Oil & Natural Gas Technology

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(October 2007 – March 2008)

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

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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 2007 – March 2008, the JIP concentrated on:

- Conducting experiments on the cores collected;
- Redesigning a new pressure corer;
- Reviewing paper for the special volume on leg 1;
- 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. **Phase III** of the project began in September of 2007 and will focus on obtaining logs and cores of hydrate bearing sands in the GOM.

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 2008 the members of the JIP were Chevron, Schlumberger, ConocoPhillips, Halliburton, the Minerals Management Service (MMS), Total, JOGMEC, Reliance Industries Limited and The Korean National Oil Company (KNOC). StatoilHydro is completing the necessary contract forms to become a member of the JIP.

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 2007.

1.6 Purpose of This Report

The purpose of this report is to document the activities of the JIP during October 2007 – March 2008. 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 October 2007 – March 2008 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 Seismic analysis of GC955 and WR313 is complete and data transferred to site selection group and hazard analysis team.

2.2 Site Selection

The site selection group selected several drilling locations for GC955 and WR313 for LWD drilling.

2.3 Pressure Corer

Analysis of the pressure corer indicates no technical problems with increasing the operating pressure. Final design is being completed and is expected by June 2008.

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. Fifteen papers and one overview paper were sent in for publication

3.0 Results and Discussion Phase II

3.1 Task 1.0 – Research Management Plan

Work on this task is complete and has been reported on in previous semi-annual reports.

3.2 Task 2.0 – Project Management and Oversight

Work on this task is complete and has been reported on in previous semi-annual reports.

3.3 Task 3.0 – Validation of New Gas Hydrate Sensors

Work on this task is complete and has been reported on in previous semi-annual reports.

3.4 Task 4.0 – Validation of the Well Bore Stability Model

Work on this task is complete and has been reported on in previous semi-annual reports.

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

Work on this task is complete and has been reported on in previous semi-annual 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.

During this period a report on the analysis of the sediments was received and is provided in Appendix C "Examining the relationship between gas hydrate and grain size distribution in the Northern Gulf of Mexico".

The conclusion of the report is that there is no significant relationship between the occurrence of coarse-grained sediment horizons and the distribution of gas hydrates in the sampled cores from Keathley Canyon and Atwater Valley. Results of grain size analysis from these cores, both containing and lacking thermal anomalies, are very similar. The above results suggest that the occurrence of gas hydrate is constrained by secondary, fault-controlled permeability. Gas-charged fluids flow through the fractures upward into the GHSZ, forming vein-filling gas hydrate within the pore space. Preliminary conclusions drawn from these results support the hypothesis that gas hydrate occurrence is related to secondary permeability as a result of faulting and hydrofracture, and not as a result of primary, lithology-controlled permeability.

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.

Marine and Petroleum Geology will publish the Scientific Results for the 2005 DOE-Chevron Joint Industry Project Gulf of Mexico methane hydrates drilling. Fifteen papers and one overview paper were received and submitted for publication.

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).

The design of the high pressure coring equipment is progressing and should be complete by June of 2008. A meeting to discuss pressure coring equipment and its associated transfer and analysis equipment is scheduled for 15 April 2008.

The measurement vessel for applying in-situ stress was constructed and tested.

3.9 Task 9.0 – Recommendation for Further Activities

Work on this task is complete and has been reported on in previous semi-annual reports.

4.0 Discussion and Results PHASE III A – Follow on Field Activities Drilling and Logging

Phase III activities are to include work focused on characterization and evaluation of hydrate occurrence within coarse-grained horizons within the Gulf of Mexico. The activities include preparation for these field activities through analyses and technology development, carrying out of the field activities and post field activity analysis and reporting. The field sites selected for Phase III activity are to include specifically locations at Alaminos Canyon 818 as recommended under Phase II Task 9. Field sites (in addition to AC 818) to be included in the investigation will be selected upon mutual agreement of the Recipient and DOE with the intent of testing alternative models of gas hydrate occurrence. Planned activities associated with Phase III are outlined in the task/subtask descriptions to follow.

4.1 Task 1.0 – Research Management Plan

The research management plan was prepared and submitted to the DOE.

4.2 Task 2.0 – Project Management and Oversight

Project Quarters 1 & 2: The project manager appointed by the JIP members held weekly conference calls with the DOE project managers and provided other reports and presentations as required. See Appendix A for a summary of milestones and progress to date.

The JIP Executive Board (EB) approved two new members—the Korean National Oil Company and StatoilHydro—to become members of the JIP.

Members of the EB also attended the site selection drill operations meeting.

The JIP web site is being maintained and a new web site at Scripps is being evaluated.

The chief scientist for the LWD leg was selected and candidates for the coring leg evaluated.

Total DOE project funds are approximately 56% spent and total project funds are 99% spent or obligated for the remaining Phase III A estimated costs.

