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Introduction to the thematic set: Fault and top seals

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The 4th EAGE Conference on Fault and Top Seals was held in Almeria in SE Spain from 20 to 24 September 2015. A total of 118 delegates attended (78 from industry, 21 from academia and 19 students). The conference provided the opportunity to learn about the latest advances in seal evaluation and the increased scientific rigour behind the technologies employed as we begin to understand more about the basin- to pore-scale processes that trap hydrocarbons. The same workflows are also readily adapted to studies for geological storage of carbon dioxide (CO_2) and nuclear waste.

Overall, the conference was dominated by research on fault seals ranging from micro to macro scale, with close attention on the role of microfabrics, flow properties and capillary properties. In addition, fault-zone architecture was discussed at length, with numerous presentations from both outcrop and 3D seismic scales. Predominantly, the presentations focused on faults in siliciclastic systems, with just a handful addressing the volumetrically important carbonate reservoirs. Top-seal evaluation included contributions from the Clay Club, and more integrated industry workflows on overall seal analysis, with a couple of presentations on laboratory testing of mechanical and flow properties. The application area of the majority of the conference presentations was to petroleum systems, but a number also related to geological storage of carbon dioxide and the nuclear waste industry. Following the 3 day conference of talks and posters, there was a whole-day field trip to the well-exposed and extensively studied Carboneras Fault Zone, led by Dan Faulkner and Ernie Rutter. The fault gouges here are probably the best exposures in the world and reach thicknesses of 20 – 30 m in places. The trip was extremely instructive for understanding fault gouge development and its variation in petroleum systems.

This thematic set comprises 12 papers, which either were given at the conference or present related studies. They are divided into four subject themes:

- geomechanical and geophysical aspects;
- methods in conventional (sand–shale) fault seal;
- fault seal in carbonate reservoirs;
- case studies and issues in field development.

In the geomechanical/geophysical section, the introduction by **Underschultz** examines the interplay between mechanical fault reactivation and capillary processes, and suggests that this may explain episodic fault 'valving' behaviour of repeated leak and refill. The paper by **Simmenes *et al.*** provides examples from offshore Norway to show how bright seismic amplitudes in overburden rocks can contribute to the identification of likely leakage locations and improved prediction of hydrocarbon–water contacts in underlying traps. **Botter *et al.*** present an integrated workflow to study the signatures of relay ramps and their fluid content on seismic data, using a geomodel of an outcrop relay ramp as a basis for flow simulation, forward seismic modelling and seismic-attribute-based volume extraction. Investigating the stability of a fault-bound gas storage site in China, **Meng *et al.*** apply a novel combination of shale gouge ratio (SGR) and geomechanics to consider the practical effects of fault heterogeneity and its impact on safe storage practice.

Two papers continue the refinement of 'conventional' fault seal in sand–shale sequences. **Grant** models the geometric variability of shale smears to investigate how discontinuous shale smear fragments in a fault plane can combine stochastically to provide a sealing pattern, with non-sealing leaky windows whose locations depend on the smear placement model and the sand–shale stacking pattern. The contribution by **Bretan** shows how existing fault-seal algorithms can be applied in an automated trap analysis that includes all the faults comprising a fault-bound trap, in order to locate the critical Fault Leak Point that controls the degree of trap fill.

The subject of fault seal in carbonate reservoirs has long been a neglected area, but here we have three important contributions. **Solum & Huisman** provide a comprehensive review summarizing known examples of static seal (cross-fault column height differences) and dynamic seal (pressure and flow effects on a production timescale), and how these might be related to carbonate fault-rock compositions and permeabilities. **Giwelli *et al.*** present laboratory direct shear experiments studying the hydraulic transmissibility of faults in travertine blocks, showing how both static and dynamic transmissibility decrease during continued fault slip. **Rotevatn *et al.*** investigate the hydraulic effects of low-permeability deformation bands in carbonates from Malta, by building small-scale, outcrop-based flow models.

The final group of papers examines the importance of fault behaviour and reservoir compartmentalization in oilfield development. **Frischbutter *et al.*** present a case study from offshore Norway where careful assessment of fault-rock core samples provided permeability calibrations for calculations of fault transmissibility multipliers in the dynamic reservoir simulation model, demonstrating that the fault properties are one of the key parameters influencing the range of recoverable oil volumes and the recovery efficiency. **Wibberley *et al.*** provide a variety of case studies of producing fields where faults showed fluid-flow behaviour not predicted prior to start-up, but demonstrate that simple analytical models would have been able to correctly predict this behaviour if they had been applied. **Islam & Manzocchi** describe a comprehensive suite of high-resolution flow models to assess the errors arising from the inaccurate across-fault transmissibility expression in industry-standard, flow-simulation software.

Despite continuing innovation and refinement over the last few decades, unresolved challenges remain in the characterization and prediction of both top seals and fault seals. Presentations at the conference highlighted a number of continuing questions, a selection of which follow below:

- How do top seals fail? Is capillarity really the best explanation? Can we predict how faults and fractures work in shaly seals?
- How do we bridge the gap between the fault-zone detail we see at outcrop and the large-scale structures mapped on seismic data?
- Are we any closer to a predictive method of fault seal in carbonate reservoirs?
- How well do we understand uncertainty in our seal predictions?

Doubtless, these points will be amongst those on the agenda for the 5th EAGE Fault and Top Seal Conference in 2018.