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Origin of the Subduction Component in North Atlantic Oceanic Basalts

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Earth's mantle is compositionally heterogeneous on multiple spatial scales, reflecting the long-term recycling of crustal materials by subduction and their redistribution. However, linking mantle heterogeneities and basalt geochemistry to specific plate tectonic processes has remained challenging. The North Atlantic provides a striking example: Mid-Atlantic Ridge (MAR) basalts erupted north of 22° N are enriched in volatiles (H_2O, CO_2) and fluid-mobile element ratios (e.g., Ba/Nd) relative to most of the global ridge system, indicating a pervasive subduction-derived mantle component with a sharp southern boundary.

We apply a recently developed tectono-thermodynamic framework that couples plate tectonic reconstructions with evolving physical and thermodynamic properties of subducting oceanic lithosphere. Our study compares two alternative plate kinematic models with time-dependent reconstructions of oceanic sediments, crust, and lithospheric mantle to quantify the storage, plate tectonic transport and release of water during subduction. Using the pyGPlates Python library, we track subducting plate segments and their associated water reservoirs through time. These kinematic histories are combined with thermodynamic modelling to simulate pressure–temperature-dependent dehydration reactions and estimate the depth and timing of water release into the mantle.

We reconstruct cumulative water accumulation in the upper mantle, focusing on the mantle wedge (~0–125 km depth), with deeper storage expected to follow similar spatial patterns. We compare two end-member scenarios in which major water accumulation begins at ~170 Ma and ~400 Ma. Subduction during the last 170 Myr cannot account for volatile enrichment north of 22° N, ruling out a dominant contribution from Farallon plate subduction. However, Late Paleozoic subduction associated with assembly of Pangea transported water farther east beneath present-day North Atlantic ridge segments, reflecting the more easterly position of North America at that time.

When referenced to modern ridge locations, the resulting Paleozoic water-enriched mantle beneath the MAR extends from near 22°N into the Arctic, consistent with observed elevated H_2O/Ce ratios. Because spreading in this region is geologically young, this subduction-derived mantle signature has not yet been erased by repeated melt extraction and mantle homogenization. In contrast, prolonged Mesozoic–Cenozoic spreading in the South Atlantic and Pacific has removed comparable subduction signatures, consistent with observed basalt geochemistry.