DOE/MC/31224 -- 5021
(DE95009751)

Naturally Fractured Tight Gas Reservoir Detection Optimization

Quarterly Report
January - March 1995

May 1995

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

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Coleman Research Corporation
Golden, Colorado

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Table of Contents

3D P-WAVE SURVEY

Western Geophysical completed their initial processing of the owner/operator's 3D P-wave survey early in the first quarter of 1995. Upon inspection by owner/operator, CRC & Lynn Inc., some anomalies were identified in the data which were thought to be a result of the processing sequence. These were addressed and a second data volume with repicked velocities was delivered to the owner/operator. This volume significantly improved the reflector image at the Lower Fort Union depths showing vertical faulting along the crest of the known anticline in depth. Some of the anticline was not manifest in the time structure suggesting large velocity anomalies above the zone of interest across the field. The owner/operator converted some of the deeper horizons to depth using well control and the anticline was restored. The quality of this product was checked by comparing the checkshots and VSP's for the field. A high correlation was obtained, thus increasing the confidence in the method. A similar approach is currently being used for the Lower Fort Union. The 3D P-wave data were acquired using circular geophone arrays which enable the DOE study to make full use of these data, and to search for azimuth-dependent amplitude anomalies. The azimuth-dependent anomalies we identify will be tied to well control when possible, and tested by drilling, eventually.

ADDITIONAL PROCESSING OF 3D P-WAVE SURVEY

A request for bid on azimuth-dependent additional processing of the 3D P-wave data was sent out in December 1994. Eight companies were identified to process the data based on previous experience. Four companies responded with bids. These included Geco-Prakla, Western Geophysical, Pulsonic, and Geophysical Development Corporation. Western Geophysical was recommended for the work, as they are already familiar with the data (Western is currently under contract to the owner/operator for the processing of the 3D data), and hence can complete the required additional processing with greater efficiency and cost saving.

Palantir was identified to perform QA/QC on the processing flow and also to perform interpretation of the data subsequent to processing. Western will initially produce two data volumes separated by source-receiver azimuth. The two different source-receiver azimuths, parallel and perpendicular to fractures, must be analyzed separately in order to use the P-wave AVO anomalies for the fracture detection.

Each azimuth must contain sufficient fold and offsets to perform AVO analysis with good velocity determination and offsets approximately equal to target depths. At the field, the fractures are believed to trend east/west in the zones of interest. Seven "azimuth super-gathers" from the 3D data volume were created by Western to display P-P common-azimuth reflection data in 18 different azimuths from N to S, each with a range of offsets from 50 ft to 10,000 ft. An azimuth super-gather is produced from a 1980 ft by 1980 ft bin in the subsurface.

Each trace in the 1980 ft by 1980 ft super gather is a three-to-six fold stack. These seven azimuth bins were also created using a 990 ft by 990 ft subsurface bin, in order to reduce any "smearing" due to geologic change in the 1980 ft by 1980 ft original bin. Azimuth gather #2, 990 ft by 990 ft bin size, is shown in Figure 1. The results seen in the 990 ft by 990 ft bins are also seen in the 1980 ft by 1980 ft bins. The azimuth gather plots indicate that the N/S stacking velocities are usually slower than the E/W stacking velocities which is consistent with the presence of E/W trending fractures. Moreover, the fast shear wave is polarized E/W in the 9C VSP well, which would be consistent with a dominant E/W fracture set. The azimuth gathers indicate that to properly image the data pre-stack, the stacking velocity must be azimuth-dependent. We expect that the migration velocities will also be azimuth-dependent.

