Oil & Natural Gas Technology

DOE Award No.: DE- FE0013961

Quarterly Research Performance Progress Report
(Period ending 06/30/2015)

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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National Energy Technology Laboratory

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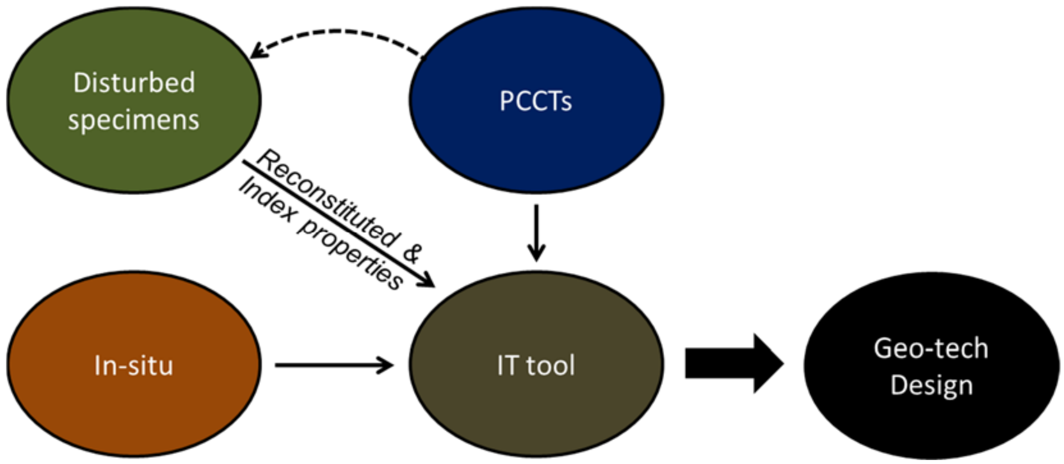
Office of Fossil Energy

DISCLAIMER:

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

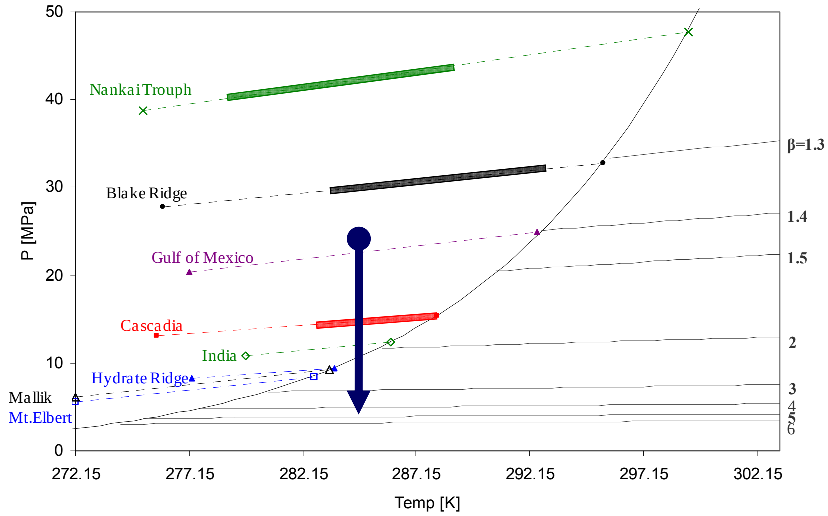
Fundamental Scientific Questions
- formation history (fluids sediments hydrates)
- energy, C-cycle, climate

