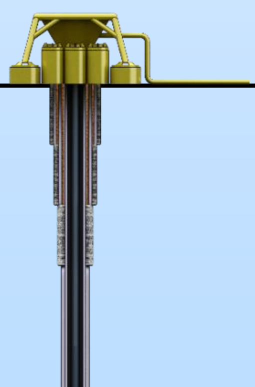
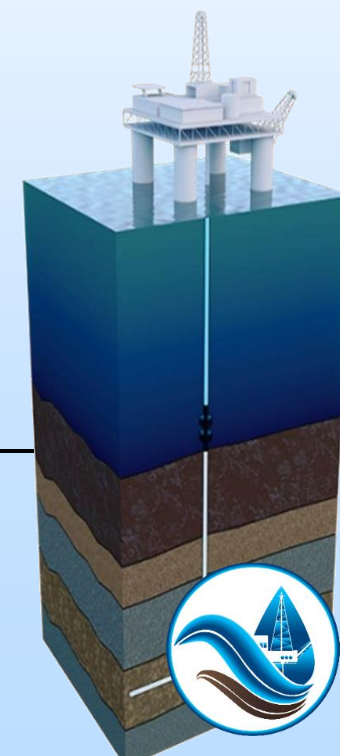
Improving Science-Base for Well Integrity, Barrier Interface Performance

Offshore Unconventional Resources FWP – Task 4

Nicolas Huerta

NETL – R&IC





U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

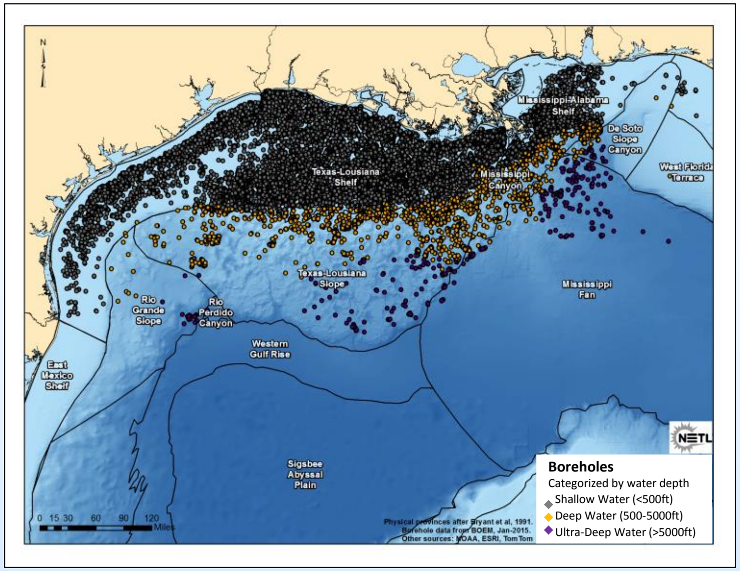
August 16-18, 2016

Presentation Outline

- Project overview and benefit to Program
- Sub-Task 1
- Sub-Task 2
- Sub-Task 3
- Future work and opportunities for collaboration
- Summary

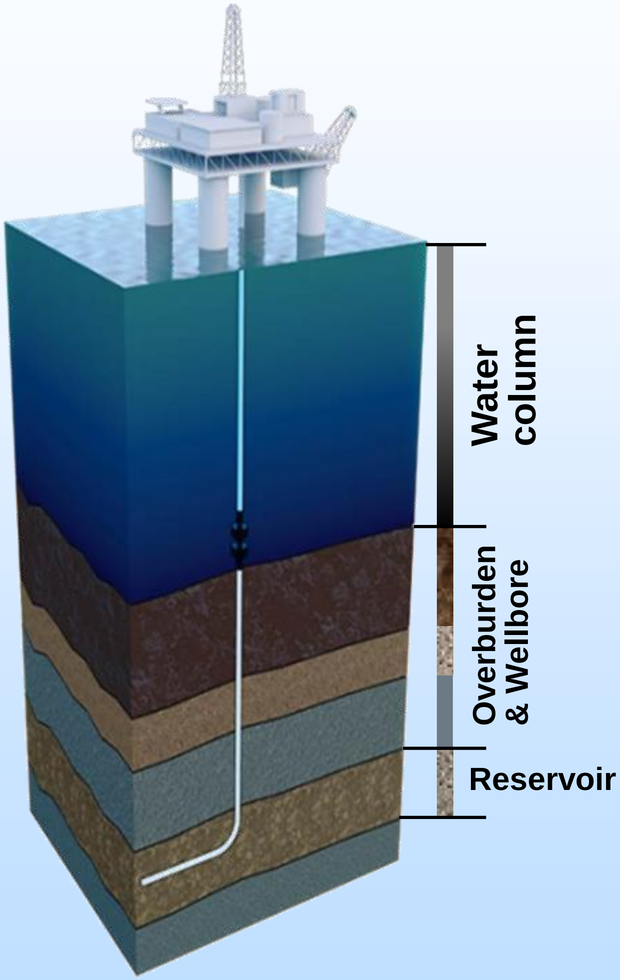
Benefit to the Program

Maintaining well integrity in the offshore remains a **significant challenge** for prudent exploration and production that **minimizes** safety **incidences** and **environmental** impacts. Safe construction and long-term well integrity in offshore hydrocarbon production depends on the appropriate choice of materials based on the specific needs of the environment. These **environments present unique challenges** including high pressure/high temperature subsurface conditions, Arctic weather conditions, complex geomechanics (e.g. narrow fracture gradients), corrosive reservoir fluids, poorly consolidated formations, and the presence of hydrates or permafrost. Well design and construction must be sufficient to withstand the particular environmental challenges over the entire life of the well.



- This work supports the DOE Fossil Energy mission of ***Responsible Development of America's Oil and Gas Resources***
- The goal of this task is to advance our understanding of the fundamental processes involved in maintaining well integrity along barrier interfaces in the offshore environment.
  - ***Additionally, this effort will establish NETL capabilities to test new and novel technologies for maintaining well integrity in challenging environment.***

Historical context of NETL's in house R&D Offshore Portfolio (2011 – Present)



Wellbore Integrity – Improved Science Base for Materials

- Characterizing the Behavior of Metal-Based Systems Used for Control Devices in Extreme Environments, *Hawk, J.* ***5:30pm Tuesday***
- Improving Science-Base for Wellbore Integrity, Foam Cements
- Evaluation of Lithology/Cement/Casing Barrier Integrity under UDW Subsurface Conditions , *Huerta, N.* ***4:05pm Wednesday***

56 presentations
22 publications

Rapid Detection and *In Situ* Characterization – Improving Safety

- Kick Detection at the Drill Bit - Adaptation of Existing Technology to Reduce Risks Associated with Deep and Ultra-Deep Drilling
- **Completed**: Improving Flow Assurance, Expediting Well Control, and Reducing Environmental Impacts Resulting from Blow-Outs in HPLT Environments

8 presentations
9 publications

Risk Reduction - Mitigating Knowledge & Technology Gaps in Offshore Systems

- Quantifying Complex Fluid-Phase Properties at High Pressure/High Temperature (HPHT)
- Assessing Risks and the Potential for Environmental Impacts for Deepwater and Ultra-Deepwater GOM Resources, *Rose, K.* ***5:05 Tuesday***

58 presentations
34 publications
8 datasets
8 tools
2 patents pending

Project Overview: Goals and Objectives

Task 4.0 – Improving Science-Base for Well Integrity, Barrier Interface Performance

The objective of this task is to **advance the science-base** for **understanding critical weak-links** in the **well integrity** system through:

