Geomechanical modelling of fault reactivation related to pore pressure changes.

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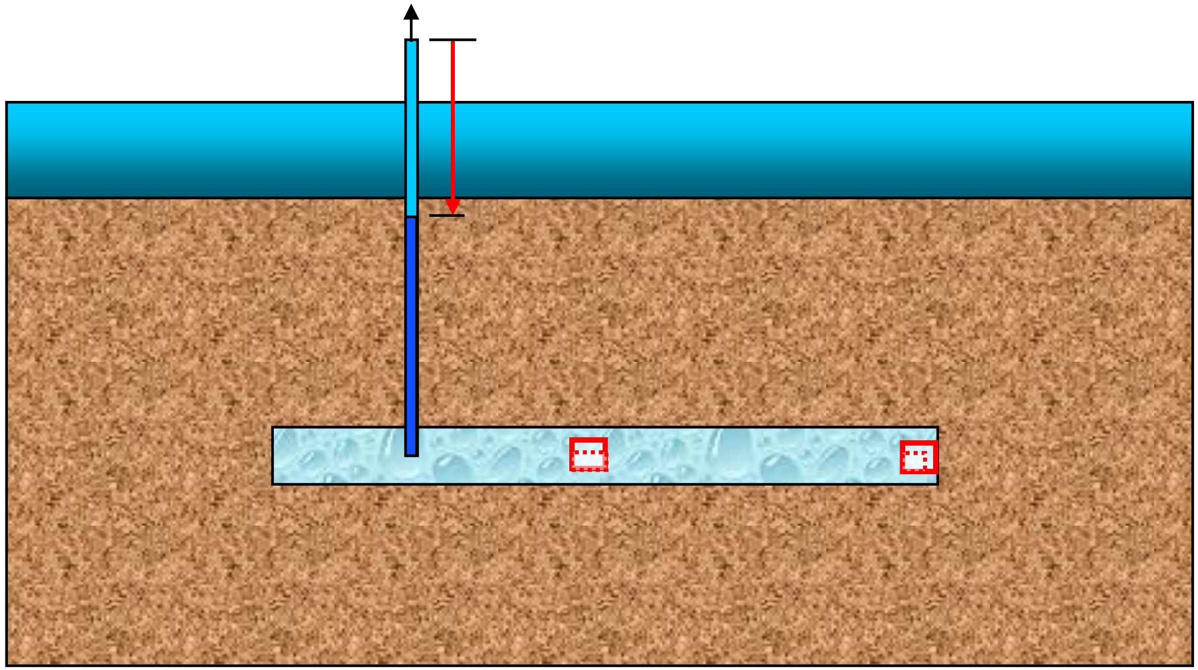
FORCE HPHT workshop 10.Nov.2010

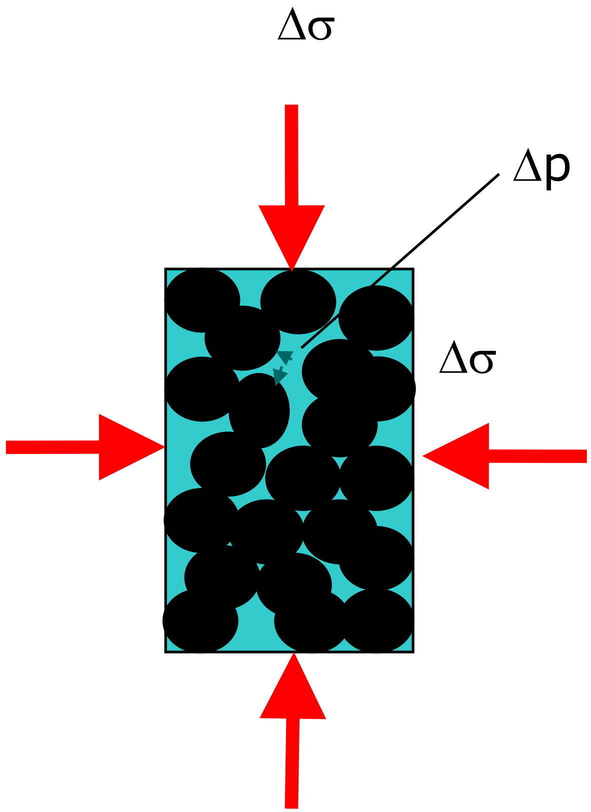
NGI

Focus of the talk

- HPHT reservoirs and depletion
- Geomechanical modelling related to depletion
- Laboratory testing of hydro-mechancial parameters
- Case studies: Kristin and Statfjord Field

