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Very high temperature bedrock deformation due to rapid glacial slip

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It is a well-known phenomenon that moving glaciers produce striations in the underlying bedrock. Low-porosity rocks, like quartzitic sandstones, may display polished striations where the fine-grained wear product has been removed by the continuing movement of the glacier. In contrast, the glacial striations of a Neoproterozoic quartzitic sandstone pavement show a pronounced topography developed from fragments of the abraded quartzite, in which an internal microstructure indicating a very high deformation has been preserved.

The polished glacial striation is underlain by highly deformed zone up to 1 mm thick. The deformation gradient dies out rapidly downwards in this zone. The highly-deformed zone contains a mixture of fine-grained and strongly deformed coarse-grained crystal fragments. In the optical microscope, pronounced undulatory extinction occurs, with patchy grain segmentation into domains of slightly different optical orientations. Low-angle subgrain boundaries, detected by EBSD orientation mapping and grain segmentation, are associated with microcracks visible in cathodoluminescence images. In fine-grained parts of the highly deformed zone, transmission electron microscopy (TEM) analysis revealed a compact fine-grained (0.2-1μm) microstructure, with frequent 120˚ grain boundary triple junctions. The grains are free of dislocation and interstitial voids are rare. It seems unlikely that the observed microstructure, with its 120˚ grain boundary fabric, reflects overgrowth of former fine-grained quartz fragments produced by crushing (cataclastic fracturing) during continuous slow sliding of pebbles across the sandstone bedrock. The very slow cementation rates at temperatures around the freezing point cannot account for the preservation of the de-

formed material in situ. Instead, the microstructure points to an equilibrium formation at elevated temperatures, either by instantaneous solid-state recrystallization or by crystallization from a silica melt. Only rapid solidification processes are able to preserve the observed topography and internally highly deformed microstructure along the polished striations during ongoing movement of the glacier. Flash temperature calculations show that glacial sliding speeds of $\sim$0.1-0.3 m/s can induce short-term peak temperatures ($\sim$1500-2500˚C) sufficiently high to cause partial frictional welding of the highly deformed quartzitic bedrock beneath an ice-loaded clast. These findings support recent suggestions that glacially generated seismicity can be attributed to episodic rapid shifts (stick-slip motion) of substantial ice masses over the substrate (Ekström et al., 2003).

Ekström, G., Nettles, M., Abers, G.A., 2003. Glacial earthquakes. Science 302, 622-624.