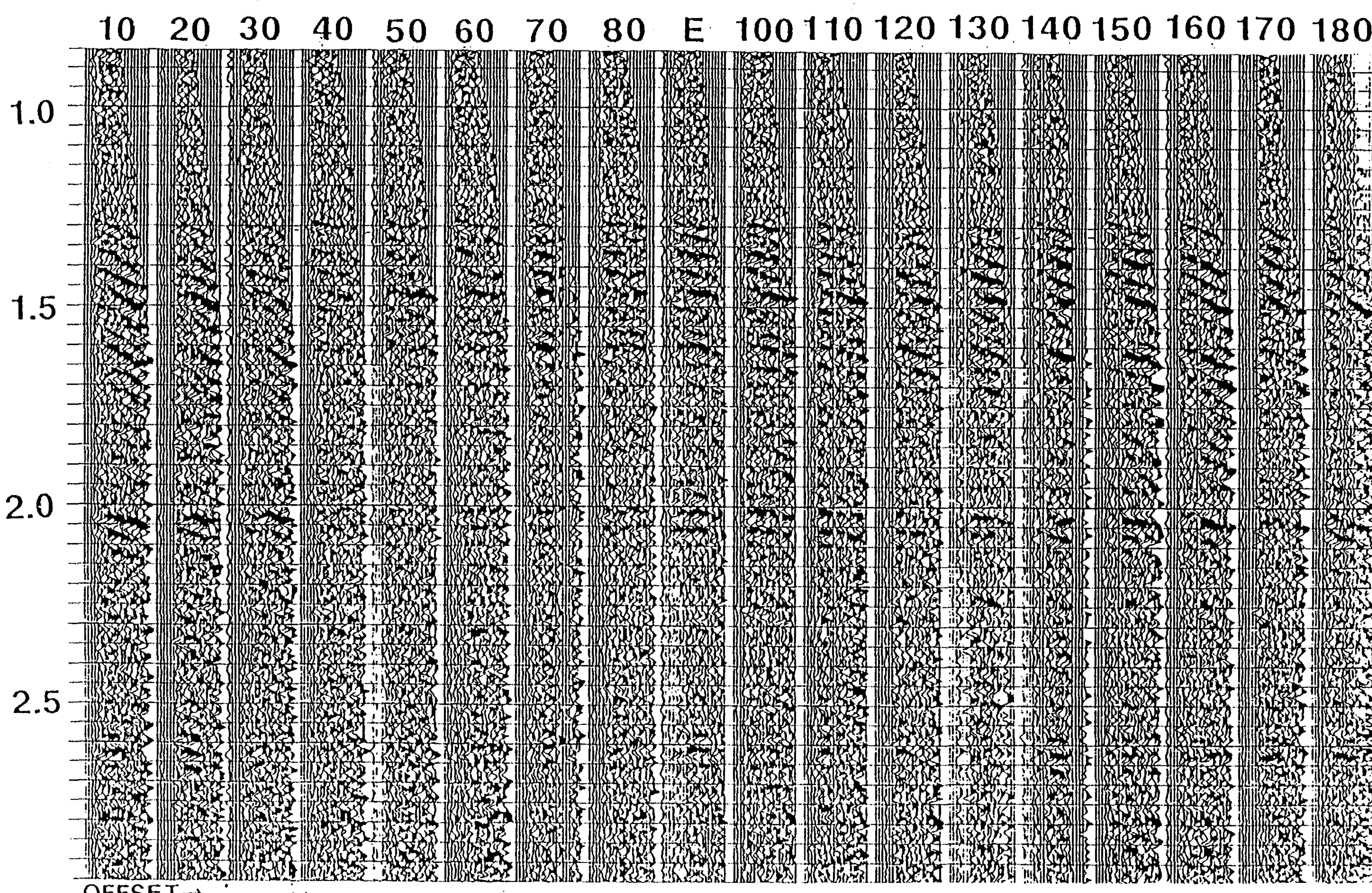
The seven azimuth super-gathers also show that reflection coefficients, the frequency content, the amplitude variation with offset (AVO), and the attenuation, as well as the travel times, are azimuth-dependent quantities.

The dip line through azimuth gather 2 is shown in Figures 2A and 2B. Figure 2A is the N/S seismic line stacked with the N/S (± 45 degrees) source-receiver azimuths. Figure 2B is the seismic line stacked with the E/W (± 45 degrees) azimuths. These lines show minimal dip in azimuth bin #2. Throughout the whole survey, CDP lines were excerpted from the P-wave 3D survey, in which E/W azimuths were segregated from N/S azimuths. These stacked lines, all stacked with the same spatially-variant velocity function, picked from azimuth-blind velocity scans, all display results consistent with slower N/S stacking velocities than E/W stacking velocities, and furthermore indicate that in the locations of five of the seven azimuth super-gathers, minimal dip is present. The dip-effect is present within two of the azimuth bins, in that the N/S azimuths need a faster stacking velocity than the E/W azimuths. Differences in these N/S and E/W sections are attributed to mis-stacking the data: the correct azimuth-dependent velocities must be applied before geologic meaning can be extracted.

These observations lead us to conclude that specific azimuth-dependent 3D data processing for the entire dataset and subsequent interpretation will yield a better understanding of the structure and the relative fracture density than conventional (azimuth-blind) processing. Western Geophysical is currently working on this azimuth dependent processing by splitting the data into two volumes, one with N/S azimuths (± 45 degrees), and one with E/W (± 45 degrees). Each volume will be separately processed with pre-stack time migration. The pre-stack and post-stack volumes of seismic data, and the velocity volumes, will be compared. Zones of equivalence and difference will be identified and tied to well control. Travel times, amplitude, frequency content, and attenuation will be compared for the two azimuths.

To demonstrate the relationship of the P-wave azimuthal anomalies to conventional P-S and S-S azimuthal anisotropy anomalies, the latter two being sensitive to relative fracture density and fracture azimuth, it is our intention to also collect multicomponent seismic. The acquisition of 3D dynamite-sourced three-component receiver data is scheduled for fall, 1995, or spring, 1986; shear wave vibrator sources will be tested on two 2-D lines in the 3D survey.