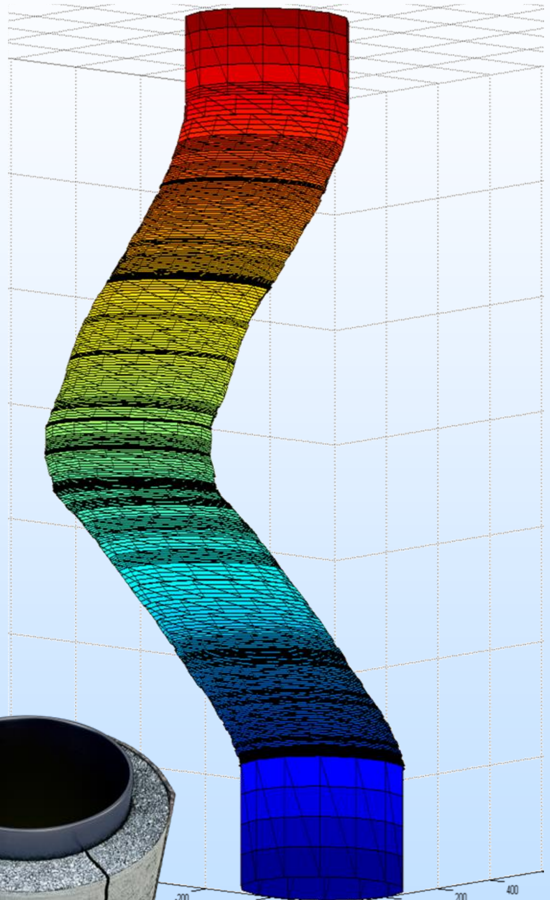
- Modeling of well system geomechanics, including poro-elasticity and thermal effects to identify conditions that lead to failure.
- Develop a borehole simulator apparatus that can simulate components of the drilling and cementing process at conditions.
- Develop a reduced-scale well system that can be subjected to thermal and fluid stresses to induce failure and to be able to image this failure and test technologies for investigating or sealing of this pathway.

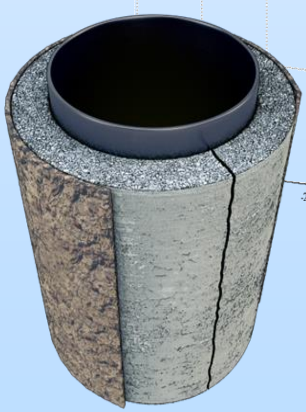
The product of this research will be tools and data that industry and regulators can use to compare with their own in-house codes and technologies. This will lead to safer operations in the offshore environment.

Sub-Task 4.1 Modeling of well system geomechanics, including poro-elasticity and thermal effects to identify conditions that lead to failure

Background

- Well that are inadequately designed for the complex offshore geomechanical environment can lead to loss of well integrity
- This is true as we move to ultra-deep waters that require new types of casing and cements
- Failure can also result from alteration of the stress state, changes in material properties, and unintended operations on the well
- Most commercial well design models that account for geomechanics are proprietary and lack external QA/QC





Technical approach

- Start simple and build off the work of others
  - Scour the literature for case studies of well failure
  - Utilize simple analytical model
- Develop FEM numerical code
  - Validate with analytical model
  - Upgrade model for thermal effects
  - Incorporate poro-elasticity

Initial results – Analytical model

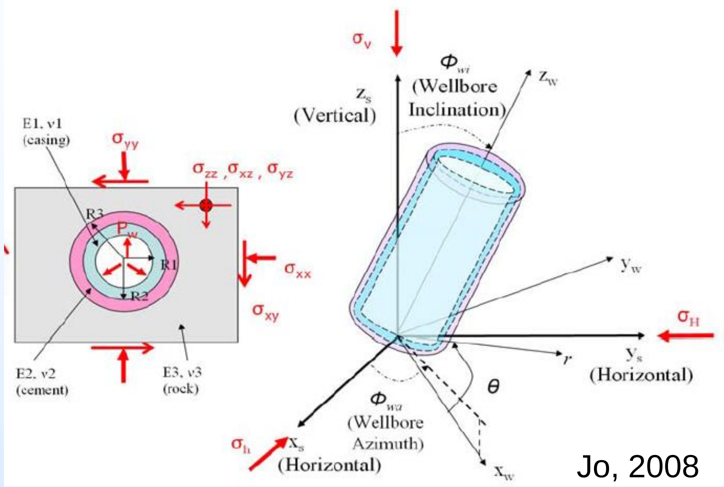
Started with dissertation work of Jo, 2008

Key assumptions:

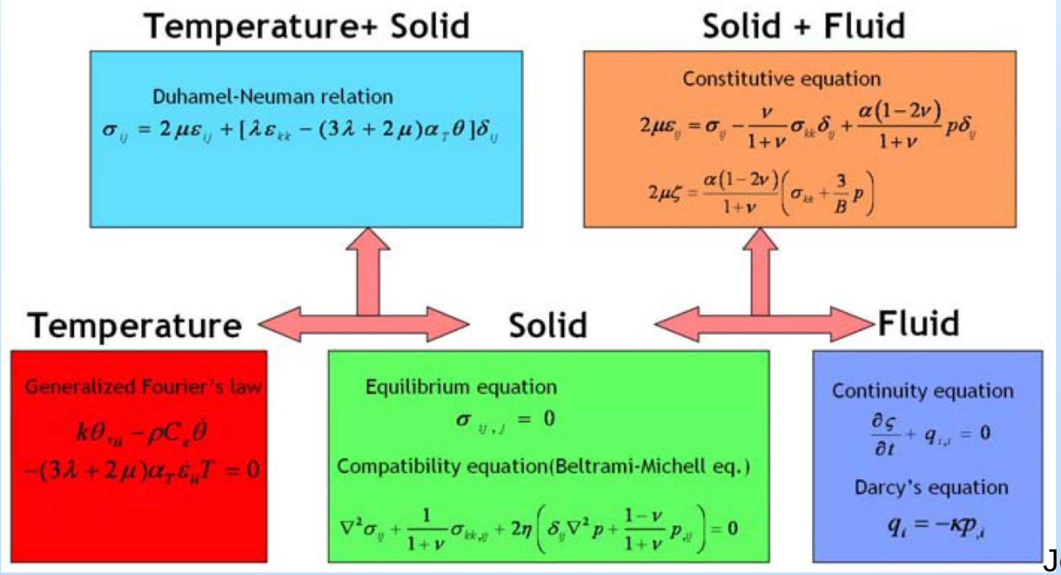
- Perfect bonds exist at interfaces
- Homogeneous, isotropic, linearly (poro)elastic
- Small displacements

Added in:

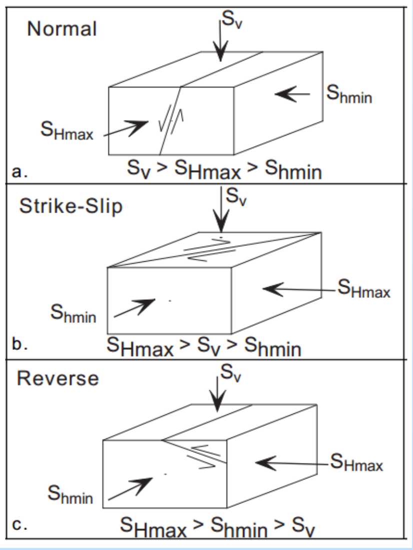
- Tectonic stress state boundary condition via tensor transformation



