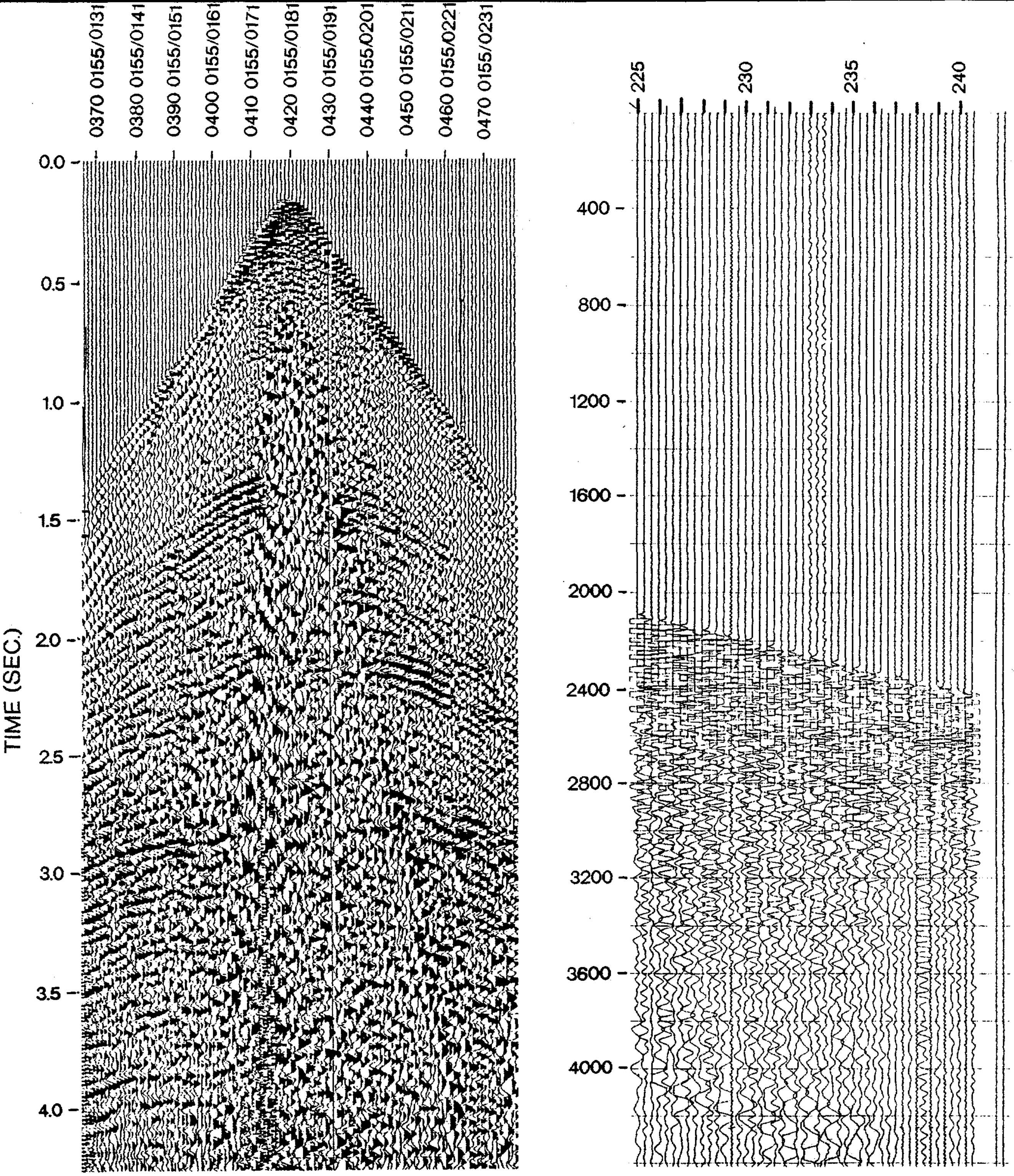
LOCATION 2 GEOPHONE ARRAY

PROJECT NO. 6805-001 FIGURE 3-3



A) SHOT RECORD 181, 160 FOR RECEIVER LINE 155 WITH I/O-2 RECORDER

B) SHOT RECORD 181, 160 FOR RECEIVER LINE 155, STATION 225 - 240 WITH DAS-1 RECORDER

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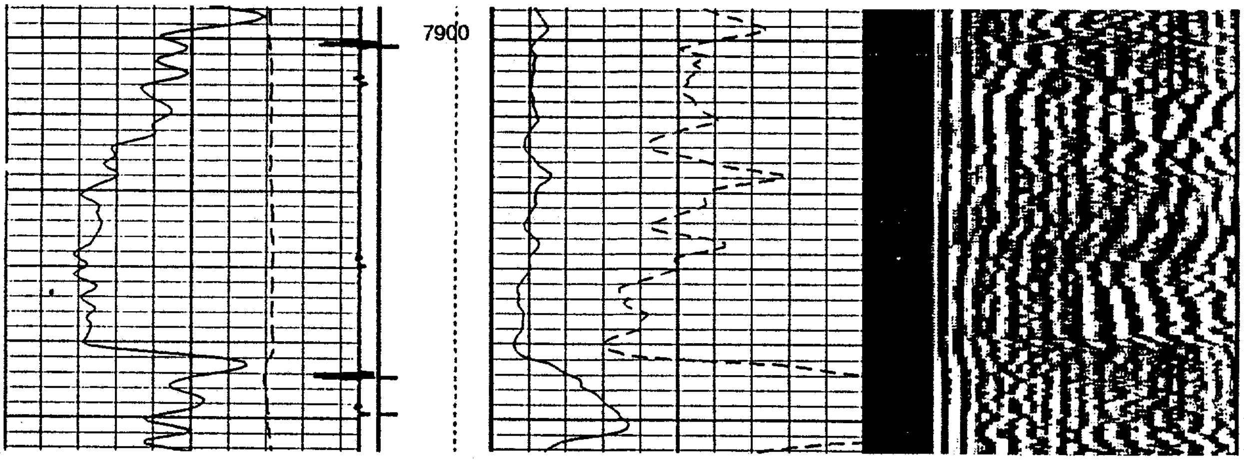
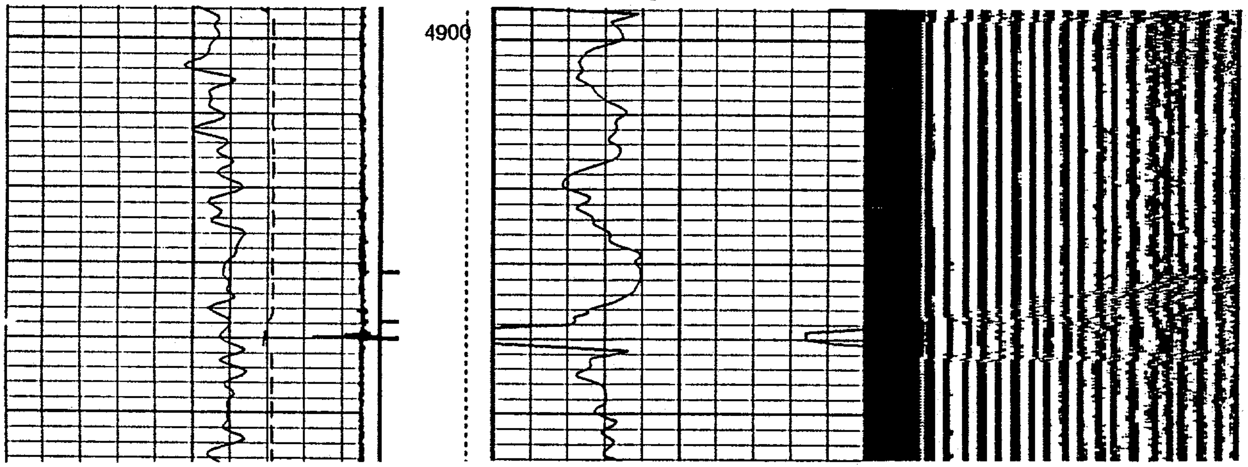
COMPARISON OF SEISMIC P-WAVE DATA FOR TIME DELAYS

PROJECT NO. 6805-001 FIGURE 3-4

A) GOOD BOND LOG INDICATING GOOD COUPLING



B) POOR BOND LOG INDICATING POOR COUPLING



Gamma Ray (GR) (GAPI) 0 – 150	Tension (TENS) (LBF) 10000 – 0	CBL Amplitude (CBL) (MV) 0 – 20	Min Amplitude Max; VDL VariableDensity (VDL) (US) 200 – 1200
Transit Time (TT) (US) 400 – 200	Stuck Stretch (STIT) 0 (F) 50	CBL Amplitude (CBL) (MV) 0 – 100	
Casing Collar Locator (CCL) (----) -19 – 1	Cable Drag From STIA to STIT	Good Bond (GOBO) (MV) 0 – 20	RUN WITH 2000 PSI ON CASING
CasCollar From CCL to T1	Tool/Tot Drag From D3T to STIA	GoodBond From ACBL to GOBO	

