Snøhvit CO_2 Storage Project

Project Number:

FWP-FEW0174 Task 4

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Developing the Technologies and Building the Infrastructure for CO_2 Storage

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Outline

- Benefit to Program
- Project Goals and Objectives
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Benefit to the Program

- The research project is focused on mechanical deformation in response to CO_2 injection at Snøhvit.

- An understanding of hydromechanical interactions is essential for effective monitoring and prediction of reservoir performance.

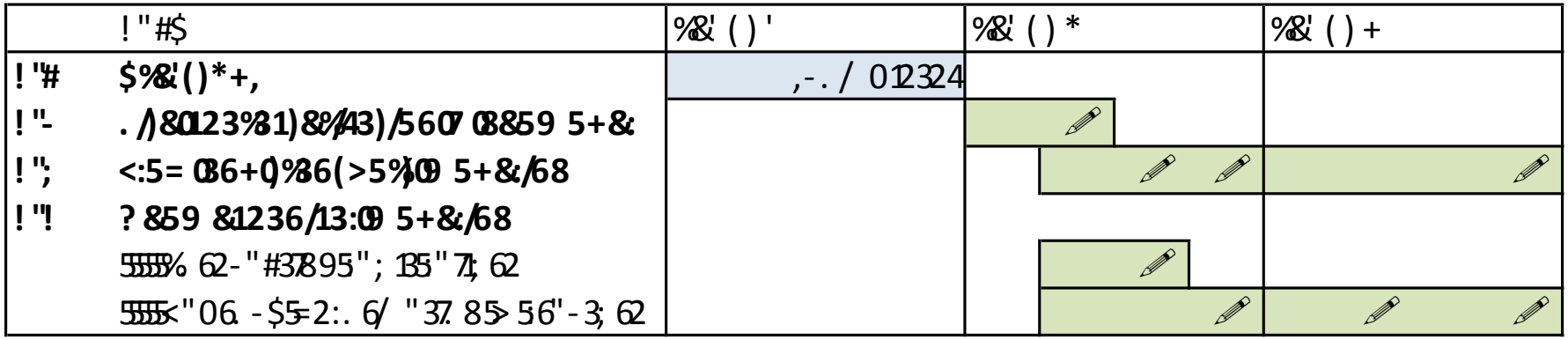
- This program meets the Carbon Storage Program goal to “conduct fields tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.”

Project Overview:
Goals and Objectives

- The project goal is to understand hydromechanical impacts of CO_2 injection into a complex storage structure:
  - Study the formation/enhancement of migration pathways within the reservoir and from the reservoir to the sea floor.
  - Validation of results based on monitoring and characterization data provide by Statoil.
  - This work can guide management and monitoring practices for sub sea floor injections and complex geologic structures.

