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Dating of Snowball Earth Meltwater Events Using *In-Situ* Hematite U-Pb Geochronology

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Constraining the extent and dynamics of Neoproterozoic ice sheets is important for refining global climate models and quantifying the erosional effects of Snowball Earth. Although modelling typically predicts near-complete ice cover upon the continents during the Cryogenian Snowball Earth glaciations (720-635 Ma), known deposits from this time are limited to continental margins and shallow marine basins. The Tavakaiv (Tava) sandstone ridges and sand injectites, hosted by fractured, chemically weathered crystalline basement, represent a rare sediment record from the cratonic interior of North America (Fig 1A). This unit displays evidence of sediment fluidization, together with pervasive soft-sediment deformation structures indicative of a subglacial environment, wherein glacial loading, fluid overpressure, and repeated sand injection occurred during meltwater events. These features are found in several locations along Colorado's Front Range, including proximal to the Great Unconformity. At two locations, the sand injectites within basement crosscut and are cut by multiple generations of hematite-quartz veins, providing a means to constrain the timing of injection.

We couple detailed sample petrography with novel Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS; CU TRaIL lab) hematite U-Pb geochronology to constrain multiple sand injection events between ~690 and ~660 Ma (Fig 1B). U-Pb data from seven individual samples is repeatable across multiple sessions and calibrated using a primary hematite reference material (HFO hematite).

Intercept dates fall within the Sturtian glaciation upon Laurentia, which occupied an equatorial setting within Rodinia. We attribute early sand injection episodes to basal melting associated with rifting and hematite mineralization to geothermal fluids circulated upon faults. Later injections ca. 660 Ma coincided with Sturtian deglaciation, and likely record overpressured meltwater pulses (Fig 1C-D). The absence of glacial scouring features below the Sturtian Tava sandstone suggests limited glacial erosion and low ice sliding-velocities during Snowball Earth, consistent with modern continental interior ice sheets.

Fig. 1. (A) Geologic map of Western North America with the location of sample sites and cross section marked. (B) Photograph of a Tava dike (red-brown) and hematite-quartz veins, with corresponding Tera-Wasserburg diagram to the right. (C-D) Schematic relationship between glaciation, deglaciation, Tava injection and hematite veining.