"Protocols for Seismic Data Acquisition and Processing to Characterize Natural Gas Hydrate Deposits in Deepwater"

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Authors:
Steve Holditch
Emrys Jones
And
Reservoir Services Group
Data Consulting Services, Schlumberger

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Submitting Organization:
ChevronTexaco Energy Technology Company
2811 Hayes Road
Houston, TX 77082

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ABSTRACT

In 2000, Chevron began a project to learn how to characterize the natural gas hydrate deposits in the deepwater portions of the Gulf of Mexico. A Joint Industry Project (JIP) group was formed in 2001, and a project partially funded by the U.S. Department of Energy (DOE) began in October 2001. The **primary objective** of this project is to develop technology and data to assist in the characterization of naturally occurring gas hydrates in the deep water Gulf of Mexico (GOM). These naturally occurring gas hydrates can cause problems relating to drilling and production of oil and gas, as well as building and operating pipelines. Other objectives of this project are to better understand how natural gas hydrates can affect seafloor stability, to gather data that can be used to study climate change, and to determine how the results of this project can be used to assess if and how gas hydrates act as a trapping mechanism for shallow oil or gas reservoirs.

The JIP believes that the best method for quantifying the aerial and vertical extent of a gas hydrate deposit in deep water has to be from seismic data. The industry needs to quantify the volumetric size of the zones containing gas hydrates, the expected hydrate saturation, and the mechanical properties of these zones so that industry can operate safely in deep water where gas hydrates are known to exist. It is not possible to gain enough information from drilling alone to comprehensively understand any naturally occurring gas hydrate deposit in deep water. Thus, the JIP has always been focused on learning how to shoot, record, process and interpret seismic data so the industry can characterize natural gas hydrates in deep water.

This report presents the results of the work by Schlumberger's WesternGeco as a subcontractor to the ChevronTexaco JIP. WesternGeco has used its seismic information, processing and interpretation expertise to develop the methods required to study the shallow formations in the deep water Gulf of Mexico so that can hydrates can be located and imaged. Their detailed results can be found in the Appendix.

More information can be found on the JIP website.

http://qpext.chevrontexaco.com/QuickPlace/wwuexpl_gashydrates/Main.nsf?OpenDatabase.

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1.0 Introduction

In 2000, Chevron Petroleum Technology Company (now ChevronTexaco) began a project to learn how to characterize the natural gas hydrate deposits in the deepwater portion of the Gulf of Mexico. ChevronTexaco is an active explorer and operator in the Gulf of Mexico, and is aware that natural gas hydrates need to be understood to operate safely in deep water. In August 2000, ChevronTexaco working closely with the National Energy Technology Laboratory (NETL) of the United States Department of Energy (DOE) held a workshop in Houston, Texas, to define issues concerning the characterization of natural gas hydrate deposits. Specifically, the workshop was meant to clearly show where research, the development of new technologies, and new information sources would be of benefit to the DOE and to the oil and gas industry in defining issues and solving gas hydrate problems in deep water.

On the basis of the workshop held in August 2000, ChevronTexaco formed a Joint Industry Project (JIP) to write a proposal and conduct research concerning natural gas hydrate deposits in the deepwater portion of the Gulf of Mexico. The proposal was submitted to NETL on April 24, 2001, and ChevronTexaco was awarded a contract on the basis of the proposal.

The title of the project is

"Characterizing Natural Gas Hydrates in the Deep Water Gulf of Mexico: Applications for Safe Exploration and Production Activities".

1.1 Objectives

The **primary objective** of this project is to develop technology and data to assist in the characterization of naturally occurring gas hydrates in the deep water Gulf of Mexico (GOM). These naturally occurring gas hydrates can cause problems relating to drilling and production of oil and gas, as well as building and operating pipelines. Other objectives of this project are to better understand how natural gas hydrates can affect seafloor stability, to gather data that can be used to study climate change, and to determine how the results of this project can be used to assess if and how gas hydrates act as a trapping mechanism for shallow oil or gas reservoirs.

