NATIONAL ENERGY TECHNOLOGY LABORATORY

OIL & GAS

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Research Performance Progress Report

(Period Ending 12/31/2016)

Impact of clays on the compressibility and permeability of sands during methane extraction from gas hydrate

Project Period (10/1/2016 to 9/30/2019)

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Signature

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Office of Fossil Energy

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EXECUTIVE SUMMARY

Background: The quantity of methane potentially recoverable from gas hydrate is large enough to motivate federally-supported production tests in several countries, which in turn motivates studies of reservoir production efficiency. Evaluating long-term production well viability involves modeling permeability evolution in the reservoir sediments around the production well because processes reducing the flow of gas into the production well also reduce the long-term economic viability of the well. Fine particles, such as clays, exist nearly ubiquitously in the permafrost and marine settings that typically host gas hydrate, and fines reacting to fluid flow by migrating and clogging pore throats can reduce flow toward the production well. Many fines are sensitive to variations in pore-fluid chemistry, swelling in reaction to in situ pore brine being displaced by fresh water liberated from hydrates during dissociation. Additionally, fine particles tend to collect at gas/water interfaces created by the multiphase flow of gas and water. Thus, as methane and fresh water flow from the hydrate-dissociation front toward the production well, fine particles in the reservoir sands, interbedded fine-grained layers and seal layers can be swelled, migrated (or both), potentially clogging pathways and limiting flow to the production well.

Objective: This project seeks to provide a quantitative basis for reservoir models to account for the impact of clays and other fine-grained material ("fines") on reservoir compressibility and permeability, two key factors controlling the flow of gas and fluids toward a production well. This overall objective is addressed through a combination of site-specific and more generalized, fundamental science goals:

Site-specific measurement goals: quantify the change in compressibility and permeability due to the reaction of fines to pore-water freshening in sediment from the 2015 NGHP-02 gas hydrates research cruise offshore India.

Fundamental measurements on pure fines goal: distinguish between, and quantify, mechanisms for sediment compressibility and permeability change due to physical and chemical responses of fines to the flow of freshened pore water and gas:

- Chemical response: quantify and catalog the sensitivity of pure fines (fines with only a single component, or "endmember" fines) to pore-water chemistry.
- Physical response: quantify the link between fines migration and clogging during single and multiphase flow.

ACCOMPLISHMENTS

The overall project timeline is shown in Figure 1. This report details activities in the first quarter of Year 1. A full list of milestones and Success Criteria is provided in the Appendix.

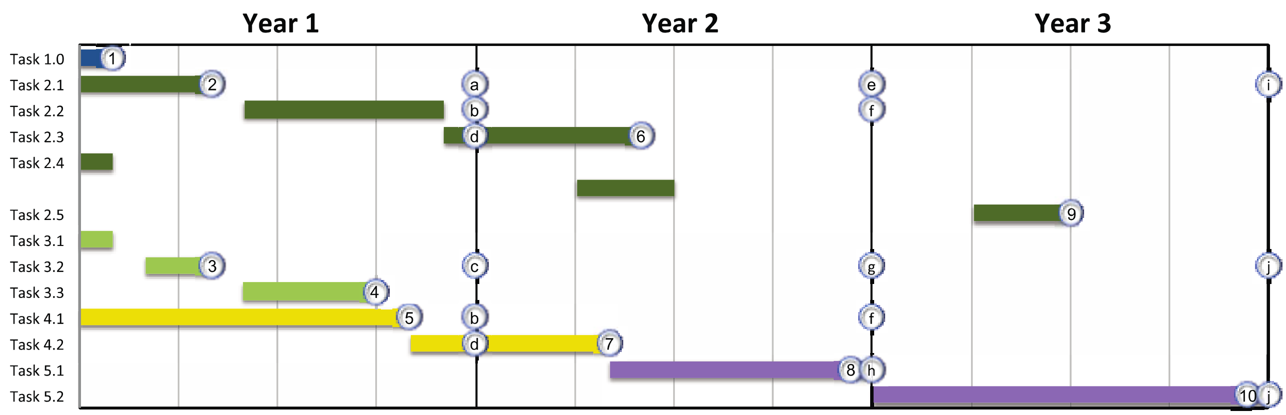

Figure 1: Project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given in the Appendix.

