GEOMECHANICAL PROPERTIES OF MESOZOIC RIFT BASINS: APPLICATIONS FOR GEOSEQUESTRATION

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U.S. Department of Energy

National Energy Technology Laboratory
DE-FOA0001037 Kickoff Meeting

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Presentation Outline

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Benefit to the Program

- One of the goals of the DOE Carbon Storage program includes reducing the risks associated with injection processes at potential carbon storage sites.

- One of the major risks associated with carbon storage comes from the possibility of reactivating preexisting faults and fractures due to a pore pressure increases in the reservoir.

- Understanding the seismic and leakage risks associated with a potential geological carbon storage site will substantially increase the security of injected fluids that may ultimately be stored at that location and reduce the uncertainty, risk, and potential damages due to the injection process.

- The results of this “case” study may be widely applied to potential field-scale geological storage projects in the future.

Project Background

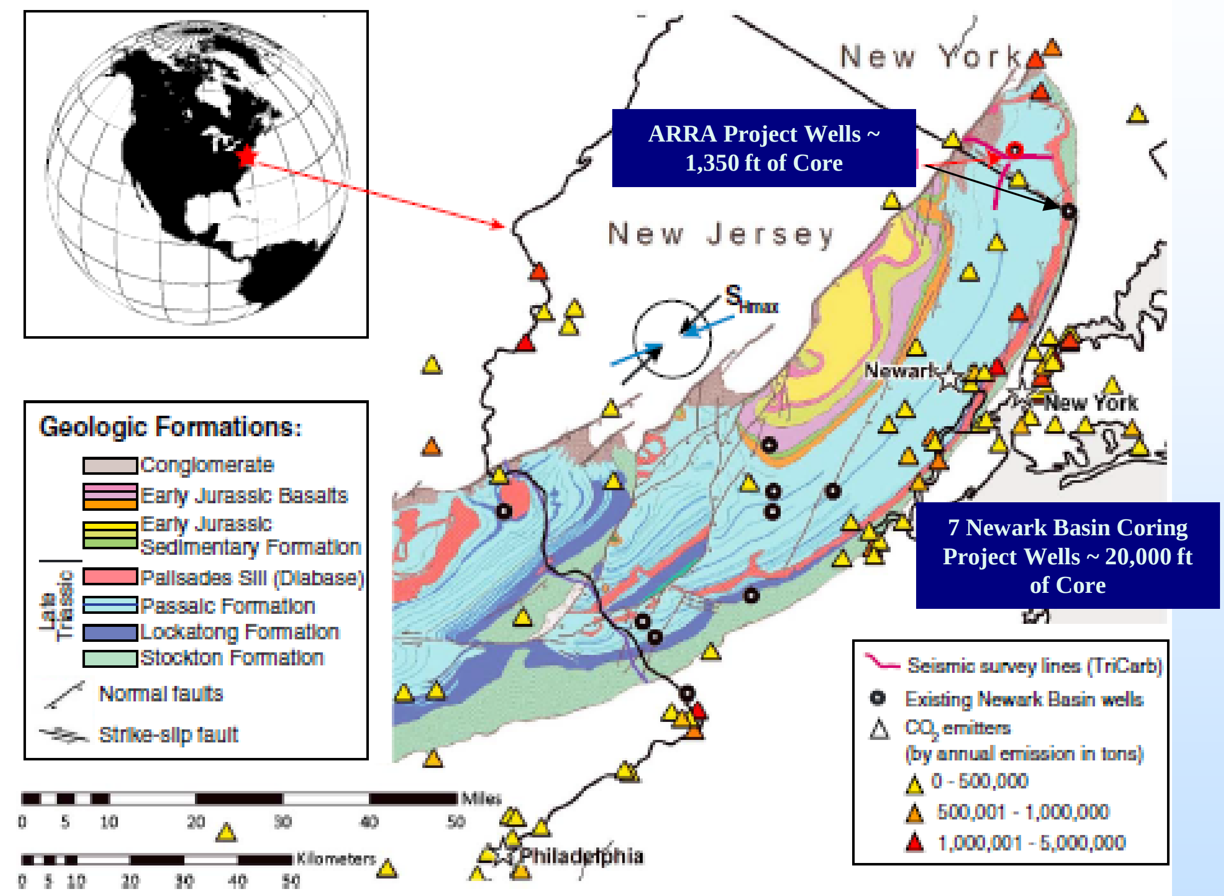
- A number of effective techniques for evaluation of in situ stress and mechanical formation properties have been developed over the years [Zoback, 2010] but detailed understanding of these parameters in situ, and standard characterization and monitoring protocols for carbon dioxide (CO2) storage sites are lacking [(NAS), 2012]

- We propose to address this using a “case study” in the northern Newark Basin, a candidate CO2-storage site near the New York Metropolitan area, where possible impacts of seismic hazards and CO2 leakage are particularly important due to a high population density.

- A preliminary analysis of in situ stress from the ARRA Characterization Project’s deep NYSTA Exit 14 Stratigraphic Test Borehole suggested significant variability in orientation of principal horizontal stresses with respect to depth [Zakharova and Goldberg, 2014].

- Despite the critically stressed nature of the brittle crust, however, preliminary results also suggested that local stress perturbation might create favorable conditions for sequestration by allowing a considerable pore pressure increase without carrying large risks of fault reactivation.

Physiogeographic Setting of the Newark Basin & Sources of Whole Core

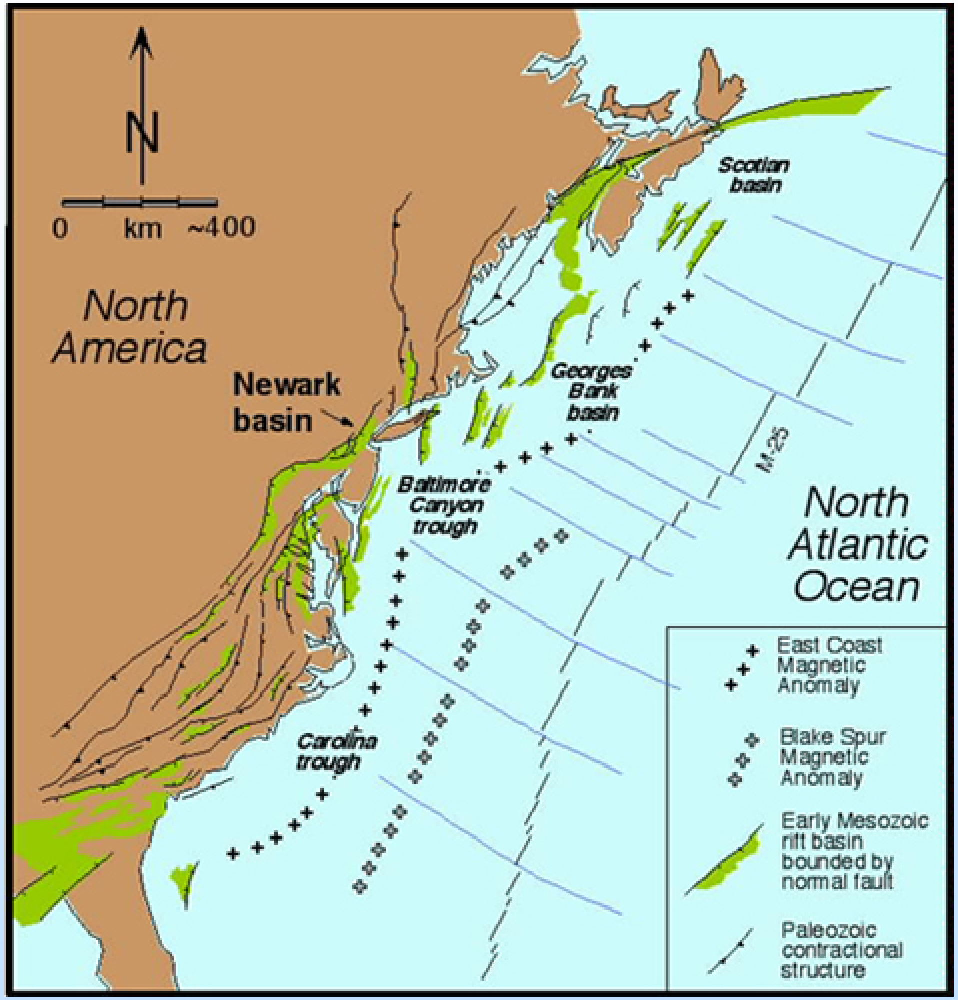

ARRA Project Wells ~ 1,350 ft of Core

7 Newark Basin Coring Project Wells ~ 20,000 ft of Core

Goldberg et al. [2003].

