Oil & Natural Gas Technology

DOE Award No.: DE-FC26-01NT41330

Semi-Annual Technical Progress Report (October 2006 – March 2007)

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

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Prepared for:
United States Department of Energy
National Energy Technology Laboratory

June, 2007

Office of Fossil Energy

“Characterizing Natural Gas Hydrates in the Deep Water Gulf of Mexico: Applications for Safe Exploration and Production Activities Semi-Annual Report”

Report Type: Semi-Annual
No: 41330R12

Starting	**October 2006**
Ending	**March 2007**

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June 2007

DOE Award Number: DE-FC26-01NT41330

Submitting Organization:
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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 Participation (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.

During October 2006 – March 2007, the JIP concentrated on:

- Conducting experiments on the cores collected;
- Conducting experiments on cores collected in India;
- Preparing a work plan for Phase III;
- Studying sites for Phase III drilling seismic analysis.

More information can be found on the JIP website.

https://cpln-www1.chevron.com/cvx/gasjip.nsf

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1.0 Introduction

In 2000, Chevron Petroleum Technology Company began a project to learn how to characterize the natural gas hydrate deposits in the deepwater portion of the Gulf of Mexico. Chevron 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, Chevron 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, Chevron 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 Chevron 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".

1.2 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.

1.3 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, Chevron will drill at least three data collection wells to improve the technologies required to characterize gas hydrate deposits in the deep water GOM using seismic, core and logging data.

1.4 Research Participants

In 2001, Chevron organized a Joint Industry Participation (JIP) group to plan and conduct the tasks necessary for accomplishing the objectives of this research project. As of March 2007 the members of the JIP were Chevron, Schlumberger, ConocoPhillips, Halliburton, the Minerals Management Service (MMS), Total, JOGMEC, and Reliance Industries Limited. The Korean National Oil Company (KNOC) has signed the necessary contract forms to become a member if the JIP starts work on a Phase III.

1.5 Research Activities

The research activities began officially on October 1, 2001. However, very little activity occurred during 2001 because of the paperwork involved in getting the JIP formed and the contract between DOE and Chevron in place. Several Semi-Annual and Topical Reports have been written that cover the activity of the JIP through September 2006.

1.6 Purpose of This Report

The purpose of this report is to document the activities of the JIP during October 2006 – March 2007. It is not possible to put everything into this Semi-Annual report. However, many of the important results are included and references to the JIP website, https://cpln-www1.chevron.com/cvx/gasjip.nsf, are used to point the reader to more detailed information concerning various aspects of the project. The discussion of the work performed during September 2006 – March 2007 is organized by task and subtask for easy reference to the technical proposal and the DOE contract documents.

2.0 Executive Summary

Chevron formed a Joint Industry Participation (JIP) group 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 Chevron 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".

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). **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 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, Chevron will drill at least three data collection wells to improve the technologies required to characterize gas hydrate deposits in the deep water GOM using seismic, core and logging data.

A website has been developed to house the data and information that were collected in the Workshop, as well as other items submitted during the course of this research endeavor. The link to the JIP website is as follows:

https://cpln-www1.chevron.com/cvx/gasjip.nsf.

2.1 Post-Cruise Comparison of Seismic Predictions to Log and Core Data

One of the objectives of the JIP was to determine if seismic analysis could be used to determine hydrate concentrations and locations. WesternGeco preformed a pre-cruise seismic analysis and then predicted the locations and concentrations of where hydrates could be found. During this period they also compared their pre-cruise predictions to log and core data collected during the cruise. The complete report is available on the JIP Web Site and a summary of the comparison is presented in Figure 3.1.

2.2 Well Bore Modeling Final Report

The well bore model developed in Phase I was used to predict pore pressure and well bore stability before the Leg 1 Cruise. During the cruise one of the staff responsible for the well bore model collected data necessary to determine the performance of the model. The final report on the well bore stability model was received in October of 2006 and is available on the JIP Web Site. The report's conclusions and recommendations are presented in Appendix B.

2.3 Georgia Tech Measurement Vessel

To gain additional operational experience with the pressure core measurement vessel, it was used to conduct experiments on cores collected by India in the summer of 2006. Sample results are presented in Appendix A.

2.4 Marine and Petroleum Geology JIP Special Volume

Marine and Petroleum Geology will publish the Scientific Results for the 2005 DOE-Chevron Joint Industry Project Gulf of Mexico methane hydrates drilling. Papers to be included in this publication have been compiled and are in final stages of review. The target date for completion of final review and acceptance of the papers is June 2007 with publication to follow thereafter.

3.0 Results and Discussion Phase II

3.1 Task 1.0 – Research Management Plan

The goals of this task are to develop a work breakdown structure and supporting narrative that concisely addresses the overall project as set forth in the agreement. Provide a concise summary of the technical objectives and technical approach for each task and, where appropriate, for each subtask. Provide detailed schedules and planned expenditures for each task including any necessary charts or tables, and all major milestones and decision points.

A Continuation Application for Phase II was submitted to the DOE on 15 May 2003. Additional documentation was supplied to the DOE in November and December of 2003, March, July, and December of 2004, and the research plan was revised again in January 2005 to allow for the additional cost of the drilling vessel. Several changes were required to the original plan because of delays due to EPA permitting, and drill ship changes. The final Phase II revision was submitted to the DOE in March of 2006 along with a revised budget to complete Phase II and prepare a proposal for Phase III.