4.3 Task 3.0 – Field Program – Drilling/Logging

Project Quarters 1 & 2: Several meetings were held in Houston between the LWD contractor (Schlumberger), Chevron drilling engineers, and the USGS Chief Scientist for the LWD leg. A design of the LWD tool string has been developed but may change before the cruise.

Safety training for the personnel on the LWD leg has been determined and will be arranged.

Locations for hazard analysis have been selected and hazard analysis will begin in April. See Appendix B for location maps of the holes.

A drill ship has been selected and drilling and logging is being planned for late June into July but could change because of drill ship schedule. In the worse case the ship schedule could slip into late 2008.

4.4 Task 4.0 – Data Analysis

Project Quarters 1 & 2: <u>No work accomplished this period</u>.

4.5 Task 5.0 – Improved Hydrate Recovery, Detection and Measurement Equipment

Project Quarters 1 & 2: <u>No work accomplished this period</u>.

4.6 Task 6.0 – Detailed Seismic Study of Selected Drilling Locations

Project Quarters 1 & 2: 3-D analysis of GC955 and WR313 is complete and a report from the site selection group is expected in May.

4.7 Task 7.0 – Well Bore Stability

Project Quarters 1 & 2: Analysis of the three sites (AC, GC, and WR) areas has been started and waiting on final well locations to be completed.

4.8 Task 8.0 – Data on Lab Samples

Project Quarters 1 & 2: <u>No work accomplished this period</u>.

5 PHASE III B – FOLLOW ON FIELD ACTIVITIES (CORING) AND FINAL REPORTING

Phase III B activities are to include work focused on characterization and evaluation of hydrate occurrence within coarse grained horizons within the Gulf of Mexico. The activities include preparation for these field activities through analyses and technology development, carrying out of the field activities and post field activity analysis and reporting. The field sites selected for Phase III activity are to include specifically locations at Alaminos Canyon 818 as recommended under Phase II Task 9. Field sites (in addition to AC 818) to be included in the investigation will be selected upon mutual agreement of the Recipient and DOE with the intent of testing alternative models of gas hydrate occurrence. Planned activities associated with Phase III B are outlined in the task/subtask descriptions to follow.

5.1 Task 1.0 – Revised Research Management Plan

Project Quarters 1 & 2: <u>No work accomplished this period</u>.

5.2 Task 2.0 – Project Management and Oversight

Project Quarters 1 & 2: No work accomplished this period.

5.3 Task 3.0 – Field Program – Coring

Project Quarters 1 & 2: No work accomplished this period.

5.4 Task 4.0 – Data Analysis

Project Quarters 1 & 2: No work accomplished this period.

5.5 Task 5.0 – Improved Hydrate Recovery, Detection and Measurement Equipment

Project Quarters 1 & 2: No work accomplished this period.

5.6 Task 6.0 – Detailed Seismic Study of Selected Drilling Locations

Project Quarters 1 & 2: No work accomplished this period.

5.7 Task 7.0 – Well Bore Stability

Project Quarters 1 & 2: No work accomplished this period.

5.8 Task 8.0 – Data on Lab Samples

Project Quarters 1 & 2: No work accomplished this period.

5.9 Task 9.0 – Technical Conference and Compilation of Scientific Papers

Project Quarters 1 & 2: No work accomplished this period.

6.0 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 semi-annual reports.

7.0 Conclusions

Several drilling targets were identified for AC818, GC955, and WR313.

Drill ship for the LWD leg has been selected and contracts are being prepared.

Redesign of the pressure corer should be complete by June 2008.

8.0 References

No external references were used for this report.

9.0 Appendix A, B & C

APPENDIX A

Milestone Table A1

#	Milestone	Plan date	Progress	Comments
1	Select LWD Locations	Q2 08	Complete	Site selection report for GC955 and WR313 is expected in May and will be included in the next semi-annual report. AC818 report was included in Semi-Annual Report 41330R13
2	Complete Design of Pressure Coring Equipment	Q2 08	Design work nearly complete; final report expected in May	
3	LWD Selected Locations	Q3 08	Drilling scheduled for June	
4	Report on LWD Phase III A Task 3 Deliverable	Q4 08		
5	Complete Research Management Plan	Q1 09		
6	DOE Approval to Proceed to Phase III B	Q2 09		
7	Complete Construction of New Pressure Coring Equipment	Q3 09		
8	Field Test Pressure Coring Equipment	Q4 09		
9	Select Sites for Coring Leg	Q4 09		
10	Conduct a Hazard Analysis of Sites and Apply for Permits	Q2 10		
11	Core Selected Locations	Q3 10		
12	Report on Lab and Coring Data	Q4 10		
13	Final Report	Q4 10		