1.2 Project Phases

The project is divided into phases. **Phase I** of the project is devoted to gathering existing data, generating new data, and writing protocols that will help the research team determine the location of existing gas hydrate deposits. During **Phase II** of the project, ChevronTexaco will drill data collection wells in at least two (2) locations to improve the technologies required to characterize gas hydrate deposits in the deep water GOM using seismic, core and logging data.

1.3 Research Participants

In 2001, Chevron (now ChevronTexaco) organized a Joint Industry Project (JIP) to plan and conduct the tasks necessary for accomplishing the objectives of this research project. As of March 2002, the members of the JIP were ChevronTexaco, Schlumberger, ConocoPhillips, Halliburton, the Minerals Management Service (MMS), Total, Japan National Oil Corporation, and Reliance Industries Ltd.

1.4 Research Activities

The research project began officially on October 1, 2001. Three Semi-Annual Reports have been written that cover the activity of the JIP from October 2001 through March 2003. Other reports were written to summarize the four (4) workshops held by the JIP during 2002 and 2003. All reports are available from the U.S. Department of Energy and from the JIP website.

1.5 Purpose of This Report

The purpose of this report is to present the detailed results of the work that WesternGeco has done using seismic data to help define the drilling targets for the wells to be drilled by the JIP in Phase II of this project.

2.0 Executive Summary

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The following has been taken from the Summary of the Schlumberger report that is included in this report as an Attachment.

"The work proceeded in two basic parts. In Part 1, we address the initial screening for gas hydrates of six deepwater Gulf of Mexico (GOM) blocks using seismic attributes calculated from the poststack data without the benefits of well logs. The issue we raise is the following: 'Can speculative data from the Gulf of Mexico that is acquired and processed with no gas hydrate focus be used for gas hydrate detection?' We obtained an affirmative answer to this question. From the initial screening of the speculative data, two prime candidate areas emerged: Keathley Canyon 195 and Atwater Valley 14. Keathley Canyon was chosen for the presence of a bottom simulating reflector (BSR) mappable over one-half of the project area. Atwater Valley was chosen for the numerous seafloor mound features, some possibly similar to Bush Hill as seen in Green Canyon 185. Green Canyon Blocks 184/185, an area with a known hydrate mound feature (Bush Hill), also provided useful knowledge for modeling and gas hydrate saturation estimation.

We designed a reprocessing flow for the data from the above mentioned blocks. Key steps of the processing that added value are: 2 ms sampling, amplitude preserving 3D Kirchhoff prestack time migration, detailed velocity analysis and demultiple. Amplitude preservation is a key requisite prior to prestack inversion for extracting gas hydrate properties from seismic data.

Part 2 concerns the application of inversion and analysis techniques to extract gas hydrate properties and saturations. For this, we designed a new workflow. We term this a 5-step workflow. This included creating a detailed stratigraphic interpretation framework for subsequent inversion, and to identify structural and depositional morphology associated with gas *hydrate features. Numerous horizons were mapped and attributes were generated for each area. These were used to further delineate potential hydrates as well as guide the elastic inversion process.*

The obtained inversion results, along with a detailed lithologic description of the shallow GOM sediments and a relationship to the seismic waveforms, were used to derive the physical rock model and hydrate elastic properties. This model was in part created using analog gas hydrate well information from both onshore and offshore wells as well as previously published theories. A key result from the modeling indicated that the seismic-inversion P-wave relationship was of primary importance in predicting hydrate sensitivity. The S-wave response was more difficult to accurately model and of only secondary importance.

The final results from the modeling were separate 3D volumes estimating gas hydrate saturation for the Keathley Canyon Block 195 area and the Atwater Valley Block 14 area. Because of the shale content in the GOM near-water bottom sediments, hydrate saturation estimation results will likely tend toward the maximum possible values. However, by exploiting the large amount of high-resolution 3D seismic coverage in the deepwater GOM, the model provides a useful tool to quantitatively estimate gas hydrate occurrences without the necessity of having a BSR present to provide primary delineation. This model is also updateable for improved accuracy when actual drilling and sampling information becomes available in the JIP Phase 2."

