A Review of Fault Modelling Approaches

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Introduction

- In the subsurface the direct observation of fault is limited to well data and seismic imaging.
- Thus, numerical models are essential to estimate fluid flow in the subsurface at different scales.
- Several approaches to model faults in sedimentary basins have been developed and applied in case studies at SINTEF recently.
- Different focus and methodology, depending on the scientific context motivating the research effort are shown from exploration, production and CO_2 storage.

Modelling approaches

Different strategies to model effect of faults on pore pressures and stresses using various meshes and grids.

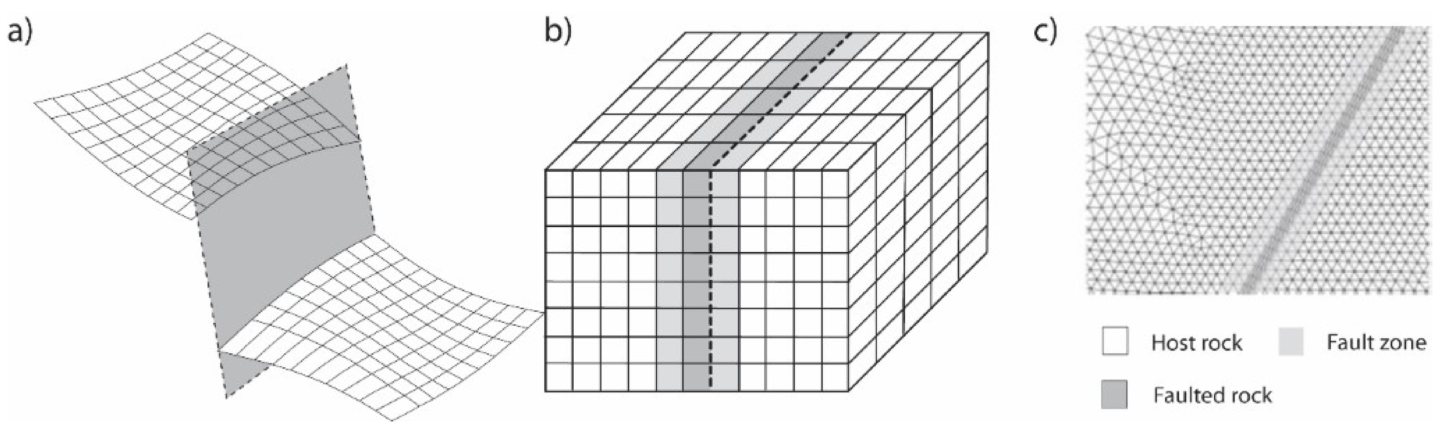

Fig. 1. a) Discontinuity sheet linking two layers (sheet can also be gridded); b) reservoir flow model with quadrilateral elements assigned fault properties; c) geomechanical fracturing model with finite size fault zone assigned different properties.

Methods

Pore pressure modelling: For 3D pore pressure modelling over millions of years, the interpreted faults from seismic define the pressure compartments. Faults are assumed to be vertical, while the fault throws and permeability will vary with subsidence, erosion and uplift. The fault transmissibility depends on the burial depth, the length, width and the dip-slip displacement of the faults, thickness of the layers and the permeability inside the fault block (Borge & Sylta 1998). The fault permeability can be calculated simply depending on the burial depth, or dependent on the shale gouge ratio along the fault planes (Sperrevik et al. 2002, Lothe et al. 2008).