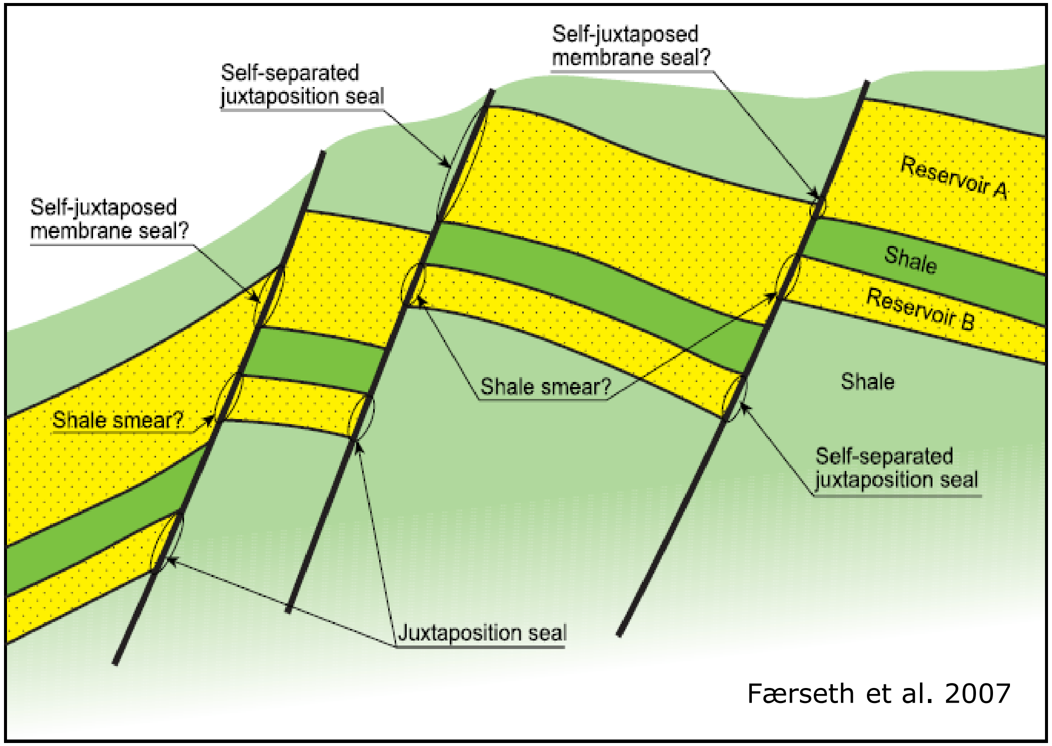
HPHT reservoirs and depletion





$$\Delta\varepsilon = (\Delta\sigma - \Delta p)/K + \Delta p/K_s$$

Effect of depletion on fault in reservoirs

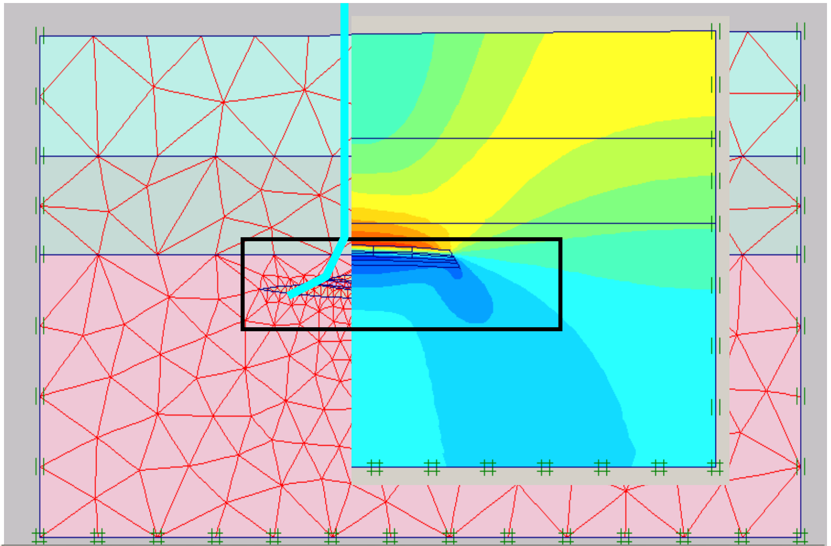


- Flow and pressure barriers
- Affect horizontal and vertical flow paths
- Pressure compartments and large differential pressure across faults
- Stress concentration

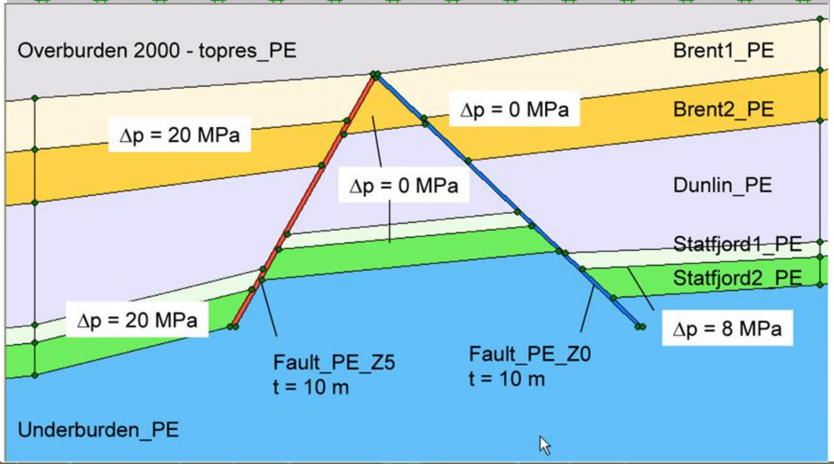
Geomechanical modelling of pressure depletion at NGI

Fault integrity

Well integrity

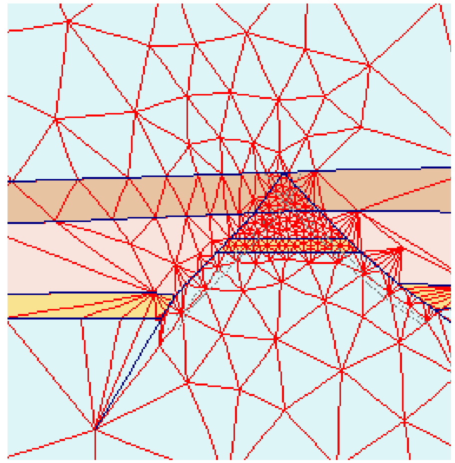


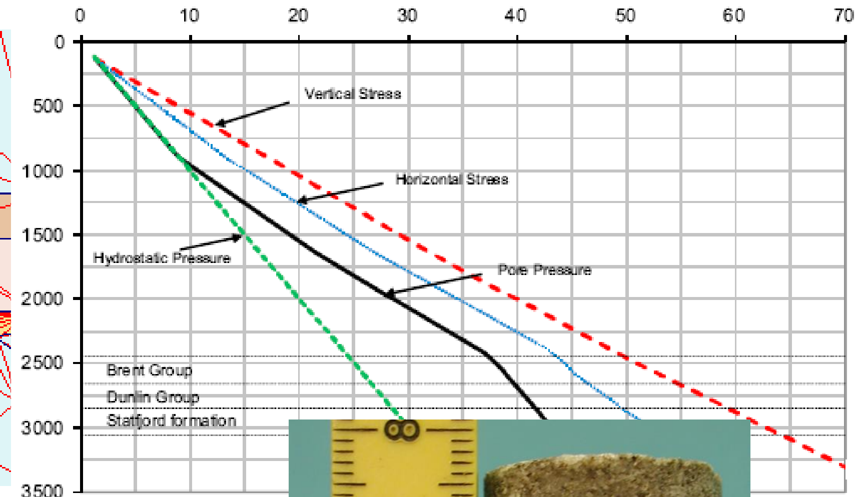
Special laboratory testing on intact and faulted material



