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Nitrogen Isotopes of Amino Acids in Meteorites and Fossils

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Nitrogen isotope ratios ($\delta^{15}N$) of amino acids constrain nitrogen sources and metabolic processes, enabling applications in ecology and organismal biology, such as establishing trophic position [1] and reconstruct feeding behavior in extant and extinct animals [2]. Applications to fossil materials, however, remain limited because proteins commonly targeted for such analyses, particularly collagen, degrade rapidly (<100 ka). Dental enamel is a rare exception, as it can preserve endogenous proteins over deep time, offering unique potential for dietary reconstruction. Yet the low protein content of enamel (~0.5–2 wt%) has historically precluded amino acid–specific nitrogen isotope analysis, because conventional gas chromatography–isotope ratio mass spectrometry (GC-IRMS) requires milligram-scale quantities of purified protein. A similar analytical challenge arises in cosmochemistry. Amino acid $\delta^{15}N$ values provide critical constraints on the origin and evolution of extraterrestrial organic matter [3,4], yet measurements remain scarce due to low compound abundances.

Here we present methodological advances based on GC-Orbitrap-based Fourier-transform mass spectrometry that overcome these limitations. Our approach enables isotopic measurements at natural abundance from sample sizes as small as ~1 ng. A recent study using similar methods reports N isotope data for amino acids in the Murchison meteorite and samples of the asteroid Bennu [5,6], with precisions of ~3–32‰. The method we present routinely reaches sub-per mil precisions, more appropriate for palaeobiological and ecological applications. We report the first amino acid $\delta^{15}N$ measurements of modern dental enamel, using GC-IRMS as a validation benchmark. These results establish a foundation for extending amino acid–specific nitrogen isotope analyses to fossil enamel, opening new opportunities to reconstruct diets and trophic ecology across deep time. More broadly, this framework enables high precision $\delta^{15}N$ measurements of nitrogen-bearing organic compounds in meteorites, returned space samples, and other abundance-limited materials.

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