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Titanium isotopes and rare earth patterns in CAIs: evidence for thermal processing and gas-dust decoupling in the protoplanetary disk

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ABSTRACT

Titanium isotopic compositions (mass-dependent fractionation and isotopic anomalies) were measured in 46 calcium-, aluminum-rich inclusions (CAIs) from the Allende CV chondrite. After internal normalization to ^{49}Ti/^{47}Ti, we found that ε^{50}Ti values are somewhat variable among CAIs, and that ε^{46}Ti is highly correlated with ε^{50}Ti, with a best-fit slope of 0.162±0.030 (95% confidence interval). The linear correlation between ε^{46}Ti and ε^{50}Ti extends the same correlation seen among bulk solar objects (slope 0.184±0.007). This observation provides constraints on dynamic mixing of the solar disk and has implications for the nucleosynthetic origin of titanium isotopes, specifically on the possible contributions from various types of supernovae to the solar system. Titanium isotopic mass fractionation, expressed as δ'^{49}Ti, was measured by both sample-standard bracketing and double-spiking. Most CAIs are isotopically unfractionated, within a 95% confidence interval of normal, but a few are significantly fractionated and the range δ'^{49}Ti is from ~–4 to ~+4. Rare earth element patterns were measured in 37 of the CAIs. All CAIs with significant titanium mass fractionation effects have group II and related REE patterns, implying kinetically controlled volatility fractionation during the formation of CAIs with those REE patterns.

1. INTRODUCTION

Calcium-, aluminum-rich inclusions (CAIs) are the first solids known to have formed in the solar nebula (Dauphas and Chaussidon, 2011; Davis and McKeegan, 2014; and references therein) and they are the objects most likely to record the initial distribution of isotopes of diverse nucleosynthetic origins in the young solar system. Titanium is a highly refractory element that is present at concentrations of up to 2.5 wt% TiO_2 in CAIs (Simon and Grossman, 2004). Several studies in the 1980s revealed the presence of excesses and deficits in the abundance of the neutron-rich isotope ^{50}Ti in CAIs (Heydegger et al., 1979; Niederer et al., 1980; Niemeyer and Lugmair, 1981, 1984; Niederer et al., 1981, 1985; Ireland et al., 1985; Fahey et al., 1987a,b; Hinton et al., 1987, 1988; Ireland, 1988, 1990). These isotope anomalies can be used to probe disk heterogeneity in the CAI-forming region and can help us understand the origin of neutron-rich isotope anomalies in the transition element mass region (see Dauphas and Schauble, 2016, for an introduction to the topic of isotopic anomalies). Except for ^{54}Cr, for which the presolar carriers