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Processes, properties, and microstructures in faults active at retrograde conditions

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Faults that are active at retrograde conditions tend to contain metastable fault rock assemblages that are prone to undergo fluid-consuming reactions. These reactions typically lead to growth of minerals that are viscously and frictionally weaker than the reactants. This is illustrated in the well-studied Outer Hebrides Fault Zone (OHFZ) of Scotland, and we add observations from the Kuckaus Mylonite Zone (KMZ), Namibia. In both locations, deformation is localised in anastomosing networks of phyllosilicates that developed during deformation of amphibolite and/or granulite assemblages at greenschist facies conditions. Microstructures of these phyllonites show generally well aligned phyllosilicates wrapping around fractured feldspars and quartz with features indicating dislocation creep.

In the KMZ, further localization occurred in ultramylonites within the mylonite zone. These are characterised by a similar phyllosilicate proportion to surrounding mylonites, but lack interconnected phyllosilicate networks. Instead, they contain a very fine-grained assemblage of quartz, feldspar, and phyllosilicate, where both quartz and feldspar lack a CPO. We interpret this assemblage as having deformed through grain-size sensitive creep, at lower shear stress than the surrounding mylonite. It is possible that the ultramylonites developed by dismembering an earlier interconnected weak phase microstructure with increasing finite strain, as has been suggested experimentally by Cross and Skemer (2017).

Whereas these exhumed fault zones deformed at greenschist facies conditions, continued activity would exhume similar fault rocks to shallower depth. We explored frictional properties and microstructure of greenschist facies fault rock at low temperature conditions by deforming chlorite-amphibole-epidote assemblages in single-direct shear at room temperature and 10 MPa normal stress under fluid saturated conditions. As inferred at greater depth, presence of chlorite weakens and promotes aseismic creep along these experimental faults. Presence of chlorite also correlates with the development of striations on fault surfaces. Lack of chlorite, on the other hand, leads to velocity-weakening behaviour and, in epidotite, a fault surface containing very fine grains that do not develop when ≥ 50 % chlorite is present. We suggest that chlorite supresses wear at contact asperities between stronger minerals, and therefore also supresses velocity-weakening behaviour.

Overall, we see that growth of retrograde phyllosilicates lead to profound weakening, strain localisation, and frictional stabilisation of major shear zones, from greenschist facies to near-surface conditions. These processes and properties are, however, reliant on external fluids to allow hydration reactions in otherwise relatively dry host rocks. From scattered syn-deformational quartz veins, in the KMZ, such fluids appear to be of surface origin, whereas in the OHFZ, fluids were likely of a deeper, metamorphic or magmatic origin. Ready incorporation of such fluids into retrograde minerals would prevent substantial or widespread fluid overpressures from developing. These fluid sources are similar to present-day inferred fluid regimes in the Alpine and San Andreas Faults, respectively. We speculate that the variable slip behaviour seen on active retrograde faults relate to their degree of retrogression, and the development of time and strain-dependent microstructures with specific strengths and behaviours.