- Newark Basin stretches from Rockland County, New York, southwest across northern New Jersey, and into southeastern Pennsylvania (140 miles long by 32 miles wide)
- Geographic extent ~ 2,700 square miles
- The Newark Basin is in close proximity to large population areas and a heavily industrialized section of the country (28 MM tons/year CO_2 in closest NY/NJ counties)
- 1990s 7 Newark Basin Coring Project wells Central New Jersey ~3,500 ft deep – More than 20,000 feet of core
- ARRA Project drilled a Deep Borehole in 2011 with 150 feet of core and a Shallow Corehole in 2013 with 1,152 feet of core

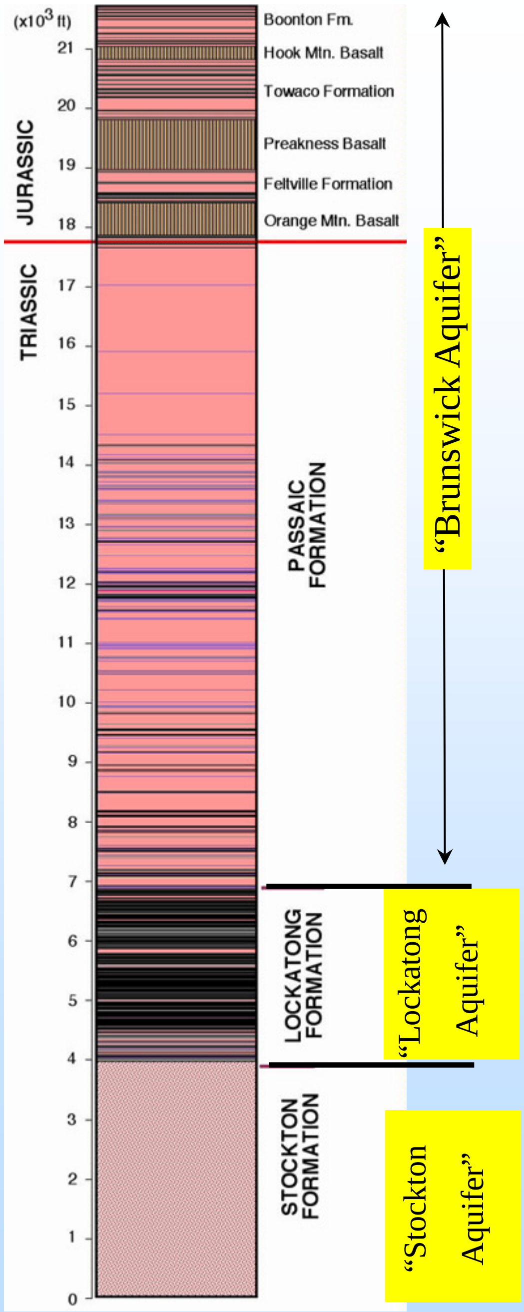
One of a Series of Basins along Eastern North America



Withjack et al., 1998

- Includes both “exposed” and “buried” basins of Jurassic-Triassic Age (Newark Basin is exposed) and offshore basins
- Formed by the “breakup” & separation of North/South America from Europe and Africa
- Basins generally set up by a border fault (western)
- Sediment infilled the basin from adjoining areas

Newark Basin Stratigraphy



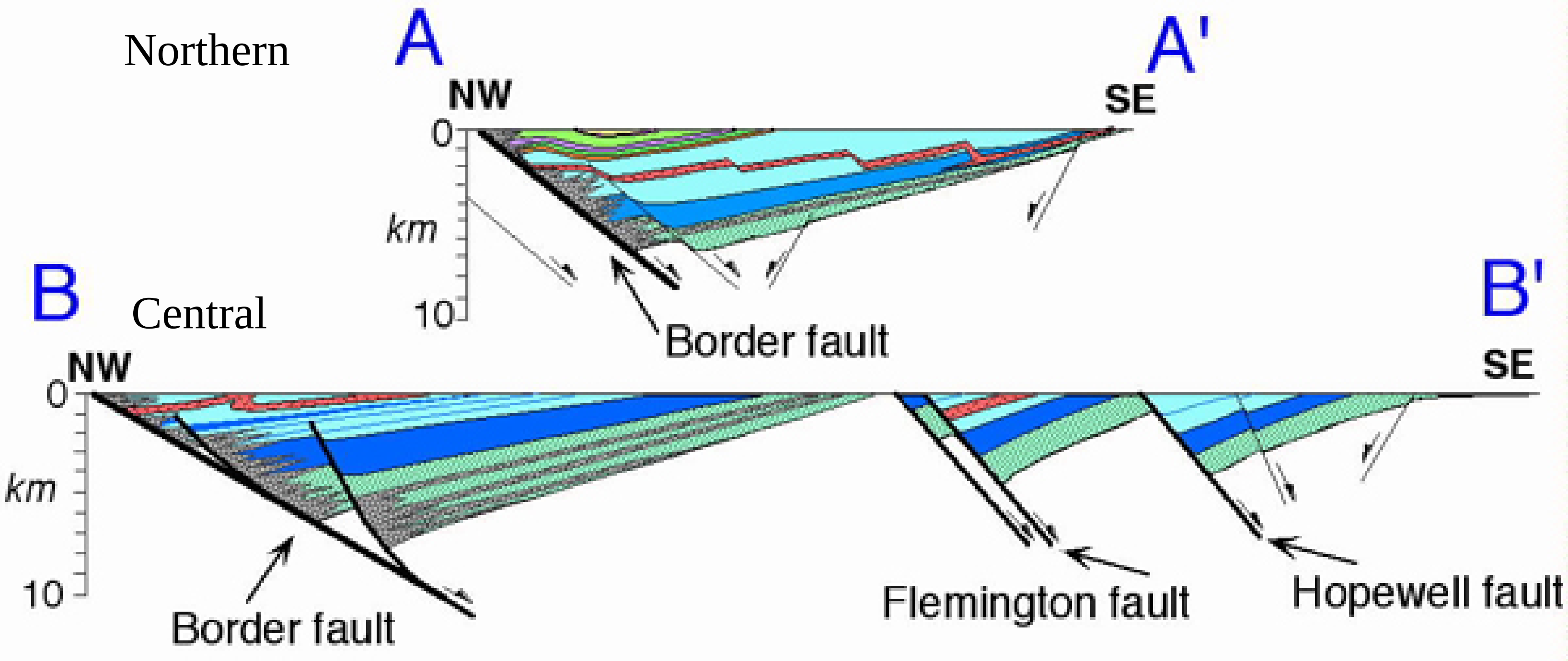
Half-graben clastic infill sequence

Playa lake and mudbank shales of the Passaic Fm provide secondary "seal" cap – up to 10,000 feet thick

Deep lake and shallow mudflat shales of the Lockatong Fm provide primary "seal" cap – up to 3,000 feet thick. Generally includes intrusive diabase "Palisades Sill"

Fluvial-alluvial sandstones and Mudstones of the Stockton Fm – up to 6,000 feet thick (or more along border fault)