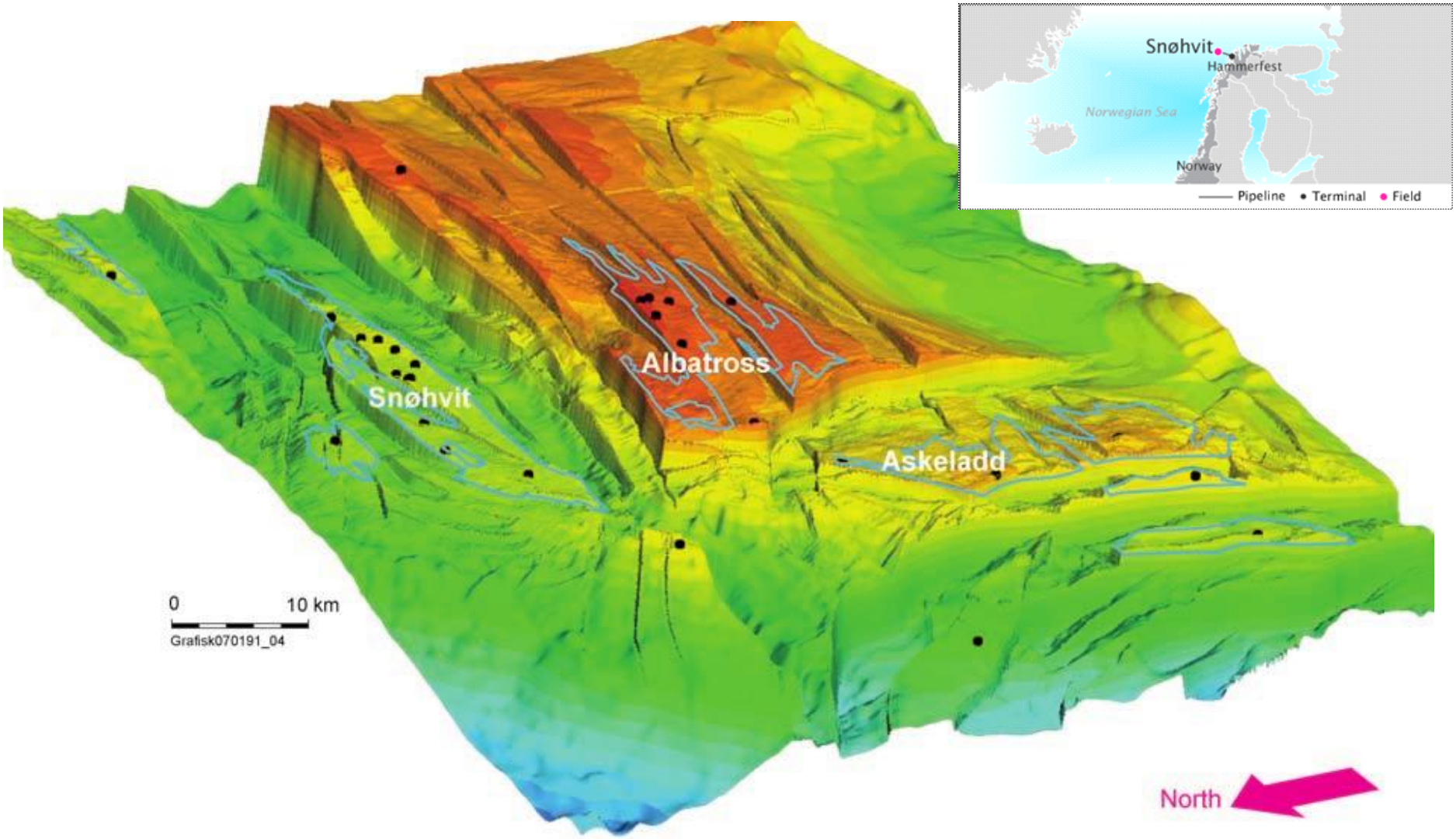
- Success is tied to ability to reproduce and predict behavior given available monitoring and characterization data, and provide useful guidance for the field operator.

Technical Status



- Due to contracting delays, only the pre-study has been completed, using a very limited data set provided by Statoil.
- Final contract paperwork is nearing completion, and LLNL is preparing to receive a full data pack from Statoil. Primary project work is expected to begin FY2013.
- **Today, primarily going to discuss results of our pre-study.**