PIP SUMMARY

⊢ Casing Collars

Time Mark Every 60 S

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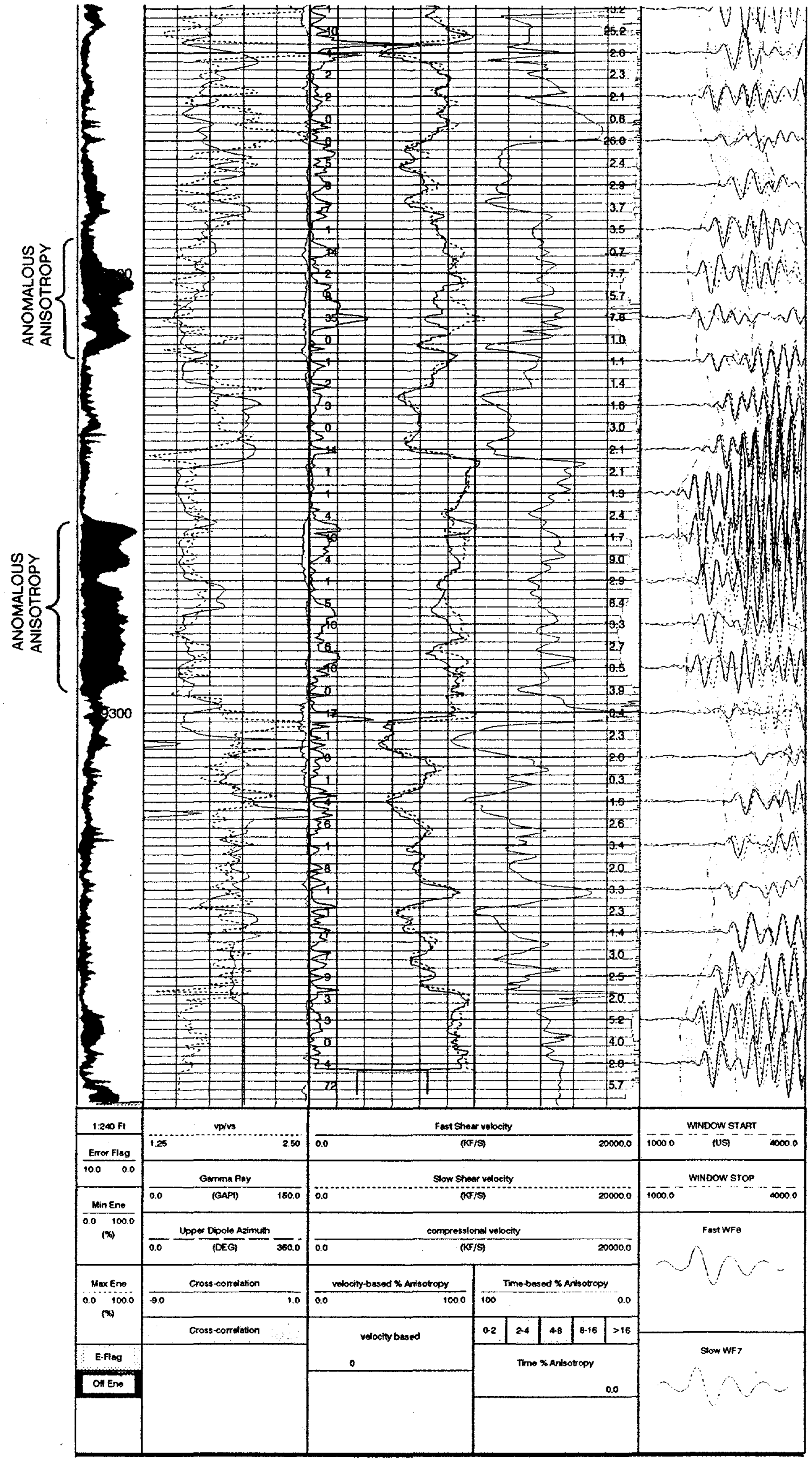
CEMENT BOND LOG

