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Mineral changes quantify frictional heating during a large low-friction landslide

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Data on thermal decomposition constrain events around the transition on 5 June 2009 from creep deformation (over many decades) with sporadic rockfalls, to catastrophic collapse of Jiweishan Mountain, China, which poured millions of tons of limestone rubble from a cliff top into the valley, causing 79 deaths. We quantified frictional resistance (μ, 0.1–0.2) and rapid frictional heating using thermogravimetry, mineral alteration close to the sliding surface, and high-speed rotary experiments. The differential thermogravimetry (DTG) trough temperature varied from 794 $\pm$ 4 [U+F0B0]C at the sliding interface to $\sim$720 [U+F0B0]C below 10 mm. We inferred that DTG trough changes reflected the substrate thermal history due to landslide frictional heating. X-ray diffraction (XRD) analysis showed products of thermal decomposition of talc (a major mineral in the shale) to magnesium metasilicate (formation temperature of $\sim$600 [U+F0B0]C) and enstatite (formation temperature of 800–905 [U+F0B0]C). The intensity of the enstatite XRD peak decreased with increasing depth below the sliding surface to disappear below 6.5 mm. Magnesium metasilicate appeared between 6.5 mm and 10.5 mm depth. We replicated the temperatures and mineral changes in high-speed rotary shear experiments. Heating above 800 [U+F0B0]C at the sliding surface was supported by temperature measurements and thermal decomposition of dolomite to magnesium and calcium oxides in the shallowest samples (which could not survive for 7 yr at our field site). We inferred that the slide surface was heated to at least 800 [U+F0B0]C by frictional sliding and that the temperature below 10.5 mm depth did not rise above 600 [U+F0B0]C. Evidence of dynamic localized recrystallization was found on both field and experimental sliding surfaces, which may be a further explanation for the ultra-low friction during the rapid sliding, besides the presence of a significant basal pore-gas pressure from CO_2 and steam.