Fault and Top Seals
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Using Probabilistic Shale Smear Factor to Relate SGR Predictions of Column Height to Fault-zone Heterogeneity

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SUMMARY

The Shale Gouge Ratio (SGR) algorithm uses the clay distribution through the wall-rocks, together with the fault displacement, to estimate an 'average' clay content at each part of the fault zone, completely ignoring the detailed fault-rock distribution. This average value is often correlated with particular fault-rocks observed in small-scale samples. However, probabilistic modelling of shale smear distributions shows that these can produce a variable sealing capacity, dependent on the arrangement of disrupted smears in the fault zone. The resulting SGR vs column height relationship is analogous to the conventional empirical calibration of SGR vs buoyancy pressure. However, it arises with only two components in the model fault zone: infinitely sealing clay smears and non-sealing remainder. Variable capillary threshold pressure of fault-rock is not required to explain the trend of trapped column height with SGR.

Analysis of microfaults in reservoir cores shows that they typically fall into one of a small number of fault-rock categories. In reservoirs of intermediate clay content, small faults are composed of 'phyllosilicate-framework fault rock', dominated by deformation-induced mixing at the grain scale. For larger faults observed at outcrop, however, the mixing process is seen to be incomplete: a heterogeneous fault-zone is typically composed of continous or discontinuous smears of clay/shale together with sand-rich shear bands. For sub-surface fault-seal prediction, the Shale Gouge Ratio (SGR) algorithm uses the clay distribution through the wall-rocks, together with the fault displacement, to estimate an 'average' clay content at each part of the fault zone, completely ignoring the detailed fault-rock distribution. For example, on a seismically-mapped fault with an SGR of 30%, the fault is almost certainly ***not*** a uniform slab of phyllosilicate-framework fault rock (PFFR) with 30% clay. The clay/shale smear components of the fault zone will have a much higher seal capacity than PFFR, but may not be continuous.
Continuity of smears depends upon the ratio of fault displacement to source bed thickness, or critical Shale Smear Factor, SSF_{crit}. As displacement increases, the smear may be disrupted, perhaps preferentially at the middle, or top, or bottom of the smear. For a large single clay bed, the breach position can potentially control the height of a hydrocarbon column trapped in the footwall (Figure 1). At increasing displacements the disrupted smears remain embedded within the fault zone and so can continue to retain a column if the geometry permits. Re-casting these results in terms of SGR, and normalizing the trapped column heights by fault displacement, a seal threshold is apparent at $SGR=1/SSF_{crit}$ see Figure 2a ($SSF_{crit}=5$ in the example). If the single thick clay bed is replaced by a group of clay beds interbedded with sands, the resulting threshold is shifted, but more importantly the curves become more gradually sloping, especially for lower breaching (Fig.2b). The form of this relationship (SGR vs column height) is directly analogous to the conventional empirical calibration of SGR vs buoyancy pressure or across-fault pressure difference. However, it arises with only two components in the model fault zone: infinitely sealing clay smears and non-sealing remainder. *Variable capillary threshold pressure of fault-rock is not required to explain the trend of trapped column height with SGR.*

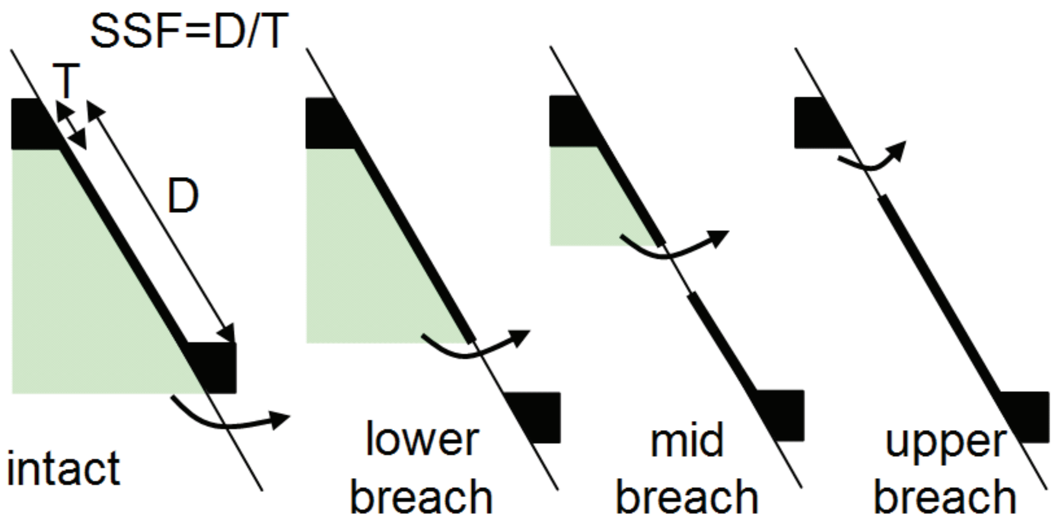

Figure 1 *Simple example of a trap formed by one shale smear. When smear is intact (SSF<critical value), seal is complete; when seal is breached, the trapped column height depends on the breach position.*

