Task 9 Webinar: Fault integrity screening
Webinar, 17 Nov 2018
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3D fault integrity screening for Smeaheia CO$_2$ injection site

Improved fault risk workflow in task 9

Geology:
- reservoir
- overburden

Geomechanics
- strength
- dynamics

Flow:
- Static
- Dynamic

Fault Knowledgebase
Vertical flow
Norwegian full scale CCS demonstration

Feasibility study

1,3 mill. tonn/year
(feasibility study)
Northern Lights project
– Equinor (former Statoil), Total, Shell

• Smeaheia suggested storage site offshore western Norway
• Johansen Fm, Aurora site, south of Troll selected for further investigation
Location

- Data:
  - Seismic
  - Two wells in Smeaheia/logs
  - Core from Sognefjord/Heather
  - Toll/Troll East, as an analogue
  - Data package, Smeaheia
Geology

- Seismic interpretation
Identified risk aspects overburden

- Juxtaposition risk?
- Contained polygonal faults
- Potential fault conduits

2.5 km
Identified risk aspects reservoir

Top Sognefjord

Vette Fault

Øygarden Fault

Relay

Synthetic (west-dipping)
Antithetic (east-dipping)
Hard linked
Soft / non-linked
Motivation

• Mature the Smeaheia fault seal system understanding
• Reduce the risk related to CO$_2$ injection in faulted reservoirs
Models for fault seal integrity

- 3D screening of fault slip stability
  - stress distribution on slip surfaces

- Fault seal capacity
  - Juxtaposition
  - Clay content

Detailed geomechanical model
Coupled hydro-mechanical model
3D screening of fault slip stability

- Simple model considering
  - Stress distribution
  - Material strength/failure criteria
  - Fault geometry
  - Deformation/strain not included
  - Assuming same pressure conditions on the fault as in the reservoir

\[ \tau_s = c + \sigma_n \tan \phi \]
Stress distribution – North Sea

Normal faulting regime
-isotropic ($S_H \sim S_h$)

Normal faulting regime
-anisotropic ($S_H$ 5% more than $S_h$)

Strike-slip regime
($S_H > OBG$)

OBG and Shmin, Equinor Smeaheia data package
Material properties and fault strength

- Well logs – only two available in Smeaheia
- Core tests – limited from Smeaheia, data from Troll/nearby areas

<table>
<thead>
<tr>
<th>Material</th>
<th>Cohesion (MPa)</th>
<th>Friction angle (deg)</th>
<th>Friction coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sognefjord, reservoir</td>
<td>5</td>
<td>15</td>
<td>0.27</td>
</tr>
<tr>
<td>Draupne, top seal</td>
<td>7</td>
<td>13</td>
<td>0.23</td>
</tr>
<tr>
<td>Static friction faults</td>
<td>0</td>
<td>31</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Equinor Smeaheia datapackage, average values
Fault stability – screening, *in situ* conditions

- **Normal faulting regime**
  - isotropic \((S_H \sim S_h)\)
  - anisotropic \((S_H \, 5\% \, more \, than \, S_h)\)

- **Strike-slip regime** \((S_H > OBG)\)

  Injection ↔ Depletion = reduced risk

- **Anisotropy** – favorable orientation more stable
- **Non-cohesion faults** - risk for shear failure during pp increase
- **Material cohesion included in model** = tensile failure risk during pp increase
Fault stability - dip

• Highest shear stress on 45°
• Most critical for shear failure: 60°
• Most critical for tensile failure: 80-90°
3D screening on selected faults

- Tool to get the overview
- Problems:
  - Different failure criteria (frictional stability) for reservoir and seal
  - Pp increase only relevant for reservoir section
Refinement of slip stability analysis

- Reservoir
- Øygarden Fault
- Vette Fault

- Draupne caprock
- Øygarden Fault
- Vette Fault

Software: MOVE
Summary of the 3D fault stability screening

• Classic fault failure criteria:
  – A very limited pp increase before the faults will be critically stressed

• Cohesion of 3 MPa on the fault
  – A tensile failure criteria/fracture gradient will apply also for faults

Can cohesion be expected for faults in Sognefjord and Draupne lithology?
How to address / quantify this?
How about overburden?
Continuation of work in task 9

- Material properties /material behavior during Pp changes
  - Sognefjord, Draupne, Cromer Knoll/Shetland, Heather (mixed zones in faults?)

- Stress path vs Strain/deformation in overburden/along faults
  - Arching effects, fault drainage conditions/temperature

- Juxtaposition/seal
  - Uncertainty in Cromer Knoll and Shetland flow properties

- Fault growth – and history
Impact of Arching-induced Stress Rotation in Overburden on Shear Slip Tendency
Shale Gouge Ratio Model

- Shetland and Cromer Knoll treated as clay-free carbonate intervals ($0.0 V_{sh}$)
- Interval $V_{sh}$ based on lithology, log-based SGR will be undertaken later and calibrated using Tusse fault results from Troll East
- Calculations limited to fault cutoffs

\[
SGR = \frac{\sum (W\Delta h \times 100\%)}{\text{throw}}
\]

Redrawn from Yielding et al., 2010

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Color</th>
<th>Lithology</th>
<th>$V_{sh}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shetland Gp</td>
<td>Yellow</td>
<td>Marl</td>
<td>0.0</td>
</tr>
<tr>
<td>Cromer Knoll Gp</td>
<td>Blue</td>
<td>Marl</td>
<td>0.0</td>
</tr>
<tr>
<td>Draupne Fm</td>
<td>Green</td>
<td>Mudstone</td>
<td>1.0</td>
</tr>
<tr>
<td>Sognefjord Fm</td>
<td>Magenta</td>
<td>Sandstone</td>
<td>0.0</td>
</tr>
<tr>
<td>Brent Gp</td>
<td>Green</td>
<td>Siltstone</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Thanks for you attention

Acknowledgement

This publication has been produced with support from the NCCS Centre, performed under the Norwegian research program Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Aker Solutions, ANSALDO Energia, CoorsTek Membrane Sciences, EMGS, Equinor, Gassco, KROHNE, Larvik Shipping, Norcem, Norwegian Oil and Gas, Quad Geometrics, Shell, TOTAL, and the Research Council of Norway (257579/E20).

Equinor, Shell, TOTAL and Gassnova are acknowledge for access to data package from the Smeaheia area. The presented results and interpretations do not necessarily reflect the views of the data owners.