3.2 Task 2.0 – Project Management and Oversight

A project manager appointed by the Joint Industry Project (JIP) Recipients will manage the technical teams, contractors, and the day to day operation of the project. Project manager will report, verbally and through required reporting, on the progress of the program to the DOE and the JIP as required.

During the period of the progress report the JIP and DOE project managers were in regular contact discussing progress on the project and changes to the research plan for Phase III.

3.3 Task 3.0 – Validation of New Gas Hydrate Sensors

Review and evaluate new hydrate sensor development (Phase I – Task 4, Subtasks 4.1 – 4.4). Prototype sensors, if available, will be field tested in well bores and protocols for use will be developed and distributed to all entities involved in drilling wells in the Gulf of Mexico.

The pressurized core measurement vessel, developed by Georgia Tech, and transfer vessels were tested during the Leg 1 Cruise. After some initial adjustment, the equipment worked and one pressure core was transferred into the measurement vessel for testing. Georgia Tech's complete report was presented in previous semiannual reports. The measurement vessel was also used in the fall of 2006 to collect data on cores collected as a part of an expedition led by the Indian Government's National Gas Hydrate Program. A brief summary of the project is provided below and example data may be found in Appendix A

Location. Krishna-Godawari basin (~36 km off the east coast of India) with a water depth of 1020 m. The location was continuously cored to more than 200 mbsf.

Sediments. Unconsolidated clay sediments

- Traces of sand and silt
- Diatoms, foraminiferan,
- Vertical fractures
- Authigenic carbonate nodules
- Water content 40-60%
- 40 to 80% hydrate concentration
- Vp: 1700 to 2300 (in situ)
- Resistivity 1 ohm-m for saturated cores, to 30 ohm-m (even 1000 ohm-m) in hydrate bearing sediments
- Thermal conductivity 0.521 and 0.968 W/(m-k) for destabilized specimens

Hydrate bearing sediments. The shallowest depth where sediments with hydrates were found was estimated to be 42 mbsf (based on thermal anomalies detected using an IR camera). On the other hand, the depth of the BSR is estimated at 169 mbsf (from marine seismic records).

Importance within the state of the art on hydrate bearing sediments. A salient feature of these sediments is the apparently high concentration of hydrates in clayey sediments.

The Georgia tech study. Took place between October 30 and November 7, 2006, at a location near Singapore's port. The goal of the study was to determine small-strain wave propagation velocity (V_P and V_S), large strain mechanical properties (un-drained shear strength), and electrical conductivity data from the sediments without de-pressurizing the cores. A complementary de-pressurization study was conducted to explore gas production while monitoring the evolution of properties in the sediment.

3.4 Task 4.0 – Validation of the Well Bore Stability Model

The goal of this task is to revise the well bore stability model, developed in Phase I – Task 5.0 – Subtasks 5.1 – 5.4, using laboratory data and to validate the model using all available information. Changes or improvements will be made and the model will be distributed for use by organizations drilling wells in the Deep Water Gulf of Mexico.

The well bore model developed in Phase I was used to predict pore pressure and well bore stability before the Leg 1 Cruise. During the cruise one of the staff responsible for the well bore model collected data necessary to determine the performance of the model. The final report on the well bore stability model was received in October of 2006 and is available on the JIP Web Site. The report's conclusions and recommendations are presented in Appendix B.

3.5 Task 5.0 – Core and Well Log Data Collection – Area A

In order to develop the necessary ground truth data, twin wells in the most favorable location for gas hydrates identified in Phase I – Tasks 11/12 – Subtasks 11.1 – 11.5 (this will be designated Area A) will be drilled. Well A-1 will be drilled without well control and will gather drilling, MWD and open hole logging information. Well A-2 will be drilled with well control and will gather drilling, MWD, core and open hole logging information. The wells will be surveyed and the core will be sent to laboratories for analyses. An additional well, A-3, will be drilled in the least favorable location for gas hydrates in Area A and appropriate core, logging and drilling data will be obtained.

Leg 1 drilling was conducted at two locations, Atwater Valley and Keathley Canyon, in the GOM. In both locations holes were drilled to collect log and core data. In addition to the two primary wells drilled in Atwater Valley, two short wells were drilled near the center of the mound. A complete operation and drilling summary was presented in previous semiannual reports.

3.6 Task 6.0 – Data Analysis – Initial Cruise

Work under this task will consist of conducting the appropriate analysis of all data obtained during initial field activities (the April—May 2005 activities at the Atwater Valley and Keathley Canyon sites) and provide an initial Scientific Results report that details the following: a) the pre-cruise seismic interpretations and an analysis comparing those interpretations with actual findings; b) the findings of the geochemical surveys; c) the findings of the well logging efforts and analysis; d) the findings of the borehole geophysical surveys; e) the performance of various sampling devices employed; f) as well as any other appropriate results emanating from shipboard or subsequent analysis of data or samples obtained during the cruise.

Leg 1 core and log data was presented in a workshop in April 2006 and in previous semiannual reports. Geotechnical data was received from Rice University and will be reported on at a later time.

