NATIONAL ENERGY TECHNOLOGY LABORATORY

OIL & GAS

DOE Award No.: DE-FE0009897

Quarterly Research Performance Progress Report (Period Ending 09/30/2017)

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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Signature

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Prepared for:
United States Department of Energy
National Energy Technology Laboratory

Submission Date: 11/15/2017

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Office of Fossil Energy

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:

- THF hydrate in clayey sediments
  - Super-cooling temperature and morphology
  - Elastic properties
  - Dynamic properties, i.e., damping

Plan - Next report will be the final report of this project

RESEARCH IN PROGRESS

THF hydrate in clayey sediments

Supercooling temperature and hydrate morphology. THF is used as a proxy of hydrate formed in clayey sediments (i.e., kaolinite). Specimens are prepared by mixing THF, water, and kaolinite with the same mass ratios but different super-cooling temperatures. Resulted hydrates in kaolinite show different morphology and saturation (Figure 1).

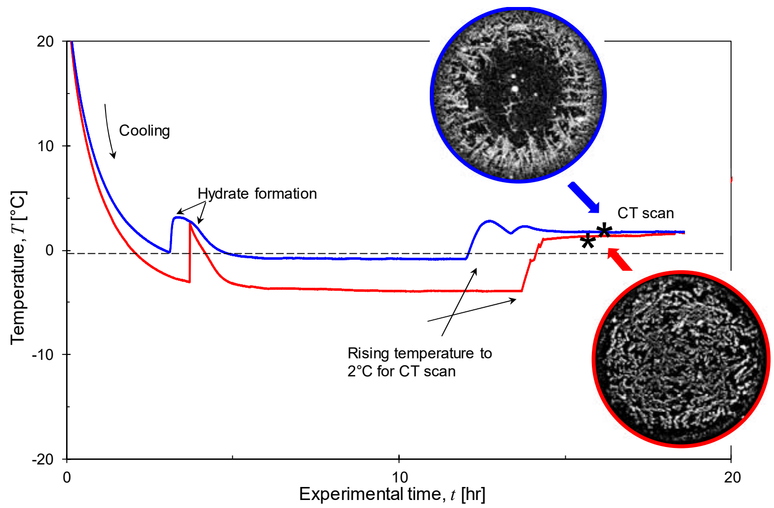


Figure 1: (Left) Temperature signatures and X-ray images of two specimens with identical initial mass ratio of 100% stoichiametric solution and clay, i.e., 60:100 in this case.

Figure 2 shows the 3D CT images of hydrate in kaolinite sediments. Hydrate morphology and saturation vary with (THF, water, kaolinite) mass fractions and super-cooling temperature.

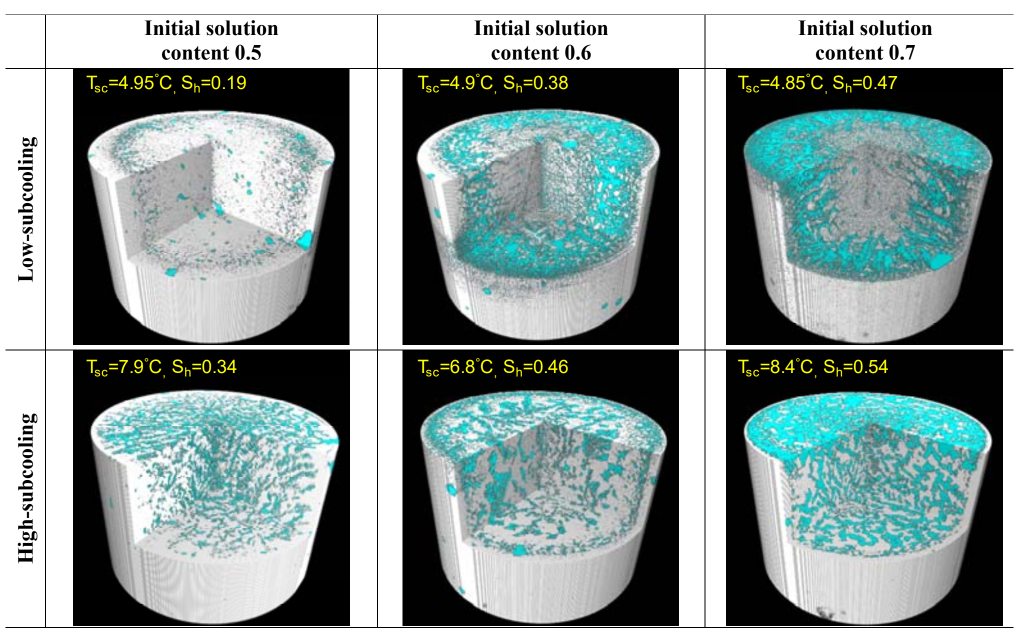


Figure 2: 3D X-ray CT images of six hydrate-bearing specimens with different initial mass ratios and supercooling temperature (T_{sc}).