Appendix B

Proposed LWD Hole Locations

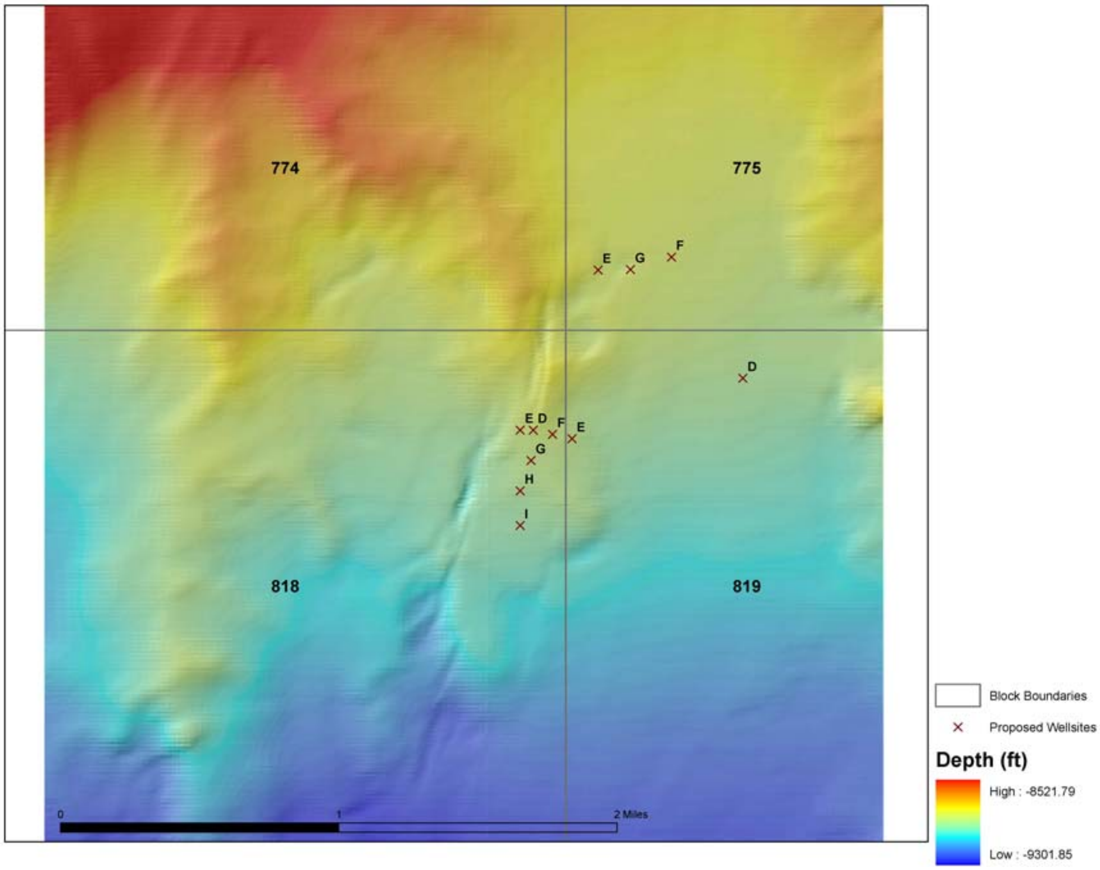

Figure B.1. Seafloor Map Showing Locations of Proposed Holes in Alaminos Canyon

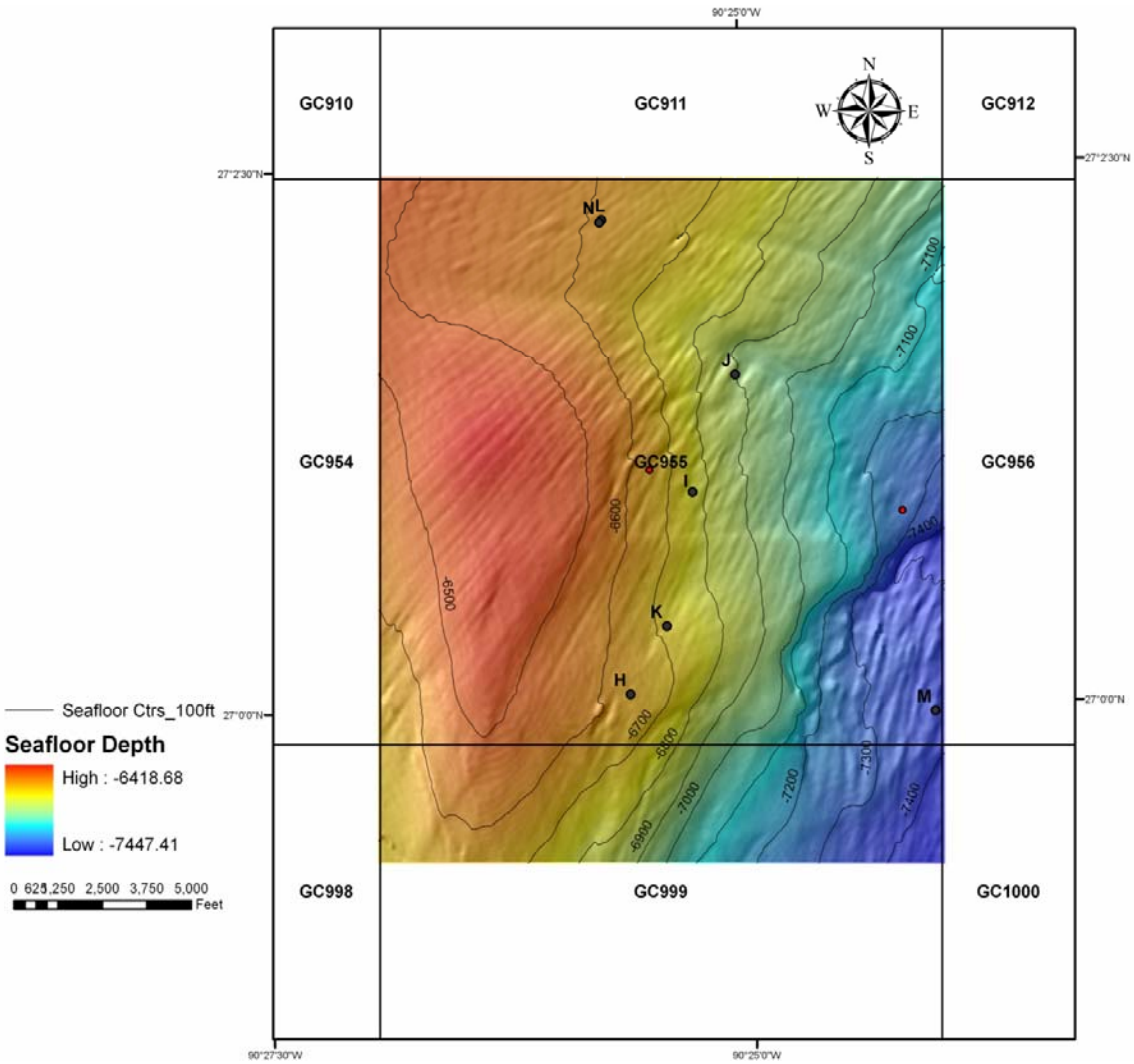

Figure B2. GC955 Proposed Hole Locations

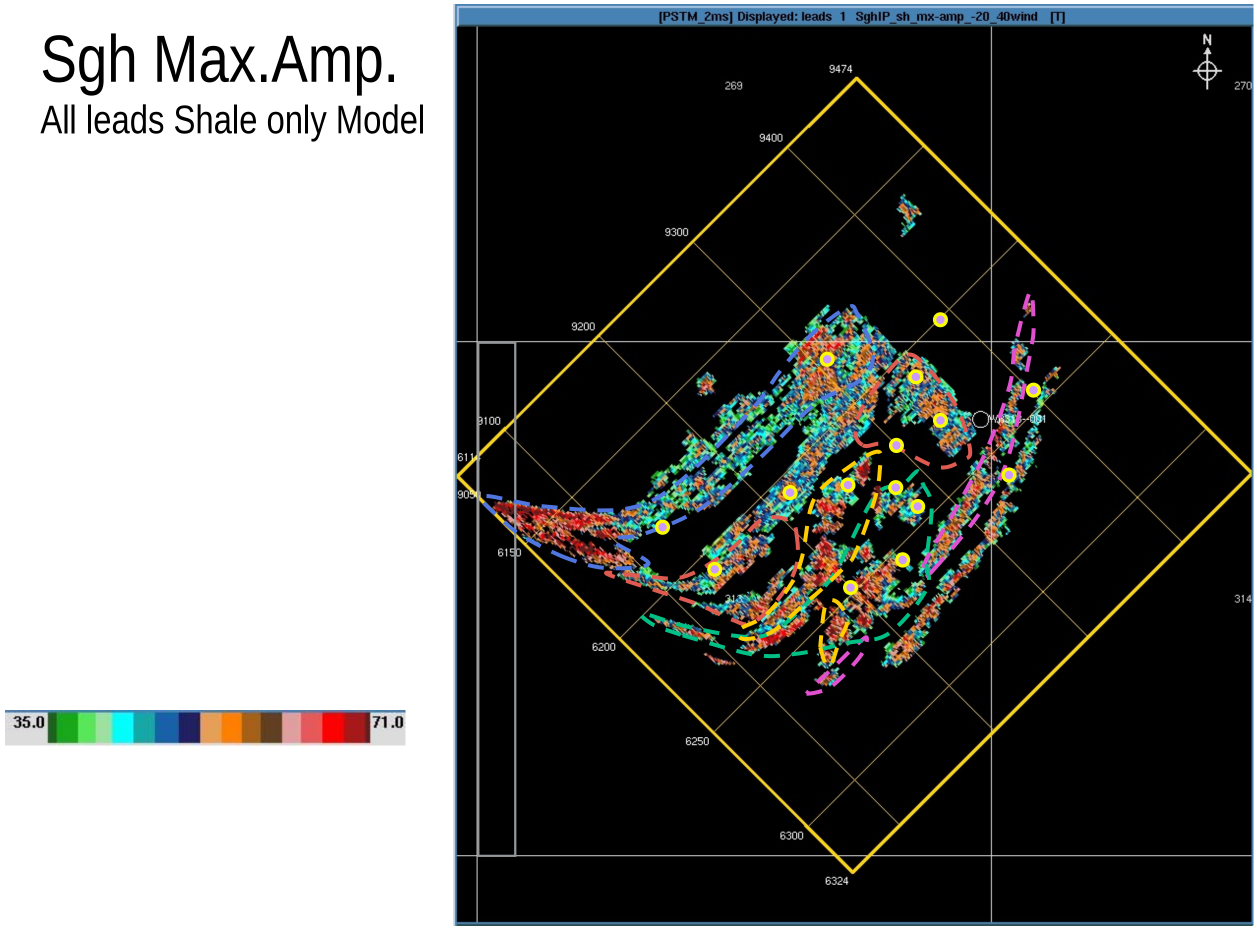

Figure B3. Walker Ridge Proposed Hole Locations

APPENDIX C

Examining the Relationship between Gas Hydrate and Grain Size Distribution in the Northern Gulf of Mexico

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November 2007

Introduction and Rationale

Gas hydrate formation and stability is controlled by temperature and pressure, as well as the availability of hydrate forming gas molecules (Sloan, 1998). Gas migration within the sediment column can occur as a result of primary permeability, where gas-charged fluids move along permeable lithologic conduits (Weinberger, et al., 2005), or as a result of secondary permeability, where fluids move along fractures and faults. Hydrate formation in the Gulf of Mexico (GOM) has an additional complication related to the occurrence of salt (Worrall and Snelson, 1989). Large volumes of autochthonous and allochthonous middle Jurassic Louann salt dissolves as fluid migrates upward through the sediment column, originating from multiple subsurface depths, forming salty brines (Sassen, et al., 2004). Gas hydrate occurrence diminishes in regions with high-salinity brines (Sassen, et al., 2004), which suppress hydrate formation and can destabilize previously crystallized formations (Milkov, et al., 2004). Oxidation of