MULTICOMPONENT SEISMIC ANALYSIS AND CALIBRATION TO IMPROVE RECOVERY FROM ALGAL MOUNDS: APPLICATION TO THE ROADRUNNER/TOWAOC AREA OF THE PARADOX BASIN, UTE MOUNTAIN UTE RESERVATION, COLORADO

Second Technical Report – May 1, 2003 through October 31, 2003

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ABSTRACT

This report describes the results made in fulfillment of contract DE-FG26-02NT15451, "Multicomponent Seismic Analysis and Calibration to Improve Recovery from Algal Mounds: Application to the Roadrunner/Towaoc Area of the Paradox Basin, Ute Mountain Ute Reservation, Colorado", for the Second Biennial Report covering the time period May 1, 2003 through October 31, 2003.

During this period, the project achieved two significant objectives: completion of the acquisition and processing design and specifications 3D9C seismic acquisition and the 3D VSP log; and completion of the permitting process involving State, Tribal and Federal authorities. Successful completion of these two major milestones pave the way for field acquisition as soon as weather permits in the Spring of 2004.

This report primarily describes the design and specifications for the VSP and 3D9C surveys.

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1 INTRODUCTION

1.1 Project Background

This section describes the project background. The first section summarizes the petroleum potential and geological habitat of the algal mound play in the Paradox Basin, while the second subsection summarizes the technical approach.

1.1.1 UNDISCOVERED OIL POTENTIAL IN THE ISMAY ALGAL MOUNDS

The U. S. Geological Survey reported in their most recent national assessment of undiscovered petroleum in the United States (Gautier and others, 1996) that the mean estimate of undiscovered oil in Porous Carbonate Buildup Play (Figure 1-1) in the Paradox Basin (Play No. 2102), of which the Ismay is the major established reservoir, is approximately 153 MMBO. They also estimate that there is a 5% probability that an undiscovered field will contain 40 MMBO, and that there would be a minimum of 10 undiscovered fields, a median of 20 undiscovered fields, and a maximum of about 50 undiscovered fields. The play is an oil and gas play. Discoveries are typically in the 1 MMBO to 10 MMBO, although the Aneth Field may contain an order of magnitude more oil in these facies

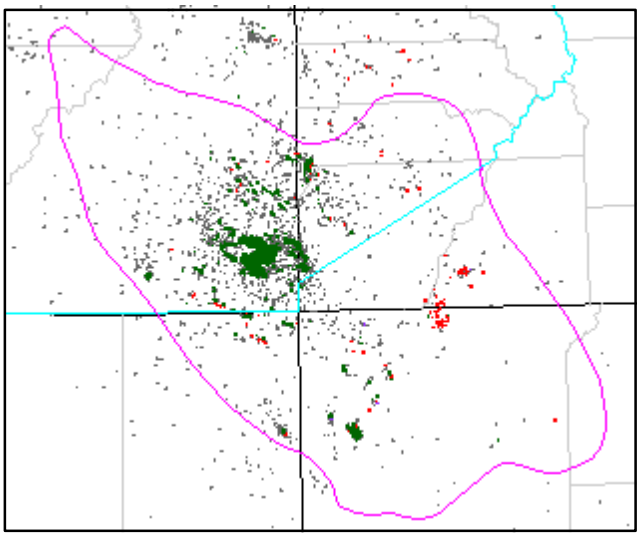


Figure 1-1 (above). Location of USGS's Carbonate Buildup Play (purple outline) and locations where wells have produced oil (green squares) and gas (red squares) from this play.

Figure 1-2 (right). Stratigraphic column for the prospective region.

Figure 1-1 shows the outline of this play, along with the locations of discovered oil and gas accumulations. The Ute Mountain Ute Tribe reservation includes the southwestern Colorado portion of the play that has discovered accumulations of oil. The reservoirs are typically mounds of algal (Ivanovia) limestone associated with organic-rich black dolimtic shale and mudstone rimming evaporite sequences of the Paradox Formation of the Hermosa Group (Figure 1-2). Net pay is on the order of 3 m – 15 m but occasionally reaches a net thickness of 30 m. Porosities typically vary from 5% to 20%. The traps are sourced by interbedded organic-rich dolimtic shales and mudstones. Oil generation occurred from the Late Cretaceous to the Paleocene. After expulsion, oil moved updip or migrated locally. There are a variety of seals, including porosity differences, overlying evaporates and interbedded shale. Most production ranges in depth from 1500 m to 2000 m. The location of the Ute Mountain Ute tribal lands are shown in Figure 1-3.