One of the objectives of the JIP was to determine if seismic analysis can be used to determine hydrate concentrations and locations. WesternGeco performed pre-cruise seismic analysis and predicted the locations and concentrations of hydrates. During this period they also compared their pre-cruise predictions to log and core data collected during the cruise. The complete report is available on the JIP Web Site and a summary of the comparison is presented in Figure 3.1.

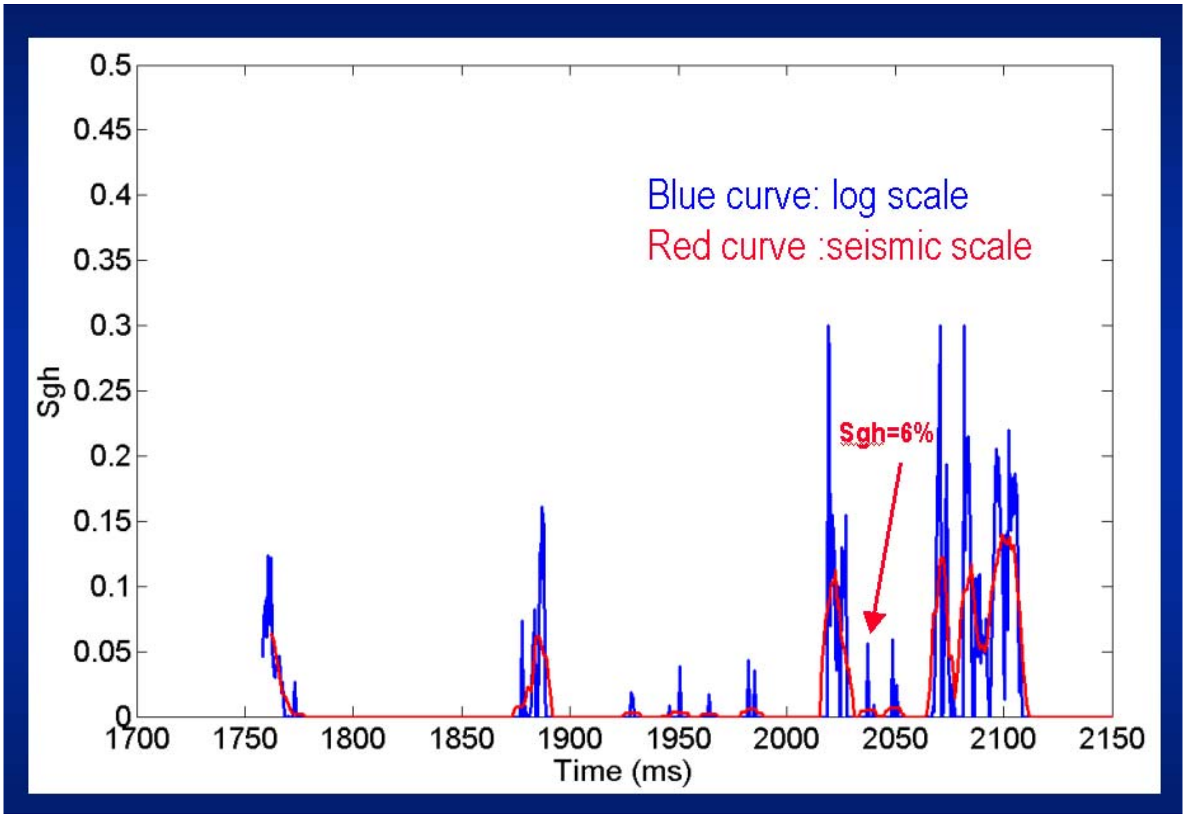


Figure 3.1. Comparison of Pre-Cruise Seismic Analysis to Log Data

3.7 Task 7.0 – Technical Conference

In order to provide the scientific community with current data from the project, a workshop will be conducted to present all information obtained during the course of the project to industry, academic, government and other interested professionals. This workshop will focus on the opportunities for improving the tools and protocols for effective field investigation of hydrates in the Gulf of Mexico. The output of the workshop will be plans for DOE consideration for acting on specific recommendations arising from this workshop.

The workshop was held in Houston on 13 and 14 April 2006. The workshop agenda is presented below. Presentations from the workshop and breakout session discussions will be reported in a DOE Topical Report.

Marine and Petroleum Geology will publish the Scientific Results for the 2005 DOE-Chevron Joint Industry Project Gulf of Mexico methane hydrates drilling. Papers to be included in this publication have been compiled and are in final stages of review. The target date for completion of final review and acceptance of the papers is June 2007 with publication to follow thereafter.

3.8 Task 8.0 – Field Sampling Device Development

In addition to any specific data/tool needs identified in the Task 7 workshop, the acquisition of improved technologies for the acquisition, retrieval and subsequent analysis of samples under in-situ pressure (and possibly temperature) conditions will be pursued. Pressure coring equipment will be evaluated both from the JIP membership and the development of new devices to accomplish these goals (both sample retrieval and extensive analysis of samples in systems capable of minimizing hydrate dissociation and sample alteration from its natural state).

After reviewing the performance of pressure coring devices and factoring in the need to sample sands containing hydrates, it was decided to develop a pressure coring tool based on the design used by Japan in the Artic and offshore Japan. Negotiations are complete and a contract is being completed with the company that owns the rights to produce the Japanese design to determine if the operating pressure can be increased and transfer capability can be added.