microbially-generated hydrocarbons, accompanied by sulfate reduction also occurs in brine, thus enhancing the formation of ^{13}C-depleted carbonate (Sassen, et al., 2004). In addition, salt buoyancy creates diapirs and related withdraw basins; this morphology may play an important role in the hydraulic conductivity in the GOM.

The dynamic nature of fluid expulsion in the northern GOM reflects the interplay between varying sediment supply, sea-level fluctuations and salt deformation. Salt movement caused by rapid shelf-edge progradation acts to uplift, slump, fold and fracture overlying sediments (Roberts and Carney, 1997), generating fault controlled permeability structures through which fluids flow. Fault lengths range from meter long faults resulting from shallow salt movement, to deeply buried growth faults, extending thousands of meters into the sediment column (Roberts and Carney, 1997). At first, these salt-related faults may act as conduits for the migration of deeply buried fluids, including salt brine, and both thermogenic (hydrocarbon gases produced by the thermal degradation of oil or organic matter) and biogenic (produced as a result of biological methanogenesis) gas-containing fluids (Sassen, et al., 1999). Through time, precipitation of gas hydrate and authigenic carbonate may inhibit these permeability pathways. As such, the salt deformation and secondary permeability might help explain the occurrence of gas hydrates in areas of the sediment column where temperature and pressure conditions are conducive for stable hydrate occurrence.