Geomechanical modelling

- Geometry
- Stresses
- Depletion
- Geomechanical properties
  - Stiffness
  - Strength
  - Permeability





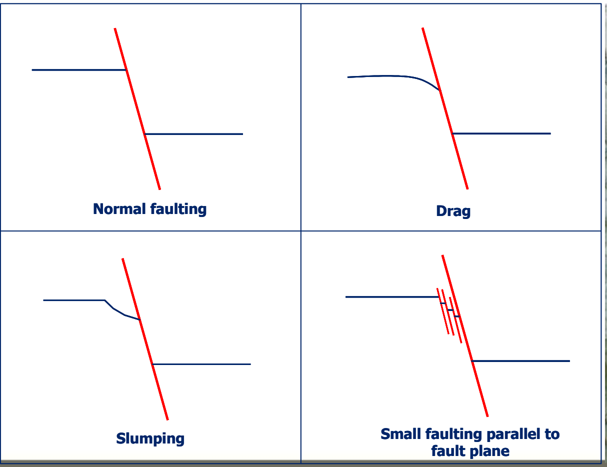
How to model fault zones

Geometry

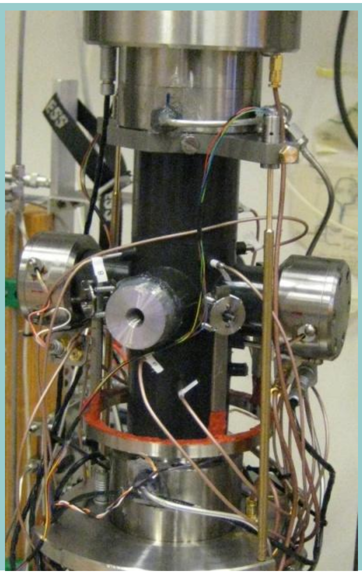
Complexity

Fault core – type of material

Damage zone



Laboratory tests
Standard Triaxial testing



Parameters

- Strength
- Deformation
- Permeability
- Seismic velocities
- Resistivity

Test conditions

- Confining Pressure up to 100 MPa
- Pore Pressure up to 80 MPa
- Temperatures up to 160^{o}C

Challenges related to testing

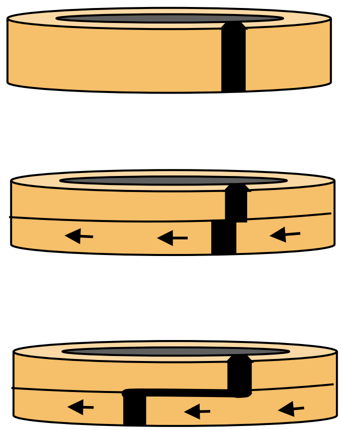
- Relevant material
- Fresh and undisturbed material
- Fault zone material – bad quality or missing

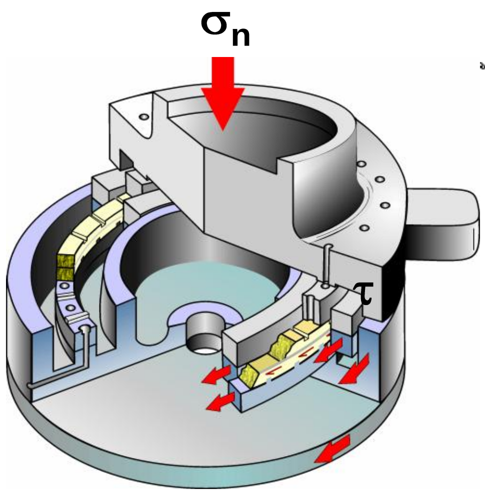
Fault zone

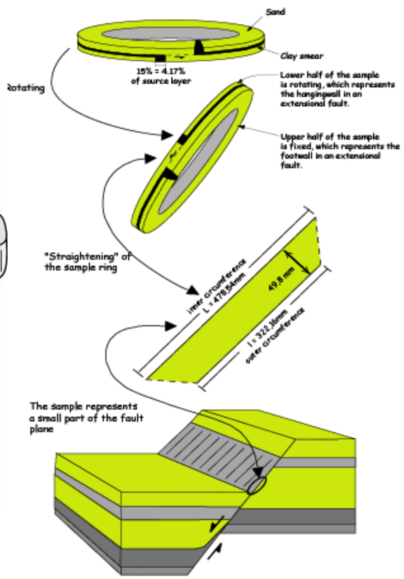
Shale

Ring shear test equipment

Investigating basic mechanisms involved in faulting







Clausen & Gabrielsen, 2002

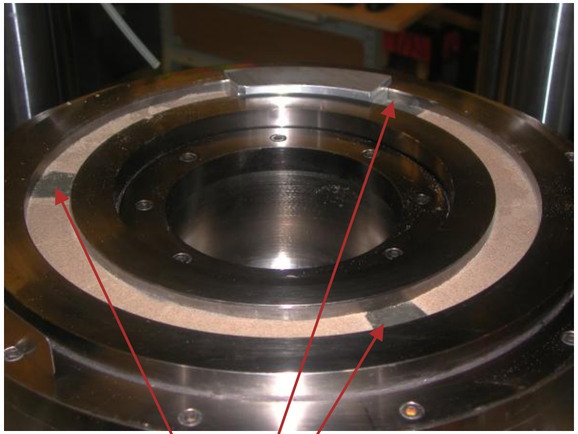
Parameters tested:

Shearing of pure sand, sand mixed with clay and clay layers producing clay smear

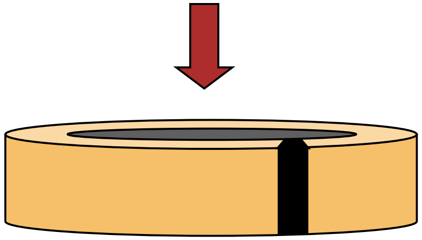
Varying porosity, burial depth, clay content, number of clay layers