Jo, 2008



Jo, 2008

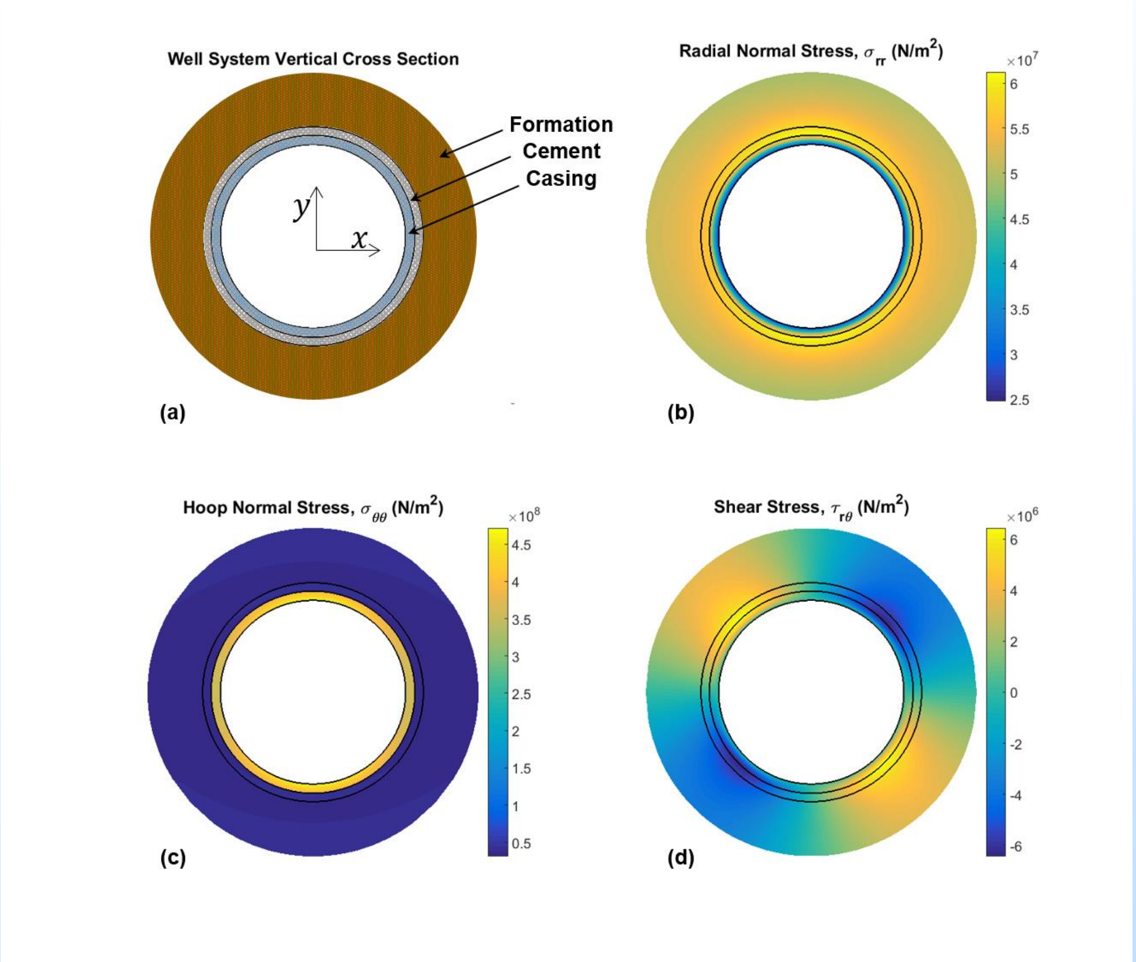


Anderson, 1951; Zoback, 2007

Preliminary Analytical Results

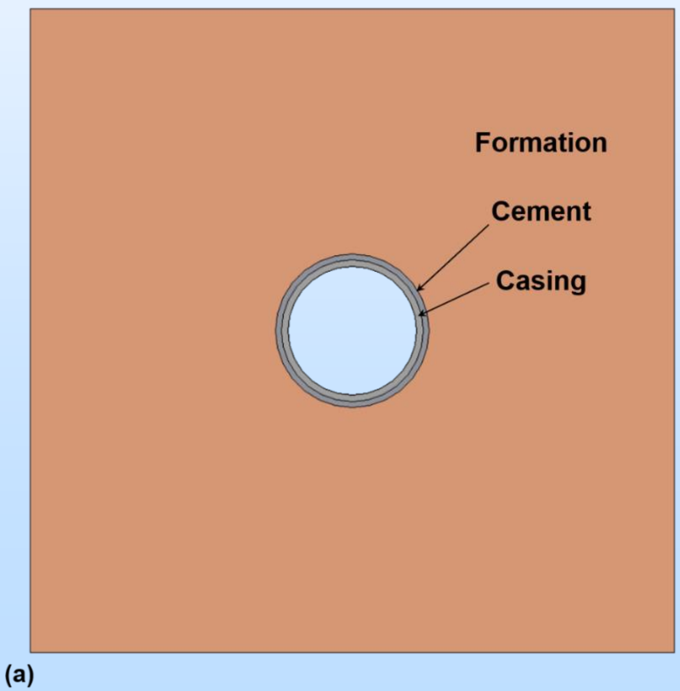
Solution shows:

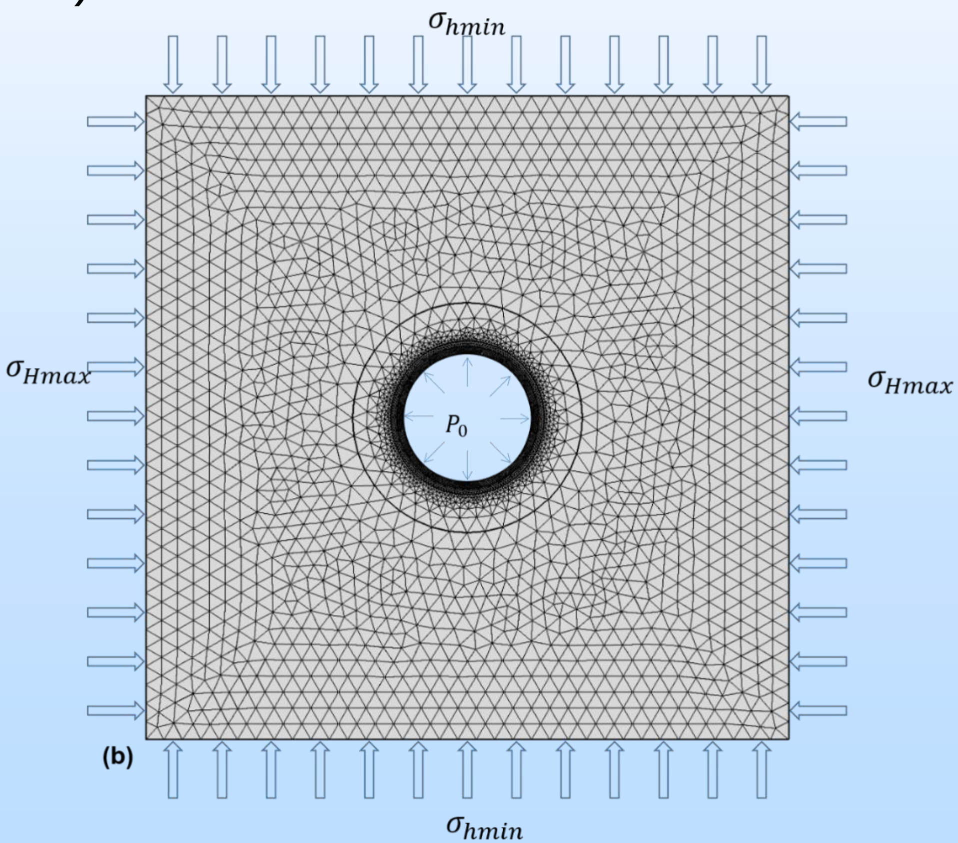
- Continuity of radially directed stress components
- **Hoop stress** – order of magnitude greater than radial stress
- **Shear stress** – greatest at 45° from σ_{Hmax} and σ_{hmin}, as expected



