Dynamic earthquake rupture preserved in a creeping serpentinite shear zone

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The mechanisms that allow stable creeping shear zones to become transiently unstable and destructive are poorly understood, yet critical for an improved understanding of seismic hazard. Recent laboratory experiments on serpentinite, a dominant rock type along the slab-mantle interface in subduction zones, suggest that extreme dynamic weakening at earthquake slip rates is accompanied by amorphisation, dehydration and possible melting, processes that may allow for efficient rupture propagation in serpentinite shear zones. However, hypotheses arising from laboratory experiments and numerical modelling remain untested in nature because direct evidence for earthquake rupture in serpentinite shear zones has not previously been recognized. Here, we document the preservation of high-temperature reaction products that formed by coseismic amorphisation and dehydration of serpentinite, and conclude that these products represent a signature of earthquake rupture in a plate-boundary-scale serpentinite shear zone. Widespread fibrous mineral growth, pervasively developed foliation and dissolution features indicate that deformation in the bulk of the shear zone occurred by slow pressure-solution mediated creep. The main shear zone fabrics are cut by polished magnetite-coated fault surfaces <300 μm thick containing small inclusions of serpentinite. Within the inclusions, Transmission Electron Microscope (TEM) observations show the progressive formation of amorphous material and high-temperature dehydration products. The highest-temperature products at distances of <50 μm from the fault surfaces are aggregates of nanocrystalline olivine and enstatite, indicating peak coseismic temperatures of c. 925 ±130°C. Finite element modelling suggests that frictional heating during earthquakes of magnitude M_w 2-2.7 can satisfy the petrological constraints on the coseismic temperature profile. Our results demonstrate that creeping shear zones in serpentinite do not represent barriers to earthquake rupture, but can become transiently unstable. The structure of serpentinite shear zones observed in the field suggests that earthquake nucleation may occur within competent blocks embedded in creeping segments, or along foliation surfaces and shear bands that concentrate strong accessory minerals like magnetite.

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