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Faults as pathways versus faults as seals: Contrasting behaviour of high and low porosity rocks

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The permeability contrast between fault zones and their host rocks plays a fundamental role in determining the size, geometry, and location of economic deposits. Focused flow through faults is generally considered essential to the formation of hydrothermal ore deposits. Conversely, faults in hydrocarbon basins commonly act as barriers to fluid flow, either by virtue of their own low permeability, or by offsetting stratigraphy to create a juxtaposition-type seal. Understanding the factors that control the permeability evolution of faults is clearly of great importance to the mineral and hydrocarbon industries. Here we focus on the relationship between fault permeability and porosity.

Triaxial tests on porous sandstones demonstrate a transition from localised brittle faulting to distributed cataclastic flow with increasing effective stress (Wong et al. 1997). The brittle faulting regime is marked by shear-induced dilation, while cataclastic flow is characterised by shear-enhanced compaction triggering a drastic decrease in permeability. Brittle faulting involves little or no change in permeability in sandstones with porosity $>$15%, whereas low porosity rocks undergo permeability enhancement in the brittle regime (Zhu & Wong 1997). The transition from brittle faulting to cataclastic flow is dependent on the ratio P/P*, where P is the mean effective stress and P* is the grain crushing pressure. P* increases with decreasing porosity, which in turn is governed by factors such as grain size, sorting, mineralogy, temperature gradient and burial history. It can be shown that P/P* first increases then decreases with increasing depth, assuming a typical porosity-depth curve with lithostatic stress and hydrostatic fluid pressure (Fisher et al. 2003). This variation in P/P* may result in a switch from brittle faulting to cataclastic flow at a shallow depth, returning to brittle faulting at an intermediate depth (the “ductile to brittle transition” or DBT). Permeability enhance-

ment is only possible below the DBT, and then only if the porosity is less than 15%. The exact depth of the DBT depends on the distribution of porosity, stress and fluid pressure with depth.

We use a numerical model to simulate faulting in a sedimentary basin, with permeability evolution coupled to volumetric strain in accordance with the experimental observations outlined above. The model is based on the Cam Clay constitutive behaviour (Roscoe & Burland 1968), which is derived from critical state soil mechanics. The failure envelope forms an asymmetric ellipse on a plot of Q (differential stress) versus P, with the size of the ellipse being determined by the magnitude of P*, which itself is a function of porosity. The peak of the ellipse occurs at P = Pc, such that failure at $P < Pc$ results in dilatant brittle faulting characterised by strain softening and localisation, while $P > Pc$ represents distributed cataclastic failure and strain hardening. The model is parameterised using data from triaxial and hydrostatic tests on porous sandstones.

Preliminary results demonstrate the transition from distributed shear-enhanced compaction to localised dilatant faulting at a depth of $\sim$4km. Dilatant brittle failure may occur at shallower depths in extensional and/or overpressured environments, or in sedimentary units where the porosity is abnormally low at shallow depths. The latter may arise in carbonates, which typically attain low porosity due to cementation at an early stage in their burial history.

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