MECHANISMS LEADING TO CO-EXISTENCE OF GAS AND HYDRATE IN OCEAN SEDIMENTS

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QUARTERLY PROGRESS REPORT
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Summary

In this first quarter of the first year of work during Phase 1/Budget Period 1, the project was initiated successfully. The Research Management Plan was prepared and submitted, as was the Technology Status Assessment. The PI visited researchers at Rice University and University of Houston, whose research on methane hydrates is also funded by DOE NETL, to discuss the respective projects. The two projects are complementary, e.g. our project focuses on the hypothesis that flow of a bulk gas phase controls hydrate distribution within the hydrate stability zone, while theirs explores the assumption that single phase flow (of brine saturated with dissolved methane). We anticipate fruitful exchanges between the two groups. The PI also briefly visited methane hydrate researchers at Texas A&M University. He also participated via WebEx in the kickoff meeting for current NETL hydrate research awards. Co-PI Juanes gave a talk on the project at the Earth Sciences Department at MIT, and had extensive discussions with associated faculty. Work on Tasks 3 and 4 commenced and useful preliminary results were obtained.

Background: Project Motivation

The mass of carbon held in sediments below the seafloor is a significant part of the Earth's carbon cycle. The amount currently in place may be very large; enough to implicate methane hydrates in global warming events in the geological past and to raise the prospect of a vast energy resource. However, estimates of this mass and the rate at which it can accumulate in or dissipate from sediments vary widely. One reason is the difficulty in ascertaining the form and spatial distribution of methane within the hydrate stability zone (HSZ). The goal of this project is to understand quantitatively the manner in which methane is transported within the HSZ. The research will seek validation of the following hypothesis: the coupling between geomechanics, the dynamics of gas/water interfaces, and phase behavior of the gas/brine/hydrate system make co-existence of free gas and hydrate inevitable in the HSZ.

If borne out, our hypothesis would provide a mechanistic basis for several observations of co-existing gas and hydrate in the HSZ. The models have implications for interpretation of seismic and borehole log data and thus for estimates of carbon held in the HSZ. It would explain observations of lateral and vertical variability in hydrate saturation, e.g. preferential occurrence in coarse grained material above and below a fine grained layer. The model would be a step toward explaining active and passive hydrate accumulations with a single set of mechanisms.

Activities in This Reporting Period

Task 1.0 – Research Management Plan

The Research Management Plan (RMP) was prepared as per NETL specifications and approved by the NETL COR and the project team.

Task 2.0 – Technology Status Assessment

A Technology Status Assessment was prepared and submitted as per NETL specifications. Notable elements of the assessment include the following:

- The state of the art in modeling teaches that it is not straightforward to explain the observed complexity of hydrate distribution. Our knowledge has improved dramatically over the past few years (Sloan, *Am. Mineral.* 2004), yet many questions remain. Thus the field is poised to take advantage of mechanistic models that can predictively and quantitatively describe hydrate growth and distribution.
- State-of-the-art models of hydrate distribution at the continuum scale do not yet account for several essential features of the natural system. These features include:
    - a three-dimensional spatial description;
    - true multiphase flow;
    - relative permeability and capillary pressure data, including the hysteresis between gas-advancing and water-advancing behavior;
    - the mechanics of the sediment, including the effect of pore pressure and multiple fluid phases in the pore space.

Our project directly addresses both of these gaps in the current technology.

Task 3.0 – Creation of Sediment Models

In this task a series of model sediments (dense random packing geometries of spheres with broad and narrow distributions of sizes and several different mean sizes) shall be created using previously validated computer codes that implement the cooperative rearrangement algorithm. During this quarter we applied research codes previously developed at UT-Austin to create a large set of model sediments using periodic boundaries to eliminate edge effects. The spatial locations of spheres and the packing porosity were recorded. A report is being prepared that describes the grain-scale and pore-scale geometry of the model sediments and compares them to hydrate-bearing sediments in different parts of the world.

A notable accomplishment was the creation of a periodic Delaunay tessellation of a model sediment. We believe this to be the first nontrivial (i.e. physically realistic) *periodic* network model of pore space. We are working on methods to simulate drainage and imbibition, which will be critical processes during gas phase invasion of the sediment, that take advantage of the periodicity. The goal is to circumvent for the first time the long-standing problems of finite-size effects, or artifacts introduced at the network boundaries. These problems particularly influence the trapping of gas and water phases during imbibition and drainage, respectively. In effect, our method will permit simulations of capillary trapping in unbounded domains, adding valuable realism without incurring the huge increases in computational overhead that swamp other approaches.

We have also compiled a database (that will grow as the project progresses) with sediment properties that are relevant for creation of model sediments. These include:

- sediment fabric (images of natural sediments that host methane hydrate);
- grain size distribution;
- porosity (and its variation with depth)
- intrinsic permeability and hydraulic conductivity
- mechanical strength in drained and undrained triaxial tests: Young modulus, Poisson ratio, yield stress, stress-strain curves, etc.

This database is organized by geographic location, and so far includes sediments from Hydrate Ridge, Blake Ridge, and the Gulf of Mexico.

<u>Task 4.0 – Fracture initiation and propagation</u>

Subtask 4.1. Initialize the model

The model sediments developed in Task 3 will be used as input to the computer code PFC2D/3D, a discrete element method code. Alternatively, we are also constructing seafloor sediment models by reproducing the sedimentation process (see **Figure 1**). In the near future, we shall compare and test both ways of generating the sediment model.

