Implications of Stress State Uncertainty on Caprock and Well Integrity (FEW0191)

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Lawrence Livermore National Laboratory

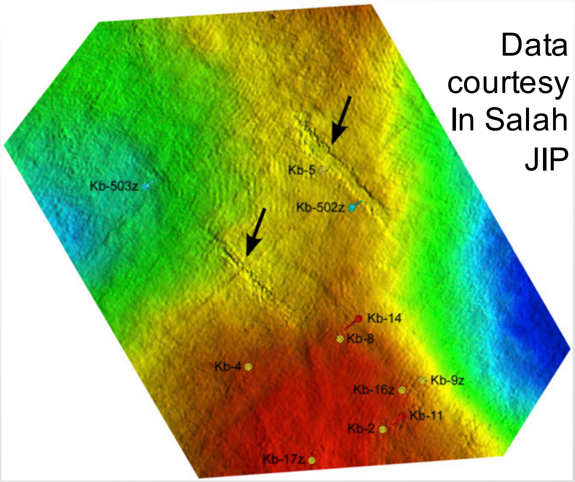
U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
August 18-20, 2015

LLNL-PRES-665424

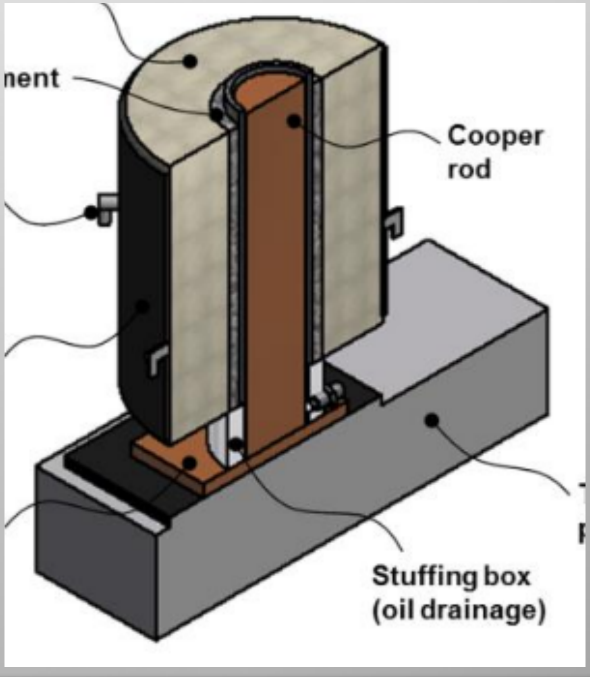
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Project Objectives

Task 3.1– Improve assessment of thermal-hydraulic fracturing risk during CO_2 injection



Task 3.2 – Illustrate modes of well failure caused by heating and cooling

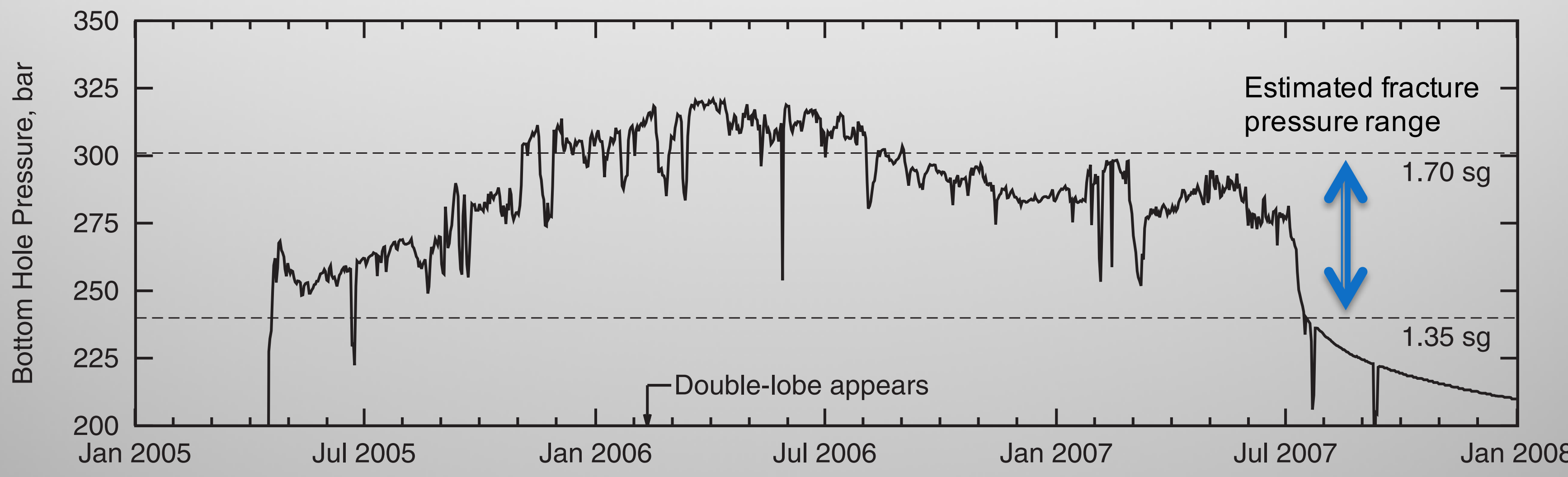


Program Goals and Benefits

- This project meets the Carbon Storage Program goals to develop and validate technologies to ensure 99 % storage permanence.
- This project develops and validates geomechanical computational tools needed to avoid caprock and wellbore failure during CO_2 injection.
- Approach
  - GEOS - multi-scale, multi-physics simulator developed at LLNL
  - Caprock Integrity
    - Update key physics to bound operational practices that might fracture the caprock during CO_2 injection
    - Test simulation results against data from the In Salah CO_2 demonstration
  - Wellbore Integrity
    - Update key physics to bound the impact of thermal stresses on well integrity
    - Constrain simulations against thermal cycling experiments conducted by SINTEF
    - Apply model to physical conditions reflecting CO_2 operations
- Success is defined as a methodology to define
  - pressure thresholds to maintain caprock integrity and
  - temperature ranges that yield minimum damage in the wellbore.