Initial Results – Numerical Model

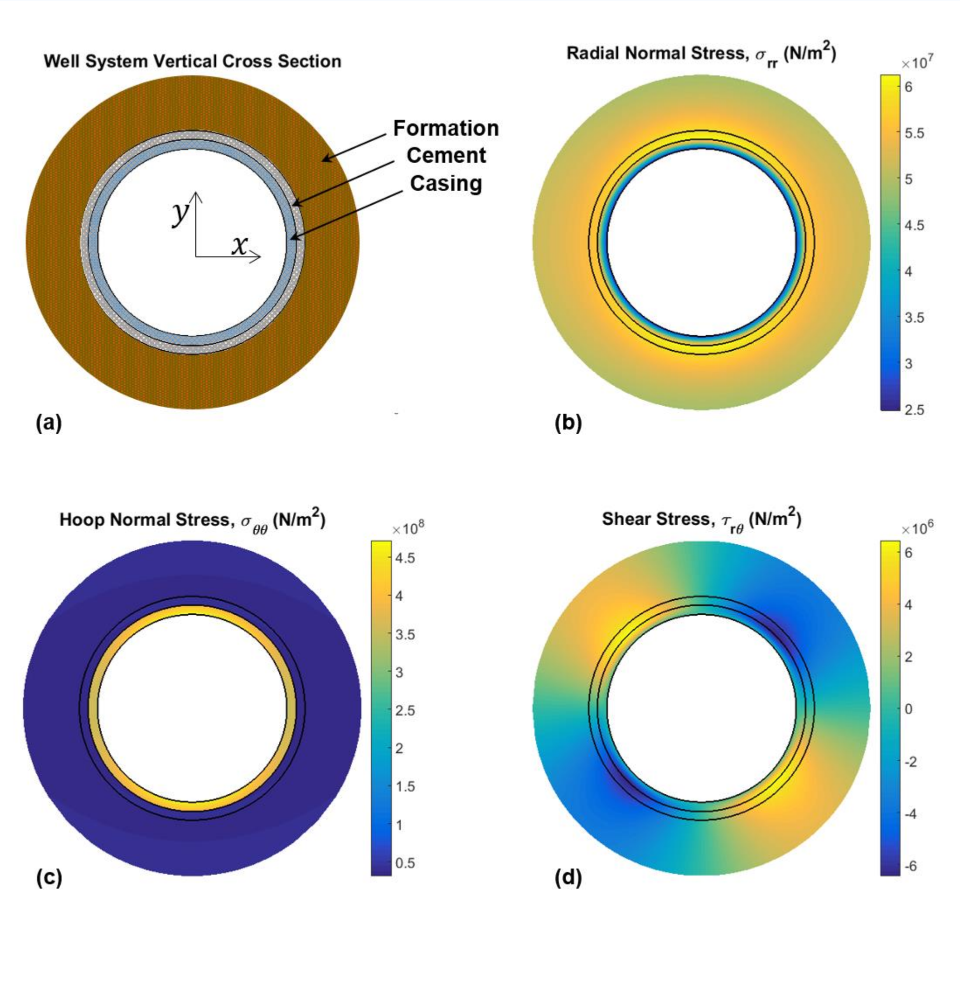
- Preliminary goal: match analytical model
- Considers:
  - In situ stresses (now)
  - Thermal stresses (later)



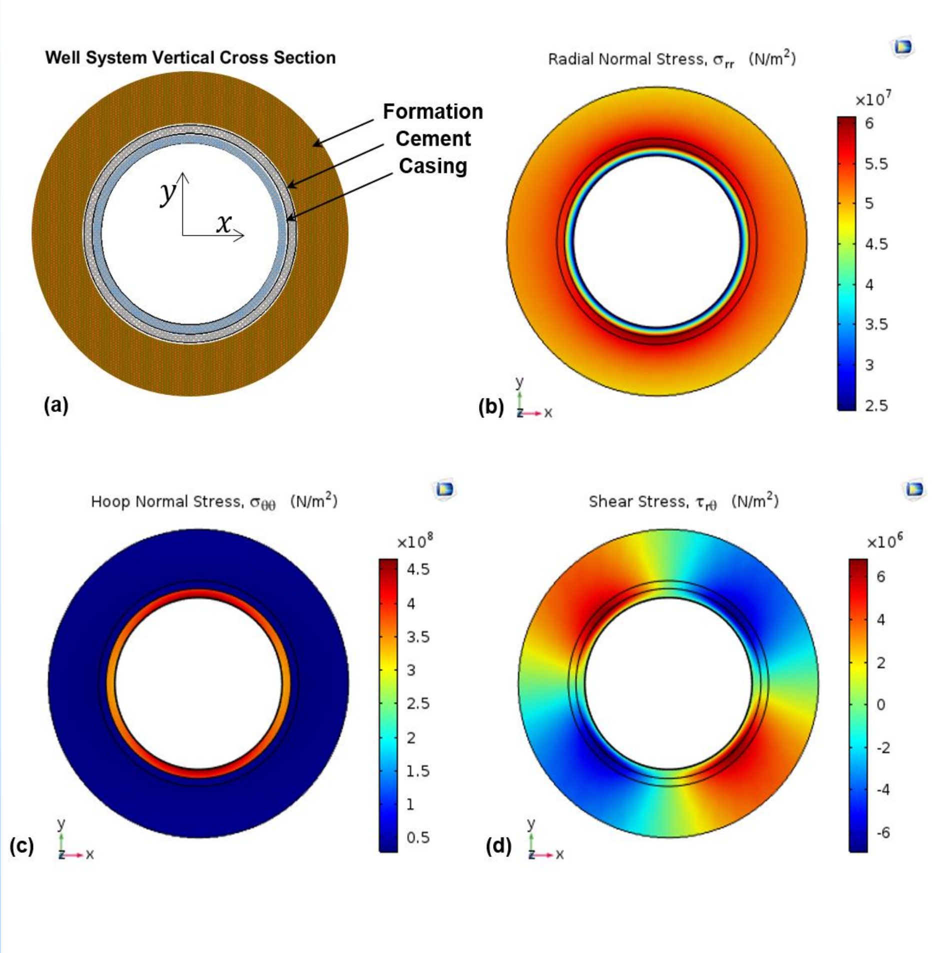


Initial Results - Comparison

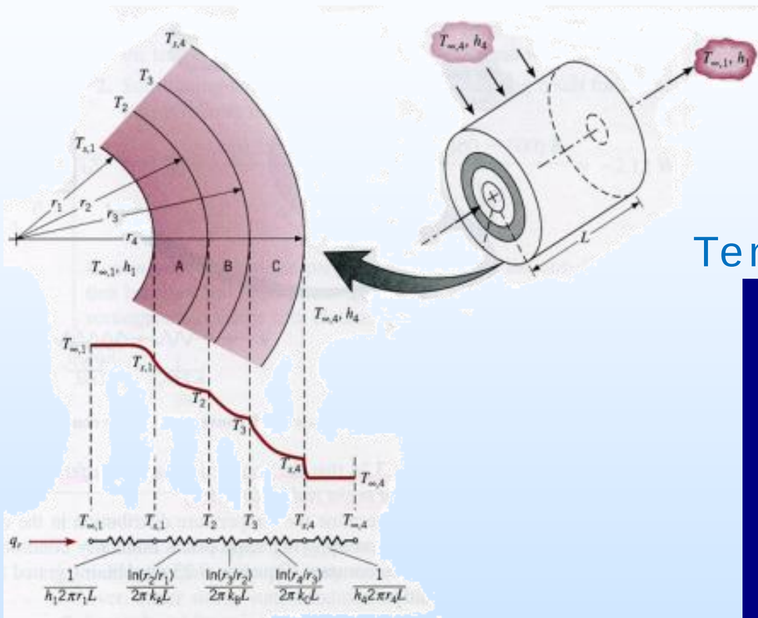
Analytical



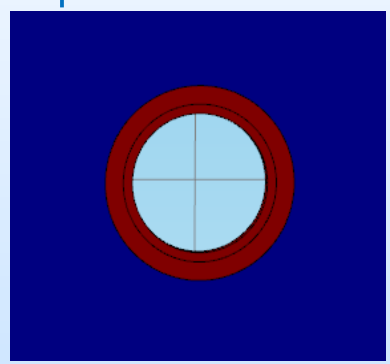
Numerical



Next steps, FY17



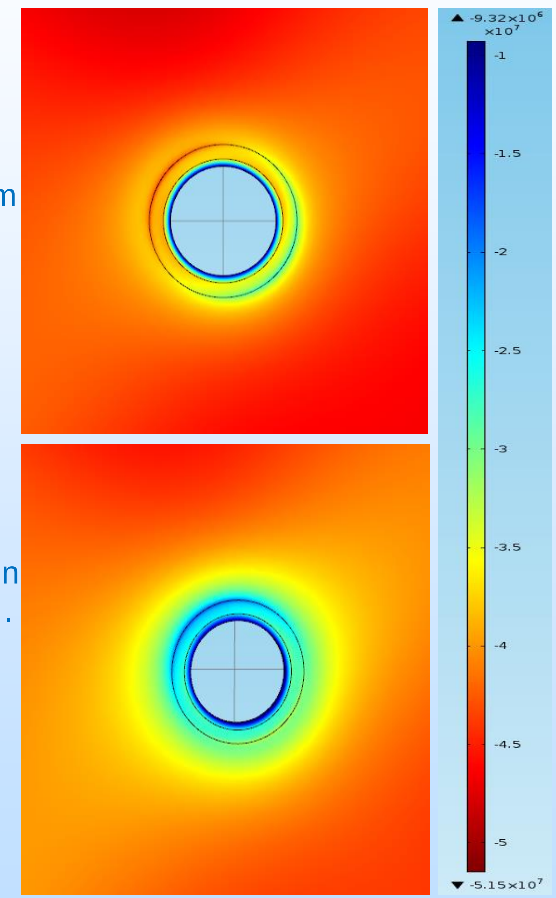
Temperature Profile



Normal Stress (Radial) σ_{rr}

Uniform Temp.

