Imposed strain localization in the mantle section of an oceanic transform zone revealed by microstructural and stress variations

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Mantle earthquakes that occur deeper than the 600 °C isotherm in oceanic transform faults indicate seismic rupturing at conditions where viscous deformation (bulk ductile behavior) is dominant. However, direct geological evidence of earthquake-related deformation at ambient upper mantle conditions is rare, impeding our understanding of earthquake dynamics in plate-boundary fault systems. The Bogota Peninsula Shear Zone (BPSZ), New Caledonia, is an ancient oceanic transform fault exhumed from upper mantle depths. Ductile structures in the BPSZ formed at temperatures > 800 °C and microstructures indicate that differential stress varies spatially and temporally. Spatial variation is observed as an increase in differential stress with strain toward localized zones of high strain; stress increases from 6–14 MPa in coarse grained tectonites to 11–22 MPa within 1–2 km wide mylonite zones. Temporal stress variation is observed by the formation of micro-deformation zones that seem to have brittle precursors, are filled with fine-grained recrystallized olivine grains and crosscut the background fabrics in the harzburgites that host them. The micro-deformation zones are not restricted to the mylonite zones, but rather are located throughout the BPSZ, having affected the protomylonites and the coarse grained tectonites. The micro-deformation zones record stresses of 22–81 MPa that are 2–6 times higher than the background, steady-state stresses in the surrounding mantle rocks. We interpret the observed spatial and temporal variations in microstructures and stresses in the upper mantle to demonstrate the influence of seismic events in the upper part of the oceanic transform fault system. We attribute the increase in stress with strain to be the result of imposed localization induced by downward propagation of the seismic rupture into the underlying mantle. The micro-deformation zones could result from brittle fractures caused by earthquake-related deformation in the mantle section of the transform fault, which are in turn overprinted by ductile deformation.
Synthesizing the spatial and temporal variations in stresses and microstructures in the Bogota Peninsula Shear Zone we propose a conceptual model where brittle fracturing and shearing take place during coseismic rupture at increased stress, ductile flow at decaying stress is concentrated in the micro-deformation zones during postseismic relaxation, and uniformly distributed creep at low stress occurs in the host-rocks of the micro-deformation zones during interseismic deformation. The critical result from the studied paleotransform zone is that the fine-grained micro-deformation zones and the mylonites do not represent weak zones. Instead, they form by dislocation creep at transient high-stress deformation during the seismic cycle. The spatial distribution of the micro-deformation zones also suggests that repeated stress cycles in oceanic transform faults may not localize strain in pre-existing shear zones but disperse strain across the structure.