AZIMUTH GATHER BIN #2 SUM OF TRACES
SORTED BY SOURCE RECEIVER AZIMUTH



AZIMUTH BIN # 2 (990' x 990')

FIGURE 1

DIPLINE (N-S) THROUGH AZIMUTH BIN #2 (N-S AZIMUTHS)

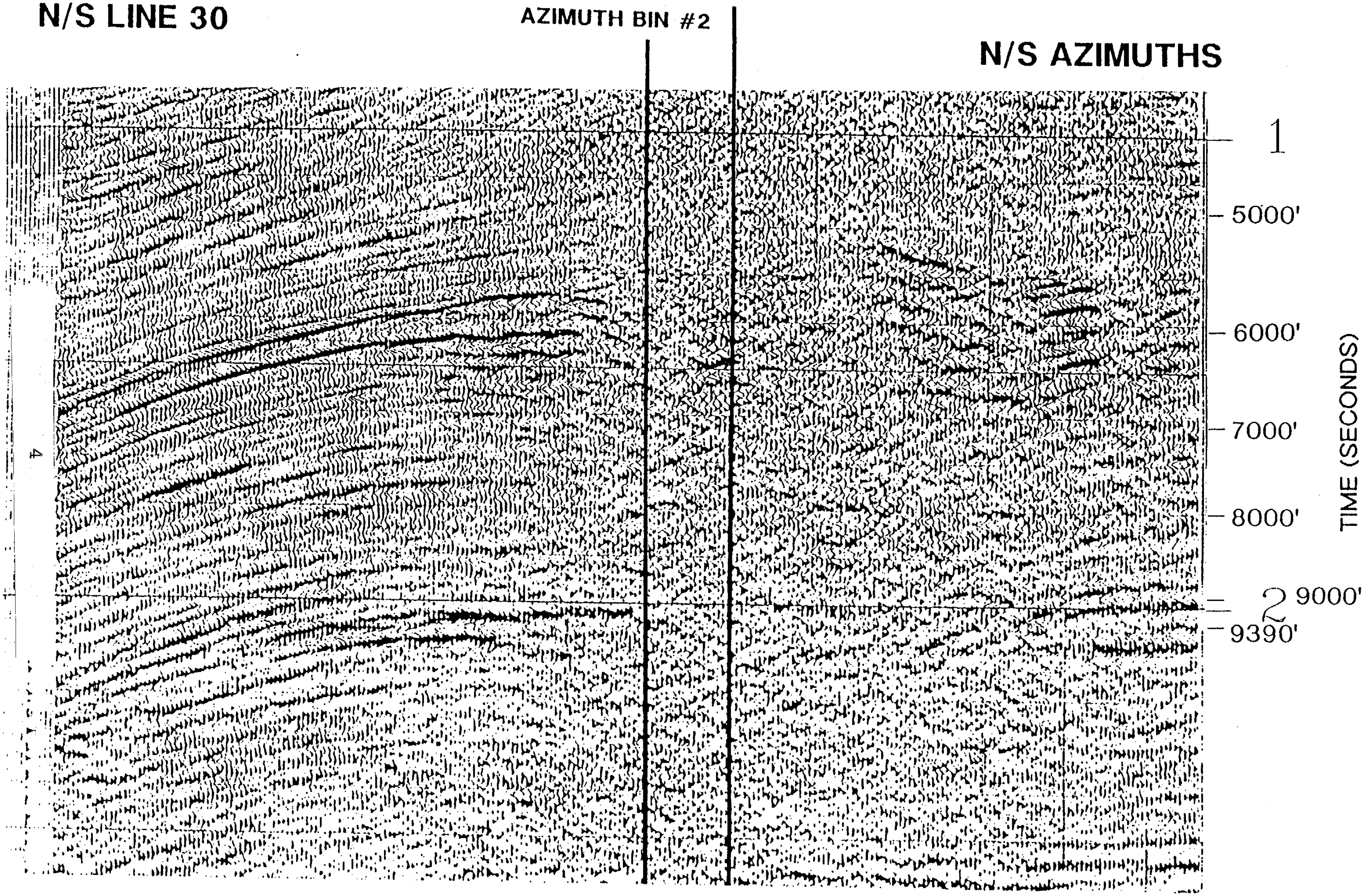


FIGURE 2A

DIPLINE (N-S) THROUGH AZIMUTH BIN #2 (E-W AZIMUTHS)

