Oil & Natural Gas Technology

DOE Award No.: DE-FE0009897

Quarterly Research Performance Progress Report (Period ending 9/30/2016)

Hydrate-Bearing Clayey Sediments: Morphology, Physical Properties, Production and Engineering/Geological Implications

Project Period (10/1/2012 to 9/30/2017)

Submitted by:
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DISCLAIMER:

ACCOMPLISHMENTS

Context – Goals. *Fine grained sediments host more than 90% of the global gas hydrate accumulations. Yet, hydrate formation in clayey sediments is least understood and characterized. This research focuses on hydrate bearing clayey sediments. The goals of this research are (1) to gain a fundamental understanding of hydrate formation and ensuing morphology, (2) to develop laboratory techniques to emulate "natural" formations, (3) to assess and develop analytical tools to predict physical properties, (4) to evaluate engineering and geological implications, and (5) to advance gas production alternatives to recover methane from these sediments.*

Accomplished

The main accomplishments for this period include:

- Capillary effect and gas production in fine-grained sediments
  - Theoretical studies
- Strength of hydrate-bearing fine-grained sediments
  - Non-slip contact between hydrate crystals and sediments
  - Slip contact between hydrate crystals and sediments
- Gas migration in soft sediments
  - Mechanism of the memory effect
  - Effect of over consolidation ratio (OCR)

Plan - Next reporting period

1. Advance understanding of crystal-sediment interaction.
2. Advance numerical experiments to predict properties.
3. Theoretical and analytical study of gas production.
4. Stiffness characterization of THF hydrate bearing clays.

RESEARCH IN PROGRESS

Capillary effect and gas production in fine-grained sediments

Capillary pressure inhibits hydrate dissociation. Figure 1a demonstrates the pressure-temperature relationship during depressurization and thermal stimulation. Figure 1b illustrates that the gas pressure around the hydrate crystal is higher than the water pressure. Before the pressure difference exceeds the characteristic capillary pressure, the gas pressure maintains the stability of the residual hydrate. The depressurization method demands a lower water pressure than the phase boundary pressure to dissociate the residual hydrate. By contrast, the thermal stimulation technique requires a higher temperature at this point to destabilize the residual hydrate.