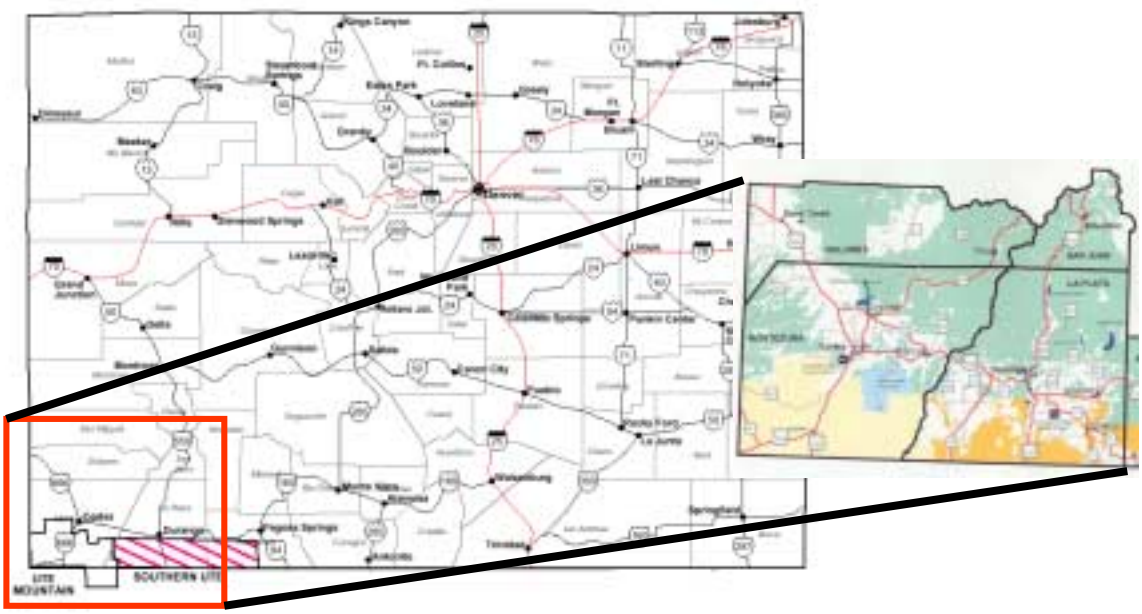


Figure 1-3. Location map for project. The Ute Mountain Ute reservation occupies the southwestern corner of the state of Colorado (unshaded region), adjacent to the Southern Ute reservation (red cross-hatching) to the east.

1.1.2 EXPLORATION AND PRODUCTION CHALLENGES

The goal of this project is to detect reliably stratigraphic features that are on the order of 200 to 1000 acres (Figure 1-4). These features have little structural expression. The mounds are surrounded and overlain by massive anhydrite. The reservoir properties of these mounds are not homogeneous throughout. From the standpoint of reservoir development of an existing algal mound field, the critical factors lie in predicting the porosity, permeability, internal mound geometries and fluid content of the mounds. While well information and production data are useful in understanding some of these variations, they cannot alone be used to make more accurate descriptions of the salient

reservoir parameters between well control. This requires the use of some tool that provides at least an indirect indication of these properties away from well control. For this purpose, seismic data is the most appropriate technology available.

The usefulness of seismic technology has been exemplified by industry's improved exploration success in the algal mound play in the Paradox Basin (Figure 1-5). 2D seismic was first applied in the early 1980's. Success rates for exploration wells were around 10%. This increased to about 25% in the mid-1990's as conventional 3D seismic data was acquired for use in delineating exploration targets. Advanced multicomponent technology, such as 3D3C and 3D9C, should improve success rates in exploration even more and also provide better static reservoir models for existing fields. The key to developing a better image of the reservoir's internal geometry and flow properties is to utilize fluid saturations and azimuthal processing that can directly respond to oriented heterogeneities and changes in fluid saturations. Thus, acquisition of shear-wave data and advanced azimuthal processing or both shear- and compressional-wave data will potentially provide a much higher resolution of internal mound geometry and, from a reservoir engineering standpoint, a better model of the distribution of reservoir porosity and permeability

Table 1-1 shows the relation between multicomponent attributes and important reservoir properties.