N/S LINE 30

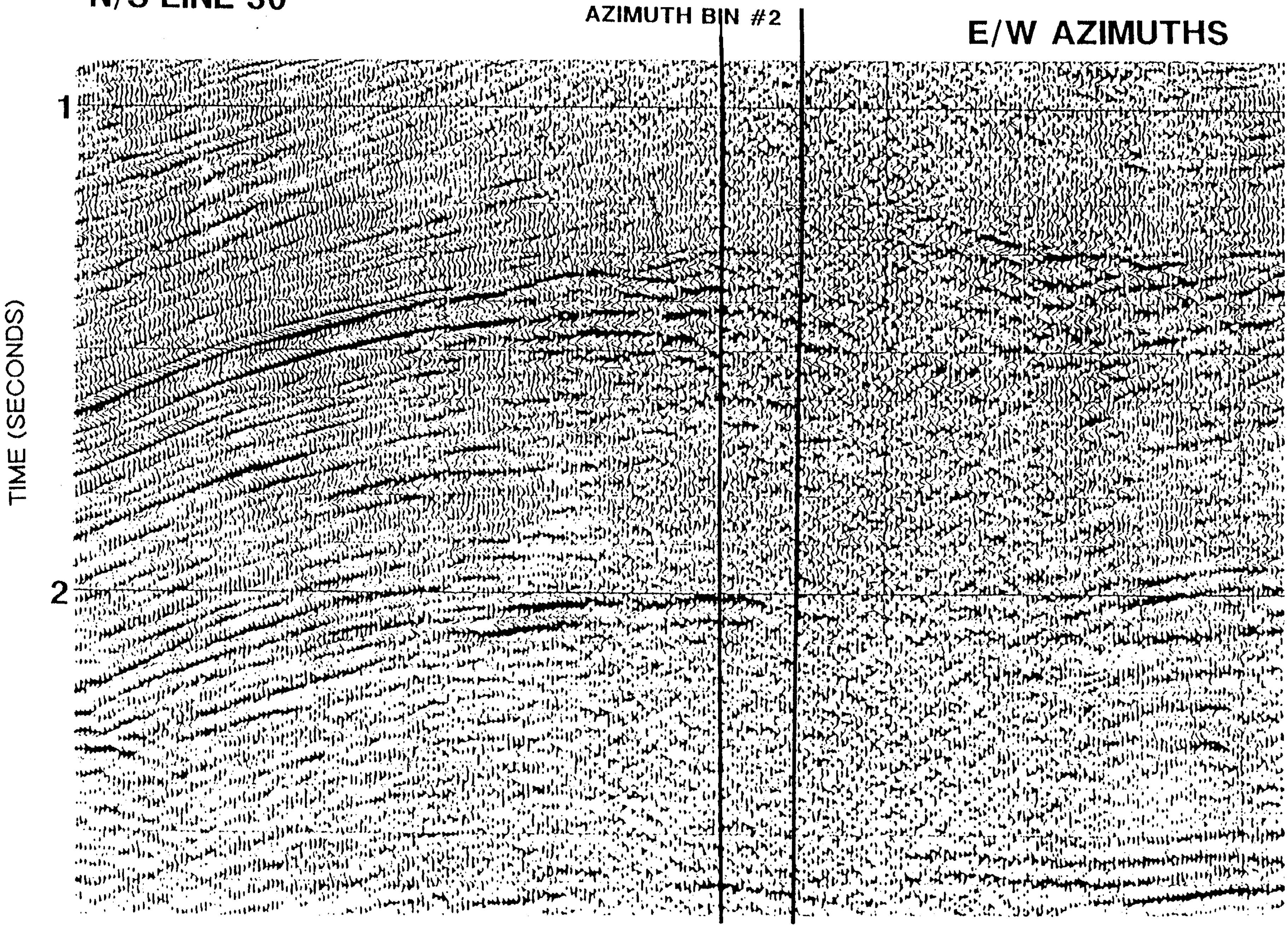


FIGURE 2B

9C VSP

Processing of the 9C-VSP continues at Schlumberger, Canada. A problem was identified with the deeper data (8,500 ft to 9,400 ft) where the compressional wave energy from far offset P-wave source was insufficient to easily achieve the necessary tool spin correction using the shear wave geophones. This data is currently under further review by Lynn Inc. and Schlumberger.

REVIEW OF MULTICOMPONENT FEASIBILITY TESTS

Multicomponent recording made during the 1994 field season have been described in the Quarterly Report for July-September 1994. A description of the results follows.

3D-3C

During the acquisition of the 3D P-wave data volume, a short line of 3-component receivers were deployed to record the dynamite explosive sources. Figure 3 shows an example of the results of this survey. On the in-line receiver components, clear P-S energy can be seen indicating that mode converted energy can be recorded at this field using dynamite sources. On the cross-line receiver components, P-S energy can also be seen indicating that shear wave splitting of the mode converted shear energy has occurred.

During the 3D P-wave acquisition seven sets of 3-C geophones were also deployed on the southern end of the seven western most receiver lines. Some of these receivers recorded P-S events from approximately 13,500 ft.

Extensive source tests were completed prior to the 3D survey, and therefore the characteristics, storage and use of dynamite at the field are well documented. The safety and use of dynamite for future work is discussed later in further detail.

Multi-Channel Vibrator Work

During the 9C VSP acquisition, 16 stations of 3-component phones (2 per station) were deployed in a line extending from the vibrators adjacent to the well. Each vibrator sweep was recorded during the 9C acquisition. The results of this exercise did not show useable data, and the conclusion is that in the future strings of 3C geophones (12 phones per string) are necessary rather than individual phones.