Different Temp.

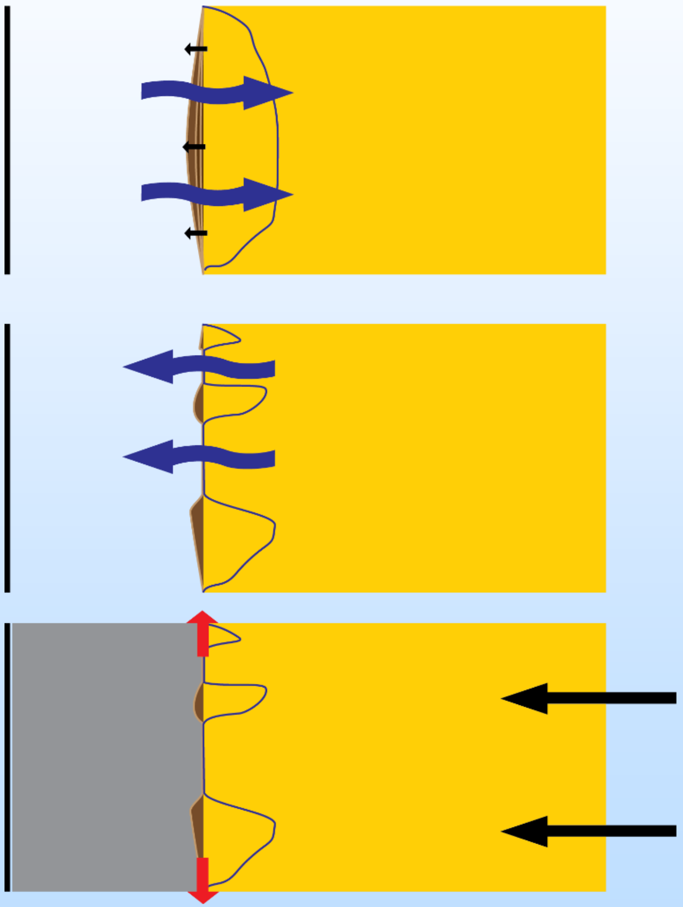


- Complete comparison between analytic and numerical model
- Identify case studied to model
- Report on geomechanical causes of well integrity failure in offshore environment

Sub-Task 4.2: Develop a borehole simulator apparatus that can simulate the drilling and cementing process at conditions.

Background

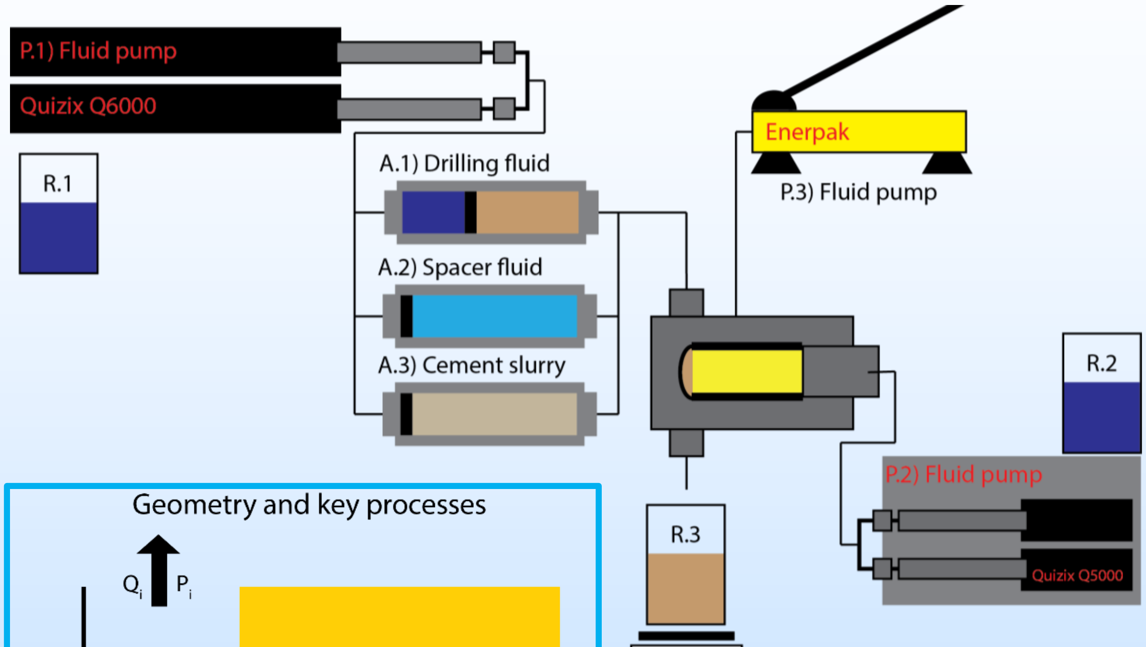
- Stability of the borehole wall during drilling and completion operations is critical for maintaining well integrity and ensuring zonal isolation
- Drilling fluid is often designed to establish a filter cake that prevents continual loss of drilling fluid into porous formations
- However, to ensure a good bond between cement and rock, the filter cake must first be removed
- Our current understanding of this process is inadequate and thus remnant filter cake often remains behind to inhibit zonal isolation
- As new drilling fluids are proposed for ever challenging environments, we must be able to verify that they will perform all their required functions

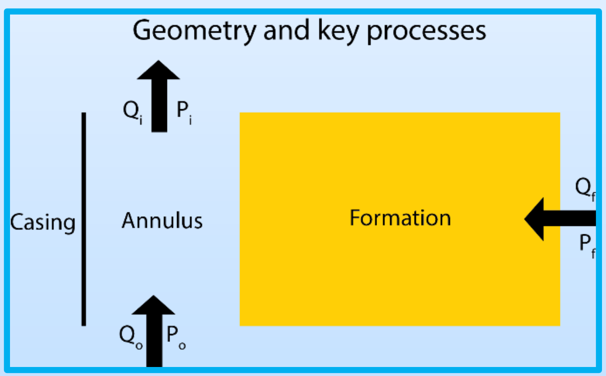


Technical approach

- Generate a design package and construct first generation apparatus to simulate the borehole flow environment
- Conduct shakedown experiments and adapt apparatus as needed
- Provide baseline data on filter cake buildup and removal
- Upgrade equipment to handle backpressure both hot and cold conditions