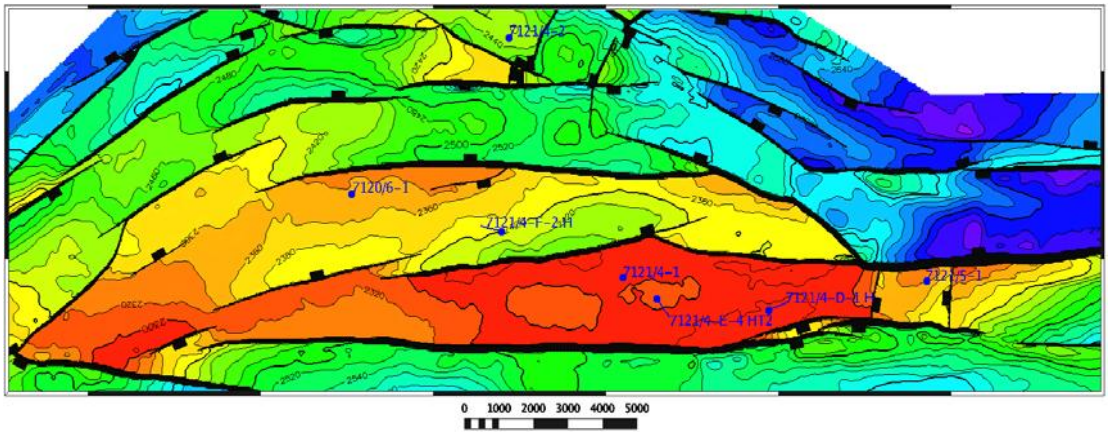
Snøhvit

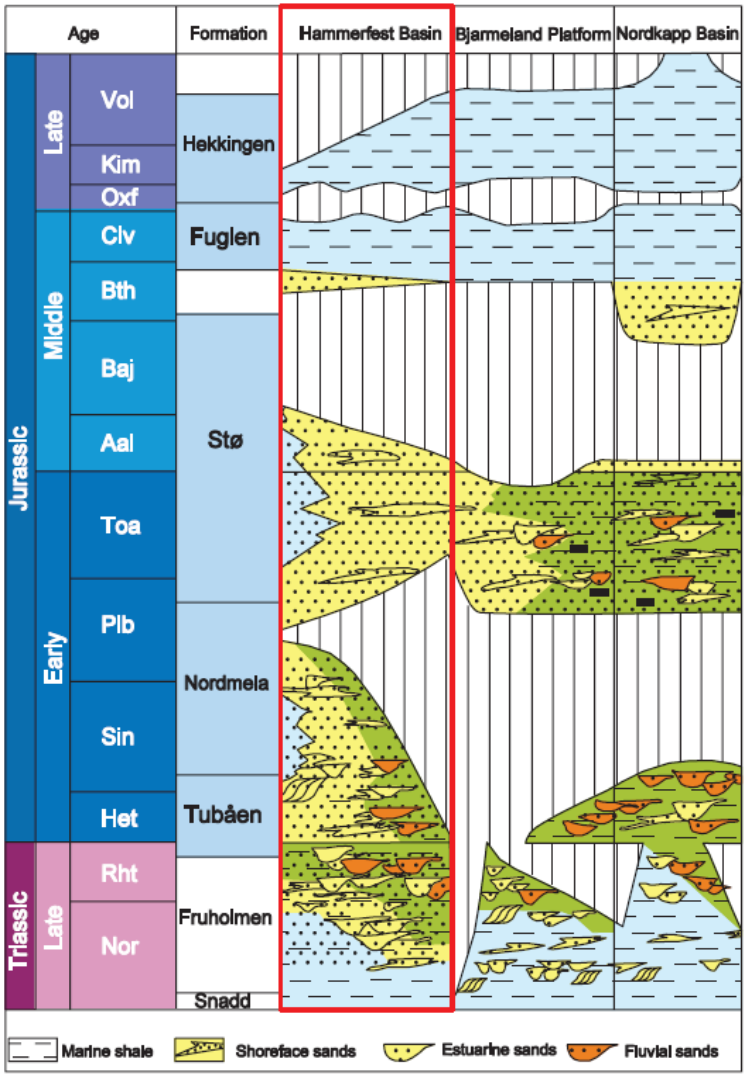


Structural diagram of Hammerfest Basin at Middle Jurassic level (approx. age of producing reservoir). Blue lines outline the gas fields [from Spencer et al., 2008].

Snøhvit

Depth map at top of Fuglen Fm. (below) and stratigraphic section (right) [from Wennberg et al., 2008]





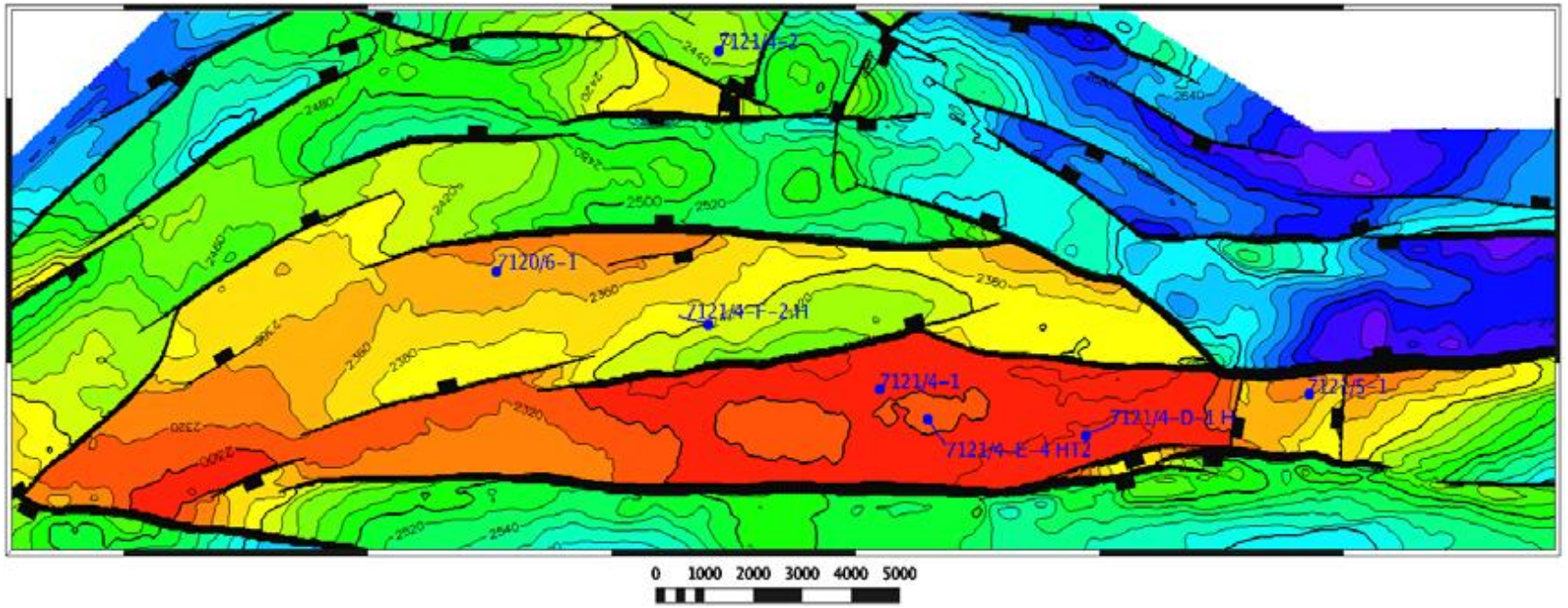
- Producing natural gas with 5-8% CO_2 content, which needs to be reduced before liquefication.
- Separated CO_2 was re-injected into Tubåen Fm. at approx. 2400-2600m depth.
- Injection began in 2008, but in 2010 Statoil announced storage capacity in Tubåen was lower than expected. Approx. 1 Mt has been stored.