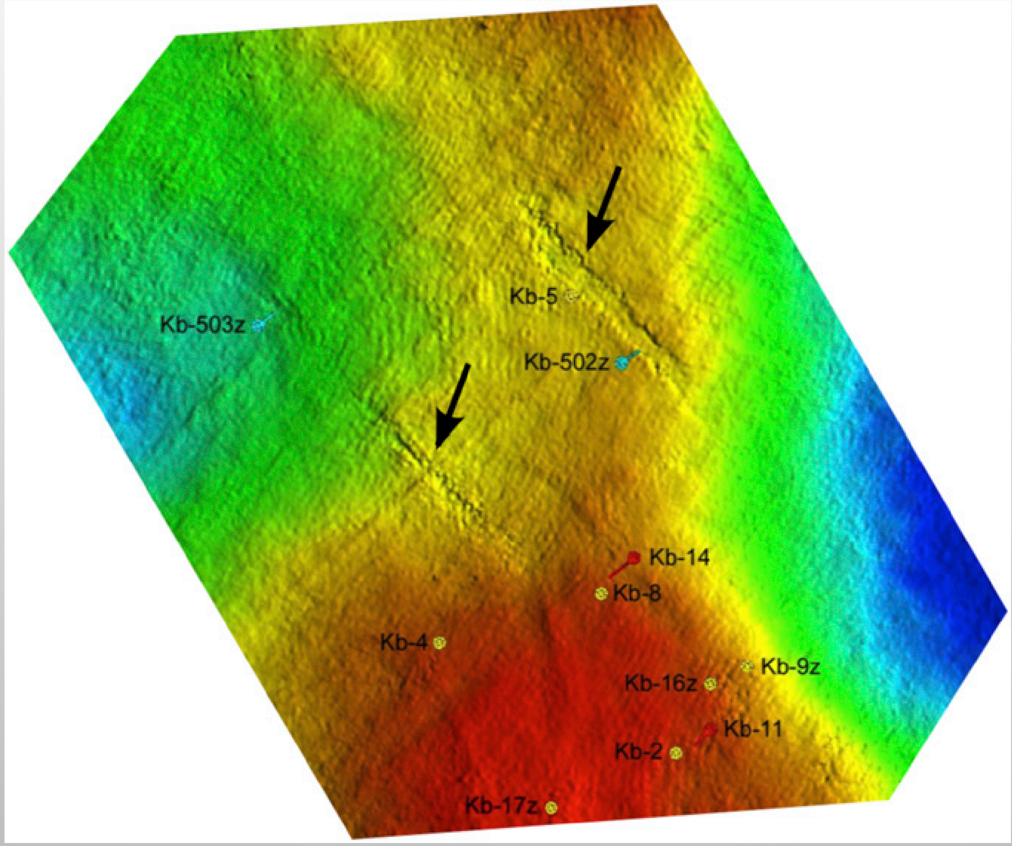
Task 3.1 – Improve assessment of thermal-hydraulic fracturing risk during CO_2 injection

Motivation: Injection of cold CO_2 at high pressure can potentially fracture reservoir rocks and caprock seals.



In Salah Case Study: Bottom hole pressure and estimated fracture pressure range at KB-502.

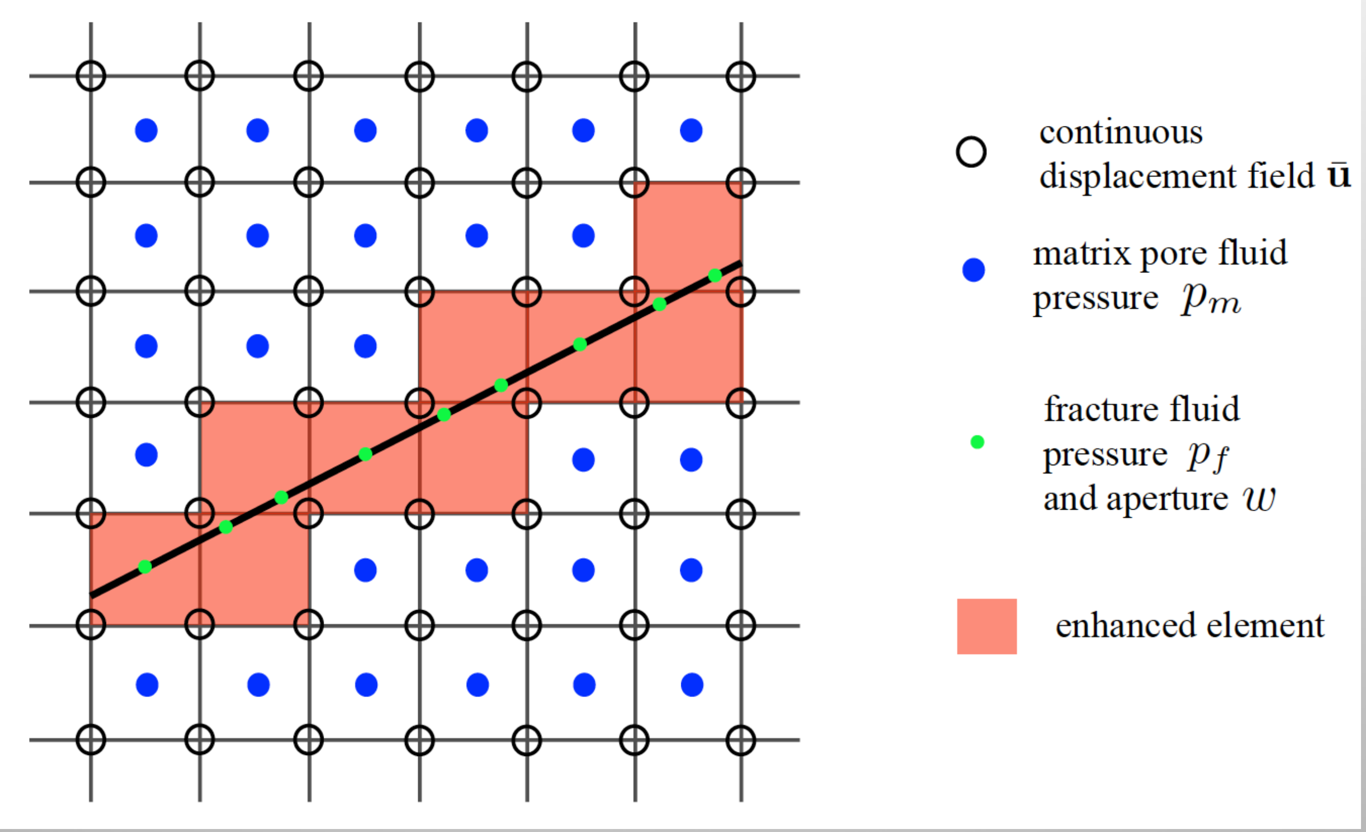
Task 3.1 – Improve assessment of thermal-hydraulic fracturing risk during CO_2 injection