Active Tasks this quarter included **Tasks 1** (Project Management and Planning), **2.1** (Index property analysis of NGHP-02 conventional core sediment), **2.4** (NGHP-02 fines sensitivity to pore fluid chemistry), **3.1** (Index properties of pure, endmember fines), **3.2** (Electrical sensitivity of pure, endmember fines) and **4.1** (Dependence of fines migration and clogging on physical conditions in porous media containing pure, endmember fines). A summary of accomplishments for each Task is provided below.

<u>Task 1: Project Management and Planning</u>

Task 1 consists of several administrative formalities involved with the Project startup. The following items have been completed:

- A Project Management Plan (PMP) has been developed, revised with input from NETL, and submitted to NETL.
- The Project participated in a webex kickoff meeting held November 22nd.

- A Project Data Management Plan has been developed, revised with input from NETL, and submitted to NETL.

Task 2.1: Index property analysis of NGHP-02 conventional core sediment

The U.S. Geological Survey acquired conventional core material from the India's 2015 National Gas Hydrate field program (NGHP-02). To help interpret planned measurements of the chemical sensitivity and migration behavior of fines from the NGHP-02 study, index property analyses are being carried out on NGHP-02 sediment. Results will be withheld from publication until the NGHP-02 publication moratorium is lifted. Accomplishments this quarter include:

- Acquisition of the shipboard sediment property measurements made during NGHP-02. These will be used as a framework for understanding spot data at USGS subsampling locations.
- USGS measurement of sediment grain size on the ~200 sediment specimens acquired by the USGS during NGHP-02.
- For a specific site of interest to NGHP, additional index property measurements were made, including grain density, specific surface, x-ray diffraction characterization and scanning electron microscope imagery.

Task 2.4: NGHP-02 fines sensitivity to pore fluid chemistry

To link the endmember electrical sensitivity studies in this Project with naturally-occurring sediment relevant to producing methane from gas hydrate, electrical sensitivity studies are being conducted on a subset of the NGHP-02 material acquired by the USGS. Accomplishments this quarter include:

- Liquid limit and plastic limit tests have been completed using three different pore-water fluids: deionized water, brine and kerosene.

Task 3.1: Index properties of pure, endmember fines

To help interpret planned measurements of the chemical sensitivity and migration behavior of several different pure, endmember fines, index property analyses are being carried out on illite, kaolin, montmorillonite, diatoms, silica silt and calcium carbonate. This selection of fines includes the fines most commonly associated with sediments associated with gas hydrate reservoirs. Accomplishments this quarter include:

- Specific surface data and XRD spectra have been acquired for all endmember fines.
- Grain density has been measured on all but one endmember.
- Grain size subsamples have been submitted for processing.

Task 3.2: Electrical sensitivity of pure, endmember fines

Electrical sensitivity provides a means of quantifying the extent to which certain fines will swell in response to changes in pore water chemistry. This swelling can increase the capacity of fines to clog pore throats, and is being studied here separately from migration and mechanical causes of pore-throat clogging by fines (the focus of Task 4). Accomplishments this quarter include:

- Sedimentation tests have been conducted for all sediments using settling tubes designed and built in house (Figure 2).
- Liquid limit and plastic limit tests, upon which the electrical sensitivity value is based, have been made for all endmember fines using three different pore-water fluids: deionized water, brine and kerosene.