Ring shear tests

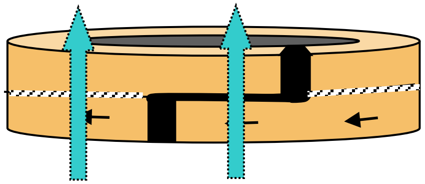
Effect of various burial depth during shearing



3 clay layers separated by sand



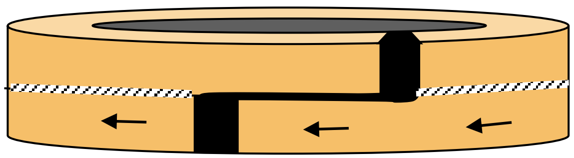
Loading the sample to required burial depth



Faulting simulated by rotating lower part of ring cell

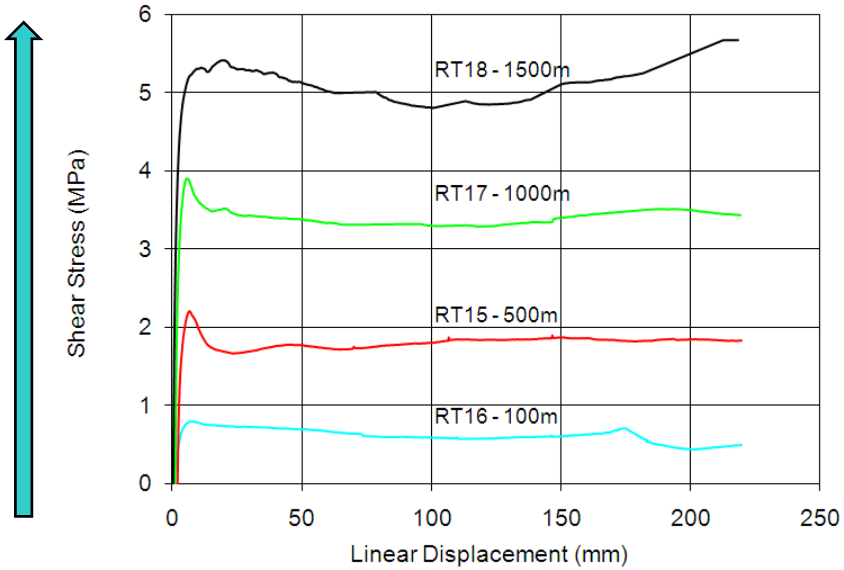
Flow measurements

Observation of shear zone

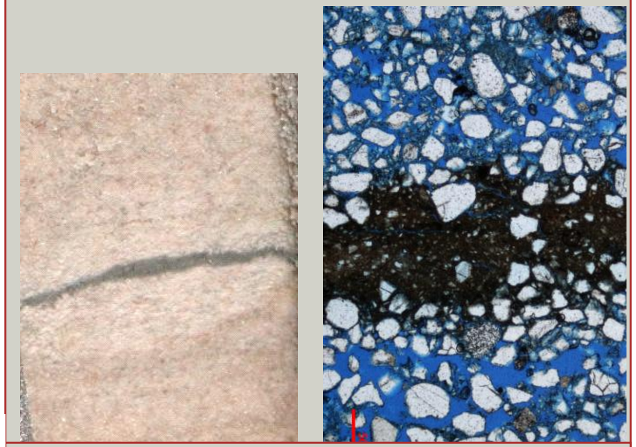


- clay smear
- grain rolling
- cataclasis

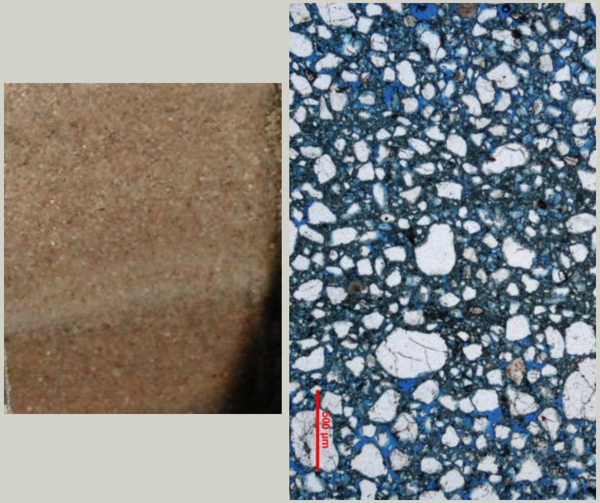
Increasing shear strength with increasing burial depth



Clay smear



Sand shear



Field cases

Kristin Field – HPHT reservoir

Statfjord Field – Statfjord Late Life

Kristin Field - Halten bank

Geomechanical modeling of depletion:

- Reservoir deformation due increased effective stress
- Total stress reduction in horizontal direction, develop shear deformation
- Stress concentration around internal faults

5000 m depth

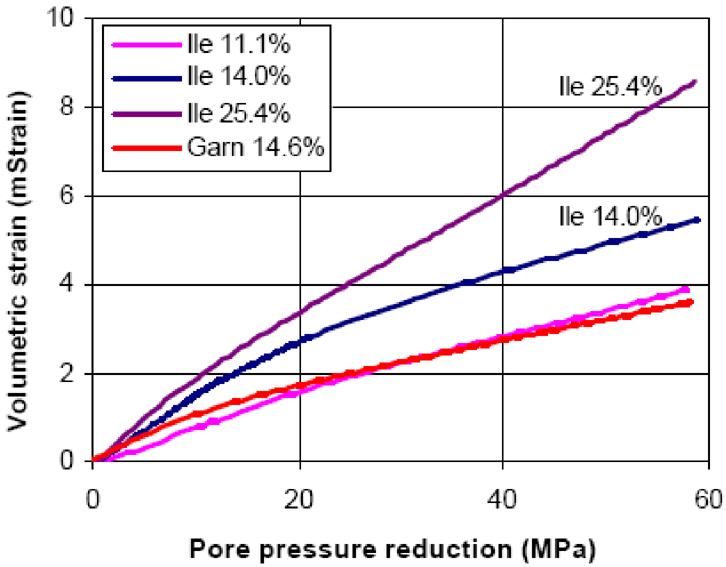
90 MPa pore pressure

Temperature 170 ºC

Planned depletion: 60 MPa

Special laboratory tests

Material properties for calculation of compaction and deformation during depletion



