NCCS

NORWEGIAN CCS RESEARCH CENTRE

Task 9 Webinar: Fault integrity screening

Webinar, 17 Nov 2018

Elin Skurtveit, J.C. Choi, J.L. Osmond, M. Mulrooney, A. Braathen

3D fault integrity screening for Smeaheia CO_2 injection site

NCCS TASK 9 WEBINAR

Improved fault risk workflow in task 9

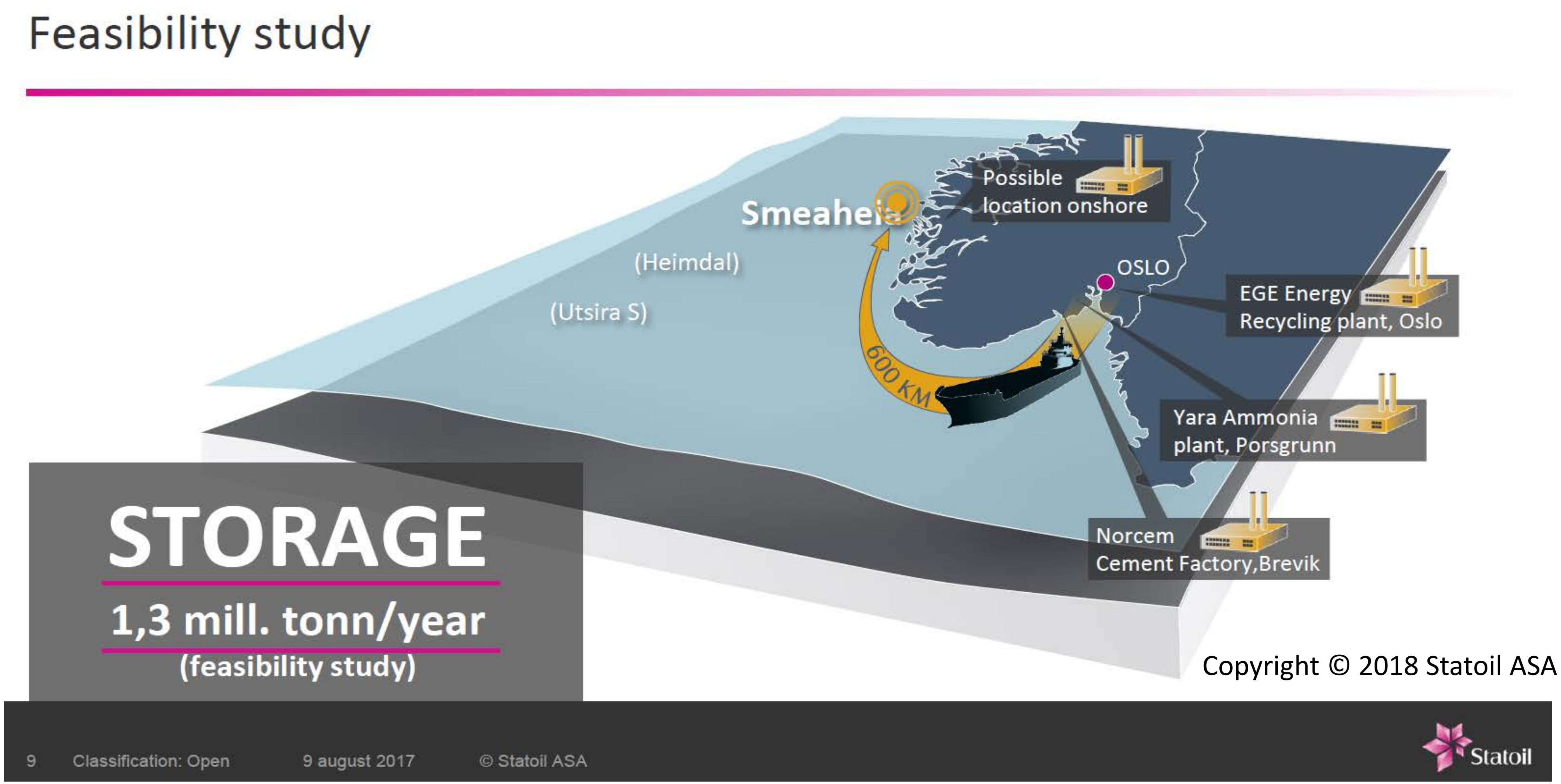
Geology:
-reservoir
-overburden

Geomechanics
-strength
-dynamics

Flow:
Static
dynamic

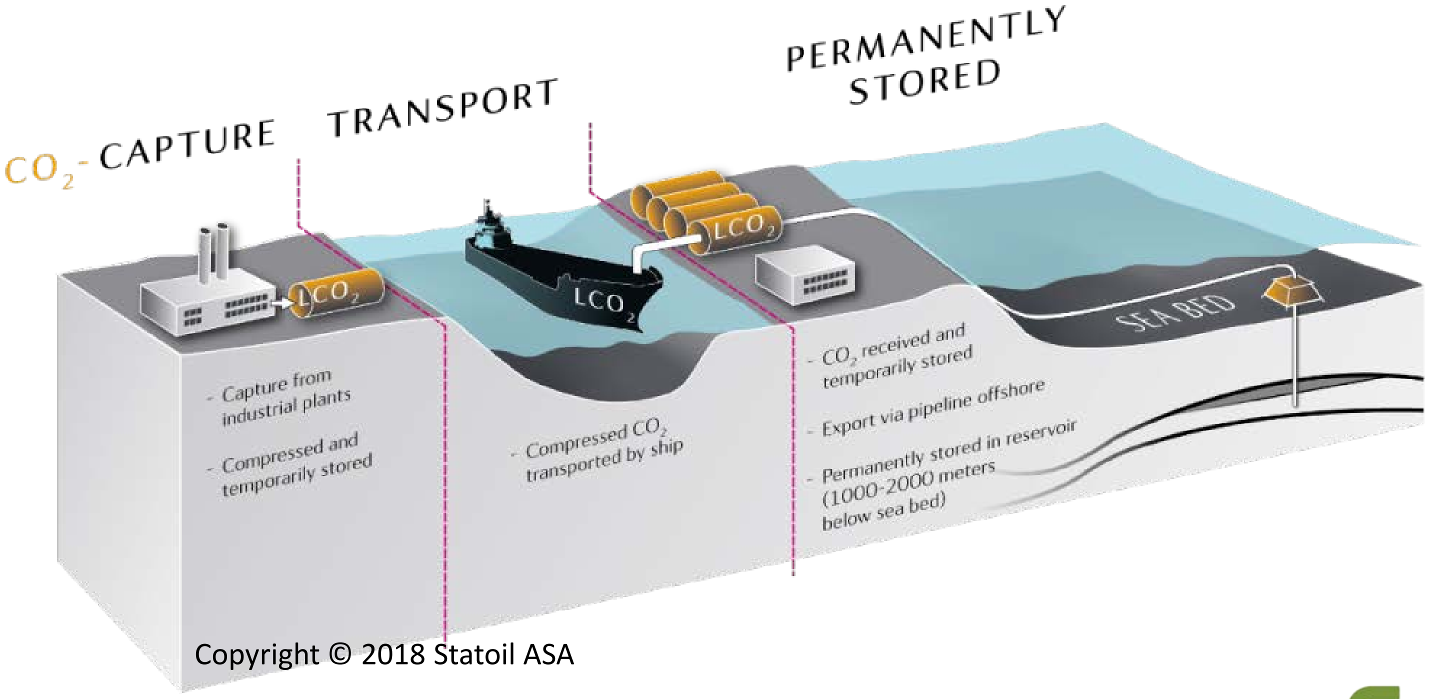
Fault