3.9 Task 9.0 – Recommendation for Further Activities

Analysis of initial cruise findings will be used to determine the need for additional field activities to properly characterize the full range of hydrate occurrences in the Gulf. New locations will be selected and evaluation of existing geophysical and well log data will be conducted to evaluate the existence of sites or the location of favorable transects in the Gulf of Mexico that have the best potential to provide the missing data. Recommendations will be prepared for a second phase of field activities, including a description of the sites and a plan for conducting field operations.

A site selection meeting was held on 7 September 2006 in Houston. The meeting followed the April 2006 breakout group's recommendations and reviewed the sites that were pulled from the MMS Data Base. The MMS Data Base was reviewed by MMS, USGS, and DOE personnel and 6 locations were reviewed in the September Meeting. The results of the meeting were presented in previous semiannual reports.

AC 818 and AC 857 were the two locations selected in the meetings and a detailed seismic analysis of these locations is in progress with analysis completion anticipated by late June 2007 and reporting of analysis results in July 2007. Figure 3.2 shows the location of AC 818 and Figure 3.3 is an example of the data being developed for the two locations.

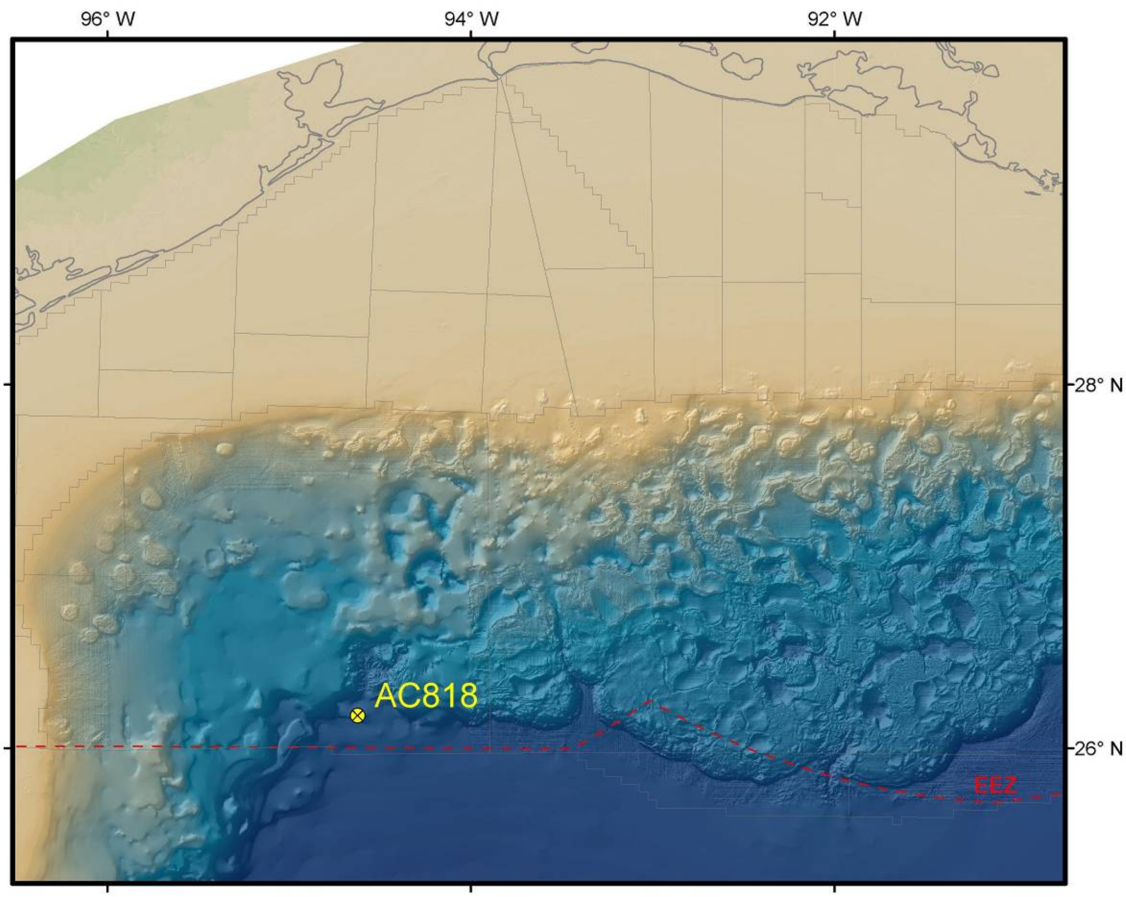


Figure 3.2. Location of AC 818

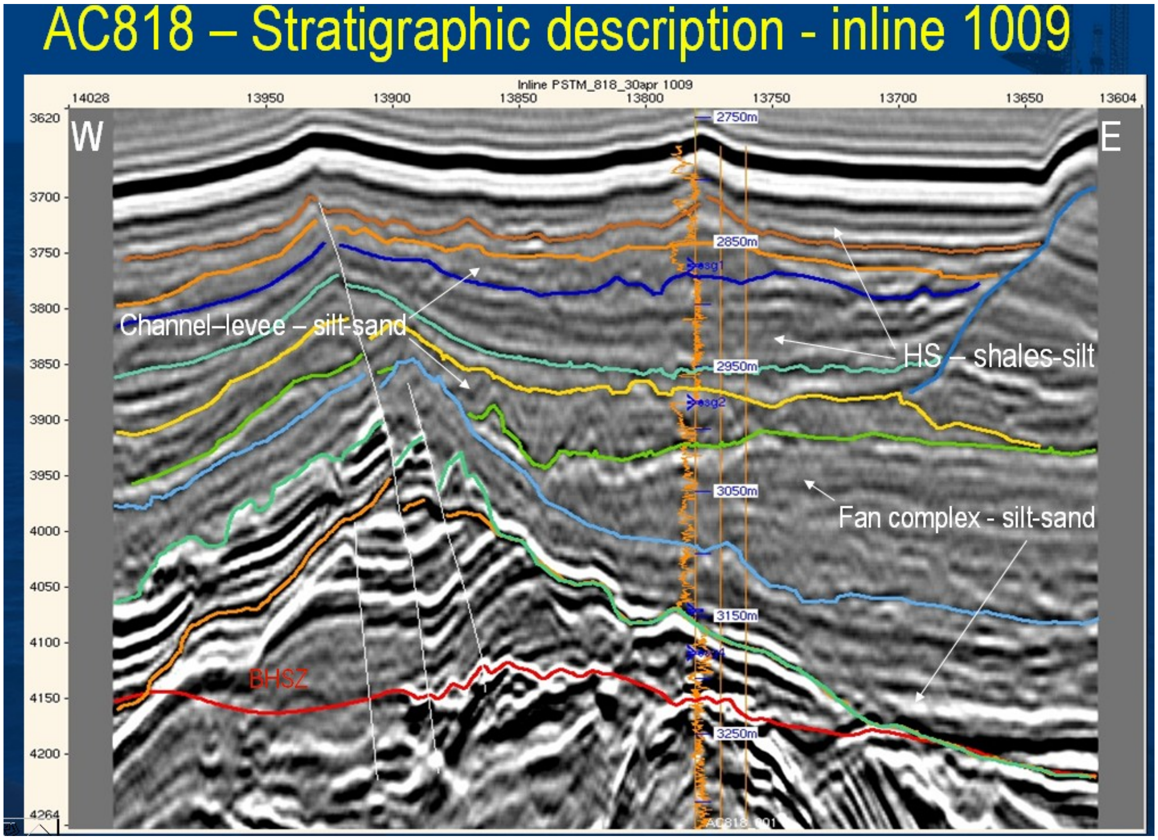


Figure 3.3. AC818 Strategic Description.

4.0 Discussion and Results PHASE III – Follow on Field Activities and Final Reporting

Tentative tasks are provided for Task III activities, which will include the execution of a second field program as identified in Phase II/Task 9.0, and full reporting to both DOE and the broader scientific community.

4.1 Task 1.0 – Research Management Plan

Develop a work breakdown structure and supporting narrative that concisely addresses Phase III activities and includes a concise summary of activities, schedules and costs for each Phase III Task.

