BEHAVIOR OF SEDIMENTS CONTAINING METHANE HYDRATE, WATER, AND GAS SUBJECTED TO GRADIENTS AND CHANGING CONDITIONS

FP00008137

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October 27, 2020
LBNL Gas Hydrate Lab Objectives

- Measure physical, chemical, mechanical, and hydrologic property changes in sediments containing methane hydrate, water, and gas subjected to varying stimuli and conditions.
  - effects of other gases (CO$_2$, N$_2$, mixtures)
  - effects of sediment layering
  - effects of stress
  - effects of relevant gradients (thermal, chemical (salinity or gas composition), and capillary pressure) on hydrate behavior.
- All tests are non-standard and new techniques must be developed.
Issues this FY

• 2 Public Safety Power Shutoffs
  – Complete lab shutdown and restarts
• Working with TAMU on hydrate relative permeability
• COVID 19
  – SIP, limited access, slow start
• Equipment issue
Project Objectives

• Laboratory benchmark geomechanical tests for code validation
  – Design task with feedback from geomechanical modelers
  – Test design and construction in existing or off-the-shelf pressure equipment
  – Perform a series of tests (cementing hydrate)
  – Devise transfer method/sample composition for pore-filling hydrate
  – Perform tests on pore-filling hydrate

• Geomechanical evaluation - compaction of hydrate-bearing and non-hydrate-bearing Alaska Field Test relevant sediments under relevant conditions, layered samples
Title: An International Code Comparison Study on Coupled Thermal, Hydrologic and Geomechanical Processes of Natural Gas Hydrate-Bearing Sediments

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Two Benchmark Problems
From the IGHCC2 Study

**BP1 (Isotropic Consolidation with Hydrate Dissociation)**

Summary: Vertical consolidation of a single, cylindrical grid cell. Homogeneous system.

- Case 1 - No hydrate
- Case 2 - Hydrate without dissociation
- Case 3 - Hydrate with dissociation

**BP2 (Extended Terzaghi Problem)**

Summary: Vertical consolidation and relaxation of a homogeneous system of sediment, water, gas, and hydrate

- Case 1 - No hydrate kinetics
- Case 2 - With hydrate kinetics
- Case 3 - With higher hydrate contribution to sediment strength
- Case 4 - Very fast hydrate kinetics
Extended Terzaghi Problem

- How does the consolidation occur?
- Can we track it spatially?

Remember this order of magnitude (4 – 6 cm / meter)
Terzaghi test apparatus design

- Fluid Pressure
- Floating piston
- Rigid Al Tube
- Fixed Platen

Endcaps with Al coupons for measuring endcap movement

16.3 cm
“New” concept – Use inclined plane for subvoxel displacement measurement

Use slanted X-ray visible coupon in platen and piston
Axial displacement is shown as lateral displacement and sensitivity is controlled by angle of coupon

Small axial translation yields large signal on CT plane
Before hydrate formation

- Sample packed with F110 sand, 30% water saturation. Pore pressure 550 psi, confining 600 psi, 20°C.
- Confining pressure was cycled 2x from effective stress of 50 to 500 psi. Observed some initial large shift of piston from initial compaction.
- Temperature was lowered to 2°C allowing hydrate to form. After hydrate formation sample was saturated with water*. Confining pressure was cycled again.
- Movement of piston in the sand pre-hydrate formation is larger than post hydrate
- Sample was repacked, experimental duplicate of shift in new hydrate experiment (new sand pack) shows similar results

After hydrate formation (2 replicates)

Terzaghi cementing hydrate – 60% saturation

- Sample consisted of sand with 60% water saturation
- Pore pressure 550 psi, confining 600 psi, 2° C. After hydrate formation sample was saturated with water*.
- Confining pressure was cycled from effective stress of 50psi to 500 psi. 60% saturation with hydrate shifted more than 30% case
- Sample was dissociated and effective stress was cycled again.
- After dissociation, shifting of piston was significantly greater.
- As with the 30% water saturation condition, piston movement was observed during dissociation