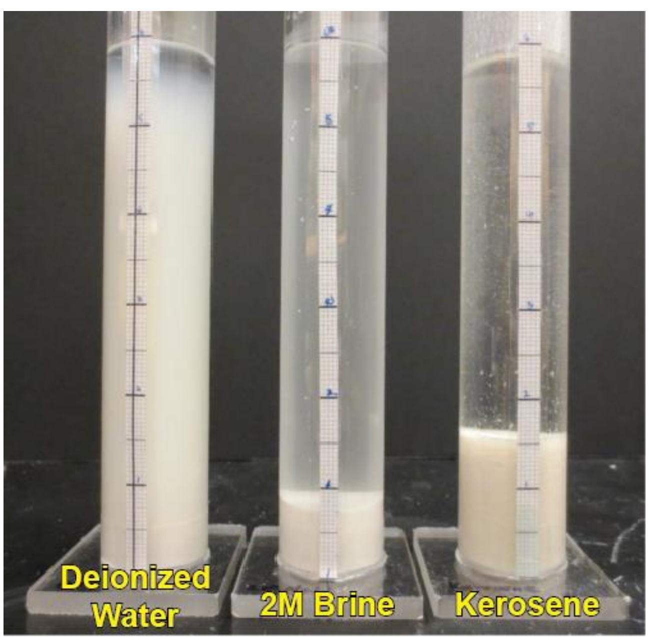

Figure 2: A settlement test with silica silt showing the difference in interparticle forces between resulting from saturation by three different pore fluids: deionized water (left cylinder) causes the small silica silt particles to remain separated, whereas these particles are attracted to each other and can therefore settle and pack more efficiently in 2-Molar brine (center cylinder). Kerosene reduces interparticle repulsion and allows the silica to settle (left cylinder), but does not remove the interparticle repulsion as effectively as the 2-Molar brine.

- Preliminary results from the index and electrical sensitivity work have been accepted for a poster presentation and conference paper at the International Conference on Gas Hydrates (June, 2017).

Task 4.1: Dependence of fines migration and clogging on physical conditions in porous media containing pure, endmember fines

Fines existing in coarse-grained material can migrate in pore-fluid flow, collect at pore-throats and clog flow pathways, reducing the overall permeability required for efficient methane extraction from hydrate-bearing sands. In this task, endmember fines are assessed in terms of their mechanical capacity to migrate and clog pores of various sizes relative to the grain size of the fines themselves. Accomplishments this quarter include:

- Fabrication on six different 2D micromechanical models, each with a different characteristic pore-throat size is underway. The pore throats of these models (in micrometers) are: 10, 20, 40, 60, 100 and a random mix of all five pore throat sizes. The values themselves were chosen based on the grain size results from NGHP-02 (Task 2.1).

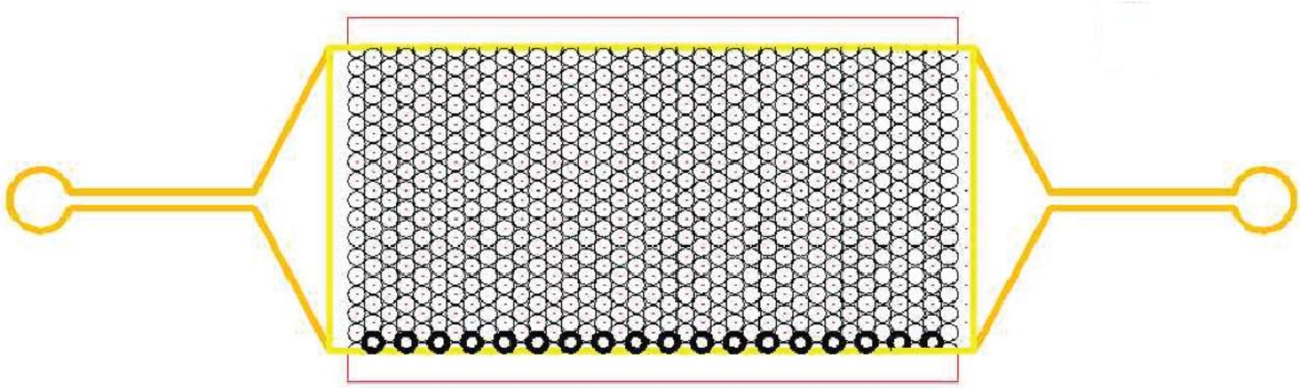

Figure 3: A template for a 2D micromodel containing uniform circular “grains” (black circles) with 580 µm diameters, arranged with 40 µm pore throats. LSU is fabricating five micromodels, each with a uniform pore size in the range of 10 – 100 µm, and one micromodel with a random mix of five chosen pore throat sizes.