Reservoir Property	Wavefield	Attribute
Porosity	P, S, PS	Amplitude, shear wave splitting
Permeability	P, S	Energy flow[1], shear wave splitting direction
Saturation	S	Shear wave splitting
Viscosity	S	Frequency and attenuation[2]
Density	P, S, PS	Amplitude variation with offset (AVO)[3]
Structure	P	Travel-time

[1] product of P- and S-wave amplitude at zero offset
[2] e.g. Duranti (2001) and Michaud (2001)
[3] Amaral (2001)

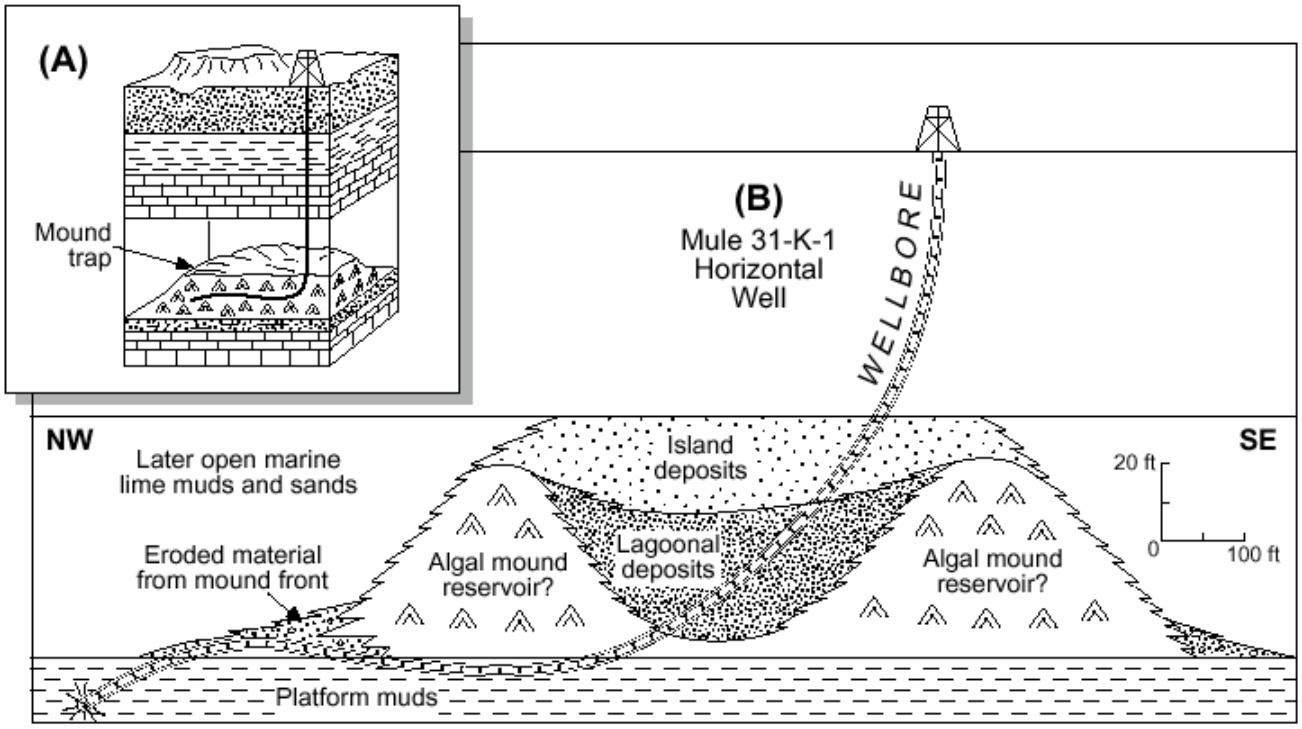
Table 1-1. Relationship between reservoir properties and multicomponent attributes. Table prepared by Tom Davis, Colorado School of Mines, Phase IX Proposal, Reservoir Characterization Project (http://www.mines.edu/academic/geophysics/rcp/)

As with any indirect means of detection, such as seismic data, the multicomponent attribute data needs to be calibrated; a connection needs to be made between the indirect data and the parameters of interest, in this case, the facies and their reservoir properties. The relations between 3D9C data and reservoir properties like porosity, permeability, internal mound geometry and fluid content of the mounds have not yet been exhaustively established through years of experience. There need to be calibration studies carried out to support the establishment of these links. For this reason, the proposed project also

contains work by a petrologist highly familiar with Paradox Basin algal mound fields, and by geologists who are experienced in developing sophisticated predictive reservoir models to help establish these linkages. The proposed project not only includes a geological and petrological description, but goes an important step further and examines the relation of these parameters to quantitative production measures of individual wells and the field as a whole.

The project will develop and test a method to improve reservoir development by utilizing a new and appropriate seismic technique (3D9C) and carrying out the necessary work to relate this indirect data arising from the 3D9C survey to the reservoir parameters and ultimately the producing characteristics of an algal mound field. As a result, the proposed multidisciplinary technical approach is both reasonable and adequate to meet the project goal of improving recovery from algal mound fields through better reservoir characterization presented in a way that helps production engineers plan wells or design recovery processes.

Likewise, exploration success can be improved using the calibrated Multicomponent data. The resulting processed and calibrated seismic data should provide much more accurate and higher resolution of the lithologic facies variations that delineate mounds



(A) Schematic block diagram of a horizontal well penetrating a small algal-mound oil trap, and (B) a vertical cross section of the rocks below ground surface in the Mule mound penetrated by the Mule No. 31-K-1 horizontal well.