General Basin Cross Sections – New Jersey



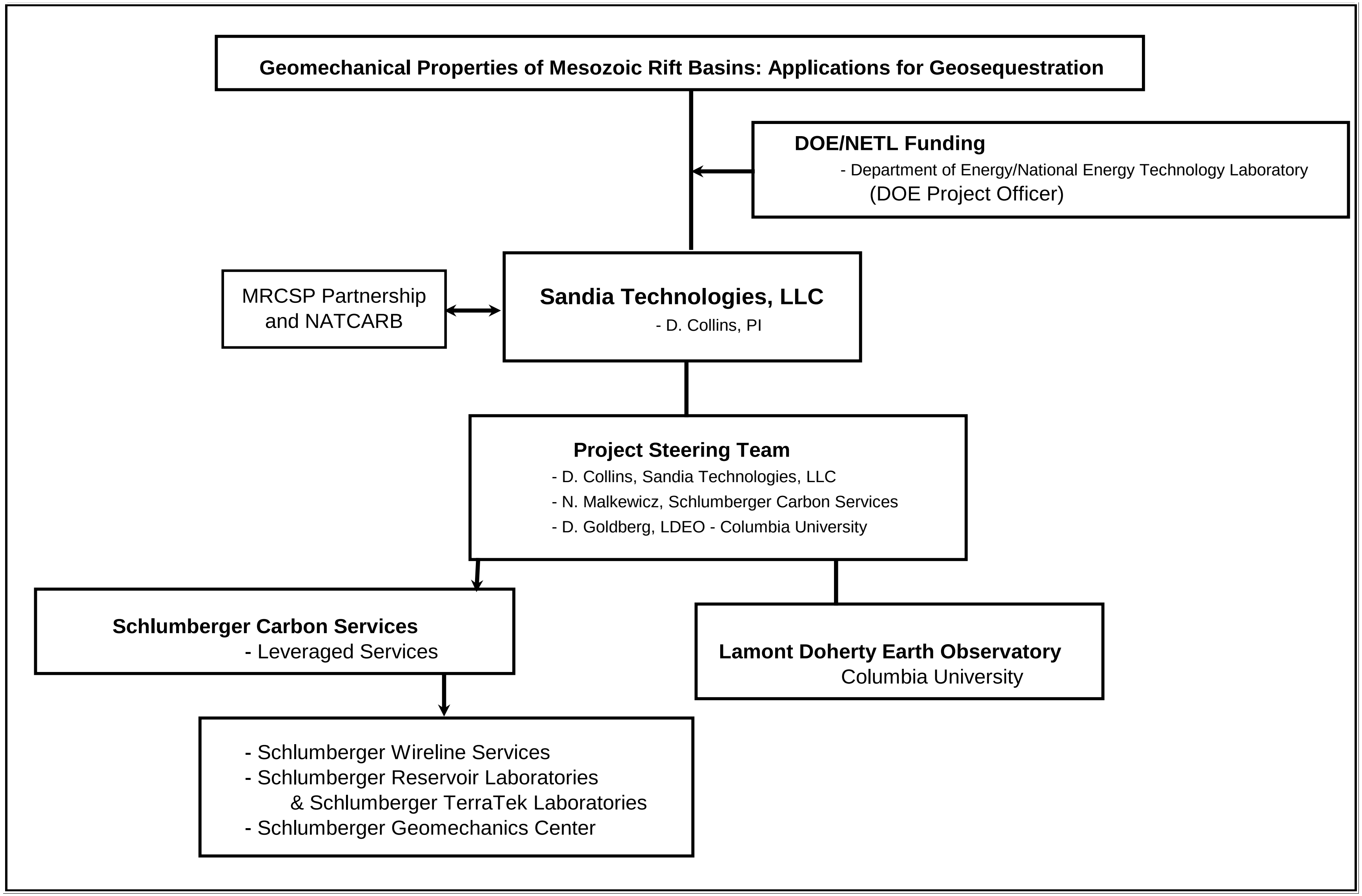
Modified from Schlische (1992)

Project Overview:
Goals and Objectives

- Primary goal of the project is to detail formation caprock characteristics, stresses, and mechanical properties in Mesozoic Basins using a "case study" in the northern Newark Basin.
  - Preliminary work suggested significant variability in orientations and magnitude of the principal horizontal stress with respect to depth
  - Objective is to measure lab-scale properties to field scale mechanical properties and stresses using an extensive core library and an existing field test well.
  - Well testing includes innovative configuration of the Modular Dynamics Tester tool for use in consolidated formations of high strength

- Budget Period 1 Success Criteria is defined as successful characterization/geomechanics testing of at least 18 of the 25 core samples selected for testing.

Project Organizational Chart



Geomechanical Properties of Mesozoic Rift Basins: Applications for Geosequestration

DOE/NETL Funding
- Department of Energy/National Energy Technology Laboratory
(DOE Project Officer)

MRCSP Partnership
and NATCARB

Sandia Technologies, LLC
- D. Collins, PI

Project Steering Team
- D. Collins, Sandia Technologies, LLC
- N. Malkewicz, Schlumberger Carbon Services
- D. Goldberg, LDEO - Columbia University

Schlumberger Carbon Services
- Leveraged Services

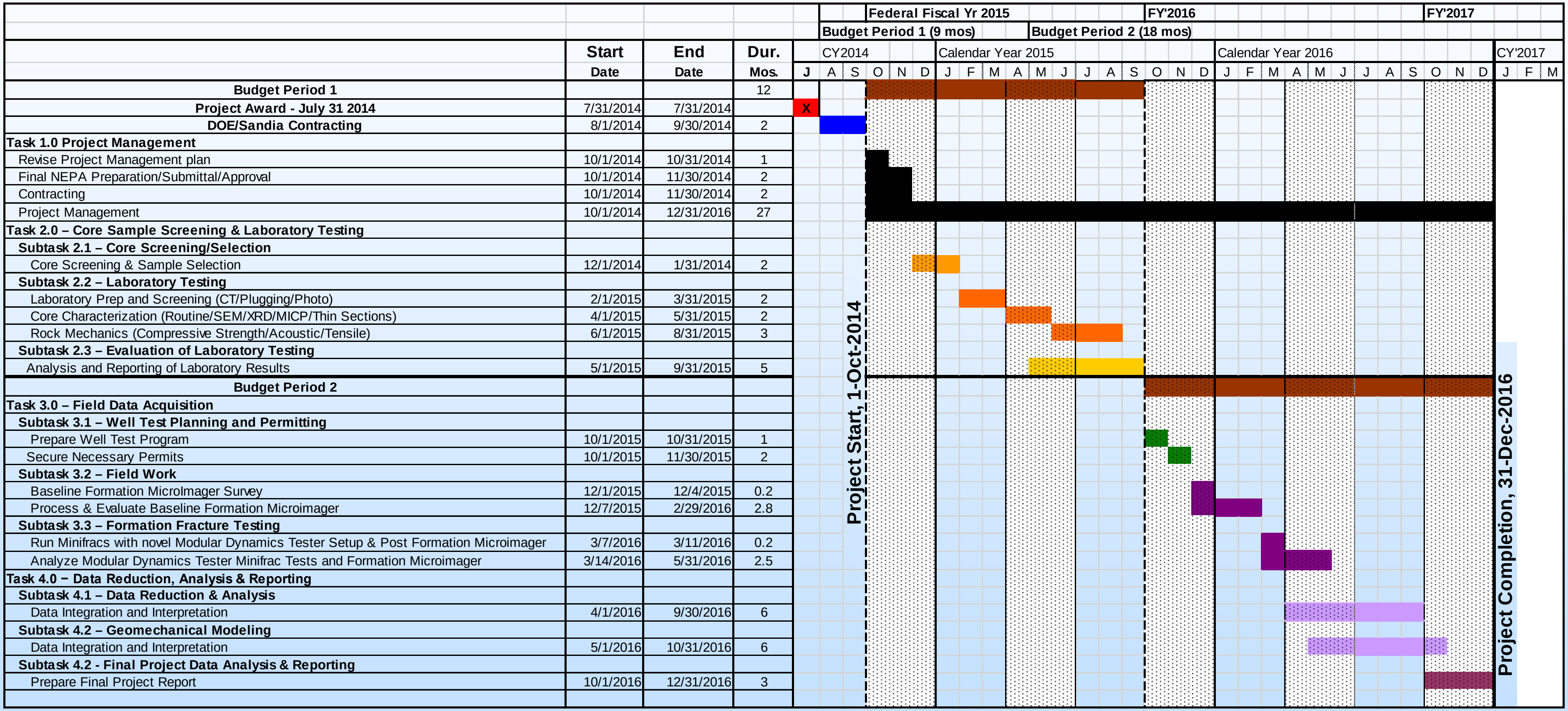
Lamont Doherty Earth Observatory
Columbia University

- Schlumberger Wireline Services
- Schlumberger Reservoir Laboratories
  & Schlumberger TerraTek Laboratories
- Schlumberger Geomechanics Center

Project Organizational Chart – (continued)

- Schlumberger Carbon Services
  - Houston Rock Laboratory – routine and special core analyses
  - TerraTek Rock Mechanics lab – Salt Lake City
  - Wireline Services – Formation Microimager and Modular Dynamics Tester
  - Geomechanics Center – technical support in laboratory and field data evaluation/ analysis and modeling support to LDEO
- Lamont Doherty Earth Observatory
  - Research staff to support scientific efforts of the project, including primary data reduction/analysis, evaluation, and geomechanical modeling
  - Access to Newark Basin core library
  - Access to Test Well No. 3 for field testing program

