OXYGEN ISOTOPE ZONING IN AN ALLENDE CAI, EGG-6. J. E. P. Matzel[1], J. I. Simon[2], I. D. Hutcheon[1], P. K. Weber[1], B. Jacobsen[1] and G. J. Wasserburg[3] [1]Lawrence Livermore National Lab, 7000 East Ave, Livermore, CA 94550, USA, matzel2@llnl.gov, [2]NASA Johnson Space Center, Houston, TX 77058, USA, [3]Lunatic Asylum, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA.

Introduction: Oxygen isotope compositions of primitive solar system materials can preserve a detailed record of the composition of the solar nebula gas from which they grew. Calcium-aluminum inclusions (CAIs) from the least equilibrated chondrites are uniformly ^{16}O-rich ($\Delta^{17}O \leq$ -20‰) indicating CAI formation in an ^{16}O-rich gaseous reservoir [1]. In contrast, CAIs from more altered chondrites (e.g., Allende) preserve a more complex history that includes partial isotopic exchange in an ^{16}O-poor reservoir [2]. This exchange resulted in large oxygen isotope heterogeneity within individual CAIs.

Recent work [3] demonstrated large and sytematic variations in oxygen isotope composition near the rim of a CAI. Data from the compact Type A Allende inclusion, A37, preserve a diffusion profile in the outer ~70 μm melilite mantle and show >25‰ variations in $\Delta^{17}O$ within the ~100 μm-thick Wark-Lovering rim. These variations suggest that CAIs formed from several oxygen reservoirs and likely reflect transport of A37 between distinct regions of the solar nebula or varying gas composition near the proto-Sun.

We measured the oxygen isotope composition of the Allende CAI, Egg-6, to determine if the oxygen isotope variation observed in A37 is preserved in other Allende CAIs. Egg-6 is a Type B1 inclusion comprising fassaite+anorthite+spinel in its core and a well-developed melilite mantle [4]. The outer ~40 μm forms a rim of Fe-rich spinel enclosing perovskite (Fig. 1). Both core and mantle are cut by grossular-bearing secondary veins that contain the Cl-rich mineral, wadalite. Matzel et al. [5] reported Cl-S isotope systematics from Egg-6 showing that wadalite formed and/or re-equilibrated with a Cl-rich fluid > 2 Ma after CAI formation.

Measurement Conditions: Oxygen isotope abundances were determined using the Lawrence Livermore National Laboratory *Cameca* NanoSIMS 50. An ~7 pA primary Cs^+ beam was rastered over 2×2 μm^2 areas. Negative secondary ions were acquired by simultaneously measuring $^{16}O^-$ on a Faraday cup and $^{17}O^-$, $^{18}O^-$, $^{12}C^{13}C^-$ (as a monitor for epoxy) and $^{30}Si^-$ on electron multipliers. The secondary ion intensities were corrected for background and counting system dead time. A mass resolving power of ~6700 was used to eliminate the contribution from $^{16}OH^-$ to $^{17}O^-$. Instrumental mass fractionation was determined by measuring terrestrial standards including Burma spinel, Miakejima anorthite, UWG-2 garnet, and San Carlos olivine. The external precision of our standards was <4.0‰ (sd) for both $\delta^{17}O$ and $\delta^{18}O$. Our precision on $\Delta^{17}O$ ranged from 1.9‰ (sd) for olivine to 3.6‰ (sd) for garnet, and the difference in $\Delta^{17}O$ among the terrestrial minerals was ~2‰, about equal to, or less than our typical uncertainty (~2.5‰).

After the isotope data were collected, the section was imaged using an FEI Inspect-F SEM in both secondary electron and backscattered electron modes to check the placement of the NanoSIMS analyses.

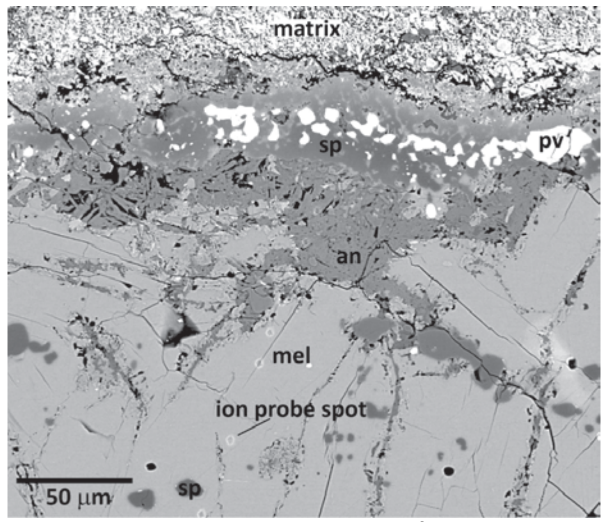

Figure 1. Backscattered electron image of the rim and outermost melilite mantle of Egg-6. Abbreviations are as follows: sp, spinel; pv, perovskite; an, anorthite; mel, melilite.