Questions

- Structural complexity of the site raises many interesting hydromechanical questions:
  - What is the role of the bounding faults at the site? Are they reservoir seals or potential gas chimneys? What happens at fault intersections?
  - Why was storage capacity lower than expected? Is it a function of the depositional setting? What is the role of observed fractures?
  - Are their ways to increase storage capacity while not compromising storage integrity?

Pre-Study

- **Goal**: Assess stability of bounding faults during long-term injection



- **Key uncertainty**: in situ stress magnitude and orientation.

Hydromechanical Model

- We compared analytical (back-of-the-envelope) analyses with a full numerical model.

- Model assumes tightly-coupled poromechanics, but with a single-phase approximation.

$$\nabla \cdot \boldsymbol{\sigma'} - b\nabla p + \rho \boldsymbol{g} = \boldsymbol{0} \qquad \text{Momentum Balance}$$

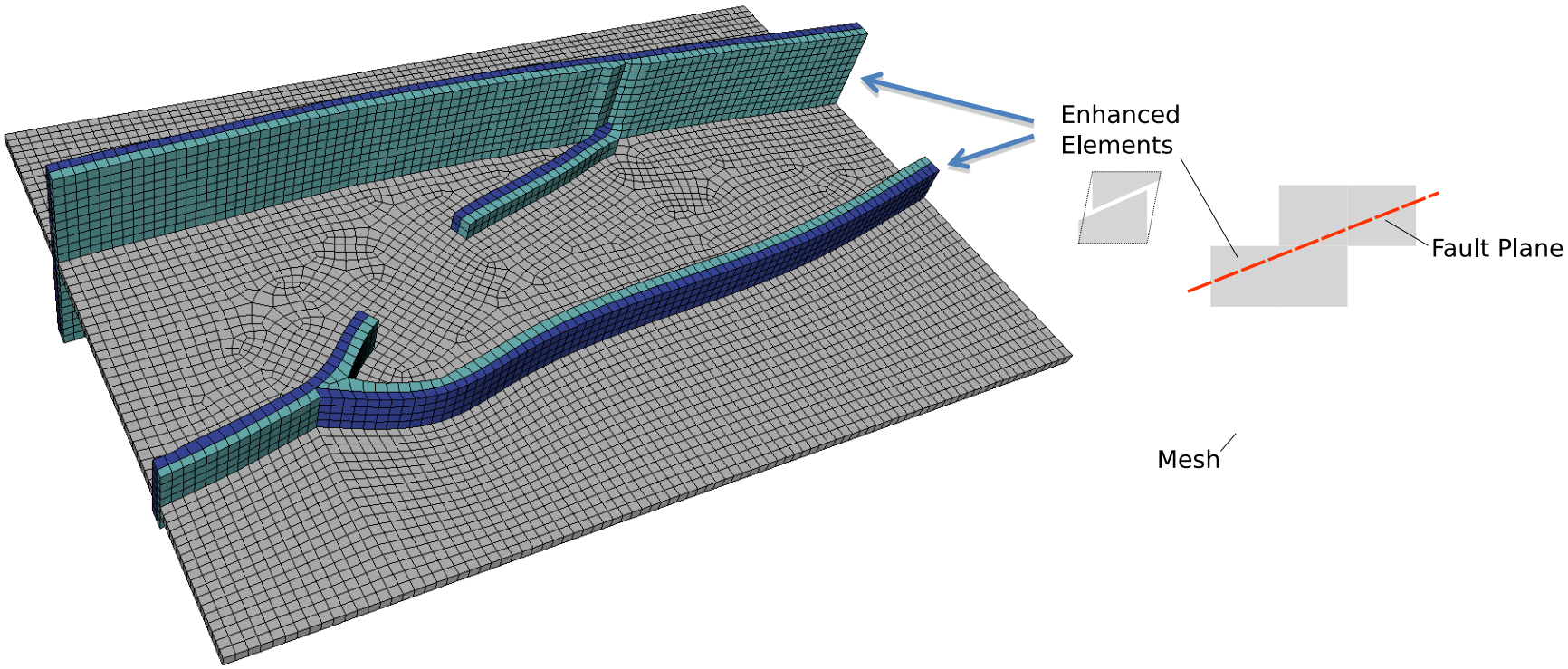
$$\alpha \dot{p} + b\nabla \cdot \dot{\boldsymbol{u}} + \nabla \cdot \boldsymbol{v} = 0 \qquad \text{Mass Balance}$$