Knowledgebase
Vertical flow

Norwegian full scale CCS demonstration

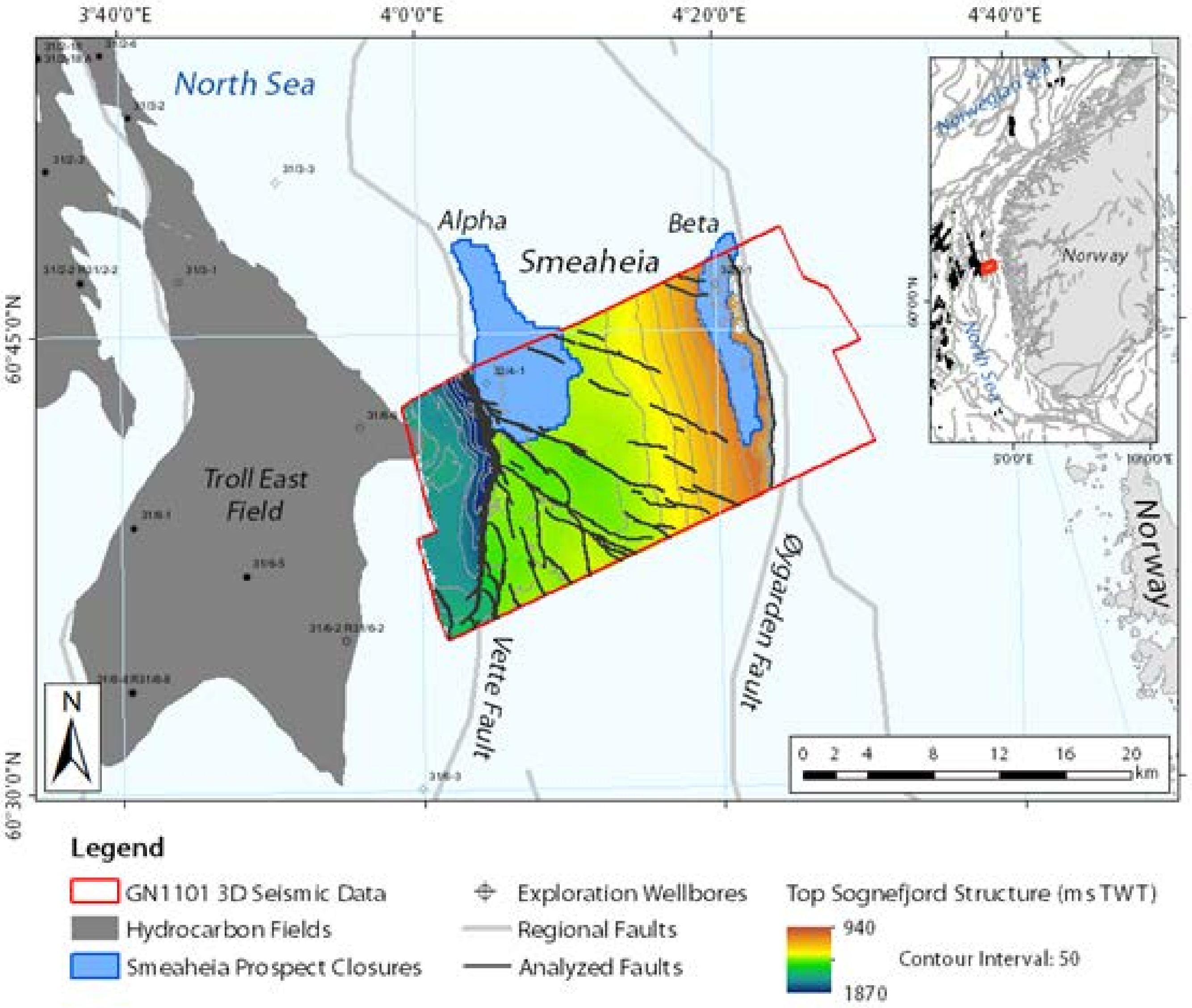


Northern Lights project – Equinor (former Statoil), Total, Shell

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



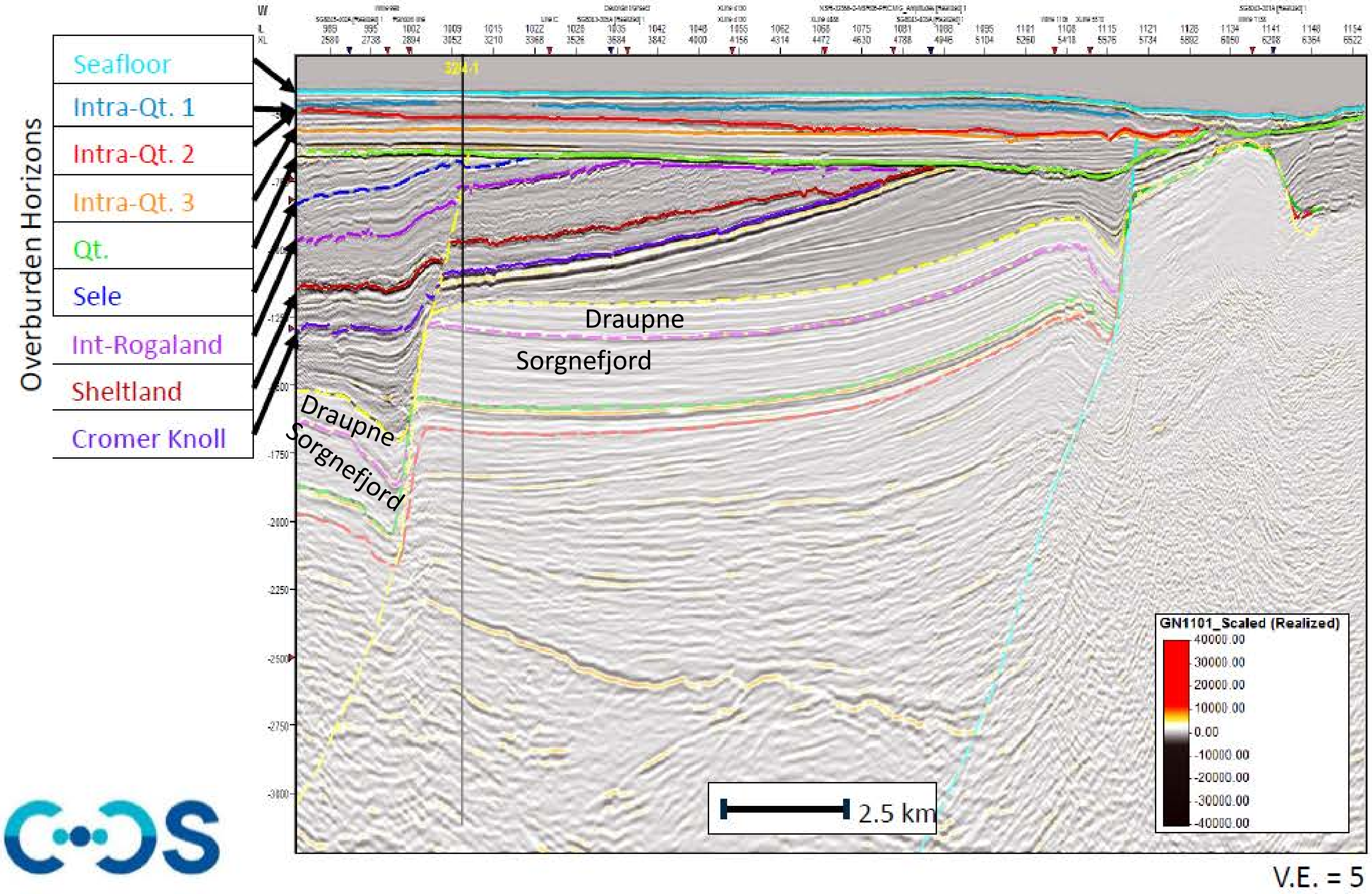
Location

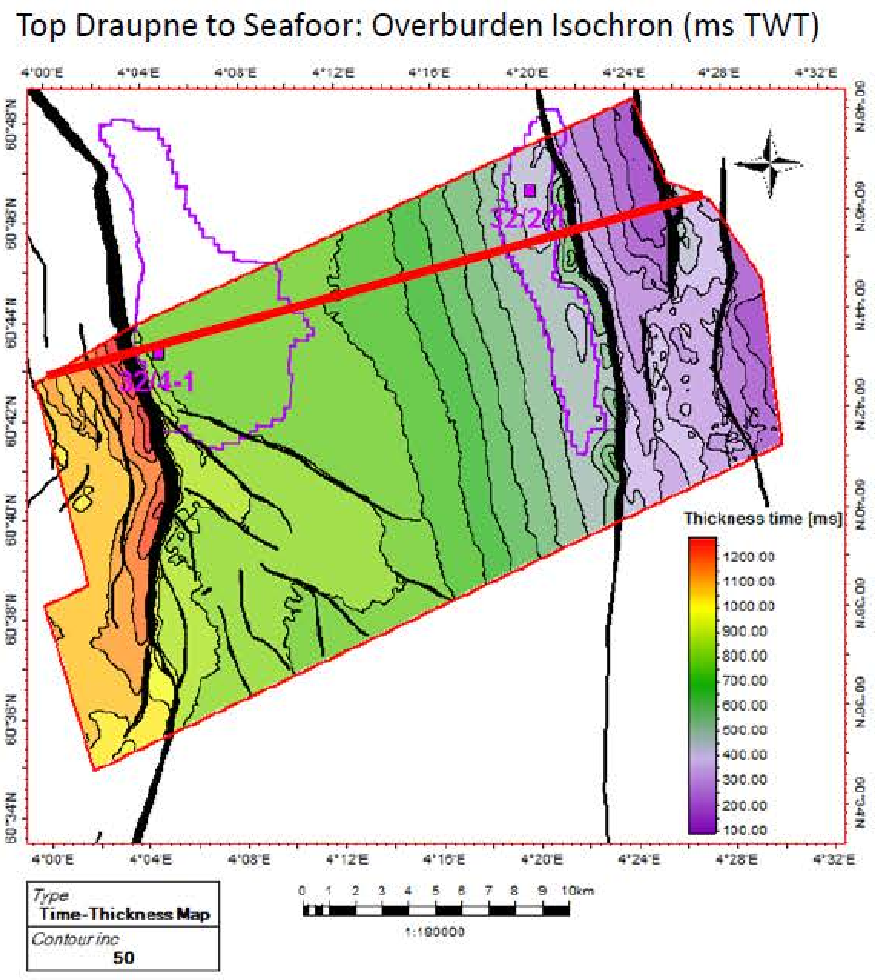


- Data:
  - Seismic
  - Two wells in Smeaheia/logs
  - Core from Sognefjord/Heather
  - Toll/Troll East, as an analogue
  - Data package, Smeaheia