Vibrator and Impact Walkaways

Subsequent to the VSP acquisition, the vibrators were recorded in walkaway mode along a line adjacent to the previous test. Single phones were used at each location with one vibrator in cross-line and in-line shear modes. Once

MODE CONVERTED (SHEAR) ENERGY FROM DYNAMITE SOURCE

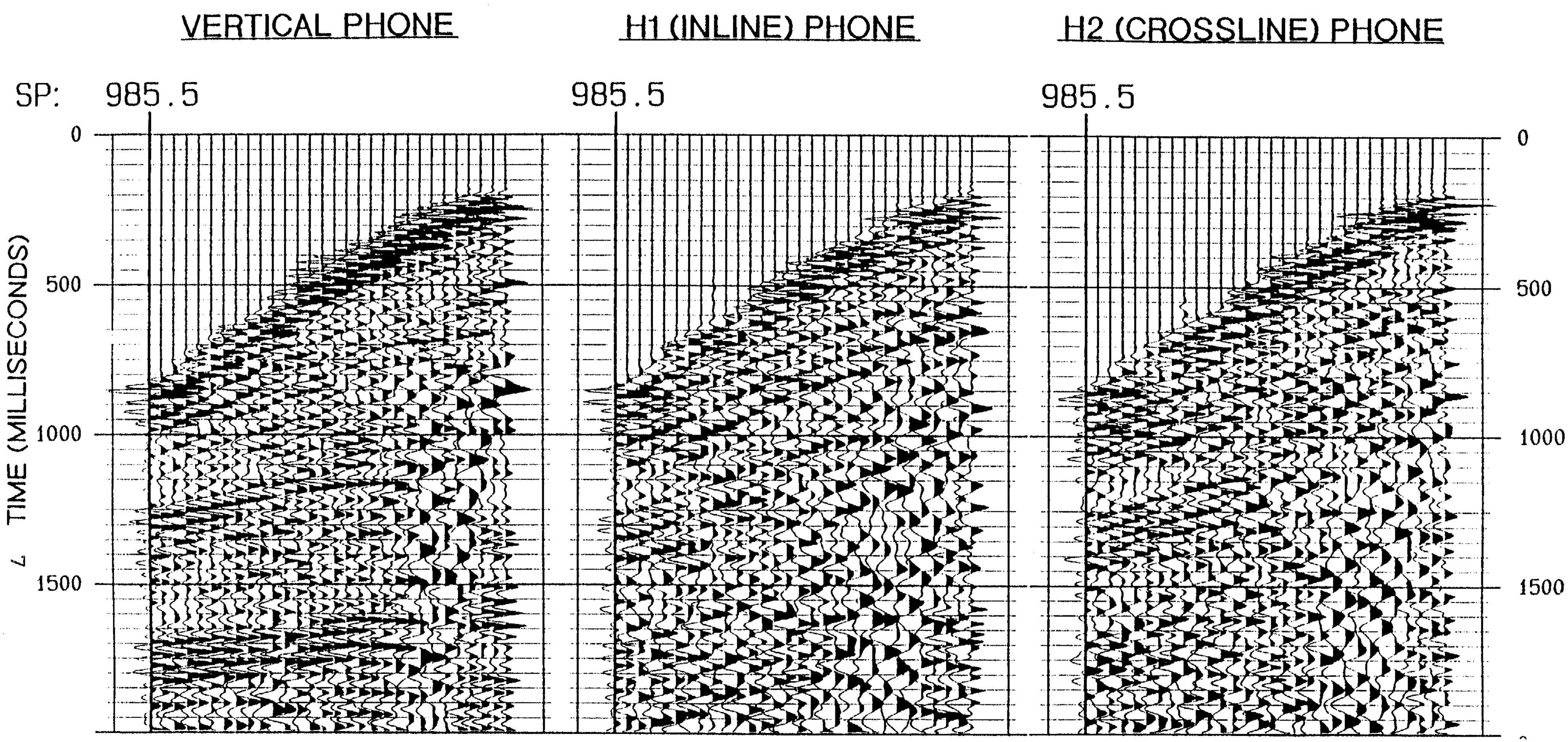


FIGURE 3

again, the results of this test proved that strings of phones are necessary for future acquisition.

MINIVIBRATOR STUDIES

The use of shear vibrators at the field for S-S reflection data to compare with the P-P anomalies is viewed as traditionally necessary to the verification of the P-wave technologies, however, the availability of the traditional shear vibrators is becoming problematic. For previous DOE multi-component work, the Amoco Mertz shear vibrators were used. Amoco has since made known that these will not be as readily available for use outside of Amoco. The two shear vibrators owned by HeavyQuip that were used on the 9C-VSP shot in September 1994, have recently been sold and may also not be available for rent in the future.