PRODUCTS

Jang, J., Waite, W.F., Jung, J., Pore-fluid sensitivity of clays and its impacts on gas production from hydrate-bearing sediments [Abstract]. Accepted for the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, Colorado.

APPENDIX: PROJECT TIMELINE

The complete Project timeline is shown in Figure A1, with Milestones and Success Criteria listed thereafter.

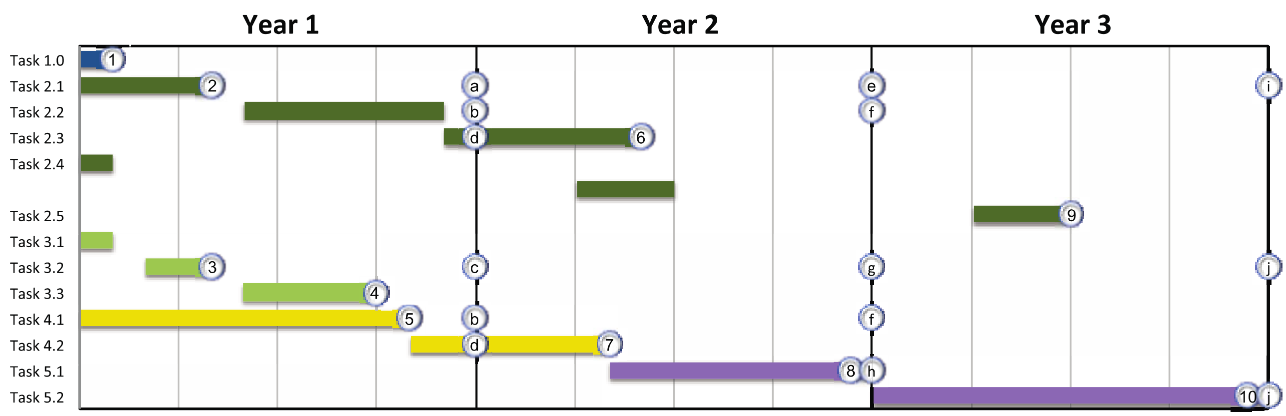

Figure A1: Project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given below.

<u>Milestones (listed according to the numbers given in Figure A1)</u>

Budget Period 1

1. Task 1, Project Management (LSU/USGS). This task will be completed October 31, 2016 and verified through DOE acceptance of the project SOPO, annual budget forecasts and Project Management Plan.
2. Task 2, Site-specific pore fluid sensitivity study (USGS). This data acquisition component of Task 2 will be completed January 31, 2017 and verified through comparison of NGHP-02 data obtained with available shipboard data from the NGHP-02 cruise offshore India.
3. Task 3, Endmember fines – electrical sensitivity index (USGS). This data acquisition component of Task 3 will be completed January 31, 2017. Results will be verified through duplicate measurements of targeted specimens using LSU equipment, literature comparison where available.
4. Task 3, Endmember fines – dependence of compressibility and permeability on pore fluid chemistry (LSU). This data acquisition component of Task 3 will be completed June 30, 2017. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.
5. Task 4, 2D micromodel studies – mechanical contribution of endmember fines to clogging (LSU). This data acquisition component of Task 4 will be completed July 31,

2017. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.

Budget Period 2

6. Task 2, 2D micromodel studies – mechanical contribution of NGHP-02 fines to clogging (USGS). This data acquisition component of Task 2 will be completed March 1, 2018. Results will be verified through linkages between imaged clogs and measured evolution of pressure and flow parameters.
7. Task 4, 2D micromodel studies – clogging dependence of endmember fines on pore fluid chemistry (LSU). This data acquisition component of Task 4 will be completed January 31, 2018. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.
8. Task 5, 3D visualization of clogging and clog fracturing – dependence on endmember fines (LSU). This data acquisition component of Task 5 will be completed September 30, 2018. Results will be verified through linkages between imaged clogs and measured evolution of pressure and flow parameters.