Data courtesy In Salah JIP

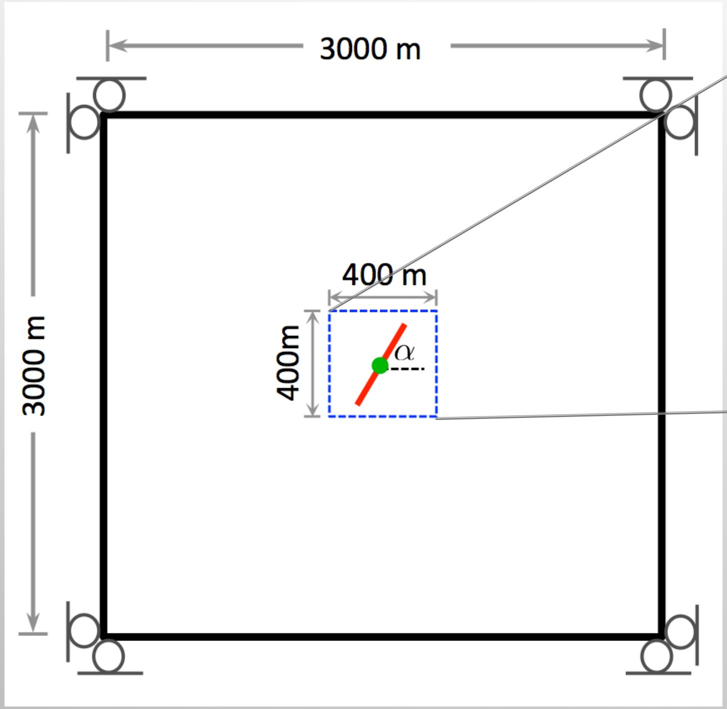
In Salah Case Study: Velocity anomalies seen in 3D/4D seismic. Features run perpendicular to minimum horizontal stress, and may indicate fracturing in the reservoir and lowermost caprock [White et al. 2014].

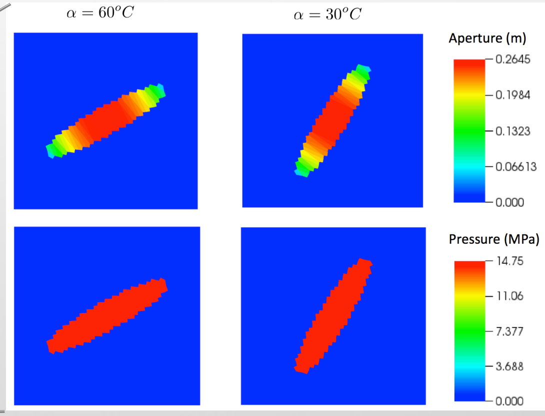
New modeling approach to allows arbitrarily oriented fractures to be embedded in a standard reservoir simulator

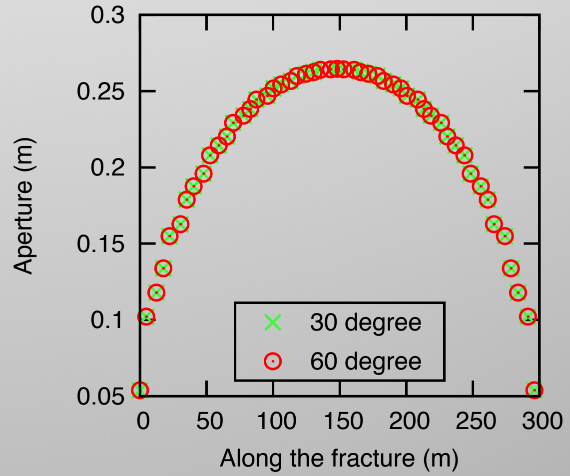


We solve for fracture pressure, fracture aperture, matrix pressure, and matrix displacement in a tightly-coupled fashion.

New modeling approach to allows arbitrarily oriented fractures to be embedded in a standard reservoir mesh