Over the past year, CRC-BGD has been testing and using commercially a new generation of vibrators, the iVi Minivib. Although originally designed and built with shallow, environmental work in mind, there has been increasing interest that these vibrators could be applicable for oil and gas work. If these vibrators prove to be an acceptable alternative to the larger, traditional vibrator, then not only are they cheaper to use, but with their availability, the logistics of multi-component vibrator work will be simplified significantly.

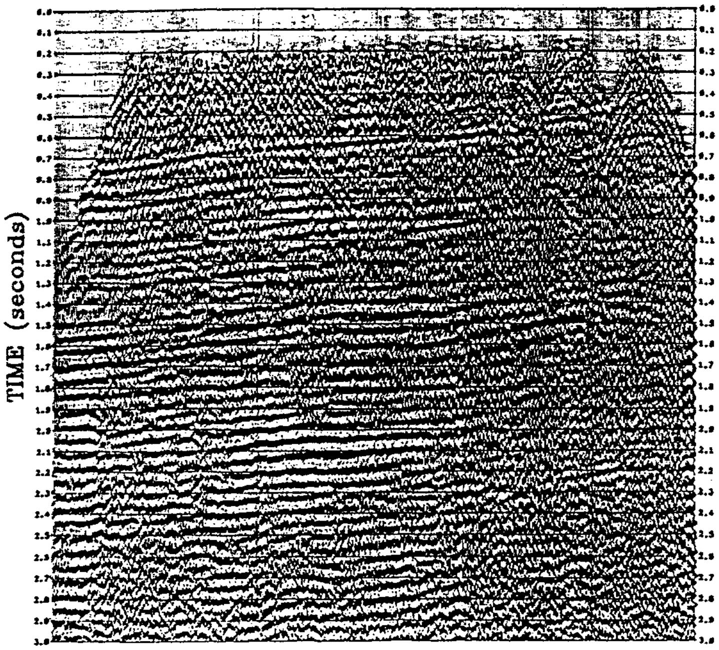
Recent Vibrator Tests

Wyoming Test.

In order to evaluate these new vibrator sources for their utility in multi-component acquisition at this field, and for future work on similar fractured gas reservoirs, a joint test with Amoco and iVi was held in Wyoming in January. Two iVi Minivibs were directly compared to four of the Mertz M-18 shear vibrators. Figure 4 shows a stacked section of 4C source and receivers. Down to the dominant reflector at 1.6 seconds (approximately 3,000 ft) the two sections compare favorably. The iVi Minivib source array have a total hold-down weight of approximately 12,000 lbs and the Mertz source array 120,000 lbs. Therefore, we conclude that to depths of 3,500 ft, two iVi vibs are preferable to four Mertz vibs (due to equal signal/noise and less costs). The target horizons at the Wind River Basin field are 5,000 - 10,000 ft and therefore it is thought that either more iVi energy or better use of the iVi energy available is needed to see to this depth.

Mertz M18
(4 vibes)

CROSSLINE/CROSSLINE



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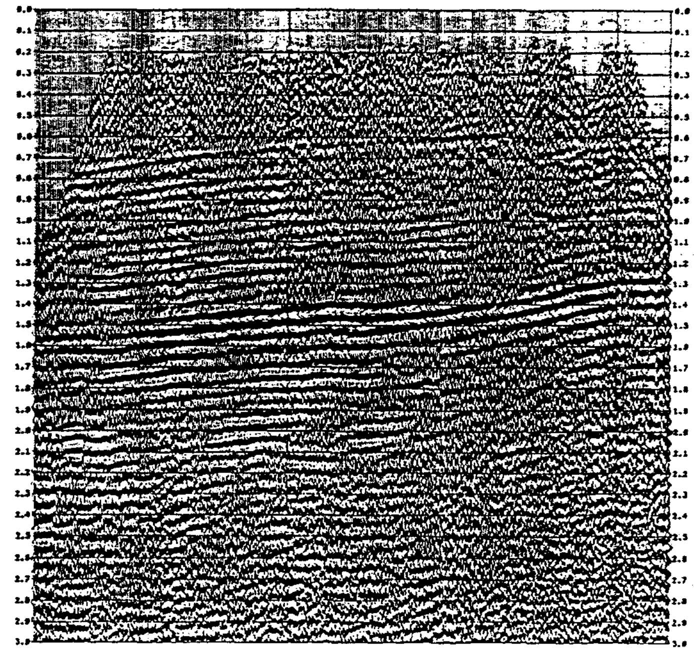

