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Igneous-Hydrothermal Insight into the Global Record of Glaciations Using Triple Oxygen Stable Isotopes

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The timings of ancient glaciations have traditionally been interpreted using surface sedimentary and chemical archives (moraines, tills, varves, etc). Here we employ isotopic signatures of altered igneous rocks, with particular emphasis on rocks that interacted with ultra-low-$\delta^{18}O$ glacial ice. Earlier work has identified the world's lowest $\delta^{18}O$ rocks (-28‰ SMOW) in Karelia, Russia, which coincides with two episodes of Paleoproterozoic glaciations, 2.23 and 2.39 Ga (Bindeman et al. 2014; Zakharov et al. 2019). These ultra-low-$\delta^{18}O$ signatures represent local subglacial meteoric hydrothermal systems driven by shallow dikes and intrusions, distributed across the ~500 km wide Archean Karelian craton, which was likely attached to Superia and Greenland during documented LIP eruptive episodes. As Karelia and Superia were located at low latitudes during the Paleoproterozoic (based on paleomagnetic evidence), isotopic signatures reaffirm that glaciations were global in nature and coincided with episodes 1 and 3 of the Huronian ice ages. The GCM climate modeling by Bindeman and Lee (2018) allows steep $\delta^{18}O$ gradients across continental ice sheets, reaching values as low as −45‰ at ~15°N/S, implying that glacial meteoric water signatures could occur at near-tropical latitudes under an equatorial water-belt hydrologic regime. The search for glacial signatures around other shallow igneous bodies emplaced during the Paleo and Neo Proterozoic continues with our collaborators. We are testing the hydrothermal alteration processes around modern and recent examples of igneous provinces, such as dikes interacting with the hydrosphere in Iceland, Antrarctica, and the well exposed 16 Ma Columbia River Basalt Province, where up to 30% of dikes, especially the feeder dikes that fed large volume surface flows, display depletion in $\delta^{18}O$ and $D'^{17}O$ as well as δ D. As triple oxygen isotopic investigation of hydrothermal process permits drawing trends in two dimensions, recognition of even minor $\delta^{18}O$ and $D'^{17}O$ shifts at low water-rock ratios allows recognition of glacial, submarine, or subaerial emplacement conditions. We thus use igneous petrology and hydrothermal processes as tools for paleoclimate. We are developing a machine learning and AI-compatible model to identify hydrothermal signatures in complex datasets, using training data acquired in our lab.