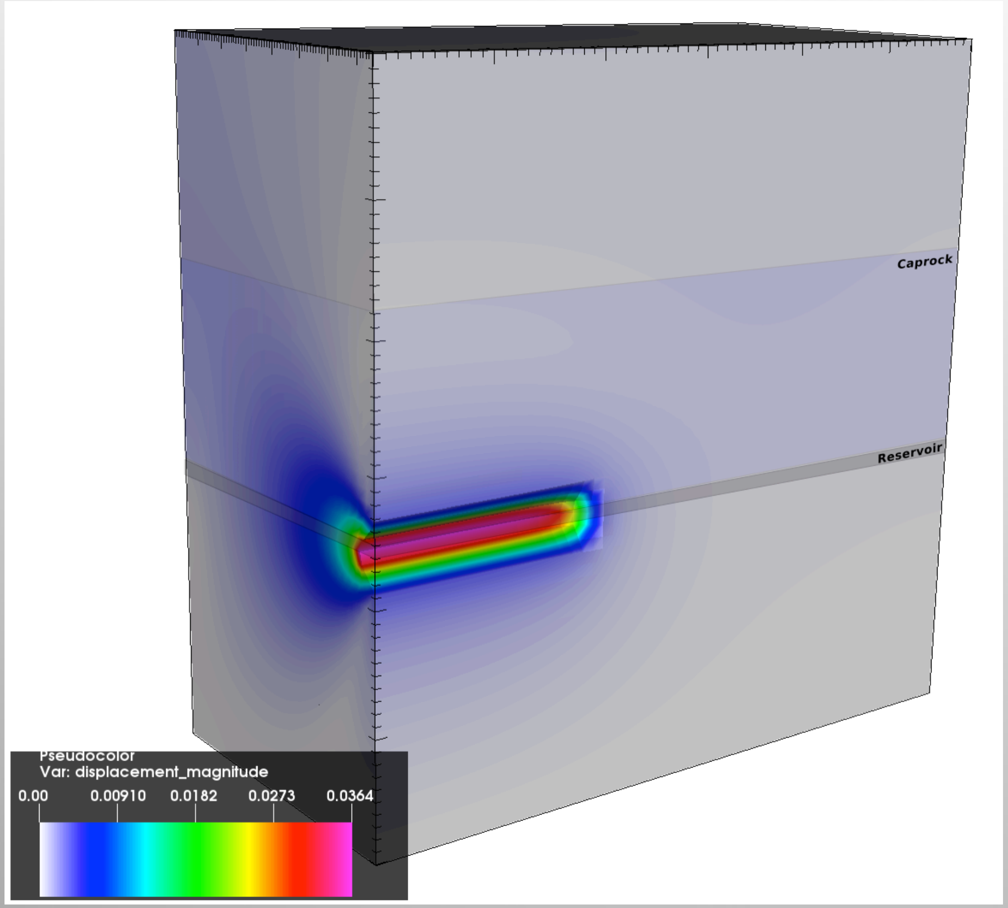






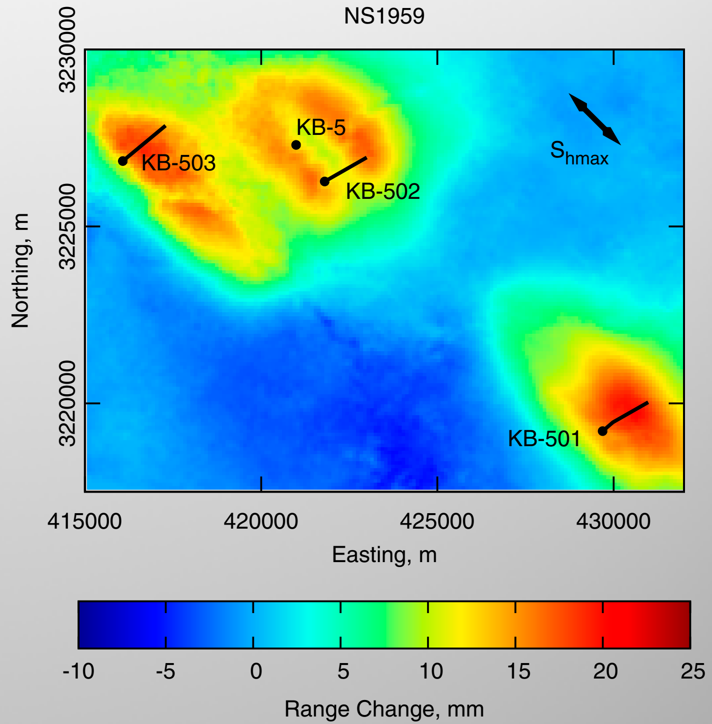
Simple test problem with a pressurized crack on a fixed background mesh. Computed response is independent of crack orientation, as expected.

Task Status – We are currently calibrating an In Salah model, using available data as constraints.



“Static” fracture model used to calibrate rock properties against surface deformation data. Next step will use a propagating fracture to look at the time-evolution of the system.