4.2 Task 2.0 – Project Management and Oversight

A project manager appointed by the Joint Industry Project (JIP) Recipients will manage the technical teams, contractors, and the day to day operation of the project. Project manager will report, verbally and through required reporting, on the progress of the program to the DOE and the JIP as required.

4.3 Task 3.0 – Field Activities

Conduct field operations as developed in Phase II Task 9.0 and outlined in Phase III Task 1.0.

4.4 Task 4.0 – Data Analysis

Conduct appropriate analysis of all data obtained during the Phase III cruise, integrate these data with those from the Phase II cruise, and provide a detailed Final Report on the findings and their implications. Recommend and pursue options for providing this report as a Special Volume in a manner similar to that provided from other large-scale hydrate research efforts (for example, the special volumes emanating from the Mallik programs).

4.5 Task 5.0 – Technical Conference

Conduct a technical conference to present all information obtained during the course of the project to industry, academic, government and other interested professionals.

5.0 Experimental

Experimental work was conducted during the period of this report. Photos and drawings of some of the experimental equipment that was used on the cruise were presented in previous semiannual reports.

6.0 Conclusions

Testing of the Georgia Tech measurement vessel on the Indian cores provided additional operational experience with the tool that will prove valuable.

Analysis of the well bore modeling showed the need for additional mechanical data on hydrate bearing sediments. This work should be done on both lab and field samples.

Post-cruise comparison of log and core data to the pre-cruise seismic predictions was good but several areas of improvement were identified.

7.0 References

No external references were used for this report.

