GEOMECHANICAL PERFORMANCE OF HYDRATE-BEARING SEDIMENTS IN OFFSHORE ENVIRONMENTS

Semi-Annual Report

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1. Executive Summary

The main objective of this study is to develop the necessary knowledge base and quantitative predictive capability for the description of geomechanical performance of hydrate-bearing sediments (hereafter referred to as HBS) in oceanic environments. The focus is on the determination of the envelope of hydrate stability under conditions typical of those related to the construction and operation of offshore platforms. To achieve this objective, we are building a robust numerical simulator of hydrate behavior in geologic media by coupling a reservoir model with a commercial geomechanical code. To be sure our geomechanical modeling is realistic, we are also investigating the geomechanical behavior of oceanic HBS using pore-scale models (conceptual and mathematical) of fluid flow, stress analysis, and damage propagation.

To generate data for our models, we are using data from the literature and we will be conducting laboratory studies that generate data to (i) evaluate the conceptual pore-scale models, (ii) calibrate the mathematical models, (iii) determine dominant relations and critical parameters defining the geomechanical behavior of HBS, and (iv) establish relationships between the geomechanical status of HBS and the corresponding geophysical signature.

There are four organizations initially involved with this project. These four are Texas A&M University (TAMU), University of California at Berkeley (UCB), Lawrence Berkeley National Laboratory (LBNL), and Schlumberger (SLB). The milestones for Phase I of this project are given as follows:

- Literature survey on typical sediments containing gas hydrates in the ocean (TAMU)
- Recommendations on how to create typical sediments in the laboratory (TAMU)
- Demonstrate that typical sediments can be created in a repeatable manner in the laboratory and gas hydrates can be created in the pore space (TAMU)
- Develop a conceptual pore-scale model based on available data and reports (UCB)
- Test the developed pore-scale concepts on simple configurations and verify the results against known measurements and observations (UCB)
- Complete the FLAC3D routines that will be linked with the reservoir model (LBNL)
- Complete the TOUGH-Fx/HYDRATE modifications and extensions (LBNL)
- Complete the TOUGH-Fx/FLAC3D interaction interface (LBNL)
- Integrate and test the coupled geomechanical numerical model TFxH/FLAC3D (LBNL)
- Demonstrate that Petrel can be used to develop an earth model for providing data to the TOUGH-Fx/FLAC3D (SLB)

The project was awarded effective October 1, 2005. However, it took several months to get the subcontracts in place with UCB and LBNL. UCB began work in January 2006 and LBNL began work in March 2006.

Even with a delayed start, the project team from the four organizations has made progress towards reaching the objectives and milestones set out in the management plan. UCB provided information on work they had been doing which helps explain the concept of pore modeling. That work can be accesses at http://petroleum.berkeley.edu/papers/patzek/twppapers.htm Since January, UCB has been working on code to model water and ice in the pore space and spherical grains in contact with spherical ice crystals. At the start, UCB was using a Hertzian model, which assumes that the solid response is purely elastic and linear, and there is no cementation and adhesion. UCB has been looking into the micromechanics of grain to grain or grain to hydrate interaction. The Hertzian model is being extended to contact mechanics of several grains. The natural coupling between inter-grain interactions makes the problem very complex. The objective is to obtain a simple, but still representative model. More specifically, we are trying to identify the key parameters that can describe the mechanics of a conglomerate of several grains and to develop a meaningful linearization procedure.

TAMU has reviewed the Ocean Drilling Program, the Chevron – DOE Deep Water Gulf of Mexico JIP, and other projects such as in the Japanese Nankai Trough to gather information necessary to describe the hydrate-bearing zones encountered by these groups in their drilling and coring operations. We are evaluating the chemical and mineral characteristics of the sediment samples recovered from the ocean floor. We have detailed the information concerning the sedimentology and mineralogy of the sediments cored during the ODP Leg 204 (Hydrate Ridge, Offshore Oregon) and Leg 164 (Blake Ridge, Offshore Carolina).

LBNL has begun the work necessary to couple the TOUGH-Fx/HYDRATE model for predicting the evolution of pressure, temperature, saturation distribution, and salt concentration in hydrate-bearing systems undergoing changes through any combination of mechanisms that can induce hydrate dissociation or formation (change in pressure, temperature and in the concentration of inhibitors) with the existing geomechanical model FLAC3D (Itasca Consulting Group, 1997) for soil and rock mechanics engineering.