Constraint 1: InSAR data

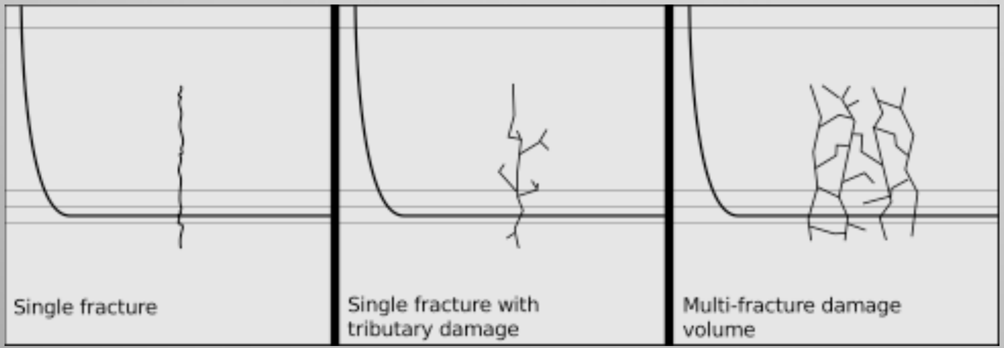


Constraint 2: pressure data

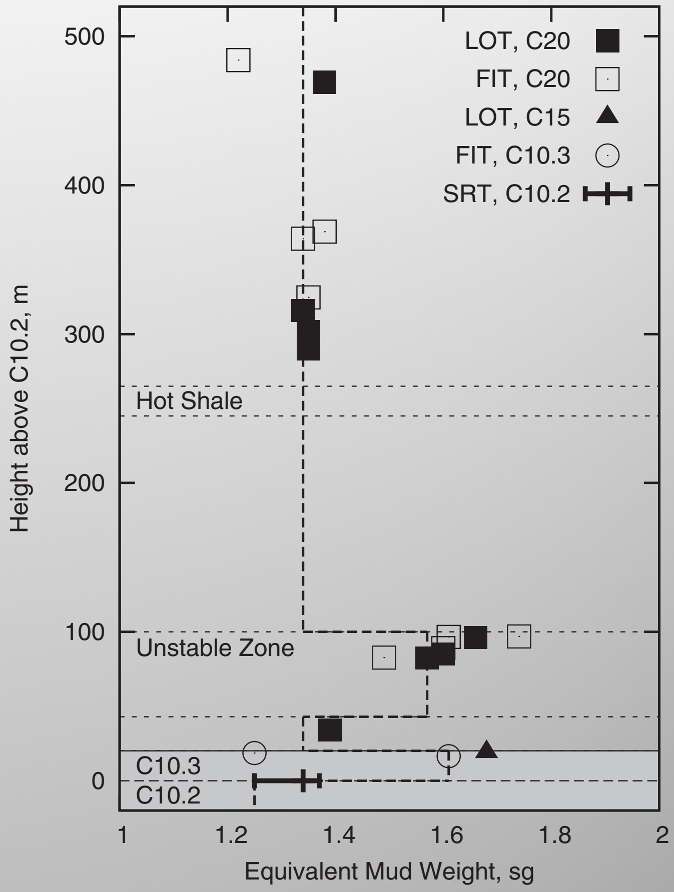
Constraint 3: 4D seismic

Goal is to understand the importance of key uncertainties on the fracturing process:

- Layered in situ stress profile
- Fluid leakoff to reservoir / caprock
- Thermal perturbations
- Single fracture vs. multiple interacting fractures

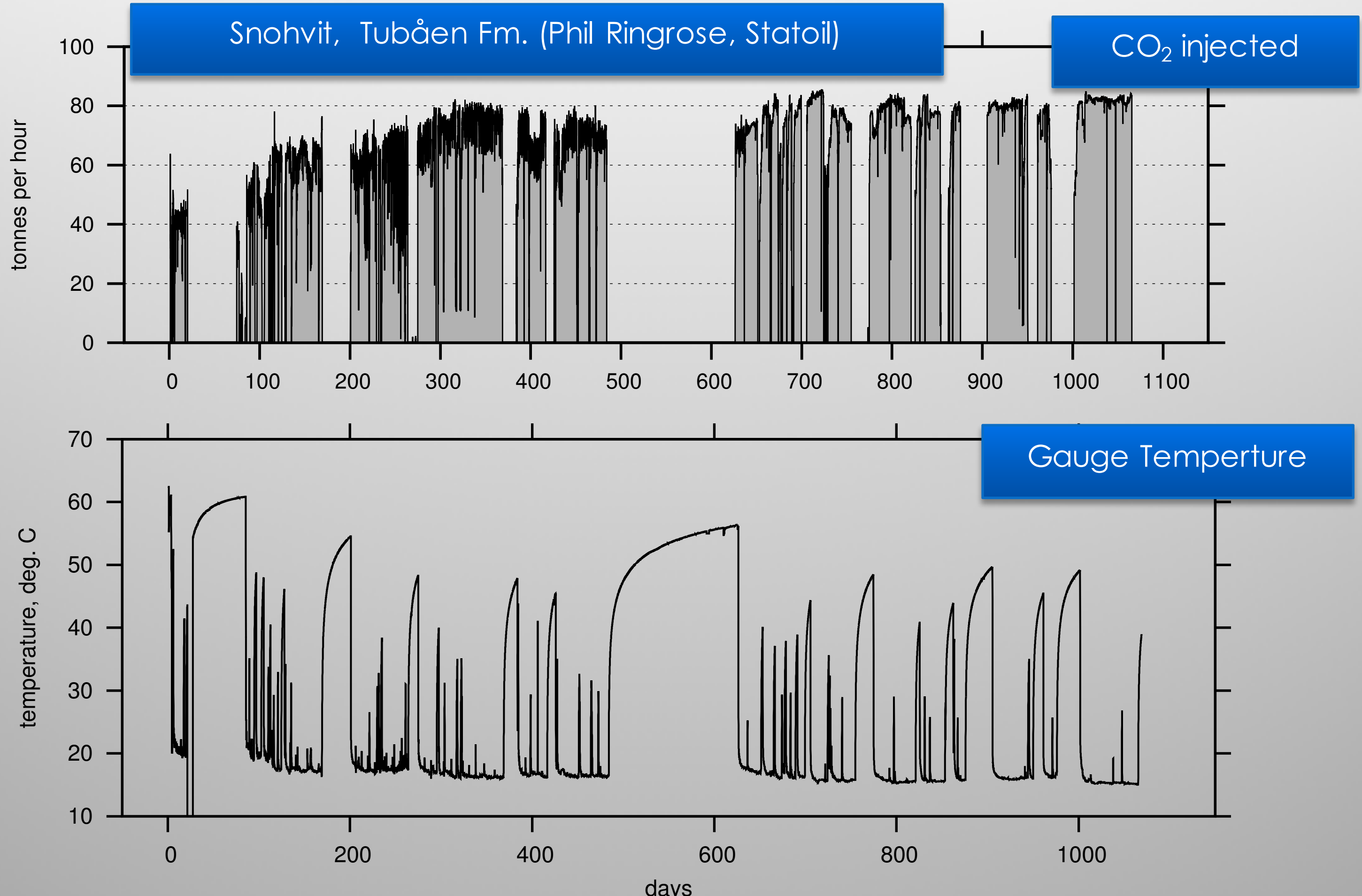


Spectrum of fracture behavior, from single mode-I fracture to a complex multi-fracture environment