8.0 Appendix

APPENDIX A. Georgia Tech Instrument Data on Indian Cores (Preliminary data)

Figure A1. Sample Pressure Core Measurement

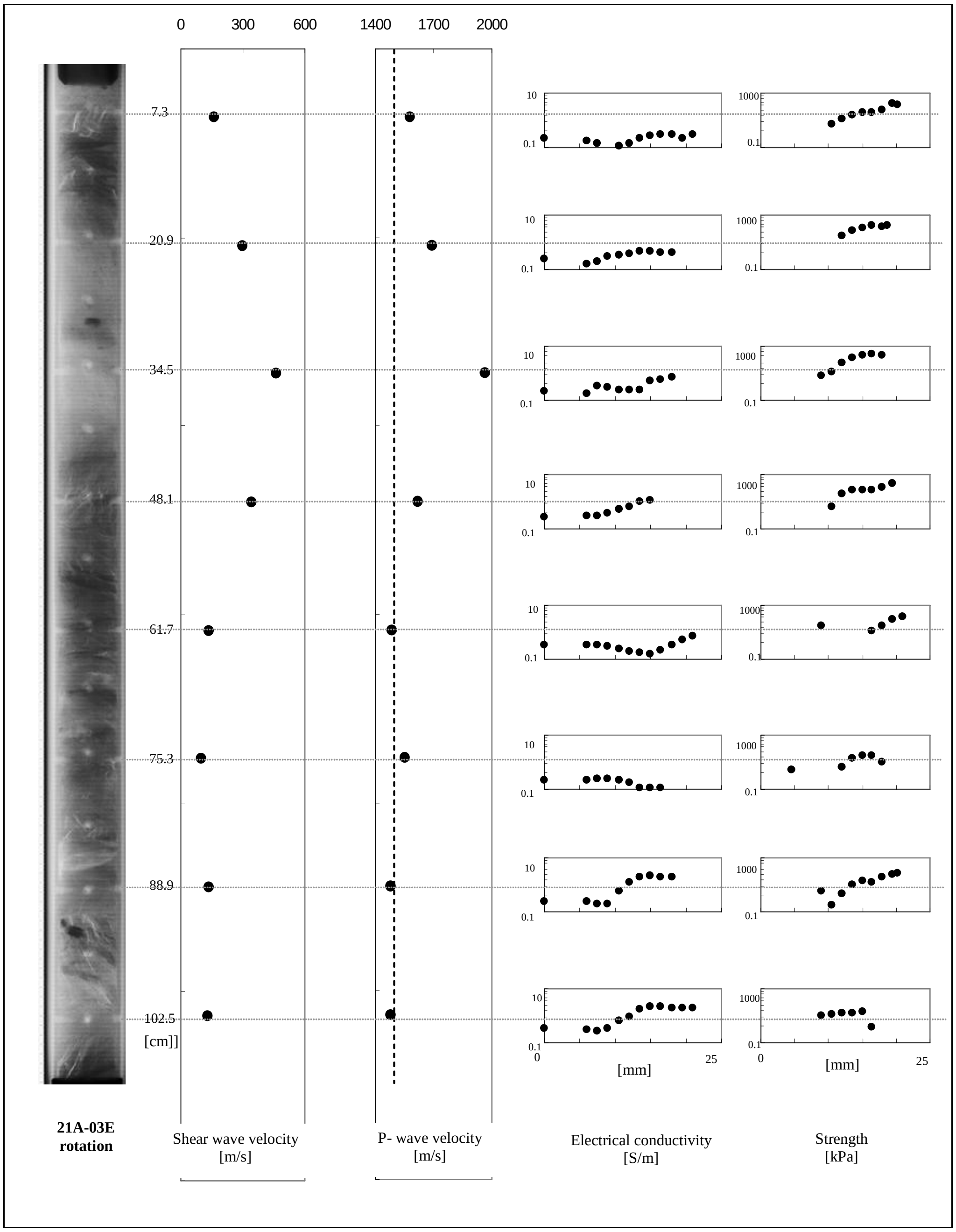
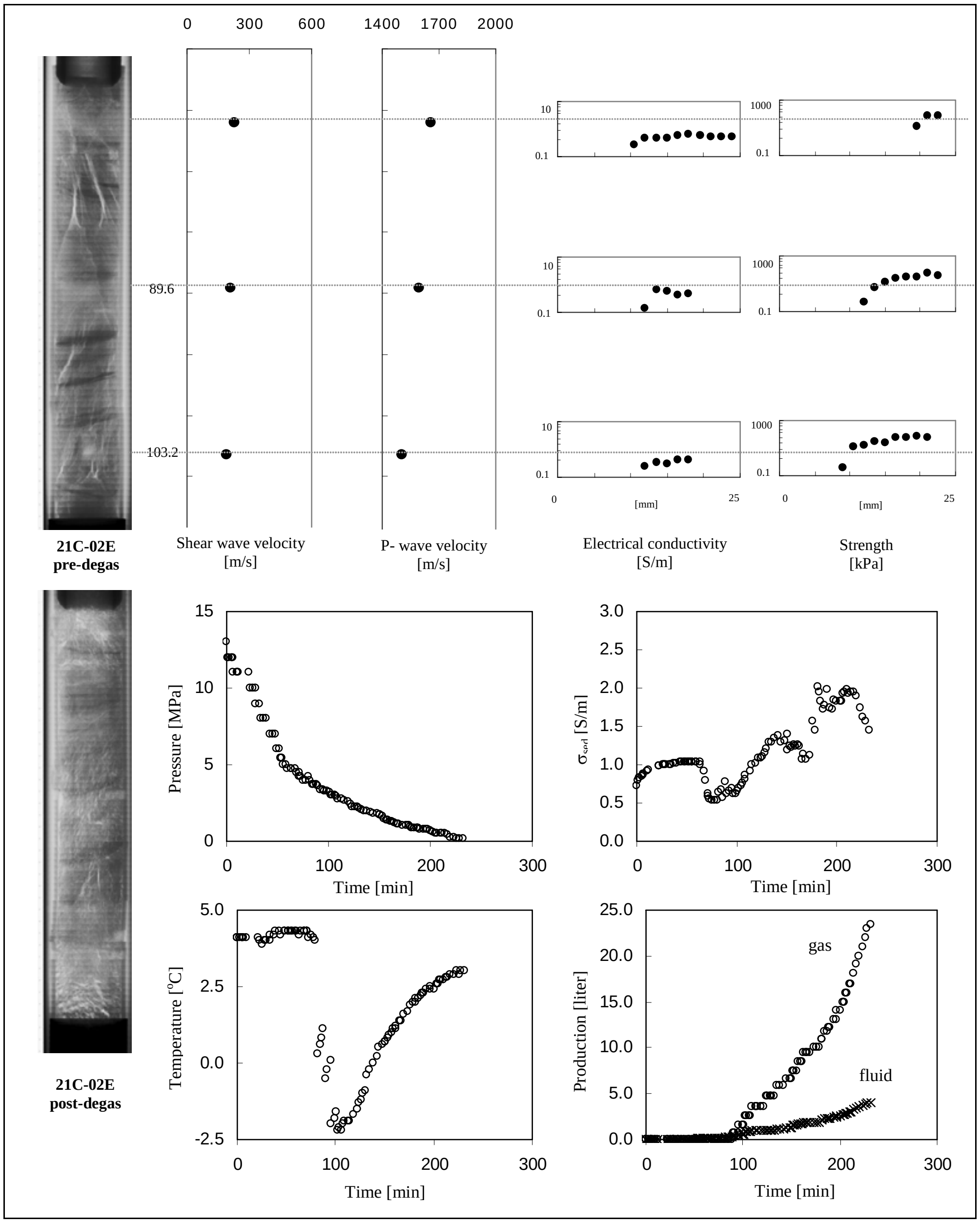


