Borehole Tool for the Comprehensive Characterization of Hydrate-Bearing Sediments

Project Period (10/1/2013 to 9/30/2016)

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

Submission date: 08/13/2015
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ACCOMPLISHMENTS

Context – Goals. *Physical properties of hydrate bearing sediments are critical for gas production strategies, geo-hazard mitigation and its impact on gas recovery engineering. Typically, the determination of physical properties rely on correlations and experimental data recovered from conventional and pressure cores. The inherent sampling disturbance and testing difficulties brings a new sets of uncertainties. In this research, we develop a new comprehensive borehole tool for the characterization of hydrate bearing sediments, and an IT tool for the physics-bases selection of appropriate parameters.*

Accomplishments

The main accomplishments for this period include:

- Borehole tool (sub-task 2.3: Parameter prediction)
  - Finite Element Simulation of Cone Penetration Testing
- Borehole tool design: body (sub-task 3.3: Design and construction)
- Borehole tool (sub-task 4.2: Lab testing)
- Borehole tool (sub-task 5.3: Deployment collaborator visit)

Plan - Next reporting period

Machining new body, upgraded electronics, and preparation for field testing in shallow sediments.

Research in Progress

Summarized in slides that follow (End-of-year 2 presentation)
Borehole Tool for the Comprehensive Characterization of Hydrate-Bearing Sediments

Transition to Phase 3 / Budget Period 3

DOE - National Energy Technology Laboratory
Agreement: DE-FE0013961

J. Carlos Santamarina
Georgia Institute of Technology
(on leave at KAUST)

Context – Goals

Physical Properties: Database & IT Tool
In Situ Characterization Tool
Developments @ KAUST

Next – Team – Schedule
Context

Goals

(additional information: see 2014 End of Year Report)

Context

Fundamental Scientific Questions
formation history (fluids sediments hydrates)
energy, C-cycle, climate

Engineering Needs
comprehensive characterization
engineering analyses
reservoir simulators
coupled HTCM processes
detection and monitoring

State-of-the-art:
properties weakest link in geo-analyses and engineering

Observation:
inherent and ubiquitous sampling effects
Hydrate ➔ Fluid: Volume Expansion

Standard Cores: Massive Destructuration

(a) In situ  (b) Effective stress relief  (c) Extra shear stress  (d) Water pressure release
Inherent Sampling Effects

Skinner and McCave, 2003
Clayton and Siddique, 1999

Inherent Sampling Effects

Sandy Soils (a)

- Sand; Stokoe’s Results - from Stokoe and Santamarina (2000)
- Alluvial Reclaimed Sandy Soil; Yasuda and Yamaguchi - from Tokimatsu and Uchida (1990)
- Fine Sand; Yasuda et al. (1989)
- Diffused Sandy Soil; Yasuda and Yamaguchi - from Tokimatsu and Uchida (1990)
- Sengangenya Sand; Shibuya et al. (1996)
- Ticino Sand; Ghionna - from Crova et al. (1992)
Inherent Sampling Effects

Characterization - Strategy

Index properties

Reconstituted specimens at proper $\sigma'$
  without hydrate
  with hydrate

Pressure cores within stability field PCCTs
  without $\sigma'$ control
  reloaded to in-situ $\sigma'$

In-situ tests ISTTs

Physical properties database ITT
Characterization – Strategy: PAST

- Disturbed specimens
- Geo-tech Design

Characterization – Strategy: FUTURE

- Disturbed specimens
- PCCTs
- Reconstituted & index properties
- In-situ
- IT tool
- Geo-tech Design
**IT Tool**

**Objectives**

- Parameter estimate with limited input data
- Design parameters for simulations and calculations
IT Tool

Objectives

- Parameter estimate with limited input data
- Design parameters for simulations and calculations

Parameters

<table>
<thead>
<tr>
<th>Properties</th>
<th>Parameters</th>
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<tr>
<td>Phase properties</td>
<td>Hydrate phase properties</td>
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<td>Gas phase properties</td>
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<tr>
<td></td>
<td>Liquid phase properties</td>
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<tr>
<td>Mechanical</td>
<td>Strength</td>
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<td>Stiffness</td>
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<td>Wave velocity</td>
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<td>Hydraulic</td>
<td>Soil water characteristic curve</td>
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<td>Hydraulic conductivity</td>
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<td></td>
<td>Permeability of HBS</td>
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<td>Relative permeability</td>
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<tr>
<td>Thermal</td>
<td>Thermal conductivity</td>
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<td></td>
<td>Heat capacity</td>
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</table>

