Faulting and Fault Seal: Progress with Prediction

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ABSTRACT
The understanding and prediction of fault behaviour is a critical component of exploration and production strategies. Faults may be either, seals, retarders of conduits for fluid flow. An integrated approach to fault evaluation has proved successful in recent years. The integrated approach involves; amalgamation of detailed microstructural and petrophysical property analysis of fault rocks, the characterisation of the population and distribution of sub-seismic faults from well, core and outcrop data, and an evaluation of the seismic scale fault array attributes. This paper will review the progress and achievements of fault seal analysis. Examples where successful application has been possible will be presented and the important uncertainties that limit application of fault seal prediction will be highlighted and used to identify the challenges for future work. We will also demonstrate how integrated fault analysis has benefited exploration, production and extending the life of specific fields.

The key factors which influence the success / failure of fault seal analysis are:
The ability to define fault geometries and architectures. Fault throws control the juxtapositions of lithologies across faults as well as the distribution of fault rocks. The uncertainty in the pattern of juxtapositions is related to two factors; a) the seismic resolution and b) the fault zone architecture, where a complex array of sub-seismic damage zone faults may be present. Multi-realisations of the impact of throw and juxtaposition patterns on communication are improved by detailed geostatistical data from core, down-hole tool images and outcrop studies on fault zones. The fault displacement population, orientations, and particularly the clustering and connectivity of faults within the structure are fundamental to the fault zone behaviour. Representing a fault zone as a single, individual fault plane (as usually imaged on seismic data) will limit the assessment of the fault zone flow behaviour, as only the cumulative displacement across the fault zone is considered. For example, an array of linked small-throw faults within the damage zone may allow preservation of clay smears and juxtapositions against low-permeability units and thus cross-fault flow retardation, while large offset faults induce smear breakdown and allow communication.

The ability to quantify the petrophysical properties of fault rocks. The permeability and threshold pressure, which are critical for evaluating sealing potential of fault rocks, depend upon: a) the host lithology being deformed, b) the conditions and mechanisms of deformation and c) the post-deformation and geohistory of the fault zone. The integration of deformation and diagenetic studies allows the evaluation of; fault zone poroperm histories, the evolution and distribution of seals, the timing of fault activity during the burial history, the identification of migration pathways as well as the changing drainage patterns which control the distribution and development of open and closed reservoir compartments. Such analysis provides critical input for the quantitative modelling of fault behaviours. The ability to incorporate the impact of fault geometries and properties into reservoir flow modelling. For efficient and effective flow modelling of reservoirs with structural discontinuities there is a need to capture the complexity of fault zone architectures for incorporation into flow simulation packages. This problem is an important limitation to current fault analysis. The transmissibility behaviour of the fault zone depends on the distribution of fault rock permeabilities and fault rock thicknesses. The complexity of fault zones renders flow prediction a demanding numerical task where, the relative permeability of the host rock and fault rocks, as well as the distribution and connectivity windows of retarding (but transmissive) faults and the pattern of effective tortuosity pathways will control the flow behaviour. Progress in the development of a new model for evaluating the behaviour of complex fault zones will be reviewed. Based on the need to assess the impact of complex fault zones with different fault offset, clustering, orientation populations, we have constructed a model where volumes containing large numbers ($>10^9$) of faults can be tested for flow characteristics. The aim is to assess the level the complexity appropriate for reservoir modelling.

Improving fault seal analysis is difficult but not impossible. Reducing the uncertainty associated with fault zone behaviour prediction is achievable if the following are recognised:

- Seismic resolution places important limitations on the characterisation the fault zone architectures needed for flow modelling.
- Robust databases on fault zone architectures and fault rock properties are required.
- New more flexible reservoir modelling packages are required which can incorporate the more detailed and more realistic fault property data now available.
- The calibration and validation of fault analysis ‘tools’ is needed from well-constrained situations so that mis-application is avoided.