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



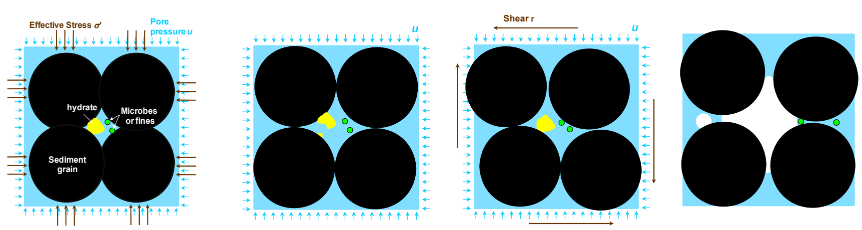
Standard Cores: Massive Destructuration

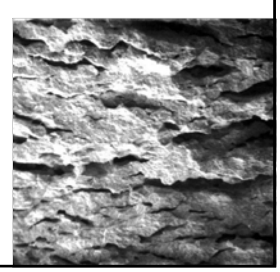
(a) In situ

(b) Effective stress relief

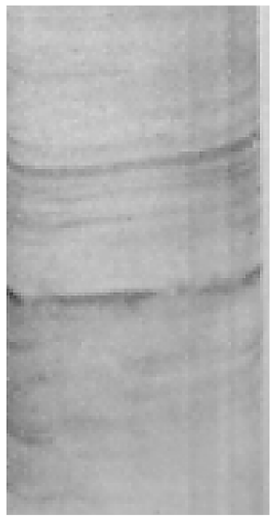
(c) Extra shear stress

(d) Water pressure release

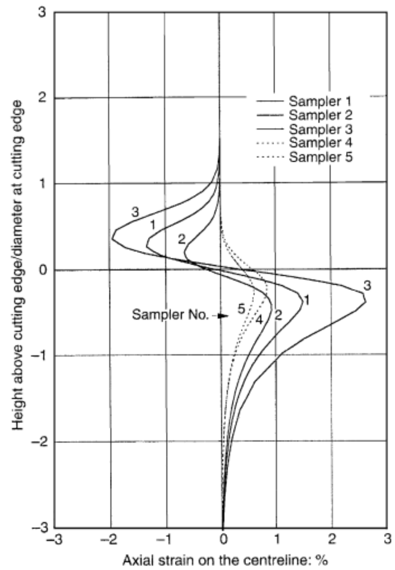




Inherent Sampling Effects

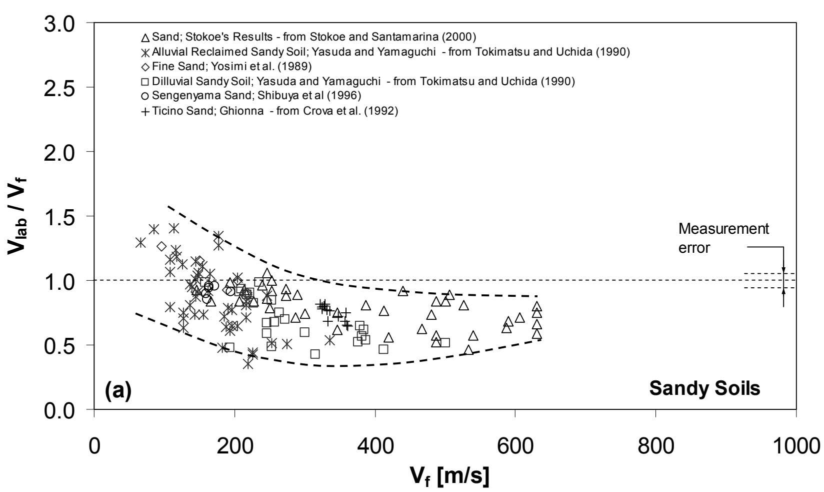


Skinner and McCave, 2003

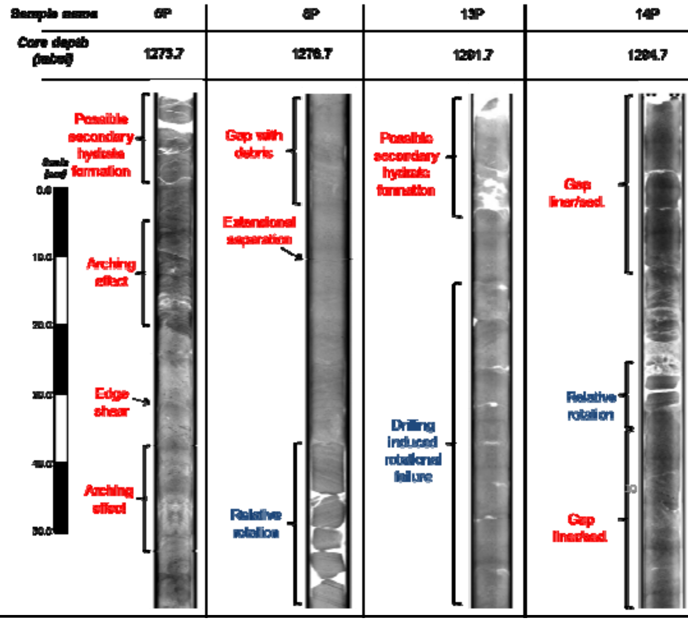


Clayton and Siddique, 1999

Inherent Sampling Effects



Inherent Sampling Effects



Characterization - Strategy

Index properties

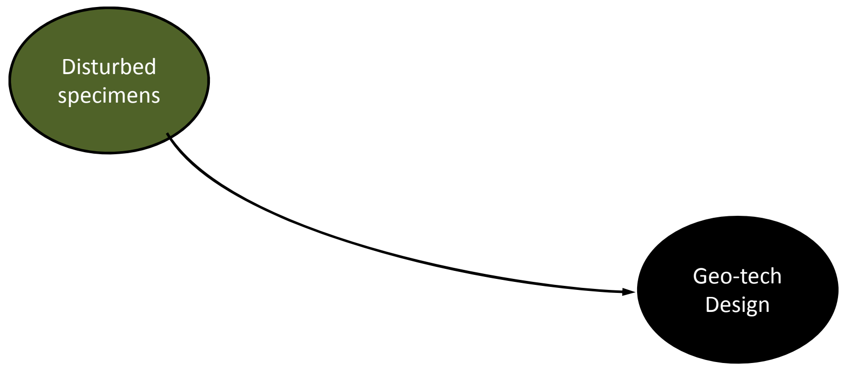
Reconstituted specimens at proper σ'
without hydrate
with hydrate

Pressure cores within stability field PCCTs
without σ' control
reloaded to in-situ σ'

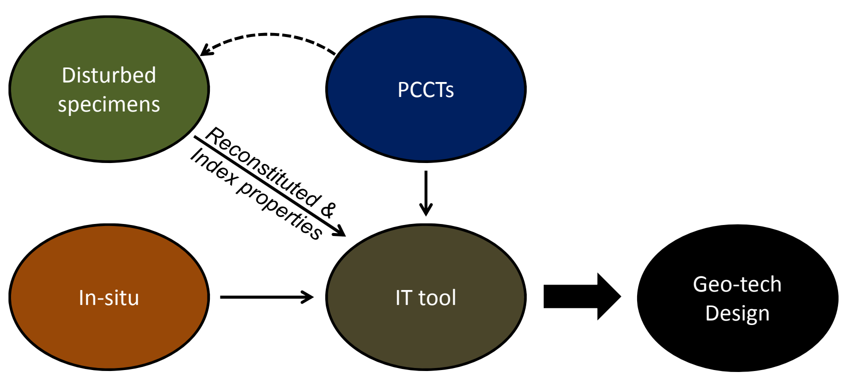
In-situ tests ISTTs

Physical properties database ITT

Characterization – Strategy: PAST



Characterization – Strategy: FUTURE



physics inspired… engineering driven !

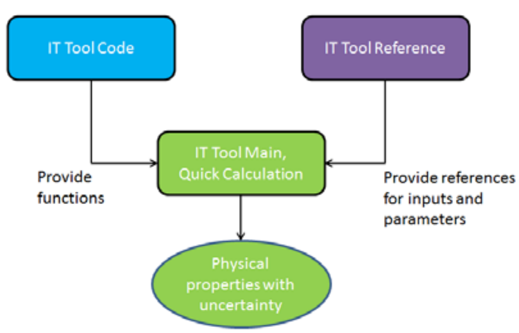
Physical Properties
Database
IT tool

(additional information: see 2014 End of Year Report)

IT Tool

Objectives

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



IT Tool

Objectives

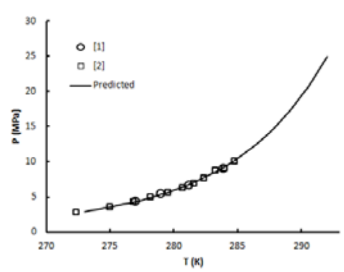
- Parameter estimate with limited input data
- Design parameters for simulations and calculations

Parameters

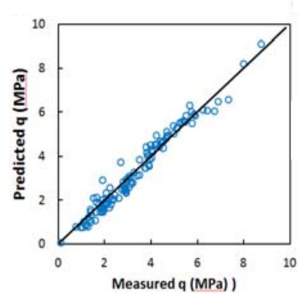
	Properties
Phase properties	Hydrate phase properties
	Gas phase properties
	Liquid phase properties
Mechanical	Strength
	Stiffness
	Wave velocity
Hydraulic	Soil water characteristic curve
	Hydraulic conductivity
	Permeability of HBS
	Relative permeability
Thermal	Thermal conductivity
	Heat capacity