LBNL modified the standard TOUGH-Fx/HYDRATE code to begin the coupling with the FLAC3D geomechanical model. Using the modified code as a basis, LBNL has added the capabilities of reading the external stress and strain files (as produced from FLAC3D), which are to be used for the computation of the updated (and evolving) porosity and permeability using an appropriate geomechanical model. Additionally, using the FISH language available to FLAC3D, new subroutines were developed to (a) read the spatial pressure, temperature and saturation distributions in the simulated domain and (b) open new files, into which the stress and strain distributions are stored.

Schlumberger has been working internally and with the developers of FLAC3D to demonstrate that Petrel can be used to develop an earth model for providing data to the TOUGH-Fx/FLAC3D. Schlumberger's Petrel model is an integrated Windows-PC software solution that enables one to solve subsurface challenges -- from seismic interpretation through reservoir simulation. Petrel helps to minimize the communication problems that exist between different software packages and associated technical disciplines. All work processes in Petrel contribute to developing and refining the same volumetric earth model, static to dynamic. We are working with the developers so we can use Petrel as the primary source for gathering, processing and entering data into TOUGHFx/FLAC3D when it is completed. Schlumberger will be providing licenses to Petrel as part of their co-funding of this project.

2. Introduction

Gas hydrate is a solid material resulting from the orderly assembly of gas molecules such as methane, carbon dioxide, and hydrogen sulfide, within a clathrate (cage like) structure of water molecules under moderate (relative to conventional oil and gas reservoir conditions) pressure and temperature. Vast amounts of hydrocarbons are trapped in hydrate deposits (Sloan, 1998). Such deposits occur in two distinctly different geologic settings where the necessary low temperatures and high pressures exist for their formation and stability: in the permafrost and in deep ocean sediments near the sea floor.

The three main methods of hydrate dissociation are (1) depressurization, in which the pressure is lowered to a level lower than the hydration pressure P_H at the prevailing temperature, (2) thermal stimulation, in which the temperature is raised above the hydration temperature T_H at the prevailing pressure, and (3) the use of inhibitors (such as salts and alcohols), which causes a shift in the P_H-T_H equilibrium through competition with the hydrate for guest and host molecules (Sloan, 1998). Dissociation results in the production of gas and water, with a commensurate reduction in the saturation of the solid hydrate phase.

Gas hydrates exist in many configurations below the sea floor including massive (thick solid zones), continuous layers, nodular, and disseminated occurrences each of which may affect the seafloor stability differently. The hydrates in all of these configurations may be part of the solid skeleton that supports overlying sediments, which ultimately support platforms and pipelines needed for production from conventional oil and gas resources, and from the eventual production from hydrate accumulations.

During dissociation, the basal zone of the gas hydrate becomes under-consolidated and possibly over-pressured because of the newly released gas (Schmuck and Paull, 1993), leading to a zone of weakness (i.e., low shear strength, where failure could be triggered by gravitational loading or seismic disturbances) that can ultimately result in submarine landslides (McIver, 1977; Paull et al., 1996). Possible mechanisms that can induce dissociation in Hydrate-Bearing Sediments (hereafter referred to as HBS) include an increase in salinity, a drop in the sea level and an increase in the sediment temperature (e.g., by warmer ocean bottom water, or by non-insulated pipes conducting fluids produced from deeper and warmer reservoir) can induce such dissociation.

Hydrate dissociation in HBS produces an enhanced fluidized layer at the base of the gas-hydrate zone. Submarine slope failure can follow, giving rise to debris flows, slumps, slides, and collapse depressions such as described by Dillon et al. (1998). Failure would be accompanied by the release of methane gas, but a portion of the methane is likely to be oxidized unless the gas release is catastrophic. A scenario illustrating submarine slope failure is shown in **Figure 1**. The possible connection between gas-hydrate boundaries and submarine slide and slump surfaces was first recognized by McIver (1982). Several hydrate-related occurrences of oceanic land-slides are discussed in the literature. These include sediment slides and slumps on the continental slope and rise of West Africa (Summerhayes et al., 1979), slumps on the U.S. Atlantic continental slope (Carpenter, 1981), large submarine slides on the Norwegian continental margin (Evans et al., 1996; Bugge et al., 1988), sediment blocks on the sea floor in fjords of British Columbia, and massive bedding-plane slides and rotational slumps on the Alaskan Beaufort Sea continental margin (Kayen and Lee, 1993).

