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Does strain progressively localize in small-scale ductile shear zones?

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Localization of ductile shear strain on zones that are narrow relative to their length is a characteristic feature of deformation in the middle and lower crust. Such ductile shear zones can have widths varying from sub-millimetre to many kilometres but direct field observation and accurate measurement is effectively limited to widths on the order of 1mm to 1m and offsets of <10m. Such shear zones are referred to here as “small-scale ductile shear zones” and are the structures described, for example, in the classic defining study of Ramsay and Graham (1970). Even for this scale limitation, systematic detailed geometric characterization and measurement are only possible with rather exceptional field examples, as is best provided by intrusive rocks exposed on polished glacial pavements or in desert regions, where the observed surface is sufficiently large and nearly planar, and details are not obscured by weathering or vegetation. We now have a very large number of observations collected over decades on small-scale ductile shear zones from both the relatively “wet” middle crust (Neves area, Eastern Alps, Italy; Adamello batholith, Southern Alps, Italy; Mono Pass Intrusive Suite, USA) and the relatively “dry” lower crust (Musgrave Ranges, Central Australia) (Pennacchioni and Mancktelow, 2018, and references therein). These observations establish that small-scale ductile shear zones localize exclusively on precursor, planar/tabular rheological heterogeneities, either within weaker layers (e.g. more biotite-rich lamprophyres) or at the boundaries to stronger layers (e.g. aplites). Fractures also represent such elongate near-planar heterogeneities, weakened in the wet middle crust by fluid-rock interaction and in the dry lower by grain-size reduction and by pseudotachylyte formation. Marker layers crosscutting sheared weaker dykes demonstrate that strain within these weaker zones is homogeneous without any tendency for further narrowing or additional localization within the high strain zone. The only exception is occasional higher shear strain at the rims, but this may reflect an initial rheological difference due to finer grained chilled margins. The geometry of shear zones developed on fractures is fully controlled by the initial fracture/damage zone geometry and, for the wet middle crust, by the pattern of fluid-rock interaction during the precursor brittle history. In this case, shear zones subsequently neither progressively localize nor widen. Evidence for this is given by (1) the lack of correlation between shear zone thickness and accumulated displacement; and (2) the similar thickness of shear zones and locally unexploited alteration haloes surrounding fracture precursors.

References:

Ramsay, J.G. and Graham, R.H., 1970. Strain variation in shear belts. Can. J. Earth Sci. 7, 786–813.
Pennacchioni, G. and Mancktelow, N.S., 2018. Small-scale ductile shear zones: Neither extending, nor thickening, nor narrowing. Earth-Sci. Rev. 184, 1-12.