Predicted Properties

Phase Properties

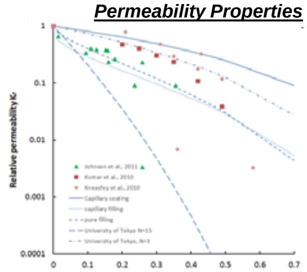


Mechanical Properties

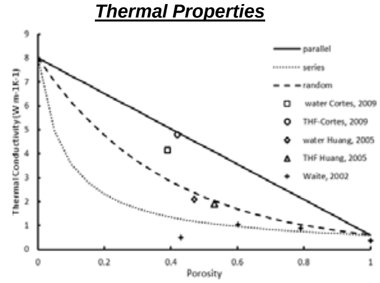


Predicted by Santamarina and Ruppel (2008)

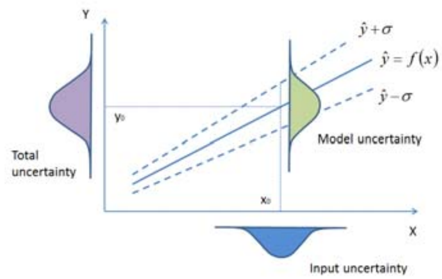
Permeability Properties

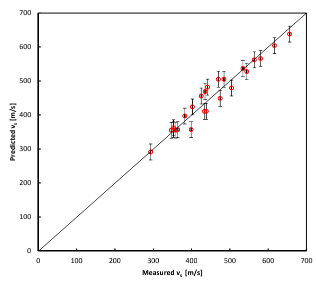


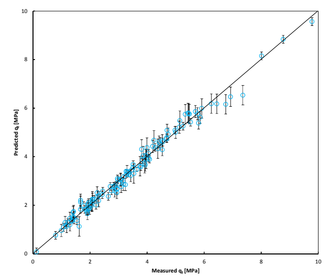
Thermal Properties



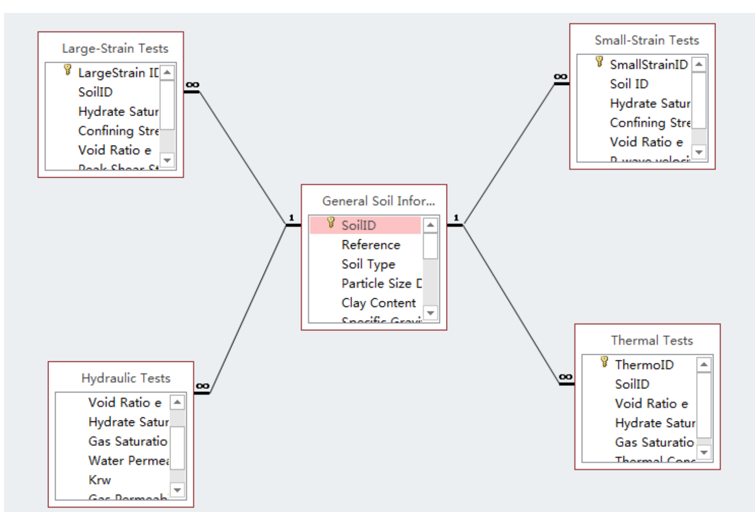
Uncertainty Analysis







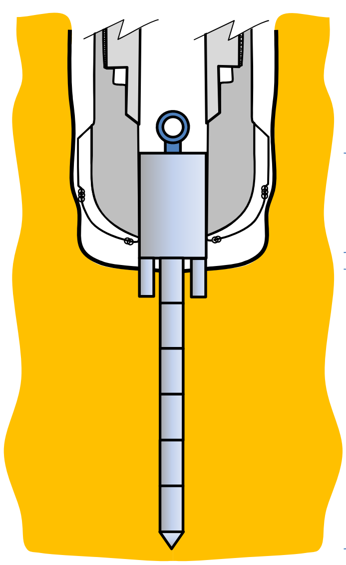
MathCad Implementation



In Situ Characterization Tool

(additional information: see 2014 End of Year Report)

