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The Structure and Rheology of Plate-Boundary Scale Shear Zones below the Brittle-Ductile Transition

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A framework now exists for predicting, at any given depth, the cumulative width, flow stress, and strain-rate for ductile shear zones comprising a plate boundary, given the relative plate velocity across the boundary. The flow stress in the shear zone is constrained by the requirement that the rock in which the shear zone develops has to deform sufficiently to cause it to weaken and localize strain. The strain-rate is controlled by the stress and by the rheology of the weakened material in the shear zone. The width of the shear zone is a function of the relative velocity and the strain rate.

The main challenges are determining the ductile yield strength of the rock cut by the shear zone, and the rheology of the material in the shear zone. Long-term yield strengths of crystalline rocks can be approximated using experimentally determined flow laws for the minerals that make them up, together with appropriate mixing models. The rheology of shear zones is controlled by a wide variety of processes, not all of which are well understood. These include phase changes and metamorphic reactions, addition of water, development of shape and crystallographic preferred orientations, grain-size reduction, and phase mixing. In polyphase materials, the degree to which weak components form interconnected networks strongly affects the bulk rheology. Thermal effects associated with crustal thinning or thickening, advection of heat due to the dip-slip component of motion, magmatic heat transport, and shear heating will also affect the rheology. Preliminary analysis suggests that the width of plate-boundary scale shear zones is likely to vary significantly with depth: they may be quite narrow (1km or less) near the brittle-ductile transition, in dry feldspar-dominated lower crust, and in the uppermost mantle below the Moho; but may be 10 km wide or more in the middle crust, and tens of km wide in the deeper part of the mantle lithosphere.