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An idealised model of strain localisation and the role in the development of continental scale transform faults

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High- or low-viscosity domains within the deforming continental lithosphere cause local variations in the strain distribution arising from plate boundary forces. Shear heating and grain-size reduction are potential strain-weakening mechanisms that cause amplification of initial viscosity variations. With continuing externally driven deformation these domains nucleate and promote the development of high strain regions in the surrounding mass. Further deformation can localise strain into narrow bands forming shear zones. Rheological variation within the lithosphere, coupled with a strain-weakening mechanism, is thus a sufficient requirement for shear-zone initiation.

Here we show by numerical experiment how, in plane-stress models representing lithospheric deformation at the regional scale, the strain localises around a weak region in an environment that would otherwise undergo homogeneous shear. Localised regions of high strain appear either side of a weak inclusion and extend parallel to the shear direction, diminishing in intensity with the distance of the inclusion. We use a simplified rheological law that incorporates strain-weakening based on damage induced at a rate proportional to the work done on the deforming medium and repaired at a rate proportional to the current local damage parameter. The latter may represent recovery by cooling or grain-size growth. We measure the development of the high-strain region with time and distance from the weak inclusion, subject to a constant regional strain-rate set by external conditions. Within the high-strain zone strain-rates initially increase exponentially and an increase in the damage parameter increases this period of exponential growth. Strain-rates then increase at a super-exponential rate that may be approximated by a power-law that is characteristic of non-linear instability mechanisms. This power-law growth is characterised by a rate of localisation that results in the shear zone collapsing to a plane of (ideally) zero thickness within a finite time that depends on the initial viscosity perturbation and the parameters that control the rate of strain-localisation.

We discuss the regional characteristics of two major continental strike-slip faults, the Altyn Tagh and North Anatolian Faults, in the light of these shear zone development models. The initiation and ongoing deformation of these fault zones are attributed to externally imposed continental deformation that has been sustained for a period on the order of 10 Myr or more. If interpreted as a consequence of crustal-scale shear weakening, the width of the observed shear zone may provide some constraint on the rates of weakening and recovery. The observations are consistent with a strain-weakening rheological law, which may represent shear heating or grain-size reduction. Although the inclusion of a damage-rate repair mechanism reduces the rate at which strain localisation occurs, the limit of ideal localisation is still achieved.