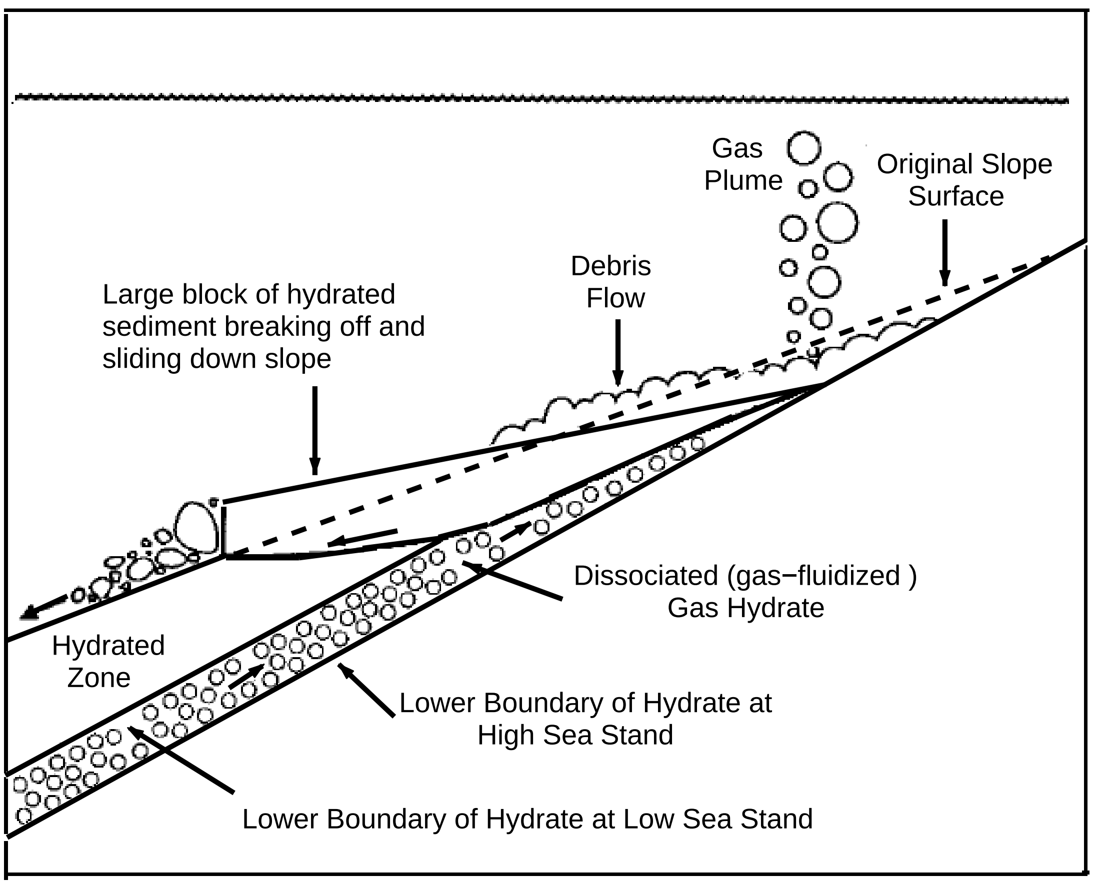

Figure 1 – Diagram showing the effects of gas hydrate dissociation on oceanic hill slope failures and gas release. Adapted from McIver (1982).

For the aforementioned stability concerns, the placement of wells and seafloor platforms associated with oil production is strongly influenced by the presence of gas hydrate on the sea floor or within the sediment lithology. These concerns will be far more pronounced if gas production from oceanic gas hydrate accumulation becomes an economically viable option. Currently, there is a lack of understanding of the mechanical and thermal properties of oceanic sediments containing gas hydrates. The general perception of instability of hydrate-bearing sediments, coupled with the lack of knowledge on the overall geomechanical behavior of such sediments, has resulted in a general strategy of avoidance of such sediments when locating offshore production platforms. By locating production platforms at sites not selected for optimum operation but dictated by the need to avoid the hydrate accumulations, the cost of production can increase significantly. Warmer oil from depth may cause gas hydrate in the neighborhood of a well or pipeline to dissociate, reducing the stability of the supports, and placing significant investments at risk. Such concerns would increase exponentially if gas is to be produced from marine hydrate accumulations, thus posing a serious impediment to the development of such resources.

