Multi-Disciplinary and High-Resolution Seismic Survey on Native American Lands in Osage County, Oklahoma

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Introduction

This work was performed by BDM Oklahoma, BDM Petroleum Technologies, and TRW Petroleum Technologies personnel for the US Department of Energy (DOE). The work was funded through Contract No. DE-AC22-94PC91008 under Contracting Officer Rhonda Lindsey of the National Institute for Petroleum and Energy Research (NIPER) in Bartlesville, OK, and the National Petroleum Technologies Office (NPTO) in Tulsa, OK.

The Multi-Disciplinary survey was designed to identify the capabilities, costs and effectiveness of conducting 3-D seismic surveys in a small operator setting through a field demonstration test. The seismic aspects of the plan were coordinated with plans for surface geochemical work and a microbial survey. As the seismic interpretation phase progressed, several innovative techniques were advanced.

Osage County was selected in part to further the goals of the President's initiatives for promoting economic progress on Native American Lands, and in part because of the high concentration of small independent operators in this county. Osage County is comprised of predominantly Osage Nation tribal land. The county was the site of an oil boom during the early part of the Twentieth Century and still has many stripper wells and small operators that have been in the business for multiple generations.

Study of old well records suggested that there were many areas in the county that still held the potential for significant new production from thinner units, subtle stratigraphic traps, and reservoirs with secondary porosity.

Geo-Microbial Technologies (GMT) of Ochelata, OK, was sub-contracted by BDM Oklahoma to conduct a microbial survey in the study area.

Objectives

This program was designed to demonstrate the capabilities of state-of-the-art 3-D seismic technology for the imaging of shallow, thin target beds in subtle traps and to determine the cost-effectiveness of current survey techniques and procedures as a prospecting tool for the smaller independent geological/geophysical exploration company.

The 3-D field test included the following tasks:

- The development of technologies for use in the identification of shallow exploration targets,
- The design of a field test on a scale appropriate for small operators or other independents, such as a native American Tribe,
- A field test of the design,
- A test and evaluation of state-of-the-art 3-D technologies to image subtle hydrocarbon traps,
- An assessment of the effectiveness and economics of the process from the point of view of the typical small operator,
- Transfer of the technology to independent operators and native tribes.

The ultimate goal of the program was to design, develop, and promote new and innovative petroleum exploration techniques, to encourage drilling activity by independents within the U.S., and ultimately to increase domestic production. In addition, a location in Osage County was chosen to further the objectives of the President's Native Tribes Initiative, which has a goal of encouraging entrepreneurial activities on Native American lands.

Approach

The study area chosen was a mature oil-producing region, with many shallow wells dating back to the early years of the century. At the same time, many thinner reservoirs were ignored and bypassed in the early days, remaining in place today behind pipe, and undrilled parcels can still be found in the region.

Initially, a multi-disciplinary geoscience survey was conducted of the county. Multiple potential study locations were selected, by:

- The **s**tudy of surface lineaments, fractures, and circular and arcuate anomalies identified from satellite images and aerial photographs.

- The **s**tudy of subsurface structure contour maps and oil and gas pool distribution maps.
- Analysis and graphical representation of fracture orientations, lengths, and density. The fundamental fracture characteristics used for structural interpretation were characterized with computer software developed specifically for this DOE program.
- Analysis of production trends by recording and studying the producing formations, cumulative production data, and other production information, such as which formations and locations had water problems, etc.
- Investigation of regional stratigraphic trends through an examination of drillers' and electric logs and the construction of cross-sections to identify regional and local stratigraphy.
- Mapping and analysis for areas with:
  - ✓ multiple structures that might contain commercial-sized quantities of hydrocarbons in older Paleozoic sediments,
  - ✓ older structures that could be identified and mapped by a 3-D seismic survey, and
  - ✓ topography allowing easy vehicle access in relatively unwooded areas.

When the original series of prospects were presented to the Osage Tribal Council for approval, it turned out that the publicity generated for the program had attracted the attention of Chevron, as well as several independents. It was determined that all of the initial prospects were already in the process of being leased by large and small operators. Well over half the county was eventually leased by outside operators during the peak period of this activity. A second major began a program in nearby counties in Kansas, significantly reviving survey and drilling activity in that region, as well.

Since one of the goals of the DOE program had been the stimulation of exploration and drilling, these activities had to be classified as a major success, although they certainly complicated the site selection process for the work plan.

A succession of six proposed locations turned out to be previously leased. Ultimately, a decision was made to combine the DOE survey with work being done by DLB, one of the independent operators who had moved into Osage County.

The plan was for this operator to shoot a large survey area using a "conventional" configuration with 110' bin size. In one nine-sq mi block, at the NW corner of this survey, DLB gathered data using a high-resolution 55' bin size. The results for the entire survey area were processed as 110' data. In addition, the information from the NW corner area was processed as 55' bin size data.