In-situ tool



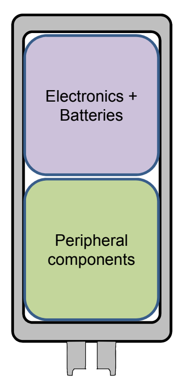
Parts

Body + Anchor + Lifting systems

Soil sampling modules

Penetrometer modules

Body

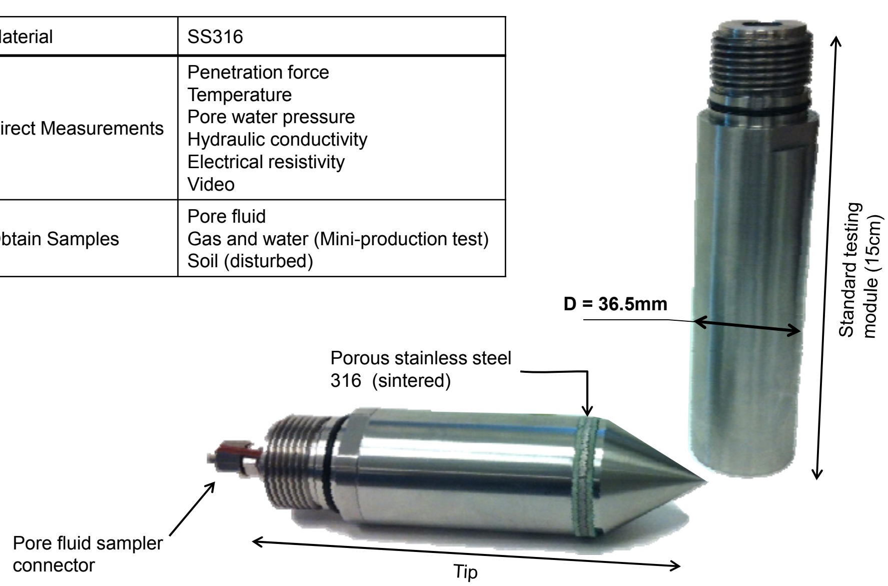


Governing Parameters

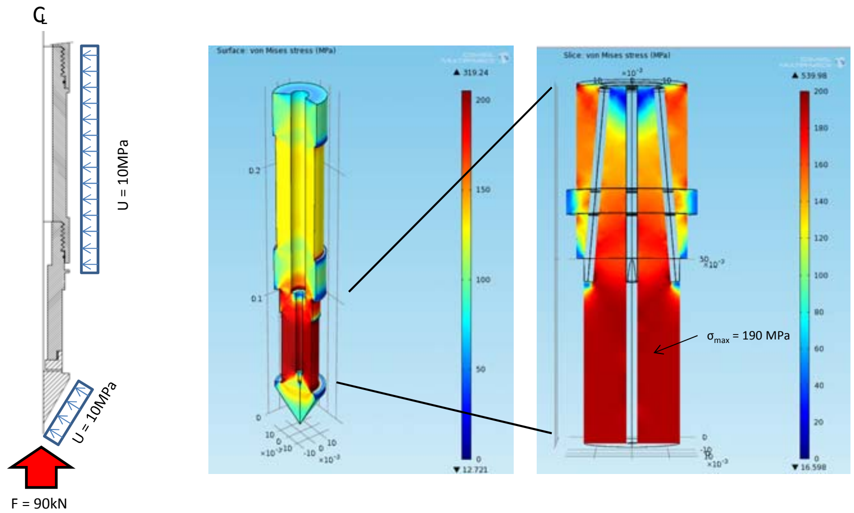
	Property	Sensor/method
Index Properties and Reservoir Characteristics	*In-situ temperature - pressure*	Direct measurement
	Porosity – Hydrate saturation	
	Grain size distribution – Fines content	From soil sampling / Video
	Stratigraphy / hydrate morphology	
	Formation history	
	Salinity	From pore water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

Tool: General

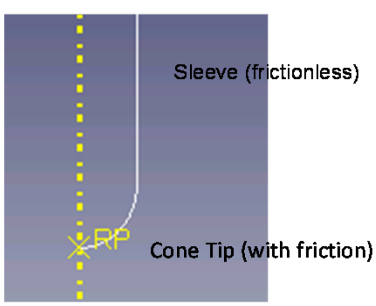
Material	SS316
Direct Measurements	Penetration force Temperature Pore water pressure Hydraulic conductivity Electrical resistivity Video
Obtain Samples	Pore fluid Gas and water (Mini-production test) Soil (disturbed)



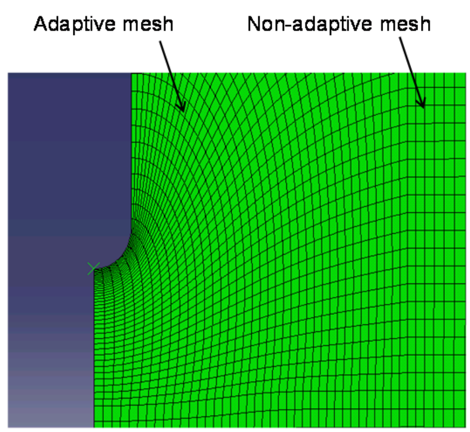
Stress verification



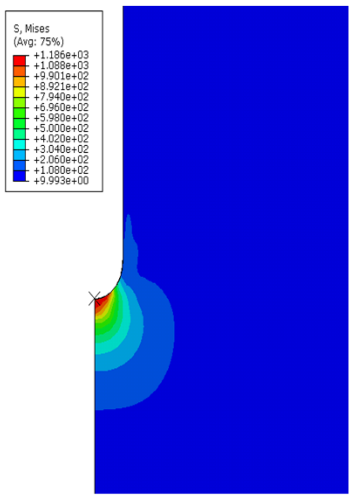
Deployment – 3D FEM Simulation



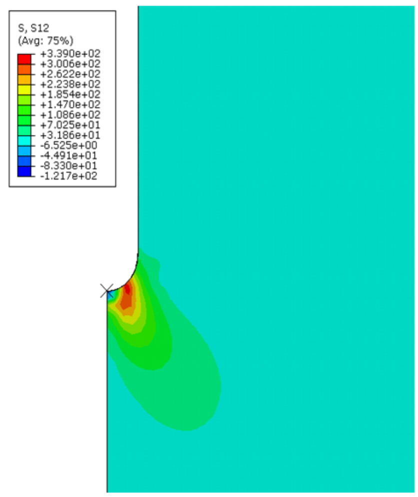
Element Type RAX2
(rigid line element)



Effect of Cone Geometry

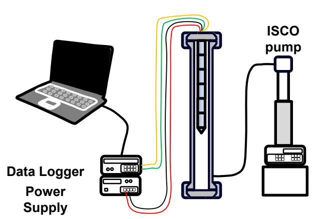


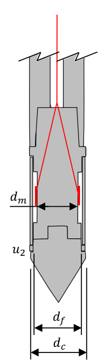
Contour Plot (von Mises stress)

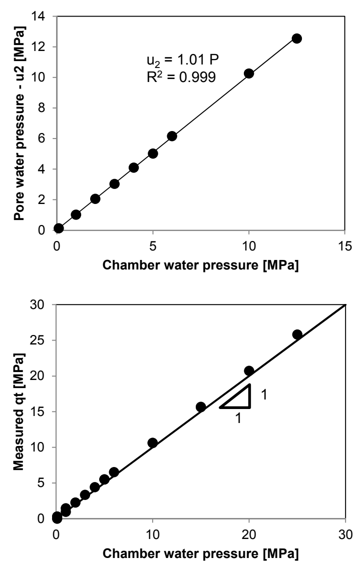


Contour Plot (Shear Stress)