Results: Oxygen isotopes were measured in two traverses from the rim of the CAI across the melilite mantle (Fig. 2) in ~10–25 μm spaced steps. The traverses show a >25‰ range in $\Delta^{17}O$ (Fig. 2); however, most of the variation in $\Delta^{17}O$ occurs within the ~40 μm thick rim. Typical uncertainties on the $\Delta^{17}O$ values are ~4‰ (2σ). Spinel is the most ^{16}O-rich mineral with $\Delta^{17}O$ from -29‰ to -19‰. Both Fe-rich spinel in the rim and partially-resorbed spinel contained within the melilite mantle are equally ^{16}O-rich. A small (~20 μm in diameter), partially-resorbed fassaite crystal within the melilite mantle has an intermediate $\Delta^{17}O$ value of -18‰. Pervoskite included within the Fe-rich spinel rim has a $\Delta^{17}O$ value of -10‰. Melilite and secondary anorthite yield the least ^{16}O-rich values averaging -3±6‰ (2 s.d.). Fine-grained grossular found in sec-

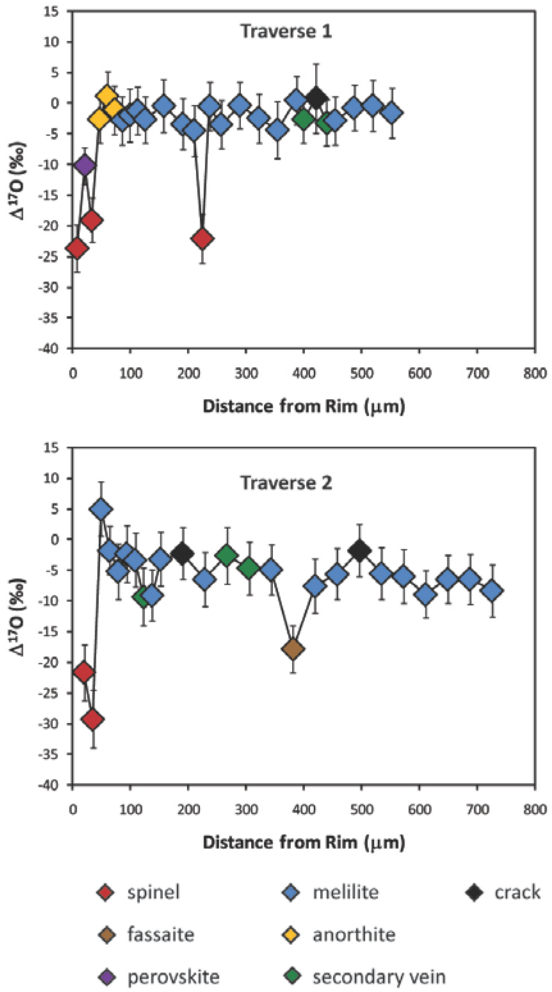

Figure 2. Oxygen isotope zoning across the rim and melilite mantle of Egg-6 defined by two NanoSIMS traverses.

ondary veins cross-cutting the CAI yield $\Delta^{17}O$ values indistinguishable from melilite and anorthite.

Discussion: The range of oxygen isotope compositions observed in the Egg-6 traverses point to mineral-specific isotope exchange. Egg 6 most likely formed from an ^{16}O-rich reservoir, as shown by the ^{16}O-rich character of the interior spinel, but subsequently experienced secondary alteration that partially exchanged O isotopes in fassaite and perovskite and almost completely exchanged melilite and anorthite. Although spinel occurs in several different petrographic settings (i.e., euhedral crystals in the core of the CAI, partially resorbed crystals in the melilite mantle, and Fe-rich spinel in the rim), the spinel does not appear to have significantly exchanged with an ^{16}O-poor reservoir, attesting to the sluggish diffusion kinetics of oxygen in spinel [6]. The enrichment of Fe at the CAI rim appears to be decoupled from the oxygen isotope profile. The fact that perovskite, contained wholly within the Fe-rich spinel rim, is partially exchanged indicates that at least some of the isotope exchange occurred after rim formation.

The data for Egg-6 can be compared to the recently published measurements from Allende CAI A37 [3]. A37 also exhibits a >25‰ range in $\Delta^{17}O$ values within a short distance from the margin of the CAI; however, A37 is unique in that it preserves oxygen zonation in interior melilite that can be modeled as solid-state diffusion of oxygen after a rapid change in the isotopic composition of the gas surrounding the CAI [3]. Egg-6, in contrast, displays a significantly greater degree of O isotope exchange of melilite, and any diffusion profile, if initially present, is no longer preserved. TS4, an Allende Type B2 inclusion, does not preserve a diffusion profile in interior melilite either (Simon et al., this volume). The Cl-S isotope systematics of wadalite in Egg-6 suggest that the CAI experienced secondary alteration more than 2 Ma after CAI formation [5].

Conclusions: Egg-6, like the previously studied A37, shows a >25‰ range of $\Delta^{17}O$ values over a very short distance in the outermost portion of the CAI. The variations are consistent with mineral-specific isotope exchange in which spinel is uniformly ^{16}O-rich, fassaite and perovskite are partially exchanged and melilite and anorthite are almost completely exchanged. Because perovskite within the Fe-rich spinel rim layer is partially exchanged, some of the exchange must have happened after rim formation. Unlike A37, Egg-6 does not preserve a diffusion profile in the interior melilite grains. The higher degree of isotope exchange in Egg-6 points to a more extensive history of alteration and suggests that studies of O-isotope zoning profiles may offer a new approach to studying the thermal history of CAIs.

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