Elastic properties. Measured p- and s-wave velocities as a fucntion of hydrate saturation are presented in Figure 3. With simoultaneous measurement of V_p and V_s, all elastic moduli (i.e., Young's, shear, constraint, and bulk) of the hydrate-bearing sediments can be computed, as well as the Poisson's ratio. Although data are scattered, the self-consistent model can still capture the hydrate saturation dependent elastic properties for hydrate-bearing clayey sediments.

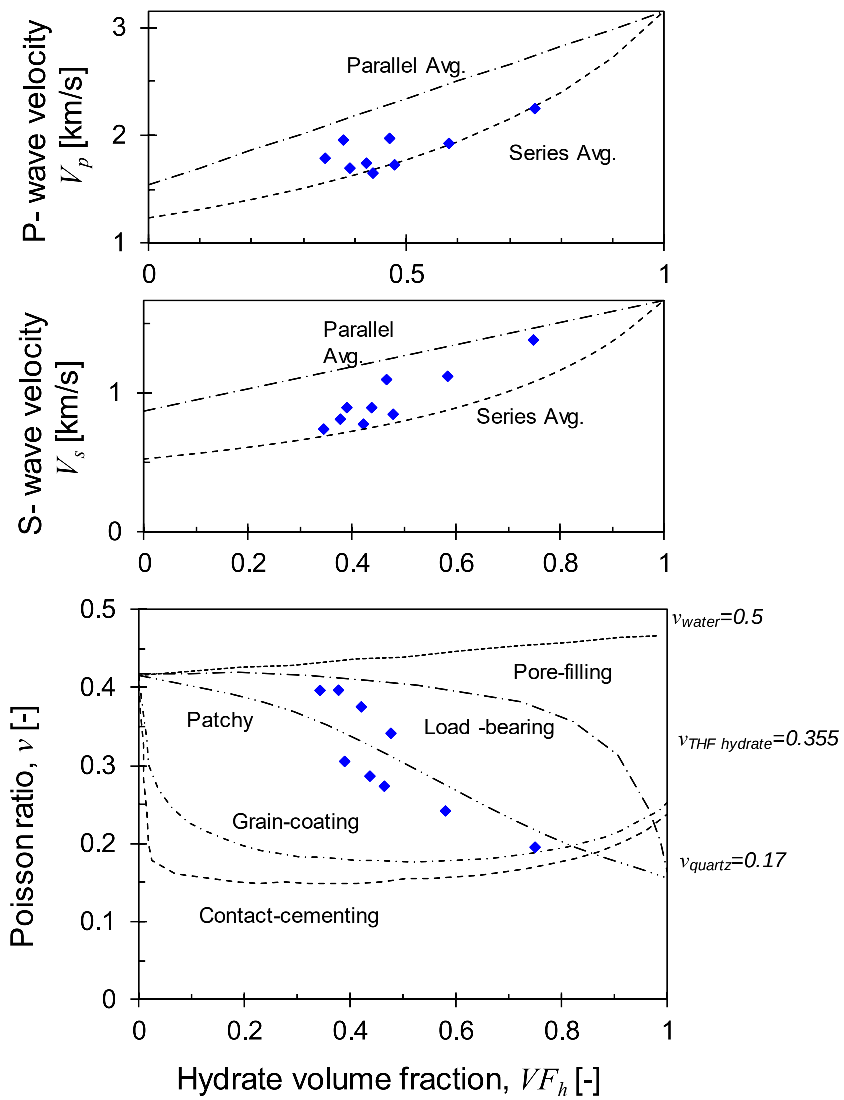


Figure 3: Elastic properties of THF hydrate-bearing sediments. (a) P-wave velocity versus hydrate saturation. (b) S-wave velocity versus hydrate saturation. (c) Poisson's ratio versus hydrate saturation. These elastic properties are not monotonically depending on hydrate

saturation mainly due to random distribution and morphology of segregated hydrate lenses.

Dynamic properties. The presence of hydrate in the sediments makes the sediments stiffer, yet attenuates the wave more efficiently. Measured quality factor Q^{-1} values range between hydrate-bearing sediments and pure THF hydrate (reported in the literature).