Figure 1-4. Hypothetical Algal Mound cross-section

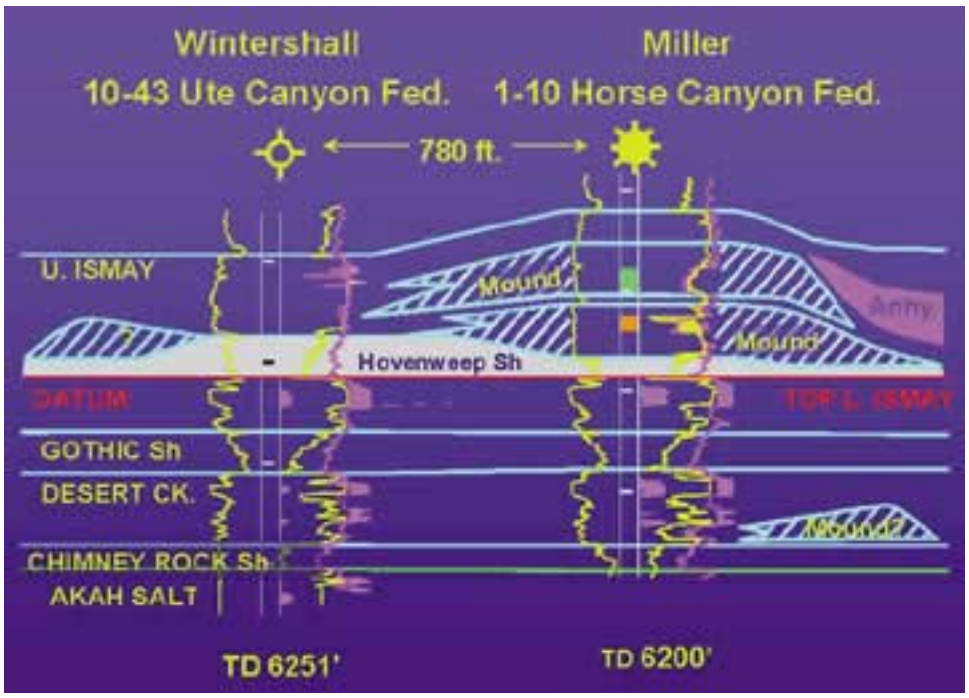


Figure 1-5. Cross section of two wells, one drilled on 2D seismic, the other on conventional 3D seismic. The Horse Canyon Federal # I - I 0 well was drilled just south of the Blanding Prospect Area by Miller Energy in 1998. This well location was based on 3D seismic data, and is only 700 feet away from a dry hole drilled in the 1980s based on 2D seismic data. The well IP'd for 960 BOPD and 3 MMCFGPD. This is a good case history illustrating that the older 2D seismic data did reliably detect a mound, but the 3D seismic data was required to image the productive portion of the mound and resulted in a prolific new discovery.

1.2 Technical Approach

1.2.1 MAIN PROJECT PHASES

The main steps in the project are outlined below:

1. Acquire 3D Multi-Component data over existing algal mound production as well as off-mound area (Towaoc & Roadrunner Fields)
2. Acquire a Multi-Component VSP (vertical seismic profile) in a well to help calibrate 3D processing and acquisition
3. Process 3D data for P-wave, S-wave, P-S wave, AVO and anisotropic velocity attributes
4. Calibrate processed seismic data against core a facies interpretations
5. Calibrate processed seismic data against reservoir engineering data

The seismic data will be acquired over portions of two existing fields, Towaoc and Roadrunner (**Figure 1-6**), as well as non-productive acreage in between, as calibration needs both positive and negative information.

