DOE/MC/31224 -- 5122
(DE96004350)

Naturally Fractured Tight Gas Reservoir Detection Optimization

Annual Report
August 1994 - July 1995

September 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

DISCLAIMER

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USDOE

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Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Coleman Research Corporation
Blackhawk Geosciences Division
301 Commercial Road, Suite B
Golden, Colorado 80401

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1.0 SUMMARY

This report details the field work undertaken Blackhawk Geosciences and Lynn, Inc. during August 1994 to July 1995 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 work described herein consisted of four parts:

- 9C VSP in a well at the site.
- Additional Processing of the previously recorded 3-D survey at the site
- Multicomponent feasibility studies during the 3D P-wave survey on the site, and Minivibrator testing
- Planning and Acquisition of a 3-D, 3-C seismic survey

The objectives of all four parts 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. The additional processing of the 3-D uses developmental techniques to determine areas of fractures in 3-D surveys. With the multicomponent studies, tests were conducted to establish the feasibility of surface recording of the anisotropic reservoir rocks. The 3-D, 3-C survey will provide both compressional and shear wave data sets over areas of known fracturing to verify the research.

2.0 BACKGROUND

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. 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.

3.0 9C VSP AND ASSOCIATED LOGGING

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

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.

Once testing had been completed, the 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 tool was unclamped, raised by 250 ft, and the sequence repeated.

The 9C VSP processing was initiated in early October and continued through the summer of 1995. After editing for noisy traces and multiple levels, stacking to obtain maximum energy after tool spin corrections was applied. These tool spin corrections were evaluated using the far offset P-wave vibrators. An inspection of the data was made at this stage to confirm that there was consistency in the data and therefore appropriate corrections had been applied.

Linear parametric inversions were subsequently produced for the NW and NE vibrators. These clearly showed anisotropy in the rock surrounding the VSP well. Preliminary Alford rotations were conducted and showed successful results down to approximately 8,000 ft. From 8,000 ft to the bottom of the hole at 9,400 ft the Alford rotations did not perform as expected, suggesting incorrect tool spin corrections. The P-wave corridor stack was output and compares favorably with the 3D P-wave. Preliminary S-wave corridor stacks were also produced.

Processing of the 9C VSP continued at Schlumberger, Canada. Tool spin corrections were successfully calculated after accounting for a source position move up during acquisition. Following this an inspection of the data revealed that a few traces needed to be reversed. This was accomplished and hodograms re-plotted over the down going shear wave energy. Preliminary analysis of this data showed that from surface to a depth to approximately 7,000 ft S1 azimuth is N70W. At 7,000 ft the azimuth of S1 appeared to change to N70E. Further processing is necessary to confirm this rotation as the initial amplitudes of the two sources are not equal thus invalidating the Alford rotation. This further processing will be conducted at the Blackhawk office. If the rotation is consistent through additional processing then the data will need to be layer striped before S1-S1 and S2-S2 corridor stacks can be produced.

4.0 ADDITIONAL PROCESSING OF 3D P-WAVE SURVEY

The additional processing of the previously acquired 3D P-wave survey to be conducted by Blackhawk includes the following:

1. For the north-south azimuths (± 45º), nominal 25 CDP fold per bin, an independent, detailed velocity analysis must be constructed for this data set to correctly image the velocity field for the "north-south" data volume. An initial velocity field used during previous processing will be supplied with the data for the starting point. Pre-stack time migration for "north-south" data.

2. For the East-West azimuths (± 45º), nominal 15 CDP fold per bin, a second, independent detailed velocity analysis must be constructed for this "East-West" data volume. Pre-stack time migration of all "east-west" data.

3. Comparison of the two velocity models. With this data we are seeking to determine differences in the imaging velocity fields, if any, and to verify that the differences in the velocity fields are clearly substantiated and visible in the pre-stack velocity analysis data.

4. Full-fold stack of the migrated data; range limited stacks; near-offset stacks, far offset stacks;

5. Determination of AVO signature for the N/S data volume, and for the E/W data volume (pre-stack amplitude analysis). Comparison of two AVO signatures (N/S and E/W); and

6. Conversion of the two stacked images to depth using well control. About 40 wells provide time-depth control points.

This additional processing is nearing it's conclusion and the preliminary results have been very promising.

5.0 MULTICOMPONENT FEASIBILITY STUDIES AND MINIVIBRATOR TESTING

5.1 Review of multicomponent feasibility tests

A description of the results of the multicomponent recording made during the 1994 field season follows.

<u>3D-3C</u>

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.

<u>Multi-Channel Vibrator Work</u>

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.

<u>Vibrator and Impact Walkaways</u>

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

5.2 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 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, Blackhawk 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. 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 lb. and the Mertz source array 120,000 lb. 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.

Catoosa Test.

During the week of March 7 through 13, the iVi Minivibrators were tested at Amoco's research facility near 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 savings 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 Blackhawk.

6.0 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 (Blackhawk, 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 + Blackhawk.
April	Full test plan submitted to DOE to include NEPA documentation, permits, etc. Request for Bid - Surface Acquisition.
June	Archaeology study
July	Land survey of site.
August	Drill and load shot holes.
September	Acquire 3D-3C survey

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

6.1 Modeling of 3D-3C acquisition parameters

The first stage in planning any data acquisition is careful modeling 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

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. The final survey geometry is shown in Figure 1.

A contract agreement was reached between Blackhawk and Northern Geophysical to survey, drill shotholes and acquire the 3-D, 3-C survey.. Ground surveying has begun, and shothole drilling will begin in August 1995.

6.2 Source Test Conclusions

From comparisons of the source test data collected by the owner/operator prior to their 3-D survey of 1994, the data quality from the 60 foot shotholes appears to be better or as good as the data from the deeper shotholes. The slightly increased amount of ground roll is not expected to significantly impact the data, and can be compensated for during processing. A shothole depth of 60 feet was selected for the 3-D, 3-C survey. In order to ensure sufficient energy for both the compressional wave and shear wave data sets, a charge size of 20 pounds was selected.

6.3 Archaeological investigation

Under Federal law, all land administered by the Bureau of Land Management (BLM) must have an archaeological study performed prior to seismic data acquisition.

Archaeological studies are required by the government to ensure that historical sites on BLM lands are not disturbed or obliterated during activities which can create disturbance of the ground surface. These activities include pipeline burial, building and construction, seismic surveys, etc. Many historical sites have already been discovered in the area of the proposed 3-D, 3-C seismic survey, including a section of the Bridger Trail. During the Archaeological survey, sites of historical significance are clearly flagged so that all vehicular traffic can avoid the area. The only access allowed on an archaeological site is by foot. The sites are also fully described and recorded on maps. These documents are then submitted to the BLM for cataloging.

Pronghorn Archaeological Services of Mills, WY was selected to perform the work, and a recommendation to use them was made to and accepted by DOE. The archaeological work was completed the beginning of June.

6.4 Permits

Permits for land damage were filed with the local land owners, pipe line operators, overhead power lines, rail road, State and County officials. No difficulties were experienced in this process.

Permit agreements were obtained with the private land owners and the State of Wyoming for access and potential damage to the land under the proposed 3D-3C. Permits were also filed with the State Road Commission and the State Water Commission for crossing county roads and drawing water from Bridger Creek for drilling.