

HIGHLY SIDEROPHILE ELEMENT AND RHENIUM-OSMIUM ISOTOPE SYSTEMATICS OF CALCIUM-ALUMINUM RICH INCLUSIONS: EVIDENCE FOR EARLY SOLAR SYSTEM PROPERTIES AND PROCESSES. G. J. Archer¹ and R. J. Walker¹, ¹Department of Geology, University of Maryland, College Park, MD 20742 (garcher@umd.edu).

Introduction: Calcium-aluminum rich inclusions (CAIs) represent the oldest and most refractory material that condensed out of the cooling solar nebula [1][2][3]. They are sub-millimeter to centimeter-sized clasts in chondrites, and are found in nearly all types of chondrites, except for the Ivuna (CI) type. The mineralogy of CAIs closely resembles the first phases that are predicted by thermodynamic calculations to condense out of the solar nebula [4], with melilite, spinel, perovskite, hibonite, Ca-pyroxene, anorthite, and forsterite being the most common phases. The most precise age for CAI formation comes from lead isotopes, which indicate that CAIs formed 4567.18 ± 0.50 Mya [5].

Because CAIs were most likely the first materials to form in the early solar system, they may preserve evidence for the earliest solar system conditions. For instance, isotopic heterogeneities that are thought to have been present in the early solar system may be recorded in these materials. Furthermore, as they have survived in chondrites to the present day, they can shed light on processes such as early solar system cosmic ray interactions, or open-system behavior caused by aqueous processes or impacts, to which they may have been subjected following their formation in the early solar system.

In these materials, the abundances of the highly siderophile elements (HSE) Re, Os, Pt, Pd, Ru, and Ir are controlled by their volatilities. Group I, III, V, and VI CAIs show suprachondritic concentrations of all HSE except for Pd, which is the most volatile HSE, and is nearly chondritic in these groups. However, group II CAIs show subchondritic concentrations for all HSE, which is probably a result of fractional condensation [6].

The Re-Os isotopic system, in which ^{187}Re decays via beta decay to ^{187}Os ($\lambda=1.666 \times 10^{-11}\text{a}^{-1}$), has the potential to date processes that affected the HSE in CAIs [7]. As CAIs are the oldest known materials to have condensed out of the solar nebula and they did not form long before IIIAB iron meteorites, they would be expected to plot on a primordial IIIAB iron meteorite Re-Os isochron [8] if the Re-Os system remained closed from formation until the present.

Methods: In order to characterize HSE, CAI material is carefully scraped from fragments of Allende and crushed into a fine powder. This material is then com-

bined with various isotopic spikes, which are enriched in ^{190}Os , ^{185}Re , ^{99}Ru , ^{194}Pt , ^{191}Ir , and ^{105}Pd . CAI, spikes, and ~3 mL 2:1 teflon distilled concentrated HCl + HNO₃ are combined in Pyrex Carius tubes [9] and heated to 260°C for three days. After digestion, Os is removed from the acid via solvent extraction using CCl₄ and back extraction into HBr [10]. The Os is then purified by a microdistillation technique [11]. All other HSE are purified using anion exchange chromatography.

Purified Os is then analyzed by negative thermal ionization mass spectrometry (N-TIMS) using a *VG Sector 54*. Re, Ru, Pt, Ir, and Pd are analyzed by multi collector-inductively coupled plasma mass spectrometry (MC-ICP-MS) on a *Nu Plasma*, both of which are at the University of Maryland.

Results: The HSE patterns of 6 Allende CAIs were characterized using the methods outlined (Figure 1). Two of the patterns, 3598 and 3529-43, are essentially chondritic. The chondritic patterns are likely caused by sampling Allende matrix rather than CAI material, given their chondrite-like abundances. 3529-40 shows a subchondritic HSE pattern, which is consistent with it being a group II CAI. The low concentrations of HSE in group II CAIs coupled with the small sample size for 3529-40 yielded signals too small for analysis of Ir in 3529-40 (I) and Pt for 3529-40 (II). All other CAIs show patterns consistent with types I, III, V, and VI.

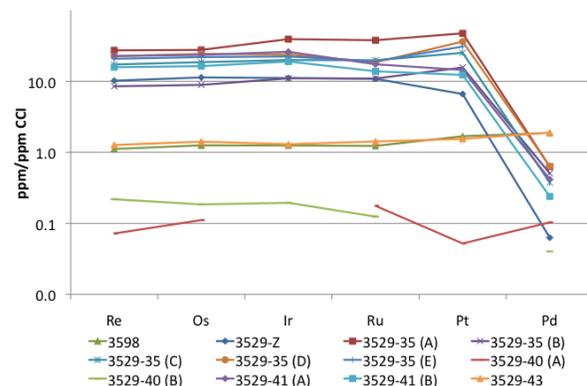


Figure 1: Abundances of HSE for six Allende CAIs normalized to CI chondrites. Letters indicate different cuts of the same CAI.