3.0 Task 6 – Seismic Modeling and Analysis

Task 6 in our proposal and research plan called for seismic modeling and analysis to better quantify the gas hydrates in the deep water Gulf of Mexico. The JIP contracted with WesternGeco to obtain existing three-dimensional seismic data in selected areas of the deep water Gulf of Mexico for review of the gas hydrate zones. These data have been used to conduct theoretical seismic modeling. The seismic modeling was used to develop protocols for acquiring, recording, processing, and analyzing seismic data to better image the gas hydrate zones.

The seismic modeling and analysis study has been designed to test the detection of and quantification of natural methane gas hydrates in sediments of the deepwater portion of the Gulf of Mexico using rock property inversion of pre-stack seismic data. Synthetic seismic modeling has been conducted on a series of generated earth models using rock physics in order to develop an improved process of seismic gas hydrate delineation and quantification. While conducting this research, WesternGeco has used datasets from six areas of interest to the JIP. The results have led to a much better understanding of the problems faced by the JIP and to the selection of drill sites for Phase II of this project.

3.1 Subtask 6.1 – Identify and Obtain Existing 3D Seismic Data (Completed)

A major goal of this project has been to determine the best ways to shoot, record, process and analyze seismic data to characterize the gas hydrates that are located in the deep water GOM. A contract was awarded to WesternGeco to provide existing seismic data in six areas in the deep water GOM and to analyze the data looking for gas hydrates

From a January 15, 2003, report by WesternGeco, the following information was presented.

> *"The objectives of the Phase 1 initial screening process were to identify possible key gas hydrate locations for subsequent reprocessing of seismic data and seismic modeling and analysis. This involved a search for hydrate features such as mounds, slumps, trapped gas, BSRs, etc., using post-stack attributes along with seismic structural and stratigraphic interpretation. Digital well logs, mud logs and drilling reports were not available for Phase 1. Only literature and published articles were used. Known seismic characteristics indicative of hydrates are listed below.*

1. *Presence of a BSR at base of the stability zone.*

2. *Underlying areas showing amplitude attenuation or "wipe out" zones.*

3. *Possible polarity reversals at or near the water bottom interface.*

4. *Elevated P-wave velocity of the sediments as opposed to the background.*

5. *Large variability in amplitude reflection strength, continuity and lateral consistency within the hydrate stability zone.*

6. *"Shingling" of reflectors with increased amplitudes at shallow depths.*

7. *Seafloor gas hydrate mounds, seafloor failures and slumping.*

8. *Gas chimneys.*

9. *Mud volcanoes.*

10. *Presence of gas and water in near surface sediments.*

11. *Thermal-pressure analysis to define the temporal and spatial limits of the hydrate stability zone.*

Many of these indicators were found on the five surveys strongly suggesting the presence of hydrates. However, this early Phase 1 work cannot positively confirm or deny the existence of hydrates at any of the locations. More definite and quantitative analysis will be forthcoming in the subsequent work. A summary of each area follows along with a ranking as to the abundance and quality of hydrate characteristics."

Using data from the WesternGeco report, a short-list of six sites was created. These six sites are as follows:

OCS Block	Water Depth (m)
Green Canyon 184, 185	538
Atwater Valley 14	1297
Alaminos Canyon 856	2243
Mississippi Canyon 802	1036
Keathley Canyon 195	1305
Mississippi Canyon 757 – Alternate	

The data for these six areas have been screened to look for bottom simulating reflectors (BSRs), shallow water flow type features, high reflectivity zones (HFZs) which may appear within the gas hydrate stability zone, widespread strongly attenuated blanking zones, and lateral changes and variations in seismic character within the gas hydrate stability zone.

3.2 Subtask 6.2 – Theoretical Seismic Modeling

Virtually all of the seismic data shot in the deep water GOM has been optimized to find oil and gas formations deep (10,000 – 20,000 ft.) below the mud line. Since gas hydrate deposits are located at or near the seafloor, the seismic data that one normally obtains has not been optimized to image the seafloor and the gas hydrate zones that lie beneath the seafloor. WesternGeco has conducted theoretical seismic modeling, using their 3-D data sets in the six areas of interest. The objectives of the seismic modeling have been to determine how seismic data must be shot, recorded, processed and analyzed to accurately image the naturally occurring gas hydrate deposits near the seafloor.

