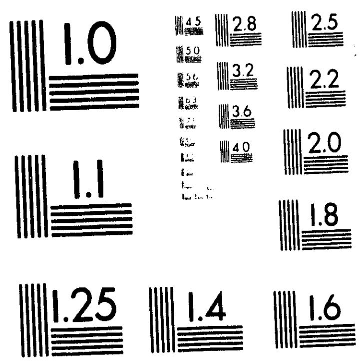
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Fracture Detection, Mapping, and Analysis of Naturally Fractured Gas Reservoirs Using Seismic Technology

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DISCLAIMER

Fracture Detection, Mapping, and Analysis of Naturally Fractured Gas Reservoirs Using Seismic Technology

CONTRACT INFORMATION

Contract Number	DE-AC21-92MC28135
Contractor	Coleman Research Corporation 5950 Lakehurst Drive Orlando, FL 32819
Contractor Project Manager	Dr. Pieter Hoekstra
Principal Investigators	Dr. Heloise Lynn, Lynn Incorporated
METC Project Manager	Royal Watts
Period of Performance	09/23/92 - 10/23/94
Schedule and Milestones	FY1993-94 Program Schedule

	(1993)						(1994)					
	S	O	N	D	J	F	M	A	M	J	J	A
Test Plan												
Fabrication	N/A											
Testing							←	→				
Analysis									←	—	—	—

OBJECTIVE

There are a number of producing gas fields in the United States where production is controlled by natural fractures. The host rock may consist of low porosity, low permeability formations, and wells completed in the unfractured rock have low productivity. On the other hand, wells intercepting fractured rocks may show good production. The objective of the research under this contract is to improve the technology for detecting fractures by surface geophysical methods. This remote detection of fractures will allow optimum placement of vertical or horizontal wells.

BACKGROUND INFORMATION

Seismic reflection prospecting is the dominant geophysical technique employed in hydrocarbon exploration. Compressional (P-) wave surveys are most common, both historically and at present. From P-wave reflection surveys structural information in sedimentary basins is derived. More recently, from reflection amplitude variation with source-receiver offset, detection from the earth's surface of a change in pore fluid has been achieved. Investigations by major oil companies and academic institutions, mainly in the last ten years, have established that relative fracture density and fracture orientation information are contained in shear-wave reflection seismic data. The specific objectives of the research is to further document and improv deriving fracture information from shear (S-) wave and P-wave multicomponent reflection surveys.

In 1985, Dr. Stuart Crampin published a theoretical treatment of seismic wave propagation in anisotropic media. His work stated that in a medium with vertical aligned fractures, only two polarizations of the vertically propagating S-wave can exist: (1) the S-wave polarized parallel to the fractures (that is, with particle motion parallel to the fractures), which travels at approximately the uncracked rock shear-wave velocity; and (2) S-wave polarized perpendicular to the fractures, which travels at a lower velocity dependent upon fracture density. These two shear waves are commonly designated as S1 and S2, respectively. When a shear wave is polarized at an intermediate orientation to the principal axis of the fractures, the shear wave will split in the fractured medium into the two allowed polarizations. The time delay between the two "split" shear waves is proportional to the fracture density. These statements have been verified by experimental observations in the field and in the laboratory.

Oil industry field data experience of shear wave splitting dates from the earliest 1980's, later published in 1986 by Amoco (Thomsen, 1986; Ral and Hanson, 1986; Lynn and Thomsen, 1986; Alford, 1986; Willis, Rethford, and Bielanski, 1986) and subsequently by other oil companies. To interpret the seismic anisotropy observed in a field data set in terms of fracture orientation and relative fracture density, requires the acquisition of a multicomponent VSP (Vertical Seismic Profile), with input from the geologic data (cores, wireline logs), knowledge of the in-situ stress field, and production data (including evidence on the preferred flow direction within the reservoir).

PROJECT DESCRIPTION

The critical components of the project are:

1) Selection of a gas field with known production from naturally occurring fractures. The project scope does not allow for drilling of wells, so that evidence for occurrence of fractures and gas production from fractures must be obtained from existing wells' field production history, and other data.

2) Acquisition of both surface and downhole seismic P-wave and S-wave data. The project will acquire one 9-component (9-C) VSP. In a 9-C VSP survey, seismic events are recorded by 3-C geophones from one P-wave, and two perpendicular oriented S-wave sources (SH and SV). Also, approximately 12 miles of 9-C surface seismic data will be acquired.

3) Processing and interpretation of 9-C VSP and 9-C surface seismic data, and correlating the seismic anomalies observed to all available geologic and production information to show how the variations in seismic response is related to fracture density, fracture orientation, lithology, structure, and production history.

RESULTS

The project goals were announced to the oil and gas industry, and they were encouraged to submit their field for the investigations. Five companies prepared a submittal, and Table 1 is a listing of the fields and their rating in terms of technical criteria. Table 2 is a listing of all the criteria applied to site selection.

Table 1. Rating According to Technical Criteria of Five Sites

Gas Field Proposed	Company	Evidence for 2-D Structure	Risk of Obtaining Low Quality Surface Seismic Data	Evidence of Production from Natural Fractures
Bluebell-Altamont Uinta Basin, UT	Pennzoil	Good	Low	Excellent
Madden Field Wood River Basin, WY	LL&E	Poor, likely 3-D structure	High (shale layer overlies producing horizon)	Excellent
Wight Unit in Texas	Conoco	Good	Low	Good
Giddings Field, Austin Chalk, Central TX	Union Pacific Resources Company	Good	Moderate (may be too deep)	Good
Mayberry Field, NW Colorado	Coastal Oil & Gas	Good	Moderate (may be too deep)	Good

Table 2. Criteria Applied to Site Selection

Technical Criteria

- Probability of acquiring high quality P-wave and S-wave reflection data at depth of occurrence of producing horizon.
- Strength of evidence of gas production from natural fractures.
- Complexity of geologic structure (2-D structures preferred over 3-D structures).