PROJECT NO. 6805 -001 FIGURE 3-5



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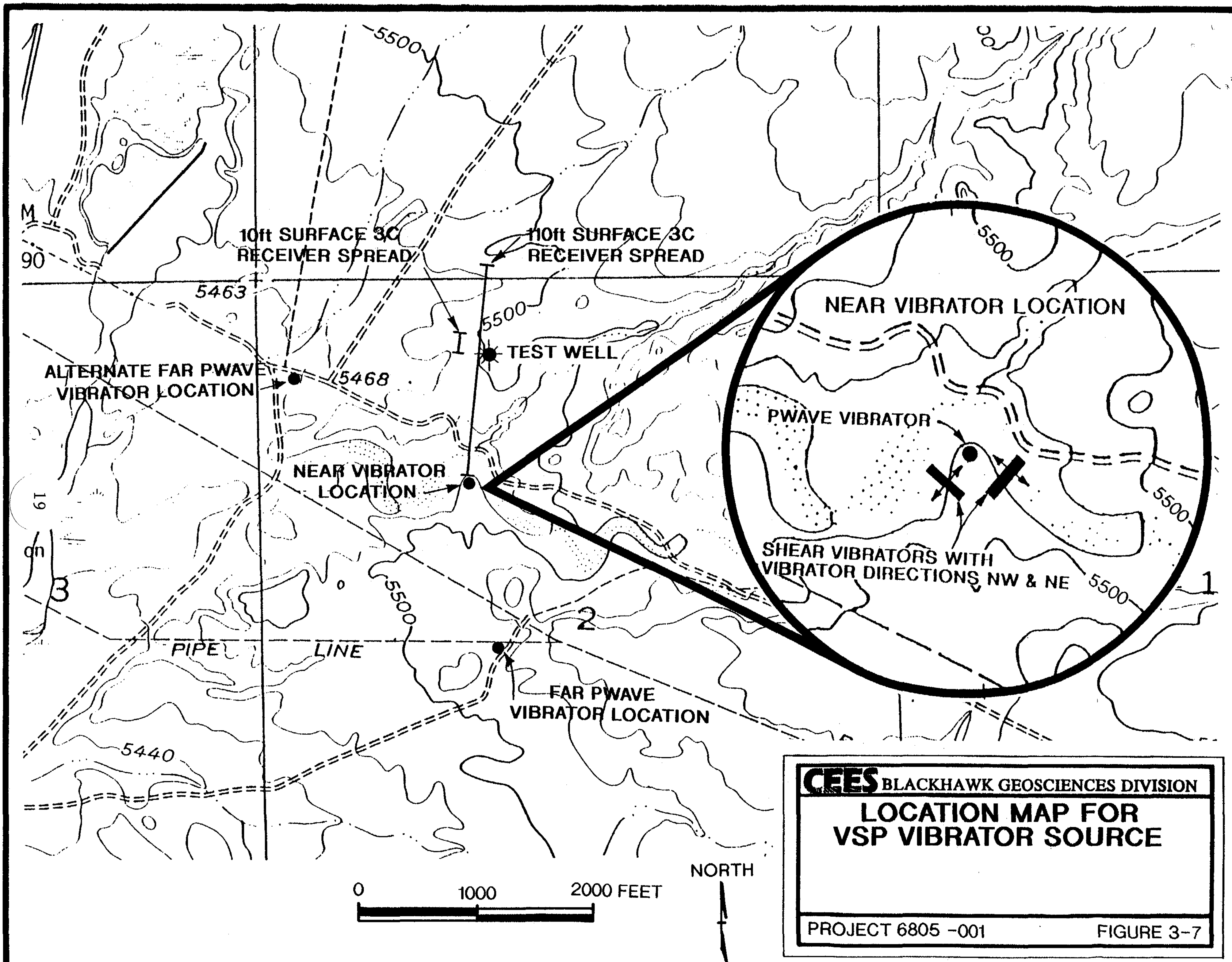
ANISOTROPY LOG FROM SCHLUMBERGER DSI TOOL