Proposed Project Schedule



	Start Date	End Date	Dur. Mos.
Budget Period 1			12
Project Award - July 31 2014	7/31/2014	7/31/2014	
DOE/Sandia Contracting	8/1/2014	9/30/2014	2
Task 1.0 Project Management			
Revise Project Management plan	10/1/2014	10/31/2014	1
Final NEPA Preparation/Submittal/Approval	10/1/2014	11/30/2014	2
Contracting	10/1/2014	11/30/2014	2
Project Management	10/1/2014	12/31/2016	27
Task 2.0 – Core Sample Screening & Laboratory Testing			
Subtask 2.1 – Core Screening/Selection			
Core Screening & Sample Selection	12/1/2014	1/31/2014	2
Subtask 2.2 – Laboratory Testing			
Laboratory Prep and Screening (CT/Plugging/Photo)	2/1/2015	3/31/2015	2
Core Characterization (Routine/SEM/XRD/MICP/Thin Sections)	4/1/2015	5/31/2015	2
Rock Mechanics (Compressive Strength/Acoustic/Tensile)	6/1/2015	8/31/2015	3
Subtask 2.3 – Evaluation of Laboratory Testing			
Analysis and Reporting of Laboratory Results	5/1/2015	9/31/2015	5
Budget Period 2			
Task 3.0 – Field Data Acquisition			
Subtask 3.1 – Well Test Planning and Permitting			
Prepare Well Test Program	10/1/2015	10/31/2015	1
Secure Necessary Permits	10/1/2015	11/30/2015	2
Subtask 3.2 – Field Work			
Baseline Formation MicroImager Survey	12/1/2015	12/4/2015	0.2
Process & Evaluate Baseline Formation Microimager	12/7/2015	2/29/2016	2.8
Subtask 3.3 – Formation Fracture Testing			
Run Minifracs with novel Modular Dynamics Tester Setup & Post Formation Microimager	3/7/2016	3/11/2016	0.2
Analyze Modular Dynamics Tester Minifrac Tests and Formation Microimager	3/14/2016	5/31/2016	2.5
Task 4.0 − Data Reduction, Analysis & Reporting			
Subtask 4.1 – Data Reduction & Analysis			
Data Integration and Interpretation	4/1/2016	9/30/2016	6
Subtask 4.2 – Geomechanical Modeling			
Data Integration and Interpretation	5/1/2016	10/31/2016	6
Subtask 4.2 - Final Project Data Analysis & Reporting			
Prepare Final Project Report	10/1/2016	12/31/2016	3

Proposed Project Schedule – Key Dates

- Budget Period 1 - 10/01/2014 to 09/30/2015
  - Revised Environmental Questionnaires – Approved
  - Updated Project Management Plan – Submitted 11/10/14
  - Subcontracting Schlumberger Carbon & LDEO – 11/30/14
  - Core Screening/Selection by Project Team– 01/31/15
  - Laboratory Prep/Screening/Down-select – 03/31/15
  - Sample Characterization (SEM/XRD/MICP/Thin Section Petrology) – 05/31/15
  - Rock Mechanics Testing (Compressive & Tensile Strength/ Acoustic Properties Testing) – 08/31/15
  - ***Deliverable = "Report on Newark Basin Caprock Characterization and Laboratory Testing" – 09/30/15***

Proposed Project Schedule – Key Dates

- Budget Period 2 - 10/01/2015 to 12/31/2016
  - Field Work Plan Development – 10/31/15
  - Baseline Formation Micro-scanner Imaging Survey – 12/04/15
  - Pre-stress Packer & Modular Dynamics Tester Formation Breakdown Experiments/Post Testing Formation Micro-scanner Imaging Survey – LDEO Test Well No. 3 – 03/11/16
  - Field Data Reduction and Analysis – 05/31/16
  - Data Evaluation/Integration – 09/30/16
  - ***Deliverable = "Geomechanical Characterization and Modeling of the Newark Basin" – 12/31/16***

Task/Subtask Breakdown – Budget Period 1

- Task 1 - Project Management & Reporting – project tracking and reporting
  - Project Management Plan (Task 1.1) – revision of PMP and SOPO
  - Revisions to Environmental Questionnaires

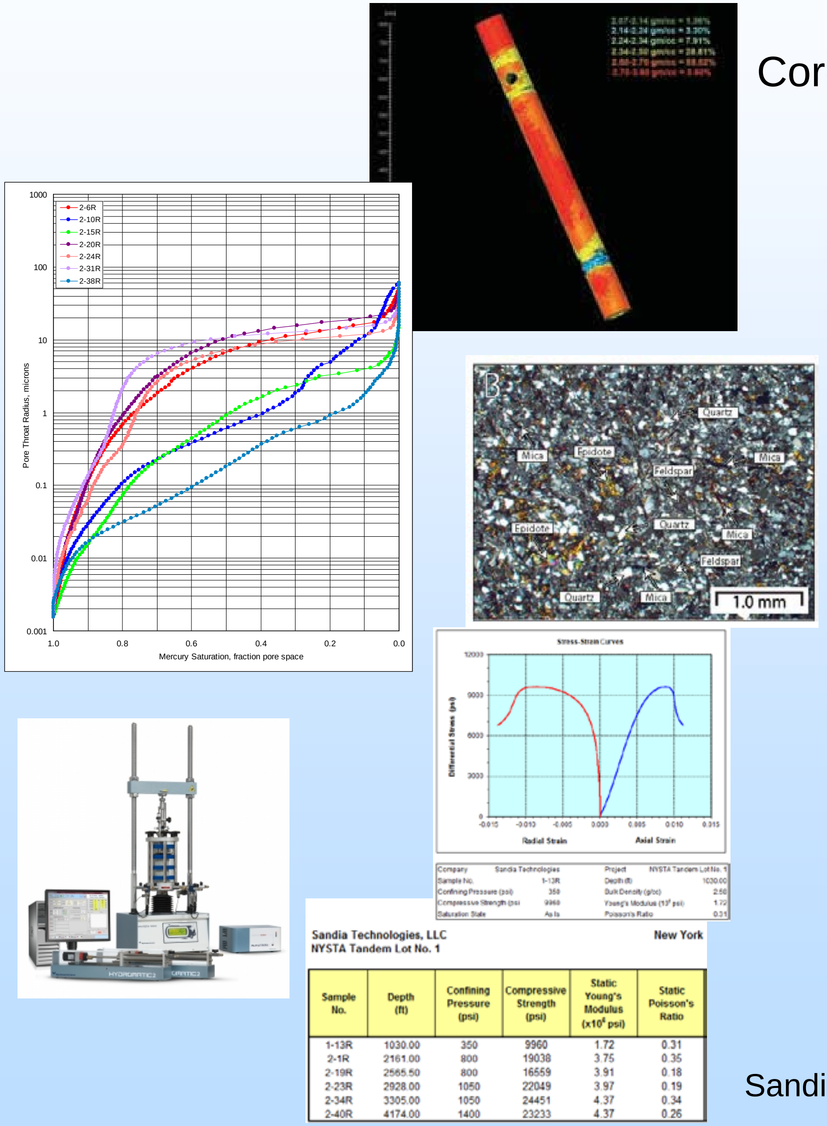
- Task 2 - Core Screening/Selection & Laboratory Testing
  - Core Screening and Samples Selection (Subtask 2.1) – selection of approximately 25 whole core rock samples
  - Laboratory Testing (Subtask 2.2) – characterization and geomechanical core testing
  - Evaluation of Laboratory Testing (Subtask 2.3) – evaluation of test results and preliminary geomechanical modeling for estimating critical pressures for inducting fractures in various caprock types

Available Whole Core in the Newark Basin

Cores include a wide range of lithology types

- >20,000 feet of whole core from 7 Newark Basin Coring Project Wells (warehoused at Rutgers University) / Passaic, Lockatong, and Stockton Formations
- +/- 200 feet of core from the ARRA Characterization Project Deep Stratigraphic Borehole (NYSTA Exit 14 Tandem Truck Lot No. 1) - 4570' – 4,650', 4,660' – 4,735', and 4,850' – 4,890' / Passaic Formation
- +/-1,152 feet of core from the ARRA Characterization Project Shallow Stratigraphic Borehole (LDEO Test Well No. 4) – 650 ' – 1,802' / includes lowermost Lockatong Formation and complete thickness of the Stockton Formation

Subtask Breakdown – Budget Period 1/Task 2



Company	Sandia Technologies	Project	NYSTA Tandem Lot No. 1
Sample No.	1-13R	Depth (ft)	1030.00
Confining Pressure (psi)	350	Bulk Density (g/cc)	2.50
Compressive Strength (psi	9960	Young's Modulus (10^6 psi)	1.72
Saturation State	As Is	Poisson's Ratio	0.31