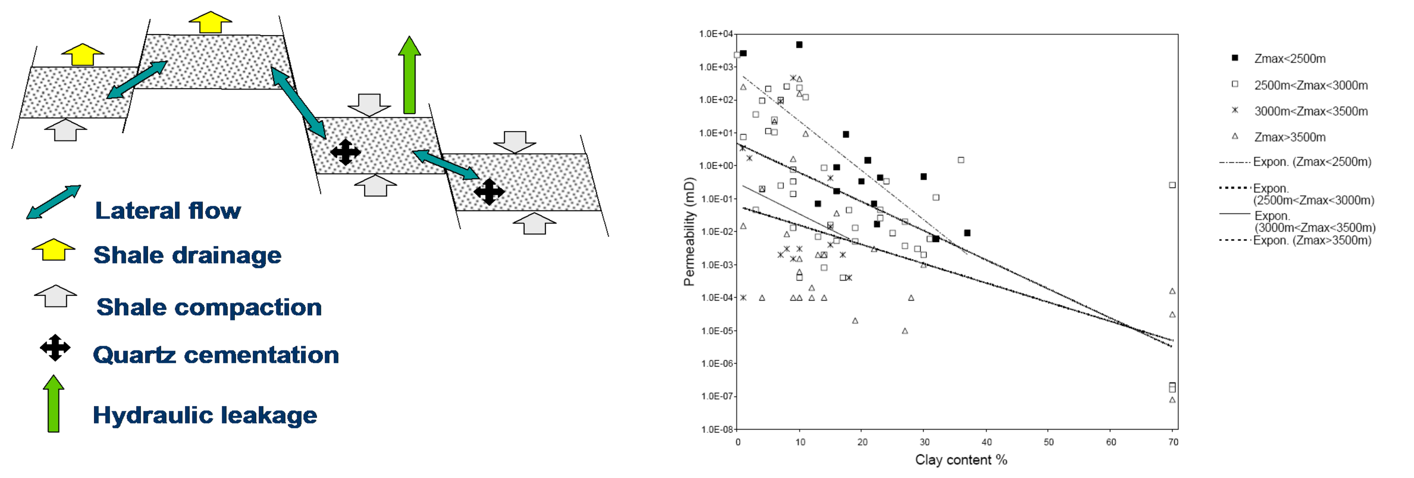

Fig. 2. a) Processes modelled using Pressim and b) Measured permeability versus clay content and depth for siliciclastic rock. Sperrevik et al. (2002).

Reservoir modelling : Faults are defined at grid block interfaces (Fig. 1b) and the transmissibility across a fault is modified using multipliers. Modelling is carried out using Eclipse 300.

Geomechanical modelling: In conventional finite-element modelling (FEM) faults are represented as collections of finite elements with reduced elastic moduli. When induced fracturing is of interest, the Modified Discrete Element model (MDEM) developed by SINTEF is used. Faults are described by aligning regular triangular elements as shown in Fig. 1c and assigning them different mechanical properties. Fluid coupling is obtained with the commercial flow simulator TOUGH2 or MRST (Lavrov et al. 2016)

Examples of user cases

- **Basin scale overpressure:** Sperrevik et al. (2002) is used to calculate permeability to faults in the study area. To simulate realistic transmissibilities, a cut-of value Vsh<0.4 is used (Lothe et al. 2008), resulting in stable runs (Fig. 3a). Faults are simulated to hold large pressures (Fig. 3b), as measured in wells in the North Sea case study.
- **Basin scale depletion:** Using the reservoir simulator, fault multiplicators in all the mapped faults are tested (Fig 3c and d). The strength with reservoir models is that both water and gas phases can be handled, making it very nicely suited for e.g. CO_2 capacity modelling. One weakness, is that new fractures cannot be modelled.
- **Detailed depletion effects on stresses:** Using a geomechanical model (MDEM code) we investigate stress arching and hysteresis effects in reactivation of faults. Results show that during depletion, shear stresses may develop such that fractures run parallel to the fault (width 20 m) all the way up to the upper aquifer, for one critical fault orientation. However, for the footwall depletion, no fractures develop towards the shallow reservoir (Fig. 3f).
- **Detailed depletion effects:** FEM is shown in Fig. 3g) and 3h). Pore pressure in the rightmost sand layer is depleted by 5 MPa over a five-year period (Fig. 2h). Depletion reduces the total horizontal stress in the depleted sand (Lavrov 2016a). The faults are softer than the surrounding rocks. As a result, due to the Skempton effect, the pore pressure around the left fault drops.