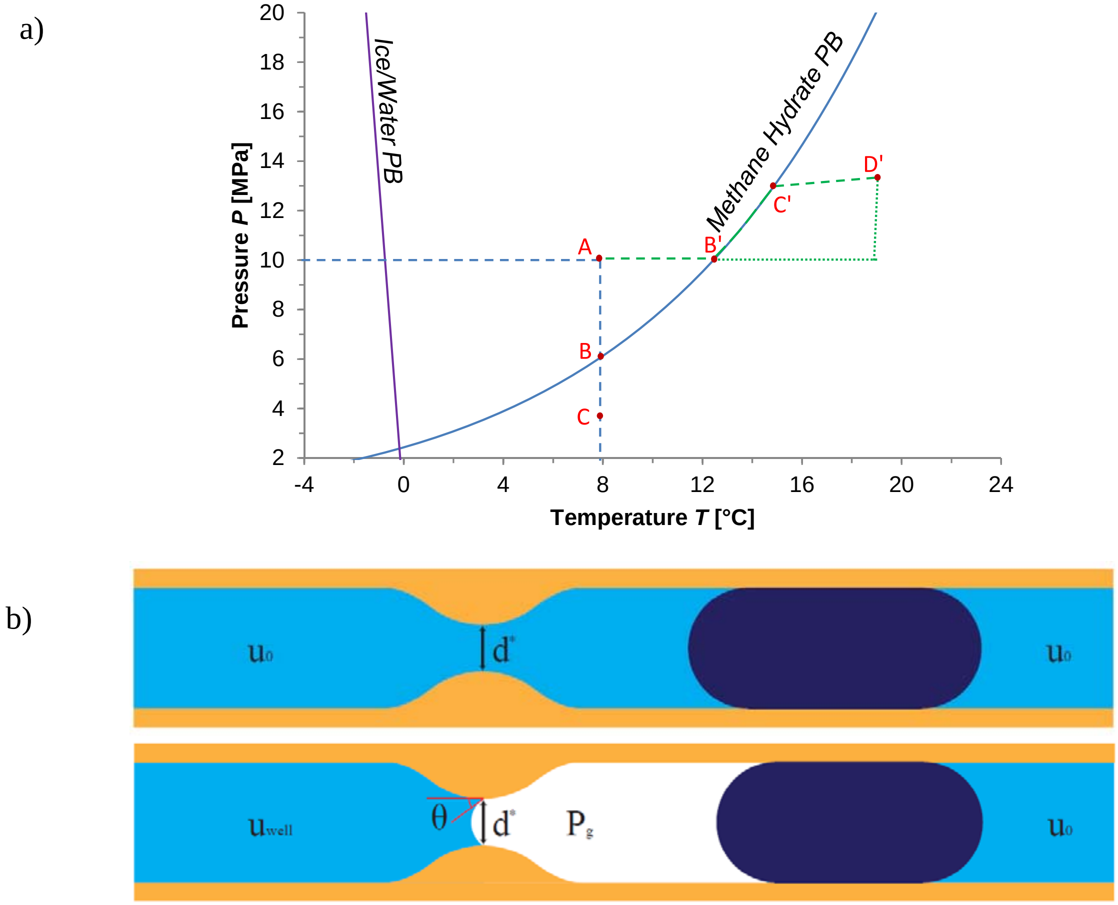


Figure 1: Gas production related phenomenon.

Strength of hydrate-bearing fine-grained sediments

The strength analyses in this section consist of two cases, bonded contact and slipping contact between hydrate lens and the sediment. Figure 2 and 3 demonstrate the vertical displacement contour, the deformed geometry and Von Mises stress field of a plane-strain specimen subjected to a 15% vertical displacement load. Figure 4 presents the strength of the soil at the end of the loading as a function of hydrate tilt angle. The strength exhibits a decrease when the lens tilts in comparison to when the lens is perpendicular or parallel to the loading direction.

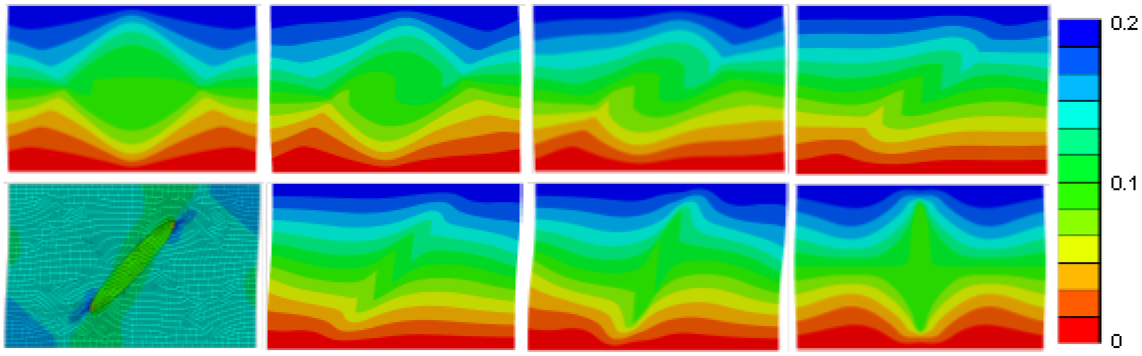


Figure 2: Vertical displacement field and Von Mises stress field at the least strength state (rotation angle = 60°), non-slip hydrate-sediment interface.

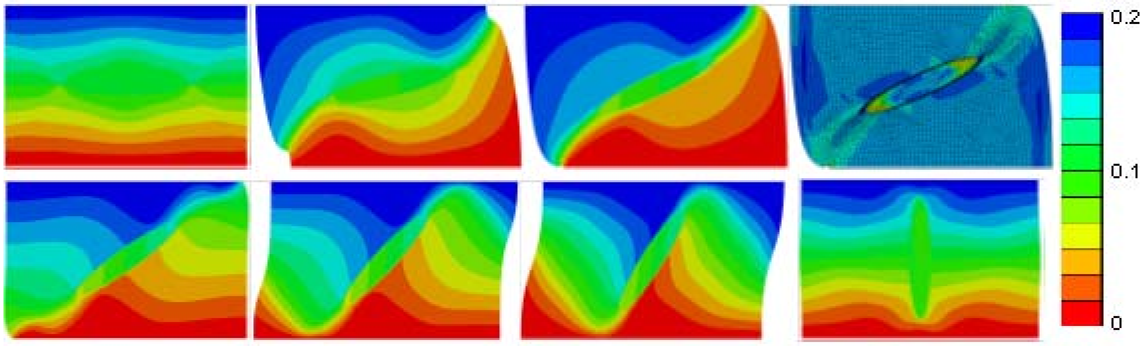


Figure 3: Vertical displacement field and Von Mises stress field at the least strength state (rotation angle = 30°), slip hydrate-sediment interface.

In addition, Figure 4 demonstrates the strength of the sediments prior to hydrate formation. The simulation in this condition uses a lower initial effective stress. The contribution of the consolidation effect to the sediments strength is dramatically higher than the contribution of the presence of hydrate lens in this condition.

