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Triple-oxygen isotopes in granitic garnets record Earth's weathering conditions from the Neoarchean to the Phanerozoic

JUAN DAVID HERNÁNDEZ-MONTENEGRO[1,2], CLAIRE E BUCHOLZ[1], PROF. DANIEL E. IBARRA, PHD[3], CHRIS SPENCER[4], JUAN ANDRES DAHLQUIST[5], PABLO HORACIO ALASINO[6], CARLOS VILLASECA[7] AND OSCAR MAURICIO CASTELLANOS ALARCON[8]

[1]California Institute of Technology
[2]Rice University
[3]Brown University
[4]Queen's University
[5]Universidad Nacional de Córdoba
[6]CRILAR-CONICET
[7]Universidad Complutense de Madrid
[8]Universidad de Pamplona

Triple-oxygen isotopes in siliciclastic rocks are sensitive tracers of low-temperature water–rock interaction, yet direct constraints on weathering conditions from the sedimentary record remain temporally and spatially fragmented. Strongly peraluminous granites (SPGs) and migmatites, formed by partial melting of sedimentary protoliths, offer an alternative archive as they can integrate the isotopic composition of large volumes of sedimentary source material[1]. Here, we present triple-oxygen-isotope data for garnet hosted in SPGs, and to a lesser extent migmatites, from diverse global localities spanning the Mesozoic to the Neoarchean. We focus on garnet because of its low oxygen diffusivity and high closure temperature, which favor preservation of isotopic signatures inherited from its parental melt[2]. Phase-equilibrium modeling is used to quantify equilibrium fractionation between garnet and bulk sediment, reconstruct protolith compositions, and isolate the chemical weathering component of the triple-oxygen-isotope signature. These reconstructions are combined with mineral–water fractionation relationships to derive estimates of weathering temperature and corresponding meteoric water $\delta'^{18}O$ values[3].

Neoarchean and Paleoproterozoic samples formed before the Great Oxidation Event (GOE, 2.4–2.1 Ga) display a wide range of inferred weathering temperatures (~2–43 °C), suggesting variable surface conditions by at least ~2.7 Ga. Paleoproterozoic post-Huronian samples record lower, more restricted temperatures (~3–17 °C), consistent with cooler conditions following the decline of a methane-rich atmosphere after the GOE. Early Neoproterozoic migmatite leucosomes from the Northern Andes yield elevated temperatures (~14–41 °C), potentially reflecting greenhouse-dominated conditions during Rodinia assembly, though the limited spatial coverage of these samples precludes robust global extrapolation. Phanerozoic samples span ~2–27 °C, in agreement with independent paleoclimate proxies. Garnet $\delta'^{17}O$-$\delta'^{18}O$ data define a trend with slope $\theta \approx 0.5232$, distinct from high-temperature magmatic fractionation ($\theta \approx 0.528$) and consistent with inheritance from low-temperature surface processes.

These results demonstrate that sediment-derived granitic magmas can preserve information about ancient weathering environments over billion-year timescales. Integrating triple-oxygen-isotope geochemistry with phase-equilibrium modeling provides a quantitative framework for linking surface processes, sediment recycling, and crustal evolution, and for evaluating their roles in Earth's long-term climate evolution.

[1] Bucholz & Spencer (2019), J.Petrol. 60,1299–1348.
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[3] Bindeman et al. (2018), Nature 557, 545–548.