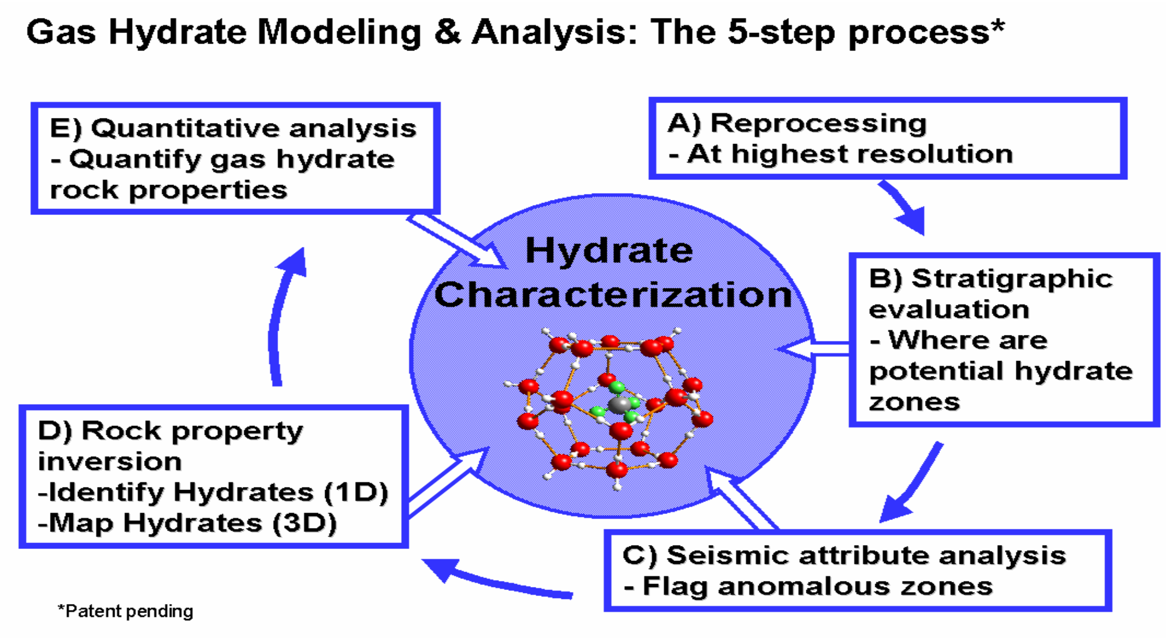
3.3 Subtask 6.3 – Protocol Development for Seismic Data

The geophysical modeling has been concluded and WesternGeco has prepared a report to explain how to record, process and analyze seismic data to better image the gas hydrate zones in the deep water GOM. As we proceed into Phases II and III of this project, we can use the results of the

WesternGeco study to perfect our methods to identify, image, and characterize gas hydrates in deep water.

The following paragraphs summarize the results from the WesternGeco report. The entire report is included at an Appendix.

"WesternGeco, an affiliate of Schlumberger Technology Corporation and as a member of the ChevronTexaco Gas Hydrates JIP consortium, proposed using 3D seismic data to screen six Gulf of Mexico blocks in five separate areas, choosing two blocks for additional work, in the search for gas hydrates prior to drilling. The absence of well logs and other hard data presented a key challenge in the study.



The primary JIP mission, which proceeded in two phases, was to determine whether speculative seismic survey data could be used to find, delineate and quantify natural gas hydrate occurrences. To that end, WesternGeco employed a proprietary five-step integrated multidisciplinary approach that included: 1). Reprocessing conventional 3-D seismic data at the higher resolution using an amplitude-preserving flow with prestack time migration, 2) a detailed stratigraphic evaluation and interpretation to identify potential hydrate zones, 3) seismic attribute analysis to further delineate anomalous zones, 4) full-waveform prestack inversion to characterize acoustic properties of gas hydrates in 1D (Mallick, 1995) and subsequent hybrid inversion in 3D (Mallick et al., 2000), and 5) quantitative estimation of gas hydrate saturation using rock property models.