Predicted Properties

Predicted by Santamarina and Ruppel (2008)
Uncertainty Analysis

MathCad Implementation
In Situ Characterization Tool

(additional information: see 2014 End of Year Report)

In-situ tool

Parts
- Body + Anchor + Lifting systems
- Soil sampling modules
- Penetrometer modules

Body
- Electronics + Batteries
- Peripheral components
## Governing Parameters

<table>
<thead>
<tr>
<th>Property</th>
<th>Sensor/method</th>
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<td><strong>Index Properties and Reservoir Characteristics</strong></td>
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<td>In-situ temperature - pressure</td>
<td>Direct measurement</td>
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<td>Porosity – Hydrate saturation</td>
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<tr>
<td>Grain size distribution – Fines content</td>
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<tr>
<td>Stratigraphy / hydrate morphology</td>
<td>From soil sampling / Video</td>
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<tr>
<td>Formation history</td>
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<td>Salinity</td>
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<td>Pore water geo-chemistry</td>
<td>From pore water sampling</td>
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<tr>
<td><strong>Thermal Properties</strong></td>
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<tr>
<td>Thermal conductivity</td>
<td>Direct measurement &amp; post-process</td>
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<td>Specific heat and Latent heat</td>
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<tr>
<td><strong>Hydraulic Properties</strong></td>
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<tr>
<td>Capillarity – Saturation curve - Relative k</td>
<td>Direct measurement &amp; post-process.</td>
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<tr>
<td>Hydraulic conductivity</td>
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<td>Potential migration pathways</td>
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<tr>
<td><strong>Mechanical Properties</strong></td>
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<tr>
<td>Lateral stress coefficient</td>
<td>Direct measurement &amp; post-process</td>
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<td>Soil Stiffness: shear and bulk stiffness</td>
<td>Direct measurement</td>
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<tr>
<td>Strength</td>
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<td>Stress-dependent dilatancy</td>
<td>From soil sampling</td>
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<td>Compressibility upon dissociation</td>
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## Tool: General

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<th>Material</th>
<th>SS316</th>
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<td><strong>Direct Measurements</strong></td>
<td>Penetration force</td>
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<tr>
<td><strong>Obtain Samples</strong></td>
<td>Pore fluid</td>
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</tbody>
</table>

Porous stainless steel 316 (sintered)

D = 36.5mm
Stress verification

\[ \sigma_{\text{max}} = 190 \text{ MPa} \]

Deployment – 3D FEM Simulation

Element Type RAX2 (rigid line element)
Effect of Cone Geometry

Contour Plot (von Mises stress)  Contour Plot (Shear Stress)

Tip: Force Calibration

$u_2 = 1.01P$

$R^2 = 0.999$
Tip: Field Test

Penetration resistance [MPa]

Depth [cm]

CPT
Load cell

Tip: Temperature Calibration

Reduced delay

To data acquisition unit

Cooling reaction time = 10 sec
Heating reaction time = 8 sec

Temperature [°C]

Time [min]

Strain gauge voltage [mV]

Temperature, T [°C]

Room and CPT temp.

Temperature, T [°C]

Time, t [min]
Hydr. Conductivity and Mini Production

PT = Pressure Transducer  
S = Solenoid valve

Filter Calibration

Permeability

Flow rate [m³/s]  
Flow rate [m³/s]

Pressure control test

Flow control test

Filter denomination:
- CPT Std (Plastic)
- 100 (SS316)
- 40 (SS316)
- 20 (SS316)
System Verification

Electrical Conductivity Calibration

AC signal:
Frequency: 100 kHz
Amplitude: 2 V ($V_{pp} = 4V$)

$$R = \frac{V_N}{V_V - V_N} R_{fxx}$$

Best fit:
$$p = 0.169 R - 0.0.26 R [k\Omega]$$
**Sampler**

- (1) Cutting shoe
- (2) Sampler tube
- (3) Catcher

---

**Sampler Field Verification**

- Sampler 1: 25.4 mm
- Sampler 2: 25.4 mm
- Sampled length
- Frequency: 0.5 Hz
- W = 1.2 kg
- Depth: 19 mm
- Width: 17.7 mm
- 29.4 mm