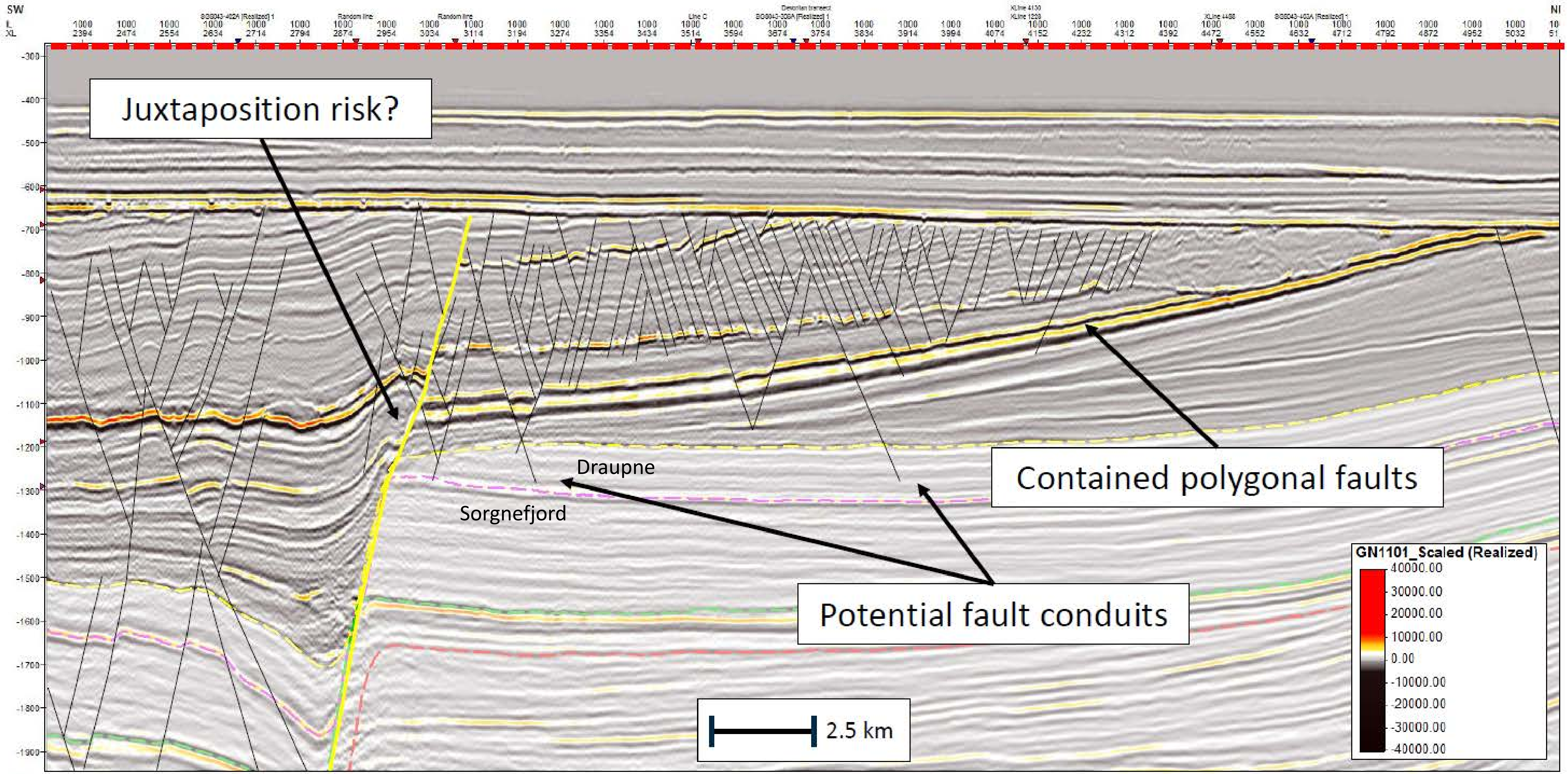
Geology

- Seismic interpretation

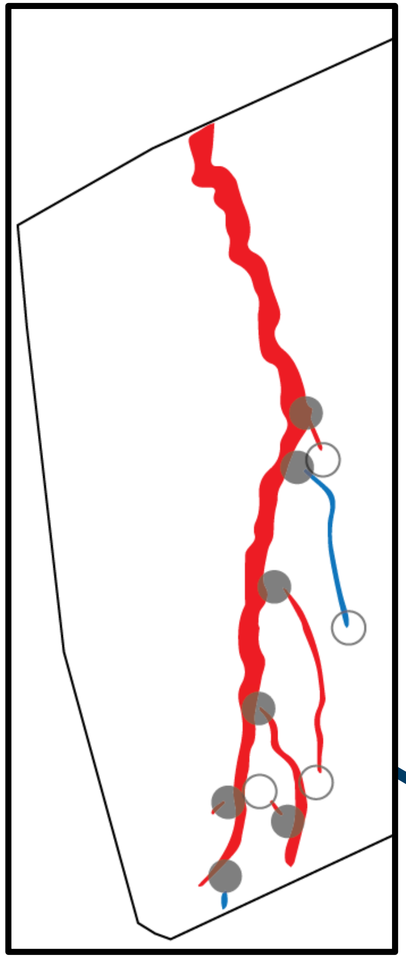




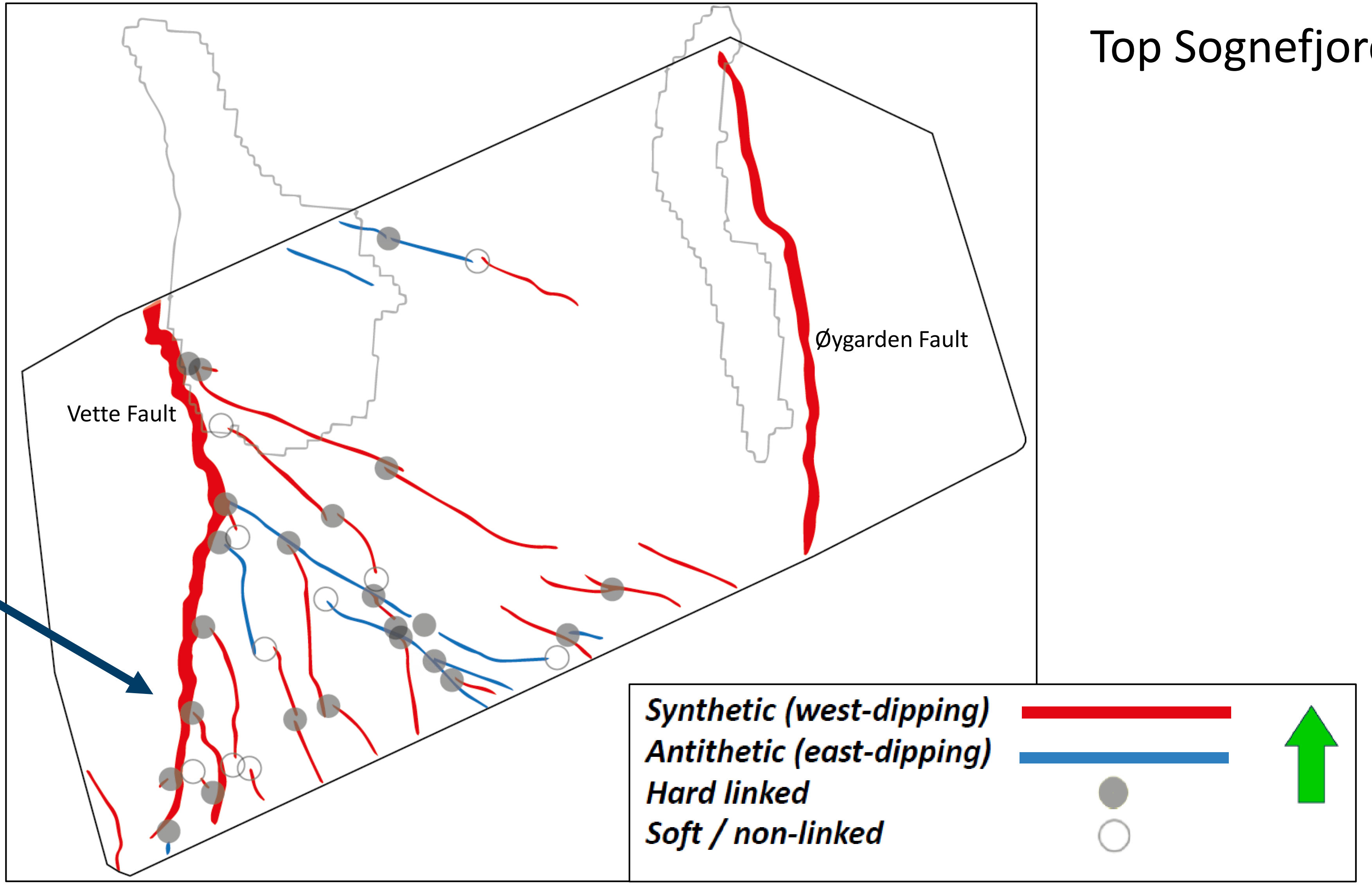
Identified risk aspects overburden



Identified risk aspects reservoir



Relay



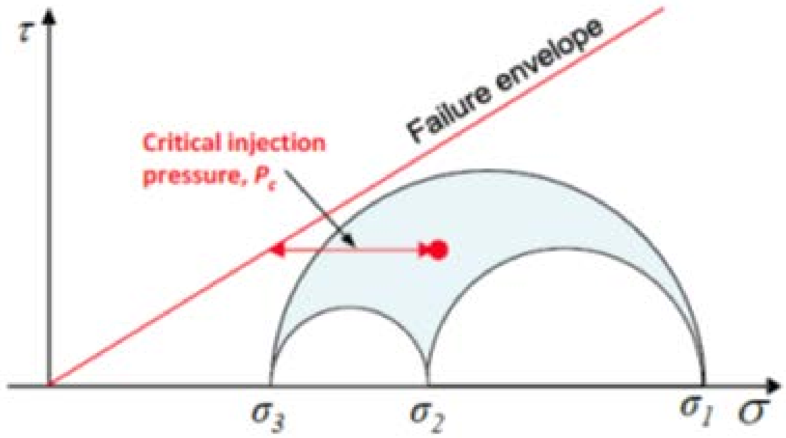
Top Sognefjord

Motivation

- Mature the Smeaheia fault seal system understanding
- Reduce the risk related to CO_2 injection in faulted reservoirs

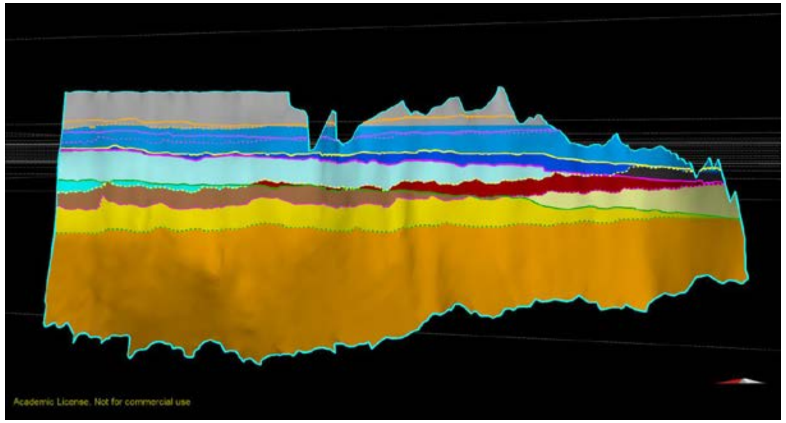
Models for fault seal integrity

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



