TITANIUM ISOTOPIC COMPOSITIONS OF REFRACTORY INCLUSIONS FROM SEVERAL CV3 AND CK3 CHONDRITES: IMPLICATIONS FOR NEBULAR HETEROGENEITY

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Introduction: Calcium-aluminum-rich inclusions (CAIs) in chondrites are the first solids formed in the early Solar System and preserve a record of the earliest processes and conditions in the solar nebula ([1] and references therein). CAIs show mass-independent anomalies in a variety of isotope systems compared to terrestrial standards, and these anomalies have been attributed largely to incomplete homogenization of distinct nucleosynthetic components in the nebular reservoirs sampled by these objects [2]. Titanium isotopic anomalies in CAIs have been studied previously by several workers (e.g., [3-13]), but most of this work has been focused on inclusions from the Allende CV3 meteorite. In considering more recent studies reporting high precision data, [12] reported homogeneous Ti isotope compositions in 4 CAIs (2 from Allende and 2 from Efremovka), while [14] observed small but resolvable heterogeneities in the Ti isotopic compositions of numerous Allende CAIs. We have begun an investigation that seeks to extend the sample set of CAIs for which high precision Ti isotope compositions are available to CAIs from a broader range of primitive chondritic meteorites. The goal of this work is to better constrain the degree of isotopic heterogeneity in the broader CAI-forming region in the early Solar System. We recently reported Ti isotope compositions for 6 CAIs from several CV3 and CK3 chondrites [15]. Here we report the Ti isotopic compositions of 6 more CAIs from additional distinct CV3 chondrites: ZT1 and ZT2 from Leoville (CV3), ZT3 from Northwest Africa (NWA) 6991 (CV3), ZT5 from NWA 7891 (CV3), and ZT7 and ZT8 from NWA 3118 (CV3).

Analytical Methods: All sample handling and chemical processing of these CAIs was conducted under clean laboratory conditions in the Isotope Cosmochemistry and Geochronology Laboratory (ICGL) at Arizona State University (ASU). Each CAI was carefully extracted from the meteorite slab using clean stainless steel dental tools. Extracted CAIs were digested in Parr bombs; a ~5% aliquot was reserved for elemental analyses and a fraction of each solution was then processed for the separation of Ti using ion chromatography methods adopted from [16]. Element abundances (including the rare earth elements) were measured with the iCAP-Q quadrupole ICPMS in the Keck Laboratory at ASU. Titanium isotopes were measured on the Neptune Multicollector Inductively Coupled Plasma Mass Spectrometer (MC-ICPMS) in the ICGL using methods described by [15]. Titanium isotope data are reported relative to the in-house SPEX Ti standard following internal normalization to ^{49}Ti/^{47}Ti (=0.749766; [5]) using an exponential fractionation law.

Results and Discussion: In the 6 CAIs analyzed here, the ε^{46}Ti values range from 1.21 ± 0.26 to 1.69 ± 0.27, and ε^{50}Ti values range from 8.88 ± 0.11 to 10.68 ± 0.22. These measured Ti values are generally consistent with those reported previously for CAIs [3-15] and the resolvable variation in Ti isotope compositions suggests significant isotopic heterogeneity in the broader CAI-forming region in the protoplanetary disk. We observe a correlation of ε^{46}Ti with ε^{50}Ti in the dozen CAIs analyzed by us thus far ([15]and this study) that is an extension of that seen in bulk meteorites and other Solar System objects [12]. Such a correlation is not expected given the different nucleosynthetic sources of ^{46}Ti and ^{50}Ti. As such, it likely represents the mixing of two distinct nebular reservoirs; this may be due to thermal processing of molecular cloud materials from which the solar nebula was formed, with selective destruction of different presolar components. The chondrite-normalized Lu/La ratio for the dozen CAIs analyzed by us thus far ranges from ~1 to ~110, representing both fractionated (Group II) and unfractionated REE patterns. While the largest ε^{50}Ti value in our sample set is indeed observed in a CAI exhibiting a Group II REE pattern, there is otherwise no clear correlation found between ε^{50}Ti anomalies and the REE patterns in these CAIs; this is consistent with the results reported by [14].

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