This allowed the results of the 55' data to be compared directly to the 110' data over exactly the same structures, beds, and geologic features, allowing direct comparison of data quality at the two spacings. Knowing the costs per mile for the conventional portion of the survey and the costs for the 55' work made it easy to determine a cost/benefit ratio for the two types of surveys.

Technology

The nine sq-mi area selected for the 55'-bin size acquisition was chosen based on the same selection criteria described above.

An important element in the area selection process was the development of a new technique for remote-sensing analysis of air or satellite photos. The software, FRAC-EXPLORE, is designed to identify areas with concentrated or unusual fracture patterns or lineaments, which can be clues to basement faulting, buried structures or fracture reservoirs. The software is available on the DOE NPTO website at www.npto.doe.gov/.

The survey specifications and parameters are described below:

- The x, y, and z coordinates for shot point (SP) and geophone placement were identified using a highly sophisticated GPS system accurate to within 15 cm.
- The seismic energy for the Bigheart 3-D seismic survey was provided by four relatively light vibroseis trucks synchronized in unison that transmitted energy into the ground. The truck size and model were selected on the basis of depth of target formations; depth to regional basement; terrain; soil type, stability, and hardness; and environmental considerations.
- Eight successive vibration sets were transmitted from each SP, and each vibration suite produced a record that was summed automatically with the sum of the previous sweep, until eight sweeps per SP had been completed. Each vibrator sweep was 8 sec long, with a listening time of 3 sec. The frequency bandwidth of the transmitted signals ranged from 30 to 120 Hz.
- Field recording was done with the input/output (I/O) Data Recording System II, with a dynamic range (DR), of 120 dB, which enabled the recording of a maximum to minimum amplitude ratio of about 1 million. This was suitable for recording even very faint signals from subtle geological features.
- DLB used 10-Hz, high-fidelity transducers. There was a string of six geophones, potted, buried, and covered at each receiver location for noise reduction. The summed signal received by these geophones produced the output of one data channel. The I/O System II was capable of simultaneously recording data from 1,008 channels for each source point. Three hundred cables and 1,650 strings of geophones were available for this survey.
- Receiver lines run east to west and are marked R1 to R133. The SP vibrator lines run north to south and are marked SP 100 to SP 257. Both shot point and receiver intervals were 220 ft and 110 ft (for 110-ft and 55-ft bin sizes, respectively), giving approximately 300 SP/mi2 for the 110-ft bins and approximately 600 SP/mi2 for the 55-ft bins.
- Nine hundred channels/SP (15 lines 60 channels pattern layout) were recorded for the 110-ft bin size; 450 channels/SP (15 lines 30 channels pattern layout) were recorded for the 55-ft bin size. Pattern dimensions were 6,160 ft north-south and 6,380 ft or 6,490 ft east-west. Recording offsets were 3,190 ft or 3,245 ft inline and 3,080 ft crossline. There was roll/on/off.
- A 2-msec sample interval and a total record length of 3 sec was used.

In the portion of the survey with the 55-ft bin size, the data were 14 fold at 1,000 ft, 24 fold at 2,000 ft, and 50 fold at 3,000 ft.

A total of 5,778 points were vibrated. All field tapes were shipped to Geo Trace Technologies for processing.

Important points about the processed 3-D data follow:

- The data from the field tapes were processed in the seismic data processing center to enhance the signal-to-noise ratio of the seismic data by the application of different data processing routines. The seismic reflections were always assumed to be from the point midway between the shot and the receiver. All seismic reflections from within a certain area (called the "bin") were averaged to represent the seismic data from the center of the bin. The final processed data were, therefore, represented by the averaged seismic traces from the various bins located throughout the seismic survey area. So the 110-ft bin data involved averaging over a larger area than the 55-ft bin data.
- At each bin location, a seismic trace was sampled at discrete intervals, say 2 m-sec and extending from 0 seconds up to the total length of the record which, for example, may be 5 secs. The length of the record was determined by the depth of investigation.

For the interpretation phase of the project, hardware and software requirements for loading and interpreting the data were considered with the needs of small independent operators in mind. A desktop computer program, 3Dpak, was used for the interpretation work. The data installation into the personal computers was straightforward, but precautions were taken to ensure that the computer had adequate disk storage space. About 600 Mb of storage space were required for data storage alone. At least 16 Mb of RAM and a math processor were also needed to run the software smoothly.

The interpretation of 3-D data was initiated by investigating certain important features of the data and then evaluating the imaging capabilities of data collected with 55-ft and 110-ft bin sizes.

