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The role of pre-existing fracture networks and cataclasis in the development of weak faults: a review

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Recent field-based research along major reactivated faults has focused on the importance of foliated, fine-grained phyllosilicate-rich fault rocks, including *phyllonite*, *foliated cataclasite* and *foliated gouge*, formed close to the main load-bearing region of the crust at the frictional-viscous transition (i.e. 5-15km depths). The textural sequences preserved in these rocks are similar to those developed during analogue deformation experiments on fine-grained 'fault rocks' that predict 'frictional-viscous' creep at sub-Byerlee friction co-efficients (μ <0.4) leading to profound long-term weakening.

Using field, microstructural and geochemical observations from the Median Tectonic Line (MTL), Japan, as a primary example, we discuss the sequential development of foliated, phyllosilicate-rich fault rocks and highlight the fundamental influence of pre-existing brittle fracturing in controlling the network architecture, fault zone evolution and mechanical behaviour. Typically, initial brittle fracture and cataclasis occur leading to the development of a system of cm- to sub-mm-spaced, fault-zone parallel fractures. As displacements accumulate, fracture systems coalesce to form interconnected zones of ultracataclasite. Fluid influx at the onset of grain-scale brittle deformation leads to precipitation of fibrous phyllosilicates such as chlorite within the ultracataclasites, ultimately leading to the development of an interconnected network of foliated, phyllosilicate-rich cataclasites and gouges in the highly deformed, shallower core regions of the fault zone (5-10km depths, e.g. Anko and Tsukide sections, MTL). At deeper levels (10-15km, e.g. Miyamae section, MTL), the phyllosilicate precipitation and retrogression is more pervasive leading to the development of phyllonite belts on cm- to tens-of-metre scales. The brittle reduction of grain-size and ingress of a chemically active fluid phase simultaneously promotes reaction softening and diffusive mass transfer in the foliated cataclasite-phyllonite networks, that are inferred to facilitate ‘frictional-viscous’ flow. Associated weakening is indicated in the field by the preferential localisation of later displacements within the foliated fault rock networks. In large structures, especially strike-slip faults, the pre-existing brittle faults allow the rapid development of a network of highly interconnected, weak foliated fault rocks. This leads to a shallowing of the frictional-viscous transition in the region of the fault zone and transmits the effects of grain-scale weakening mechanisms up to crustal scales.

Whole-rock major and trace element analyses show that the foliated fault core rocks display geochemical signatures that appear much less altered relative to the protoliths compared to those in the enveloping cataclastic damage zone. This seemingly paradoxical relationship is tentatively linked to the development of a sealed fault core with high foliation-parallel permeabilities that link to the protolith fluid reservoir at shallower crustal depths. Sealing is facilitated by the development of the phyllosilicate foliation and a protracted sequence of carbonate mineralisation and cementation. These events also suggest episodic periods of fluid overpressuring which may further facilitate fault zone weakening on shorter timescales.