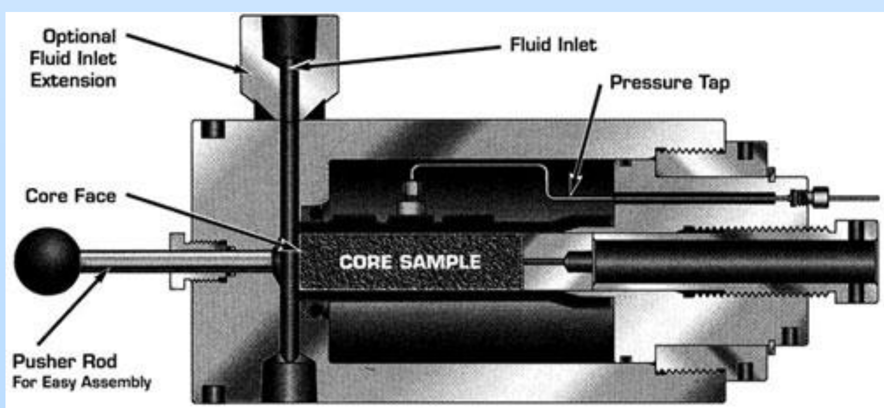
Borehole Simulator Apparatus



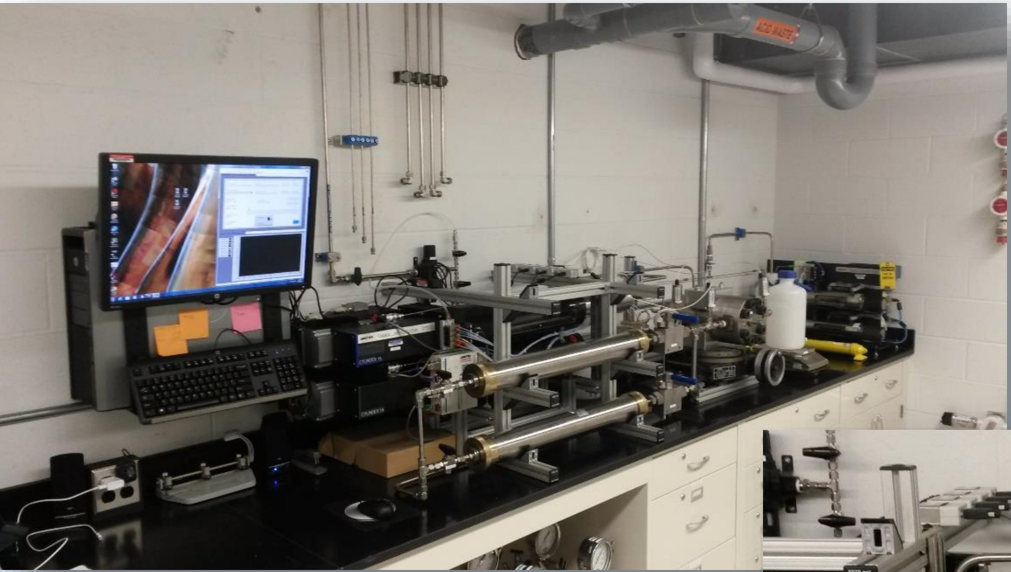


Key features, v.1:

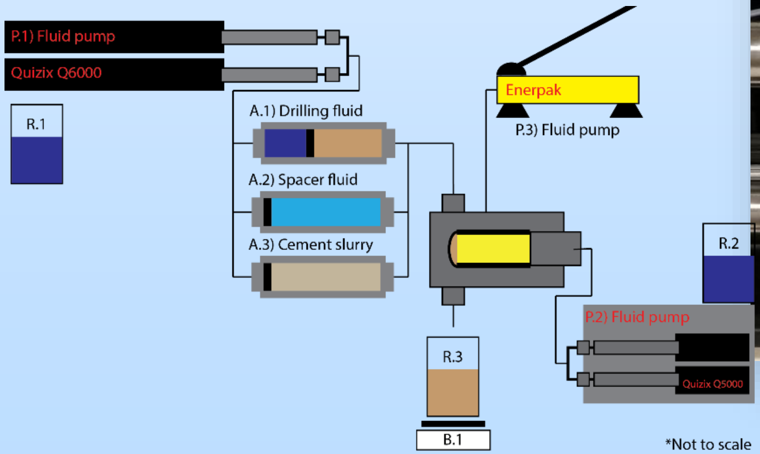
- All wetted parts are either Hastalloy or SS316
- Maximum operational pressure is 4,500 psi
- High-rate Quizix Q6000 pump for mud and spacer fluid flow
- Formation pressure maintained with Quizix Q5000 pump
- Multiple Quartzdyne pressure taps
- TEMCO 2 L fluid accumulators
- TEMCO coreholder that allows for flow across core sample face
- Data acquisition using custom-built NI-Labview software

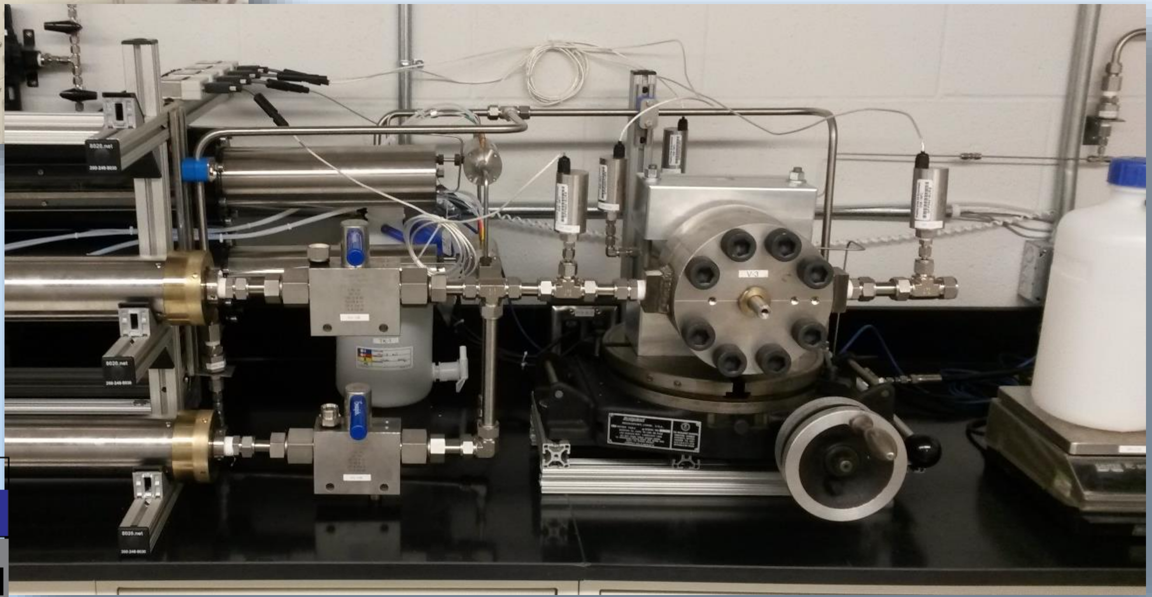


Status slide, FY16



- Equipment was assembled
- Safety permitted for operations in July, 2016
- Shakedown testing commencing (next week!)





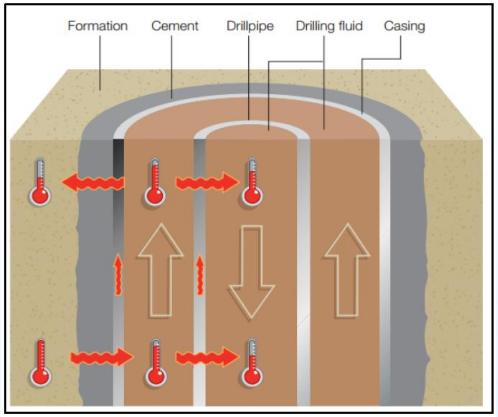
Next steps, FY17

- Shake-down testing (does the thing even work)
  - Water based mud:
    - Can a filter cake be developed and observed in the pressure signal?
    - Can we remove the filter cake?
    - Any operational or equipment issues?
- Conduct series of experiments to compare with current mathematical models on filter cake build and removal. Compare with industry Recommended Practices.
- More upgrades!
  - Install back pressure regulator and ISCO confining pressure pump
  - Heaters and chillers on system
  - Design cementing system
    - Accumulator
    - New head for core holder