The first step in the interpretation of the seismic data was the identification of the various reflections on the seismic section. This correlation of seismic reflection with geology was best done with the help of synthetic seismograms generated from the sonic and the density logs. Well logs were collected for the study area.

Key horizons of interest, representing producing formations or distinctive seismic marker beds were identified on the seismic sections that passed through wells with synthetic seismograms. These seismic reflectors were mapped along inlines and crosslines forming a closed loop to ensure that the starting and the ending reflectors were the same.

Key reflectors included the:

- Seismic Basement,
- Bartlesville Sandstone, and the
- Layton Sandstone.

Detailed mapping of the basement reflector can permit identification of basal Paleozoic sandstones and conglomerates and of Cambrian-aged Reagan sandstone reservoirs. Mapping of the study area showed that the southern portion was cut by a large number of faults, with several small popup blocks and local lows with a good potential for the accumulation of basal sands.

As expected, the 110-ft bin data were much smoother than the 55-ft bin data and lacked detail. The reflector definition was much sharper on the high-resolution data, permitting small structures, including probable fault traps and "bright spots," to be identified.

The Final Report for the project, "An Exploration 3-D Seismic Field Test Program in Osage County, Oklahoma," Reeves et al, DOE publication DOE/PC/91008-0376, includes a detailed discussion of several methodologies that were used, refined, or specifically developed for this project. These included techniques to:

- Detect and map small faults
- Image subtle geological features in platform deposits with rapid changes in lithology and facies,
- Map subtle stratigraphic features
- Track a thin gas sand on a high-resolution section
- Perform statistical time-series analysis of amplitude data
- Combine Fourier analysis and statistical analysis of the 3-D data for a spectral study of a time series
- Utilize color on a workstation display to assist in the identification of subtle features on high-resolution sections

In addition, an analysis was made to determine if basement structures were exercising influence on the location of the shallow oil fields. These showed a slight positive correlation in the southern area, where the basement was most disturbed, but little correlation was seen to the north where there was little basement relief.

A surface geochemical survey was designed to complement the high-resolution seismic work in Osage County. The aim was to examine several surface geochemical techniques that could be used for locating oil or gas seeps by independents with limited budgets and personnel. To this end, both the sample collection and analytical techniques had to be inexpensive. This translated to collecting samples within 1 ft of the surface. It also eliminated integrated soil-gas methods in which a gas absorber is placed in the ground for a period of time and collected at a later date.

The surveys used in Osage County were essentially noninvasive. To further reduce costs, the techniques did not require extensive expertise in soil science for sample collection, because many independents do not have formal training in this area.

The area of the seismic survey was the target for the surface geochemical survey. The seismic survey was designed on a grid with a 440-ft spacing with survey points every 110-ft along these grid lines. Each of these points was located using a GPS survey. Using multiple benchmarks and satellites, survey points were pinpointed to within 15 cm. Geochemical samples were taken at the intersection of the grid points, corresponding to 12 sample points per mile.

Three types of samples were collected at each grid point:

1. Approximately one-half of a 1-quart polyethylene storage bag of soil was collected from within the top 1–1.5 inches of the surface using a small (Army-style) trenching shovel. This sample was collected for iodine analysis.
2. A 6-inch long X 0.75-inch diameter soil plug was taken with a standard soil sampler. These samples were collected for pH, and possibly metals or magnetic susceptibility analysis.
3. After the first 6 inches of sample were removed with the soil sampler, each hole was reentered and a second 6-inch sample was retrieved (6–12 inches below the ground surface). This sample was used for soil gas analysis.

The results from the iodine survey showed two strong anomalies, and possibly a third. These anomalies appeared as normal levels of iodine at the center and a ring, or arc, of unusually high values surrounding this center. The iodine values in these rings were more than 1.5 standard deviations above the background. In addition, there were conspicuous “holes” in the iodine map where the anomalies exist.

The raw pH data did not readily reveal anomalous areas. Upon using a mild smoothing routine, anomalies were easily seen as areas of low pH surrounded by high pH. These high pH values were in turn surrounded by low pH values. The pH anomalies were centered on the same area as the iodine anomalies, except that the ring of high pH values encompassed the highest iodine values. The third pH anomaly is the most evident feature in this survey.

Cultivated fields of winter wheat, maize, and Bermuda grass did not appear to correlate with any anomalous iodine or pH values. There was also no correlation with stream beds. There was an identifiable correlation between the pH values and the location of a gravel road along row R-85. pH values along the road were unusually high, possibly because of lime applied to the road. A few abandoned oil wells exist within one anomaly. Although several dry holes exist within the survey area, none are within any of the anomalies identified here.

The same gridwork used for the seismic and geochemical surveys was used by GMT, of Ochelata, Oklahoma, to collect samples for a microbial survey. GMT’s objective was to look for biomarkers in the shallow subsurface. The GMT work was performed under a separate subcontract.