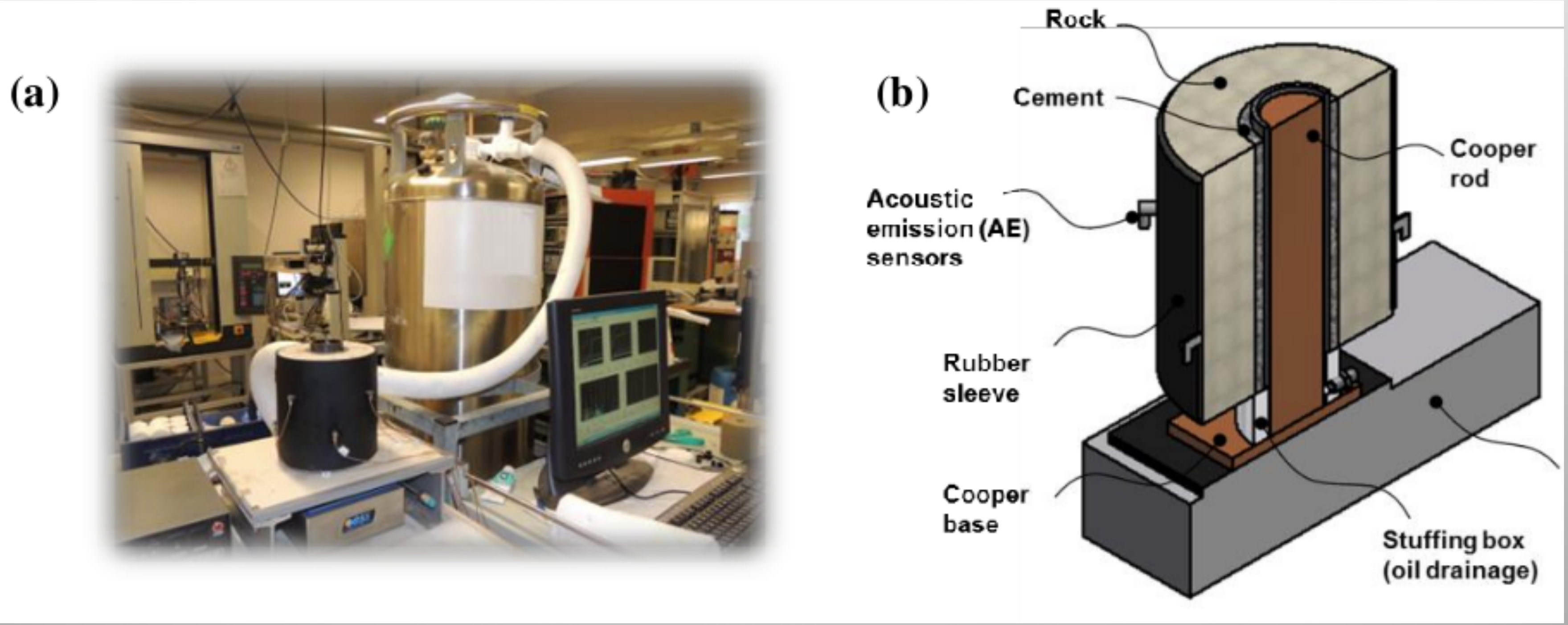


In Salah leak off test and formation integrity test data.

Task 3.2 – Assess the impact of thermal stresses caused by injection of cold CO_2 into warmer storage reservoirs on wellbore integrity



Task 3.2 – Experimental Setup at SINTEF

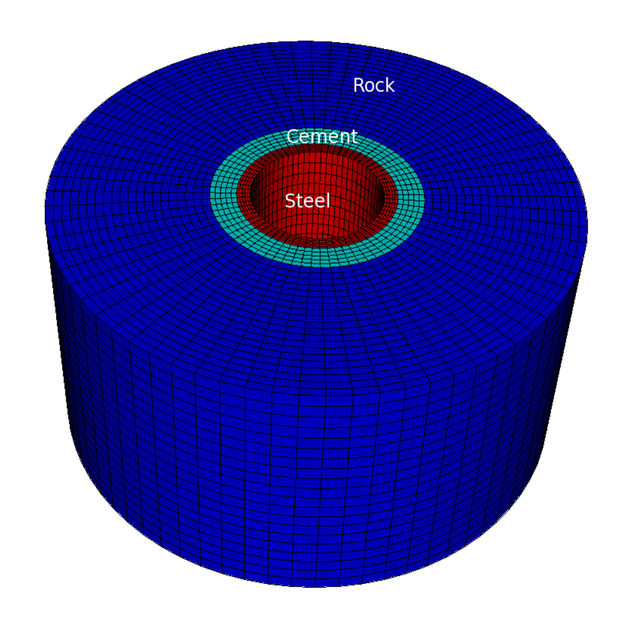


Simulation Specifications

- Thermal and Linear Elastic Solvers

- Variable Temperature at inner radius
- Constant Temperature at outer radius
- Temperature range = 6 – 106 ^{o}C
- Heating or cooling rate = 1.5 – 2 ^{o}C/min

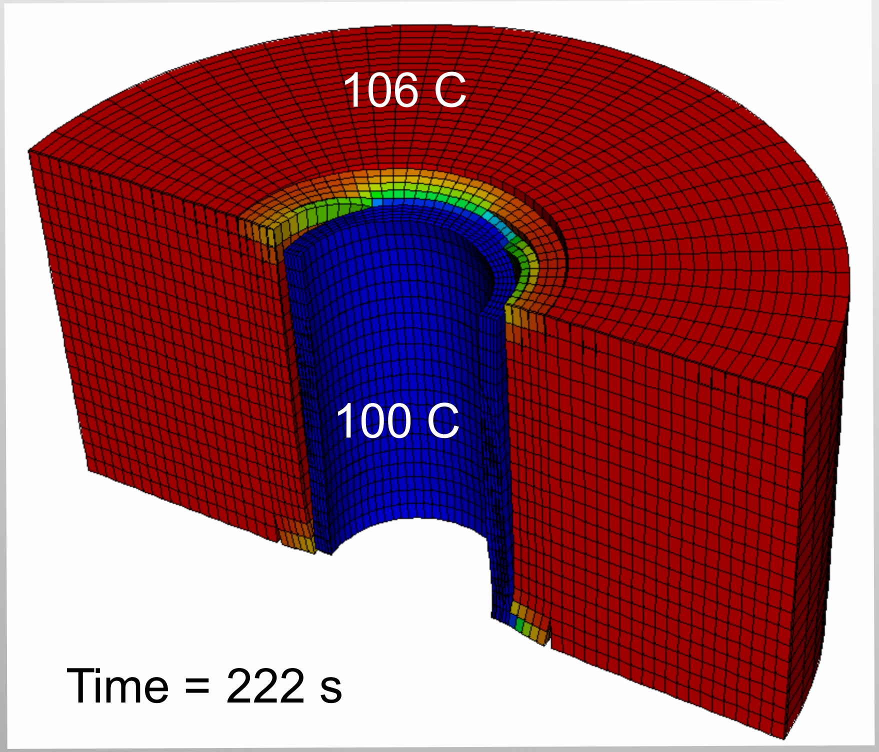
- Fail Strength
  - Steel-Cement interface = 1.0 Mpa
  - Cement-Rock interface = 1.5 MPa