The 5-step workflow for gas hydrate detection and quantification is independent of whether a BSR is present or absent. It is intended to provide a framework for gas hydrate characterization using an integrated geological and geophysical approach. Full-waveform prestack inversion (FWPI) and a detailed assessment of rock physics models for gas hydrates are centerpieces of the methodology. The remainder of the report will follow this workflow."

4.0 Conclusions

Based on WesternGeco's analysis of the six potential sites for Phase II drilling, the Sea Floor Team and several invited outside experts selected Keathley Canyon 195 and Atwater Valley 14 for further analysis.

1. A 5-step process has been used to characterize and quantify gas hydrate deposits in the Gulf of Mexico in the Keathley Canyon and Atwater Valley Areas using long offset 3-D seismic data. Key steps of the process include: Seismic data reprocessing (highest resolution); stratigraphic evaluation and geologic interpretation, seismic attribute analysis, full wave form prestack inversion (FWPI) of rock properties and quantitative analysis to obtain estimates of hydrate saturation.

2. Seismic interpretation of sequence stratigraphy is a critical step used to identify the geologic framework and depositional environments of near ocean bottom sediments (1000m BML). Regional and sub-regional screening of post stack seismic data (including seismic attributes) provided valuable qualitative evidence required to identify gas hydrate deposits and associated "seismic indicators" by conventional seismic interpretation methods.

3. High quality, long offset seismic data and targeted processing or re-processing is essential for accurate delineation and quantification of gas hydrates deposits. Seismic data must be processed using a sample interval of 2 milliseconds or less in order to obtain the highest possible resolution. Further, the relative amplitudes of seismic event reflections must be carefully preserved in data processing flow so that accurate measurements of elastic rock properties may be recovered through inversion. Noise treatment requires special attention particularly due to high noise interference in near ocean bottom reflections and noise attenuation is critical to the success of seismic methods. Special processing consideration is required to correct for variation in ocean bottom reflection amplitudes resulting from the data acquisition "foot print". Results of the study also suggest that a separate processing flow is required to enhance resolution and imaging for conventional post stack structural interpretation.

4. Full wave form prestack seismic inversion (FWPI) is an essential process used to obtain high resolution elastic rock property estimates (Vp, Vs and bulk density) from long offset seismic data. The resultant pseudo well logs provide direct estimates of rock properties used to estimate hydrate saturation and the essential constrains and calibration needed for conventional 3-D AVO based "hybrid inversion" of P and S wave impedance. FWPI requires good signal to noise seismic data and a proper earth model to constrain inherent non-linearity and ambiguity of the process.

5. Rock physics is key to development of the macro earth model and quantitative analysis of rock properties and hydrate saturation. Elevated P-wave and S-wave velocities are diagnostic features of the occurrence of gas hydrates in the shallow sediments, which provide the basis for gas hydrate detection and quantification (saturation and volumetrics) both from acoustic logs and seismic data (through inversion).

6. Paramount to future development and success of the seismic modeling and analysis of gas hydrate deposits will be the validation and calibration of the results of this study with actual wireline logs, rock samples and cores and laboratory tests. Hard measurement data from well bore must be used to assess the predictive value of current methods, refine models, optimize the processes employed and identify best practices and requirements for future work.

7. Special consideration should be given to analysis of other seismic data acquisition technology that we strongly recommend to enhance the quality, significance and value of the seismic methods employed. These would include: Single sensor data recording utilizing WesternGeco Q-Marine™ technology which will offer very significant improvements in vertical and lateral resolution, seismic bandwidth and most importantly, considerable improvement in signal to noise. Alternatively, we would recommend ocean bottom cable (OBC) employing the use of multi-component (4-C) technology. OBC data would be particularly suitable and useful in areas with gas chimneys and gas plumes, often associated with gas hydrates.

5.0 References

No external references were used in this report.

APPENDIX A

Theoretical Modeling and Analysis for Gas Hydrate Quantification from Prestack Seismic Data in the Northern Deepwater Gulf of Mexico

See separate document: Appendix A.