To investigate the link between primary and secondary permeability and gas hydrate distribution, we examined the grain size distribution of hydrate-bearing sediments in Atwater Valley and Keathley Canyon in the GOM (Figure 1). The overarching goal of this study is to determine the relationship between grain size, permeability, and gas hydrate distribution. On Hydrate Ridge, gas hydrate distribution is controlled by primary permeability, where hydrate preferentially forms in coarse-grained sediments (Weinberger, et al., 2005). Given the fine-grained sediments found in the GOM, our initial hypothesis is that the gas hydrate distribution is related to structurally controlled permeability as a result of hydrofracture and faulting, and thus primary permeability is not the controlling factor in hydrate distribution in the areas we investigated in the GOM.

Methods

Gas hydrate dissociation is an endothermic reaction, which cools the surrounding section of the sediment column. Therefore, temperature is used as a proxy for hydrate occurrence in cores that have been recovered. Core sections exhibiting a negative thermal anomaly are characterized as hydrate-bearing sediments (Weinberger, et al., 2005). Ford, et al., 2003, were the first to use infrared (IR) imaging to identify cold thermal anomalies in cores recovered during the Ocean Drilling Program (ODP) Leg 201. The work conducted on ODP Leg 204 expanded on this concept, identifying large amounts of methane hydrate through the location of thermal anomalies using an IR camera (Shipboard Scientific Party, 2003).