---

8/4/2015
Sampler Field Test Results

Video

Final design not finalized
Body Assembly – Test: Shallow Sediments

Electronics

<table>
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<th>Specification</th>
<th>Description</th>
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<td>CPU</td>
<td>16 MHz ATmega328</td>
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<tr>
<td>Sampling frequency</td>
<td>Up to 1 ms</td>
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<tr>
<td>Memory flash</td>
<td>32 K</td>
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<tr>
<td>Size</td>
<td>2.7in x 2.1in</td>
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<tr>
<td>Power</td>
<td>Batteries / USB / AC-to-DC adapter</td>
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<tr>
<td>Pc connection</td>
<td>USB port</td>
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<tr>
<td>Resolution</td>
<td>10 bits (expandable)</td>
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<tr>
<td>Memory storage</td>
<td>Peripheral / SD card</td>
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<tr>
<td>Price</td>
<td>~$30</td>
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Arduino works as a Power Supply and Data Logger
Electronics Calibration

Power Consumption

Developments @ KAUST
Seeps
*Shallow marine accumulations*
Collaboration ➔ KAUST’ CMOR

Main Building
High Pressure Testing Vessel

CMOR Testing Fleet

Seeps? Shallow Hydrate Accumulations?

Skarke et al. (2014)

Skarke et al. (2014)
Seeps? Shallow Hydrate Accumulations?

Gas Migration and Hydrate Formation
Context – Goals

Physical Properties: Database & IT Tool

In Situ Characterization Tool

Developments @ KAUST

Next – Team – Schedule

Coming up?

**IT Tool**
Completion - Release

**Characterization Tool**
Complete modules and pressure test

Deploy Red Sea
implications to gas seeps
implications to shallow marine accumulations

Develop Coupling Method to Drill
Team:

NN (1st year)

Sheng Dai

Marco Terzariol (PostDoc – GT/KAUST)
Zhonghao Sun (PhD – GT @ KAUST)

Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<tbody>
<tr>
<td>Task 1.0 Project Management and Planning</td>
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<tr>
<td>Task 2.0 - Knowledge and IT</td>
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<tr>
<td>2.1 - Properties - database</td>
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<td>2.2 - Robust correlations</td>
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<tr>
<td>2.3 - Parameter prediction IT tool - Uncertainty</td>
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<td>Task 3.0 Borehole Tool Design - A: Body</td>
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<td>3.1 - Insertion alternatives</td>
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<td>3.2 - Preliminary mockups</td>
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<td>3.3 - Design and construction of components</td>
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<td>3.4 - Complete construction and assembly</td>
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<td>Task 4.0 Borehole Tool Design - B: Instrument</td>
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<td>4.1 - Interchangeable tools - Electronics</td>
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<td>4.2 - Prototypes - Lab testing</td>
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<td>4.3 - Complete construction and assembly</td>
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<td>Task 5.0 - Full-Scale Prototype Lab-Assessment</td>
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<tr>
<td>5.1 - Analogue sediment / Set up</td>
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<tr>
<td>5.2 - Test tool operation</td>
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<td>5.3 - Discuss with Industry Collab.</td>
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<td>Task 6.0 - Field Deployment</td>
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## MILESTONE LOG

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<th>Verification method</th>
<th>Milestone</th>
<th>Completion Date</th>
<th>Comments</th>
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<td>Insertion – Tool design</td>
<td>September 2014</td>
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<td>9/2014 Paper in preparation</td>
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<td>Electronics in operation</td>
<td>January 2015</td>
<td>Continued progress</td>
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<td>Lab testing of prototype</td>
<td>September 2015</td>
<td>Continued progress</td>
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<td>Tool deployment</td>
<td>Before September 2016</td>
<td>In progress</td>
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## PRODUCTS

- **Publications – Presentations:** None at this point
- **Website:** Publications and key presentations are included in [http://egel.kaust.edu.sa/](http://egel.kaust.edu.sa/). (for academic purposes only)
- **Technologies or techniques:** None at this point.
- **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 is shown next. We anticipate including external collaborators as the project advances.

IMPACT
None at this point.

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 (Note: in our academic cycle, higher expenditures typically take place during the summer quarter):
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<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
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<td>Total Incurred Costs</td>
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<td>45,109</td>
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