Sandia Technologies, LLC **New York**
NYSTA Tandem Lot No. 1

Sample No.	Depth (ft)	Confining Pressure (psi)	Compressive Strength (psi)	Static Young's Modulus ($x10^6$ psi)	Static Poisson's Ratio
1-13R	1030.00	350	9960	1.72	0.31
2-1R	2161.00	800	19038	3.75	0.35
2-19R	2565.50	800	16559	3.91	0.18
2-23R	2928.00	1050	22049	3.97	0.19
2-34R	3305.00	1050	24451	4.37	0.34
2-40R	4174.00	1400	23233	4.37	0.26

Core Laboratory Testing (+/- 25 rock samples)

- Characterization Testing – Helical CT sample scanning ahead of characterization testing for detection of nonuniformities & anomalies, passing samples will undergo routine porosity/permeability, bulk density, scanning electron microscopy, x-ray diffraction, mercury injection capillary pressure, and thin sectioning for lithologic description
- Geomechanical Laboratory Testing – Tri-axial compressive strength tests to define rock failure and elastic wave properties testing (Vp & Vs) for determination of elastic moduli and anisotropy

Task/Subtask Breakdown – Budget Period 2

- Task 1 - Project Management & Reporting – project tracking and reporting (continuation from BP 1)

- Task 3 – Field Data Acquisition
  - Well Testing Planning (Subtask 3.1) – Field Work Plan
  - Baseline Imaging Survey (Subtask 3.2) – Baseline formation imaging survey in Lamont-Doherty Earth Observatory Test Well No. 3
  - In situ Formation Testing (Subtask 3.3) – formation stress tests (5) using modified Modular Dynamics Tester tool with pre-stress packer element in LDEO Test Well No. 3. Complete testing with final formation imaging survey to characterize the post-stressed formation intervals

In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer

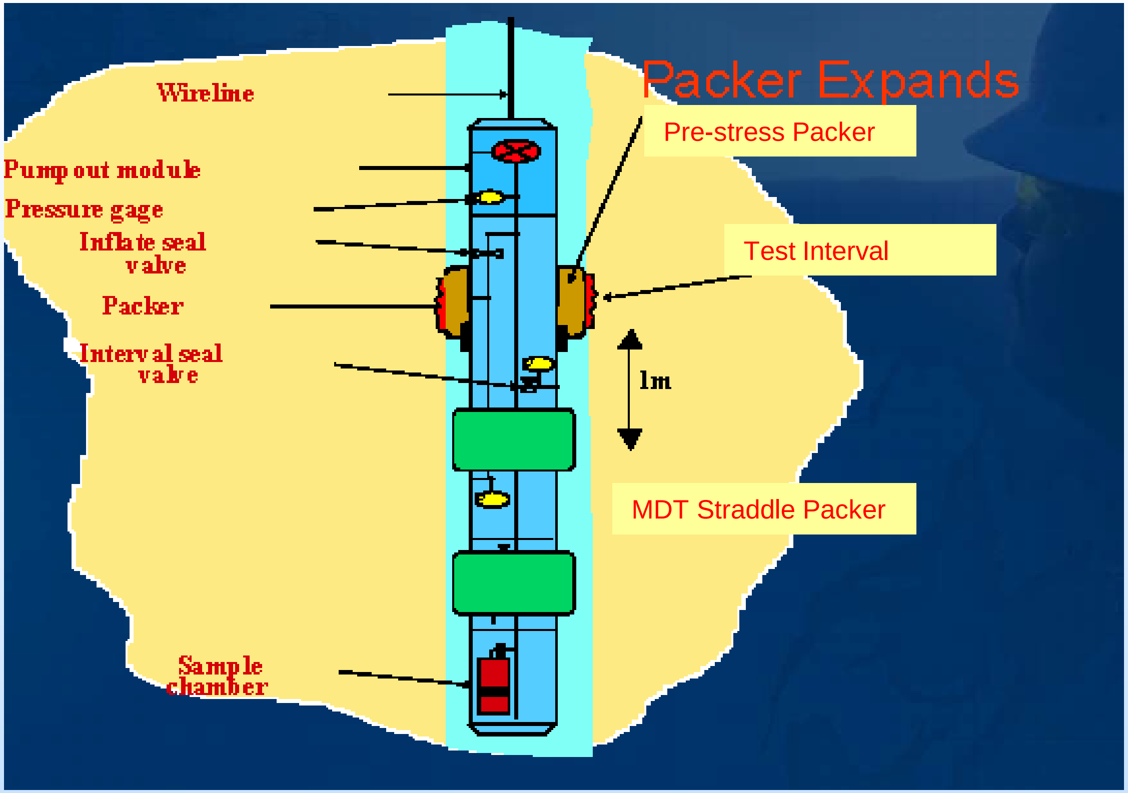
- We will use a novel wireline tool setup for performing the well testing portion of the project. Prior to 2013, the root cause of many job failures was the inability to break down the formation.
  - In the deep ARRA Characterization well, formation breakdown tests were attempted at 3,510 ft (5,700 psi) and 2,927 ft (5,500 psi);
  - At the time, the tool packers could only hold ~4,000 psi differential pressure

- New/novel developments that enhance MDT formation breakdown testing include:
  - 1) packers that can perform at a 5,000 psi differential;
  - 2) tool pumps that have been modified to deliver a constant injection rate as the pressure varies;
  - 3) New software, custom built for MDT test observation and interpretation will used for this project, replacing the older Frac-Cade* software package that was designed for pumping services.

In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer (Continued)

- A more significant development is the addition of a second MDT packer module to the traditional tool string, which allows for pre-stressing the test interval;
- This additional packer is inflated across the test interval creating break in the formation using the force of the packer itself pushing against the borehole wall. As such, the packer is designed to hold a very high inflation pressure;
- Following formation breakdown, the pre-stress packer is deflated and the tool-string is moved up in order to straddle the test interval;
- Testing then proceeds using the traditional dual inflatable packer setup, which consists of injecting fluid to propagate the break in the formation, followed by a shut in period to determine fracture closure pressure.
- Field testing is under way with a pre-stress packer that can be inflated to 8,000 psi, testing the concept, pumps, and other equipment under field conditions. Development of additional packer sizes and configurations should be ready for deployment in time for our field program, including a packer that can undergo inflation to 12,000 psi to break down high-strength formations.

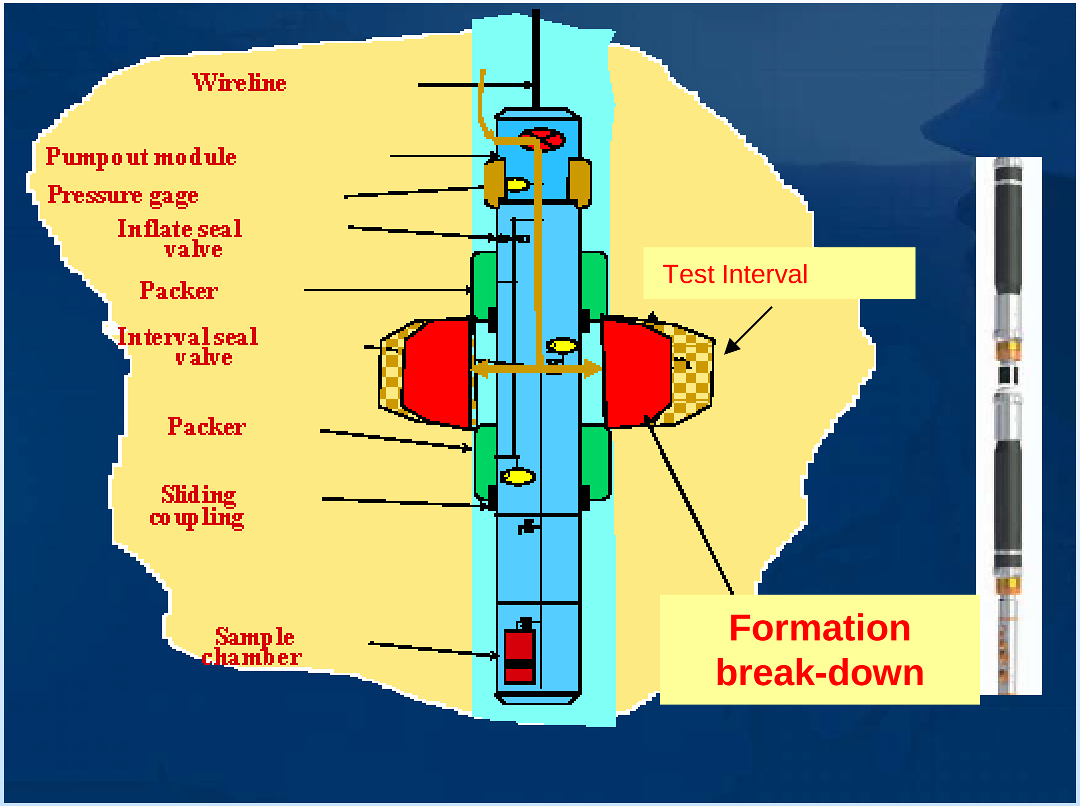
In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer



(Mishra, V., 2011)

- Innovative addition of an inflatable "pre-stress" packer on MDT tool allows for greater pressure to be placed on the test interval
- Pre-stress packer is deflated following initial stress event and MDT tool is placed straddling the pre-stressed test interval
- Standard formation breakdown test can then be run

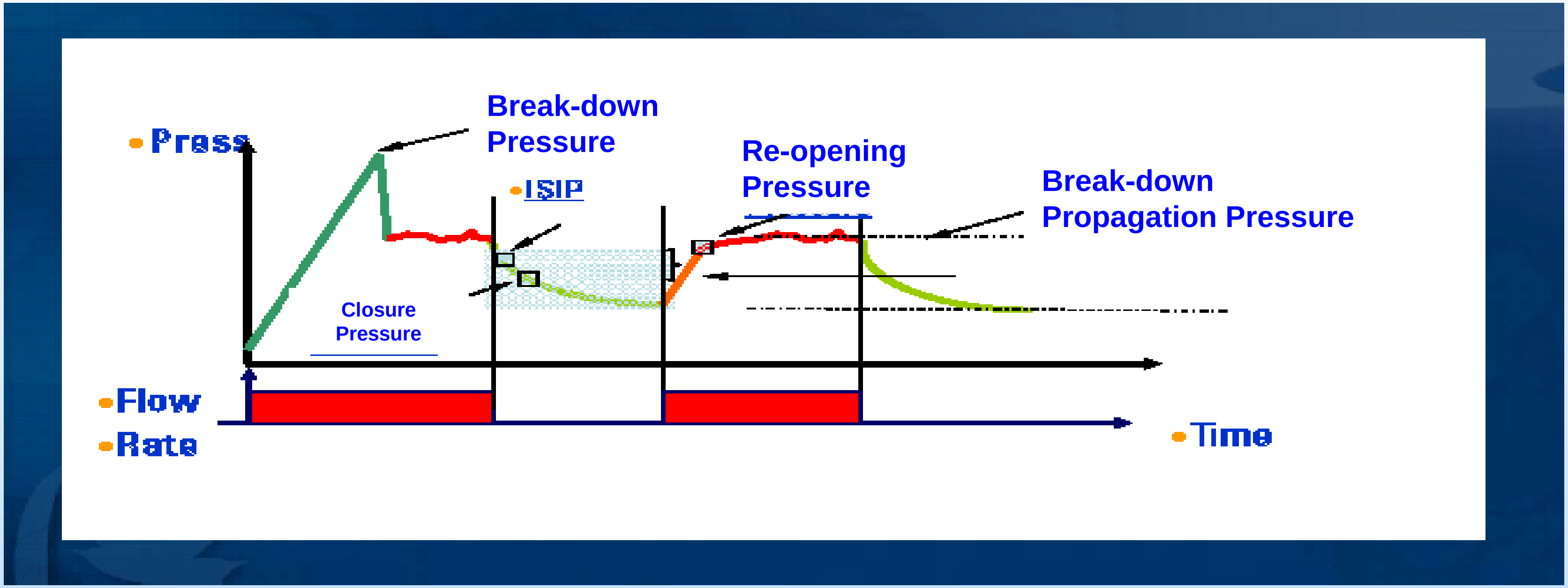
In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer



(Mishra, V., 2011)

- MDT tool is placed straddling the pre-stressed test interval
- MDT pump module is used to further breakdown the formation, propagating the break a short distance out into the formation
- Tool allows for constant monitoring of pump rate and pressures with time during pumping and recovery

In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer



(Mishra, V., 2011)

General test sequence

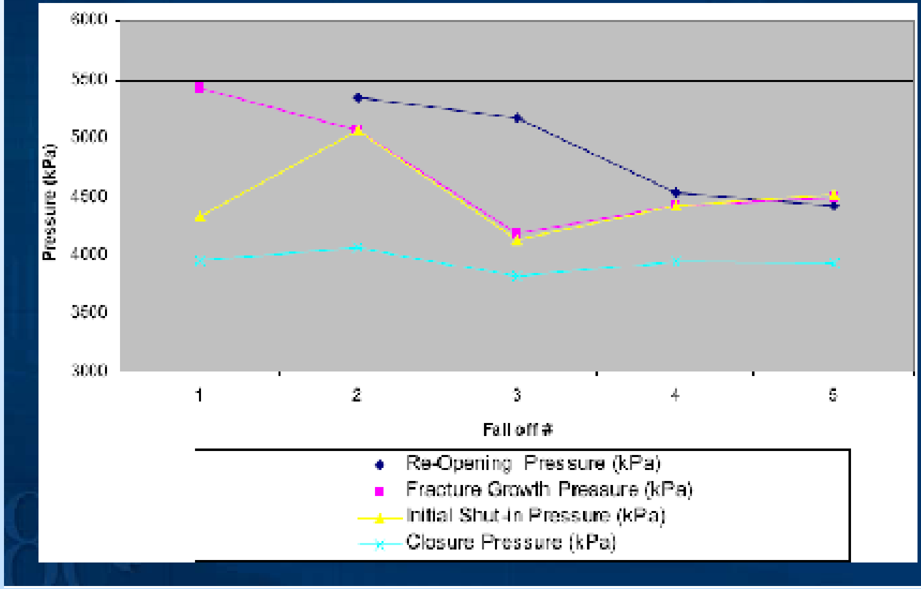
In Situ Testing Methodology – Modular Dynamics Tester with Pre-stress Packer

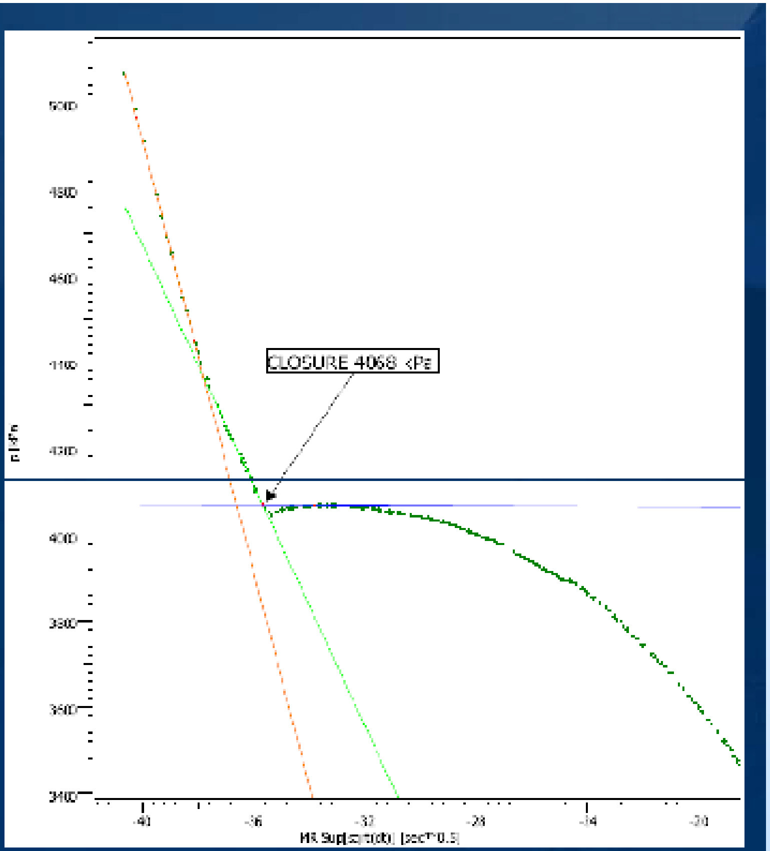
Shale Formation Break-down Test

Pre-closure & After-closure Analysis

Interpreted Results

- **Closure Pressure**
- **Breakdown initiation/breakdown growth**



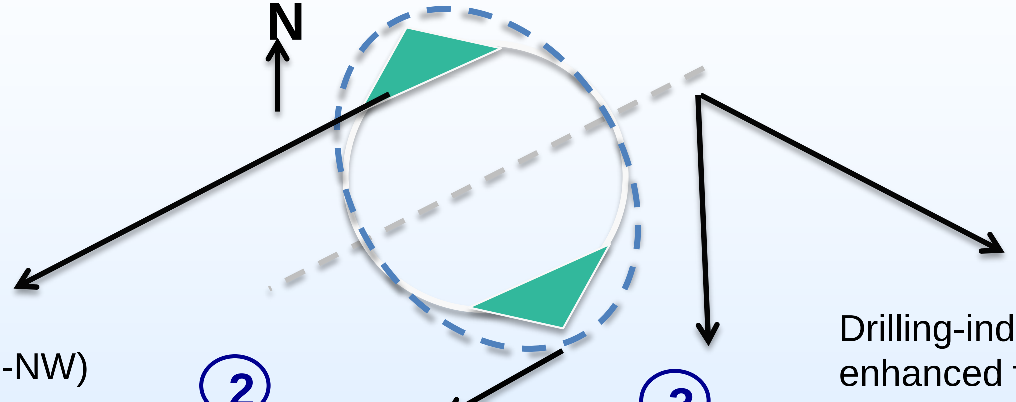


(Mishra, V., 2011)

