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Rheological structure of the lithosphere in plate boundary strike-slip fault zones

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How well constrained is the rheological structure of the lithosphere in plate boundary strike-slip fault systems? Further, how do lithospheric layers, with rheologically distinct behaviors, interact within the strike-slip fault zones? To address these questions, we present rheological observations from the mantle sections of two lithospheric-scale, strike-slip fault zones. Xenoliths from $\sim$40 km depth (970–1100 °C) beneath the San Andreas fault system (SAF) provide critical constraints on the mechanical stratification of the lithosphere in this continental transform fault. Samples from the Bogota Peninsula shear zone (BPSZ, New Caledonia), which is an exhumed oceanic transform fault, provide insights on lateral variations in mantle strength and viscosity across the fault zone at a depth corresponding to deformation temperatures of $\sim$900 °C.

Olivine recrystallized grain size piezometry suggests that the shear stress in the SAF upper mantle is 5–9 MPa and in the BPSZ is 4–10 MPa. Thus, the mantle strength in both fault zones is comparable to the crustal strength ($\sim$10 MPa) of seismogenic strike-slip faults in the SAF system. Across the BPSZ, shear stress increases from 4 MPa in the surrounding rocks to 10 MPa in the mylonites, which comprise the core of the shear zone. Further, the BPSZ is characterized by at least one order of magnitude difference in the viscosity between the mylonites (10^{18} Pa·s) and the surrounding rocks (10^{19} Pa·s). Mantle viscosity in both the BPSZ mylonites and the SAF ($7.0 \cdot 10^{18}$–$3.1 \cdot 10^{20}$ Pa·s) is relatively low.

To explain our observations from these two strike-slip fault zones, we propose the "lithospheric feedback" model in which the upper crust and lithospheric mantle act together as an integrated system. Mantle flow controls displacement and the upper crust controls the stress magnitude in the system. Our stress data combined with data that are now available for the middle and lower crustal sections of other transcurrent fault systems support the prediction for constant shear strength ($\sim$10 MPa) throughout the lithosphere; the stress magnitude is controlled by the shear strength of the upper crustal faults. Fault rupture in the upper crust induces displacement rate loading of the upper mantle, which in turn, causes strain localization in the mantle shear zone beneath the strike-slip fault. Such forced localization leads to higher stresses and strain rates in the shear zone compared to the surrounding rocks. Low mantle viscosity within the shear zone is critical for facilitating mantle flow, which induces widespread crustal deformation and displacement loading. The lithospheric feedback model suggests that strike-slip fault zones are not mechanically stratified in terms of shear stress, and that it is the time-dependent interaction of the different lithospheric layers—rather than their relative strengths—that governs the rheological behavior of the plate boundary, strike-slip fault zones.