

## A CASE FOR NEBULA SCALE MIXING BETWEEN NON-CARBONACEOUS AND CARBONACEOUS CHONDRITE RESERVOIRS: TESTING THE GRAND TACK MODEL WITH CHROMIUM ISOTOPIC COMPOSITION OF ALMAHATA SITTA STONE 91A

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**Introduction:** There is an increasing number of Cr-O-Ti isotope studies [1-6] that show solar system materials are divided into two main populations, one carbonaceous chondrite (CC)-like and the other is non-carbonaceous (NC)-like, with minimal mixing attributed to a gap opened in the protoplanetary disk due to Jupiter's formation [5,7,8]. The Grand Tack model [9] suggests there should be large-scale mixing between S- and C-type asteroids, an idea supported by our recent work on chondrule  $\Delta^{17}\text{O}-\epsilon^{54}\text{Cr}$  isotope systematics [10].

The Almahata Sitta (AhS) meteorite provides a unique opportunity to test the Grand Tack model. The meteorite fell to Earth in October 2008 and has been linked to the asteroid 2008 TC<sub>3</sub> which was discovered just prior to the fall of the AhS stones [11-13]. The AhS meteorite is composed of up to 700 individual pieces with ~140 of those pieces having some geochemical and/or petrologic studies [14]. Almahata Sitta is an anomalous polymict ureilite with other meteorite components, including enstatite, ordinary, and carbonaceous chondrites with an approximate abundance of 70% ureilites and 30% chondrites [14,15]. This observation has led to the suggestion that TC<sub>3</sub> 2008 was a loosely aggregated rubble pile-like asteroid with the non-ureilite sample clasts within the rubble-pile (e.g., [14,15] and references therein). Due to the loosely-aggregated nature of AhS, the object disintegrated during atmospheric entry resulting in the weakly held clasts falling predominantly as individual stones in the AhS collection area. However, recent work [16] has identified one sample of AhS, sample 91A, which may represent two different lithologies co-existing within a single stone. The predominant lithology type in 91A appears to be that of a C2 chondrite based on mineralogy but also contains olivine, pyroxene, and albite that have ureilite-like compositions.

Previous Cr isotope investigations into AhS stones are sparse and what data is available show nearly uniform isotopic composition similar to that of typical ureilites with negative  $\epsilon^{54}\text{Cr}$  values [17,18].

**Methods:** The aliquot for Cr isotopic analysis (24.77 mg) was prepared from a small chip of material from Almahata Sitta 91A. Chromium was separated from the sample matrix using a three-column chromatography procedure [19]. The Cr isotopic composition was measured using a Thermo *Triton Plus* thermal ionization mass spectrometer at the University of California, Davis.

**Results and Discussion:** The Cr isotopic composition of AhS 91A shows clearly resolved excesses in both  $^{53}\text{Cr}$  and  $^{54}\text{Cr}$  with an  $\epsilon^{53}\text{Cr} = +0.09 \pm 0.05$  and  $\epsilon^{54}\text{Cr} = +1.83 \pm 0.08$ . This is the highest  $\epsilon^{54}\text{Cr}$  value observed thus far in any CC-like reservoir. In fact it is the highest  $\epsilon^{54}\text{Cr}$  in any bulk planetary materials in hand. This  $\epsilon^{54}\text{Cr}$  is clearly resolved from ureilites that have negative  $\epsilon^{54}\text{Cr} \sim -0.90$  [18] as the extreme end member of the NC reservoir in terms of  $\epsilon^{54}\text{Cr}$  value. The difference indicates that the AhS 91A fragment originated from a Cr isotopic reservoir distinct from ureilites. The recent work studying the bulk mineralogy inferred that AhS 91A was likely comprised of material similar to C2 chondrites [16]. However, the  $\epsilon^{54}\text{Cr}$  of AhS 91A is higher than CI, CM, and CR chondrites and has a  $\epsilon^{54}\text{Cr}$  composition higher than any observed in any carbonaceous materials ([4,6] and references therein). This would indicate that the material that comprises AhS 91A is not typical CI-like material and instead is a carbonaceous chondrite material that we have yet to sample in our collections as a separate meteorite. Oxygen isotopes are still pending, but even if oxygen isotopes were similar to CI, CM, or CR chondrites or another carbonaceous chondrite group, the difference in  $\epsilon^{54}\text{Cr}$  would indicate a unique source. The observation of a different  $\epsilon^{54}\text{Cr}$  in AhS 91A compared to ureilites or the other AhS samples [17] has implications for large scale nebular wide mixing between NC and CC-like reservoirs, as suggested by the Grand Tack model [9]. This is supported by a rubble-pile like nature of the AhS asteroid.

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