- Fault seal capacity
  - Juxtaposition
  - Clay content

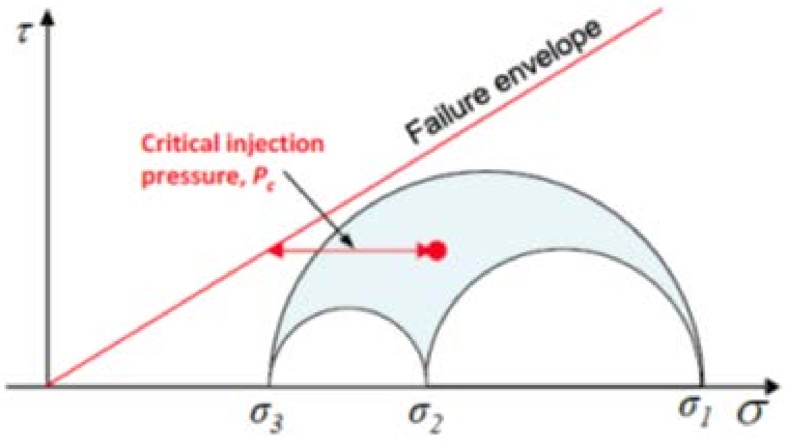
+



→ Detailed geomechanical model

→ Coupled hydro-mechanical model

3D screening of fault slip stability



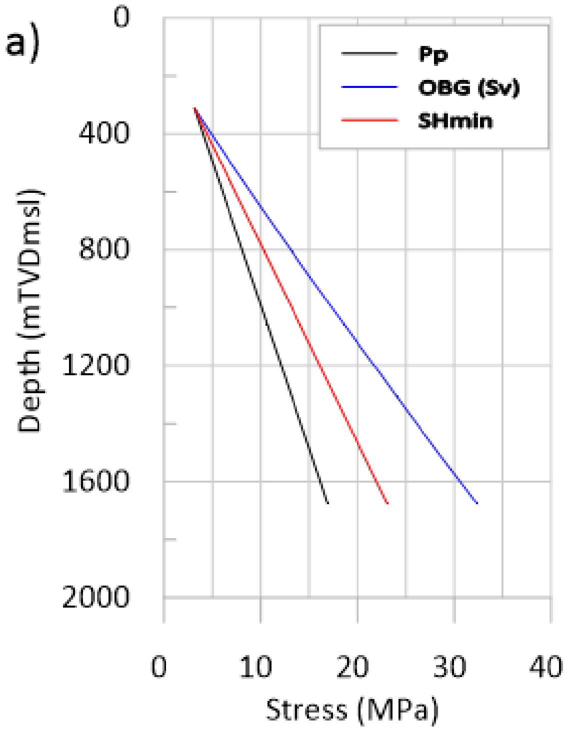
$$\tau_s = c + \sigma_n \tan\phi$$

- Simple model considering
  - Stress distribution
  - Material strength/failure criteria
  - Fault geometry

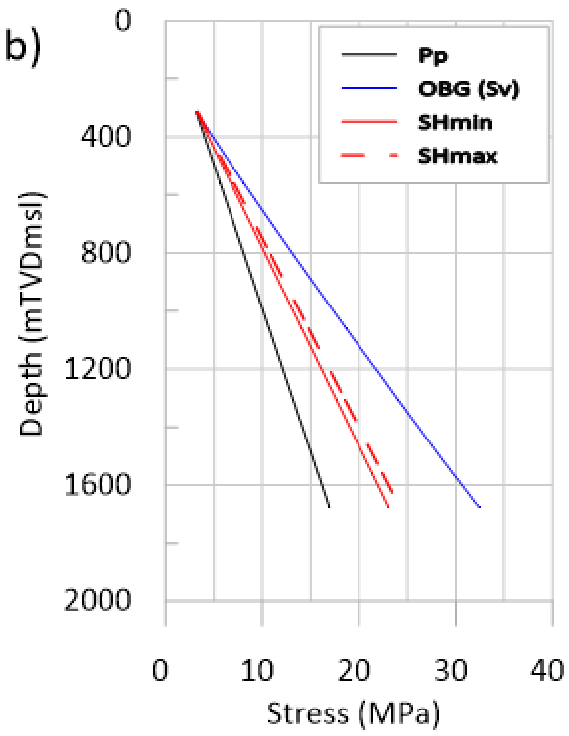
  - Deformation/strain not included
  - Assuming same pressure conditions on the fault as in the reservoir