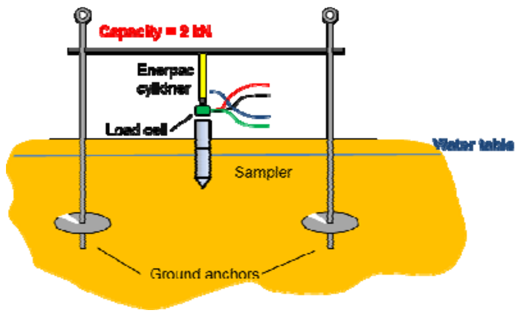
Tip: Force Calibration

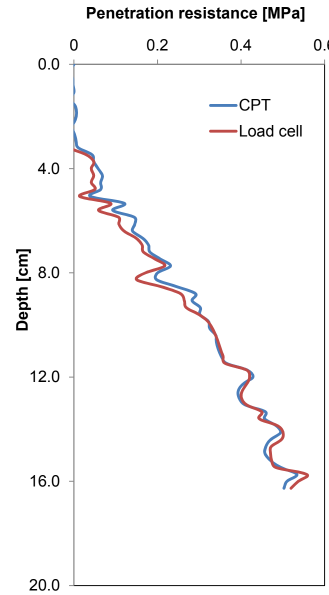






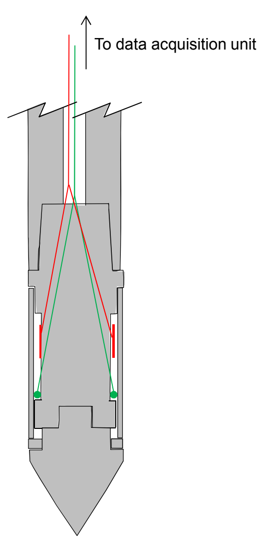
Tip: Field Test

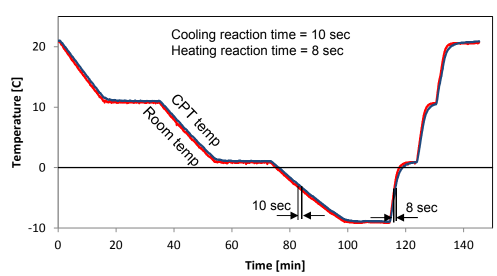


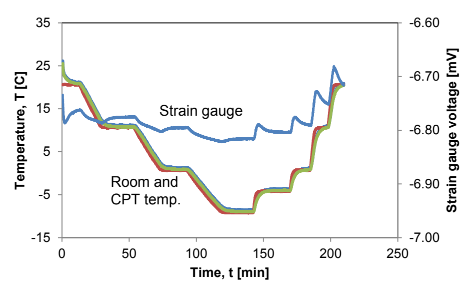


Tip: Temperature Calibration

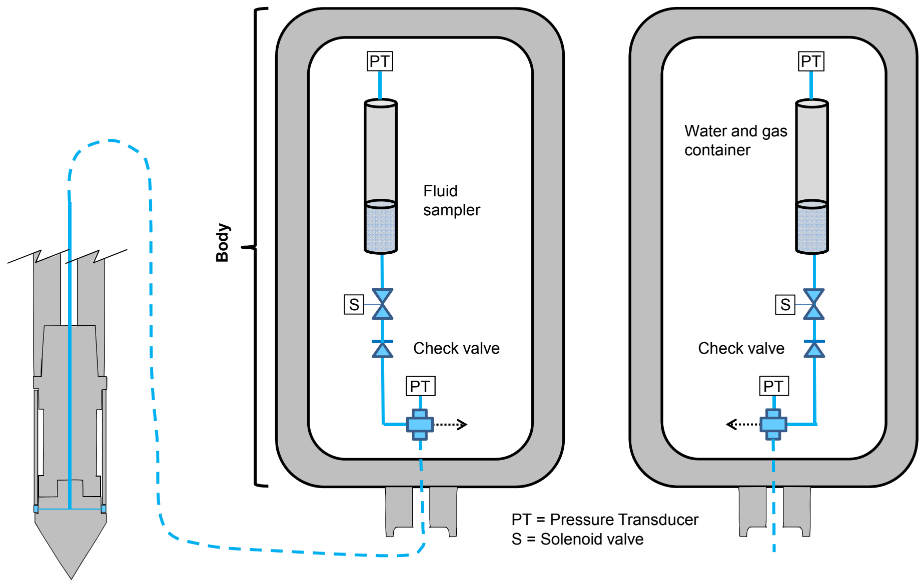
Reduced delay



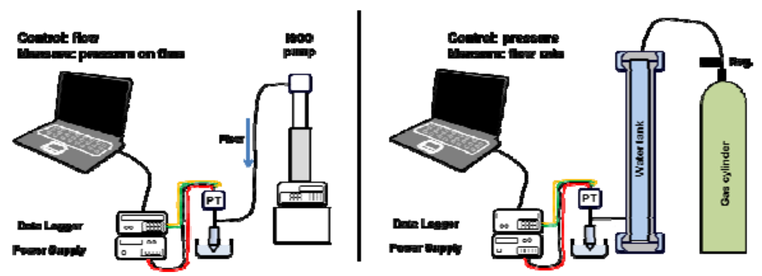


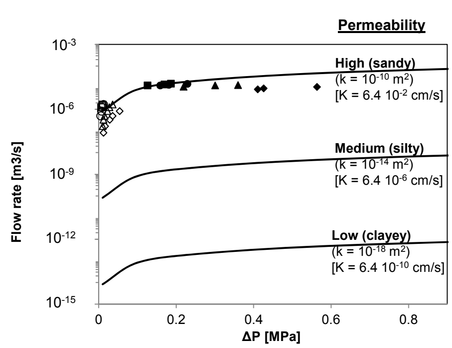


