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High-Resolution 2D Impurity Mapping of Million-Year-Old Antarctic Ice by Cryo-LA-ICP-MS

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Polar ice cores preserve a continuous archive of Earth's ancient atmosphere, recording air temperature, accumulation rate, aerosol chemistry, dust flux, and sea level over the past 800,000 years. Antarctic Blue Ice Areas (BIAs) contain some of the oldest known ice, including ice up to ~6 million years (Ma) from the Allan Hills [1]. However, ice older than ~0.8 Ma is commonly stratigraphically disturbed and folded, complicating interpretation of glacial–interglacial signals due to thinning and deformation. Recent advances in cryogenic laser ablation inductively coupled plasma mass spectrometry (cryo-LA-ICP-MS) enable non-destructive, high-spatial-resolution imaging of impurity distributions in ice [2,3]. Here we present optimized line scans and two-dimensional raster maps of impurities in selected Antarctic ice cores.

Analyses were performed using a 193 nm excimer laser hosting a cryo-cell, coupled to an Agilent 8900 QQQ-ICP-MS equipped with a Dual Concentric Injector (DCI) for rapid washout. Washout times determined using full-width at 10% and 1% maximum criteria were ~80–90 ms and ~210–240 ms, respectively, permitting high-resolution imaging without signal smearing. A total acquisition time of 0.41–0.48 s yields ~19–25 µm along-track sampling (2–3 data points per beam width), providing sub-beam spatial fidelity in both stacked line scans and 2D raster images.

Element concentrations are reported in counts per second calibrated externally using NIST SRM 612. To improve matrix matching, HPS 6A and NIST 1643f aqueous standards were flash-frozen in micro-drilled mounts to produce homogeneously crystallized artificial ice standards. Preliminary results indicate uniform elemental distributions, suggesting that flash-frozen standards provide a promising approach for quantitative calibration of ice-core analyses.

We focus on five elements (Na, Mg, Al, Ca, and Sr) that can serve as paleoclimate proxies to distinguish marine- from continental impurity sources. Two-dimensional maps reveal micron-scale heterogeneity, grain-boundary enrichment, and impurity banding consistent with sea-salt aerosol input and continental dust deposition.

[1] Shackleton et al., 2025, *PNAS* 122, e2502681122.
[2] Bohleber et al., 2020, *J. Anal. At. Spectrom.* 35, 2204–2215.
[3] Hoffmann et al., 2023, *J. Anal. At. Spectrom.* 38, 1912–1926.