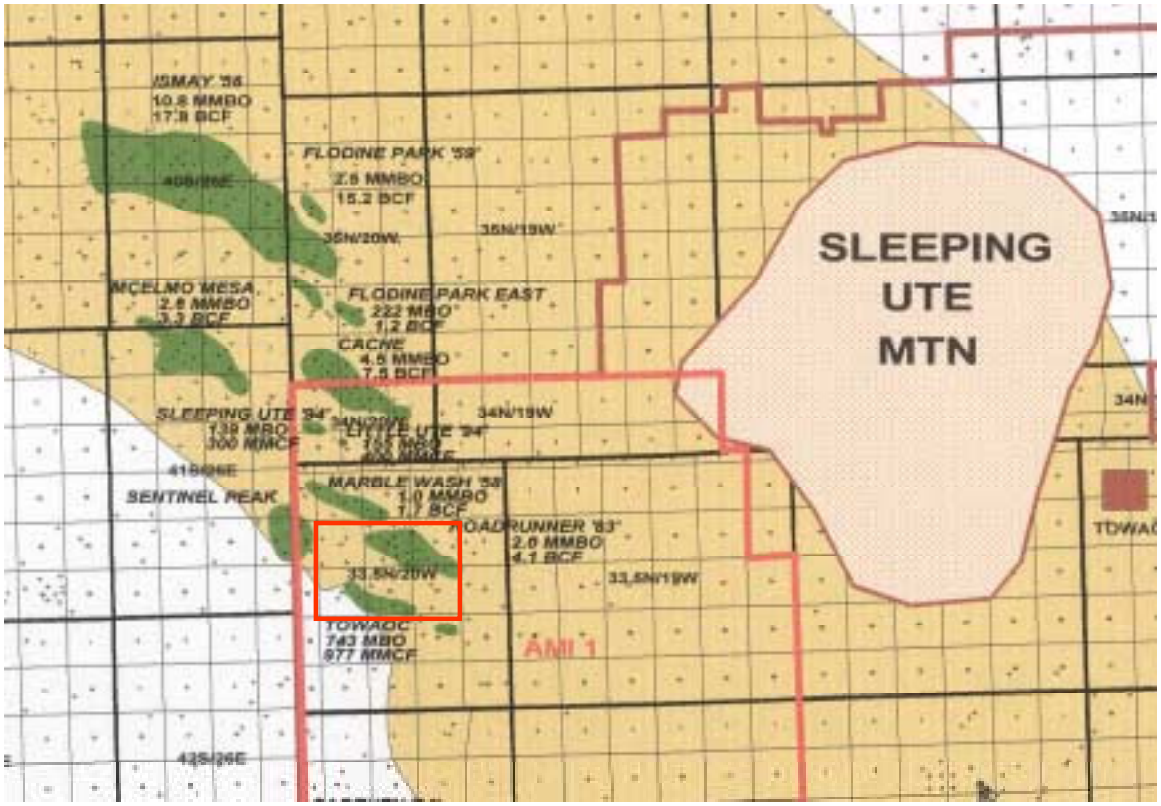


Figure 1-6. Location of the 6 square miles (outlined by red rectangle) where 3D9C seismic data will be obtained. Also shown are the outlines of existing algal mound fields.

In addition to the seismic data to be acquired, additional existing data, listed below, may be used as needed.

Core and Well Data

- 10 cores in either the Upper or Lower Ismay in the immediate area. Including relevant core from the surrounding area a total of 500 feet of core.
- 34 wells with well histories and conventional logs. 19 of the 34 wells are producing wells and have production data
- Detailed tops database and subsurface mapping (Red Willow)

Existing Seismic Data

- 600 miles of conventional 2-D data already acquired. 100 miles of which have been reprocessed by Red Willow.

1.2.2 REPORT OUTLINE

The remainder of this report describes the progress made to date. In the fall of 2002, WesternGeco, who had been the project's seismic acquisition contractor, decided to no longer provide this service in North America. The contract was opened to re-bid among those companies able to acquire this type of data, and SolidState, a division of Grant Geophysical has been selected based on cost and crew availability. Also during the re-bid process, the project was able to upgrade the seismic survey from 3D3C to 3D9C. The difference between these two surveys is that the 3D9C survey uses orthogonal shear wave

sources, as well as records the seismic waves using orthogonal horizontal geophones. Shear wave sources are oriented inline and crossline to the receiver lines, as are the horizontal geophones. Additional information concerning 3D9C surveys, acquisition and processing can be found in Simmons and Backus (2001).

Section 3 describes the experimental methods used to date, which consists of the design of the seismic survey and the seismic processing approach.

Section 4 describes and discusses results to date. As the seismic data have not yet been acquired, the primary project accomplishments have been in the finalization of the technical design for the acquisition and processing, and in the completion of the permitting process required for acquisition.

Section 5 describes conclusions.

2 EXECUTIVE SUMMARY

This report describes the results made in fulfillment of contract DE-FG26-02NT15451, "Multicomponent Seismic Analysis and Calibration to Improve Recovery from Algal Mounds: Application to the Roadrunner/Towaoc Area of the Paradox Basin, Ute Mountain Ute Reservation, Colorado", for the Second Biennial Report covering the time period May 1, 2003 through October 31, 2003.

Project activities during the second semi-annual performance period of this project focused on the completion of the seismic acquisition and processing design and the securing of all necessary permits for acquisition of the 3D surface multicomponent and subsurface VSP data.