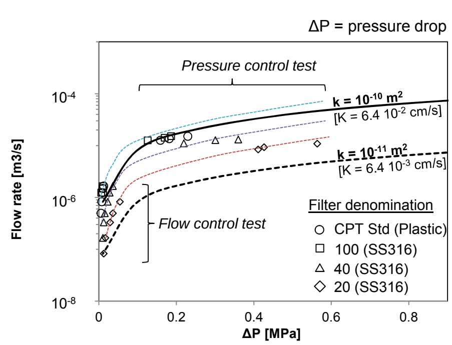
Hydr. Conductivity and Mini Production



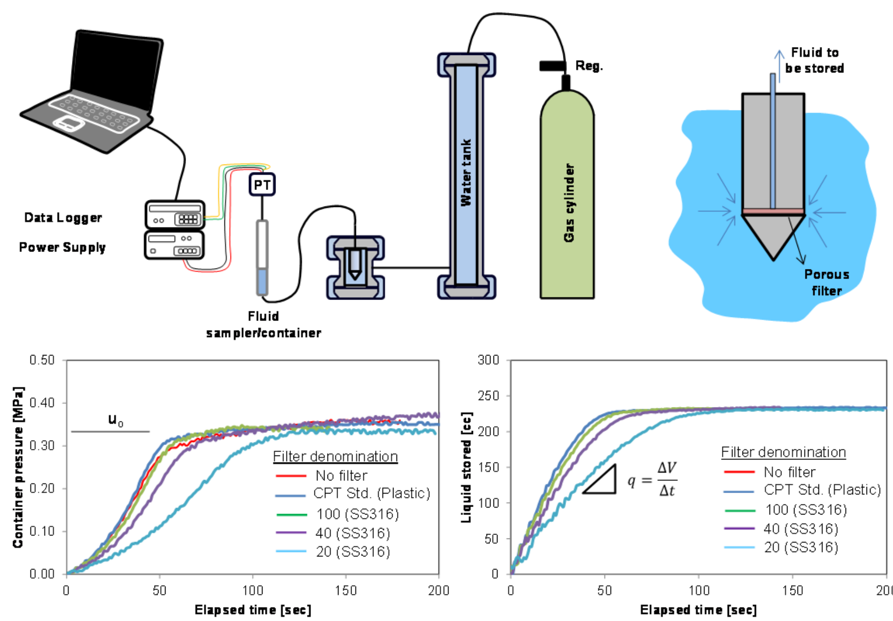
Filter Calibration



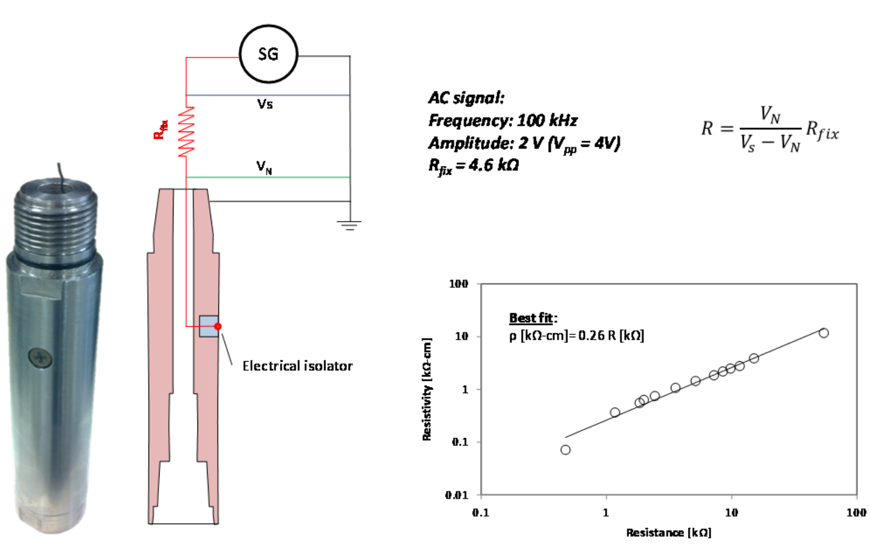




System Verification



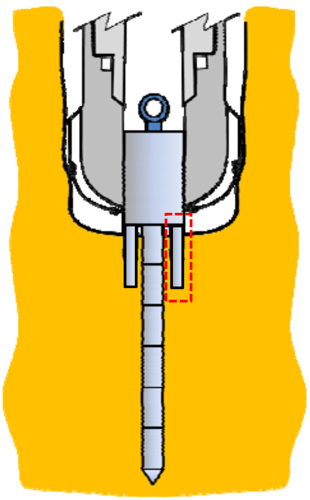
Electrical Conductivity Calibration

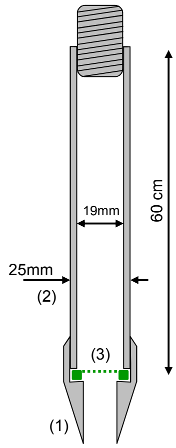


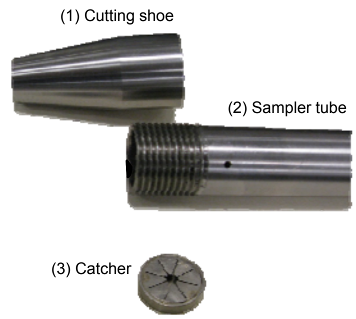
AC signal:
Frequency: 100 kHz
Amplitude: 2 V (V_{pp} = 4V)
R_{fix} = 4.6 kΩ