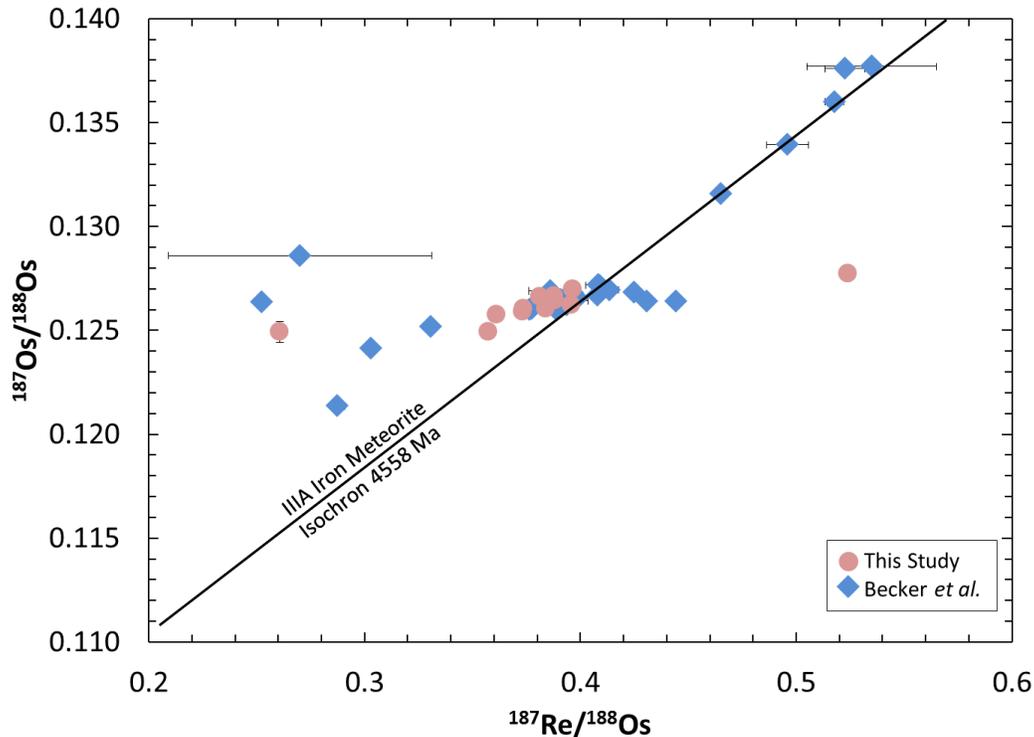


Figure 2: $^{187}\text{Os}/^{188}\text{Os}$ vs. $^{187}\text{Re}/^{188}\text{Os}$ for the 6 Allende CAIs analyzed by this study compared to Becker et al. (2001) [7]

Re-Os systematics have also been studied in these Allende CAIs (Figure 2). Most of the CAIs plot close to or on the primordial IIIAB iron meteorite isochron. However, several of the CAIs plot off this isochron. These data agree with data from Becker et al. (2001), who found that many, but not all, Allende CAIs plot on a primordial isochron.

Discussion: HSE abundance data are consistent with previously published results from these CAIs [12].

There are several explanations for why some CAIs do not plot on a primordial Re-Os isochron. The simplest and most likely explanation is that the Re-Os system may have been disturbed by late-stage open system behavior. This is consistent with the shallow slope of the non-isochronous data trend shown in Figure 2. Another possibility is that cosmic ray interactions changed the isotopic composition of Re, leading to the deviations of some CAIs from a primordial isochron. If resolvable cosmic ray interactions did occur, they would have happened early in

solar system history and very near to the protosun. More analyses of CAIs, particularly with respect to nuclides that have very large neutron capture cross-sections (e.g. Gd), will need to be made to further study this possibility.

References: [1] Amelin Y. et al. (2002) *Science* **297**, 1678-1683 [2] Gray C.M. et al., (1973) *Icarus* **20**, 213-239 [3] MacPherson G.J. et al. (1995) *Meteoritics* **30**, 365-386 [4] Grossman L (1972) *Geochim. Cosmochim. Acta* **36**, 597-619 [5] Amelin Y. et al. (2010) *Earth Planet. Sci. Lett.* **300**, 343-350 [6] MacPherson G.J., (2003) *Meteorites, Planets, and Comets* **Vol. 1** 201-246 [7] Becker H. et al. (2001) *Geochim. Cosmochim. Acta* **65**, 3379-3390 [8] Smoliar M.I. et al. (1996) *Science* **271**, 1099-1102 [9] Shirey S.B. and Walker R.J. (1995) *Anal. Chem.* **67**, 2136-2141 [10] Cohen A. S. and Waters F. G. (1996) *Anal. Chim. Acta* **332**, 269-275 [11] Birck J.L. et al. (1997) *Geostand. Newsl.* **21**, 19-27 [12] Mason B. and Taylor S.R. (1982) *Smithson. Contrib. Earth Sci.* **25**, 1-30.