$$\boldsymbol{v} + \frac{\boldsymbol{k}}{\mu}\nabla p = \boldsymbol{0} \qquad \text{Darcy's Law}$$

- We use Geocentric, a massively parallel finite element code for geomechanics.

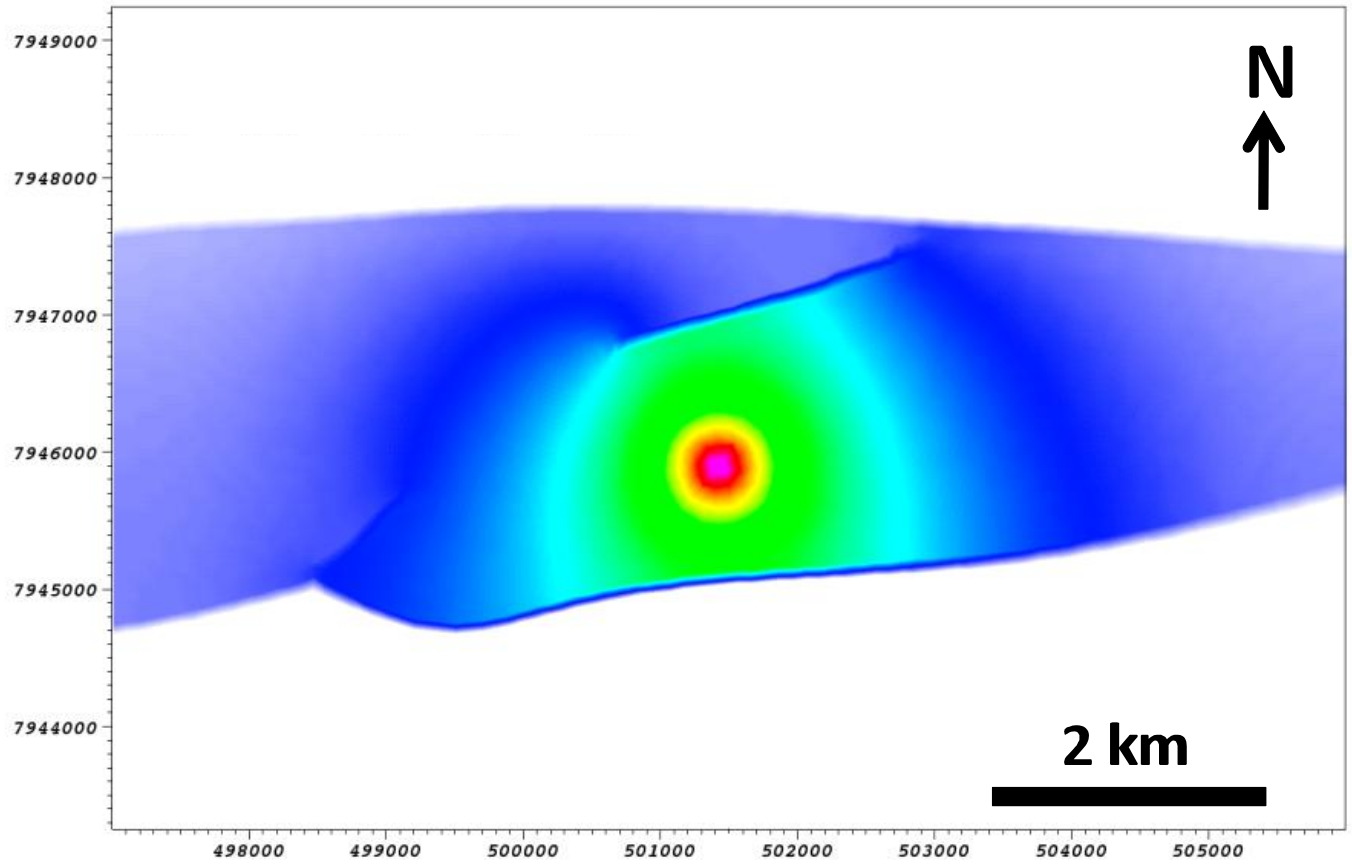
Hydromechanical Model

- Model geometry includes major bounding faults, but a simplified stratigraphy.