Few data are available to allow one to manage the risks associated with gas hydrates on the sea floor. Understanding the thermal properties is important because heat transfer through the system is one factor that controls the rate at which the sediments are altered due to hydrate dissociation. Understanding the mechanical properties for a range of hydrate-sediment compositions will allow the prediction of stability and the management of the risks. Measurements of thermal properties have been made of mixed quartz sand and hydrate laboratory samples in addition to pure hydrate samples (Cherskii et al., 1983; Cook and Leaist, 1983; Kneafsey et al., 2005; Moridis et al., 2005a; Stoll and Bryan, 1979; Waite et al., 2002), and strength measurements have been made on laboratory-made pure methane hydrate samples (Durham et al., 2003; Stern et al., 1996). A series of measurements of mechanical, thermal, and electrical properties of tetrahydrofuran hydrate in sediment is underway (Santamarina et al., 2004). Tetrahydrofuran hydrate is stable at atmospheric pressure and near-freezing temperatures; and dissociates to tetrahydrofuran and water without the formation of a gas phase. The applicability of these measurements to the strength of gas hydrate-bearing sediments as would be found below the sea floor has yet to be established. Another study of the mechanical behavior of hydrate bearing sediments concluded that it is essential to collect more data (Hyodo et al., 2005).

The available information is not sufficient to design seafloor platforms or wells (let alone permit the design of future gas production systems from hydrates) in the vicinity of HBS considering the safety, environmental, and economic risks posed by unstable seafloor behavior. We propose to develop the necessary knowledge that will allow the determination of the envelope of safe conditions when locating and operating an offshore production platform for either conventional oil or gas production, or for production from gas hydrates. This knowledge will also provide the necessary tools to evaluate the expected stability performance of hydrate-bearing sediments, and to select optimal sites for production facility installation.

3. Technical Approach

Objective

The main objective of this study is to develop the necessary knowledge base and quantitative predictive capability for the description of geomechanical performance of hydrate-bearing sediments (HBS) in oceanic environments. The focus is on the determination of the envelope of hydrate stability under conditions typical of those related to the construction and operation of offshore platforms.

Scope of Work

To achieve the objectives of the proposed study, the following approach is being employed:

1. The geomechanical behavior of oceanic HBS shall be investigated using pore-scale models (conceptual and mathematical) of fluid flow, stress analysis, and damage propagation.
2. Laboratory studies shall be conducted to (i) evaluate the conceptual pore-scale models, (ii) calibrate the mathematical models, (iii) determine dominant relations and critical parameters defining the geomechanical behavior of HBS, and (iv) establish relationships between the geomechanical status of HBS and the corresponding geophysical signature.
3. A robust numerical simulator of hydrate behavior in geologic media shall be coupled with a commercial geomechanical code, thus developing a numerical code for the stability analysis of HBS under mechanical and thermal stresses.
4. Numerical studies shall be conducted to analyze the HBS stability performance under conditions (i) representative of an offshore platform installation and operation, and (ii) typical of oceanic hydrate accumulations under production.

Organizations

There are four organizations initially involved with this project. These four are as follows:

- Texas A&M University (TAMU)
- University of California at Berkeley (UCB)
- Lawrence Berkeley National Laboratory (LBNL)
- Schlumberger (SLB)

4. Project Milestones

Phase I - Will be from October 1, 2005 to September 30, 2006

Status of Milestones for Phase I as of March 30, 2006

TAMU	Completion of literature survey on typical sediments containing gas hydrates in the ocean	May 2006	We are working on the literature review. All papers and reports have been found and we are in the process of summarizing the content. We will probably not complete this milestone until early September.
TAMU	Completion of recommendations on how to create sediments in the laboratory	June 2006	We have found the information we need. This milestone will not be completed until mid-September.
TAMU	Demonstration that typical sediments can be created in a repeatable manner in the laboratory and gas hydrates can be created in the pore space	Sept 2006	This milestone should be completed by the end of September but it is possible this work could continue into October.
UCB	Development of a conceptual pore-scale model based on available data and reports	July 2006	This milestone has been completed. After trying testing several approaches, we have selected the one based on most comprehensive contact mechanics.
UCB	Testing the developed concepts on simple configurations and verification of the result against known measurements and observations	Sept 2006	The approach has been tested on simple and not very simple configurations of grains. Right now we are in the middle of incorporation of tangential forces. There is a chance that this work will continue into October, subject to obtaining a relevant data set.
LBNL	Completion of FLAC3D routines	Aug 2006	On track for completion
LBNL	Completion of TOUGH-Fx/HYDRATE modifications and extensions	July 2006	Completed
LBNL	Completion of the TOUGH-Fx/FLAC3D interaction interface	Sept 2006	On track for completion

