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Effect of length-scale on localization of shear zones along precursor fractures and layers during deformation of middle to lower crustal rocks

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Deformation of high grade rocks at middle to lower crustal levels involves both distributed and more highly localized ductile strain, with localized shear zones developing on elongate near-planar rheological precursors. These planar heterogeneities may be compositional layers (e.g. dykes) or pre-existing or newly developed fractures, with or without pseudotachylyte. Usual rheological models for viscous rock deformation are scale independent. The geometry of developing localized shear zones should therefore be scalable and depend only on the pre-existing geometry and imposed boundary conditions, as shown in numerical and analogue models. However, this is not what is observed in natural examples. Shear zones preferentially or exclusively develop on long fractures and dykes, typically on the scales of many (tens of) metres to (tens of) kilometres, whereas smaller-scale healed fractures, basic enclaves and short layers or inclusions are less prone to reactivation and locally may be largely ignored. Preferential localization of strain on these longer structures means that the intervening rock volumes remain low-strain domains, so that the smaller-scale planar heterogeneities are effectively shielded during progressive deformation. Any localized deformation of these intervening low-strain domains requires the formation of new elongate fractures acting as a necessary precursor for subsequent localization.

These field observations suggest that ductile shear zone localization is more effective with increasing length of the approximately planar precursor. Localized shear zones do not develop by propagation away from an initial small heterogeneity. Instead, their length is largely predetermined by the length of the controlling precursor structure and in-plane propagation of the tips appears to be very limited. Preferential shear reactivation of longer precursors introduces a length-scale dependence from the very initiation of localized “viscous” or “ductile” shear zones, qualitatively similar to that established for faults and earthquakes. However, because the amount of shear localized on a precursor of fixed length is affected by time (e.g. development of new fractures) and other factors (e.g. fluid availability, presence or absence of pseudotachylyte), the ratio of displacement to length can be very variable. In the field, this is reflected in the observation that similarly oriented and elongate precursors (dykes, compositional layers, fractures) can show strong variation in the amount of shear localization.