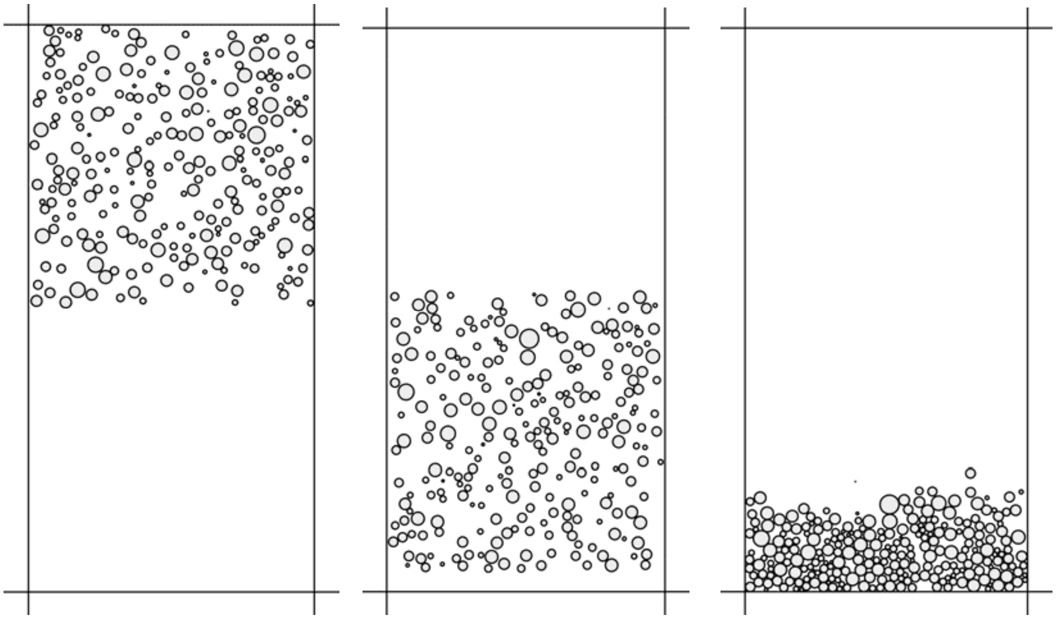

Figure 1. Generation of the model sediment. **Left:** Initial distribution of particles before sedimentation. The particles, with a Gaussian grain size distribution similar to the field sample, are randomly placed in the top half of the box. **Center:** Snapshot of the configuration of the particles as they settle due to gravity. **Right:** Model sediment after settling. This computer-generated model is then subject to triaxial compression, to reproduce the stress-strain behavior of actual samples of seafloor sediments.

Our grain size distribution falls in the range of the compiled data. Micromechanical parameters, such as particle stiffness and bond strength, are set iteratively so that the model sediment packings behave closely to actual sediments that have been collected in scientific drilling voyages and subjected to compression testing. Model sediment packings are subjected to triaxial loading at various confining pressures. The top and bottom walls apply compressive vertical stresses to the sample, while the vertical walls maintain a specified confining pressure. The stress-strain behavior of the model should closely match the actual sediment stress-strain behavior reported from laboratory tests under various experimental conditions. Because of the difference in dimensionality (2D vs. 3D), we will not seek perfect agreement between the PFC2D model and the actual sediment in terms of porosity reduction and stress-strain curves. We do see, however, good quantitative agreement, which illustrates the potential of the proposed approach. A sample stress-strain curve is shown in **Figure 2**.

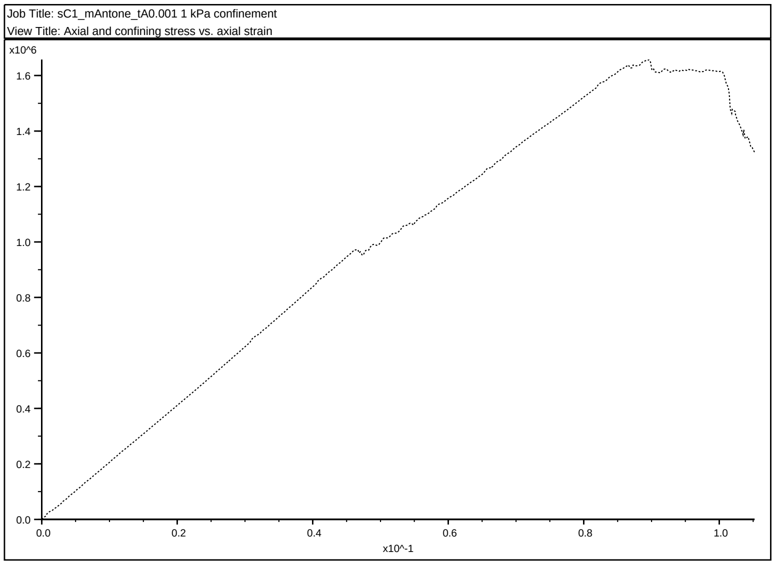

Figure 2. Example of a stress-strain curve generated with PFC2D, for the sediment model shown in Figure 1. The confining stress for this computer experiment is 1kPa. The peak stress is about 1.6MPa, which occurs at a vertical strain of about 8%.

We have started by evaluating the behavior of “dry” samples, that is, ignoring the effect of the pore fluid on the mechanical response of the sediment. In the next step, we will move to model sediments fully-saturated with brine (Subtask 4.2), and then gas-brine two-phase systems with an elastic membrane representation of the gas-liquid interface (Subtask 4.3).