Stress distribution – North Sea

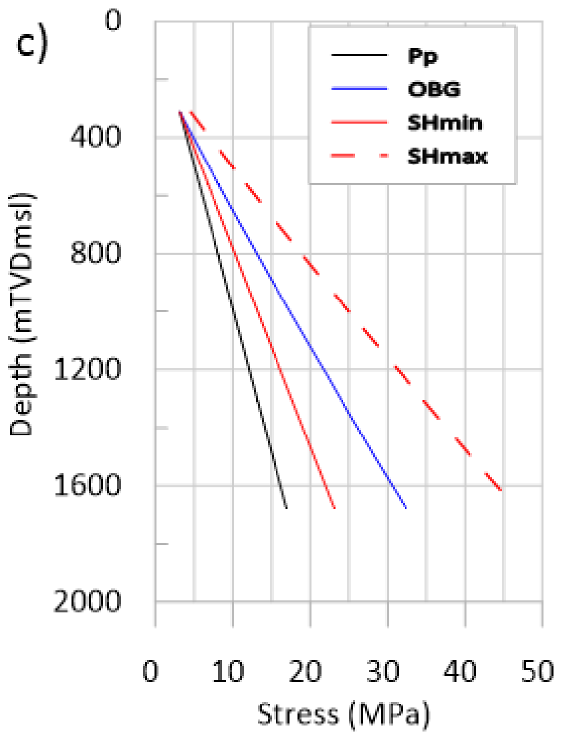
Normal faulting regime
-isotropic ($S_H \sim S_h$)



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

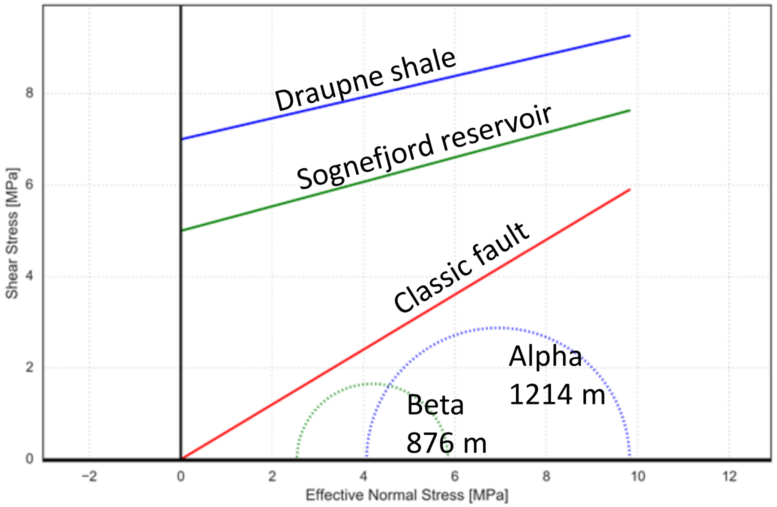
- Well logs – only two available in Smeaheia
- Core tests – limited from Smeaheia, data from Troll/nearby areas

Material	Cohesion (MPa)	Friction angle (deg)	Friction coefficient
Sognefjord, reservoir	5	15	0.27
Draupne, top seal	7	13	0.23
Static friction faults	0	31	0.6

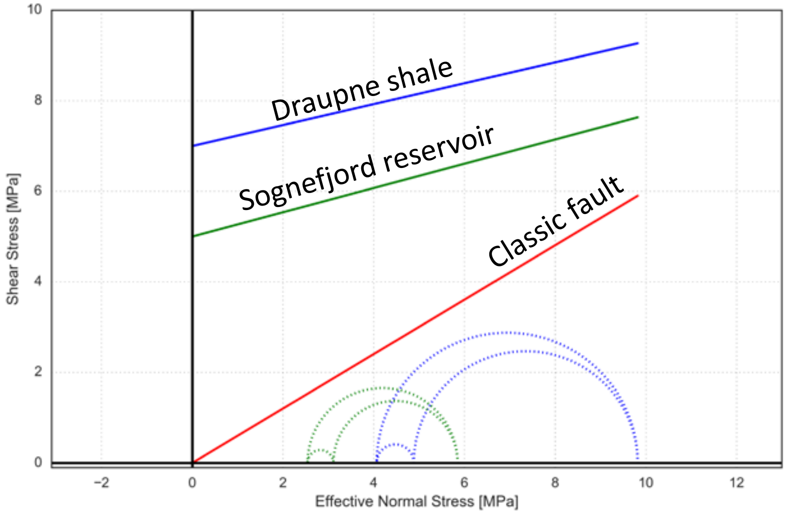
Equinor Smeaheia datapackage, average values

Fault stability –screening, *in situ* conditions

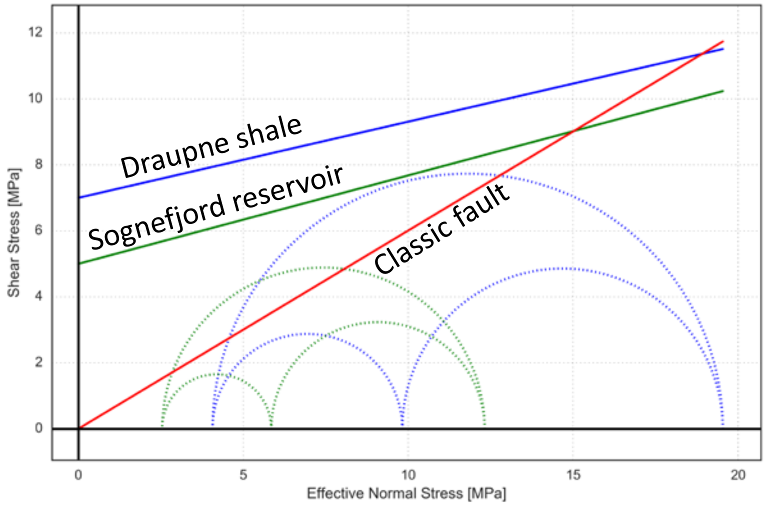
Normal faulting regime
-isotropic (S_H~S_h)



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



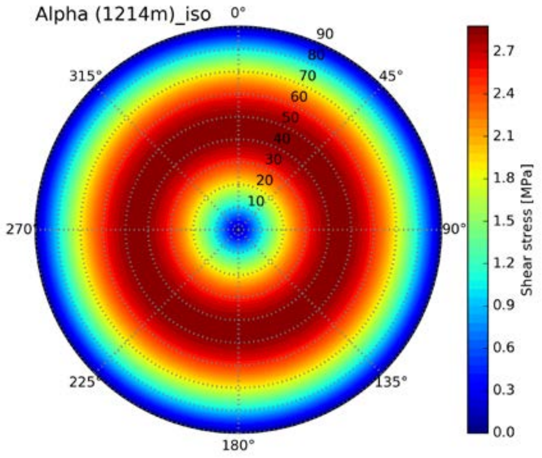
Strike-slip regime
(S_H > OBG)