$$R = \frac{V_N}{V_s - V_N} R_{fix}$$

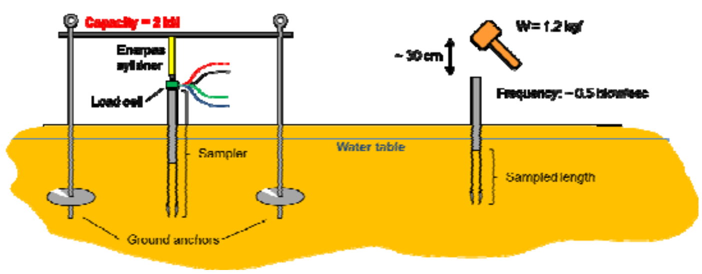
Sampler

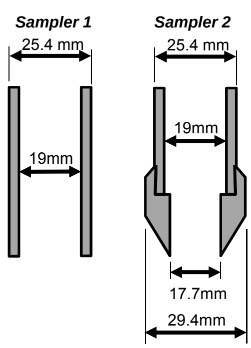




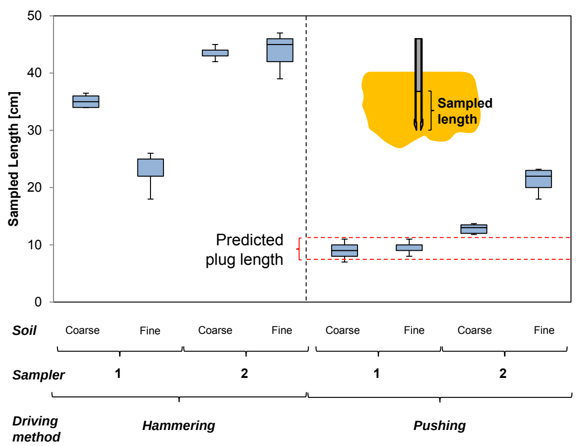


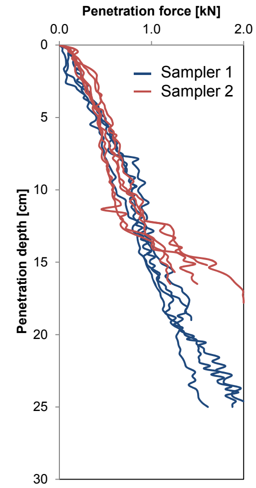
Sampler Field Verification



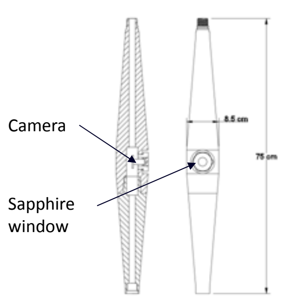


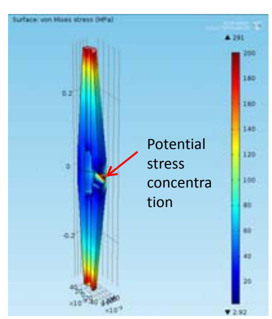
Sampler Field Test Results





Video



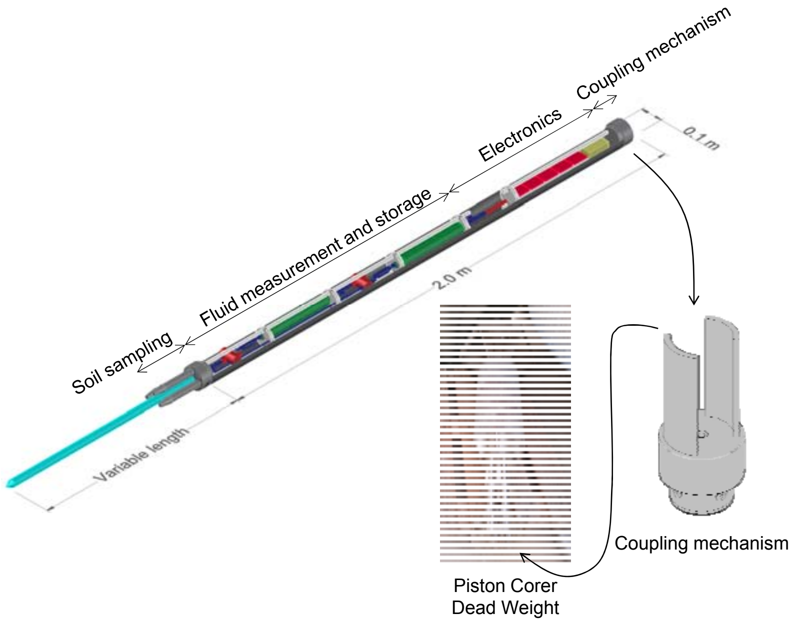


Final design not finalized

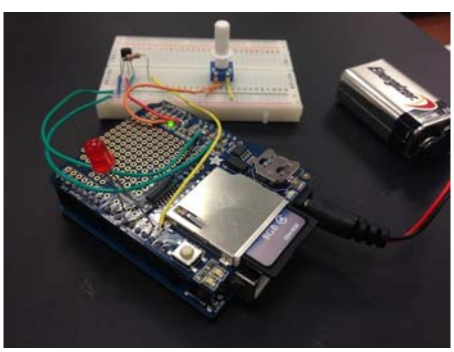
Blasting Sand

Ottawa 20-30

Body Assembly – Test: Shallow Sediments



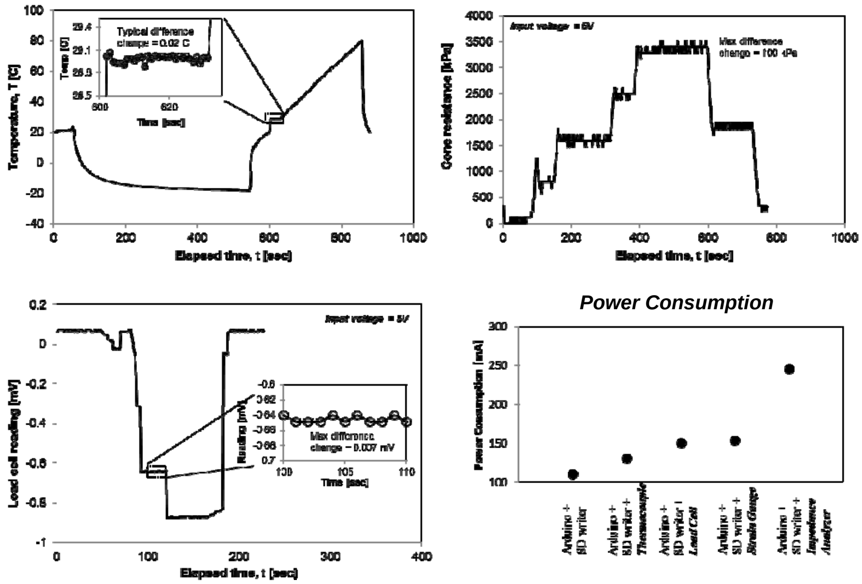
Electronics



CPU	16 MHz ATmega328
Sampling frequency	Up to 1 ms
Memory flash	32 K
Size	2.7in x 2.1in
Power	Batteries / USB / AC-to-DC adapter
Pc connection	USB port
Resolution	10 bits *(expandable)*
Memory storage	Peripheral / SD card
Price	**~$30**