- Faults explicitly modeled using an embedded discontinuity technique.

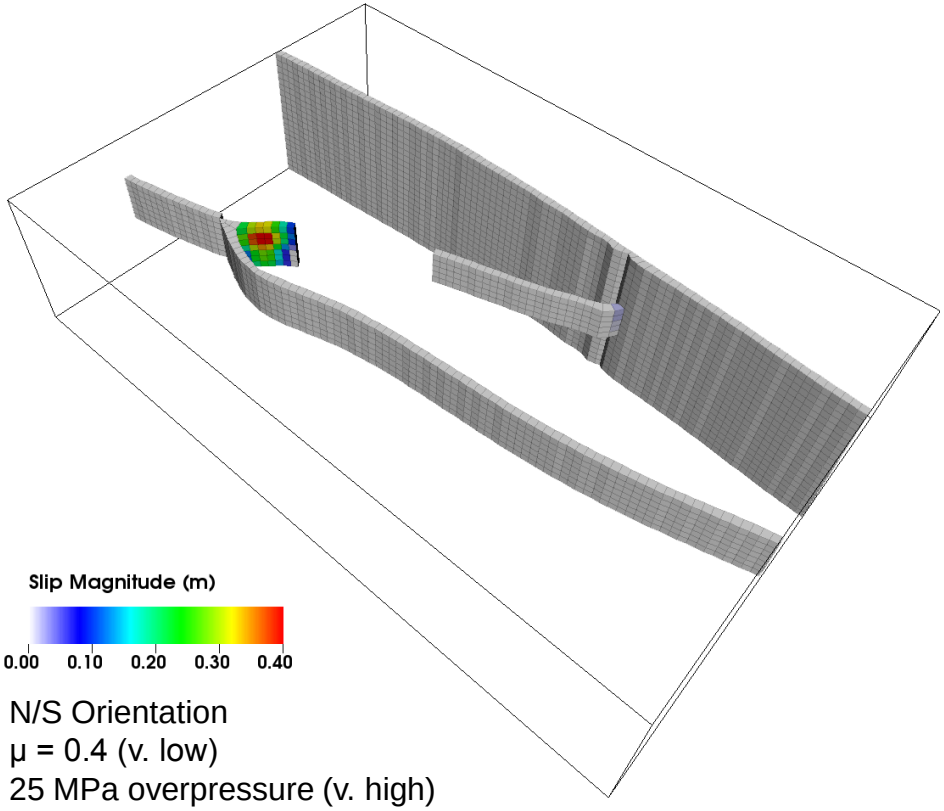
Hydromechanical Model



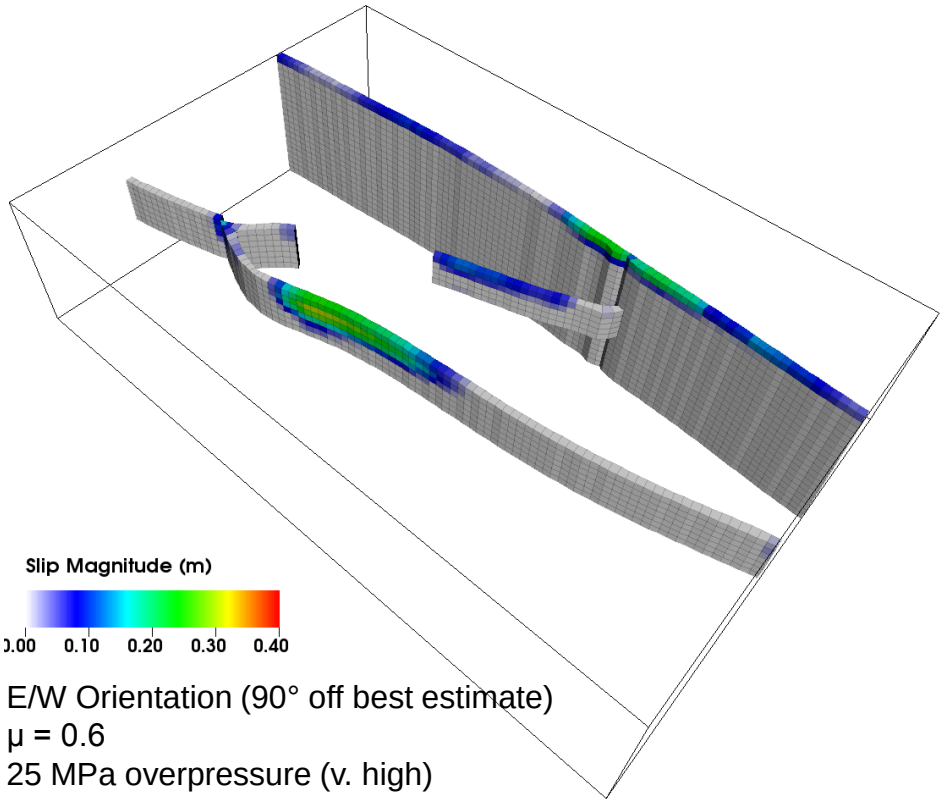
- We computed the pressure evolution in the reservoir under a variety of injection conditions and assumptions about fault sealing behavior.
- Model assumes constant reservoir permeability.

