Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35259

Boron-rich fluid and precipitated tourmaline control seismic slip on N-S normal faults in the Himalayan orogen

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A prominent set of N-S trending normal faults hosts most of the destructive earthquakes in the central Tibetan Plateau, including the 2025 M_w7.1 Dingri earthquake. The source physics of these earthquakes is unclear. However, fault mirrors provide important records of fault slip. We found a special type of fault mirror, tourmaline fault mirrors (TFMs), to be remarkably widespread in the N-S normal fault systems of the Himalayan orogen, these being intermittently yet repeatedly exposed for tens of kilometers along strike, suggesting that the TFMs likely hosted large earthquakes. Here, we report the first field to nanoscale study of these TFMs from the Everest area. Microstructural analyses show that a typical TFM consists of three distinct layers, from the slip surface to the gneiss host rock: a 30~80 nm-thick film of amorphous tourmaline, a net-textured layer (20~100 μm) containing tourmaline clasts in an amorphous tourmaline matrix, and a dynamically recrystallized layer of tourmaline grains (≤ 400 μm). The observed amorphous material, micropores, and embayed residual tourmaline grains, combined with Ti-in-Qtz thermometry implying T > 840 °C at the slip surface, suggest that the TFMs formed by frictional melting during seismic slip on tourmaline-filled veins. Combining unstable frictional slip data for tourmaline gouge at 200~300 ℃ with the coexistence of tourmaline cataclasites and TFMs, we propose that tourmaline veins play a key role in controlling seismic rupture on the N-S normal fault systems of the Himalayan orogen.