The preliminary acquisition geometry was designed in cooperation with all of the seismic team members in this project, including AXIS and WesternGeco, who will be carrying out the processing. This preliminary design was reviewed and formed the basis for the various permitting activities that require specification of line locations, access, etc. Lines geometry, access and other aspects of the survey were adjusted where required to mitigate impact on biota, the environment and cultural or historical resources in the Roadrunner/Towaoc area. This refined acquisition layout then formed the basis for the permit application to relevant authorities. The proposed action is in conformance with the Ute Mountain Ute Indian Tribe Energy Development Program as presented in Appendix F of the Environmental Assessment of Oil and Gas Leasing and Development on Ute Mountain Ute Indian Reservation (USDI, Bureau of Indian Affairs 1993). BIA authorization for the geophysical operation on tribal land is consistent with regulations of 43 CFR 3150. In addition, the proposed action and analysis conform with and meet requirements of:

- Endangered Species Act (ESA) of 1973 (as amended)
- National Environmental Policy Act (NEPA) of 1969
- 43 CFR Part 3150
- National Historic Preservation Act of 1966, amended 1992
- The Antiquities Act of 1906
- The Archaeological Resources Protection Act of 1979

The US Bureau of Indian Affairs (BIA) issued a Finding of No Significant Impact on Sept. 17, 2003, followed by a 30-day public comment period, which did not lead to a change in the finding.

Acquisition is now ready to proceed pending the appropriate weather conditions in the Spring of 2004.

3 EXPERIMENTAL METHODS

3.1 3D9C Seismic Acquisition

Prior to acquiring the seismic, several permits must be obtained. These include surveys to determine the impact, if any, on cultural and historic resources, plants and animals, and on the environment. In order to carry out these surveys, it is necessary to have a design for the seismic acquisition, which in turn requires an interactive cooperation between the acquisition team and the processing teams to insure that the resulting survey design meets the processing needs, but that does not require design aspects that are either too costly or compromise any of the cultural or natural resources that might be in the survey area.

Following discussions between Legacy Energy, Red Willow, Grant Geophysical, Axis Geophysic, WesternGeco and Dr. Tom Davis (Colorado School of Mines), the following acquisition design specifications were developed (Table 3-1):

Data Acquisition Parameters	
Area	6.0 Sq. Mi (15.54 sq. kms)
Line Parameters	
Receiver Point Interval	220 ft (67.06 m)
Source Point Interval	220 ft (67.06 m)
Total Receiver Points	1784
Total Source Points	848
Source Type	
P Waves	4 sweeps x 10 seconds
Shear 1	4 sweeps x 10 seconds
Shear 2	4 sweeps x 10 seconds
I.V.I Triax Vibrator	
Record Length	6 seconds
Recording Parameters	
Geophone Array	6 over 45 ft (13.72 m)
Live Patch	14 lines x 60 panels
Roll On/ Roll Off	Yes
Filters	½ Nyquist
Sample Rate	2 ms.

Table 3-1. Data acquisition parameters for 3D9C survey.

3.2 3D Zero-Offset VSP Acquisition

The 3D VSP data is being acquired to aid in the 3D9C seismic data processing (Figure 3-1). Zero Offset VSP has many benefits, including:

- Improved time-depth relationship
- True wavelet corridor stack
- Multiple free corridor stack
- Identify surface seismic events as primary reflection or multiple reflections
- Identify depth at which seismic event intersects wellbore
- Depth prediction of seismic events ahead of the drill bit
- Improved vertical resolution compared to surface seismic data Wavelet extraction and wavelet shaping
- Phase determination and matching of surface seismic data
- Complex structure and wellbore deviation to allow for offset imaging with improved lateral resolution
- Attenuation studies (Q estimation)
- Extraction of parameters for enhanced surface seismic processing

The offset VSP will be used to get a C-wave tie. The final output will also include corridor stacks from the P-wave, SH-Wave and SV-Wave.

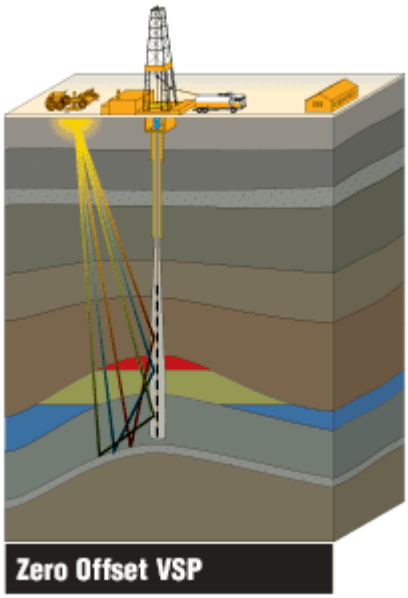


Figure 3-1. Schematic of 3D, Zero-offset VSP acquisition (from VSFision, http://www.vsfusion.com/app_wavelet.htm).

