Origin of Ti isotope heterogeneity in the protoplanetary disk

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Isotopic anomalies of nucleosynthetic origin in meteorites provide a record of the stellar sources that contributed material to the solar system's parental molecular cloud. These heterogeneities are commonly interpreted as reflecting inefficient thermal processing of presolar dust. Owing to its refractory nature, Ti is ideally suited to track the nature and extent of nucleosynthetic variability in early-formed solids. Here, we report high-precision Ti isotope measurements of various meteorites obtained by MC-ICPMS.

Except for enstatite chondrites and lunar meteorites, all bulk meteorites and meteoritic components display correlated anomalies in ^{50}Ti and ^{46}Ti, when using the ^{49}Ti/^{47}Ti ratio to internally correct for instrumental mass bias. Carbonaceous chondrites (CC) exhibit excesses in ^{50,46}Ti, while ordinary chondrites (OC), most achondrite meteorites and CC chondrules record deficits. Fine- and coarse-grained CAIs, and AOAs identically display the most extreme ^{50,46}Ti enrichments. Stepwise leaching of bulk CCs using acids of increasing strengths reveal ^{46}Ti-^{50}Ti excesses/deficits that resonate with previously published ^{54}Cr variations for the same meteorites.

Our results suggest that the carrier of the anomalous ^{46,50}Ti and, by extension, ^{54}Cr is a non-refractory presolar silicate that originated in AGB stars. This component is most enriched in the CAI-forming reservoir, but depleted in the accretion regions of differentiated planetesimals, OCs and the terrestrial planets. High-temperature experiments under vacuum conditions of CC matrices show that thermal processing at temperatures ~1000°C can result in the loss of the ^{46,50}Ti-^{54}Cr carrier by sublimation. This suggests that nucleosynthetic variability in solar system objects may not reflect primordial heterogeneity, but instead selective thermal processing of their precursor material in the protoplanetary disk.

'Clumped isotope' thermometery in foraminifera

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Accurate constraints on past ocean temperature and composition are critical for documenting climate change and resolving its causes. Most inorganic and organic geochemical paleothermometers are fundamentally underconstrained because they reflect seawater composition as well as temperature. In addition, some of the most frequently used thermometers — ^{18}O/^{16}O and Mg/Ca ratios in biogenic carbonate — deviate from inorganic calibrations and can exhibit species-specific temperature dependencies. These offsets or 'vital effects' are poorly understood and lend an unquantifiable source of uncertainty to reconstructions of past temperature. Here we report 'clumped isotope' [1] measurements of benthic and planktic foraminifera from sediment core-tops showing that the proportion of ^{13}C-^{18}O bonds in calcite and aragonite shells exhibits the same temperature dependence as inorganic calcite. The 'clumping' of heavy isotopes into bonds with each other is independent of the isotopic composition of the water in which the mineral precipitated, and thus avoids the ambiguity intrinsic to some other thermometers. These observations suggest the clumped isotope thermometer can yield accurate determinations of past seawater temperature, even when applied to the remains of extinct taxa. The lack of discernable 'vital effects' in foraminifera and other forms of biogenic calcite and aragonite [1-4] indicates that these organisms precipitate calcium carbonate in isotopic equilibrium with the dissolved inorganic carbon (DIC) pool from which they calcify. The lack of difference between calcite and aragonite may indicate that the 'clumping' of these heavy isotopes into bonds with each other reflects the thermodynamically-controlled exchange of stable isotopes amongst DIC species in water, rather than similar exchange equilibria within the solid precipitates [5].

[1] Eiler (2007) *EPSL* **262,** 309-327. [2] Ghosh *et al.* (2006) *Geochim. Cosmochim. Acta* **70,** 1439-1456. [3] Came *et al.* (2007) *Nature* **449,** 198-201. [4] Ghosh *et al.* (2007) *Geochim. Cosmochim. Acta* **71**, 2736-2744. [5] Schauble *et al.* (2006) *Geochim. Cosmochim. Acta* **70,** 1439-1456.