NATIONAL ENERGY TECHNOLOGY LABORATORY

OIL & GAS

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Research Performance Progress Report

(Period Ending 06/30/2018)

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

Project Period (10/1/2016 to 9/30/2018)

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Office of Fossil Energy

DISCLAIMER

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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 third quarter of Year 2. A full list of milestones and Success Criteria is provided in the Appendix.

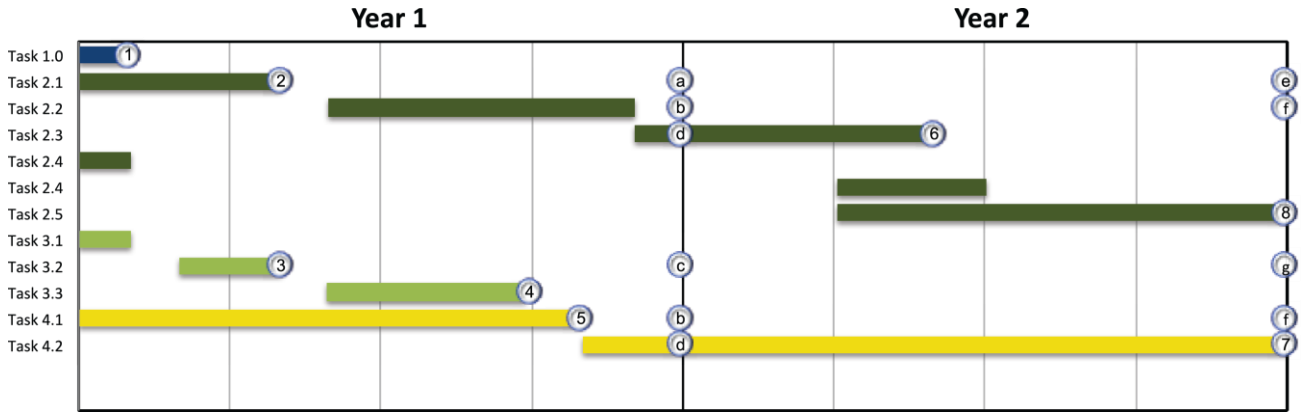

Figure 1: Project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given in the Appendix.

Active Tasks this quarter included **2.5** (Compressibility and permeability dependence of NGHP-02 sediment on pore-fluid chemistry), and **4.2** (Dependence of fines migration and clogging on pore-fluid chemistry in porous media containing pure, endmember fines). Additionally, a journal manuscript covering **Task 3** (Electrical sensitivity of fines) was accepted. A summary of accomplishments for each Task is provided below, along with a highlight from the journal manuscript.

Task 2.5: Compressibility and permeability dependence of NGHP-02 sediment on pore-fluid chemistry

In Year 1, 4Q, pressure core testing was completed on NGHP-02 specimens from a fine-grained overburden seal, and a coarse-grained reservoir. Compressibility and permeability measurements have been made while the specimens were in various combinations of fresh and in situ water. This quarter, the manuscript covering both permeability and

compressibility issues prepared for the *Journal of Marine and Petroleum Geology* (special volume covering the NGHP-02 program) is in revision.

Task 4.2: Dependence of fines migration and clogging on pore-fluid chemistry in porous media containing pure, endmember fines

In addition to the mechanical drivers for pore-throat clogging by fines, there are chemical stimuli as well. Fine-grained particles are generally smaller than the pore throats they end up clogging, so many of the clogging behaviors studied in this task are caused when clusters or clumps of fine-grained particles form, growing large enough to span the pore throats. As shown in Task 3.2, clustering depends on the combination of the type of fine and the pore fluid, and cannot be predicted if only the fine type or only the pore fluid is known. A suite of micromodel clogging tests have been run for pure, endmember fines as well as sediment from two sites in the NGHP-02 field program. This quarter, a 2D-micromodel-based manuscript detailing these analyses was submitted to the *Journal of Marine and Petroleum Geology* for inclusion in their special volume covering the NGHP-02 program (Joint with Task 2.3).

