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What major faults look like, and why this matters for lithospheric dynamics

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Earthquakes involve seconds to minutes of frictional sliding on a discontinuity, likely of sub-cm thickness, within a damage zone. Earthquakes are separated by an interseismic period of hundreds to thousands of years, during which a number of healing and weakening processes occur within the fault zone. The next earthquake occurs as shear stress exceeds frictional resistance, on the same or a different discontinuity as the previous event, embedded within the fault damage zone. After incremental damage and healing in multiple earthquake cycles, the fault zone rock assemblage evolves to a structure and composition distinctly different from the host rock(s). This presentation presents field geology evidence from a range of settings, to discuss the interplay between the earthquake cycle, long-term deformation, and lithospheric rheology.

Classic fault zone models are based on continental transforms, which generally form discrete faults in the upper crust, and wide, anastomosing shear zones in the lower crust. In oceanic crust, transforms are considered frictionally weak, and appear to exploit dyke margins and joint surfaces, but also locally cross-cut these structures in anastomosing networks. In the oceanic lower crust and upper mantle, serpentinisation significantly alters fault structure.

In old continental crust, previous deformation events leave a heterogeneous geology affecting active faulting. For example, the amagmatic, southern East African Rift has long been thought to exploit weak Proterozoic ’mobile belts’. However, detailed look at the Bilila-Mtakataka border fault in Malawi indicates that this fault locally exploits weak foliation in existing deformed zones, but also locally forms a new set of anastomosing fault surfaces cross-cutting existing weak foliation. In exhumed lower crust, the Antarctic Maud Belt provides an example of multiple phases of plastic deformation, where the second event is only visible in localised shear zones, likely inherited from the first event.

The subduction thrust interface provides an example of fault evolution in underthrust sediments as they deform and dewater. At shallow levels, distributed shear leads to development of scaly cleavage, which in places provides weak, clay surfaces on which earthquakes can propagate to the sea floor. With further deformation, a melange is progressively developed, with increasingly dismembered, sheared lenses of higher viscosity sedimentary rock and slivers of oceanic crust, in a low viscosity, cleaved matrix.

The range of examples presented here illustrate how long-term deformation results in weak structures that likely control future deformation. Yet, the rheology of these structures is modulated by strength fluctuations during the earthquake cycle, illustrated by common evidence of episodic fault healing. The take home message from these field studies of fault zones is therefore the heterogeneity of the Earth’s crust, the importance of long-term weak zones as a first order control on crustal deformation, and short-term strength fluctuations within these zones as a consequence of, and reason for, the earthquake cycle.