PROJECT NO. 6805-001 FIGURE 3-6



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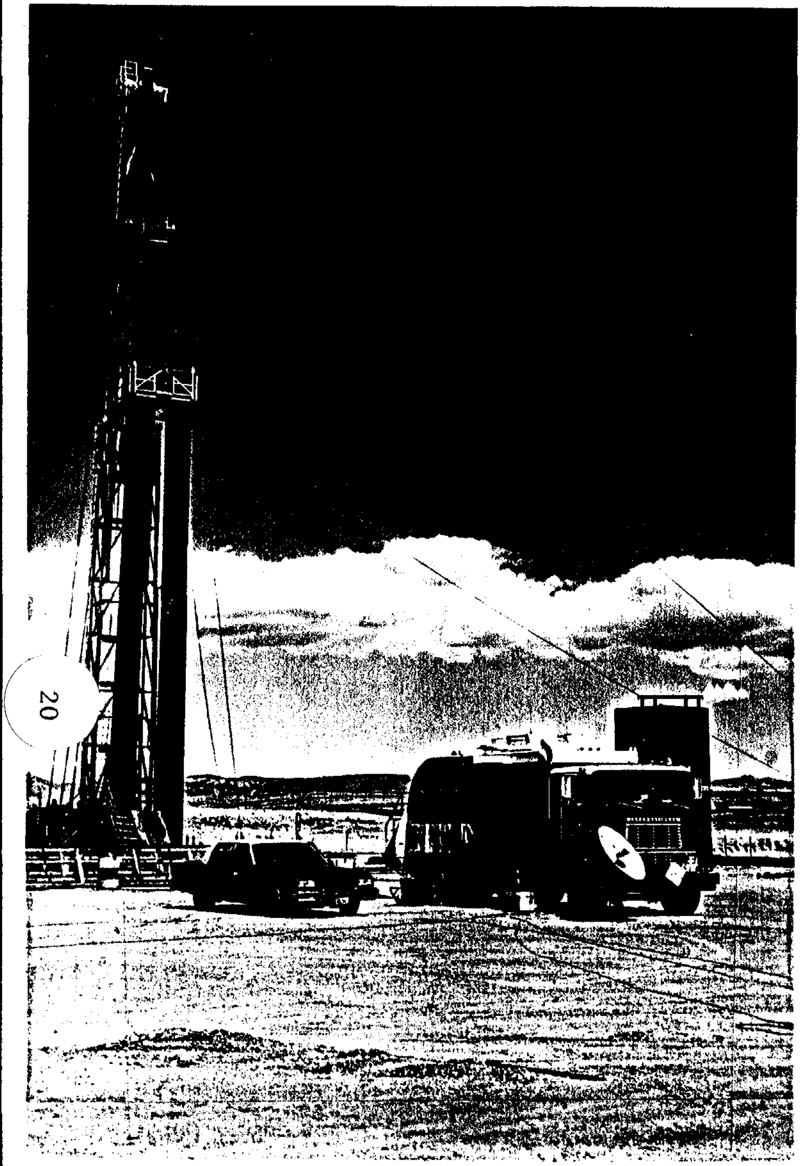
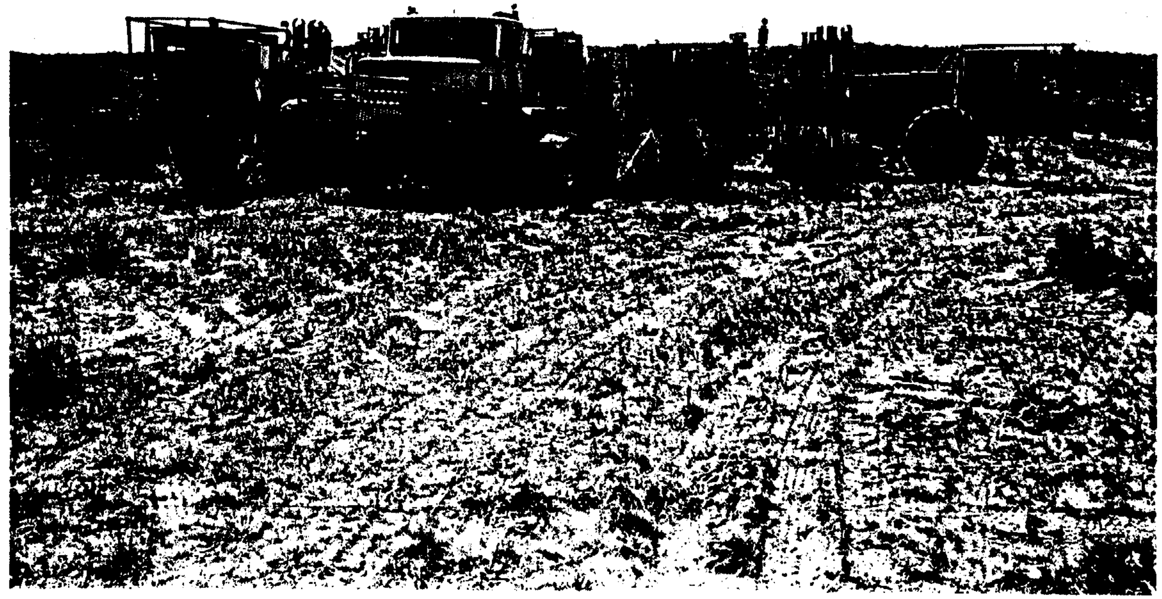
LOCATION MAP FOR VSP VIBRATOR SOURCE

PROJECT 6805 -001

FIGURE 3-7



A) 9C VSP SITE AND SCHLUMBERGER LOGGING TRUCK.



B) HEAVYQUIP SHEAR VIBRATORS AND NORTHERN P-VIBRATOR.

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9C VSP SITE AND VIBRATORS

PROJECT NO. 6805-001 FIGURE 3-8