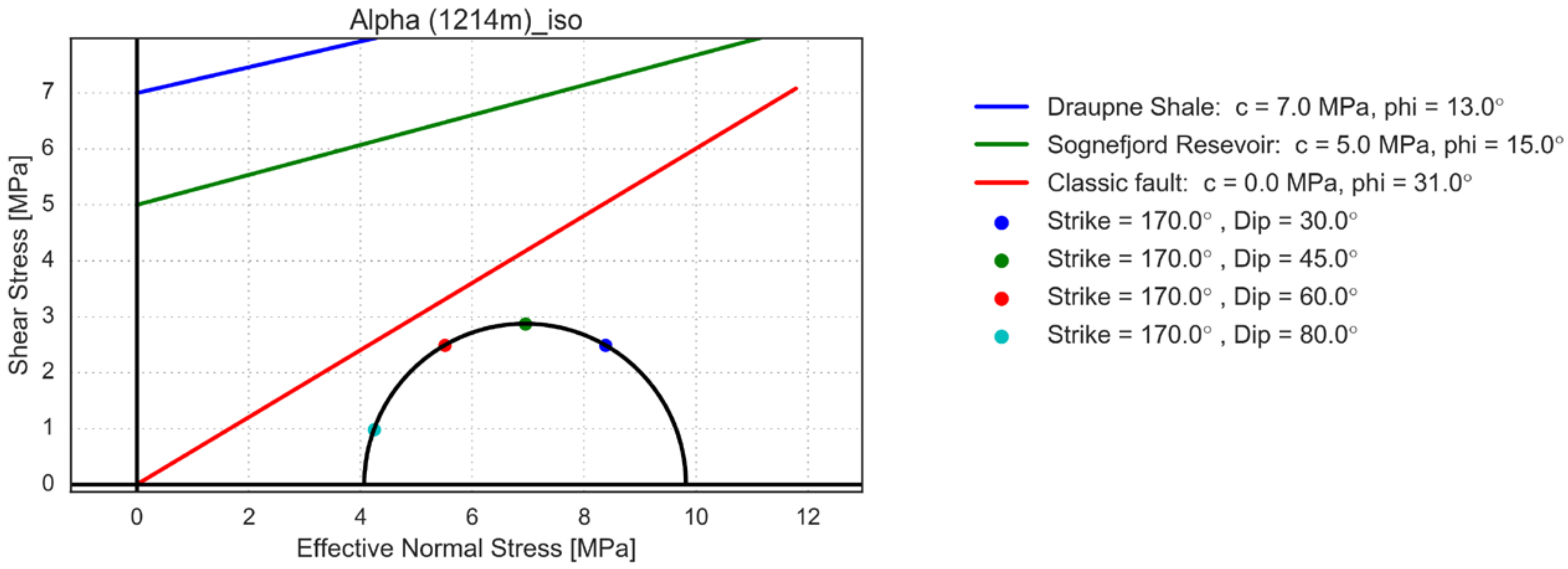


Injection ⬅ ➡ Depletion = reduced risk

- 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

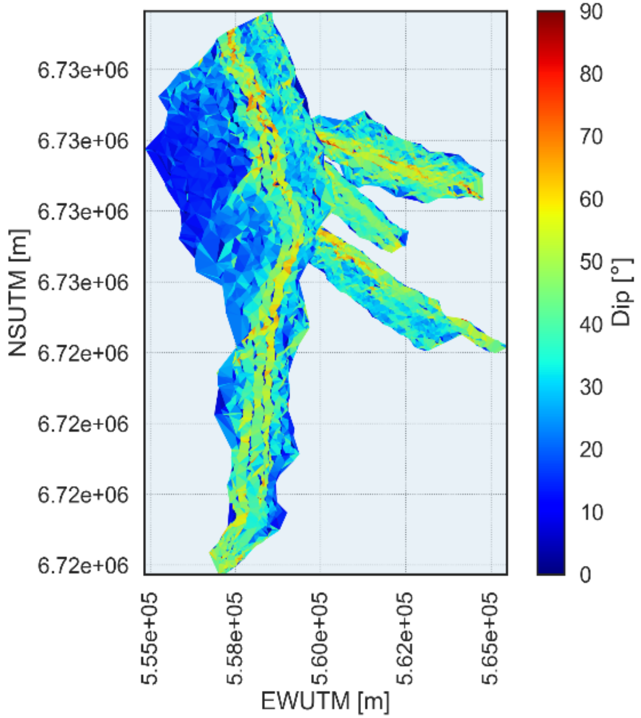




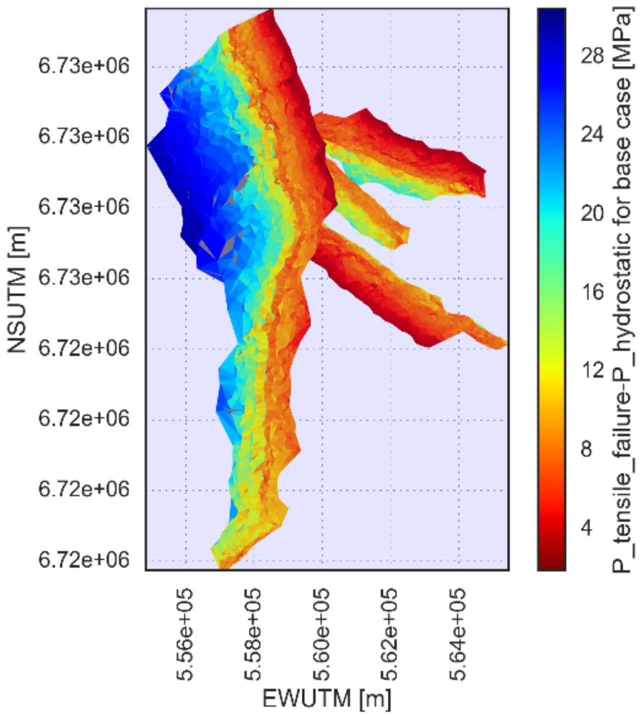
- Highest shear stress on 45°
- Most critical for shear failure: 60°
- Most critical for tensile failure: 80-90°

3D screening on selected faults

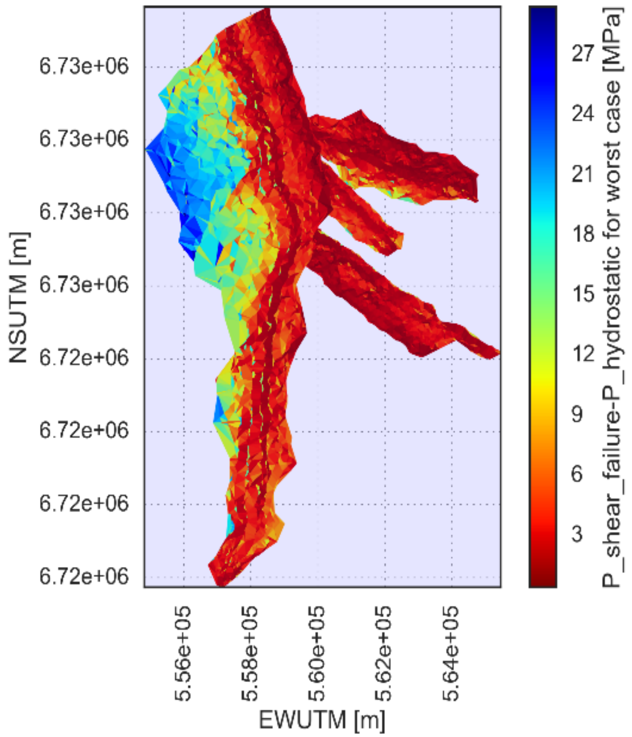
Dip



Tensile failure
- Intact rock failure criteria

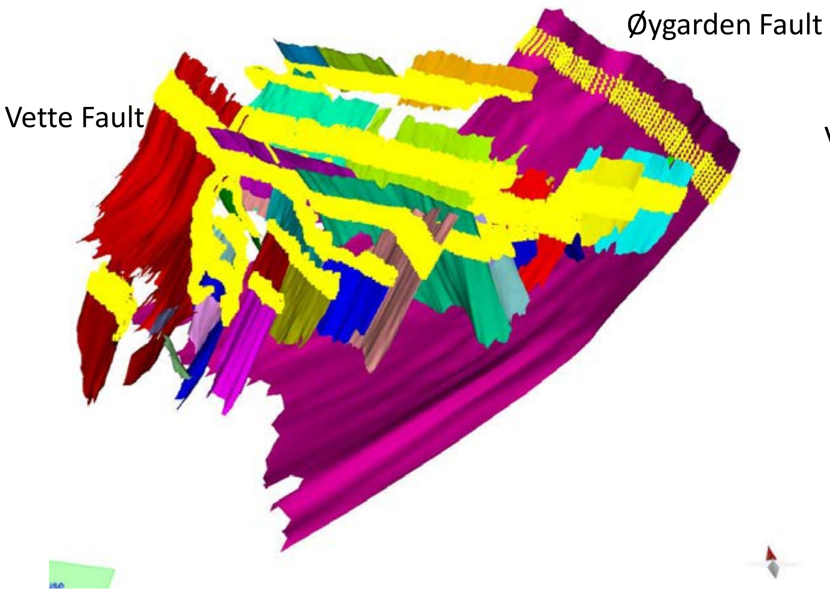


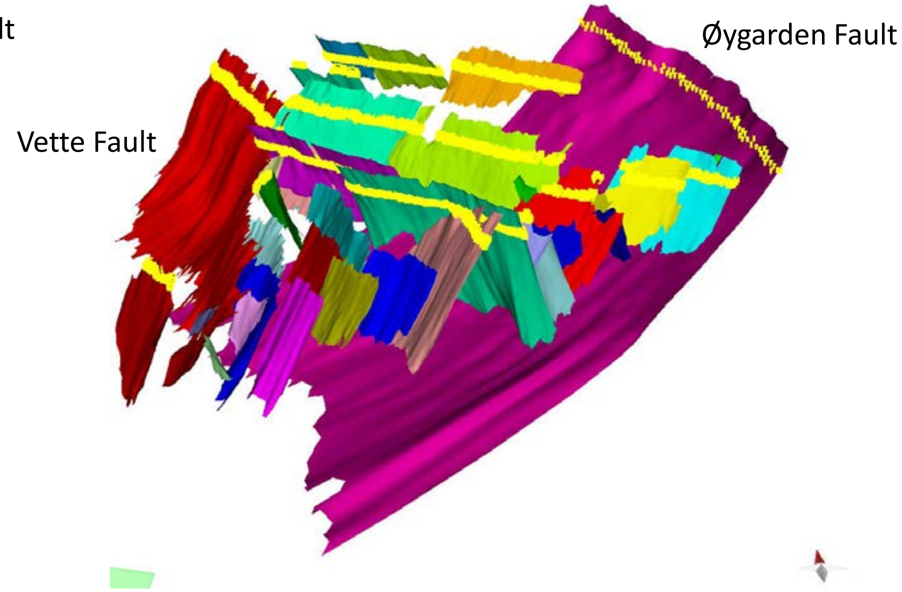
Shear failure
- Non-cohesion fault – classic, ϕ=0.6