LBNL	Component integration and final testing of the coupled geomechanical numerical model TFxH/FLAC3D	Oct 2006	On track for completion
SLB	Demonstration that Petrel can be used to develop an earth model for providing data to the TOUGH-Fx/FLAC3D	July 2006	Surfaces have been exported to FLAC. We have demonstrated that surfaces can be transferred to FLAC 3D

5. Results of Work During the Reporting Period

The following summarizes the progress during this reporting period and current status of the work for each task that is part of PHASE I (Budget Period I) – Initial Fundamental Studies and Model Development.

Task 1.0 – Research management plan

The research management plan has been written and approved by DOE.

Task 2.0 – Technology Status Assessment

The first draft of the Technology Status Assessment report was written and sent to the DOE. Substantial revisions were required and a second draft has been sent recently for circulation among the research parties.

Task 3.0 – Fundamental Studies Part I

Subtask 3.1 - Fundamental studies of pore-scale geomechanical behavior of hydrates in porous media

The University of California at Berkeley is evaluating the issue of mechanical strength and failure of hydrate sediments, to include the following:

- Using Discrete Element Method (DEM) to model the impact of hydrate dissociation on mechanical strength of the formation at pore-scale level;
- Studying the stress field modification caused by fluid flow and fluid pressure depletion using simulation of the evolution of the rock flow properties; and
- Modeling of formation strength loss using simulation of the process of inter-grain bonds failure and loss of pressure support due to the dissociation.

During November and December, the administrators at Texas A&M University and at the University of California at Berkeley (UCB) worked to prepare the necessary subcontract papers and to transfer money to UCB. UCB policy does not let them begin research until all the documents are signed and they have money to fund the work. As such, no work occurred in 2005. Work began in January 2006 as UCB started looking at what ice will do to the pore space. The papers UCB has published recently on pore modeling can be found at

http://petroleum.berkeley.edu/papers/patzek/twppapers.htm

At this stage, efforts are considering the mechanical properties of gas hydrates imbedded in a subsea sediment layer (for now, unconsolidated), referred to as HBS. No matter how the mechanical/thermal properties of HBS are described (as a part of the matrix, or cementation agent between the sediment grains, or as different solid grains), these properties will change when the hydrate dissociates. Dissociation will release fresh water and gas and increase the local pressure, while reducing the temperature (due to the highly endothermic nature of the dissociation). Noting that this process stabilizes the hydrate, to continue dissociation additional heat or pressure drop is required. To understand the effect of dissociation on the mechanical properties of the solid (and fluid to which it joins), a micro-mechanical description of contact mechanics is being incorporated.

As a first approximation, only water and ice present in the pores is being considered. Then, the layer of spherical grains in contact with spherical ice crystals is being modeled. As melting begins, one needs to calculate the amount and state of water and gas that will form using thermodynamic considerations. Then, using mass balance together with momentum balance, contact mechanics will enable calculation of forces, stresses and strains close to the contract regions of the spheres. This, together with the material properties of the individual grains/fluids, can be used to formulate a macroscopic constitutive model for the composite layer, and its dependence on the amount of dissociation. Note that currently, again as a first approximation, the Hertzian model is being used, which assumes that the solid response is purely elastic and linear, and there is no cementation and adhesion. The Hertzian model, together with several geometrical assumptions (e.g., the grain contact area is much smaller than the size of the grain and its radius of curvature), simplifies the boundary conditions, and allows the use of the extensive analytical results available in literature for such elastic composites. Obviously, in the near future many of the above assumptions will need to be relaxed to create a more realistic picture.

Loss of stress support due to hydrate dissociation may result in significant reduction of rock strength. The strength of hydrate-bearing sedimentary formation is a sum of the strength of the inter-granular bonds and the interaction between the rock grains and the hydrates in the pore space. Myriads of such bonds and contacts define macroscopic rock strength parameters. It is expected that the history of hydrate formation has a great impact on the character of hydrate distribution and, consequently, on the character of possible scenario of hydrate-bearing rock failure.