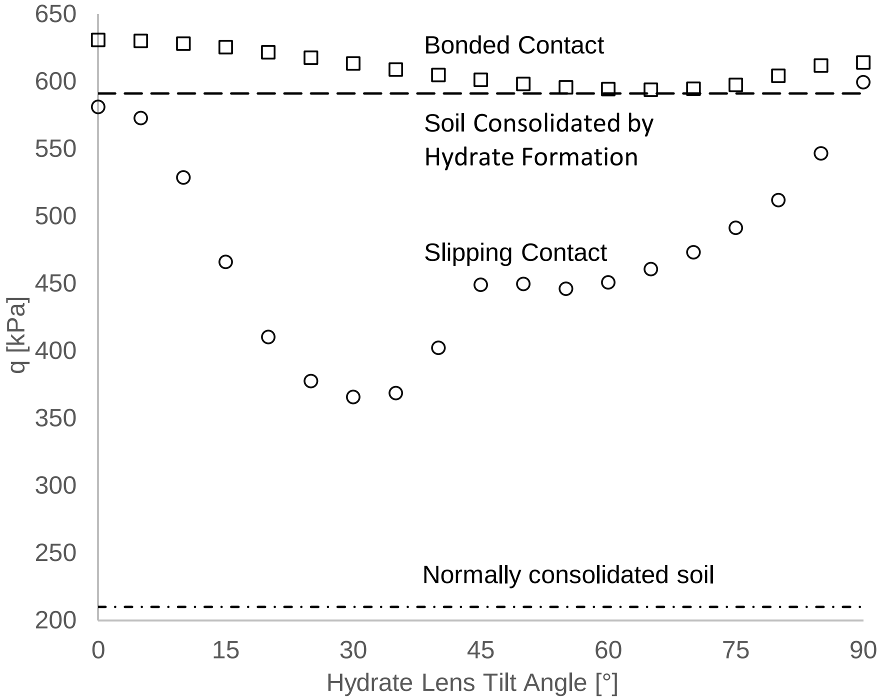


Figure 4: Sediment strength at 15% vertical strain

Mechanism of the memory effect

Transparent soil exhibits memory effect, one possible reason is the break of any historical bonding due to diagenesis during the first injection, so less pressure is needed for the second injection. Besides, the compression process during the first injection and contraction during the "fracture" healing causes irreversible changes of horizontal effective stress and void ratio distribution (Figure 5). This redistribution of horizontal effective stress and void ratio creates a zoon with lower horizontal effective stress and higher void ratio at the previous "fracture" location which is easier for a new "fracture" to nucleate. The presence of discontinuities in sediments alter the original stress and properties fields and create a relaxation zoon when discontinuities close. This memory effect also suggests burrows and roots of plants can serve as preferential pathways for gas leakage. These potential discontinuities can facilitate gas migration in sediments

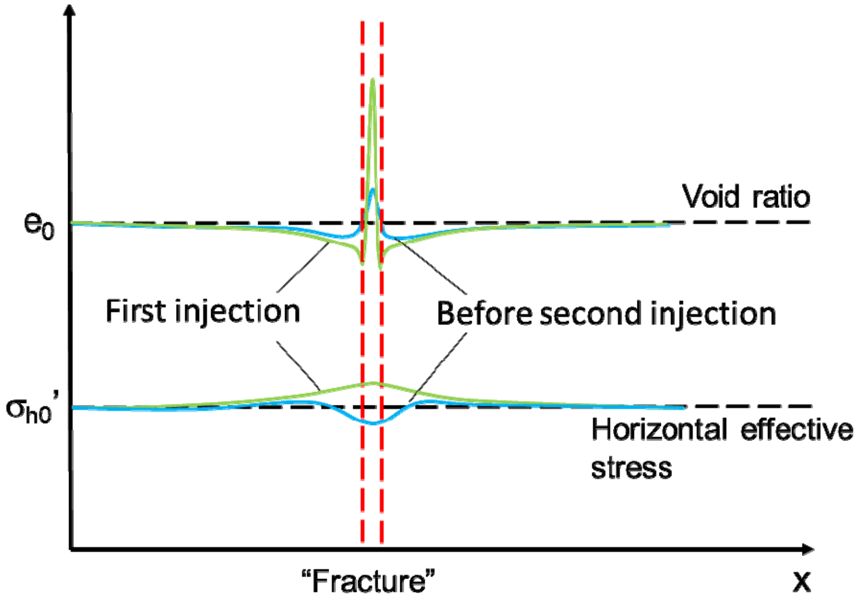


Figure 5. Mechanism of memory effect.

