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Stochastic Modeling of Permeability Reduction and Enhancement in Faults and Damage Zones

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SUMMARY

During appraisal, development and production of oil and gas fields a large amount of effort is applied to understanding the impact of changes in permeability around faults. In this paper we describe a methodology for calculating distributions of static permeability in and around faults incorporating, geomechanics.

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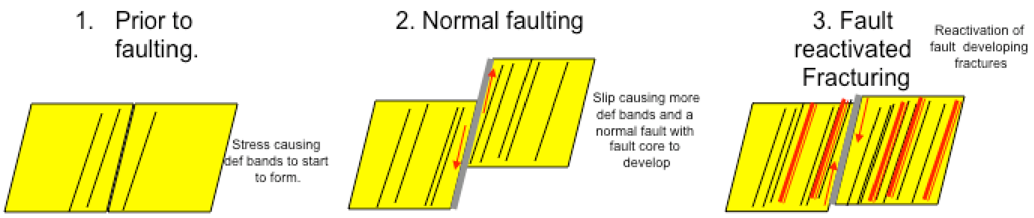
In any analysis of faults there needs to be a thorough handling of uncertainty. Many of the fault analyses for static reservoir models are at or below seismic resolution. This primarily impacts the across fault inter-reservoir flow. Uncertainties also exist for intra-reservoir flow that can be effected by bulk reservoir and intra-reservoir permeability within damage zones.

It is vital for calibration and integration with dynamic reservoir models that permeability be integrated back into the static reservoir model. Each of these parameters is provided as deciles of permeability tensors and transmissibilities.

Figure A



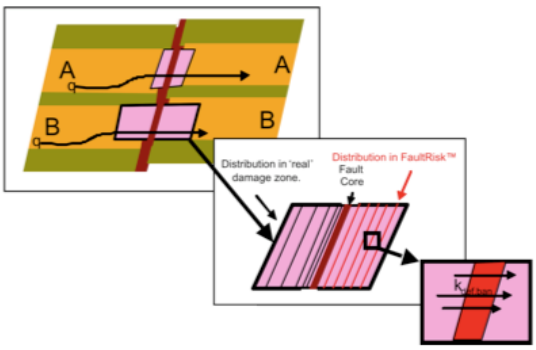
Reduction in Permeability: Shale Cored Fault Zones Deformation Bands

When considering the anatomy of a fault it is important to think about the kinematics and dynamics of the fault movement and the impact on permeability modification. It is useful to consider the broad sequence of development of the fault (***Figure A***):

1. Prior to the development of a fault deformation bands may or may not be developed depending on the permeability of the reservoir rock. These form a broad zone of semi-systemically organized planes sub parallel to the proto fault.
2. As the fault propagates it has been proposed that with fault movement faults can sort clay from the country rock and preferentially develop a shale rich core.
3. With continued movement juxtaposition of reservoirs and shale across the fault becomes an increasingly important aspect of any fault analysis

These three processes serve to reduce flow across the fault at a number of scales see

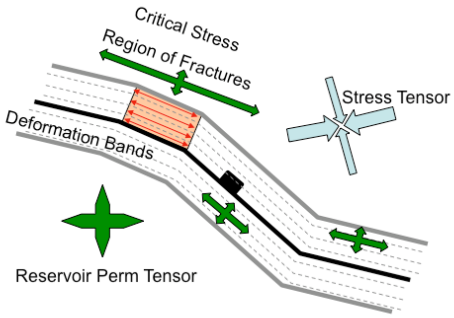
(FIGURE B)



Enhancement in Permeability: Reactivation of faults and subsequent fracturing

With fault movement, fractures and antithetic faulting will occur in the hanging wall of the fault as it moves over the footwall. The development of fractures will enhance permeability sub-parallel to the fault. It is likely that fractures generated early in the life of the fault will be re-cemented and healed.

Figure C



Fault movement (reactivation) that occurs post charge can reactivate fractures or generate new transmissive fracture networks. The integration of present day in-situ stress and fault geometries can discriminate regions where fault slip is possible.

For each reservoir juxtaposition, shear and normal stress can be calculated based on the fault geometry. Fault segments or elements where the ratio of the shear stresses and effective normal stress have been calculated using a probabilistic geomechanical model exceeds the coefficient of internal friction (including cohesion) are interpreted to be critically-stressed and most prone becoming conduits of fluid flow. Associated damage zones are flagged as having recent fractures. A transmissivity for a damage zone can be estimated using analytical fracture network solutions.

The integration of the fault and fault-damage-zone structures allows a permeability tensor to be described see (Figure C).

Impact of Uncertainty on Calculations

The integration of deformation bands, shale cored fault reservoir rocks, juxtaposition and fault reactivation involves considerable uncertainties. To model the impact of all these features a Monte Carlo simulation is run on a range of 3D fault geometries. For each realization a fault geometry, stratigraphy, rock properties and the stress tensor is varied.

For each realization the probability of juxtaposition is calculated and the flow along and across the juxtaposition is calculated for a range of pressure drops.

A key finding is that juxtaposition area has a first order effect on the range of flows expected across a fault whilst reactivation has a first order effect on along fault flow.