UCB has been looking into the micromechanics of grain to grain or grain to hydrate interaction. The Hertzian model is being extended to contact mechanics of several grains. The natural coupling between inter-grain interactions makes the problem very complex. The objective is to obtain a simple, but still representative model. More specifically, attempts are being made to identify the key parameters that can describe the mechanics of a conglomerate of several grains and to develop a meaningful linearization procedure. This model then will be used to simulate interaction of large numbers of grains and to account for loss of strength when some bonds break due to dissociation taking place. Local rock failure in one location leads to a redistribution of the load and may cause failure elsewhere, and this chain of failures continues resulting in damage propagation. This is why from the very beginning the microscopic model is strongly coupled. A Newton-Raphson iterative procedure is being used for solving the coupled contact problem.

Subtask 3.2 **Literature Review and Development of Constitutive Models**

Schlumberger has been working internally on developing new methods for extracting mechanical properties from log measurements in weak sediments. There is good potential to tie that work to the discrete particle modeling work being done at U.C. Berkeley and interpretation of the new Sonic Scanner tool to the rock properties measured in the laboratory.

Schlumberger has also been investigating how to use Petrel as a platform for entering geologic and reservoir data into the ToughFX-FLAC3D model when it is completed. There are two requirements for using Petrel to populate FLAC3D with geological surfaces and rock properties. One is to demonstrate that FLACK 3D can import surfaces and properties from Petrel.

The other is to verify that Petrel can generate the geologic structures characteristic of the hydrate zone offshore. After a series of meetings between Schlumberger and ITASKA, ITASKA has told us they can import properties and surfaces from Petrel. They have demonstrated the ability to import into FLAC3D surfaces generated in Petrel. For the second part, Schlumberger is working internally to characterize geologic structure from 2D seismic lines crossing the hydrate zone in the Gulf of Mexico.

Geomechanical modeling of the near-seafloor sediments in the hydrate probability zone requires structural characterizing the seafloor topography in the hydrate zone. A review of literature on seafloor stability reveals a wide range of geological features in areas that are known to contain gas hydrate deposits. Structures range from un-deformed sediments deposited on shallow sloping continental rise to intensely faulted sediments in regions of steeper bathymetric slope.

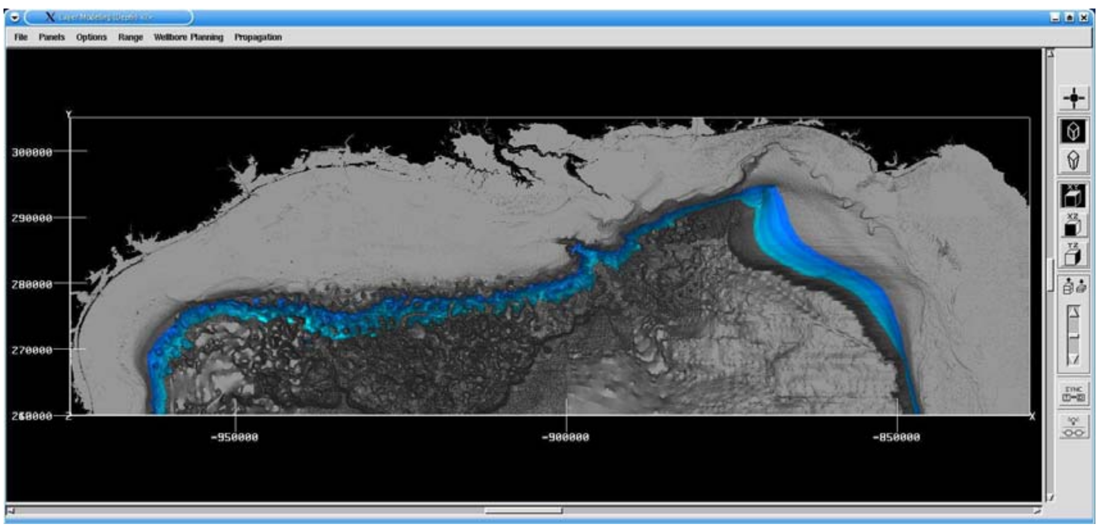

Figure 2 – A digital bathymetric model of the Gulf of Mexico

Figure 2 shows a digital bathymetric model of the Gulf of Mexico. The region shaded in blue corresponds to water depths ranging from 1500-to-3000 ft. Sediments located in this region are within the hydrate stability zone. It can be seen that much of the bathymetry in the central and western regions of this zone has a dimpled appearance caused by salt diapirism. The eastern and western limits of the hydrate zone show smoother contours. The salt diapirism and shallow faulting lead to complex structures in parts of the hydrate stability zone (Figure 3).