Figure A2. Sample Production Data



APPENDIX B. Well Bore Model Conclusions and Recommendations

CONCLUSIONS

In order to analyze the mechanical stability of boreholes drilled during the JIP expedition, a semi-analytical Mohr Coulomb elastoplastic code called HYDRAPLASTIC© was developed. The code was benchmarked against the ABAQUS™ finite element simulator. The stresses predicted by the code were in excellent agreement with those computed by ABAQUS™. However differences in the plastic strains were seen in some cases. These discrepancies were attributed to slight variations in the versions of the Mohr Coulomb formulation used by the two codes. The assumption of proportional loading used to derive the semi-analytical Mohr Coulomb formulation was shown to be reasonable for select cases.

In order to estimate the mechanical properties required by the code, triaxial and oedometric tests performed by the Georgia Institute of Technology were analyzed. Unfortunately the tests were not ideally suited for wellbore stability modeling and the results were compromised by barrelling of test specimens. Assumptions were made in order to extract data required for this project. However these assumptions may have resulted in errors that are difficult to quantify. Additional testing of hydrate bearing sediments is highly recommended.

In recognition of the fact that wellbore stability is partly influenced by the tendency of hydrates to dissociate, temperatures developed in the borehole during drilling were simulated. Suitable methods were chosen from the literature to predict the thermal properties of hydrate-bearing sediments. Temperature simulations were performed to determine the conditions under which hydrate dissociation could occur while drilling with seawater in a hypothetical field. A sensitivity study was carried out on the factors that affect downhole temperature. It was observed that for shallow wells, the temperature at the wellbore wall was not particularly sensitive to the formation thermal properties when these were varied within an expected range.

The simulations also revealed that temperature in the shallow subsurface is governed primarily by heat transfer in the ocean section of the drill pipe. The temperature in the borehole could be reduced significantly by lowering the circulation rate as this increased the transit time of the drilling fluid through the ocean. It was also shown that for normal pore water salinities, the risk of dissociation due to drilling induced temperature disturbances was small for moderate circulation rates. However, high salinity and fast circulation rates greatly increased the risk of dissociation. Reduction of the circulation rate was shown to be an effective strategy for reducing the risk of dissociation.

The methods developed for predicting the mechanical and thermal properties of hydrate bearing sediments were used to estimate properties at the JIP sites. The estimated mechanical properties were supplied as inputs to HYDRAPLASTIC© and the wellbore stability evaluation made by code was compared with data from LWD logs. Good agreement was seen in all three cases where LWD logs were acquired. In Atwater Valley, the minimum horizontal stress was consistent with model predictions whereas in Keathley Canyon, the absence of shear failure in the wellbore was accurately determined by the code. It appears that the assumed effective stress ratio of 0.9 was reasonable at both Keathley Canyon and Atwater Valley. Evidence of significant horizontal stress anisotropy was also seen in Atwater Valley. The maximum horizontal stress was directed E-W and the minimum horizontal stress deduced from drilling induced fractures was about 14 ppg.

