Oxygen and nitrogen under the ice: trace elements and $\delta^{15}N$ evidence for oxic weathering and oxygenated waters during the Snowball Earth Marinoan glaciation, Ghuab formation, Namibia

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We present the first nitrogen isotopic and trace element analyses from during a "Snowball Earth" glaciation, and suggest they indicate oxidative continental weathering and mildly oxygenated marine waters. Specifically, we measured three sections of the Ghaub formation, which is the Marinoan glacial unit in northern Namibia. The Marinoan is the second of two Cryogenian Snowball Earth glaciations.

In all sections, we analyzed $\delta^{15}N$ values and redox sensitive trace elements, including U, V, and Mo. All measured units are from a marginal marine environment [1]. Two sections are synglacial; one composed of detritial siliciclastics and on of detrital carbonate, both with a minor clay fraction. The third section was deposited during the terminal deglaciation, and is comformably overlain by the basal Ediacarab Keilberg cap dolostone.

Trace element data demonstrate two key observations. First, the presence of trace elements in a marine setting is consistent with delivery from the continents via oxic weathering. Active weathering occurred on the continents during Snowball Earth. Secondly, enrichments are consistent with mildly oxygenated subglacial ocean waters [2].

$\delta^{15}N$ values from both synglacial sections range from +1 to +3‰, consistent with small but persistent volumes of oxygenated water. Most dissolved N was NH_4^+ from N-fixing ($\delta^{15}N$=0‰), with small reservoirs of NO_3^-. Denitrification of NO_3^- enriched the oceanic N isotopes a few per mil. An increase in oxygenated water during the deglaciation was accompianed by increased NO_3^- and denitrification, causing $\delta^{15}N$ values to increase to near modern levels. Deglacial values are thus more enriched, between +3 to +5‰.

[1] Hoffman, Paul. 2011. Sedimentology 58 (1), 57–119.

[2] Algeo, T. J., Tribovillard, N., 2009. Chemical Geology 268 (3), 211–225.