Task 3: Electrical sensitivity of fines

A fundamental objective in this project is to quantify links between sediment composition and macroscopic properties such as sediment compressibility and permeability. The journal manuscript, accepted in the *Journal of Geophysical Research: Solid Earth*, shows how the sediment's electrical sensitivity can provide this link. Fundamentally, the sediment's macroscopic properties depend on the sediment fabric, the arrangement of sediment particles. For fluid-saturated sediments, the fabric itself can depend on the pore fluid chemistry, and electrical sensitivity helps link the sediment mineralogy and pore fluid chemistry to the sediment fabric and hence, to macroscopic properties. For gas hydrates, a critical issue is that pore water freshens in gas hydrate-bearing reservoirs as gas hydrate is dissociated to extract methane as an energy resource. This change in

pore water chemistry can alter the sediment fabric and thus alter the sediment response to effective stress changes that occur as the reservoir is depressurized to release methane from the gas hydrate. A key finding in the paper is that the sediment's electrical sensitivity can help quantify the pore-pressure change impact on sediment behavior (see Figure 2).

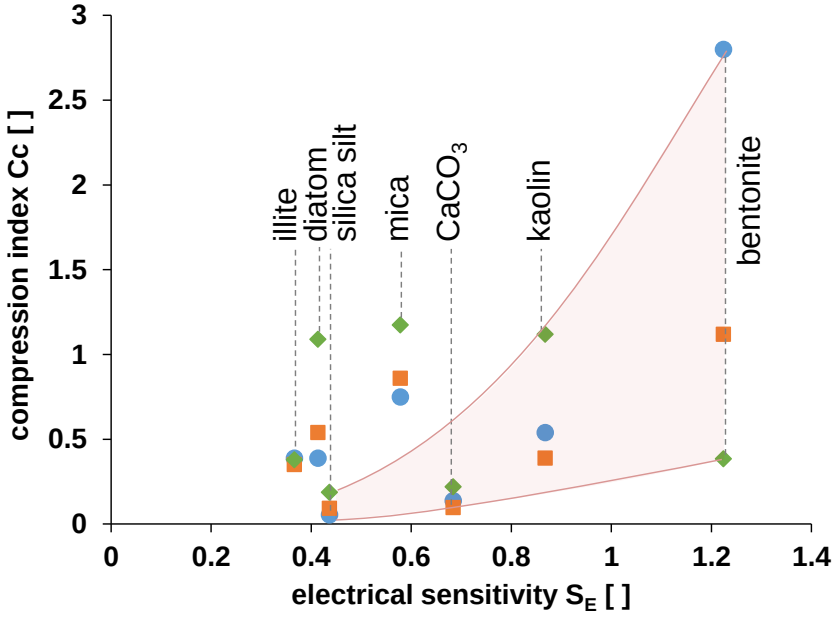

Figure 2: Dependence of the compression index on electrical sensitivity (pore fluid legend is: circle = deionized water, square = 2-Molar brine and diamond = kerosene). The shaded area represents possible ranges of the compression and recompression index as a function of electrical sensitivity after removing sediments that have unusually high void ratios due to their physical shapes. With increasing electrical sensitivity, the sediment becomes more prone to changes in macroscopic properties such as compressibility when pore fluid chemistry changes.

PRODUCTS

Cao, S.C., Jang, J., Waite, W.F., Jafari, M., Jung, J., A 2D micromodel study of fines migration and clogging behavior in porous media: Implications of fines on methane extraction from hydrate-bearing sediments [Abstract]. Talk presented at the 2017 Fall American Geophysical Union Conference, New Orleans, LA, December 11-15, 2017.

Jang, J., Cao, S., Waite, W.F., Jung, J., Impact of pore-water freshening on clays and the compressibility of hydrate-bearing reservoirs during production. Conference paper accepted by the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, Colorado.

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

Jang, J., Cao, S., Stern, L.A., Jung, J., Waite, W.F., Impact of pore-fluid chemistry on fine-grained sediment fabric and compressibility, 2018. *Journal of Geophysical Research, Solid Earth* (Accepted).

APPENDIX: PROJECT TIMELINE & MILESTONE TRACKING

Figure A1 is the updated Project timeline. Milestones and Success Criteria are listed thereafter, with updates given for elements in the current reporting period.

