STALKING A LARGE CARBONACEOUS CHONDRITE ASTEROID USING ε^{54}Cr-Δ^{17}O ISOTOPE SYSTEMATICS OF THE UNIQUE XENOLITH ALMAHATA SITTA 202. A. M. Miller[1], S. Dey[1], Q.-Z. Yin[1], C. A. Goodrich[2], V. E. Hamilton[3], M. H. Shaddad[4], and P. Jenniskens[5]. [1]Department of Earth and Planetary Sciences, University of California at Davis, Davis, CA 95616 USA (Email: aumiller@ucdavis.edu, qyin@ucdavis.edu); [2]Lunar & Planetary Institute, USRA, Houston, TX 77058 USA (Email: goodrich@lpi.usra.edu); [3]Southwest Research Institute, Boulder, CO 80302 USA; [4]Dept. Astronomy, Univ. of Khartoum, Khartoum, Sudan; [5]SETI Institute, Mountain View, CA 94043 USA.

Introduction: The Almahata Sitta (AhS) meteorite was delivered to Earth in October 2008 when F-type asteroid 2008 TC_3 entered Earth's atmosphere [1,2]. This event marked the first instance in which an observed asteroid gave rise to a recovered meteorite fall. The asteroid disintegrated in the atmosphere, with 99% of its mass being lost and only its strongest clasts surviving to become the recovered stones. AhS/2008 TC_3 is a polymict ureilite, containing clasts of both ureilitic and xenolithic materials [1,3–6]. AhS 202, from the University of Khartoum collection [2], is a xenolithic clast.

AhS 202 is an ungrouped carbonaceous chondrite (CC), exhibiting a unique combination of aqueous alteration and fluid-assisted metamorphism [5,7]. It contains ≥10% amphibole (specifically tremolite), a mineral that has previously been found only in trace amounts in any CC. Amphibole forms under higher temperature and pressure conditions than previously inferred for CC parent bodies [7,8]. The presence of this mineral, along with the minerals clinochlore, serpentine, and diopside, indicates a prolonged period of greenschist facies metamorphism, requiring a large (and still unknown) parent asteroid with a diameter between 640-1800 km [7]. These data illustrate the intriguing yet unknown genealogy of AhS 202.

The oxygen isotope composition suggests that AhS 202 could be closely related to CM, CR, or CV chondrites [5]. However, oxygen isotopic data alone are not sufficient to decipher genealogy. An important next step in determining the provenance of AhS 202 is using nucleosynthetic isotope anomalies (e.g. ^{54}Cr) combined with the oxygen isotopic composition as a genetic fingerprint. Isotope systematics have revealed a stark dichotomy in ε^{54}Cr-Δ^{17}O space that illustrates the spatial origin of meteorites in the early Solar System [9–15]. The CC have higher ε^{54}Cr values and are thought to have originated in the outer Solar System; whereas the non-carbonaceous chondrites (NC)—along with the terrestrial planets and most achondrites, with low ε^{54}Cr values—are thought to have originated in the inner Solar System [6,9,10,13-15]. Furthermore, recent work has documented large-scale material inward and outward transport and mixing between NC and CC reservoirs in the protoplanetary disk, which accentuates the value of isotopically mapping where early Solar System material originated [6,13,14]. Thus, combined ε^{54}Cr-Δ^{17}O isotope forensics can provide crucial information on the spatial origin of the AhS 202 parent asteroid. Oxygen isotope data for AhS 202 have been reported earlier, with Δ^{17}O = -1.7‰ [6]. Here, we present the chromium isotopic composition of AhS 202, and discuss its provenance by using ε^{54}Cr-Δ^{17}O as a genetic fingerprint. By understanding the provenance of AhS 202, we can provide insights into the CC parent body of AhS 202, and better piece together the large-scale distribution of isotopic reservoirs in the early Solar System and subsequent mixing that occurred between them.

Methods: An interior, fusion-crust free chip of AhS 202 was homogenized by grinding using an agate mortar and pestle. For dissolution, an aliquot (~15 mg) of the whole-rock powder was placed into a PTFE capsule with a 3:1 mixture of HF:HNO_3 that was sealed in a stainless-steel Parr bomb jacket. The Parr bomb was heated at 190°C for 96 hours. After complete dissolution, the sample was processed through a 3-column Cr extraction procedure to separate Cr from all other matrix elements [16]. The Cr isotopic composition was measured at UC Davis using a Thermo Triton Plus thermal ionization mass spectrometer. Cr was loaded on four outgassed W filaments, with 3 µg Cr per filament. The sample measurement was bracketed with an equal amount of NIST SRM 979 Cr standard. All reported ^{54}Cr/^{52}Cr ratios are expressed in ε-notation (parts per 10,000 deviations from the measured standard).