The GMT field collection procedure was highly efficient and quickly completed. The GMT samples were analyzed at the GMT laboratories. The results of the GMT survey were extremely interesting.

Sample collection across an old oil field showed little of interest. This is what would be expected in a depleted area.

There was one highly distinctive anomaly of particular note. It was located in the northern portion of the study area, and generally coincided with a distinctively-shaped apparent channel sand identified on the 55-ft high-resolution seismic data. The anomaly was large in amplitude and had the same distinctive shape as the seismic feature.

Results

The DOE Osage County program was designed to be a comprehensive demonstration program, testing a wide variety of processes and procedures.

The initial publicity surrounding the project stimulated a multi-county/multi-state flurry of exploration and drilling, benefiting a Native American tribe and their neighbors, and increasing the domestic oil supply.

The well-location phase of the program involved the development and first field test of a new remote-sensing exploration and regional evaluation software program, FRAC-EXPLORE. This software program worked well, has been refined and upgraded, and is now available for free on the NPTO website, www.npto.doe.gov/.

The overlapping technique of shooting the precise same area in both 55-ft bin and 110-ft bin size graphically demonstrated the significant advantages of the higher-resolution approach. Repeatedly, the 110-ft survey showed gross structures, and little more, while the 55-ft survey could be manipulated to identify very small faults and other structures.

The high-resolution data also made it possible to use waveform characteristics, including amplitude studies, to detect lithologic properties, including porous zones and fluid-filled reservoirs within formations with variable porosity.

Several innovative statistical approaches were developed and applied to the 55-ft data for a variety of time-series and spectral analysis.

Three surface geochemical survey techniques were designed and tested in the study area, using the same survey points from the seismic study. Two of these techniques identified prominent anomalies. The third data set required some data manipulation before a similar pattern emerged from the data. There was relatively good correspondence between the results of the three approaches.

Geo-Microbial Technologies (GMT) conducted a microbial survey of the study area, using the same survey points as the seismic and surface geochemical surveys. This survey had been totally isolated from the work by BDM/TRW until after the analyses of all the surveys had been completed.

The final results from the GMT survey displayed an extremely close correspondence to the seismic maps, although neither team knew anything about the work of the other. The largest microbial anomaly matched a key feature on the seismic interpretation, both in size, position, and overall configuration.

Benefits

The DOE survey brought immediate economic benefits to Osage County and surrounding regions, including nearby parts of southern Kansas. Early press releases and publicity efforts from NIPER and the Osage tribe led to significant interest in the county by Chevron and several independents. A mini boom of exploratory activity resulted, followed by a wave of drilling and increased production. This activity helped meet the goals of the President's Native American Initiative.

The remote-sensing analysis software, FRAC-EXPLORE, that was first used in Osage County has been available to industry for several years now and has received praise from majors and independents, alike. The package is described in the final report, DOE Report No. DOE/PC/91008-0376. It is available, free, for use by small or large operators on the DOE NPTO website, www.npto.doe.gov/.

The comparison of the 55-ft bins to the 110-ft bin-size in the seismic surveys clearly demonstrated a massive superiority for the high-resolution techniques. Although costs for the entire survey were impacted negatively by a succession of storms that may have been related to the onset of El Niño conditions, several suggestions were offered listing ways to contain costs for seismic field work, even in the face of adverse weather conditions.

The Final Report described several innovative ways to use this type of high-resolution data for facies interpretation, for the identification of micro-structures and fluid-filled reservoirs, for statistical analysis and other unconventional methods for interpretation, including taking maximum advantage of the new types of computer displays.

A key goal of the surface geochemical survey was to design a field technique that could be quickly utilized by a new, non-specialized crew, hired by an independent, with minimal training or learning-curve time. The results were highly successful.

The survey analyses produced varying results, with the iodine and magnetic susceptibility maps both revealing intriguing anomalies. The pH survey required some smoothing of the data before similar features became evident. The field technique and sampling procedures proved to work very efficiently.

The Geo-Microbial Technologies (GMT) survey produced a map showing several anomalies, with one particularly interesting one. This anomaly was quite strong and matched a channel and overbank splay deposit seen on the seismic map in both location and general configuration. The description of this work is contained in the Appendix to the Final Report.

The GMT survey used proprietary techniques. The work was conducted in a rapid, highly-professional manner, with a very fast analytical turn around. The extremely close correspondence between the seismic and GMT results were extremely interesting.

Reference

Reeves, T. K., et al. 1999. An Exploration 3-D Seismic Program in Osage County, Oklahoma. DOE Report No. DOE/PC/91008-0376, OSTI_ID: 3181 January. With one Appendix.