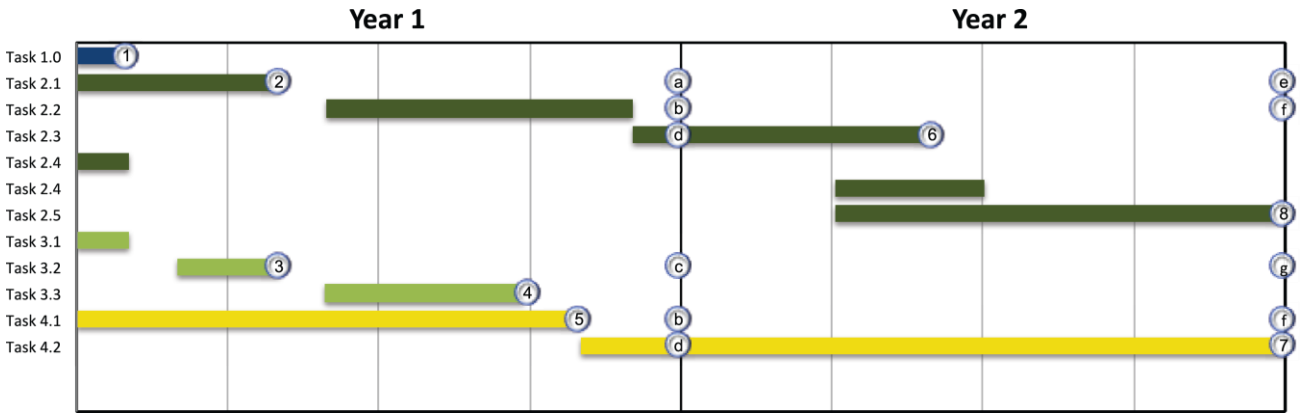

Figure A1: Updated project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given below.

Milestones (listed according to the numbers given in Figure A1)

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.

   Status: Completed. SOPO and PMP accepted by DOE. Kickoff meeting presentation complete.

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.

   Status: Initial phase of milestone completed. NGHP data has been collected on shipboard depressurized core material, but project will take the opportunity to collect additional data as pressure core material becomes available. Data will be integrated into a set of NGHP-02 special science volume papers currently with a February 2018 submission deadline.

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.

   Status: Completed. Data from this milestone have been incorporated into a conference paper and poster presented at the Ninth International Conference on Gas Hydrates (June 25- 30, 2017 in Denver, CO).

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.

   Status: Completed. Data from this task is partly included in the conference paper and poster presented at the Ninth International Conference on Gas Hydrates (June 25-30, 2017 in Denver, CO). Remaining data are being incorporated into a manuscript for peer-reviewed journal publication.

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.

   Status: LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for peer-reviewed journal publication. Micromodels to be used at the USGS will be constructed at LSU in the first quarter of BP 2 and shipped to the USGS.

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.

   Status: 2D micromodel studies on NGHP-02 fines have been completed, including data about mechanical clogging processes. A manuscript has been prepared for submission to the Journal of Marine and Petroleum Geology for inclusion in their special volume covering the NGHP-02 program. Submission planned for early in Year 2, 3Q (Joint with Task 4.2).

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

September 30, 2018. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.

8. Task 2, Site-specific dependence of compressibility and permeability on pore fluid chemistry (USGS). This data acquisition component of Task 2 will be completed September 30, 2018. Results will be verified for brines and freshened pore water by comparisons with pressure core data obtained elsewhere in the NGHP-02 project.

Success Criteria (listed according to the letters given in Figure A1)

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.

   Status: Initial phase of criteria completed. NGHP data has been collected on shipboard depressurized core material, but project will take the opportunity to collect additional data as pressure core material becomes available. Data will be integrated into a set of NGHP-02 special science volume papers currently with an April 2018 submission deadline.

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.

   Status: LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for the NGHP-02 special science volume, with an April 2018 submission deadline.

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.

   Status: Criteria complete. Conference paper and poster have been presented on this material at the Ninth International Conference on Gas Hydrates (June 25-June 30, 2017 in Denver, CO).

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.

Status: LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for the NGHP-02 special science volume, with an April 2018 submission deadline.

End of Budget Period 2

e. Subtasks 2.1, 2.4, 2.5: NGHP-02 fines properties (Offshore India). Index property measurements, liquid limit, compressibility and permeability 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. 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 2.

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.

Status: Manuscript has been accepted by the Journal of Geophysical Research: Solid Earth. As of June 17, 2018, the manuscript is in the journal's formatting stage.

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