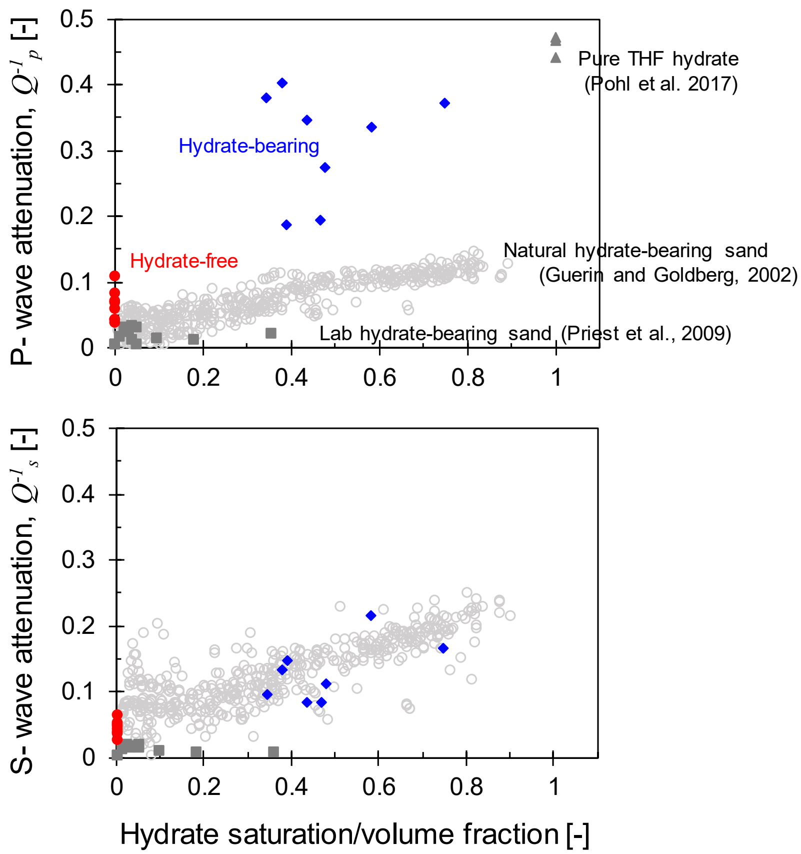


Figure 4: Measured quality factor Q^{-1} (i.e., damping) from both p- and s-waves in THF hydrate-bearing clayey sediments.

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)	Additional CT images of THF hydrate in clays
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)	
Experimental studies on gas production	12/2015	12/2015	Report (with data)	Additional stiffness and damping measurement in THF hydrate-bearing clays.
Early numerical results related to gas production	5/2016	2/2016	Report	
Comprehensive results (includes Implications)	9/2016	9/2016	Comprehensive Report	Final report due 30/12/17

PRODUCTS

- **Publications & Presentations:**

Liu, Z., Kim, J., and Dai, S. THF hydrate in clayey sediments: formation, morphology, and elastic properties. (In preparation).

Jang, J., Sun, Z. and Santamarina, J.C., (2017). Capillary pressure across a pore throat in the presence of surfactants. *Water Resources Research*. (Published online).

Dai, S., and Santamarina, J.C., (2017). Stiffness evolution in frozen sands subjected to stress changes. *Journal of Geotechnical and Geoenvironmental Engineering* (Published online).

Park, J., & Santamarina, J. C. (2017). Revised Soil Classification System for Coarse-Fine Mixtures. Journal of Geotechnical and Geoenvironmental Engineering, (Published online).

Lei, L., Liu, Z., Seol, Y., Boswell, R. and Dai, S. (2017) Hydrate formation in an unsaturated system - Impacts of fine particles and water content. 9th International Conference on Gas Hydrate, Denver, CO.

Jang, J. and Santamarina, J.C., (2016). Hydrate bearing clayey sediments: Formation and gas production concepts. *Marine and Petroleum Geology*, 77, pp.235-246.

Shin, H. and Santamarina, J.C., (2016). Sediment–well interaction during depressurization. *Acta Geotech-*

nica, pp.1-13.

Dai, S., Shin, H. and Santamarina, J.C., (2016). Formation and development of salt crusts on soil surfaces. *Acta Geotechnica*, 11(5), pp.1103-1109.

Jang, J., & Carlos Santamarina, J. (2015). Fines Classification Based on Sensitivity to Pore-Fluid Chemistry. *Journal of Geotechnical and Geoenvironmental Engineering*, 142(4), 06015018.

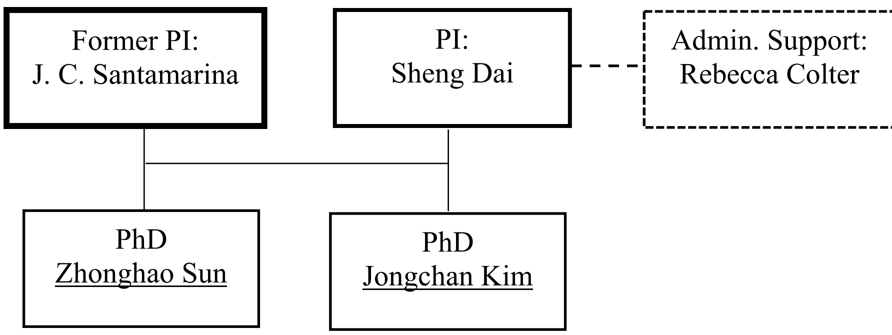
- **Website:** Publications and key presentations are included in http://pmrl.ce.gatech.edu/ (for academic purposes only)
- **Technologies or techniques:** X-ray tomographer and X-ray transparent pressure vessel
- **Inventions, patent applications, and/or licenses:** None at this point.
- **Other products:**

Lei, L (2017). Gas Hydrate in Fine-grained Sediments - Laboratory Studies and Coupled Processes Analyses. PhD Thesis, Georgia Institute of Technology.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Research Team: The current team involves:

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



IMPACT

Understanding of fine grained hydrate-bearing sediments.

CHANGES/PROBLEMS:

None.

SPECIAL REPORTING REQUIREMENTS:

None.

BUDGETARY INFORMATION:

All budget has been zeroed out. Details will be presented in the final report.

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