NEBULA SCALE MIXING BETWEEN NON-CARBONACEOUS AND CARBONACEOUS CHONDRITE RESERVOIRS: TESTING THE GRAND TACK MODEL WITH ALMAHATA SITTA STONES.

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Introduction: There is an increasing number of Cr-O-Ti isotope studies [1-6] that show that solar system materials are divided into two main populations, one carbonaceous chondrite (CC)-like and the other is non-carbonaceous (NCC)-like, with minimal mixing between them attributed to a gap opened in the propoplanetary disk due to Jupiter's formation [5,6,7,8]. The Grand Tack model [9] suggests that there should be a particular time in the disk history when this gap is breached and ensuring a subsequent large-scale mixing between S- and C-type asteroids (inner solar system and outer solar system materials), an idea supported by our recent work on chondrule $\Delta^{17}O$-$\varepsilon^{54}Cr$ 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 from the impact of asteroid 2008 TC_3 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 ~190 of those pieces having some geochemical and/or petrologic studies [14,23]. Almahata Sitta is an anomalous polymict ureilite with other meteorite components, including enstatite, ordinary, and carbonaceous chondrites with an approximate abundance of 70-80% ureilites and 20-30% chondrites [14,15]. This observation has lead to the suggestion that TC_3 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. These stones are regarded as clasts from a highly heterogeneous breccia that probably represents ureilitic regolith [15]. Recent work [16,23] has identified one sample of AhS, sample 91A, which shows both ureilitic and chondritic lithologies co-existing within a single stone. The predominate lithology type in 91A is a C1 chondrite based on mineralogy, but the C1 material contains clasts of olivine, pyroxene, and plagioclase that have ureilite-like compositions, as well as chondrules derived from OC and primitive CC, and metal blebs from OC and EC [26,23]. It has been suggested that similar material comprised the bulk of asteroid 2008 TC_3 [16,23]. A second AhS stone, 671, has now been discovered to be very similar to 91A [23].

Previous Cr isotope investigations into AhS stones are few and limited to wholly ureilitic samples. The data show nearly uniform isotopic composition similar to that of typical ureilites with negative $\varepsilon^{54}Cr$ values [17,18].

Analytical Methods: The aliquot for Cr isotopic analysis was prepared from small chips of material from Almahata Sitta 91A (24.77 mg) and 671 (10.84 mg). 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.
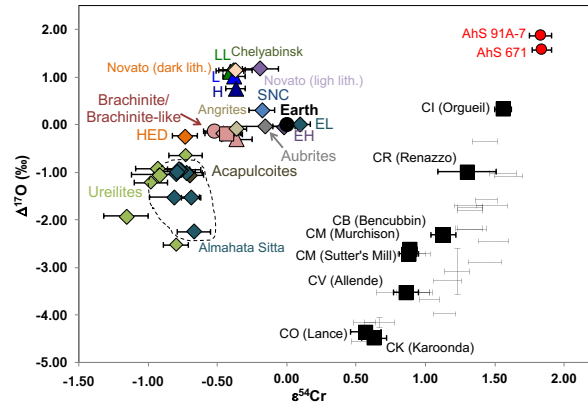

Figure 1. $\Delta^{17}O$-$\varepsilon^{54}Cr$ compositions of AhS 91A and 671 clasts in comparison to other ureilitic stones of Almahatta Sitta, other ureilites and planetary materials. Literature data for Cr and O from [20-22] and references therein.

Results and Discussion: The Cr isotopic composition of AhS 91A and 671 shows resolved excesses in both ^{53}Cr and ^{54}Cr with an $\varepsilon^{53}Cr = +0.09 \pm 0.05$ and $\varepsilon^{54}Cr = +1.83 \pm 0.08$ and $\varepsilon^{53}Cr = +0.04 \pm 0.03$ and $\varepsilon^{54}Cr = +1.84 \pm 0.07$, respectively. These are the highest $\varepsilon^{54}Cr$ values observed thus far in any CC-like reservoir. In fact, it is the highest $\varepsilon^{54}Cr$ in any bulk planetary materials in hand. This $\varepsilon^{54}Cr$ is clearly resolved from ureilites that have negative $\varepsilon^{54}Cr \sim -0.90$ [18] as the extreme end member of the NC reservoir in terms of $\varepsilon^{54}Cr$ value. The difference indicates that the AhS 91A and 671 fragments originated from a Cr isotopic

reservoir distinct from that from which ureilites formed. The ε^{54}Cr of AhS 91A is higher than CI, CM, and CR chondrites and has a ε^{54}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 and 671 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.

Typical polymict ureilites commonly contains clasts of dark materials identified as CC-like [24-27]. Since at least one of these [27] has been found to have an oxygen isotope composition almost identical to that of 91A, it is possible that typical polymict ureilites contain more samples of new lithologies like 91A/671.

The observation of a different ε^{54}Cr in AhS 91A and 671 compared to ureilites or the other AhS samples [17] has important implications for large scale nebular wide mixing between NCC 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. Details of our model will be presented at the time of conference.

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