Skomedal et al 2002

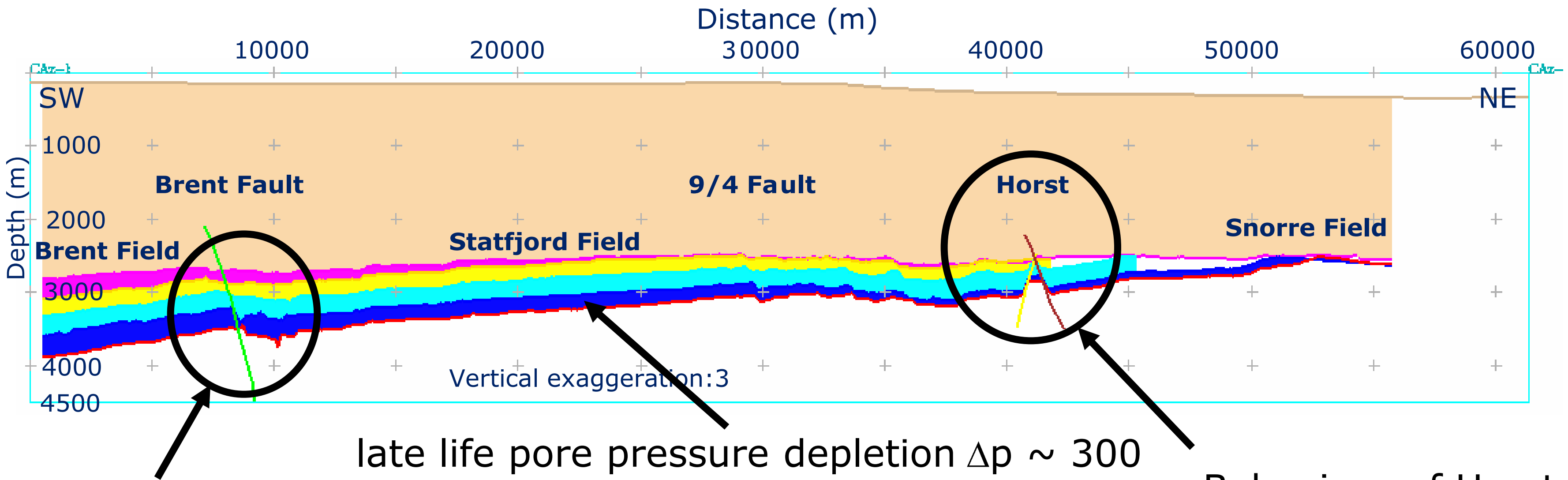
Defining bulk modulus

Compressibility of the reservoir depends on the initial porosity and possibly quarts cementation

Fault integrity during depressurization of the Statfjord Field

Poroelastic model to account for grains compressibility during depletion

Use existing observations from Brent-Statfjord as verification/calibration



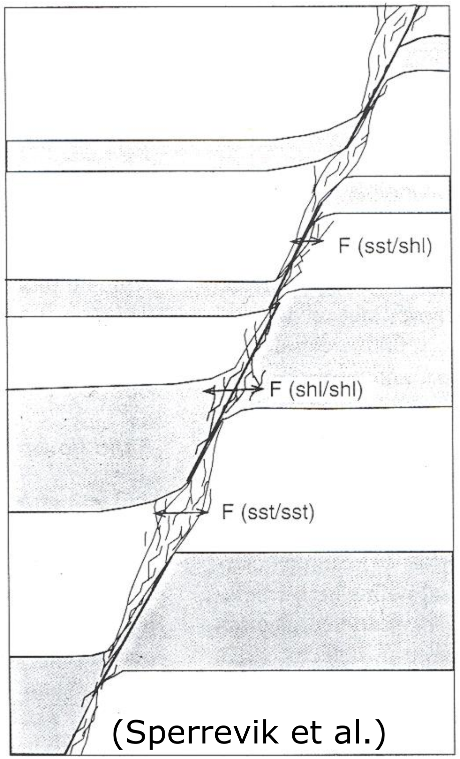
late life pore pressure depletion $\Delta p \sim 300$ bar

Sealing fault under existing pressure depletion in Brent field (300 bars)

Behaviour of Horst barrier during depletion?

Fault properties

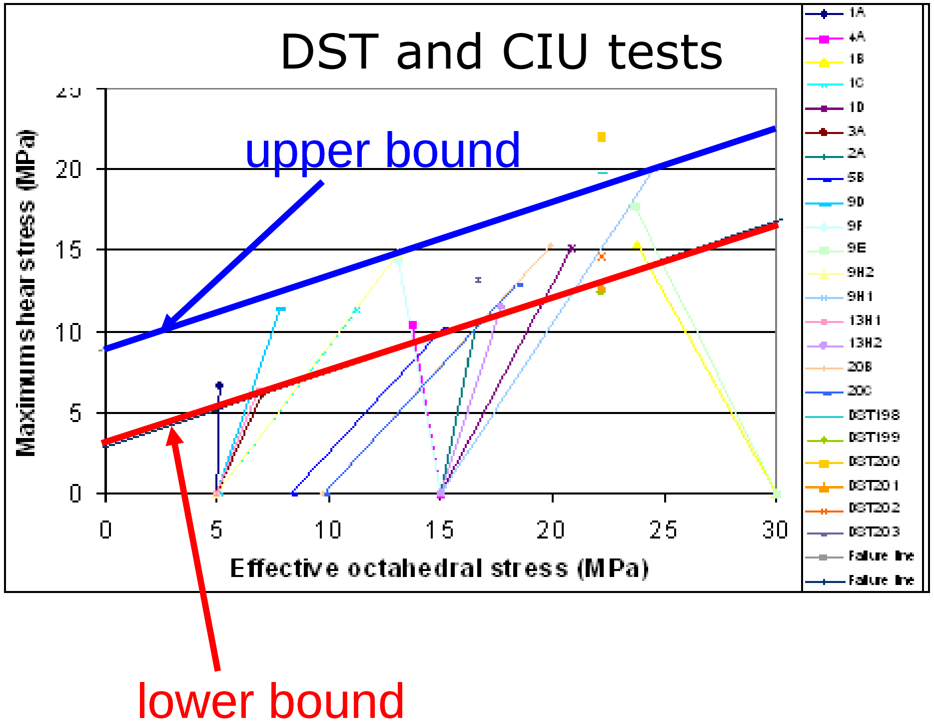
- Throw from seismic sections
- Empirical relationship between fault throw and thickness from field analogue
- Shale Gauge Ratio to define the clay content of the fault
- Uncertainty in thickness and damage zone investigated in parametric study