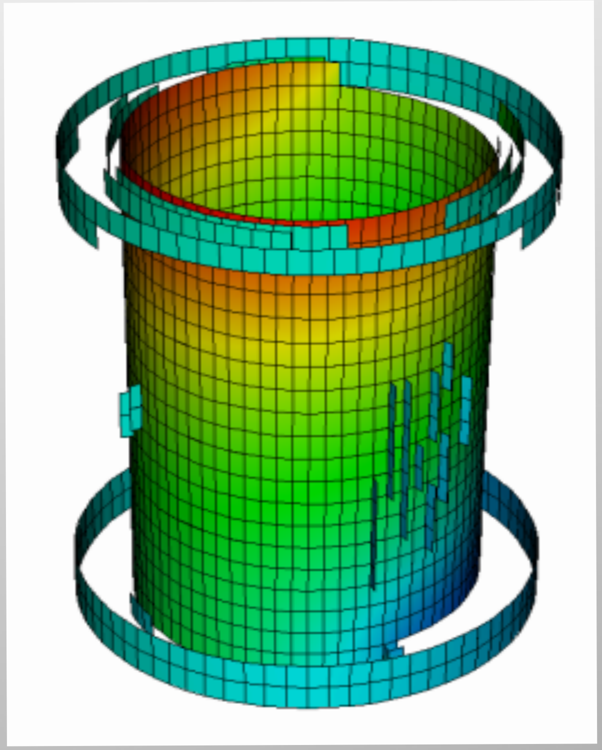
Properties/ Material	Steel	Cement	Rock
Density (kg/m^3)	8000	2300	2500
Thermal Exp. Coeff (K^{-1})	12.0 x 10^{-6}	7.9 x 10^{-6}	10.0 x 10^{-6}
Thermal Conductivity (W/m/K)	50	1	2.1
Specific Heat (J/kg/K)	450	1600	2000
Fail Strength (MPa)	200	2	6
Fracture Toughness (Mpa.m$^{1/2}$)	40	1	2.5

