Probabilistic Geomechanical Analysis of Compartmentalization at Snøhvit

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Focus areas where modeling can help monitoring and project management:

1. **Decision-based Modeling**
   - Using modeling to inform instrument design and deployment schemes

2. **Data Integration and Data Assimilation**
   - Merge diverse monitoring data sets into unified interpretations
   - Deterministic or stochastic inversion of monitoring data

3. **Uncertainty Quantification and Risk Assessment**
   - Quantify how uncertainty impacts performance and risk
Snøhvit Case Study 1
Using modeling to address uncertainty in stress measurements

[Spencer et al. 2008; Chiaramonte et al. 2014]
Regional stress measurements show significant variation in orientation and data quality.

[Chiaramonte et al. 2014]
A key project concern was whether excess fluid pressure could reactivate faults and create leakage paths.

**Figure:** Model prediction of excess pressure (MPa) necessary to initiate fault slip with the base case scenario parameters, which corresponds to a SS/NF environment with N-S $S_{H\text{max}}$ direction.
Sensitivity analyses reveal that critical uncertainty is SHmax orientation, but overall leakage risk is low.

Figure: SHmax azimuth dominates critical pressure sensitivity

- Suggests highest-value target for future characterization efforts
Snøhvit Case Study 2
Welltest analysis and continuous inversion of gauge data

**Figure:** 4D difference amplitude maps, 2003-2009, lower perforation.

(Hansen et al. 2012)
Pressure response indicative of a partially compartmentalized system

BHP estimated from permanent pressure/temperature sensors at 1782 mTVDss, hourly data.
Well tests commonly used to look for flow barriers and other indications of reservoir structure.

Figure 1.21. One sealing fault. Pressure profile at time $t_4$. The fault is reached, and it is seen at the well. Hemi-radial flow.

$t_1$: the fault is not reached, radial flow
$t_4$: the fault is reached.
Falloff analysis showed clear indications of flow barriers

- Results suggested flow barriers at 110, 110, and 3000m

**Figure**: Falloff analyses using permanent gauge (2009) and PLT data (2011). 

(Hansen et al. 2012)
Falloff testing has proven value, but requires shutting in the well for significant periods

• **Motivating question:** Could we derive the same information from ongoing injection data, without shutting in for long periods?
Generalized superposition well-test method

- Multi-rate injections are difficult to analyze.

- Can use superposition principle to transform a multi-rate injection into an “equivalent” single-rate test.

- Solve for a characteristic buildup curve, as a constrained least-squares problem.

\[ p(t) = q \times p_C(t) \]

\[ p(t) = \left( \sum_{i} q_{i+1} - q_i \right) \times p_C(t - t_i) \]

**Single rate:** \[ p(t) = q \times p_C(t) \]

**Multi-rate:** \[ p(t) = \sum_{i} \left( q_{i+1} - q_i \right) \times p_C(t - t_i) \]
Automatic calibration to Snøhvit data (~5 seconds)
Superposition tool can potentially be used in two modes:

1. **Reservoir characterization mode**
   - Calibrate to gauge data, extract equivalent falloff test
   - Apply standard well-test analysis techniques to results

2. **Pressure forecasting mode**
   - Calibrate to gauge data, project forward in time
   - Quickly explore alternative injection scenarios
Fast-running pressure forecasting

![Graph showing pressure over time with different periods highlighted.]

- Measurement
- Forecast / Precast
- Calibration period

Equivalent buildup test:

- Time, days
- Pressure, bar
Fast-running pressure forecasting

pressure, bar

measurement  forecast / precast  calibration period

time, days

equivalent buildup test

0  50  100  150  0  500  1000

time, days
Fast-running pressure forecasting

![Graph showing pressure over time with measurement, forecast/precast, and calibration period phases.](#)
Fast-running pressure forecasting

measurement  forecast / precast  calibration period

time, days

pressure, bar

equivalent buildup test

time, days
Fast-running pressure forecasting

- Measurement
- Forecast/precast
- Calibration period

Pressure, bar vs. time, days graph with equivalent buildup test.
Fast-running pressure forecasting

- Measurement
- Forecast / Precast
- Calibration Period

Pressure, bar vs. Time, days for equivalent buildup test.

Inset: Pressure buildup test over time.
Retrospective analysis of a brine pre-production scenario
What makes a model **useful**?

1. Captures essential physics (and not much more)
2. The impact of assumptions and limitations is clear
3. Has necessary calibration and verification data
4. Can deliver useful results in a timely manner
5. Has a clear modeling objective

   - Decision-making drives modeling, not code capabilities driving decision-making
Acknowledgements

- This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Data and co-funding were provided by the DOE Carbon Sequestration Program and Statoil.

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