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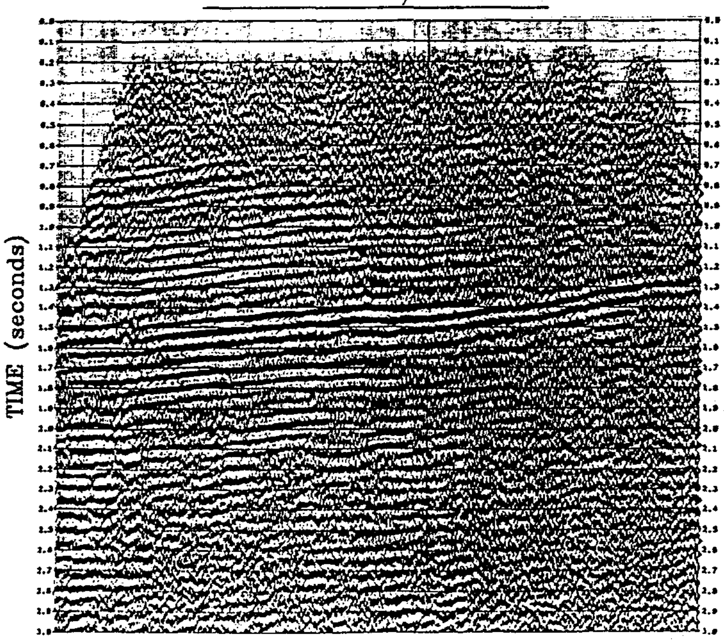
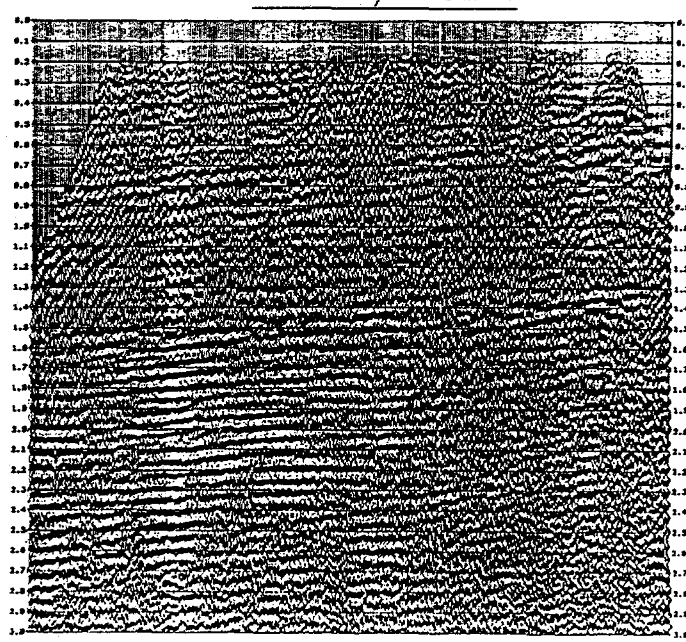


INLINE/INLINE



Catoosa Test.

During the week of March 7 through 13, the iVi Minivibrators were tested at Amoco's research facility, Catoosa, OK. The tests consisted of three parts:

1. Source Characterization. Four Minivibrators were used in various combinations, patterns, and orientations with different sweep types (frequency, upsweep/downsweep, linear/non-linear). The optimum minivibrator source array was then chosen for the subsequent 4C surface acquisition.

2. VSP Acquisition. A multi-component, multi-offset VSP was acquired using three of the Minivibrators. Since the Minivibrator mass is rotated on these units, only one source was necessary for each offset location. This represents a significant saving in both time and cost for this type of VSP acquisition. This data is currently being processed by Amoco.

3. 4C Surface Seismic Profile. The minivibrators were also used to collect a short (2,400 ft) reflection profile. The area is known for poor P-wave reflection data, however clear high signal-to-noise results were obtained in shear wave mode. This data is currently being processed by CRC.

In addition to these tests, Amoco, under the direction of Mike Mueller, commissioned Schlumberger, Western Atlas and Aquitech to run each of their respective companies Dipole Sonic Imager (DSI) tools in the VSP hole. The DSI log will evaluate the shear wave velocities as a function of depth and the amount of birefringence (shear wave anisotropy) at the wireline log scale (1 kHz). Both of these quantities are also recorded in the S-wave VSP at seismic frequencies (10-100 Hz) and will be compared. The S-wave synthetic seismogram from the DSI and the S-wave corridor stacks from the VSP also provide two estimates of the S-wave reflectivity and will be compared, and used with the S-wave surface seismic reflection data. The objectives of this collaborative project were to evaluate the minivibrators as shear wave sources for the proposed acquisition in October in Wyoming, and also to evaluate their potential for similar acquisition in the future. The minivibrators have the advantage of smaller size than conventional vibrators and hence less environmental impact, less expense to operate, and easier permitting. From this test, and other similar tests with Amoco in Wyoming reported earlier by CRC, it would appear that the minivibrators have the potential to survey to depths in excess of 5,000 ft. It is hoped that further evaluation of the results will determine the maximum depth of survey for the minivibrators. A full report on the minivibrator tests will be submitted to DOE when processing is complete.

If these tests with the iVi minivibrators indicate that the required survey depths should be obtainable, then the iVi vibs will be tested at the field during the 3D-3C acquisition. The potential cost saving of these vibrators is 1/3 to 1/4 of conventional S-wave vibrator costs, and thus represents a significant new technology for seismic characterization of fractured gas reservoirs where multi-component seismic is to be used.