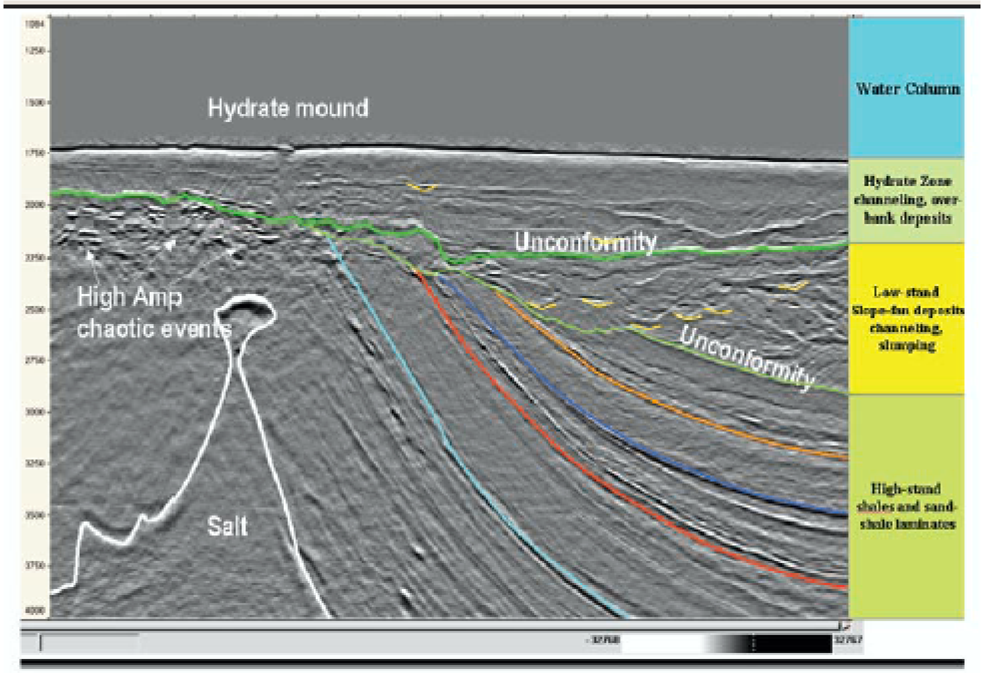

Figure 3 – An interpreted seismic section of the Atwater Valley study area showing salt diapir, general stratigraphy and hydrate mound (after Dai et al., 2004).

To characterize the geologic structures we will be reviewing seismic lines running perpendicular to the shelf break and crossing the hydrate bearing sediments shown in Figure 2. Once we have characterized the range of geologic structures we will meet with the software developers to evaluate Petrel's ability to model them.

***Subtask 3.3* – Description of hydrate-bearing zones as documented by the Ocean Drilling Program and the Chevron-DOE Gulf of Mexico JIP to determine typical gas hydrate bearing sample characteristics**

Review is in progress for the Ocean Drilling Program and the Chevron – DOE Deep Water Gulf of Mexico Joint Industry Project to gather information necessary to describe the hydrate-bearing zones encountered by these groups in their drilling and coring operations. Investigation includes evaluation of the analysis of the samples of hydrate-bearing cores obtained by the ODP in Oregon, Blake Ridge, and other projects, such as the one in Japan gathering data on the Nankai Trough deep water areas, to determine the chemical and mineral characteristics of those samples.

We have been downloading of papers, then reading and summarizing the information in the papers to obtain information needed to describe typical sediments in deep water that contain gas hydrate deposits. The information concerning the sedimentology and mineralogy of the sediments cored during the ODP Leg 204 (Hydrate Ridge, Offshore Oregon) and Leg 164 (Blake Ridge, Offshore Carolina) has been detailed, and the hydrate bearing sediments for theses areas have been classified according to the major and minor lithological constituents.