Arduino works as a Power Supply and Data Logger

Electronics Calibration



Developments @ KAUST

Seeps
Shallow marine accumulations

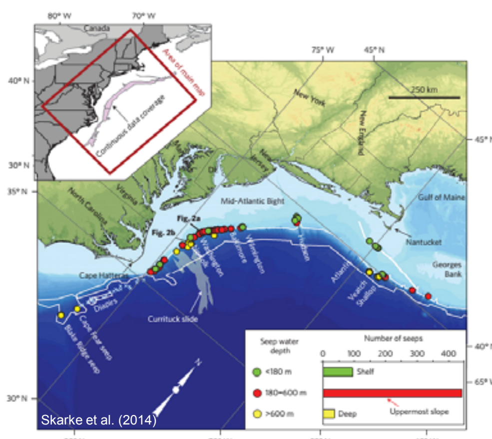
Collaboration ➔ KAUST' CMOR

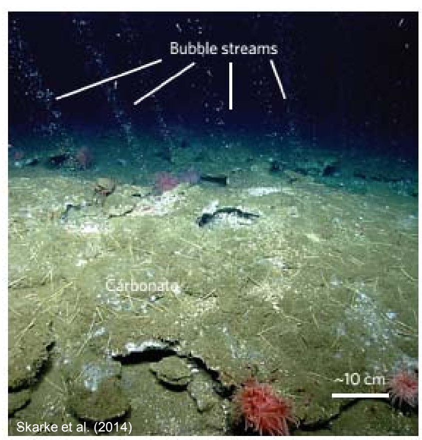
Main Building

High Pressure Testing Vessel

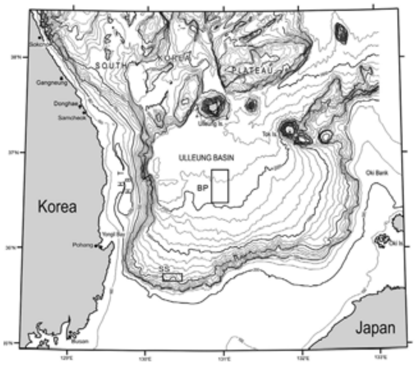
CMOR Testing Fleet

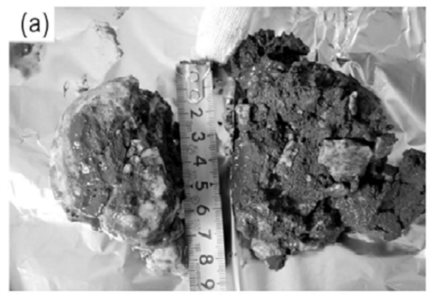
Seeps? Shallow Hydrate Accumulations?





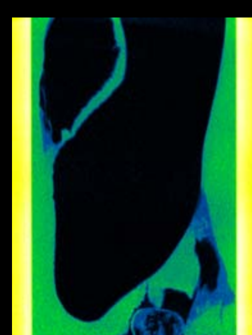
Seeps? Shallow Hydrate Accumulations?

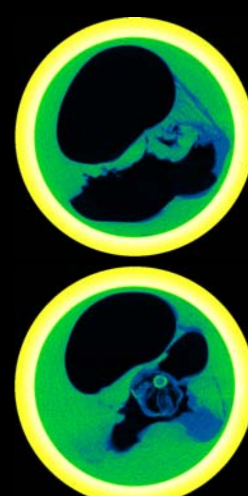




Bahk et al. (2009)

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

	Year 1 10/1/2013 → 9/30/2014	Year 2 10/1/2014 → 9/30/2015	Year 3 10/1/2015 → 9/30/2016
Task - 1.0 Project Management and Planning			
Task 2.0 - Knowledge and IT			
2.1 - Properties - database			
2.2 - Robust correlations			
2.3 - Parameter prediction IT tool - Uncertainty			
Task 3.0 Borehole Tool Design - A: Body			
3.1 - Insertion alternatives			
3.2 - Preliminary mockups			
3.3 - Design and construction of components			
3.4 - Complete construction and assembly			
Task 4.0 Borehole Tool Design - B: Instrument			
4.1 - Interchangeable tools - Electronics			
4.2 - Prototypes - Lab testing			
4.3 - Complete construction and assembly			
Task 5.0 - Full-Scale Prototype Lab-Assessment			
5.1 - Analogue sediment / Set up			
5.2 - Test tool operation			
5.3 - Discuss with Industry Collab.			
Task 6.0 - Field Deployment			

MILESTONE LOG

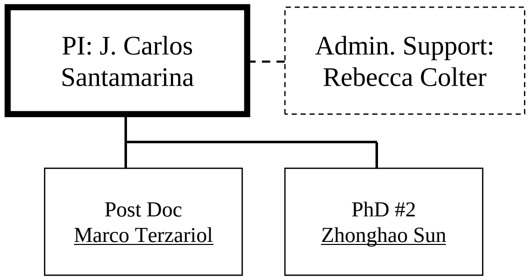
	Milestone	Completion Date	Comments
Title Planned Date Verification method	Completion PMP November 2013 Report	11/2013	
Title Planned Date Verification method	Insertion – Tool design September 2014 Report	9/2014	
Title Planned Date Verification method	Database and IT tool September 2014 Report	9/2014	Paper in preparation
Title Planned Date Verification method	Electronics in operation January 2015 Report	Continued progress	
Title Planned Date Verification method	Lab testing of prototype September 2015 Report	Continued progress	
Title Planned Date Verification method	Tool deployment Before September 2016 Report	In progress	

PRODUCTS

- **Publications – Presentations:** None at this point
- **Website:** Publications and key presentations are included in 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):

Baseline Reporting Quarter DE-FE0013961	Budget Period 1								Budget Period 2							
	Q1		Q2		Q3		Q4		Q1		Q2		Q3		Q4	
	10/1/13 - 12/31/13		1/1/14 - 3/31/14		4/1/14 - 6/30/14		7/1/14 - 9/30/14		10/1/14 - 12/31/14		1/1/15 - 3/31/15		4/1/15 - 6/30/15		7/1/15 - 9/30/15	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baseline Cost Plan																
Federal Share	34,736	34,736	34,736	69,472	34,736	104,208	34,736	138,944	30,000	168,944	30,000	198,944	30,000	228,944	86,571	315,515
Non-Federal Share	13,326	13,326	13,327	26,653	13,327	39,980	-	39,980	10,495	50,475	10,495	60,970	10,495	71,465	10,945	82,410
Total Planned	48,062	48,062	48,063	96,125	48,063	144,188	34,736	178,924	40,495	219,419	40,495	259,914	40,495	300,409	97,516	397,925
Actual Incurred Cost																
Federal Share	-	-	20,865	20,865	45,109	65,973	55,929	121,902	64,746	186,648	38,605	225,253	19,041	244,294		244,294
Non-Federal Share	-	-	-	-	39,980	39,980	-	39,980	10,601	50,580	27,525	78,105	-	78,105		78,105
Total Incurred Costs	-	-	20,865	20,865	85,089	105,953	55,929	161,881	75,347	237,228	66,130	303,358	19,041	322,399	-	322,399
Variance																
Federal Share	-34,736	-34,736	-13,871	-48,607	10,373	-38,235	21,193	-17,042	34,746	17,704	8,605	26,309	-10,959	15,350		
Non-Federal Share	-13,326	-13,326	-13,327	-26,653	26,653	0	0	0	106	105	17,030	17,135	-10,495	6,640		
Total Variance	-48,062	-48,062	-27,198	-75,260	37,026	-38,235	21,193	-17,043	34,852	17,809	25,635	43,444	-21,454	21,990		

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