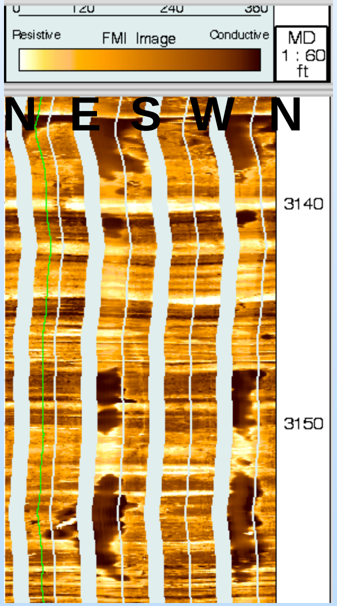
Task/Subtask Breakdown – Budget Period 2 (continued)

- Task 4 – Data Reduction/Analysis, Geomechanics Modeling, & Project Reporting
  - Data Reduction/Analysis (Subtask 4.1) – integration of laboratory and field testing data to establish relationships between formation strength and geophysical properties
  - Geomechanical Modeling (Subtask 4.2) – Use of commercial software to determine the state of stress in the Newark Basin and evaluation of risks of induced seismicity and leakage through confining layers along faults/fractures due to CO_2 injection.
  - Project Data Analysis & Reporting (Subtask 4.3) – Construction of mechanical earth model of the basin and preparation of final project report.

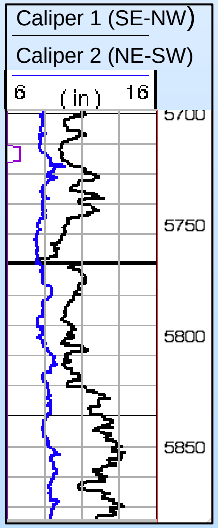
Analysis of Borehole Stress Indicators



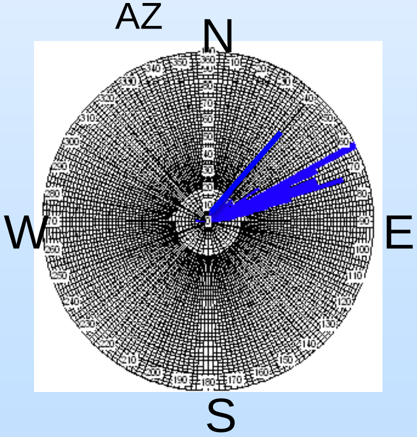
① Breakouts in sediments (SE-NW)



② Wellbore deformation in the sill (SE-NW)

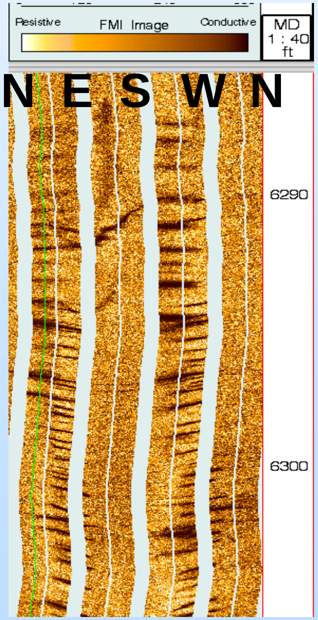


③ Fast shear AZ

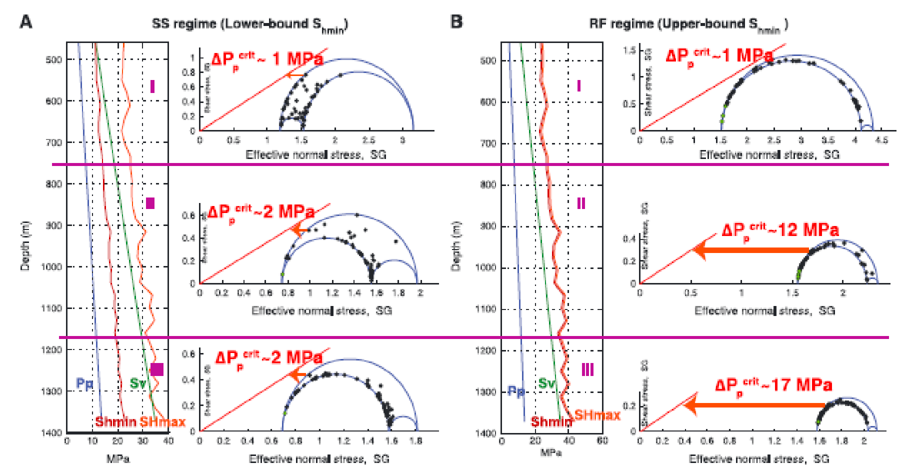


(from sonic anisotropy analysis by Schlumberger)

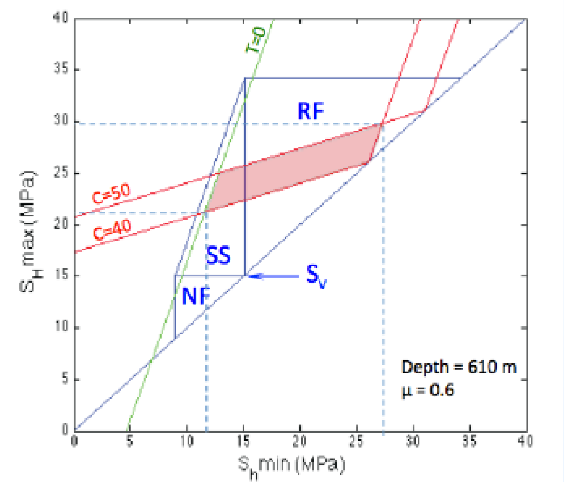
④ Drilling-induced and drilling-enhanced fractures (NE-SW)



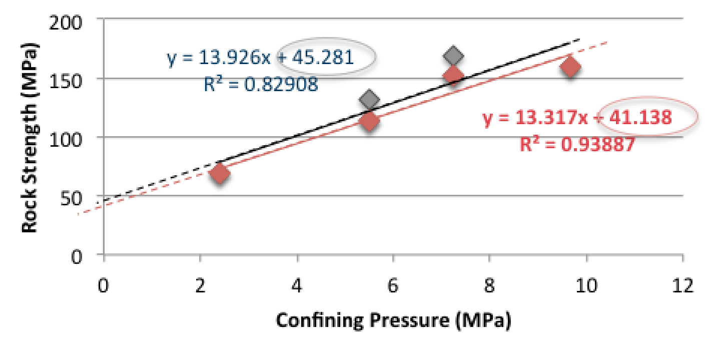
Standard Analysis Methodologies



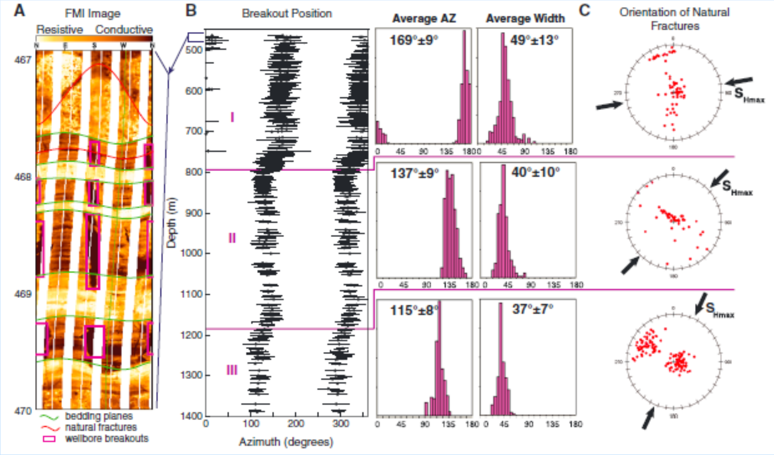
Zakharova & Goldberg et al. [2013].