The cores recovered from the Gulf of Mexico Hydrate Joint Industry Project (GOM/JIP) cruise in May 2005 onboard the drilling vessel *Uncle John* are stored at the Geological Collections at Scripps Institution of Oceanography (SIO). 5,540ft of sediment was recovered from seven wells at Atwater Valley and Keathley Canyon (Detailed list of cores included in Table 1). We sampled sediment from core sections that exhibited negative thermal anomalies to determine if there is a correlation between gas hydrate concentration and grain size.

To minimize alteration of the gas hydrates once recovered, the cores were packed in ice until they could be transferred to the refrigerated core-processing container. The cores were imaged with both a track-mounted and a hand-held IR camera (Conte and Bloys, 2006). The IR images were then processed, resulting in the generation of downcore temperature profiles using the ThermaCam Researcher software (FLIR Systems). Interstitial water samples were taken at regular intervals in each core recovered, as well as from sections of core adjacent to prominent IR-detected thermal anomalies (Table 2). The sections of core removed for the purpose of chemical analysis were extruded from the core liner, scraped clean of any sediment that was possibly contaminated by seawater (drilling fluid), and then placed in a pressurized titanium squeezer in order to recover the interstitial water from the sediment. The squeezed sediment section is termed “squeezecake”. Squeezecakes taken from sections of the core that were adjacent to IR-detected thermal anomalies were targeted for grain size analysis. Background samples were taken from areas with no IR-detected thermal anomaly. Classification of the grain-size distribution employed the use of wet sieving to separate the coarse (sand particles >63μm) and fine (<63μm) fractions, along with use of a Coulter Counter to determine the size distribution of silt (4-63μm) and clay (1-4μm) sediment particles within the fine-grained fraction. The grain size analysis methods used were modified from Poppe, et al., 2000.

Nine core sections, with the most complete recovery and minimal deformation, were targeted for grain size analysis from three different sites: Keathley Canyon (151-3), Atwater Valley (13-2) and Atwater Valley Mound Site 2. Of these nine, five core sections displayed strong negative thermal anomalies, while the remaining four core sections were selected as background samples because they exhibited no thermal anomalies.

Here, we present two representative cores, one containing a thermal anomaly and one without (Figures 2 and 3). To characterize the entirety of the negative temperature anomaly, samples were acquired immediately above and below each negative temperature excursion. Data gaps shown in the figures are locations where shipboard samples were removed for other analyses, and thus these intervals were unavailable for grain-size analysis.

Results

Two representative cores are shown in this report, capturing the end members of background and hydrate-bearing samples. A pronounced temperature anomaly observed in KC (Keathley Canyon) 151-3 core 15C (Figure 2) at approximately 253.45 mbsf exhibits a 2°C anomaly. Examination of the grain-size distribution shows little to no variability in this core. Notice that the data gaps in the grain-size analyses occurs where samples were removed for use in other research objectives. Within the squeezecake, an average grain-size is reported because it is difficult to determine exact depth within the core. Within the hydrate-bearing core, coarse-grained (>63μm) percentages vary only slightly between 0.37% and 1.70%. The highest coarse-grained percentage corresponds to the sampled squeezecake sediment, which does not contain a prominent temperature anomaly. If primary permeability is responsible for hydrate occurrence, it would be likely that core sections characterized by negative thermal anomalies, and thus gas hydrate occurrence, would have high percentages of coarse-grained sediment particles. Outside of the squeezecake sediment, the fine-grained (<63μm) percentages within KC 151-3 core 15C vary insignificantly, with no relation to the location of the thermal anomaly observed within this core. Fine-grained sediment makes up the highest percentage within KC 151-3 core 15C, fluctuating between 98.3% and 99.6%. The lowest fine-grained percentage was recorded within the squeezecake at a depth of approximately 253.45 mbsf, a region of the core lacking a negative thermal anomaly. Within the fine-grained fraction, the majority of sediment particles, between 66.4% and 85.2%, fell within the clay size-fraction (4-1 μm). Between 2.7% and 19.5% of fine particles fell within the silt size-fraction (63-4 μm), while 2.8% to 16.1% of fine-grained particles were less than 1 μm. Within the fine fraction, the size distribution of sediment particles exhibited little to no correlation with the thermal anomalies.

AT (Atwater Valley) 13-2 core 13H (Figure 3) does not contain a marked temperature deviation, with only a slight downcore change in temperature from 18.9°C to 21.2°C. Grain-size distribution in this core only exhibits minor variability within the coarse-grained (>63μm) percentage, changing between 2.16% and 3.95%. Fine-grain (<63μm) percentages range between 96.0% and 99.3%, with silt particles ranging between 2.6% and 45.8%, clay particles fluctuating between 47.8% and 86.4%, and a range in particles less than 1μm between 0 and 9.99%. The slight cooling seen downcore through the sampled interval corresponds to a statistically insignificant decrease in coarse-grained and increase in fine-grained percentages. The silt and clay percentages vary inversely to one another and do not vary with the slight decline in temperature. No major trends are observed in the grain size distribution within AT 13-2 core 13H.