Mechanical properties of fault material

Controlled by clay content from SGR analysis

- Clay rich fault rock assumed same properties as intact shale
- Sealing fault rock with less clay assumed same properties as sandstone or even stronger/stiffer (cataclasites)

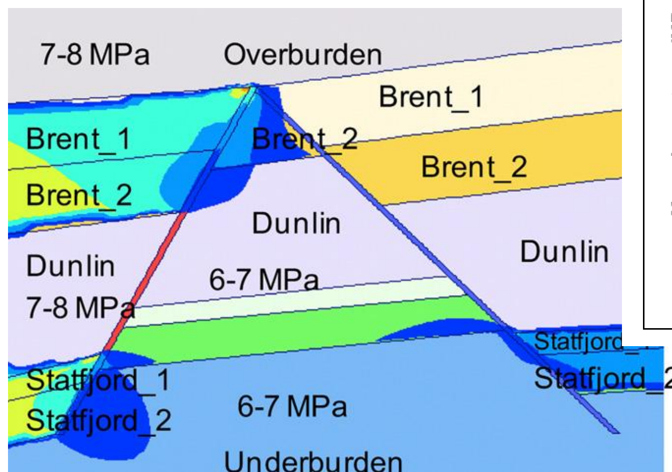


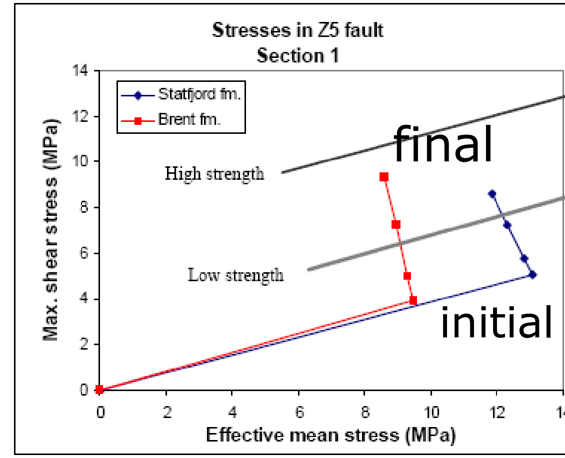
Max. shear stress in Horst structure

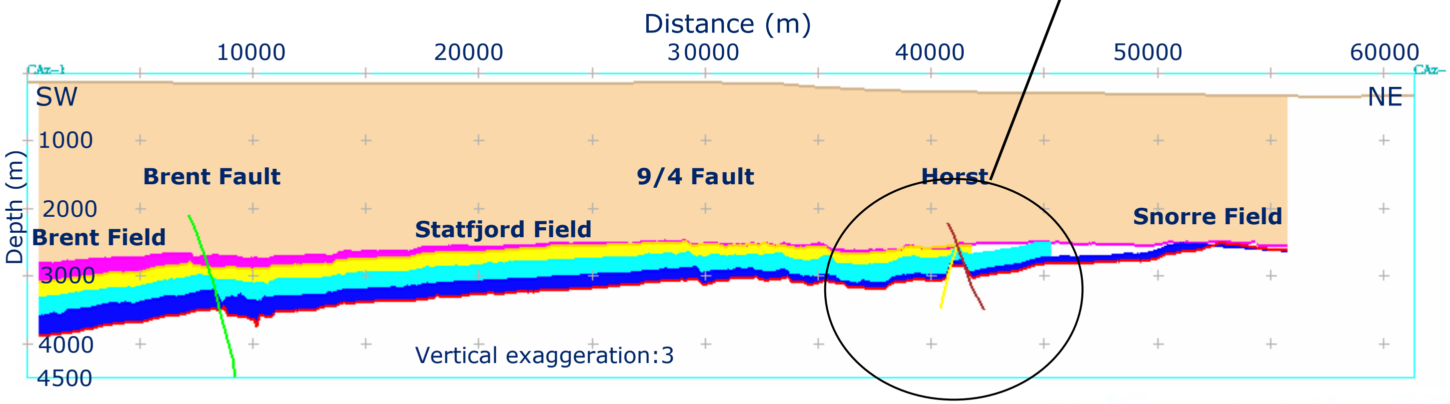
Highest shear stress for Brent group

Failure possible in Brent group

Stress changes less than for Brent fault



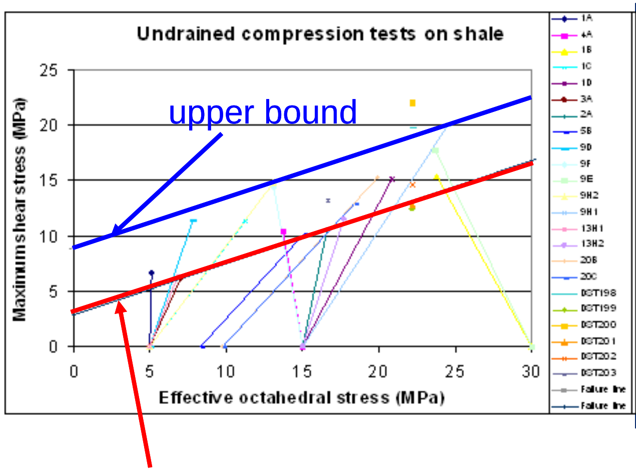