Hydromechanical Model

- **General Conclusion**: Faults are very stable in the best-estimate stress field. Unrealistically high injection pressures, a weak coefficient of friction, or a significant rotation of the in situ stresses is required to trigger slip.



N/S Orientation
μ = 0.4 (v. low)
25 MPa overpressure (v. high)



E/W Orientation (90° off best estimate)
μ = 0.6
25 MPa overpressure (v. high)

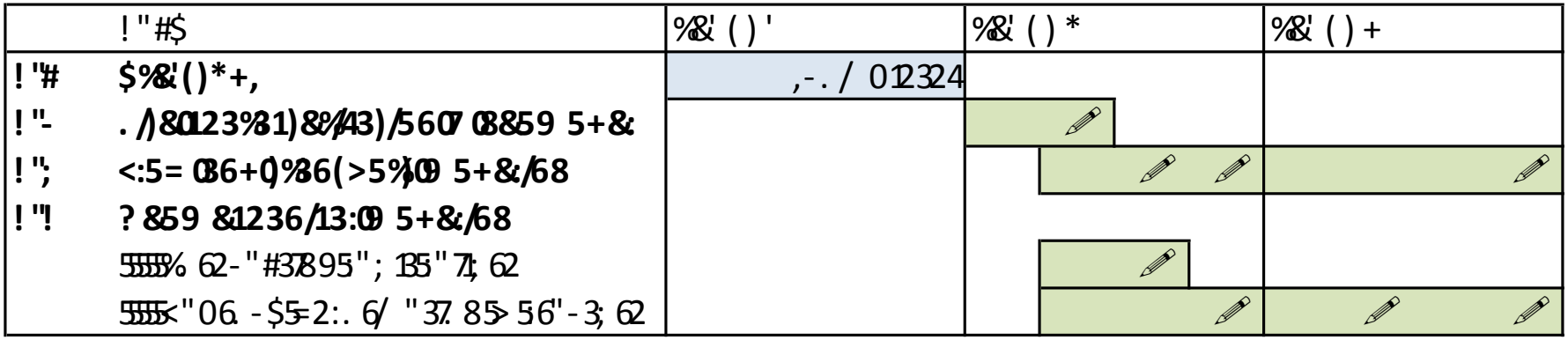
Summary & Accomplishments

- Have developed a simplified hydromechanical model for study injection induced fault slip. Results compare favorably with analytical solutions.
- Have used the model to assess stability of faults at Snøhvit based on best estimates of stress orientation and magnitude.
- General conclusion is that faults have a low probability of slip due to injection operations.
- Keep in mind, however, that damage zones around faults make serve as pre-existing permeable pathways.

Future Work

- To this point we have only used a simplified characterization data set. About to begin construction of a more complete geomodel based on Statoil monitoring and characterization data.

