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Mechanical and lithological controls on the development of heterogeneous fault zones: an example from the southern Dead Sea Fault System, Israel

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The mechanical weakening processes involved in the development of major crustal fault systems have been widely documented, and it is recognised that clay-bearing fault rocks frequently have a significant influence on fault strength and slip behaviour in the upper crust. It is less well-understood how mechanical processes, such as cataclasis and the mechanical entrainment of fault rock materials along fault zones (e.g. “smearing”), interact with chemical processes, such as clay mineral transformations and phyllonitisation during fault rock development. These processes can combine to form fault zones that may be both lithologically and mechanically heterogeneous, and which may also evolve over time, changing the nature of observed heterogeneities.

We present here data from exhumed sections of the southern Dead Sea Fault System, Israel, an active continental transform fault that has accumulated 105 km of sinistral displacement since the mid-Miocene. These faults are estimated to have been active at shallow depths (<5 km, but potentially significantly less. The so-called “fault cores” of these sections are highly heterogeneous and are comprised of material formed by a variety of processes: fault gouges formed by cataclasis; coarser-grained, variably crushed crystalline basement rocks; mechanically entrained highly mobile units, derived from shale in adjacent cover sequence wall rocks; and growth of authegenic mineral phases through alteration and pressure solution. Through operation of grain-size reduction and diffusive mass transfer processes, we see a bulk change from fault rocks dominated by relatively strong phases displaying no obvious fabric, such as feldspars and calcite, through to foliated phyllosilicate-rich (illite, chlorite, smectite) fault rocks which likely have much lower frictional strengths. Mechanically entrained shale that has not undergone significant brittle deformation can also efficiently introduce large volumes of relatively weak material into fault zone cores. All these phyllosilicate-rich gouges contain microfolds on the centimetre to micron-scales, and preserve evidence of “ductile” deformation at shallow depth and low temperature conditions.

We demonstrate here how the heterogeneous nature of mechanically complex fault zones is influenced not only by the initial mineralogy of protolith rocks, but also by syn-tectonic processes, leading to the evolution of fault rock mineralogy with time. The development of layers of aligned phyllosilicate minerals have the potential to significantly alter the physical properties and mechanical strength of a fault zone, even if they are not present in large volumes (perhaps as little as 10-20%). The precipitation and/or entrainment of weak mineral phases may account for the evidence of both aseismic creep (microfolding) and potential seismogenic slip (rock pulverisation) within these fault zones, recording different stages in their evolution.