These results can be extended to finer scales using the PSSF (Probabilistic Shale Smear Factor) approach of Childs et al (2007). Here, the position of the disrupted smear is random between the two halves of the source bed. With multiple overlapping smears, the PSSF measure is defined as the probability that a gap is present in the smears at a particular point on the fault. Conversely, (1-PSSF) gives the probability that any point is sealed by smear. Figure 3a shows how this probability varies with SGR as a function of SSF_{crit}, for a sequence

of 30 rhythmically-bedded sand/clay couplets. Again, there is a progressive increase in likelihood of seal with SGR, even though clay smear is the only sealing fault-rock component in the model. The actual column-heights that might occur in a particular instance are critically dependent on the actual arrangement of smears, and therefore must be generated as multiple stochastic realisations. Figure 3(right) shows one example of 100 realisations of column heights trapped on the downthrown side of a fault where SSF_{crit}=5, displacement = 30x shale thickness, and SGR=0.33; although column height is most often less than half the fault displacement, occasional alignments of smears allow a larger proportion of the fault to be sealing and trap a taller column. As SSF_{crit} and SGR are increased, the distribution shifts so that a greater proportion of taller columns are held in the trap.
These simple models of fault-zone heterogeneity, based on outcrop observations of faults, suggest that observed trends in seal capacity (SGR vs column height) might result from random distributions of disrupted smears, and not from a simple trend in fault-rock capillary threshold pressure.

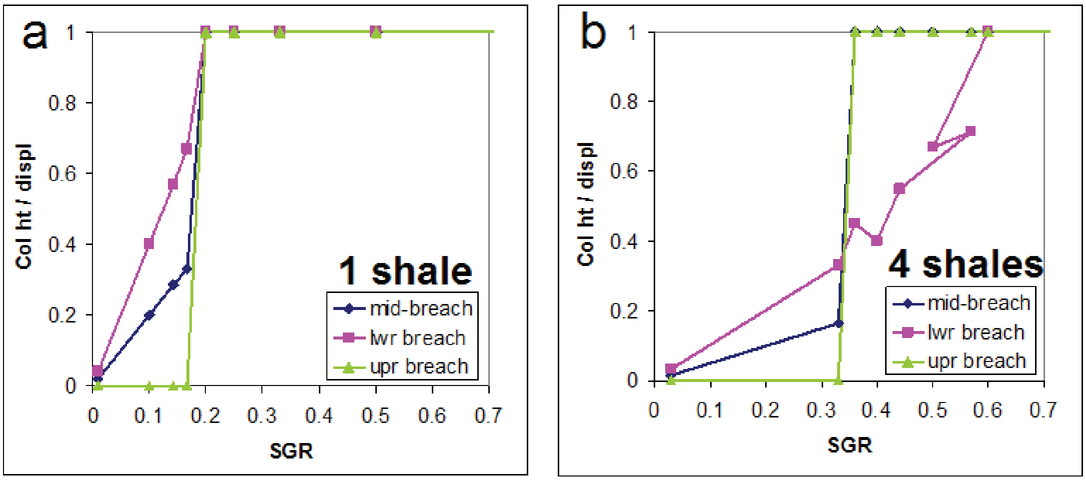

Figure 2 *(a) Column heights (as Fig.1) at various displacements, as a function of SGR (sand=0% clay, shale=100%. (b) Same but for a group of 4 shales.* SSF_{crit} *= 5 in both cases.*

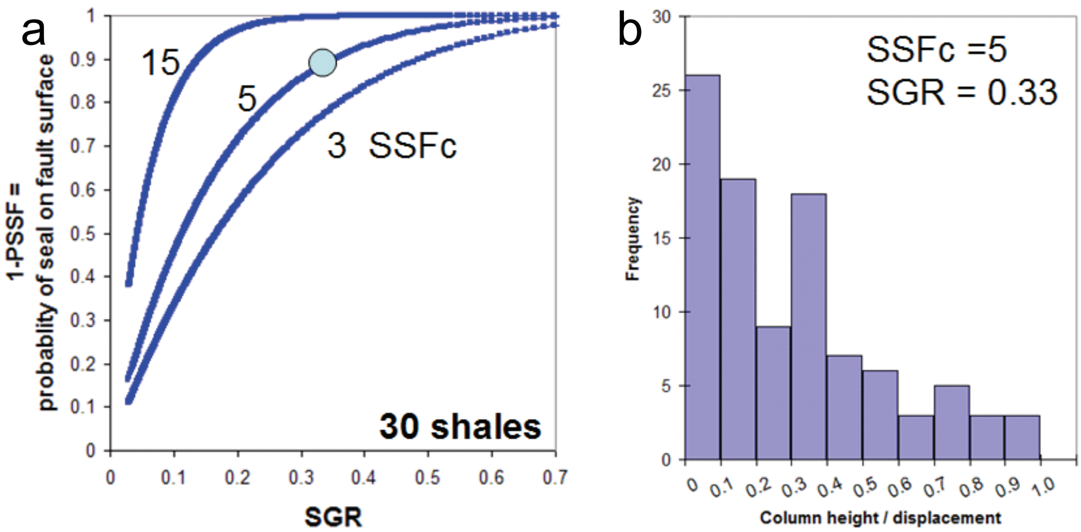

Figure 3 *(a) probabilistic measure of seal as a function of SGR, for different values of* SSF_{crit}. *(b) 100 realisations of trapped column for the circled point in (a).*

Childs. C,. Walsh, J.J., Manzocchi, T., Strand, J., Nicol, A., Tomasso, M., Schöpfer, M.P.P., & Aplin, A.C., [2007]. Definition of a fault permeability predictor from outcrop studies of a faulted turbidite sequence, Taranaki, New Zealand. In: Jolley, S.J., Barr, D., Walsh, J.J., & Knipe, R.J., (eds) *Structurally Complex Reservoirs*, Geol.Soc. London Spec. Publ. 292, 235-258.