- 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



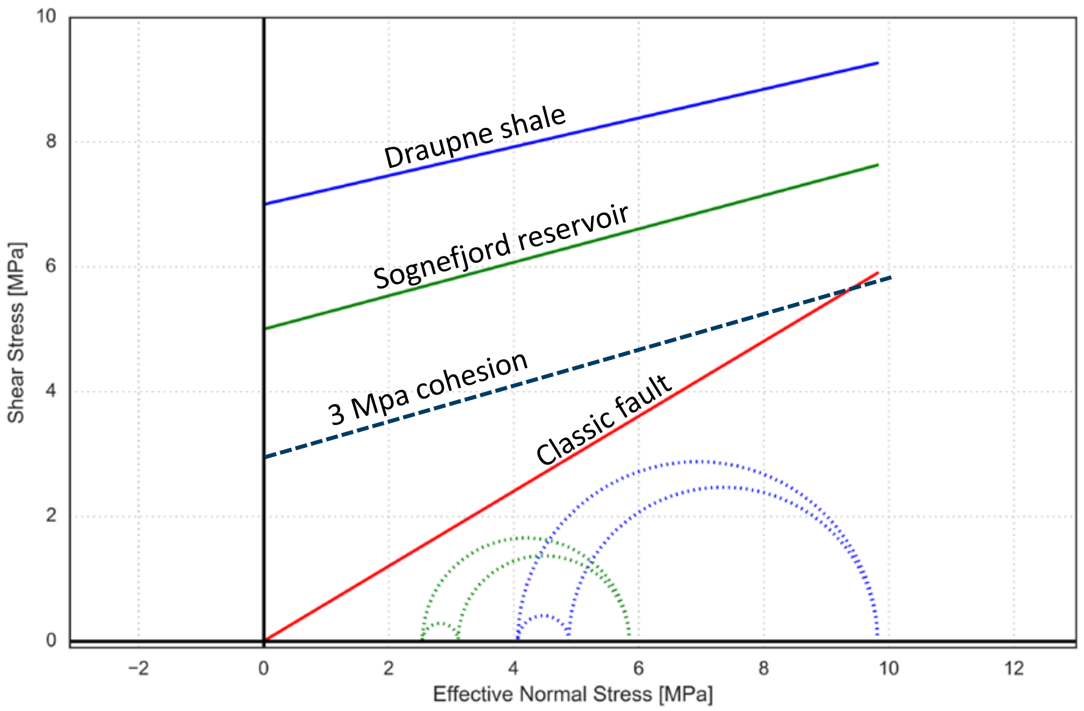


- Reservoir
- Draupne caprock

Software: MOVE

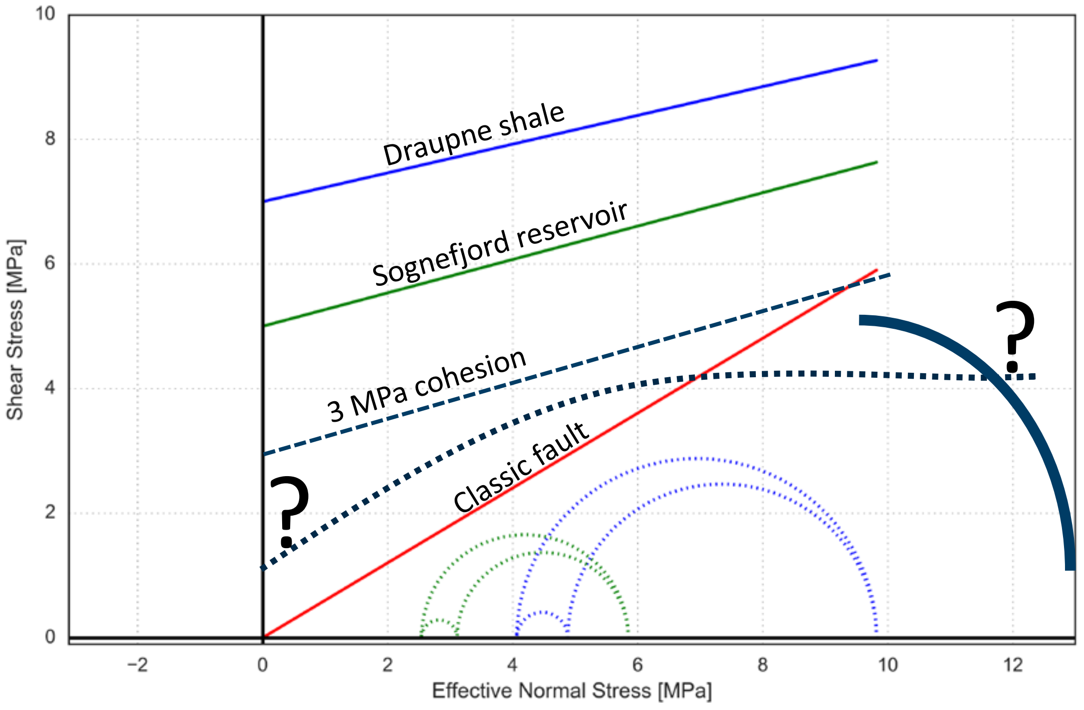
Summary of the 3D fault stability screening

- 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



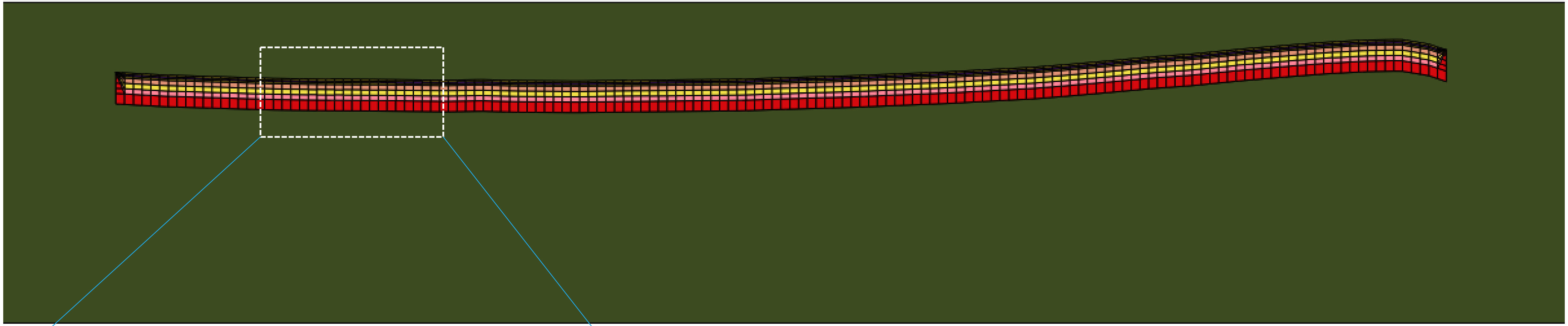
Can cohesion be expected for faults in Sognefjord and Draupne lithology?
How to address / quantify this?
How about overburden?