3.3 Permitting

The environmental assessment was designed to meet federal requirements and address potential environmental impacts that would result from the proposed Roadrunner /Towaoc project on the Ute Mountain Ute Indian Reservation and BIA administered lands.

The plan for the assessment was to ensure conformity with prevailing legal and statutory requirements. The proposed seismic acquisition is in conformance with the Ute Mountain Ute Indian Tribe Energy Development Program as presented in Appendix F of the Environmental Assessment of Oil and Gas Leasing and Development on Ute Mountain Ute Indian Reservation (USDI, Bureau of Indian Affairs 1993). Moreover, BIA authorization for the geophysical operation on tribal land is consistent with regulations of 43 CFR 3150. In addition, the proposed action and analysis in this document conform with and meet requirements of:

- Endangered Species Act (ESA) of 1973 (as amended)
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- 43 CFR Part 3150
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Figure 3-2 shows the table of contents for the submitted assessment. This outline illustrates the experimental method developed for carrying out the Environmental Assessment whose findings were subsequently submitted to the Bureau of Indian Affairs.

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Figure 3-2. Table of contents for environmental assessment report.

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Appendices

Figure 3-2. Table of contents for environmental assessment report (cont.).

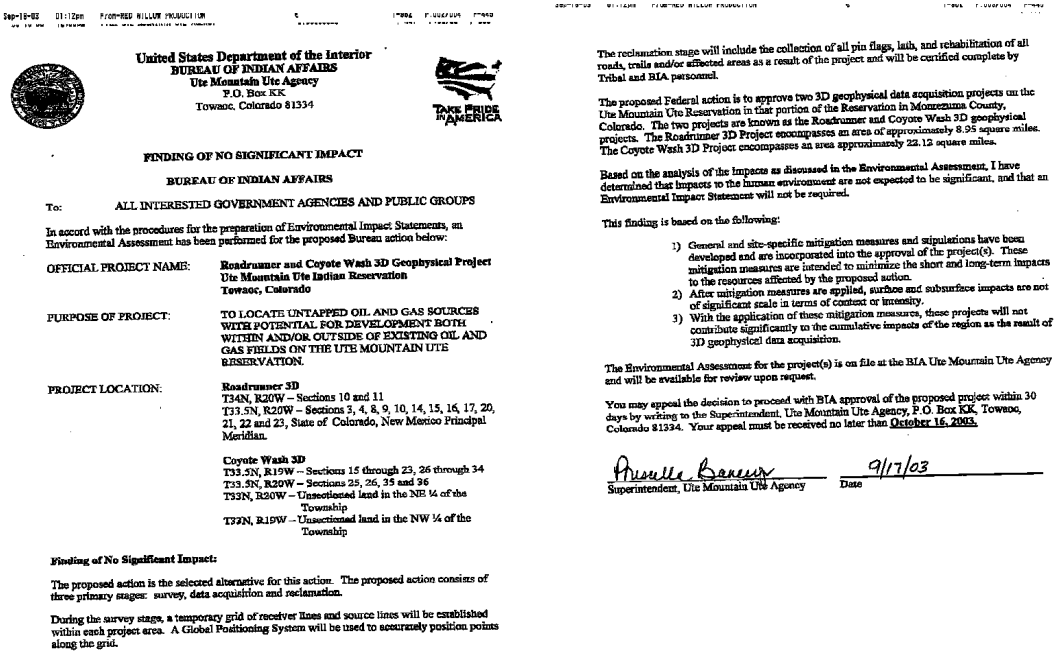
4 RESULTS AND DISCUSSION

4.1 Seismic Acquisition & Processing

During the second six-month project period, the designs for the 3D9C and 3D VSP surveys were finalized and used for planning the required surveys in support of cultural, historic and environmental impact permits. The US Bureau of Indian Affairs (BIA) issued a Finding of No Significant Impact on Sept. 17, 2003 (Figure 4-1), followed by a 30-day public comment period, which did not lead to a change in the finding.

The completion of the permitting process unfortunately coincided with the onset of winter weather in the project area, which greatly increases the chances of project delays in the field due to weather. In order to maintain the cost of the acquisition with the project's budget, the acquisition has been postponed until Spring when potential weather delays are less likely.

The costs for permitting are detailed in Table 4-1 below. These represent in-kind contributions from team member Red Willow Production Company as part of its commitment to this project.