3D-3C ACQUISITION

During February 1995 a preliminary field test plan for 3D-3C (P-SV) surface seismic acquisition was submitted for review to DOE. A schedule of activities is given below in Table 1.

Table 1	
Schedule for 3D-3C and 9C Surface Seismic Acquisition (Fall 1995)	
Date (1995)	**Activity**
January 31	Kick-off meeting of surface seismic actions (CRC, Lynn Inc., DOE).
February	• Submission of broad field test plan for seismic actions. • Testing of iVi Minivibrator sources. • Modeling begins on 3D-3C data volume - Don Lawton.
March	• Planning begins for 3D-3C. Contact landowners, pipeline companies, etc. Permit agent + CRC.
April	• Full test plan submitted to DOE to include NEPA documentation, permits, etc. • Request for Bid - Surface Acquisition.
June	• Land survey of site.
July	• Archaeology site survey, flagging critical locations.
August	• Drill and load shot holes.
October 1	• Acquire 3D-3C and 9C lines.

The proposed acquisition is for September-October 1995. This time period is viewed as critical in order to complete the complex processing by end of contract.

MODELING OF 3D-3C ACQUISITION PARAMETERS

The first stage in planning any data acquisition is careful modeling of the consequences of the acquisition parameters. The modeling of 3D-3C (converted wave) data is not offered by many contractors due to the complexity of data acquisition and lack of commercial surveys. To date, the most complete modeling service is offered by Dr. Don Lawton, University of Calgary. A brief summary of his modeling are detailed below. A full report will be submitted in the final field test plan.

Converted-wave (P-SV) and P-P fold, offset and azimuth distribution were evaluated for the 3C-3D seismic acquisition program. Optimum parameters for the 3C-3D acquisition were found to be a straight-line shooting strategy with orthogonal source and receiver lines. Source lines are oriented east-west with a separation of 1100 ft and a nominal source separation of 440 ft, decreasing to 220 ft within the central region of the survey area, encompassing the receiver patch. A fixed receiver patch is proposed, consisting of 9 receiver lines oriented north-south, with a receiver line separation of 660 ft, a receiver spacing of 220 ft, and 51 receiver locations per line. This recommendation requires 459 3-component geophones (1377 channels) and a total of 1212 shots. Some reduction in the total shot count can be provided through tapering the source lines at each corner of the source patch.

A summary of the acquisition geometry is given below in Table 2.

Table 2 Summary of Survey Geometry	
Source parameters:	
Line orientation	East-West
Source interval	440 ft (220 ft in infill area)
Source line interval	1100 ft (straight line pattern)
Number of source lines	24
Number of source-points/line	42 (+ 17 in infill area)
Total number of source points	1212
Receiver parameters:	
Line orientation	North-South
Receiver interval	220 ft
Receiver line interval	660 ft (straight line pattern)
Number of receiver lines	9
Number of receivers/line	45
Total number of receivers	459
Number of recording channels	1377
Patch parameters:	
All receivers live	
P-P fold (nominal)	25
P-S fold (nominal)	30

ACQUISITION PLANNING

A request for bid for the 3D-3C acquisition will go out to prospective companies in the early part of the second quarter. Planning of the acquisition is ongoing at CRC in conjunction with Lynn Inc., the owner/operator, and Jenkins & Associates. It is CRC's recommendation to use Jenkins & Associates for permitting and for logistical oversight throughout the acquisition in a similar manner to that which the owner/operator used them during last years 3D P-wave acquisition. A justification for this will be submitted to DOE in April.

<u>Shotholes</u>

Based on the multicomponent feasibility test results of 1994, and the BLM recommendations to avoid excessive use of vehicle impact at the site, it is CRC's recommendation that dynamite P-P sources rather than P-wave vibrator sources are used for the acquisition. The disadvantage with P-wave vibrator sources is their high surface disturbance. During the owner/operator's 3D acquisition in 1994, excessive vehicle impact was the major concern of the BLM. Therefore, in order to keep this at a minimum, we recommend against the use of P-wave vibrators. The use of explosive sources in shot holes has been proven to be a safe and efficient method. All shot hole practices will adhere to the International

Association of Geophysical Contractors Guidelines for land geophysical operations and also to all local and state regulations. Only licensed shot hole explosive handlers and pluggers will be authorized to complete the holes. A secured, safe storage area has been designated at the site and inventory checks will be made daily by CRC and Jenkins & Associates during the time when dynamite is stored there. A full discussion of this and a request for categorical exclusion for its use was made in the preliminary field test plan.

ARCHAEOLOGY AND NEPA DOCUMENTATION

A request for bid on the archaeology will be submitted in the second quarter. NEPA documentation will also be filed with the DOE at this time.

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DETECTION OPTIMIZATION

USDOE