During cooling –
Thermal contraction causes interfacial debonding

Temperature contours



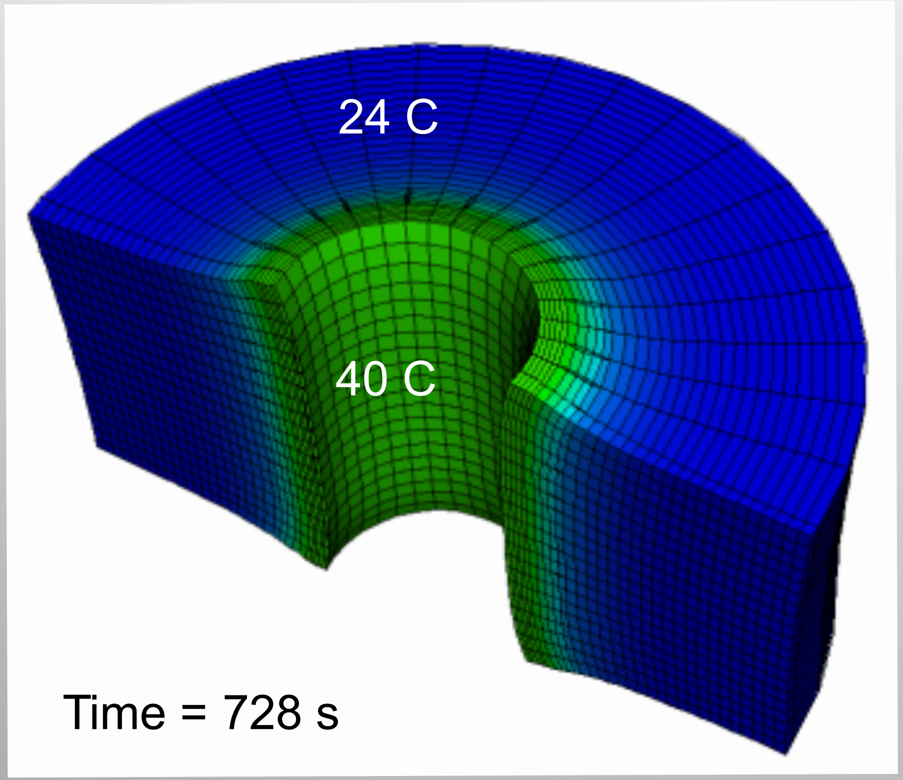
Fracture propagation



Adding confining pressure slows fracture propagation

During heating –
Thermal expansion causes radial cracks

Temperature contours



Fracture propagation

Adding confining pressure slows fracture propagation

Summary and Future Work

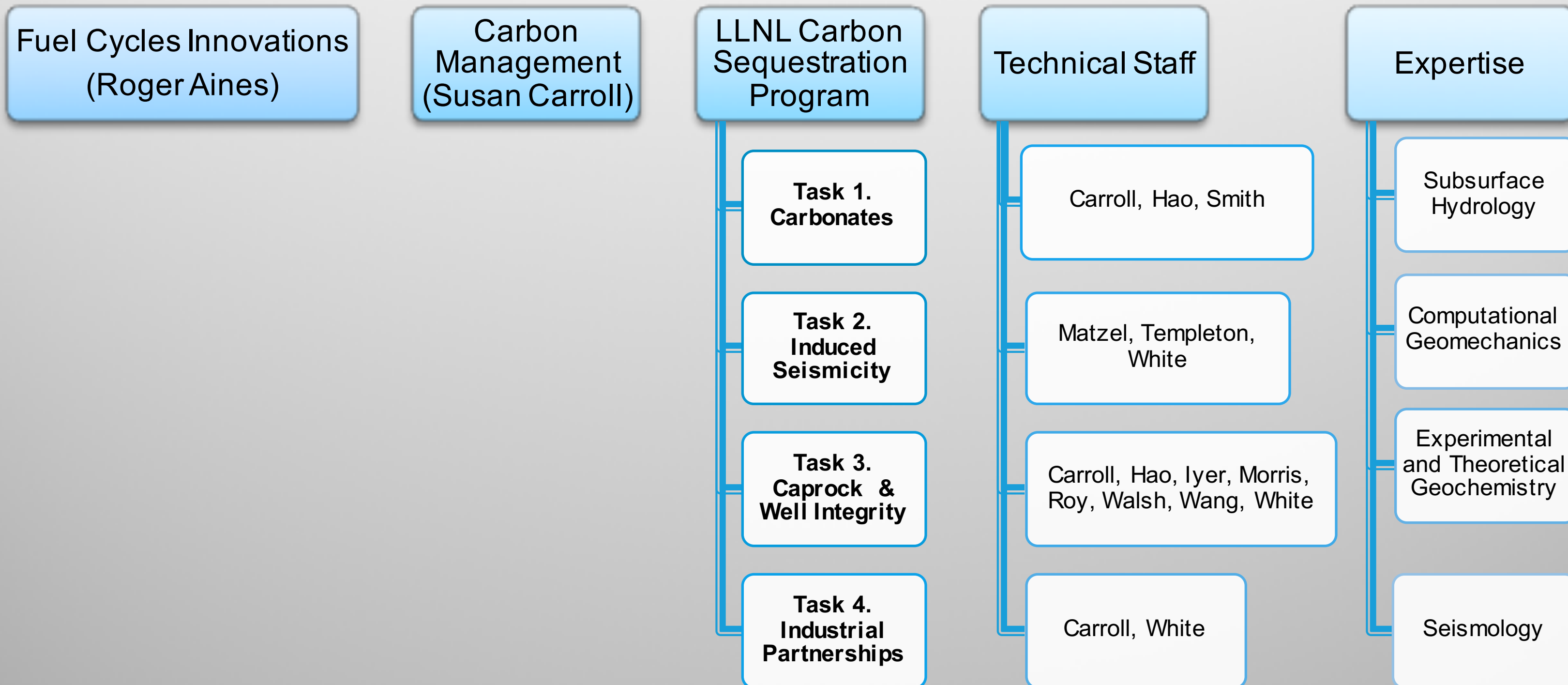
- 3.1 – Caprock Integrity
  - Implementation of an embedded fracture model in a continuum geomechanics / flow simulator
  - Future model improvements, including:
    - Multiphase effects
    - Non-isothermal conditions
  - Finalize the In Salah case study
- 3.2 – Successfully modeled modes of deformation of wellbore upon heating and cooling separately
  - Update model to account for thermal cycling
- 3.3 Model SINTEF experiments (on – going)
- 3.4 Refine simulation tools for sharing with industrial partners
- 3.4 Development of best practices for risk management

Synergy Opportunities

- Collaboration with SINTEF and In Salah JIP
  - Provides detailed field and experimental data to constrain models
  - Provides strong ties with industry to identify real and practical questions from an operators point of view

Appendix

FEW0191


Fuel Cycles Innovations (Roger Aines)
Carbon Management (Susan Carroll)
LLNL Carbon Sequestration Program
Task 1. Carbonates
Task 2. Induced Seismicity
Task 3. Caprock & Well Integrity
Task 4. Industrial Partnerships
Technical Staff
Carroll, Hao, Smith
Matzel, Templeton, White
Carroll, Hao, Iyer, Morris, Roy, Walsh, Wang, White
Carroll, White
Expertise
Subsurface Hydrology
Computational Geomechanics
Experimental and Theoretical Geochemistry
Seismology

Project Timeline for FEW0191

Task	Milestone Description*	Project Duration	Start : Oct 1, 2014					End: Sept 30, 2017						Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
		Project Year (PY) 1				PY 2				PY 3								
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12					
1.1	Calibrate Reactive Transport Model						x							1-Oct-14	30-Mar-15			
1.2	Calibrate NMR Permeability Estimates						x							1-Oct-14	30-Mar-15			
1.3	Scale Reactive Transport Simulations from the core to reservoir scale										x			1-Jul-15	28-Feb-17			
1.4	Write topical report on CO2 storage potential in carbonate rocks												x	1-Dec-16	30-Sep-17			
2.1	Algorithm development and testing				x									1-Oct-14	30-Sep-15			
2.2	Array design and monitoring recommendations								x					1-Oct-15	30-Sep-16			
2.3	Toolset usability and deployment												x	1-Oct-16	30-Sep-17			
3.1	Analysis of monitoring and characterization data available from the In Salah Carbon Sequestration Project				x									1-Dec-14	30-Sep-15			
3.2	Wellbore model development				x									1-Oct-14	30-Sep-15			
3.3	Analysis of the full-scale wellbore integrity experiments										x			1-Mar-14	28-Feb-17			
3.4	Refining simulation tools for sharing with industrial partners												x	1-Oct-16	30-Sep-17			
4.1	Engage with industrial partnerships		x											1-Oct-14	28-Feb-15			Future tasks pending discussions with industrial partners
4.2	Develop work scope with industrial partners				x									1-Mar-14	30-Sep-15			

* No fewer than two (2) milestones shall be identified per calendar year per task