United States Department of the Interior
BUREAU OF INDIAN AFFAIRS
Ute Mountain Ute Agency
P.O. Box KK
Towaoc, Colorado 81334

TAKE PRIDE IN AMERICA

FINDING OF NO SIGNIFICANT IMPACT

BUREAU OF INDIAN AFFAIRS

To: ALL INTERESTED GOVERNMENT AGENCIES AND PUBLIC GROUPS

In accord with the procedures for the preparation of Environmental Impact Statements, an Environmental Assessment has been performed for the proposed Bureau action below:

OFFICIAL PROJECT NAME: **Roadrunner and Coyote Wash 3D Geophysical Project Ute Mountain Ute Indian Reservation Towaoc, Colorado**

PURPOSE OF PROJECT: TO LOCATE UNTAPPED OIL AND GAS SOURCES WITH POTENTIAL FOR DEVELOPMENT BOTH WITHIN AND/OR OUTSIDE OF EXISTING OIL AND GAS FIELDS ON THE UTE MOUNTAIN UTE RESERVATION.

PROJECT LOCATION:

Roadrunner 3D
T34N, R20W – Sections 10 and 11
T33.5N, R20W – Sections 3, 4, 8, 9, 10, 14, 15, 16, 17, 20, 21, 22 and 23, State of Colorado, New Mexico Principal Meridian.

Coyote Wash 3D
T33.5N, R19W – Sections 15 through 23, 26 through 34
T33.5N, R20W – Sections 25, 26, 35 and 36
T33N, R20W – Unsectioned land in the NE ¼ of the Township
T33N, R19W – Unsectioned land in the NW ¼ of the Township

Finding of No Significant Impact:

The proposed action is the selected alternative for this action. The proposed action consists of three primary stages: survey, data acquisition and reclamation.

During the survey stage, a temporary grid of receiver lines and source lines will be established within each project area. A Global Positioning System will be used to accurately position points along the grid.

The reclamation stage will include the collection of all pin flags, lath, and rehabilitation of all roads, trails and/or affected areas as a result of the project and will be certified complete by Tribal and BIA personnel.

The proposed Federal action is to approve two 3D geophysical data acquisition projects on the Ute Mountain Ute Reservation in that portion of the Reservation in Montezuma County, Colorado. The two projects are known as the Roadrunner and Coyote Wash 3D geophysical projects. The Roadrunner 3D Project encompasses an area of approximately 8.95 square miles. The Coyote Wash 3D Project encompasses an area approximately 22.12 square miles.

Based on the analysis of the impacts as discussed in the Environmental Assessment, I have determined that impacts to the human environment are not expected to be significant, and that an Environmental Impact Statement will not be required.

This finding is based on the following:

1) General and site-specific mitigation measures and stipulations have been developed and are incorporated into the approval of the project(s). These mitigation measures are intended to minimize the short and long-term impacts to the resources affected by the proposed action.
2) After mitigation measures are applied, surface and subsurface impacts are not of significant scale in terms of context or intensity.
3) With the application of these mitigation measures, these projects will not contribute significantly to the cumulative impacts of the region as the result of 3D geophysical data acquisition.

The Environmental Assessment for the project(s) is on file at the BIA Ute Mountain Ute Agency and will be available for review upon request.

You may appeal the decision to proceed with BIA approval of the proposed project within 30 days by writing to the Superintendent, Ute Mountain Ute Agency, P.O. Box KK, Towaoc, Colorado 81334. Your appeal must be received no later than **October 16, 2003.**

Superintendent, Ute Mountain Ute Agency — Date 9/17/03

Figure 4-1. Letter from the Bureau of Indian Affairs stating the Finding of No Significant Impact for the proposed seismic survey.

Permitting Item	Cost
Archeology and SHPO Report	$60,615.13
Source and Receiver Point Surveying	$41,750.00
Biology, Threatened & Endangered Species Surveys and EA Report	$28,312.00
Total Permitting Costs to Date:	$130,677.13

Table 4-1. Costs to date expended for permitting of seismic acquisition.

4.2 Project Website

A project website has been updated to include new reports and links.. The homepage for this project is at: http://thebe.golder.com/utemtn/Home/.

5 CONCLUSIONS

Although the seismic acquisition has not yet occurred, the successful re-bidding of the 3D9C and 3D VSP acquisition and completion of the permitting process represent important steps forward in this project. The technical design of both surveys has been completed, with iterative consultation among the acquisition teams, the processing teams and Dr. T. Davis of the Colorado School of Mines.

It is anticipated that acquisition will occur as soon as weather permits during the Spring of 2004, followed by 3-4 months of processing and interpretation.

6 REFERENCES

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7 LIST OF ACRONYMS AND ABBREVIATIONS

3D3C – three dimensional, three component

3D9C – three dimensional, nine component

AVO - amplitude variation with offset

BIA – U. S. Bureau of Indian Affairs

DOE – U. S. Department of Energy

RW – Red Willow Production

SU – Southern Ute Tribe

UM – Ute Mountain Ute Tribe

VSP – Vertical Seismic Profiling