Piston shift (µm) for different experimental conditions

<table>
<thead>
<tr>
<th>Effective stress psi</th>
<th>30% pre hydrate</th>
<th>30% hydrate - 1</th>
<th>30% hydrate - 2</th>
<th>60% hydrate</th>
<th>60% post hydrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td>100</td>
<td>-30</td>
<td>64</td>
<td>62</td>
<td>55</td>
<td></td>
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<tr>
<td>300</td>
<td>126</td>
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<td>350</td>
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<td>104</td>
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</tr>
<tr>
<td>500</td>
<td>273</td>
<td>152</td>
<td>163</td>
<td>197</td>
<td>650</td>
</tr>
<tr>
<td>50 dissoc</td>
<td>126</td>
<td>128</td>
<td>47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Effective stress

### After hydrate formation

- 1473 - 60% hydrate

### After hydrate dissociation

- 1474 - 60% after dissociation - no hydrate
Issues

1. Tracking consolidation throughout the sample
2. Type of hydrate (cementing, pore filling)
3. Hydrate as a more significant part of the porous medium frame
Since the sliding piston only measured compaction of the end of the sample, spheres of various materials with different densities were placed throughout the sample to monitor changes in compaction along the sample.

Analysis is ongoing for the quantitative measurement of the movement of these spheres for the 30% water saturation and 60% water saturation experiments.
Tracking Consolidation – Tracer Method

Method needs improvement for efficient implementation!
Particle Image Velocimetry – compares 2 images and quantifies displacements

![Graph showing PIV for sub-voxel displacement quantification](image)

- 1 voxel = 0.625 mm

Legend:
- 50 layer average 101_102
- 150 layer average 101_103
- layer average 101_104
- layer average 101_105
- layer average 101_106
- layer average 101_107
- layer average 101_108
- layer average 101_109
- layer average 101_110
- layer average 101_111
- layer average 101_112
- layer average 101_113

1506 Sand/Ice
Sample prep for pore filling hydrate

1. Ice was made by freezing water droplets over liquid N2.
2. All components of the system were chilled to -20°C, including sand, pressure vessel, sleeve, confining fluid, packing tools.
3. Sand was mixed with ice, sieved through 1 mm sieve to remove potential large ice aggregates.
4. Sand/ice mixture was added in layers with intermediate tamping. (like packing powder)
Displacement (mm) vs. Effective Stress (psi) for Dry Hydrate and Ice

- Sand/Ice
- Hydrate-Bearing
- PostDissociation

Approximately 4 cm/m
Ice and Dry Hydrate Sand-Based Porosity

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>PreHyd</th>
<th>Post Hyd</th>
<th>Post Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand-Based Porosity (l)</td>
<td>0.50</td>
<td>0.49</td>
<td>0.48</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Ice and Saturated Hydrate

Sand/Ice

Sand/Hydrate

Approximate Density (g/cm$^3$)
Displacement under 500 psi effective stress during dissociation

Maximum Displacement (mm)

~2.3 cm/m
### Dissociation

<table>
<thead>
<tr>
<th>Ice and Saturated Hydrate</th>
<th>Approximate Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissociation</td>
<td></td>
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<tr>
<td>Sand/Water</td>
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<td>Ice and Saturated Hydrate</td>
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Unlock
Ice and Saturated Hydrate Sand-Based Porosity

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<tbody>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td>0.52</td>
<td>0.51</td>
<td>0.50</td>
<td>0.49</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Cementing hydrate

Hydrate present – 60% saturation

33% hydrate present – water saturated

Pore filling hydrate

Hydrate present – 30% saturation

36% hydrate present – not water saturated
Other Relevant Work

In addition to the above work:

- With TAMU, we devised a method to quantify capillary pressure in hydrate-bearing sediments and demonstrated it.
- In collaboration with TAMU, we aided a student to attempt to measure relative permeability using a newly developed technique. Unfortunately, the technique was accompanied with a number of complications. Although we were not successful with the relative permeability measurements, a positive result was that improvement to approaches in making measurements on hydrate-bearing sediments were made.
- In collaboration with a student from the School of Petroleum Engineering at the China University of Petroleum, East China, we used lattice-Boltzmann simulations to investigate relative permeability for grain coating and pore filling hydrate, and mineral wettability.
Conclusions, future work

Our funding this year enables us to continue geomechanical evaluation of Alaska Field Test-relevant samples - Measurement of compaction of hydrate-bearing and non-hydrate-bearing sediments under relevant conditions and layered samples.

We seek to capitalize on the improvement of codes and development of numerical models from IGHCC2 and obtain enhanced analysis of the data.