Preliminary Conclusions

There is no significant relationship between the occurrence of coarse-grained sediment horizons and the distribution of gas hydrates in the sampled cores from Keathley Canyon and Atwater Valley. Results of grain size analysis from these cores, both containing and lacking thermal anomalies, are very similar. The above results suggest that the occurrence of gas hydrate is constrained by secondary, fault-controlled permeability. Gas-charged fluids flow through the fractures upward into the GHSZ, forming vein-filling gas hydrate within the pore space. Preliminary conclusions drawn from these results support our hypothesis that gas hydrate occurrence is related to secondary permeability as a result of faulting and hydrofracture, and not as a result of primary, lithology-controlled permeability.

Figures and Tables

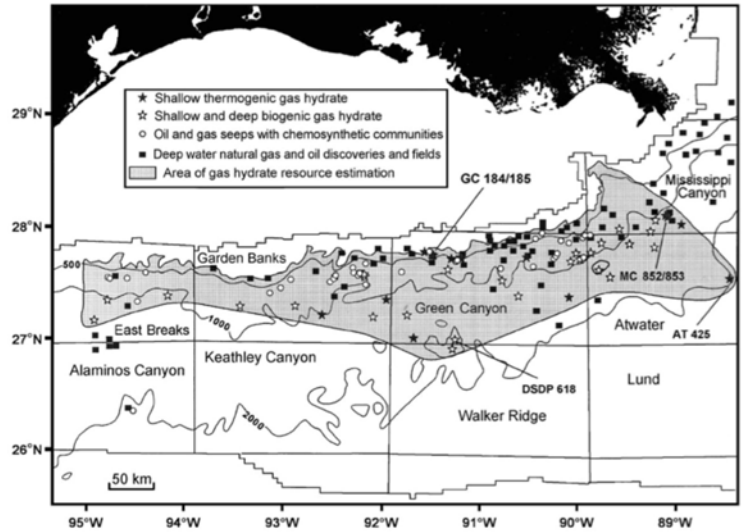

Figure C1. Location of petroleum fields, hydrocarbon seeps, gas hydrate occurrence, and the area of gas hydrate boundaries in the northwestern GOM continental slope (Sassen, et al., 1999).

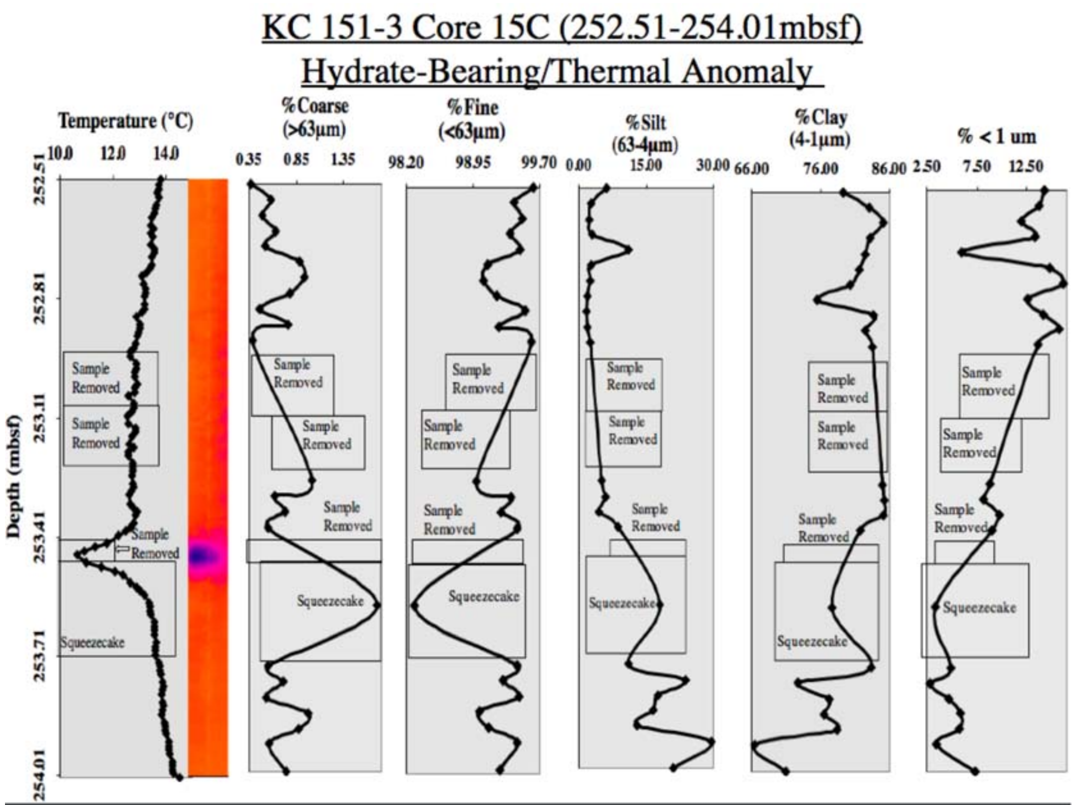

Figure C2. Data from Keathley Canyon site 151-3 core 15C. This core section contained a negative thermal anomaly, which indicates the presence of disseminated gas hydrate.

