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Juxtaposition of different fault rocks into fault cores in sandstone-dominated formations

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We analyze normal faults in porous quartz sandstones at two sites to characterize the juxtaposition of three well-known processes along faults: cataclasis, brecciation and smearing.

At the first study site (Jurassic sandstone in Utah, USA), deformation structures formed during a single tectonic episode, displacing sandstones including 10-60 cm thick layers of silt and clay from 2 to 6 m. We observe that cataclastic deformation takes place and thickens along the sandstone/sandstone juxtaposition producing clusters of deformation bands up to tens of centimeters in thickness. With further displacement, the cluster is shifted against the developing silt/clay smear that provides reduced strength. A displacement of 2 meters is sufficient to create a major slip-surface along the clusters of deformation bands. The presence of thin layers of silt/clay therefore induces a fault core made of two adjacent types of fault rocks, namely cataclastic deformation and smear.

At the second study site (Permian sandstone in Scotland, UK), two overprinting episodes of faulting occurred within an evolving sandstone lithology. The studied fault is of seismic scale and accommodates a total displacement of 20 to 50 m. Structural analysis based on macroscopic and microscopic observations allows showing a first stage of cataclastic deformation occurring in unlithified sandstone. A second subsequent stage of faulting corresponds to brecciation formed in hardened material (cemented sandstone and cataclastic structure). The breccia currently comprises over 40% of oxides in its composition of meteoric income. In this case, the diagenetic evolution of the sandstone permitted the juxtaposition of these two types of fault rocks.

The process of cataclasis causes a porosity reduction of 32 to >90% of the initial porosity and a permeability reduction of 2 to 5 orders of magnitude compared to the host rock. Silts and clays do not undergo significant porosity and permeability reduction through smearing but have respective porosity as low as 18% and 3%, and permeability as low as 100 mD and 0.00000001 mD, respectively. The huge amount of oxides deposit in the breccia evidences the dilatant behavior and large permeability of this fault rock.

In conclusion, our study allows showing that sub-seismic displacement (<20 m) are sufficient to induce continued low-permeability structures through the juxtaposition of clusters and smear. These structures are likely to act as barriers for fluid flow since clusters of cataclastic deformation bands can form linked-segmented fault zones of several kilometers in length. We also show that such structures can evolve into seismic-scale faults and interact with diagenetic processes during the burial history. Host and fault rocks hardening due to cementation allow changing the deformation mechanisms and drastically increase along fault core permeability.