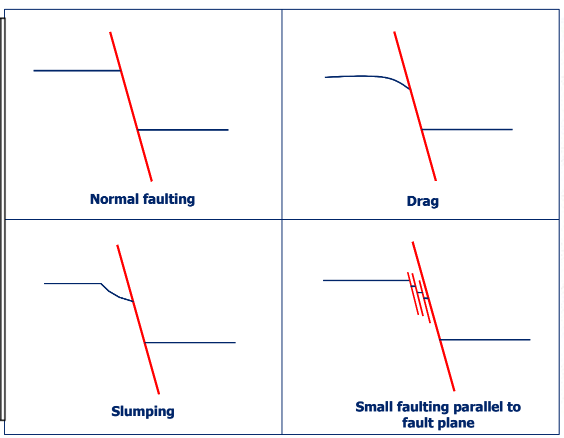


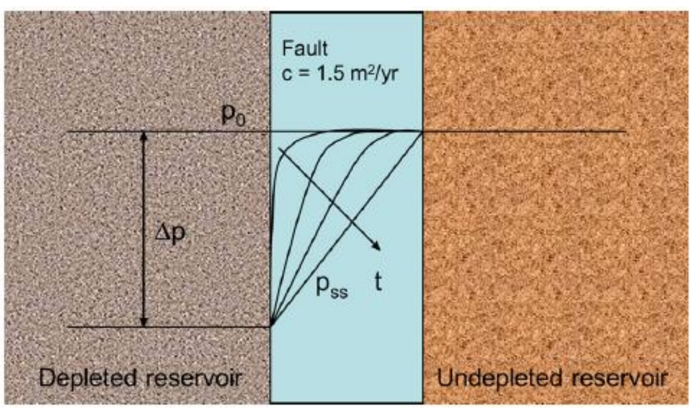
20 MPa depletion

Sources of uncertainties – parameter study

- stiffness properties (reservoir, shale layers and overburden)
- fault geometry (inclination, thickness, drag and juxtaposition);
- pressure distribution and drainage of fault core zone.



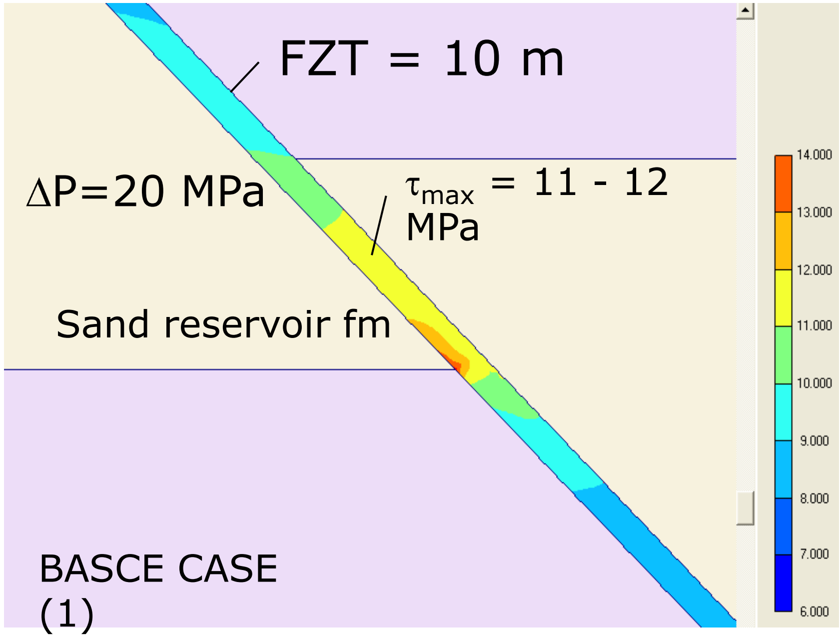


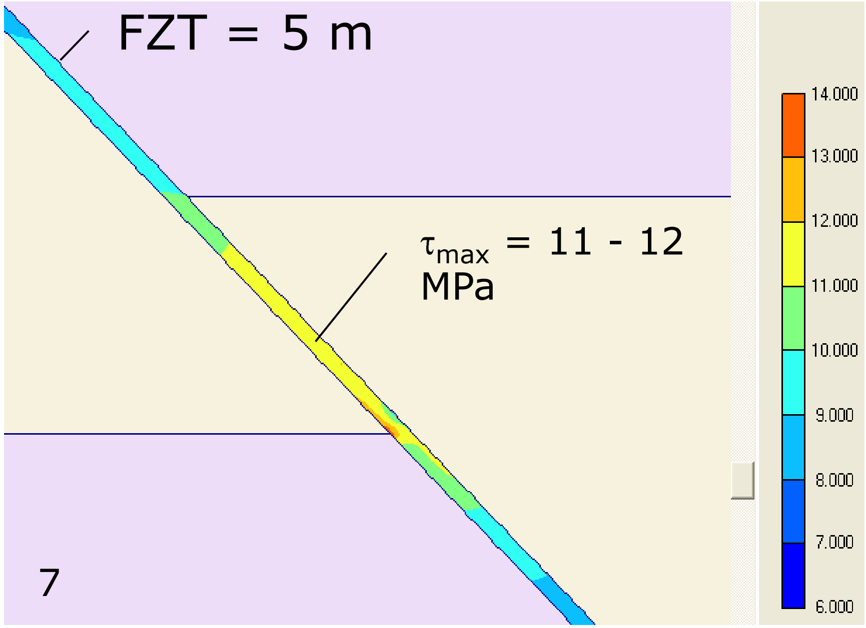


Effect of fault core thickness

Highest shear stress mobilisation in sand:sand juxtaposition at the bottom of the depleted reservoir.