Government Benefit Criteria

- Cost-sharing by industry.
- Release of proprietary information.
- Federal lease.

The field selected was Pennzoil's Bluebell-Altamont Field, Upper Green River gas production, northern Uinta Basin, northern Utah. The Upper Green River gas field has established production from the last major lacustrine deposition within the Uinta Basin. Natural gas is being produced from the upper Green River formation between 6,500 - 8,500 ft. Producing rates from these zones ranges from 100 MCFPD to over 5000 MCFPD. Prior lacustrine deposits comprise the Wasatch (oil) and Lower Green River (oil and gas). Gas reservoirs within the upper Green River are trapped by updip pinchouts of the prograding lake margin. Producing intervals consist of fractured lake-margin sandstones encased within tight shales and carbonates of the lacustrine deposits. The evidence of fractures are seen in: (1) cores, (2) FMS, (3) sonic logs, and (4) production rates from perforated zones whose core matrix permeability and porosity would not support observed production rates. The sandstones which produce gas have matrix porosity of < 8% and permeability of < 1 md. Production has been enhanced in several wells with hydraulic sand fracturing. Sandstones in non-fractured wellbores are capable of producing at rates of 100 to 300 MCFPD, whereas wells from naturally or artificially fractured wellbores produce at rates from 1000 to 5000 MCFPD. There is concurrent Class I Reservoir DOE work in the Bluebell-Altamont field being conducted by the Utah State Geological Survey, Salt Lake City, Utah. It is planned to examine this data and to evaluate its potential use within this project.

The terrain is believed to be accessible to vibroseis (seismic sources), and seismic reflection crews are operating in this part of the Rocky Mountains. Crew mobilization fees could thus be kept to reasonable levels. The quality of previously acquired P-wave seismic data is good to excellent, showing minimal problems with either statics or near surface velocity anomalies. An on-going drilling program will use the results of the DOE study to help pick well locations. Identification of by-passed pay might also be established by this study, and Pennzoil would be interested to test this information.

In July 1993 a site visit was made to the field. During this visit the existence of orthogonal joints and fracture sets in outcrops were verified, and locations of approximately 12 linear miles of seismic lines were selected parallel and perpendicular to the fracture trends. During this visit it was also determined that access for use of vibrators along the seismic lines was good. A NEPA report for the investigation was submitted to DOE.

FUTURE WORK

The acquisition of the 9-C surface seismic and 9-C VSP's is planned for the spring of 1994. An important incentive for acquiring both S-wave and P-wave reflection data is that P-wave amplitude variation with offset (AVO) data is available for hundreds of thousands of P-wave reflection surveys. Knowledge about the location of the fractures, as determined from the S-wave analyses, will highlight zones of interest within the P-wave data set for detailed study. Thus, a way for reprocessing and re-interpreting the P-wave data for fracture information may be achieved.

Also, S-wave reflection surveys are more expensive (≈ $30,000 per mile) to acquire than P-wave reflection surveys (≈$10,000 per line mile). Therefore, if it can be proven that fracture information can also be derived from special processing of P-wave surveys, there is a large cost advantage.

In processing and interpretation of the 9-C VSP and 9-C surface seismic line, emphasis will be placed on correlating four diverse data sets. These are (1) the seismic anisotropy, (2) the in-situ horizontal stress field orientation, (3) the natural fractures' orientation and magnitude from cores, FMS, borehole televiewer, etc., and (4) the direction of preferred flow direction in the reservoir. All four items are necessary to add to the reservoir characterization.

Since this research offers an unique opportunity to directly correlate anomalies in seismic data to known fracture information, the data set will be carefully processed to bring out special events in P-wave and S-wave data, such as:

1) A change in P-wave velocity (decrease) in zones identified to be fractured in S-wave data.

2) Information about relative fracture density from P-wave AVO data, and the influence on AVO of orientation of the seismic line with respect to the fracture. This is the impetus for acquiring data both parallel and perpendicular to the fracture.

3) Changes in seismic polarization in highly fractured zones. These changes can be documented by the borehole VSP.

4) Information from the mode-converted (P-S) seismic data sets.

REFERENCES

Alford, R.M., 1986, "Shear data in the presence of azimuthal anisotropy; Dilley, Texas", Expanded Abstracts, 56th Ann. Int. SEG Meeting, Houston, 1986, pp. 476-479.

Crampin, S., 1985, Evaluation of anisotropy by shear-wave splitting, Geophysics. vol. 50, no. 1, pp. 142-152.

Lynn, H.B., and Thomsen, L.A., 1986, "Reflection shear-wave data along the principal axes of azimuthal anisotropy", Expanded Abstracts, 56th Ann. Int. SEG Meeting, Houston, 1986, pp. 473-476.

Ral, C.S., and Hanson, K.E., 1986, "Shear-wave birefringence: a laboratory study", Expanded Abstracts, 56th Ann. Int. SEG Meeting, Houston, 1986, pp. 471-473.

Thomsen, L.A., 1986, "Reflection seismology in azimuthally anisotropic media", 1986, Expanded Abstracts, 56th Ann. Int. SEG Meeting, Houston, 1986, pp. 468-470.

Willis, H.A., Rethford, G.L., and Bielanski, E., 1986, "Azimuthal anisotropy: occurrence and effect on shear-wave data quality", Expanded Abstracts, 56th Ann. Int. SEG Meeting, Houston, 1986, pp. 479-481.

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