CALCIUM ISOTOPIC ANOMALIES IN THE ALLENDE CAIS AND THE ANGRITE ANGRA DOS REIS.

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Introduction: : How and to what degree the mixing and homogenization processes took place in the solar nebula has always been of great interest. Isotopic studies of planetary materials (meteorites, lunar and terrestrial samples) have shown that most heavy isotopes (Mg and up) are homogeneous at tens of ppm level in bulk samples and individual refractory inclusions [1-5]. This suggests that the (inner) early Solar System was a well mixed isotope reservoir. However, exceptions can be found in certain neutron-rich isotopes, namely ^{48}Ca, ^{50}Ti, ^{54}Cr. The deviations of these isotope anomalies from terrestrial range from percent-level in rare inclusions, such as hibonite and FUN inclusions, to hundreds to thousands of ppm level in Ca-Al-rich Inclusions (CAIs). What led to and how to preserve such heterogeneity in the well-mixed inner Solar System remain a mistery.

To help understand the mixing history in the solar nebula, a coordinated study of these neutron-rich isotopes in the same inclusions is necessary. Earlier works on ^{48}Ca-^{50}Ti have shown that the sign of anomalies of the two isotopes are correlated in CAIs, although not a simple 1:1 correlation [6]. Recent studies also revealed a strong, but not simple, correlation between ^{50}Ti and ^{54}Cr in CAIs and bulk meteorite samples [2]. From this view, a correlation should also be found between ^{48}Ca and ^{54}Cr. However, such measurements have not been performed. In addition, analytical precisions of earlier ^{48}Ca measurements were relatively large compared to its variations. This might have obsecured any simple correlation with other neutron-rich isotopes, if present. Here we report new data on Ca isotopes in the Allende CAIs and an achondritic meteorite Angra dos Reis (ADOR) to readdress the correlation between ^{48}Ca and other neutron-rich nuclides.

Experimental Procedures: One type-A CAI (ALDC01) and four type-B CAIs (ALTL01, Big AL, Egg3 and Egg6) from the Allende meteorite and the angrite ADOR were prepared for this study. Meteoritic samples were dissolved in 1:1 warm concentrated HF/HNO_3 mixtures, and dissolved elements were sequentially eluted through three ion exchange columns (filled in TRU spec, AG1Wx8, and AG50Wx8 resins, respectively) to separate REEs, transition elements, and calcium. Each extracted calcium was loaded on a flat rhenium filament and delivered into our thermal ionization mass spectrometrer- Triton to measure its calcium isotopic composition. Based on repeated standard (NBS915a) measurements, the external analytical precisions (2σ) of ^{40}Ca/^{44}Ca, ^{43}Ca/^{44}Ca, ^{46}Ca/^{44}Ca and ^{48}Ca/^{44}Ca were 1.6ε, 0.4ε, 6.6ε and 0.8ε after normalizing to ^{42}Ca/^{44}Ca as reference ratio [7].

Table 1

Samples	ε ^{40}Ca/^{44}Ca	ε ^{43}Ca/^{44}Ca	ε ^{46}Ca/^{44}Ca	ε ^{48}Ca/^{44}Ca
ALDC01(4)*	0.4±0.8	0.3±0.2	0.4±3.3	1.2±0.4
ALTL01(4)*	1.7±0.8	0.3±0.2	0.9±3.3	5.0±0.4
Big AL(5)*	0.8±0.7	0.3±0.2	3.3±3.0	4.4±0.4
Egg3(5)*	0.4±0.7	0.3±0.2	1.4±3.0	3.2±0.4
Egg6(4)*	0.3±0.8	0.2±0.2	3.1±3.3	4.6±0.4
ADOR(3)*	-0.3±0.9	0±0.2	-0.8±3.8	-1.3±0.5

*:the number in bracket means total runs of analyzed samples.

Results and discussion: The results are shown in Table 1 and indicate that all meteoritic samples showed isotopic normal ratios on ^{40}Ca/^{44}Ca, ^{43}Ca/^{44}Ca, and ^{46}Ca/^{44}Ca within analytical errors, and resolvable anomalies on ^{48}Ca/^{44}Ca. The endemic ^{48}Ca anomalies in the Allende CAIs support that the refractory neutron rich isotopes could preserve their anomalies signal in carbonaceous chondrites and imply that they might have the same carrier dust. However, there is no simple linear correlation between ^{48}Ca and ^{50}Ti anomalies in CAIs, indicating that some unknown processes might have decoupled calcium and titanium during the CAI fomation.

A "negative" ^{48}Ca anomaly in the angrite ADOR is correlated with ^{50}Ti anomaly (-5.4±3.2ε, determined by our Ti LA-ICP-MS technique [8]), which supports negative ^{50}Ti anomalies in achondrites [2]. This implies that carbonaceous chondrites preserved positive ^{48}Ca, ^{50}Ti, and ^{54}Cr anomalies while achondrites peserved negative ones, and the Earth was "NORMAL". This radial heterogeneity was most likely derived from a heterogeneous distribution of presolar neutron rich carriers or from incomplete mixing of meteoritic parent bodies.

Several mechanisms have been proposed to explain the mixing and homogenization process in the early Solar System. Triggered collape of presolar dense cloud model [9] depends on shock waves and self-gravity of the molecular clouds to form the Solar System. On the other hand, the X-wind model [10] offers an effective location of bombardment by solar flares to make refractory inclusions which might preserve most of neutron rich presolar dust. Ejection of refractory inclusions by X-wind and falling back onto the solar disk could provide a possible explanation for not only the observed radial heterogeneity of ^{48}Ca, ^{50}Ti, and ^{54}Cr but volatility controlling of lack of anomalies on iron, nickel, and zinc as well.

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