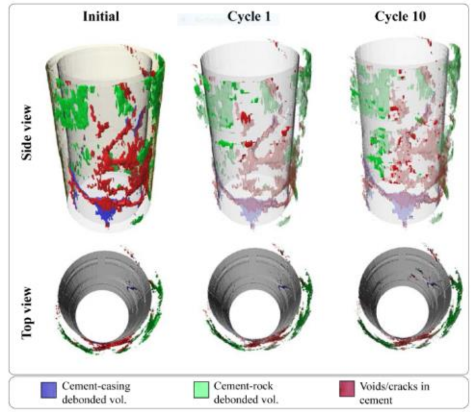
Sub-Task 4.3: Develop a reduced-scale well system that can be subjected to thermal and fluid stresses to induce failure and to be able to image this failure and test technologies for investigating or sealing of this pathway

Background

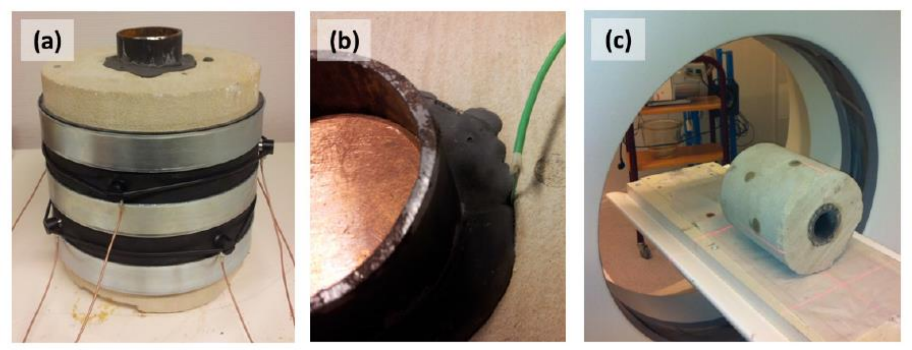
- The development of leakage pathways from thermal stresses and fluid pressure cycling remains an issue for well integrity
- Studying this phenomena under realistic conditions has been a challenge at the laboratory scale
- Recent advances in laboratory methods have shown that it is possible to study this phenomena at a smaller scale