LWD logs were used to diagnose the reasons for drilling problems in Atwater Valley. It was shown that a major cause of hole enlargement was washout at connections. High ECD leading to extensive drilling induced fractures was seen in both LWD wells. It appears that both wells were effectively sealed from the sea bottom within the first 100 odd feet of drilling. Time-lapse analysis of LWD logs showed evidence of coarse-grained solids falling into the BHA annulus and causing packoffs. Data was presented to support the hypothesis that these solids may have originated from overpressured sands, possibly serving as conduits for shallow water flow. The video evidence from the ROV should be studied in order to validate this hypothesis. There was insufficient data to confirm or reject the hypothesis that creep was responsible for these problems.

Thermal properties estimated from geophysical data were used to predict temperatures in the boreholes of Atwater Valley and Keathley Canyon. Analysis of LWD temperatures at both sites revealed much cooler borehole temperatures than was predicted by pre-drill models. The reason for this is not fully understood in Keathley Canyon, but has been clearly diagnosed in Atwater Valley. At the latter location, the presence of excessively high loop currents that were an order of magnitude higher than the current velocities used in pre-drill models greatly enhanced the transfer of heat from the drill pipe to the ocean. The current velocities used in pre-drill models were obtained from a sparsely populated NOAA database. These velocities may have provided a reasonable indication of average conditions. However strong loop currents were not anticipated. Once loop currents are accounted for, model predictions were shown to agree quite well with LWD temperatures.

Post-drill simulations indicated that the LWD boreholes in Atwater Valley and Keathley Canyon were sufficiently cool to prevent hydrate from dissociating. This was due in part to management of circulation rates in the borehole. However it was also shown that in the absence of loop currents at Atwater Valley, the risk of dissociation would have been significant.

RECOMMENDATIONS

Recommendations for Improving the Wellbore Stability Model

- Develop a model for formations with unequal horizontal stresses. Such formations apparently exist in Atwater Valley

- Incorporate friction hardening into the rheological model. Friction hardening was seen in the Georgia Institute of Technology data

- Do more comprehensive studies to validate the proportional loading assumption underlying the semi-analytical Mohr Coulomb formulation

Recommendations for Mechanical Testing of Hydrate Bearing Sediments

Additional testing of hydrate bearing sediments is highly recommended. In such tests:

- Care should be taken to prevent samples from barrelling. If barrelling cannot be prevented, lateral displacements should be measured at several positions along the length of the sample. Alternatively or in addition, volume strains should be measured by monitoring the transfer of fluid required to maintain a constant confining pressure.
- Shear and compressional wave velocities should be measured during triaxial testing.
- Where possible drained tests should be conducted. If this is not feasible, pore pressure should be measured (except in extreme cases where no percolation can occur).
- If fully saturated conditions are required such conditions should be rigorously verified via the following steps:
    - Evacuate and de-air sample behind the sleeves, porous discs, pipe work etc.
    - Saturation and tests should be done with some fluid back-pressure (not at atmosphere).
    - Use several cycles of vacuum/saturating/pressuring/flushing etc. as necessary.
    - Measure Skempton's pore pressure parameter B to establish saturation. If necessary, do several cycles of saturation and un-drained hydrostatic loading, checking for B each time until some constant value is reached. This is best done starting with some back pressure, rather than trying to estimate B from the pore pressure increase from atmospheric pressure. Also, check B for a few different pore pressure increments.
    - If side-filters are not used, the pore pressure decay after un-drained loading could be monitored at one end of the sample whilst drainage occurs from the other end.

- Minimize volumes in the pore fluid pipe work by having transducers at the platens, micro-bore pipe work, no potential high points (i.e., air traps) in the system (unless there's a de-airing valve there) and keep valves as close to the cell as possible.

Recommendations for Future Drilling

The following steps are recommended reduce washouts due to hydraulic erosion:

- Increase the TFA of bit nozzles, e.g.: try using bits with four nozzles instead of three. These bits generally have a center nozzle in addition to three peripheral nozzles.
- Do not use extended nozzles.
- Ensure that bit nozzles are aligned to prevent impact between jets and the sidewalls of the borehole.
- Reduce the amount of time spent by the bit in one spot. Move the bit as much as possible during connections and reduce the number of connections by using stands longer than 30 ft.
- Use gels to promote laminar flow. Turbulent flow exacerbates erosion problems.
- Reduce the flow rate – with properly designed mud system and controlled ROP, it may have been possible to use a lower circulation rate in these holes. Use a hydraulics program to ensure proper cuttings removal.
- Ensure that the flow horsepower per square inch is below 1.5.

To prevent sealing of the borehole

- Reduce the severity of washouts
- Use a hydraulics program to ensure proper cuttings removal

- Monitor the ECD, borehole temperature, and hookload carefully. Use more aggressive hole cleaning measures or reduce ROP in order to forestall impending problems.

- Scrutinize seismic data for evidence of shallow water flows. Use high-resolution data if available.

- Use jetting and driving to avoid premature hole closure due to creep

Recommendations for Borehole Temperature Management

- Continue to manage temperatures in the borehole when drilling in hydrate zones. Success in maintaining low borehole temperatures in the last drilling campaign does not guarantee success in future campaigns.

- Monitor the temperature of the drilling fluid as close to the inlet of the drill pipe as possible.

- Measure ocean temperatures and current velocities prior to and during drilling. Adjust drilling strategy accordingly. For example, high current velocities would permit higher circulation rates to be employed.

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