Effect of over consolidation ratio (OCR)

Gases prefer to propagate along the direction perpendicular to the minimal principle stress. This was observed by injecting gas in an over consolidated sample. The sample in Figure 6 was loaded to 48 kPa and unloaded to 2 kPa.

Figure 6. A gas-driven "fracture" in an over consolidated transparent soil sample.

MILESTONE LOG

Milestone	**Planed completion date**	**Actual completion date**	**Verification method**	**Comments**
Literature review	5/2013	5/2013	Report	
Preliminary laboratory protocol	8/2013	8/2013	Report (with preliminary validation data)	
Cells for Micro-CT	8/2013	8/2013	Report (with first images)	
Compilation of CT images: segregated hydrate in clayey sediments	8/2014	8/2014	Report (with images)	
Preliminary experimental studies on gas production	12/2014	12/2014	Report (with images)	
Analytical/numerical study of 2-media physical properties	5/2015	5/2015	Report (with analytical and numerical data)	Additional studies in progress
Experimental studies on gas production	12/2015	12/2015	Report (with data)	Additional studies in progress
Early numerical results related to gas production	5/2016	2/2016	Report	Additional studies in progress
Comprehensive results (includes Implications)	9/2016	9/2016	Comprehensive Report	

PRODUCTS

- **Publications & Presentations:**

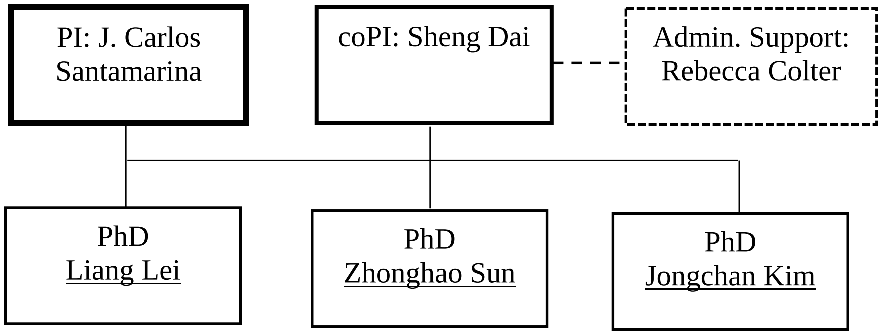
  Jang, J. and Santamarina, J.C., 2016. Hydrate bearing clayey sediments: Formation and gas production concepts. *Marine and Petroleum Geology*, 77, pp.235-246.
- **Website:** Publications and key presentations are included in http://pmrl.ce.gatech.edu/ (for academic purposes only)
- **Technologies or techniques:** X-ray tomographer and X-ray transparent pressure vessel
- **Inventions, patent applications, and/or licenses:** None at this point.
- **Other products:** None at this point.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Research Team: The current team involves:

- Liang Lei (PhD student)
- Zhonghao Sun (PhD student)
- Jongchan Kim (PhD student)
- Sheng Dai (Assistant Professor)
- Carlos Santamarina (Professor)

Research Team:



IMPACT

Understanding of fine grained hydrate-bearing sediments.

CHANGES/PROBLEMS:

None at this point.

SPECIAL REPORTING REQUIREMENTS:

We are progressing towards all goals for this project.

BUDGETARY INFORMATION:

As of the end of this research period, expenditures are summarized in the following table.

Baseline Reporting Quarter DE-FE009897	Budget Period 4							
	Q1		Q2		Q3		Q4	
	10/1/15 - 12/31/15		1/1/16 - 3/31/16		4/1/16 - 6/30/16		7/1/16 - 9/30/16	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baseline Cost Plan								
Federal Share	41,547	502,751	41,547	544,299	41,547	585,846	41,547	627,393
Non-Federal Share	11,935	146,969	11,935	158,904	11,935	170,839	11,935	182,774
Total Planned	53,482	649,720	53,482	703,203	53,482	756,685	53,482	810,167
Actual Incurred Cost								
Federal Share	22,802	461,960	32,381	494,341	45,285	539,627	17,607	557,234
Non-Federal Share	15,167	152,445	10,111	162,556	5,056	167,612	2,505	170,116
Total Incurred Costs	37,969	614,405	42,492	656,897	50,341	707,238	20,112	727,350
Variance								
Federal Share	-18,745	-40,791	-9,166	-49,957	3,738	-46,219	-23,940	-70,159
Non-Federal Share	3,232	5,476	-1,824	3,652	-6,879	-3,227	-9,430	-12,658
Total Variance	-15,513	-35,315	-10,990	-46,305	-3,141	-49,447	-33,371	-82,817

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