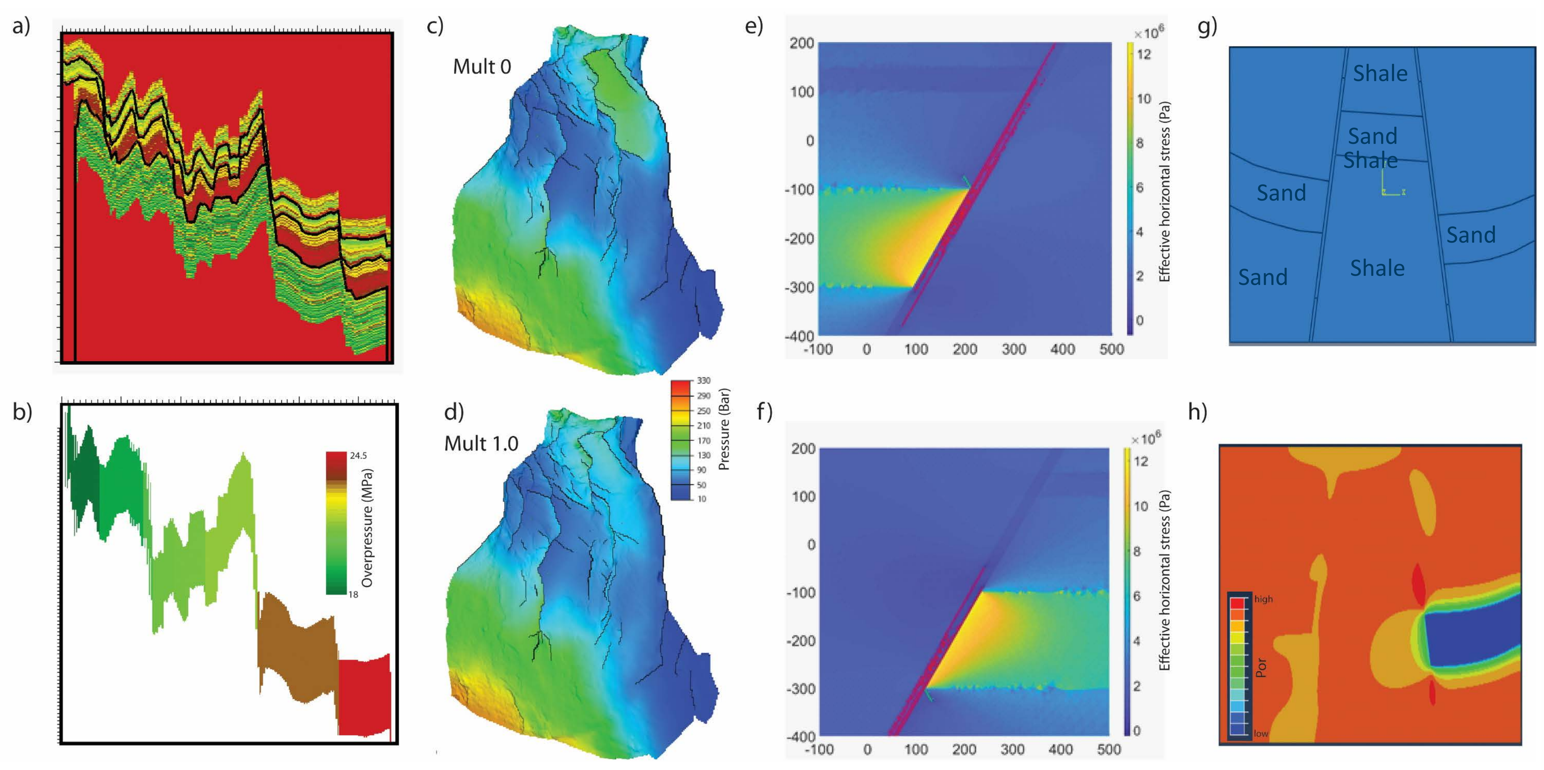

Fig. 3 Results from different modelling approaches. ore pressure modelling approach with a) calculated shale gouge ratio distribution of four reservoir units along a cross section. Red colour is 100 % clay, dark green is 100% sand. b) Corresponding simulated overpressure in the lowest reservoir unit. Sealing faults are controlling the lateral pressure distribution (from Lothe et al., 2008). Simulating depletion assuming c) sealing faults and d) assuming open faults (Lothe et al. 2018). e) For reservoirs in a hanging wall shear fractures propagate all the way up to a shallower reservoir when depletion reaches 10 MPa. The failed elements are shown in red; For reservoirs in the footwall (f), the picture is reversed, with no breakthrough to the upper reservoir (Rongved et al. 2018). g) normal faults in a shale-sand-shale sequence and h) pore pressure distribution after 5 years of sand depletion.

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Conclusions

- Different simulation techniques help address different aspects related to fault behaviour in an efficient manner.
- Scarce and uncertain input data encourage focusing on particular properties while simplifying others.
- Computing power is still an issue and prohibits detailed modelling at the basin scale where both flow, pore pressure and stresses are to be calculated.
- The different methods should be compared on the same dataset

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