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Dynamic earthquake rupture preserved in a creeping serpentinite shear zone

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Laboratory experiments on serpentinite suggest that extreme dynamic weakening at earthquake slip rates is accompanied by amorphisation, dehydration and possible melting. However, hypotheses arising from experiments remain untested in nature, because earthquake ruptures have not previously been recognised in serpentinite shear zones.

We document the progressive formation of high-temperature reaction products that formed by coseismic amorphisation and dehydration in a plate boundary-scale serpentinite shear zone. Magnetite-coated slip surfaces within the serpentinite mélange of the Livingstone Fault, New Zealand, contain microstructural and mineralogical evidence for coseismic dehydration and amorphisation of serpentinite due to frictional heating. Directly adjacent to the principle slip surface are encapsulated the highest-temperature products of serpentinite dehydration consisting of aggregates of nanocrystalline olivine and enstatite, indicating minimum peak coseismic temperatures of ca. $925 \pm 60\,^{\circ}$C. Further from the slip surface, nanocrystalline olivine co-exists with talc, grading into amorphous and poorly-crystalline material. Below the magnetite layer, no products of dehydration or amorphisation are identifiable. Finite element modelling suggests that frictional heating during earthquakes of magnitude 2.7–4 can satisfy the petrological constraints on the coseismic temperature profile, assuming that coseismic fluid storage capacity and permeability are increased by the development of reaction-enhanced porosity. Our results indicate that earthquake ruptures can propagate through serpentinite shear zones, and that the signatures of transient frictional heating can be preserved in the fault rock record.