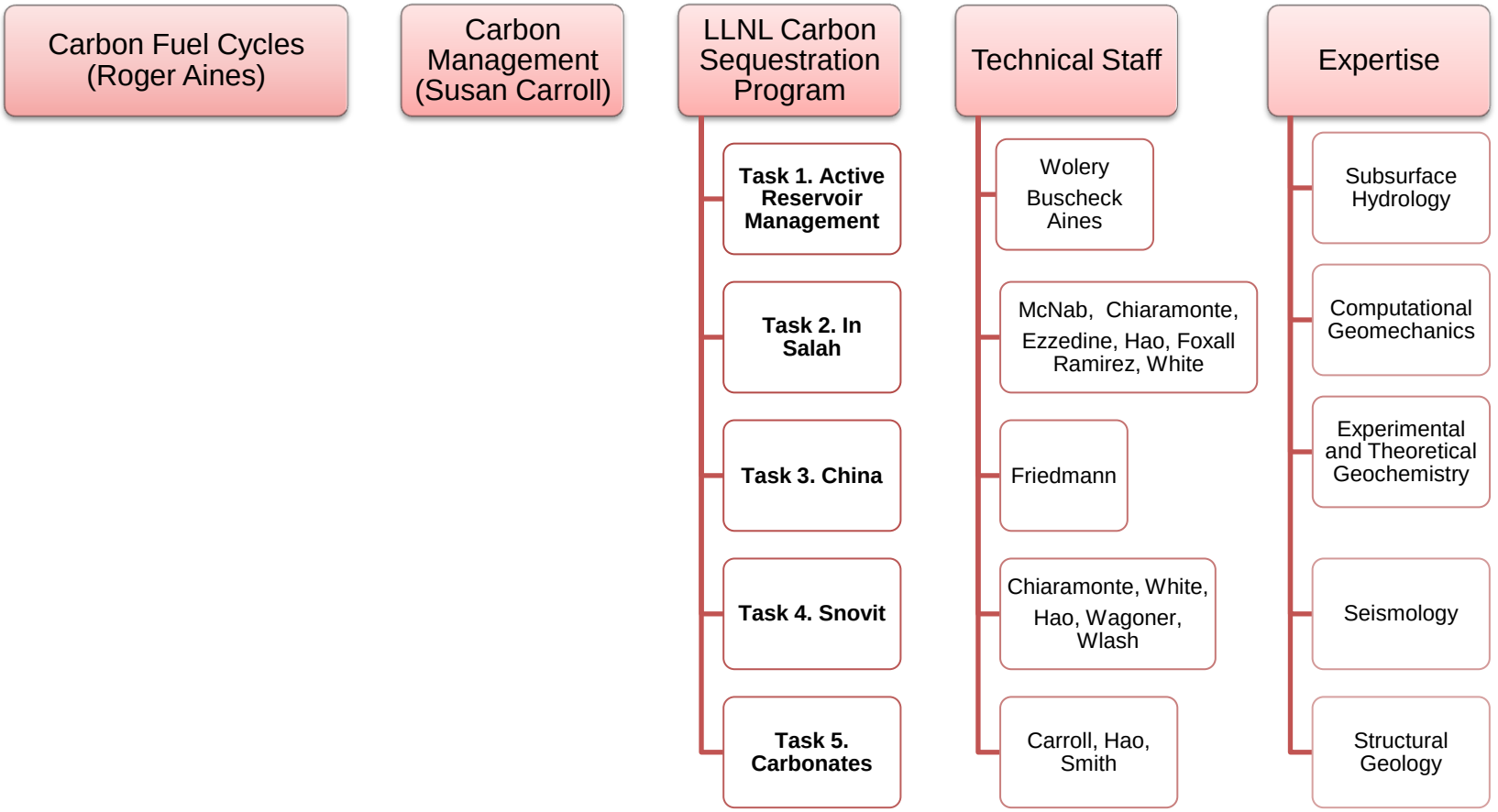
- Future work will explore hydromechanical behavior around fault intersections and possibility of direct caprock damage.



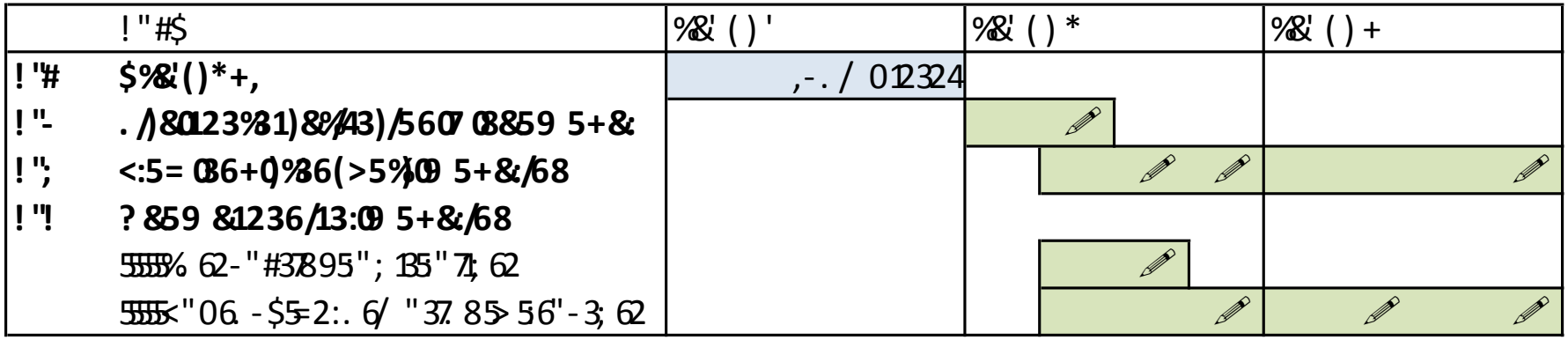
Appendix

- Organization Chart
- Gantt Chart
- Bibliography

Organization Chart



Gantt Chart



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Bibliography

– L. Chiaramonte, J.A. White, and S. Johnson (2011). Preliminary geomechanical modeling of CO2 injection at Snohvit, Norway. 45th U.S. Rock Mechanics/Geomechanics Symposium. San Francisco, CA, June.