Budget Period 3

9. Task 2, Site-specific dependence of compressibility and permeability on pore fluid chemistry (USGS). This data acquisition component of Task 2 will be completed March 31, 2019. Results will be verified for brines and freshened pore water by comparisons with pressure core data obtained elsewhere in the NGHP-02 project.
10. Task 5, 3D visualization of clogging and clog fracturing – dependence on pore water chemistry (LSU). This data acquisition component of Task 5 will be completed September 30, 2019. Results will be verified through linkages between imaged clogs and measured evolution of pressure and flow parameters.

<u>Success Criteria (listed according to the letters given in Figure A1)</u>

End of Budget Period 1

a. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should have begun on NGHP-02 conventional core sediment. Additional index property and liquid limit tests can be run on NGHP-02 material as the material becomes available from pressure cores that were previously dedicated for USGS study during NGHP-02.
b. Subtasks 2.2 and 4.1 (linked): 2D microfluid models – clogging via physical processes. Measurements of clogging by endmember fines should have been run separately by both participants. Results should be quantified in terms of clogging potential due to mechanical activity (fines migration) and geometry (pore throat size relative to grain size of the fines). Results should demonstrate similar behavior within the subset of LSU and USGS tests that are paired for interlaboratory verification purposes.

c. Task 3: Endmember fines assessment of pore fluid chemistry impact on compressibility and permeability. All data for a manuscript detailing the implications of the electrical sensitivity (pore fluid sensitivity) of fines on compressibility and permeability should be in hand, and a conference abstract prepared.
d. Subtasks 2.3 and 4.2 (linked): 2D microfluid models – clogging dependence on pore fluid chemistry. 2D micromodel experiments should have been started by both participants to assess the dependence of clogging by fines in relation to fluid chemistry. Initial comparisons between participants should guide subsequent efforts and dictate any additional tests that may need to be run.

End of Budget Period 2

e. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should continue on NGHP-02 pressure core sediment as the material becomes available from pressure cores that were previously dedicated for USGS study during NGHP-02. The publication moratorium should have expired in time to allow a conference abstract submission covering the NGHP-02 fines study to date.
f. Subtasks 2.2, 2.3 and Task 4: 2D Micromodel studies of clogging by endmember fines. All data for a manuscript detailing the implications of mechanical and chemical controls on clogging by endmember fines should be in hand. A joint manuscript should be submitted for peer reviewed journal publication, though the review process will likely be ongoing at the end of Budget Period 2.
g. Task 3: Endmember fines assessment of pore fluid chemistry impact on compressibility and permeability. Based on feedback from presenting this material at a conference, a peer-reviewed journal manuscript should have been written and submitted during this budget period, though the review process will likely be ongoing at the end of Budget Period 2.
h. Subtask 5.1: 3D micromodel imagery of the role of endmember fines in clogging, clog fracturing, and relative permeability. This Subtask is a 3D extension of the Subtasks 2.2 and 4.1 2D micromodel tests. By the end of Budget Period 2, comparisons between 2D and 3D observations of fines clogging based on mechanical and geometric factors should be providing insight into how the 2D micromodel results scale up to 3D, and these insights should be captured in a submitted conference abstract.

End of Budget Period 3

i. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should be complete on NGHP-02 pressure core sediment as the material. Based on feedback from presenting this material at a conference, a peer-reviewed journal manuscript should have been written and submitted during this budget period, though the review process for an NGHP-02 special volume may be ongoing even by the end of Budget Period 3.
j. Tasks 3 and 5: Interaction of fines with pore water – effect of pore water chemistry on index properties and flow behavior of endmember fines. Tying the macroscopic property insights from Task 3 with the 3D pore-scale behaviors observed in Task 5

provides the scientific content for the capstone publication in this project. Based on reviewer feedback from Task 3 and conference feedback from Subtask 5.1, a manuscript covering the interaction between fines and pore water and the subsequent impact on index and flow properties will be submitted.

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