Planetary genealogy of AhS 202: The new Cr isotopic data along with the previously reported Δ^{17}O = -1.7‰ [6,8] are presented in the ε^{54}Cr-Δ^{17}O space in Fig. 1 (green triangle). AhS 202 is indistinguishable in the ε^{54}Cr-Δ^{17}O space from previously reported CR6 chondrites along with some CR-like achondrites (see Fig. 1) [14]. This confirms that AhS 202 is a xenolith in AhS, as its ε^{54}Cr is clearly resolved from ε^{54}Cr values of ureilites, which plot in the NC field with a negative ε^{54}Cr between -0.5 and -1.2 (see Fig. 1). The ε^{54}Cr value of AhS 202 indicates that the parent asteroid of this CC xenolith originated from the same isotopic reservoir as CR chondrites.

However, the provenance of AhS 202 is distinct from that of other unique CC found as AhS clasts [5,6]. Xenoliths AhS 91A and AhS 671 have been shown to originate from the CC reservoir but are distinct from AhS 202 in the ε^{54}Cr-Δ^{17}O space, representing a previously unseen isotopic reservoir (Fig. 1, yellow diamonds); [6]. A CC clast found in another polymict ureilite, NWA 10657 clast #28 (Fig. 1), also represents a potentially new isotopic reservoir, although it does show some similarity to the CI chondrites [6]. In contrast, AhS 202 is derived from a CR-like isotopic reservoir. This is a significant finding because, previously, no CC-like clasts in polymict ureilites have been genetically linked to known chondrite groups, although many are mineralogically similar to CI chondrites [6,28].

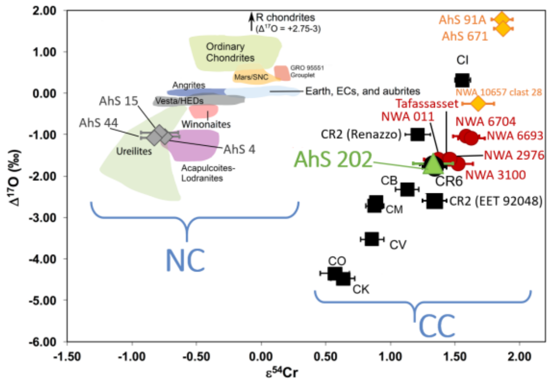

Fig. 1. The ε^{54}Cr-Δ^{17}O diagram reveals the provenance of AhS 202 xenolith from a CR chondrite-like isotopic reservoir. AhS 202 has a distinct origin compared to previously discovered xenoliths AhS 91A and AhS 671. Literature ε^{54}Cr data for CR chondrites and CR-like achondrites are from [14]; AhS ureilites Cr and O data from [17,18]; AhS xenolithic clasts data from [6]; Tafassasset and NWA 011 data from [19,20].

Nebula-scale mixing between CC and NC reservoirs: AhS 202 is a carbonaceous chondrite xenolith originating from the CC reservoir (outer Solar System) and later incorporated into a polymict ureilite breccia formed from precursor materials in the NC reservoir (inner Solar System), thereby adding to a growing list of carbonaceous chondrite-like xenoliths found in polymict ureilites [5,6,21,22,28,29]. Thus, the ε^{54}Cr-Δ^{17}O data from AhS 202 provide further evidence of widespread nebular-scale mixing of bulk materials from CC and NC reservoirs [6,22]. This mixing may have been associated with one or more large-scale dynamical events [e.g., 23], but the timing of the mixing is debated [3,6,21,22].

AhS 202 parent body: Hamilton et al (2020) concluded that AhS 202 formed in a large, possibly Ceres-sized parent body based on its observed metamorphic mineral assemblage. Our measured Cr-O isotopic composition suggests that the AhS 202 parent body could have been CR-like.

One possible scenario is that AhS 202 is derived from a Ceres-sized parent body (different from the parent body of known CR chondrites) that formed in a CR-like isotopic reservoir and underwent catastrophic disruption early in the Solar System's history. Most of the disrupted material may have been lost due to collisional erosion, and a small fragment luckily survived to be implanted into ureilitic regolith as the AhS 202 xenolith.

Alternatively, it is possible that the CR2, CR6, and CR7 chondrites, along with various CR-like achondrites, all originated from a single, large parent body. In this scenario, the CR parent body may have been Ceres-sized [7] and differentiated with a chondritic veneer [14,24–26], like an onion shell structure [27]. In this scenario, the CR6 chondrites may have been metamorphosed at depth, whereas the CR2 chondrites were aqueously altered closer to the surface. The CR-like achondrites could have formed deep within the differentiated parent body. The xenolith AhS 202 could have formed at an intermediate depth between the surface CR2 and deeper CR6, where it underwent aqueous alteration as well as prolonged metamorphism at high P-T. This large CR parent body was later disrupted and AhS 202 survived as a xenolithic clast.

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