Zakharova [2013].

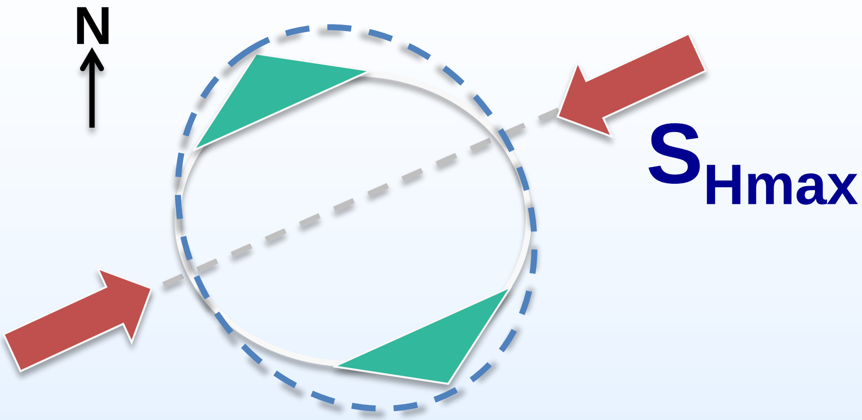


Zakharova [2013].



Zakharova & Goldberg et al. [2013].

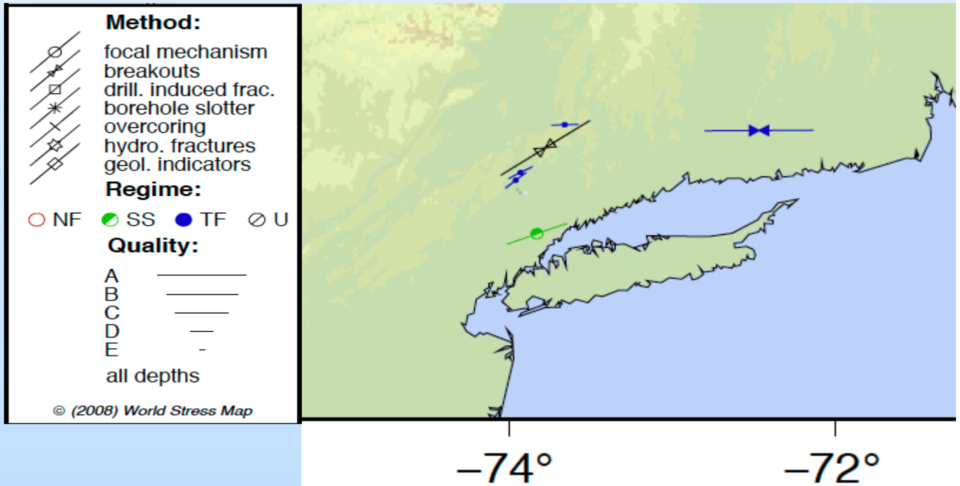
Regional Stress Orientation



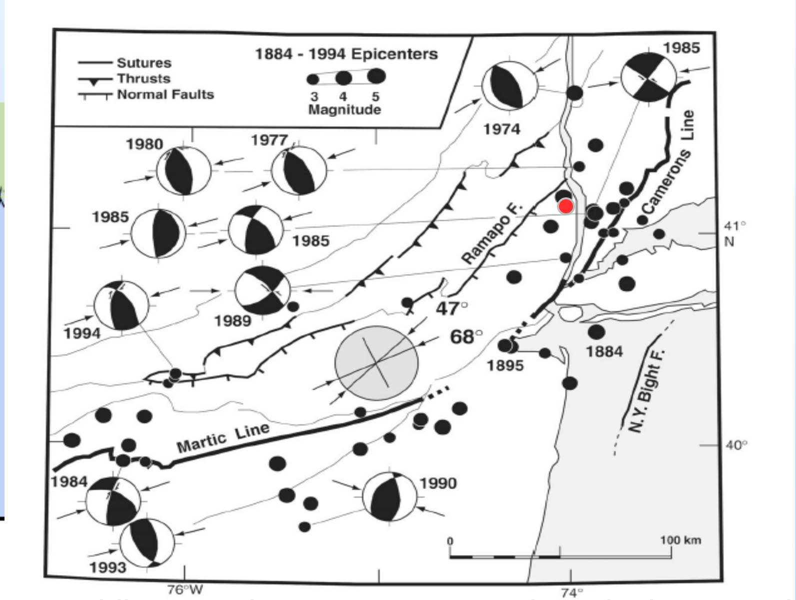
Lamont Doherty Earth Observatory

Early Findings:

- All stress data suggest maximum horizontal stress oriented NE-SW
- Basin Seismicity potential
- Data is consistent with other regional evidence for reverse/strike-slip regime



Reinecker, et al., (2008), The World Stress Map (www.world-stress-map.org)



Goldberg et al., 2003, Stress Regimes in the Newark basin: evidence from core and downhole data

Communication Plan/Technology Transfer

–Interim and final project results will be presented at the annual American Geophysical Union scientific conference held in San Francisco. (others as applicable – ARMA, etc.)

–To reach a wider audience, significant interim and final project results will be submitted for publication in scientific journals.

–The Project Team will prepare a comprehensive project report that will include a geomechanical model of the Newark Basin (*Geomechanical Characterization and Modeling of the Newark Basin*).

–The project will participate in DOE organized conferences.

–The dedicated www.Tricarb.org website will be used for data transfer between project participants and other interested parties.

Project Milestones

Task/ Subtask	Milestone Title	Planned Completion Date	Verification method
Budget Period 1			
1.1	Project Management Plan	10/31/14	Revised Project Manag. Plan
1.2	Kickoff Meeting	11/12/14	Presentation file
1.3	Completed EQ’s	10/1/14	DOE Approval Forms
2.2	Initiation of Laboratory Testing	02/01/15	Notification to PO
2.2	Completion of Laboratory Testing	08/31/15	Notification to PO
2.3	*Report on Newark Basin Caprock Characterization and Laboratory Testing*	09/30/15	Submittal of Report to PO
Budget Period 2			
3.2	Final Field Testing Work Plan	10/31/15	Submittal of Plan to PO
3.2	Notification of mobilization of equipment to site for initial FMI	12/1/15	Notification to PO
3.3	Notification of mobilization of equipment to site for Mini-fracs and final FMI	3/7/2016	Notification to PO
3.3	Notification of completion of field testing activities	3/11/2016	Notification to PO
4.3	*Geomechanical Characterization and Modeling of the Newark Basin*	12/31/2016	Submittal of Report to PO

Summary of Project Deliverables

- Budget Period 1 Deliverable
  - ***"Report on Newark Basin Caprock Characterization and Laboratory Testing" due no later than September 30, 2015***

- Budget Period 2 Deliverables -
  - ***Final Field Testing Work Plan due no later than October 31, 2015***

  - ***"Geomechanical Characterization and Modeling of the Newark Basin" due no later than December 31, 2016***

Risk Matrix

- Budget Period 1 - Risk minimized by leveraging existing core from the basin. Low Risk/High Return Value
- Budget Period 2 – Risk lowered by using existing well controlled by project team member (no access issues/ no permits required)
- Potential risk of inability to break down test intervals during in situ testing
  - Mitigation strategy is to use innovative “pre-stress” high pressure packer set-up on standard tool string to form initial breakdown in test intervals prior to standard/proven testing methodology

Expected Outcomes

- Comprehensive geomechanics “case study” of the northern Newark Basin leveraging existing whole core and geophysical well logs, with new in situ well testing to determine the full stress field in the basin
- Assessment of seismic and leakage risks associated with potential CO_2 sequestration
- Demonstration of innovative Modular Dynamics Tool for breakdown testing in high-strength formations
- Results can be used for similar basins, both onshore and offshore

Summary

- Project consists of a 27 month study to define cap rock properties using the Newark Basin as a “case study”.
- The initial project phase consists of detailed evaluation, characterization, and geomechanical properties analyses leveraging more than 21,000 feet of existing whole core consisting of a range of lithology types
- Field phase involves formation breakdown testing of varying lithology types in the LDEO Test Well No. 3 well using a for purpose, innovative Modular Dynamics Tool for breakdown testing in high-strength formations
- Results can be used for similar basins, both onshore and offshore

Questions?

End