Maximum shear stress τ_{max} in fault not significantly affected by reduced fault zone

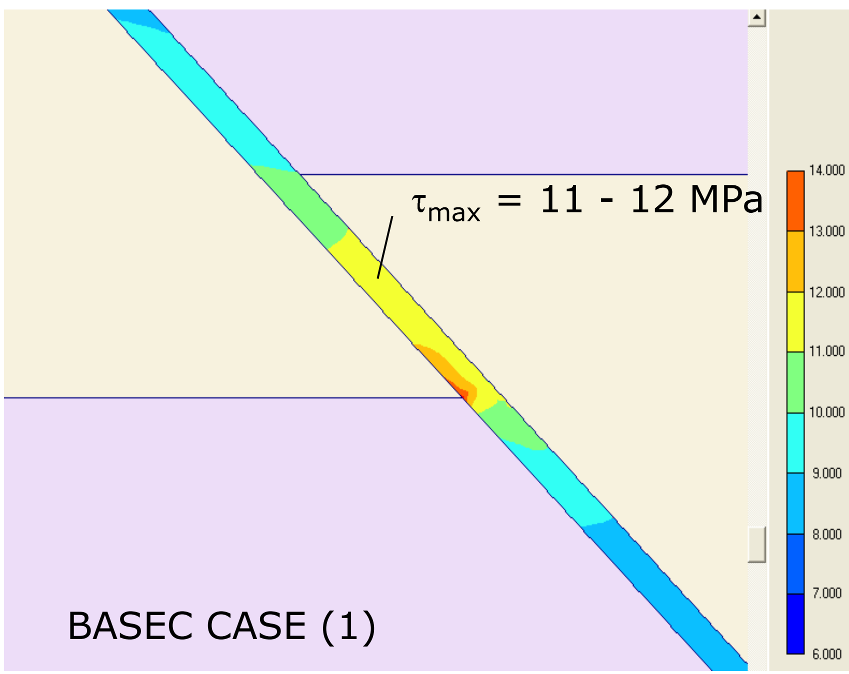




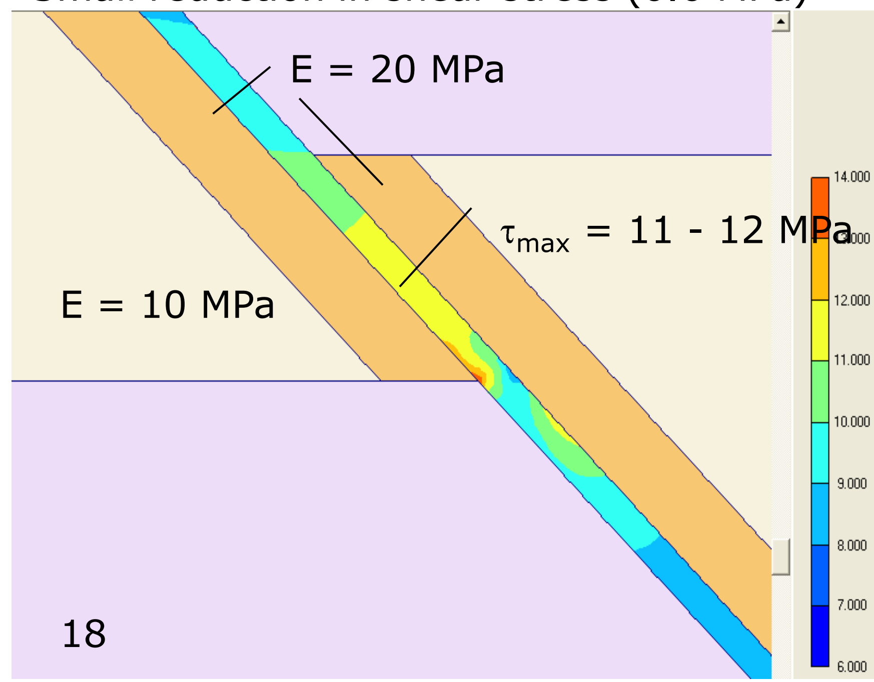
Effect of damage zone

'damage zone' modelled as stiffer material

small positive effect

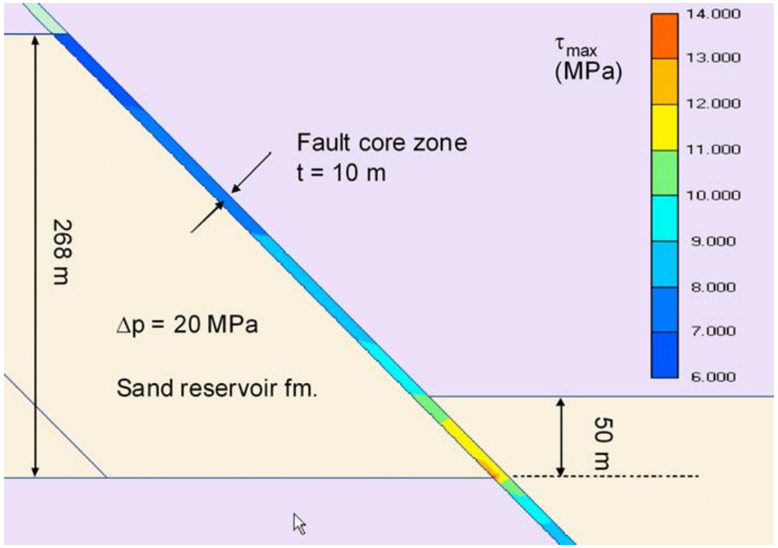


Small reduction in shear stress (0.6 MPa)



Results from parametric study

- Maximum shear stress in fault core zone is relatively insensitive to variations in geometry and stiffness parameters
- positive effect of drag
- largest uncertainty related to the fault peak shear strength



Conclusions

- Geomechanical modeling tools for fault integrity during depletion and methods for assessing material properties has been presented
- 2D models have been used but 3D is needed for more complex geometries
- Largest uncertainty related to the fault (core) peak shear strength
- Further work:
  - Effect of shear mobilization on hydraulic communication
  - Determination of fault strength

Thanks!

PROFUSE Project (JIP)

Statoil

Statoil TOTAL bp

F. Cuisiat, E. Skurtveit. (2010) An experimental investigation of the development and permeability of clay smears along faults in uncemented sediments". Journal of Structural Geology, In press. 2010

Fabrice Cuisiat, Hans Petter Jostad; Lars Andresen; Elin Skurtveit; Eiliv Skomedal; Marc Hettema; Kellfrid Lyslo. (2010) Geomechanical integrity of sealing faults during depressurisation of the Statfjord field". Journal of Structural Geology. In press. 2010

Skomedal, E.; Jostad, H.P.; Hettema, M.H. (2002) Effect of pore pressure and stress path on rock mechanical properties for HPHT application. SPE/ISRM Rock Mechanics Conference. Irving, Texas 2002. CD-rom. Paper SPE 78152. 10p.