***Subtask 3.4* – Definition of methodology for creation of Synthetic Hydrate-Sediment mixture samples**

We plan to prepare and present to DOE for review and approval, a detailed description of the methodology and techniques required to create synthetic hydrate-sediment samples that provide chemical and mineral characteristics representative of the actual hydrate bearing cores reviewed under Subtask 3.3 activities. DOE will review the proposed sample creation methodology and will provide concurrence with proposed techniques or may request definition of alternate sample creation techniques. The methodology developed under this activity will be used in the preparation of all samples used to conduct laboratory testing under Task 7 activities. Through March 2006, no work has been conducted on this sub task.

Task 4.0 – Development of the coupled geomechanical numerical model

Work has begun to couple the TOUGH-Fx/HYDRATE model with FLAC3D. The TOUGH-Fx/HYDRATE model is used to predict the evolution of pressure, temperature, saturation distribution, and salt concentration in hydrate-bearing systems undergoing changes through any combination of mechanisms that can induce hydrate dissociation or formation (change in pressure, temperature and in the concentration of inhibitors). The FLAC3D model is a geomechanical model (Itasca Consulting Group, 1997) for soil and rock mechanics engineering. Simulations using the coupled code will execute the two component codes on compatible numerical grids and will link the component codes through synchronization coupling modules and external files, which serve to pass relevant information between the field equations that are solved in the respective codes.

Lawrence Berkeley National Laboratories (LBNL) had to negotiate its final contract with NETL. This was accomplished in January 2006. LBNL policy does not let them begin a project until all the documents are signed and they have money to fund the work. As such, no research was accomplished in 2005. George Moridis attended the meeting in Morgantown on January 24. LBNL could not begin work on this task after they received their final contract and funding from DOE. The money was received in February and LBNL began work in March.

During March, LBNL modified the standard TOUGH-Fx/HYDRATE hydrate code to begin the coupling with the FLAC3D geomechanical model. Using the modified code as a basis, capabilities were added for reading the external stress and strain files (as produced from FLAC3D), which are to be used for the computation of the updated (and evolving) porosity and permeability using an appropriate geomechanical model. Additionally, using the FISH language available to FLAC3D, new subroutines were developed to (a) read the spatial pressure, temperature and saturation distributions in the simulated domain and (b) open new files, into which the stress and strain distributions are stored.

6. Conclusions from the Reporting Period

On the basis of the work performed during this reporting period, the following conclusions are presented.

- There have been numerous reports by the Ocean Drilling Program (ODP), the Chevron JIP – DOE Gulf of Mexico project, the Japanese Nankai Trough work, and other work sponsored by DOE and the USGS to provide a representative range of the types of sea-floor and near seafloor sediments that can contain gas hydrates. We are using that information to describe several typical sediments that can be formulated in the laboratory so appropriate experiments can be conducted to better understand the physical, chemical, electrical and geophysical properties of these sediments with and without the presence of gas hydrates.

- There was significant progress in the pore-scale modeling of mechanical properties of a hydrate-bearing formation. Hertzian contact mechanics theory has been applied to develop algorithms and codes for simulating rock mechanical deformation and damage. A comprehensive model including tangential inter-granular forces is under development and testing of the code will start soon. Application of the efficient conjugate gradient algorithms made possible processing of large grain packs without involving large powerful computers. A comparison of the results of computations based on normal contact forces with the available experimental data and preliminary calibration of the input parameters is planned for September 2006. For a brief summary of Berkeley results to-date, please see the Appendix.

- We will enhance the model of inter-granular contact mechanics and incorporate the physics of interaction between hydrate residing in the inter-granular space and rock grains into the simulations. The objective of the study will be creating a framework allowing for computation of constitutive relationships suitable for TOUGH-Fx/HYDRATE – FLAC3D simulations. Pore-scale simulations will use three-D high-resolution images of computer-generated sedimentary rocks. This analysis will provide clues to what processes and phenomena define rock strength or failure in the course of hydrate formation or dissociation. .

- The process to link the TOUGH-Fx/HYDRATE model with FLAC3D to solve the coupled problem of fluid flow and mechanical properties in oceanic hydrate-bearing sediments is proceeding fast. We are confident that the work will be completed by the end of October 2006, which is four months ahead of schedule.

- We confirm that we will be able to use state of the art software to build the structural framework models of the sediments at and near the seafloor for input into our newly coupled models.

- We have secured approval from Schlumberger to provide Petrel licenses to Texas A&M University, University of California at Berkeley and Lawrence Berkeley National Laboratory, who are all contributing to this study.

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