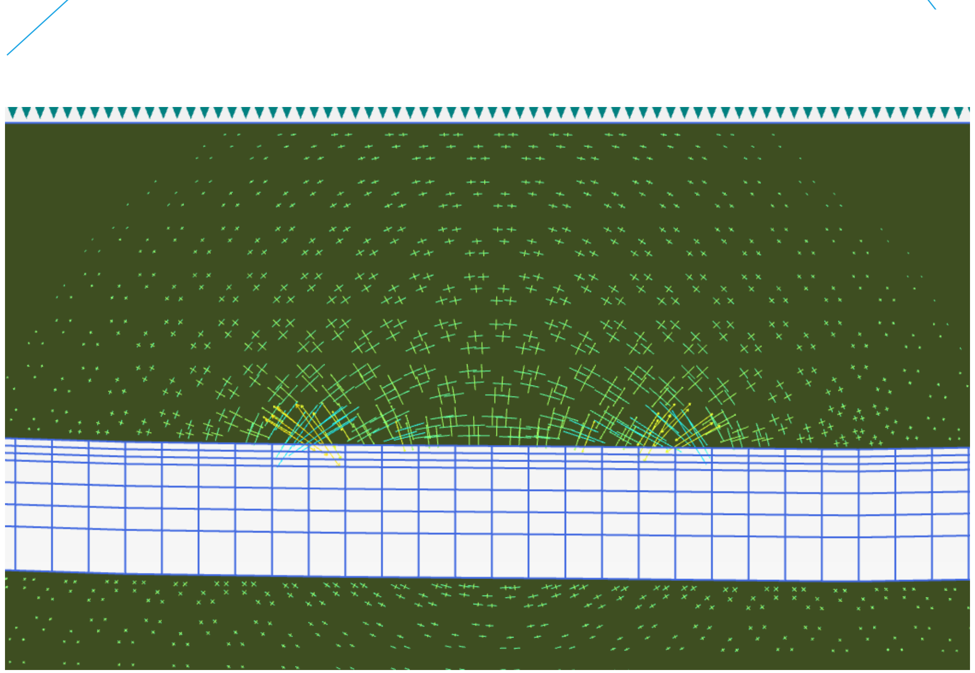
Continuation of work in task 9

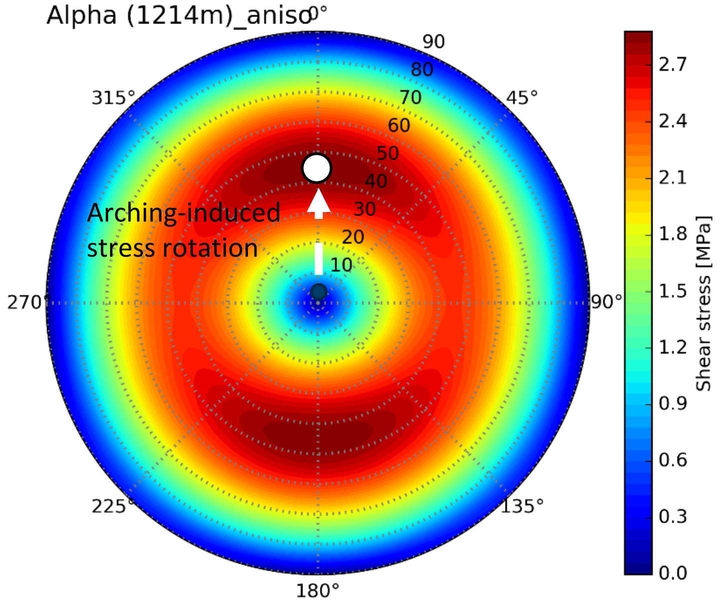


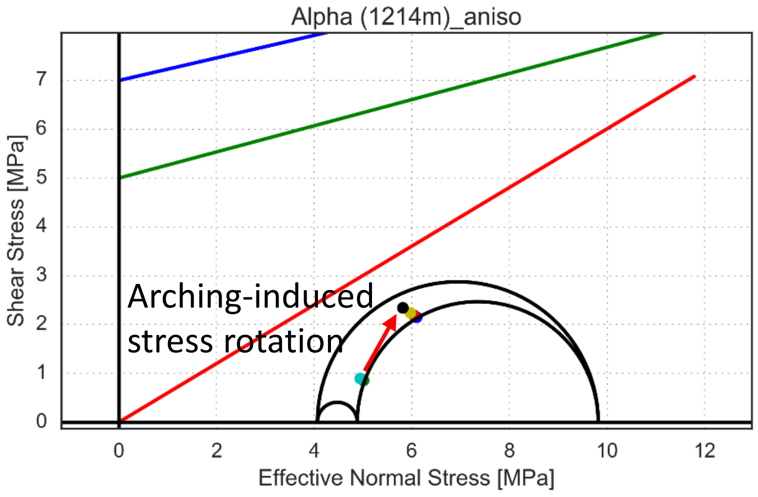
- Material properties /material behavior during Pp changes
  - Sognefjord, Draupne, Cromer Knoll/Shetland, Heather (mixed zones in faults?)
- Stress path vs Strain/deformation in overburden/along faults
  - Arching effects, fault drainage conditions/temperature
- Juxtaposition/seal
  - Uncertainty in Cromer Knoll and Shetland flow properties
- Fault growth – and history

Impact of Arching-induced Stress Rotation in Overburden on Shear Slip Tendency



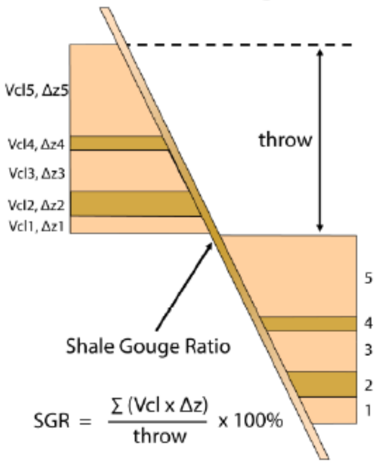






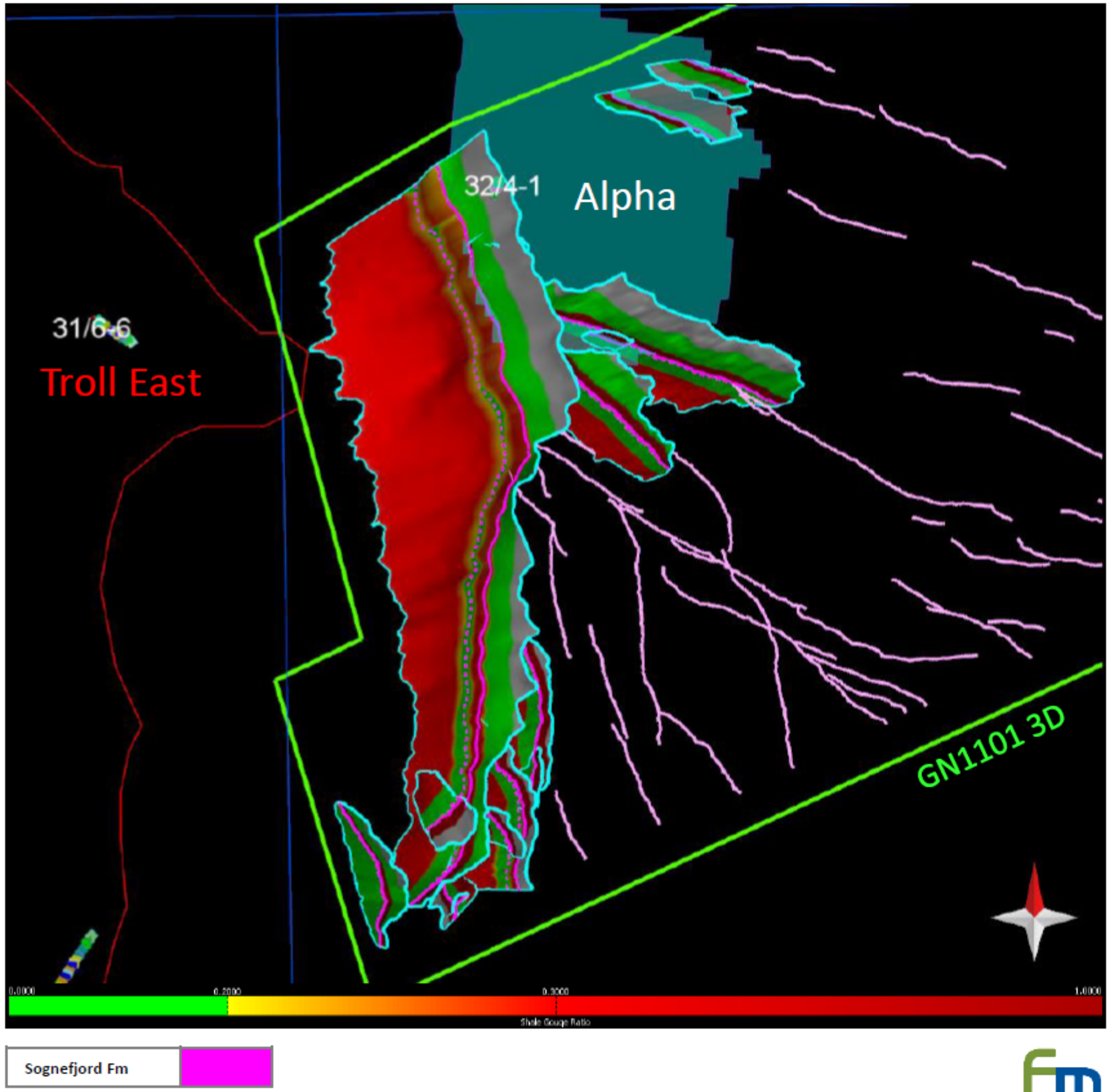
Shale Gouge Ratio Model

- Shetland and Cromer Knolltreated as clay-free carbonate interavals (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 limted to fault cutoffs



Redrawn from Yielding et al., 2010

Horizon	Color	Lithology	V_{sh}
Shetland Gp		Marl	0.0
Cromer Knoll Gp		Marl	0.0
Draupne Fm		Mudstone	1.0
Sognefjord Fm		Sandstone	0.0
Brent Gp		Siltstone	0.5



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.

NCCS

NORWEGIAN CCS RESEARCH CENTRE

Industry-driven innovation for fast-track CCS deployment

fme

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

The Research Council of Norway