Schlumberger, 1998

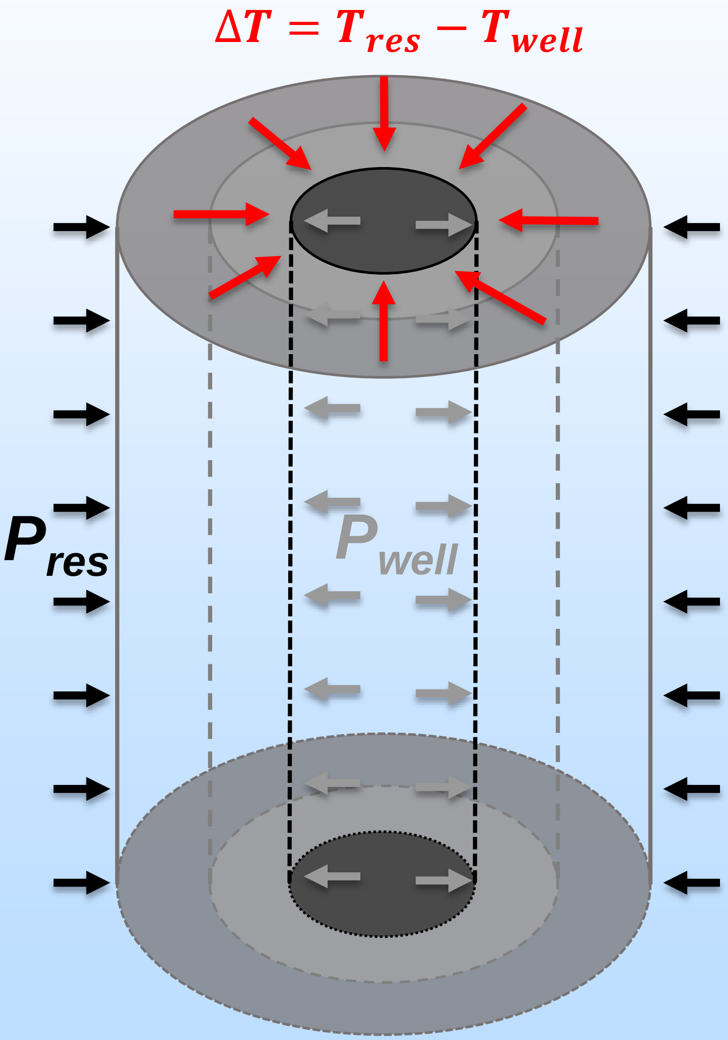


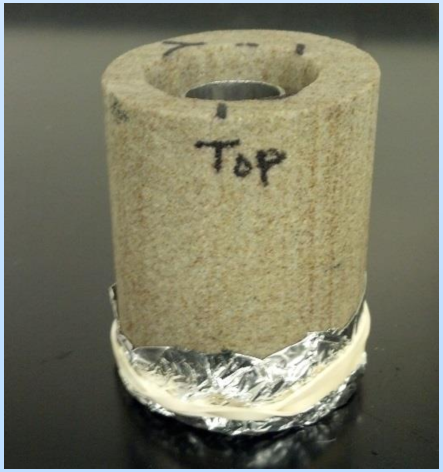
De Andrade et al., 2016

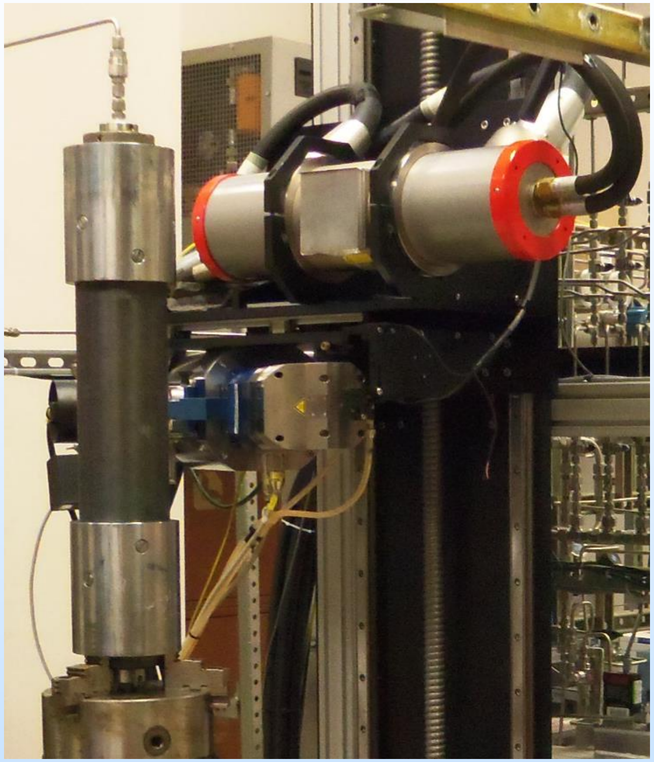


Albawi et al., 2014

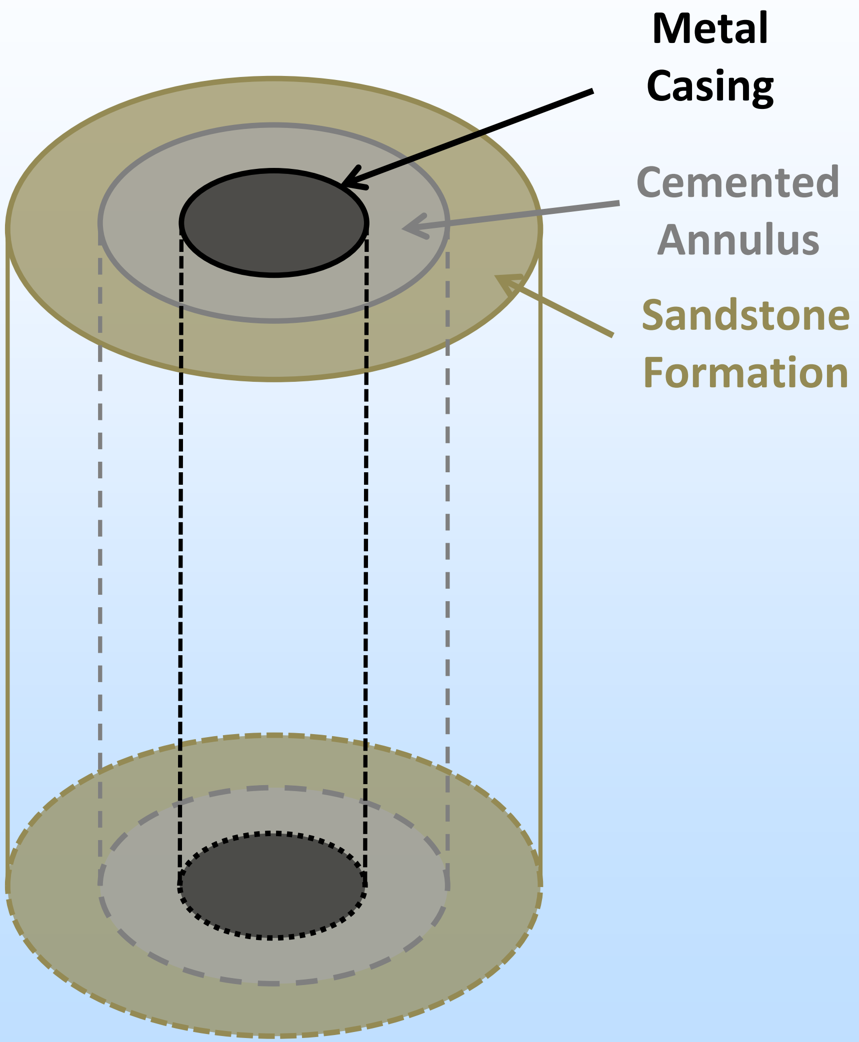
Experimental setup

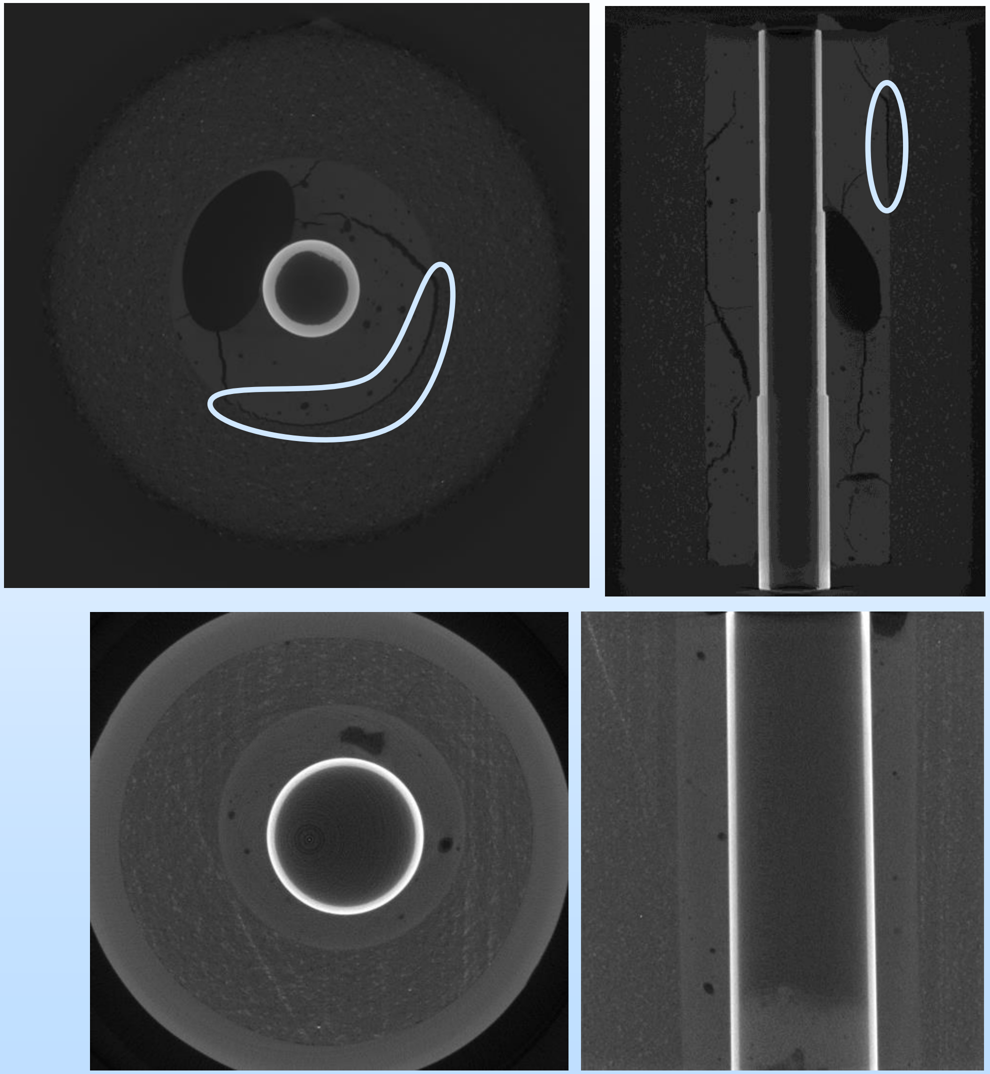






Initial results





Next steps, FY17

- Pressure cycle sample to generate debonding along interfaces
- Upgrade system to allow for thermal fluxes due to fluid circulation
- Compare experimental results with numerical simulations in Sub-task 4.1 to address the issue of scale

Synergy Opportunities

- The capabilities being developed in this task have already begun to be leveraged to support other work.
  - BSEE: Funding opportunity to look at effects of thermal shock in the offshore environment
  - EERE: Testing performance of a new geothermal cement formulation
- We are always looking for ways we can apply our capabilities to help solve the cross-cutting issue of well integrity

Summary

- We are developing several capabilities that allow us to address the issues related to loss of well integrity from a science-base

- The knowledge gained will be incorporated into the offshore risk assessment tools

NETL Research Presentations and Posters

TUESDAY, AUGUST 16, 2016

- **12:40 PM** Monitoring Groundwater Impacts - Christina Lopano
- **1:55 PM** Multi Variate Examination of the Cause of Increasing Induced Seismicity – Kelly Rose
- **4:00 PM** Exploring the Behavior of Shales as Seals and Storage Reservoirs for CO_2 – Ernest Lindner
- **5:05 PM** Risk Assessment for Offshore Systems – Kelly Rose
- **5:30 PM** Metal-based systems in Extreme Environments – Jeff Hawk
- 6:15 p.m. **Poster Session**
  - Kelly Rose - Developing a carbon storage resource assessment methodology for offshore systems
  - Doug Kauffman - Catalytic Conversion of CO2 to Ind. Chem. And eval. Of CO2 Use and Re-Use
  - Liwel Zhang - Numerical simulation of pressure and CO2 saturation above an imperfect seal as a result of CO2 injection: implications for CO2 migration detection

WEDNESDAY, AUGUST 17, 2016

- **12:30 PM** MVA Field Activities – Hank Edenborn
- **2:35 PM** Resource Assessment – Angela Goodman
- **2:35 PM** Understanding Impacts to Air Quality from Unconventional Natural Gas – Natalie Pekney
- **4:05 PM** Improving Science-Base for Wellbore Integrity, Barrier Interface Performance – Nik Huerta
- **5:20 PM** Wellbore Integrity and Mitigation – Barbara Kutchko

THURSDAY, AUGUST 18, 2016

- **1:00 PM** Advances in Data Discovery, Mining, & Integration for Energy (EDX) – Kelly Rose
- **1:25 PM** Methods for Locating Legacy Wells – Garrett Veloski
- **2:05 PM** Reservoir Performance – Johnathan Moore
- **3:05 PM** Geochemical Evolution of Hydraulically-Fractured Shales – Ale Hakala

UCR Unconventional Resources

https://edx.netl.doe.gov/carbonstorage/
https://edx.netl.doe.gov/offshore/
https://edx.netl.doe.gov/ucr/

NETL RESEARCH CARBON STORAGE PROGRAM