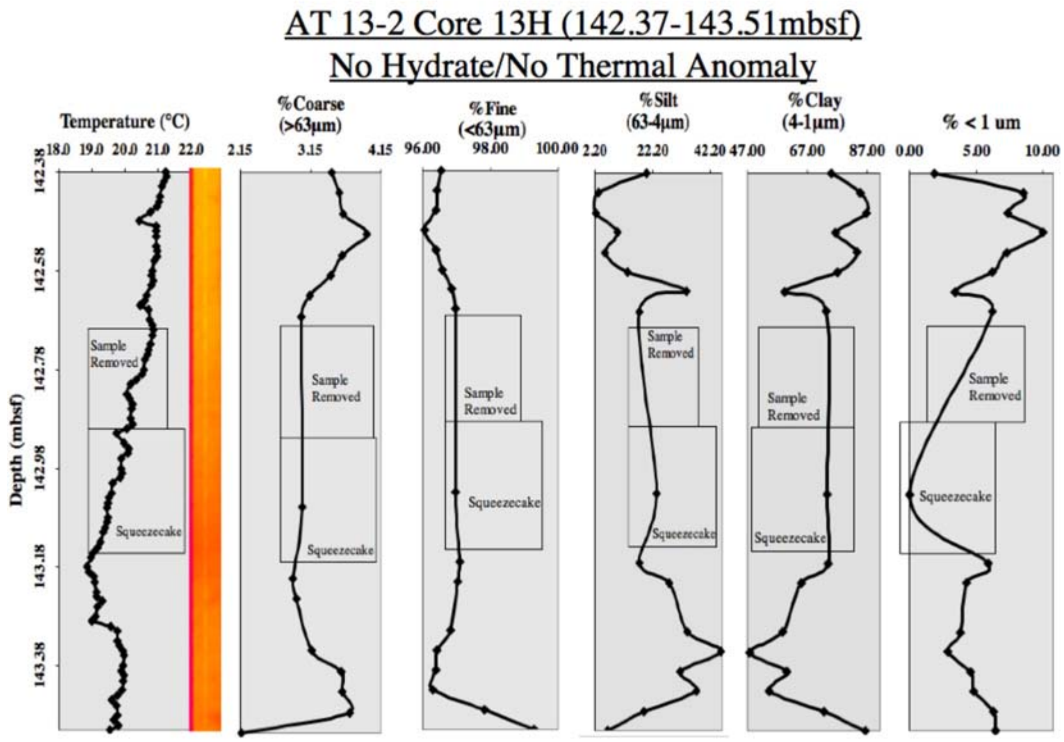

Figure C3. Data from Atwater Valley site 13-2 core 13H. This core section did not contain a negative thermal anomaly, which negates the presence of disseminated gas hydrate.

Table C1. Total depth drilled for each site. Bold print indicates sites from which samples used in this study were taken.

Location and Site	Depth (Feet BML*)
AT 13 #1	809
AT 14 #1	941
AT 13 #2	**656**
ATM 1	80
ATM 2	**103**
KC 151 #2	1506
KC 151 #3	**1445**

Below Mud Line

Table C2.
Pore Fluids Subsampling Plan at Each Site

1st Core	Excise a 10-15 cm whole round from the bottom of every section.
2nd Core	Excise a 10-15 cm whole round from the bottom of every 2nd section.
3rd Core	Excise a 15-20 cm whole round from the bottom of every 1st and 4th (or 2nd and 5th) section for 5 meter-long cores. Excise a 15-20 cm whole round from the bottom of every 1st, 4th and 7th sections for 8 meter-long cores.
4th and following cores	Excise a 15-30 cm whole round from the bottom of every 3rd section for 5 meter-long cores; except when in estimated BSR depth range, in which case, at the bottom of the 2nd and 4th sections. Excise a 15-30 cm whole round from the bottom of every 2nd and 6th sections for 8 meter-long cores

Additional Subsamples taken from Each Site:

Adjacent to prominent IR-detected gas hydrates	Excise 10-20 cm whole rounds adjacent to IR detected gas hydrate, with a maximum of one per core.
Gas Hydrates (To be sub-sampled for gas analysis)	Remove a 3-5 cc (larger if possible) sample for water analysis Wrap gas hydrate sample in aluminum foil and cotton bag that has been labeled. Store in liquid N_2 dewar.

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